Risk Management Assessment Report (Consequence Analysis) of Rutherglen BESS and Substation Project

For Red Hill Renewable Energy Pty Ltd

28 April 2026

Doc. No.: J-000859-REP-01

Revision: 2

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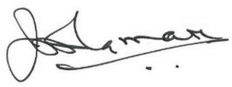
Distribution List

Name	Organisation	From (Issue)	To (Issue)
Sera Rohan	Gilvear Planning	Rev A	Rev 2
James Basham	Gryphon Energy	Rev 0	Rev 2

Document History and Authorisation

Rev	Date	By	Description	Check	Approved
A	14 Oct 2025	RR	First draft for client review	JL	RR
0	15 Oct 2025	RR	Final issue	-	RR
1	20 Oct 2025	RR	Minor corrections and update	-	RR
2	28 Apr 2026	RR	Updated to include reference to State Code 27	-	RR

Issued by: Dr Raghu Raman, RPEQ No. 15457



Contents

List of Figures

List of Tables

Notation

Abbreviation	Description
AC	Alternating Current
ACH	Air Changes per Hour
AEGL	Acute Emergency Guideline Level
AEP	Annual Exceedance Probability
Ah	Ampere hours
AS	Australian Standard
BESS	Battery Energy Storage System
BMS	Battery Management System
C_2H_4	Ethylene
C_2H_5OH	Ethanol
C_2H_6	Ethane
C_3H_8	Propane
C_6H_6	Benzene
C_7H_8	Toluene
CCTV	Closed Circuit Television
CFM	Cubic Feet per Minute
CH_3OH	Methanol
CH_4	Methane
cm^2/s	Square centimetres per second
CO	Carbon Monoxide
CO_2	Caron Dioxide
DC	Direct Current
EMR	Electro Magnetic Radiation
ERGP	Emergency Response Planning Guideline
FACP	Fire Alarm Control Panel
ft	Feet
g	Acceleration due to gravity
H_2	Hydrogen
ha	hectares
HCl	Hydrogen Chloride
HCN	Hydrogen Cyanide
HF	Hydrogen Fluoride

Abbreviation	Description
HV	High Voltage
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IDLH	Immediately dangerous to Life and Health
kg/s	Kilograms per second
km	kilometres
kPa	Kilopascals
kV	kilo-volt
kVA	Kilo-Volt Amps
kW/m^2	Kilowatts per square metre
L	Litres
L/Ah	Litres per Ampere-hour
LCS	Local Control Station
LEL	Lower Explosive Limit (also referred to as Lower Flammability Limit)
LFL	Lower Flammability :Limit
LIB	Lithium Ion Battery
LiFeP4	Lithium Iron Phosphate
LiPF6	Lithium Fluorophosphate
m	metres
m/s	Metres per second
m^2	Square metres
m^3	Cubic metres
mg/m^3	Milligrams per cubic metre
mm	millimetres
MMI	Modified Mercalli Index
MVA	Megavolt Amperes
MW	Mega Watt
MWh	Mega Watt hour
N/A	Not Applicable
NFPA	National Fire Protection Association
NSHA	National Seismic Hazard Assessment
O&M	Operations and Management
PGA	Peak Ground Acceleration
PO	Performance Outcome

Abbreviation	Description
ppm	Parts per million by volume
ppm	Parts per million
RFS	Rural Fire Service (NSW)
RHRE	Red Hill Renewable Energy
RMAR	Risk Management Assessment Report
SCADA	Supervisory Control and Data Acquisition
SDAP	State Development Assessment Provisions
TC	Tropical Cyclone
UFL	Upper Flammability Limit
UN	United Nations
USGS	US Geological Survey
V	Volt
VAD	Visual Alarm Devices
WHS	Work health and Safety

1 STATEMENT REGARDING ACHIEVEMENT OF PERFORMANCE OUTCOMES

Red Hill Renewable Energy Pty Ltd (RHRE) is proposing to construct a Battery Energy Storage System (BESS) at 837 Red Hill Road, Bororen, Queensland. It is referred as the Rutherglen BESS facility.

1.1 Requirements of State Code 21

RHRE has decided to undertake a hazard and risk assessment of the facility under Queensland State Development Assessment Provisions (SDAP) Code 21: Hazardous chemical facilities [1]. State Code 21 applies to a material change of use application made under the Planning Act 2016 for a new or expanding hazardous chemical facility. The proposed Rutherglen BESS facility is not a 'hazardous chemical facility' by definition, as there are no chemicals stored or handled at the facility. The only dangerous goods are Lithium-ion battery packs. The SDAP State Code 21 has been used by RHRE to inform the assessment.

This Hazard and Risk Assessment undertaken by Arriscar Pty Ltd has identified the following compliance with the Performance Outcomes in State Code 21 [1] for the proposed Rutherglen BESS facility.

Table 1: Compliance with Performance Outcomes

Performance outcomes	Response
Off-site impacts—vulnerable land use or land zoned for a vulnerable land use	
PO1 The **hazardous chemical facility** does not create a **dangerous dose to human health**.	☒ Compliant ☐ N/A ☐ Performance Solution As detailed in Section 11.1
Off-site impacts—sensitive land use or land zoned for a sensitive land use	
PO2 The **hazardous chemical facility** does not create a **dangerous dose to human health**.	☒ Compliant ☐ N/A ☐ Performance Solution As detailed in Section 11.2
Off-site impacts—commercial or community activity land use or land zoned for a commercial or community activity land use	
PO3 The hazardous chemical facility does not create a dangerous dose to human health.	☒ Compliant ☐ N/A ☐ Performance Solution As detailed in Section 11.3
Off-site impacts—open space land use or land zoned for an open space land use	
PO4 The hazardous chemical facility, does not create: a. a **dangerous dose to human health**; or b. where (a) cannot be achieved, an **individual fatality risk level** of 10 x 10^{-6}/ year and the societal risk criteria in figure 21.1.	☒ Compliant ☐ N/A ☐ Performance Solution As detailed in Section 11.4
Off-site impacts—industrial land use or land zoned for an industrial land use	

Performance outcomes	Response
PO5 The **hazardous chemical facility**, does not create either of the following: a. a **dangerous dose to the built environment**; and b. an individual fatality risk level of 50x10^{-6}/ year.	☒ Compliant ☐ N/A ☐ Performance Solution As detailed in Section 11.5
Storage and handling areas	
PO6 Storage and handling areas for **fire risk hazardous chemicals** are provided with a 24-hour monitored fire detection system that has the ability to detect a fire in its early stages and notify an **emergency responder** at all times.	☒ Compliant ☐ N/A ☐ Performance Solution As detailed in Section 11.6
PO7 Storage and handling areas for **packages** of liquid or solid **fire risk hazardous chemicals** are provided with a spill containment system with a working volume capable of containing a minimum of 100 percent of all **packages** (**prescribed hazardous chemicals** and/or non-hazardous chemicals) within the area plus the output of any **fixed firefighting system** provided for the area over a minimum of 90 minutes.	☐ Compliant ☒ N/A ☐ Performance Solution As detailed in Section 11.7
PO8 Storage and handling areas for liquid or solid **fire risk hazardous chemicals** in **tanks** are provided with a spill containment system with a working volume capable of containing a minimum of: a. 110 percent of the largest **tank** within a spill compound or 25 percent of the aggregate where multiple **tanks** are located within a spill compound, whichever is the greater; and b. the output of any **fixed firefighting system** provided for any bulk **tank** within a spill compound over a minimum of 90 minutes.	☐ Compliant ☒ N/A ☐ Performance Solution As detailed in Section 10.8
PO9 Storage and handling areas for **prescribed hazardous chemicals** that, if in contact with each other, may react to produce a fire, explosion or other harmful reaction, or a flammable, toxic or corrosive vapour are designed to prevent contact between the prescribed hazardous chemicals.	☐ Compliant ☒ N/A ☐ Performance Solution There are no incompatible substances that may come into contact.
PO10 Development is designed and sited to mitigate impacts on **storage and handling areas** from **natural hazard** including, but not limited to: a. flood; b. bushfire; c. erosion; d. storm tide inundation; e. landslide; f. earthquake; g. wind action; h. extreme rainfall events.	☒ Compliant ☐ N/A ☐ Performance Solution See flood mitigation in Appendix C of Ref. [2]
All development	

Performance outcomes	Response
PO11 Development is designed and sited to mitigate the risks from **hazard scenarios** occurring at existing **hazardous chemical facilities**.	☐ Compliant ☒ N/A ☐ Performance Solution There are no existing hazardous facilities on the proposed development site

1.2 Requirements of State Code 27

State Code 27 [3] requires a risk management and assessment report to comply with PO2 to PO4 of the Code. The Planning Guideline for Code 27 [4] requires that

> *"A Risk Management Assessment Report (RMAR) be prepared and lodged with the application to demonstrate compliance with PO2-PO4. The risk assessment process supporting the RMAR should be aligned with AS ISO 31000:2018 Risk Management - Guidelines, or analogous processes in technical standards such as AS/NZS 5139."*

A risk assessment requires the following:

- Hazard identification
- Assessment of consequences of potential hazardous events
- Estimation of likelihood of the hazardous events
- Assessment and evaluation of risk

The RMAR has been carried out in two stages:

The hazard identification and consequence analysis has been carried out by Arriscar for the Rutherglen BESS facility, and detailed in this study.

The likelihood assessment and risk evaluation part of the RMAR has been carried out in Ref. [5]. The present report must be read in conjunction with the RMAR Consequence assessment in Ref. [5].

Together with Ref. [5], the studies follow the requirements of AS ISO 31000-2018 [6], as required by State Code 27 Planning Guideline [4].

The compliance with the Performance Outcomes of Code 27 is assessed in the second part of the RMAR in Ref. [5].

2 INTRODUCTION

2.1 Background

Red Hill Renewable Energy Pty Ltd (RHRE) is proposing to develop a standalone Battery Energy Storage System (BESS) at 837 Red Hill Road, Bororen, Queensland. The site is located at approximately 52 km from Gladstone Central and falls within the Gladstone regional Council.

The facility will have a capacity of 400 megawatts (MW), up to 4 hours of energy storage from each charge (1600 MWh).

As part of the Due Diligence process for this project, RHRE has undertaken a risk/hazard assessment addressing the requirements of Queensland State Development Assessment Provisions (SDAP) Code 21 [1]. Arriscar Pty Ltd has been commissioned by Gilvear Planning on behalf of RHRE to conduct the hazard/ risk assessment.

2.2 Scope of the Study

- Conduct a hazard and risk assessment of the Rutherglen BESS facility in accordance with the requirements of State Code 21 .
- Demonstrate that the facility meets the Performance Outcomes (PO) in SDAP Code 21.
- Where the PO is not met, recommend performance solutions to satisfy the POs.

3 SITE LOCATION AND SURROUNDING USES

3.1 Location

The proposed site is approximately 7 km east of the township of Bororen, Qld. The site boundary encompasses an area of approximately 1,278 hectares (ha) (refer to Figure 1). The site address is 837, Red Hill Road, Bororen, Queensland 4678.

The site is located at approximately 52 km southeast of Gladstone Central, and the local government authority is Gladstone Regional Council.

Figure 1: Location of Rutherglen BESS Facility

Source: Google Earth Pro

3.2 Site Description

The site is designated as Lot 132 in FD 700 and is located at 837 Red Hill Road, Bororen, Queensland.

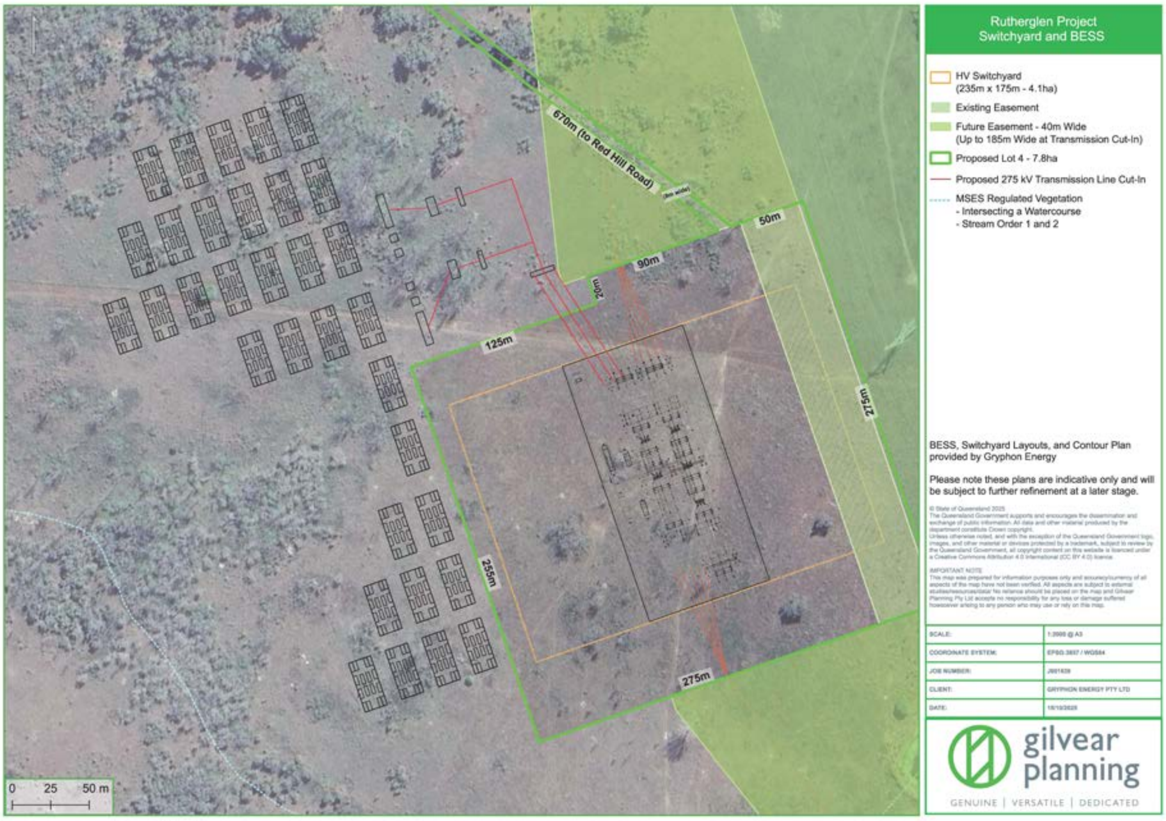
A site plan is shown in Figure 2. Site access is from Red Hill Road. The land is described as plain and undulating. The area surrounding the site consists of gorges and mountains. The Erimbula National Park abuts the eastern boundary of the site.

The site consists of 4 Lots as described below:

- Lot 1: Includes the existing 513 ha part of Lot 132 to the west of Red Hill Road.

- Lot 2: Occupies an area of 288 ha and includes the middle 'triangle' part of the existing lot, bound by Red Hill Road to the west and an unnamed road to the east. A 30 hectare part of the site will contain the battery storage, connection, inverters, laydown and Operation and Maintenance (O&M) facility.
- Lot 3: Includes the 472 ha eastern portion of Lot 132, bound by the unnamed road along the western boundary and adjoins Eurimbula National Park along the eastern boundary.
- Lot 4: Occupies a total area of 7.3 ha and will accommodate the Substation.

Figure 2: Rutherglen Project BESS and Switchyard Site Plan



3.3 Meteorology

The nearest weather station to the Rutherglen Project is at Auckland Point, Gladstone (Station ID: 039123). Weather data was obtained from the Bureau of Meteorology. The data was processed into a rationalised form consisting of six wind speed/Pasquil stability group classes arranged into sixteen wind direction groups.

The annual average temperature is 22.4°C, average wind speed 4.7 m/s and the average humidity is 74%.

The processed meteorological data is summarised in Table 2.

Table 2: Meteorological Data for Gladstone Weather Station

	Wind Direction (FROM)	Wind Speed/ Weather Stability Class						Total
		B3	D1.5	D5	D9	E3	F1.5	
Probabilities (%)	N	0.2	0.5	0.6	2.7	0.2	0.1	4.3
	NNE	0.5	0.9	0.4	3.2	0.1	0.1	5.1
	NE	1.6	0.8	0.4	5.4	0.1	0.1	8.3
	ENE	1.2	3.5	0.3	5.8	0.1	0.1	10.9
	E	0.6	9.5	0.3	5.0	0.1	0.1	15.5
	ESE	0.3	4.3	0.3	4.0	0.1	0.1	9.0
	SE	0.2	2.8	0.3	8.2	0.2	0.1	11.7
	SSE	0.2	0.9	0.3	8.2	0.2	0.1	9.9
	S	0.3	0.1	0.5	4.6	0.3	0.1	5.9
	SSW	0.2	0.1	0.4	2.6	0.2	0.1	3.6
	SW	0.3	0.1	0.6	2.6	0.2	0.2	3.9
	WSW	0.3	0.1	0.8	2.0	0.2	0.2	3.6
	W	0.4	0.0	0.9	1.1	0.1	0.2	2.6
	WNW	0.2	0.0	0.4	0.7	0.1	0.1	1.5
	NW	0.2	0.0	0.3	1.1	0.1	0.1	1.9
	NNW	0.2	0.0	0.3	1.4	0.1	0.1	2.1
	Total	6.9	23.8	6.9	58.5	2.2	1.6	100.0

The data indicates that unstable weather conditions prevail for approximately 6.9% of the time, neutral stability for 89.2% of the time, and stable conditions for 3.8% of the time. This means that unstable and neutral conditions are present for more than 90% of the time and therefore gas releases would disperse to acceptable levels more readily than stable conditions.

It should be noted that the meteorological data is for coastal conditions. The weather pattern would differ for inland region at Bororen, but no local data is available.

The bushfire assessment report [7] states that ” the predominate wind direction is from the South East. In times of severe fire weather, the wind direction will be from the North to South West. The Topography will create microclimates, which will cause swirling, which will modify the apparent wind direction according to primary direction and velocity.”

4 DESCRIPTION OF FACILITY

4.1 Overview

The Project involves the construction, operation and commissioning of a battery energy storage system with associated electrical equipment for grid interface. It operates by storing energy in batteries and converting it between AC and DC using power electronics, while interfacing with the Powerlink transmission network through a 275kV Substation.

High voltage (HV) AC power from power grid system is connected to power transformers that step down the voltage from 275 kV to 33 kV. Power converters convert the 33 kV power to 1500V direct current (DC) used to charge the battery units.

When power is to be drawn from the battery system, the power converters invert the DC power to 33 kV AC, which are again stepped up to 275 kV AC for feeding the grid.

The BESS an energy storage capacity of 400 megawatts (MW) and up to 4 hours of storage per charge (1600 MWh).

There is no power generation on the site.

The key components of the Project are:

- 33 'modules' in each BESS DC block area, and contain 12x20 foot BESS containers of Lithium-iron phosphate batteries, and 4 x inverter/transformer stations;
- There are 132 x FP4203MH inverter/transformer stations. The DC side voltage of FP4203MH station is at 33kV AC.
- 33kV Switch rooms.
- Two 250MVA three winding transformers which step the voltage up from 33kV to 275kV, located in a HV switchyard.
- Auxiliary transformers that step down the voltage from 33 kV to 440V to supply cooling load for up to 21 liquid cooled BESS containers.
- Operations and management (O&M) building where the control room is located;
- SCADA system for control and monitoring;
- internal access roads;

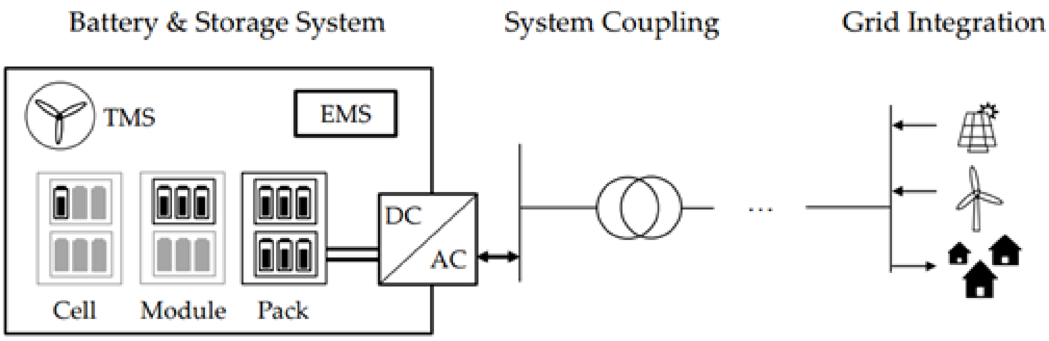
4.2 Battery Energy Storage System (BESS)

A Battery Energy Storage System (BESS) is an advanced technology developed for storing the electricity by using specially developed batteries.

The BESS includes battery cells, assembled into modules and packs, and stored in cabinets inside 20 ft. containers in the open. The DC electricity from the packs is fed through power converter system (PCS) also referred to as inverters to convert to AC, voltage boosted through power transformers and fed to the power grid.

A schematic of an example BESS is shown in Figure 3 [8].

Figure 3: Schematic of Example Battery Energy Storage System



4.2.1 Lithium-Ion Battery

The most common BESS consists of an array of lithium-ion batteries (LIB). There are different LIBs, such as lithium cobalt oxide, lithium manganese oxide and lithium iron phosphate. They all use the technology of transferring lithium ion between an anode and cathode. The anode is mainly carbon, due to its cost effectiveness and higher energy density. The differences are in the cathodes.

The cathode accepts lithium ions during discharge and releases them during the charge cycle. In the proposed facility, the cathode consists of Lithium-Iron Phosphate [8].

The electrolyte is typically composed of an organic solvent and a lithium-based salt, commonly Lithium Fluorophosphate (LiPF6). In between the anode and cathode is a polymer membrane separator.

Because of the mixture of a range of chemicals, a decomposition reaction from overheating of the cell can result in the evolution of flammable and toxic gases. Ignition of these gases can result in a battery fire or explosion in the confined volume.

4.2.2 Battery Storage

Multiple cells are typically assembled into a module by connecting them in series and parallel arrangements. The modules are stacked and interconnected in a battery rack. The racks are stored in a cabinet for small installations and containerised storage for large installations. Depending on the capacity of BESS, several containers can be stored.

The BESS will consist of 33 x 20ft storage containers. An example layout is shown in Figure 4 [9].

Figure 4: Example Layout of BESS Containers

A typical container is shown in Figure 5 [9].

Figure 5: Example of a Battery Container

The container has the following features:

- Cable penetrations.
- A cooling system maintaining the container temperature within safe operating limits (liquid cooling with chiller unit and fan).
- Smoke/heat/combustible gas detectors
- Fire protection system installation (aerosol units, sounders and Visual Alarm Devices (VADs), ventilation system, and water sprinkler heads).
- Explosion venting panels

The batteries are stacked and connected to the Battery Management System (BMS). The BMS is typically designed with a range of safeguards, such as:

- Prevention of overcharging and current surges.
- Maintaining voltage levels.
- System trip in the event of electrical shorts or overheating.
- Fire alarm control panel (FACP) and a local control station (LCS).

4.3 BESS Arrangements Considered for Study

The proposed development will have a capacity of 400 MW providing energy for 4 hours (1600 MWh).

Each individual BESS is containerised, and will use lithium-iron ($LiFePO_4$) cell. The containers are grouped into 'modules', each modules occupying an area of 15.2m x 33.4m, and separated by 10m access path on all sides.

The proposed configuration is summarised in Table 3.

Table 3: Features of BESS

Parameter	Description
No. of modules	33
No. of BESS 20 ft. containers per module	12
No. of inverters per module	4 (1 inverter for 3 BESS containers)
Battery storage capacity per container	5MWh
No. of racks (string of cells) per container	12
No. of LiFePO4 cells in each string	416
Ampere hour rating	075 Ah per cell (314 Ah per BESS container)

4.4 BESS Cooling and Ventilation System

Maintaining the temperature within limits is critical to the safety of the operations and this is typically achieved by dedicated cooling system for each container and controlled by the BMS.

The cooling system consists of the following [9]:

- Chiller unit for each container. The chiller cools the batteries via liquid cooling plates installed beneath each battery pack;
- Ventilation fan that would be started on detection of combustible gas at 10% lower explosive limit (LEL), based on hydrogen detection, and would not stop until the flammable gas concentration is reduced to less than 10% LEL.

4.5 Operations and Management Hub

The site operations are managed from an operations and management hub (constructed). Structures include an office control building with SCADA system, staff amenities, and equipment storage. These are the receival point for all equipment delivery during construction and all management activities during the project's operational period.

Car parking facilities are also provided for employee and service vehicles.

Normal facility working hours are 8 hours per day, 7 days per week.

4.6 Fire Protection System

Each BESS container will have the following fire protection [10]:

- Fire alarm control panel (FACP)
- Local control station (LCS)
- Smoke/heat detectors
- Combustible gas detectors
- Aerosol fire suppression units
- Alarm sounders and visual alarm devices (VADs)

- Ventilation system, and
- Water sprinkler heads.

The fire control logic for the BESS containers is as follows:

- Gas detector sensing 10% LEL of combustible gas will initiate a LEVEL 1 alarm and start the exhaust fan. The fan will not stop until the detector shows < 10% LEL.
- In the event of ignition, a smoke detector or heat detector (1-oo-2) will initiate a LEVEL 1 fire alarm in the BMS, activate sounder and VAD for operator intervention.
- If both the smoke detector and heat detector are activated, a LEVEL 2 fire alarm is raised in the BMS. Sounder and VAD are activated and aerosol is released (automatically if in AUTO mode or manually from control room. The ventilation fan is stopped to prevent the aerosol being extracted out.
- Finally, a dry pipe water sprinkler unit is installed that can be activated once the firewater pump is manually started.

The nearest fire brigade is located at Bororen rural fire station.

The fire protection and suppression system for the BESS are designed to meet the requirements of NFPA 855 [11] and other Australian Standards listed in Ref. [10].

5 HAZARD IDENTIFICATION

5.1 BESS Hazards

The Lithium-ion battery is classified as a Class 9 dangerous good (UN No. 3480) for transport purposes. The main hazards are [12]:

- Overheating with toxic gas generation and emission to atmosphere and potential exposure to toxic gases such as Carbon Monoxide (CO), Hydrogen Chloride (HCl), Hydrogen Fluoride (HF) and Hydrogen Cyanide (HCN).
- Overheating with flammable gas generation within the container (CO, Hydrogen, and hydrocarbons such as Benzene, Ethylene), ignition and explosion within the container, and potential for escalation to adjacent containers.
- Fire in Lithium-ion battery, escalating into the packs in the container, with potential for escalation to adjacent containers.

5.2 Electrical Hazards

- Power converter fire and explosion.
- Transformer oil fire and potential for escalation.
- Transformer fire/ explosion in sub-station from arcing etc.
- Human contact with electricity.

5.3 Other Hazards

Other hazards include:

- Vehicle interaction with infrastructure.
- Electromagnetic radiation from high voltage sources.
- Natural hazards (earth tremor, adverse weather, bush fires).

There are no other dangerous goods stored on the site.

5.4 Hazard Register

A hazard identification register has been compiled, outlining the consequences of the identified hazards and the safeguards provided in the design towards prevention and mitigation. This register provided in Table 4.

Table 4: Hazard Identification and Safeguards Summary

No.	Hazard Scenario	Causes	Consequence	Potential for Offsite Impact	Identified / Recommended Safeguards
I	**BESS Hazards**				
1	Battery Fire	- Electrical failures – overcharging/ over discharging - Internal short-circuit - Damaged battery - Battery overheating - Frequent charging and discharging of the battery capacity and degradation of battery resulting in overheating [13]	- Thermal runaway from exothermic reaction - Escalation to other battery packs and modules - Thermal radiation and escalation to adjacent battery container - Toxic gas generation (CO, HF, benzene and other flammable gases - Part of the off gases may combust depending on generation rate and oxygen availability, but combustion gases are still toxic (HF, HCl)	Yes	Safeguards provided are: • Battery inspection and testing during installation (quality control) • Cooling system in each battery pack container, designed to maintain temperatures within operating limits • Adequate spacing between battery racks to prevent escalation between containers • Fire detection and alarm • Gaseous fire suppressant • A water mist system in each BESS and PCS container that can be remotely activated manually on fire alarm • A regular inspection and maintenance regime for the battery assemblies.
2	Battery Explosion	- Battery overheating and off gases generation that are flammable. - Ignition of off gases within container resulting in confined explosion	- Significant damage to the container - Explosion may be followed by fire - Escalation to adjacent containers	Yes	• Cooling system for temperature control • Temperature monitoring and high temperature trip by BMS • Combustible gas detectors and alarm, and automatic electrical shutdown of the container. • Automatic exhaust system initiated by the gas detectors to remove off gases generated and keep the container atmosphere several times below the lower explosive limit *Recommendation: The motor for the exhaust fan must have ‘Ex’ rating to prevent ignition.*

No.	Hazard Scenario	Causes	Consequence	Potential for Offsite Impact	Identified / Recommended Safeguards
II	**Electrical Hazards**				
3	Power converter fire/ explosion	- internal failure of a power capacitor - Overvoltage and cables overheated - Overcurrent and cables overheated - Arc fault	Localised fire damage. Plant shutdown Injury if personnel present in the vicinity	No	• Equipment certified and installed to relevant standards • Inverters tested for compliance with Australian Standard AS 4777.1-2015 • Voltage rating to match maximum open circuit voltage • Overcurrent trip if maximum current exceeded Quality checks of installation before commissioning
4	Inverter mode failure	- Reverse polarity of cables, human error	Electric shock and serious injury/ fatality	No	• Certified electrician Quality checks of installation before commissioning
		Overvoltage	Overheating and fire Electric shock	No	• System trip/shutdown • Voltage rating to match maximum open circuit voltage Equipment tested & approved
5	Power Transformer Fire	- Coolant leak and ignition - Overheating - Earth leakage	- Transformer fire - Injury to personnel in the vicinity - Potential for escalation	No	• Designed to AS 2374.8:2000 – Power Transformers – Application Guide • Fire protection provided • Separation distance/ fire isolation of transformers
6	Transformer explosion	Gases generation inside from transformer enclosure from arcing (hydrogen and hydrocarbons)	Overheating of transformer and explosion from overpressure	No	• Relief valve on transformer to vent off gases • High temperature trip • Bucholz relay trip for sensing gases
7	Contact with electricity	- Vermin exposing conductors	Personal injury / fatality	No	• Implement Isolation procedures. • Install fit for purpose electrical systems.

No.	Hazard Scenario	Causes	Consequence	Potential for Offsite Impact	Identified / Recommended Safeguards
		- Contact with live electrical sources; - Cranes impacting overhead lines; - Hitting underground services; - Overhead services damaged during natural hazards; and - Security issues with trespassers in contact with electrical lines.			• Ensure that installation is carried out by suitably qualified electrical personnel. • Adherence to AS 3000. • Site and Electrical Inductions • Follow underground utility identification protocols, including Before You Dig Australia. • Contractor management, including: - Sign on/off registers. - Ensuring familiarity with site WHS procedures. - Appropriate permit to work procedures. Crane height limitations where works are undertaken in the vicinity of overhead power lines – overhead work height limits.
III	**Vehicle Interaction**				
8	Vehicle collision with site infrastructure	- Vehicle movements in vicinity of personnel, - Vehicle impact to infrastructure	Personal injury Damage to equipment	No	• Construction management plan that includes standard traffic rules and signage. • Traffic management plan that includes implementation of site speed limits, ensuring driver competency, fencing / bollards and positioning of batteries to minimise vehicle interaction. • Ensuring driver competency through licensing and induction
IV	**Electromagnetic Radiation**				
9	EMR	- EMR generated from BESS, High Voltage Power lines, Grid infrastructure)	Exposure to EMR and personal injury	No	• All designs will be in accordance with the Guidelines for limiting exposure to Time varying Electric, Magnetic and Electromagnetic Fields (ICNIRP, 1998; ICNIRP, 2010b) and relevant codes and industry best practice standards in Australia.

No.	Hazard Scenario	Causes	Consequence	Potential for Offsite Impact	Identified / Recommended Safeguards
					• All relevant procedures in relation to a high voltage installation will be adhered to throughout the life of the Project. • The security system for the site, including safety fencing and closure of gates, will be maintained throughout the construction and operation, to provide safe exposure distances to personnel. • Restricted access to site and access only to safety inducted personnel.
V	**Natural hazards**				
10	Earthquake	- Earthquake	Personal injury, Facility shut down	Yes– typically a large scale external event	• Project infrastructure will be built to relevant construction codes.
11	Bushfires	- Bushfires	Personal injury, Facility shut down, Possible fire	Yes – typically a large scale external event	• Bushfire management plan has been prepared for the site . The report contains details of bushfire management and is not further assessed in this report.
12	Flooding	- Excessive rain/ cyclone conditions	Flooding on site. Potential form electrical equipment/ water contact	No	• Hydrological study indicates that stormwater flows would be contained in the within the natural channel traversing through the site and would not impact on the electrical infrastructure.
VI	**Flammable and Combustible Materials Storage and Handling**				
13	Loss of containment of chemicals, including dangerous goods	• There are no dangerous goods stored on site apart from the batteries. • Transformer oil is a potential fire source. This is addressed in this study.			

No.	Hazard Scenario	Causes	Consequence	Potential for Offsite Impact	Identified / Recommended Safeguards
VII	**Site Security**				
14	Security breach	- Persons seeking theft of property/battery components	- Theft of equipment Personal injury	No	• Installation of fencing around facility and battery facility separately. • CCTV where practical on critical infrastructure/battery units. • Alarms/locks on battery doors. • Inspections to monitor for potential security concerns.

Only the hazards that could result in an offsite impact, and those hazards that may impact on emergency service providers are analysed in detail.

6 HAZARD CONSEQUENCE ANALYSIS

6.1 Battery Fires

The causes of battery fires are outlined in Table 4. This section describes fire modelling of a battery storage fire and its consequences.

There is no established methodology for quantitatively assessing fire hazards. Earlier studies were based on the total quantity of electrolyte in the container and treated the fire like other batteries. This had led to unrealistic separation distances [14].

Experiments on a Tesla Battery Pack conducted by Exponent Inc. [14] found the following:

- The propagation of fire within the container is slow when the source of fire was inside the container.
- The smoke is associated with thick white fumes vented through the container vent, with flames of up to 4m in height.
- At the centre of fire, temperatures up to 1100˚C were experienced, but outside temperature of container was not significantly higher than the ambient.
- The walls of the container did not fail for a fire that lasted 90 minutes. Many panels were unaffected and could be reused.

The study concluded that separation distances between containers was not required except for access to the end door(s). NFPA has included mitigation controls for these findings in NFPA 855 [11].

Some of the earlier studies on BESS fire assessment [15] have postulated a fire temperature of the panel as 500˚C and calculated thermal radiation from a planar surface (battery container dimensions) to a receiving plane. The distances were quite short, 3m to 4.7 kW/m^2, and 1m to 23 kW/m^2. This approach does not reflect the nature of the battery fires described in the experiment [14].

A battery container fire behaves quite differently whether the container is naturally ventilated or forced ventilated. In a detailed study sponsored by the NFPA in the USA, Hutchison [15] described a battery container fire development with forced ventilation as follows:

(a) Local heating and generation of off gases containing significant flammables.

(b) Ignition of flammables resulting in jet fire of high intensity but does not last long.

(c) The fire further heats the battery racks and generates more off gases and jet fire.

(d) Thus, the fire is a cyclical phenomenon, alternating between a jet fire and developing fire in target racks.

(e) Not only the decomposing electrolyte, but the battery materials, cables and insulation materials containing plastics also get involved in the fire, as the fire spreads.

(f) Without fire protection, the fire spreads to the whole of the container, whose wall may collapse due to excessive pressure inside, if the ventilation system cannot remove the smoke layer effectively.

(g) In a fully developed fire, the radiating rectangular surface of the container wall can radiate heat to the surrounds by heating an adjacent container and generating off gases from the battery rack on the heat receiving container.

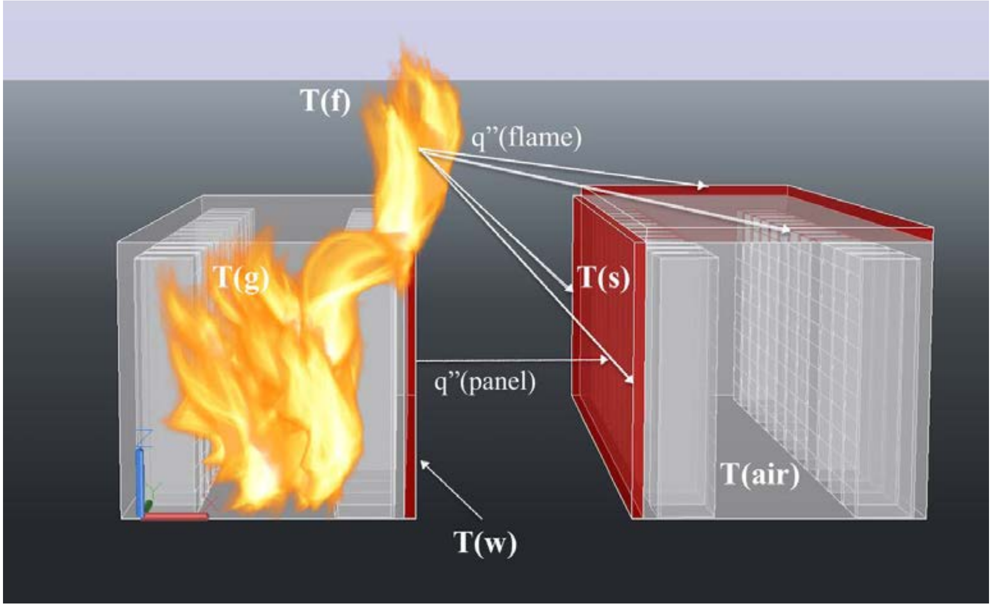
(h) The fully developed fire may be modelled as a surface fire of the whole side wall of the container, radiating with a surface temperature of $500^{O}C$, and high emissivity, similar to a plastic material fire.

(i) With fire protection, the container would remain intact and while the fire gradually abates, the generated gases and combustion products are vented through the ventilation exhaust duct on the roof.

(j) The vent itself can catch fire and the torch fire of ignited flammable gases can radiate high intensity thermal radiation to the surroundings, an additional source of thermal radiation that helps to heat up adjacent container and impact on personnel in the vicinity.

The fire growth is schematically shown in Figure 6, reproduced from [15].

Figure 6: BESS Container Fire Radiation Modelling Schematic



While Figure 6 shows the fully developed fire, it is necessary to take into account the fire protection aspects into account as an integral part of fire modelling, which makes the modelling more complex, but more representative of the fire.

The following fire protection is provided:

(a) Fire detection and shutdown/ alarm.

(b) Automatic activation of gaseous fire suppressant.

(c) Manual activation of water mist firefighting system on fire alarm.

(d) Provision for cooling adjacent containers, if required by emergency services.

Since the BESS fire modelling is still in the developmental stages, with limited field data and some experimental data [14], this study has not quantitatively modelled BESS fires. Instead, based on the available data and given the fire protection provided, it can be concluded that fire escalation to adjacent containers can be prevented by the implementation of the gas detection and fire protection measures.

Given the gas detection shutdown and fire protection measures, the thermal radiation effects of BESS fires would be confined within the site and there would be no offsite thermal radiation effect. The separation distances between containers also enables approach of the fire by firefighting personnel.

Based on a 2021 fire in Victoria [16], the fire brigade approach appears to be to let a container burn itself out, evacuate non-essential personnel and protect exposures – i.e. other containers exposed to the original fire.

6.2 Gas Releases in Container

When a battery pack gets overheated, it produces off gases that are flammable and toxic. Typical composition of off gas for Lithium Iron Phosphate battery is listed in Table 5 [12].

Hydrogen (H_2) is missing from the reported data. In experiments conducted [12], it is reported that the H_2 sensor was saturated at a value of 1%, and that this saturation occurs almost immediately upon the onset of thermal runaway. This could explain why H_2 values in off gases have not been reported in many studies.

The DNV study states that literature data reports values of hydrogen between 5% and 30% by volume. In this study, a sensitivity analysis with 5% and 30% hydrogen was undertaken in the absence of hydrogen in reported experimental data.

Table 5: Off Gas Composition from Overheating of Lithium Phosphate BESS

Chemical	Name	% in off gas (v/v)	
		5% H_2	30% H_2
CO_2	Carbon Dioxide	35.18	28.41
CO	Carbon Monoxide	11.34	9.16
CH_4	Methane	5.62	4.54
C_2H_6	Ethane	20.11	16.24
C_2H_4	Ethylene	5.82	4.70
C_3H_8	Propane	4.77	23.09
H_2	Hydrogen*	4.48	3.62
HCl	Hydrogen Chloride	1.05	0.85
HF	Hydrogen Fluoride	3.62	2.93
HCN	Hydrogen Cyanide	0.57	0.46
C_6H_6	Benzene	0.29	0.23
C_7H_8	Toluene	0.67	0.54
C_2H_5OH	Ethanol	4.00	3.23
CH_3OH	Methanol	2.48	2.00
	Total	100.0	100.00
Average Molecular weight		33.76	27.65
Density (kg/m^3)		1.102	0.903

The total flammable gas content is 59.6% (5% H_2) to 67.4% (30% H_2). Toxic gas concentration varies from 39.3% to 31.7% (CO, HCl, HF and HCN) for 5% and 30% hydrogen in gas respectively.

The combustible gas detectors in the proposed BESS have sensors calibrated to act on detecting 10% LEL of hydrogen, i.e. 0.4% hydrogen present in the off gas.

The off gas generation rate is calculated as follows (normalised to 100^{O}C), and using the molecular weight in Table 5:

- It is assumed that one string (416 cells) can be overheated over a period of 240 sec, based on the data in Ref. [17].
- The rating of the BESS is 314 Ah,
- The rating of a cell is taken as 0.75 Ah, and off gas generation rate = 4 L/Ah [12].
- Off gas generated (5% H_2) = [416 x 0.75/240] x4 L/Ah x (1/1000) m^3/s] x 1.102 kg/ m^3]

  = 1.43E-03 kg/s.
- Emission temperature = 100^{O}C.

Similarly, emission rate for 30% hydrogen content in off gases = 1.17E-03 kg/s

6.3 Time to Activate Exhaust Fan

The exhaust fan is activated by the combustible gas detector at 10% LEL hydrogen concentration. The LEL for hydrogen is 4% in air, or 3.34E-04 kg/m^3.

The calculated time taken to reach 10% LEL H_2 concentration in the container is listed in Table 6.

Table 6: Time to Reach 10% LEL H_2 Concentration

Container Parameters				Value
Volume of 20’ container 6.1m(L) x 2.5m (W) x 2.6m (H)				39.65 m^3
Free volume in container (25% assumed)				9.91 m^3
H_2 in off gas	**Off gas generation rate, kg/s**	**H_2 in off gas, kg/m3**	**LEL H_2 kg/m^3**	**Time to reach 10% LEL, seconds**
5%	1.43E-03	4.08E-06	3.3E-03	13.3
30%	1.17E-03	1.98E-05	3.3E-03	2.8

Depending on the hydrogen content of the off gases, the gas detector would activate exhaust fan between 2.8 and 13.3 minutes and shut down the container (charging or discharging).

In the even the exhaust fan fails to start on demand, gas generation would continue for some time and a flammable gas concentration would result.

6.4 Toxic Gas Dispersion

Until Gas dispersion calculation were conducted for the two generation rates emitted through the roof vent, at a height of 3m above ground level, using the gas composition in [12].

The DNV software package PHAST 9.0 was used for dispersion.

6.4.1 Toxic Exposure Levels

Toxic impacts for injury are expressed in terms of Acute Exposure Guideline Levels (AEGL). The definitions of AEGL are reproduced from Ref. [18].

AEGLs are calculated for five relatively short exposure periods – 10 minutes, 30 minutes, 1 hour, 4 hours, and 8 hours – as differentiated from air quality standards based on longer or repeated exposures. AEGL "levels" are dictated by the severity of the toxic effects caused by the exposure, with Level 1 being the least and Level 3 being the most severe.

All levels are expressed as parts per million or milligrams per cubic meter (ppm or mg/m^3) of a substance above which it is predicted that the general population could experience, including susceptible individuals:

- AEGL 1: Notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
- AEGL 2: Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
- AEGL 3: Life-threatening health effects or death.

The safeguards provided (gas detection, shutdown and exhaust fan activation) would ensure that any toxic gas emission through exhaust vent above the container roof would last no more than 15 minutes. However, if the safeguards fail, the duration can exceed 15 minutes. A release duration of 1 hour was used for dispersion modelling as a conservative measure.

The AEGL2 concentrations are listed in Table 7 [19].

Table 7: AEGL2 Concentrations (ppm) for Toxic Components

No.	Component	Symbol	10 min	30 min	60 min
1	Hydrogen Chloride	HCl	100	43	22
2	Hydrogen Fluoride	HF	95	34	24
3	Carbon Monoxide	CO	420	1590	83
4	Hydrogen Cyanide	HCN	17	10	7.1

The AEGL3 concentrations are listed in Table 8 [19].

Table 8: AEGL3 Concentrations (ppm) for Toxic Components

No.	Component	Symbol	10 min	30 min	60 min
1	Hydrogen Chloride	HCl	620	210	100
2	Hydrogen Fluoride	HF	170	62	44
3	Carbon Monoxide	CO	1700	600	330
4	Hydrogen Cyanide	HCN	27	21	15

Toxic exposures were tracked at the above concentrations for HCl, HF, HCN and CO. For high toxic concentration case of lower hydrogen generation lasting less than 15m, the exposure time concentrations for 30 minutes were selected for the analysis.

6.4.2 Exposure to Carbon Dioxide

The gases emitted in a thermal runaway contain significant amounts of CO_2. Exposure to CO_2 can cause adverse health effects.

An AEGL for CO_2 is not defined. SADP Code 21 [1] states that in the absence of AEGL values, Emergency Response Planning Guidelines (ERPG) can be used. However, ERPG is also not defined for CO_2. The third option is to evaluate exposure to toxic concentrations that could produce adverse health effects. The dose-response relationship for CO2 exposure is listed in [20].

Table 9: Acute Health Effects of Exposure to Carbon Dioxide

Concentration of CO_2 (%)	Exposure duration	Effects
3	1 hour	Mild headache, sweating, and dyspnoea at rest
4-5	Within a few minutes	Headache, dizziness, increased blood pressure, uncomfortable dyspnoea
6	1-2 minutes <=16 minutes Several hours	Hearing and visual disturbances Headache, dyspnoea Tremors
7-10	A few minutes 1.5 minutes to 1 hour	Unconsciousness, near unconsciousness Headache, increased heart rate, shortness of breath, dizziness, sweating, rapid breathing

The immediately dangerous to life and health (IDLH) for CO_2 has been set at 4% [21]. For the present study, a value of 3% has been selected as the exposure criterion, in the absence of AEGL or ERPG values.

6.4.3 Dispersion to AEGL-3 Concentrations

AEGL-3 concentrations are not required by SDAP Code 21 [1]. Fatality risk criteria have been specified for open space land use, and industrial land use. If it can be shown AEGL-3 does not extend offsite, then the fatality risk criteria is satisfied with respect to toxic and corrosive gases. This approach has been adopted in this study.

The dispersion modelling results are shown in Figure 7 to Figure 10 for HCl, HF, HCN and CO. Maximum footprints at a height of 1.5m from the ground did not result as the dispersing plume mostly remained at the height of release. Therefore, side views of the dispersion profiles are presented below.

Figure 7: Dispersion Profile (Side View) for HCl to AEGL-3

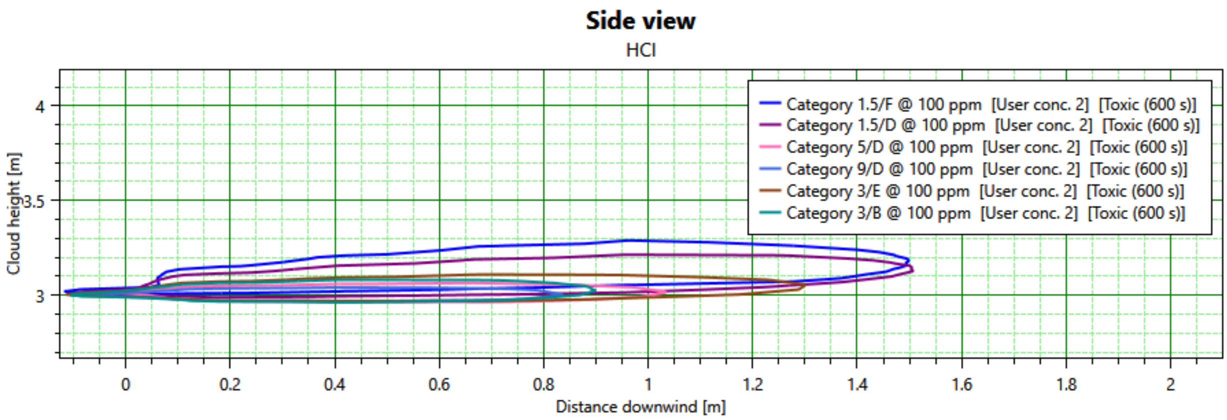


Figure 8: Dispersion Profile (Side View) for HF to AEGL-3

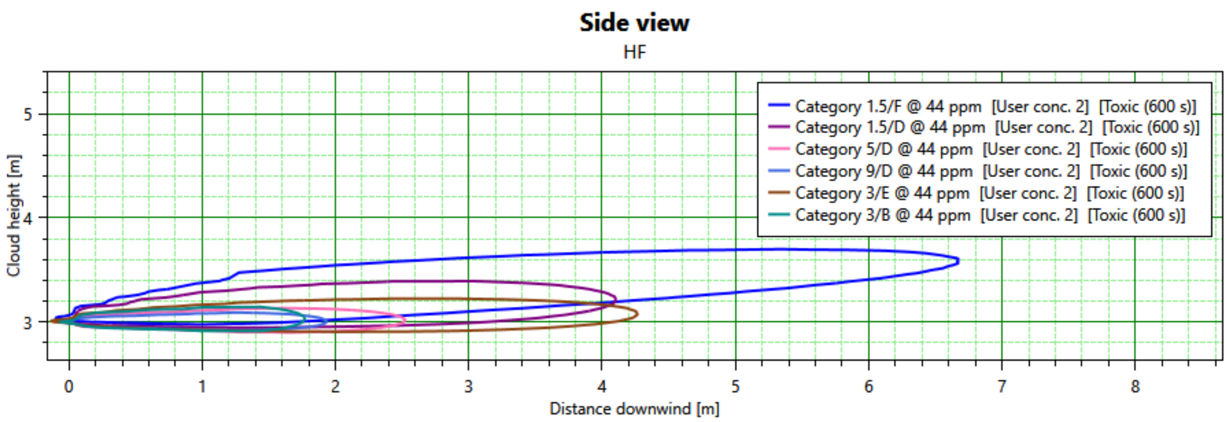


Figure 9: Dispersion Profile (Side View) for HCN to AEGL-3

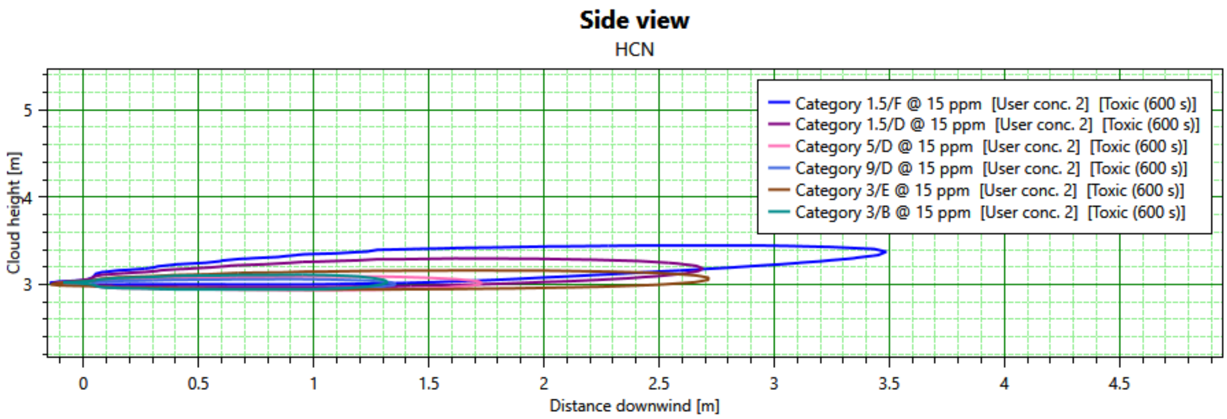
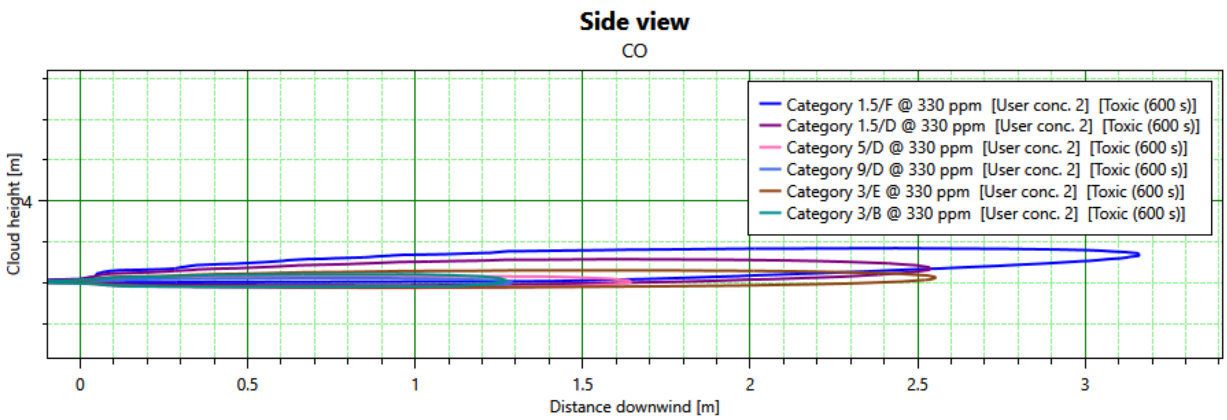


Figure 10: Dispersion Profile (Side View) for CO to AEGL-3



Findings from the dispersion modelling are summarised below:

- The dispersion profiles do not reach a level down to 1.5m above ground level (breathable concentrations), and remain essentially at the release height of 3m.
- Potentially lethal AEGL-3 toxic concentrations of HCl, HF, HCN and CO do not result at 1.5m above ground level, indicating that there are no lethal concentrations to people.

- The AEGL-3 concentration levels vary from 1.6m to 3.2m at release height and do not reach outside the site boundary, and there is no toxic lethality impact to personnel or public from the emission of off gases.
- Entry into the container for firefighting will require self-contained breathing apparatus to be worn by the fire fighters.

6.4.4 Dispersion to AEGL-2 Concentrations

The toxic concentrations at which a person exposed may experience adverse health effects are taken as the AEGL-2 levels.

The dispersion modelling results for AEGL-2 levels are shown in Figure 11 to Figure 14 for HCl, HF, HCN and CO.

Figure 11: Dispersion Profile (Side View) for HCl to AEGL-2

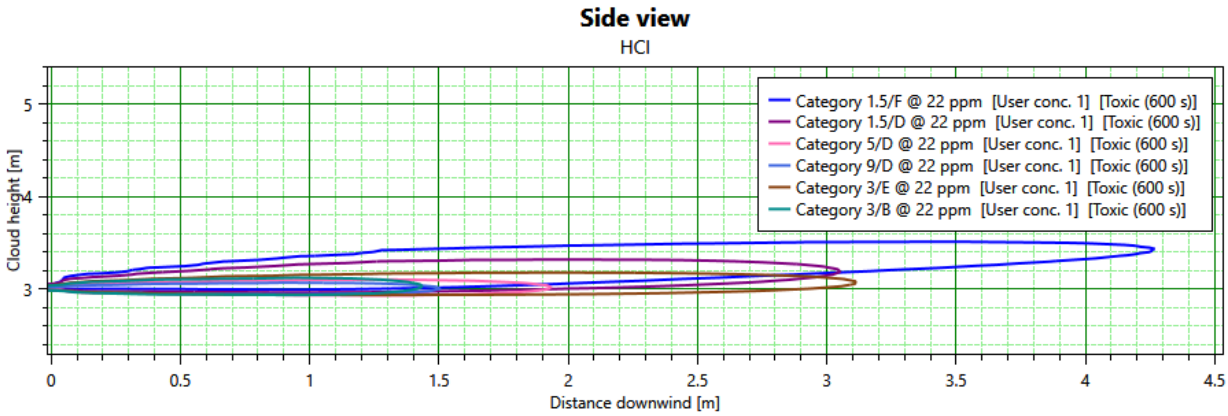


Figure 12: Dispersion Profile (Side View) for HF to AEGL-2

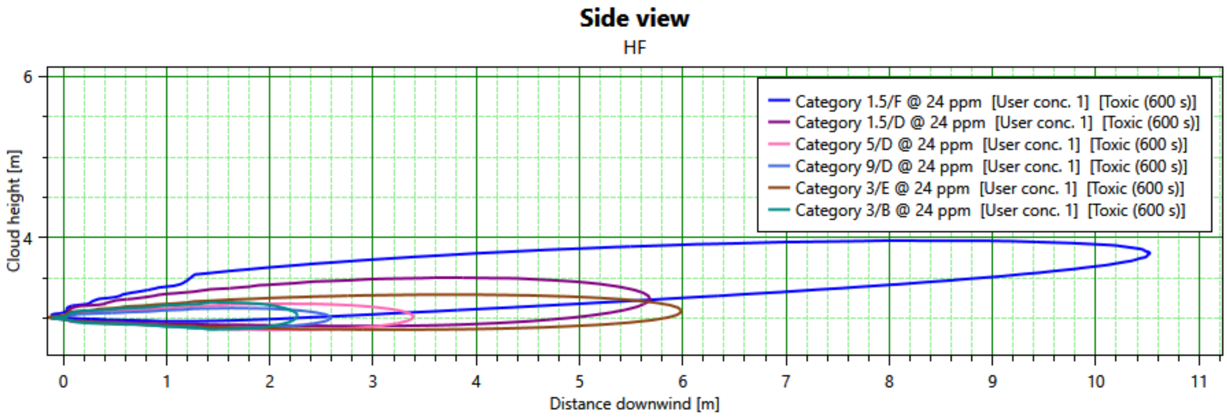
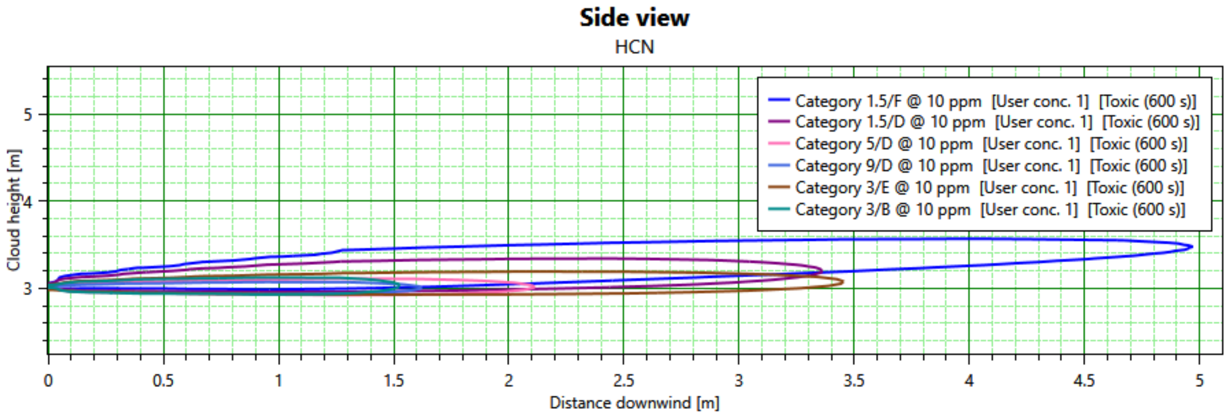
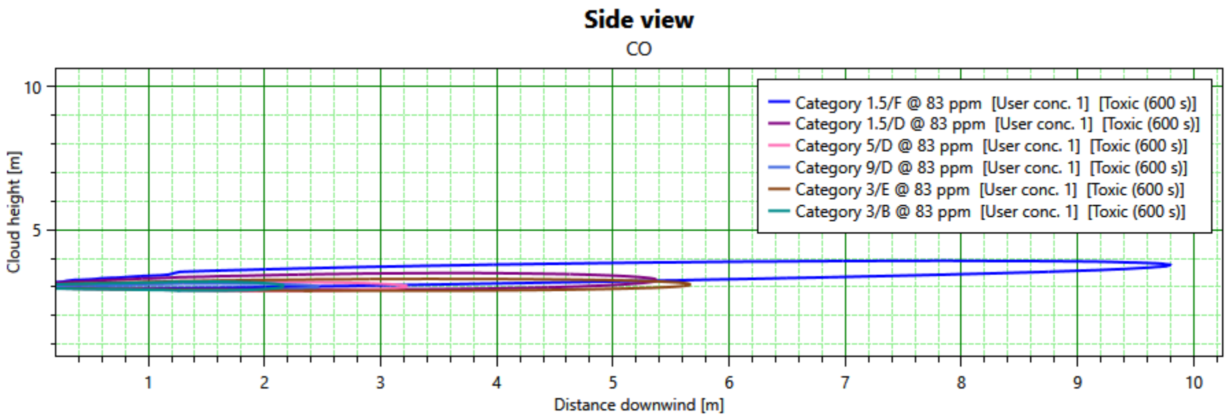


Figure 13: Dispersion Profile (Side View) for HCN to AEGL-2



Note: AEGL-2 for 60 minute exposure for HCN is 7.1 ppm. Phast 9.0 has a limitation that the minimum HCN concentration required to generate a dispersion profile is 10 ppm.

Figure 14: Dispersion Profile (Side View) for CO to AEGL-2



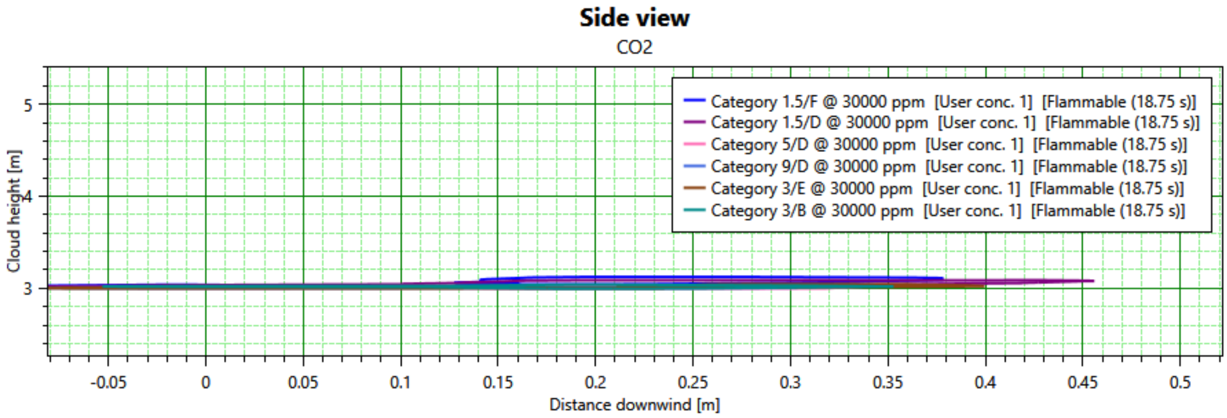
Findings from the dispersion modelling are summarised below:

- Toxic concentrations to AEGL-2 level for HCl, HF, HCN and CO do not reach ground level and there no adverse health effects are expected.
- The dispersion plume stays close to the height of release and extends downwind, covering distances ranging from 5 to 11m for the various toxic gases for low wind speeds and F stability class.
- F stability occurs for only 1.6% of time.
- A frequency assessment was not carried out because AEGL-2 concentrations do not extend beyond the site boundary.

6.4.5 Exposure to carbon Dioxide

The dispersion modelling results for CO_2 dispersion to 3% concentration are shown in Figure 15. Only the case with 5% Hydrogen in the off gases was modelled as this has a higher CO_2 concentration.

Figure 15: Dispersion Profile (Side View) for CO_2



- The dispersing plume stays at the release height and does not reach ground levels.
- The distance to 3% concentration is less than 1m and is local to the point of discharge
- There will be no adverse effect to people from the CO_2 emission in the off gases.

6.5 Battery Storage Container Explosion

When a battery string gets overheated, it produces off gases that are flammable and toxic.

The off gas composition in Table 5 does not show hydrogen. According to Ref. [12], hydrogen evolves as part of the off gases, and gets consumed in the process by the time the gas reaches the sensors and hence H_2 was not reported. A maximum of 30% hydrogen could be present (conservative). The DNV study [12] assumed 30% in the off gas and normalised the composition of the measured gas to arrive at the gas composition as it evolves from the battery pack.

The gas composition adjusted for hydrogen is shown in Table 10.

Table 10: Calculated Off Gas Contents Incorporating Hydrogen Content

Chemical	Name	% in off gas	
		5% H_2	30% H2
CO	Carbon Monoxide	19.04	13.60
CH_4	Methane	9.44	6.74
C_2H_6	Ethane	33.76	24.11
C_2H_4	Ethylene	9.76	6.97
H_2	Hydrogen	8.00	34.29
C_3H_8	Propane	7.52	5.37
C_6H_6	Benzene	0.48	0.34
C_7H_8	Toluene	1.12	0.80
C_2H_5OH	Ethanol	6.72	4.80
CH_3OH	Methanol	4.16	2.97
	Total	100.00	100.00
	Molecular weight	28.55	20.97

The off gas generation rate is calculated as follows (normalised to 25^{O}C):

- Overheating is assumed to evolve off gases until ignition occurs, after which the gas themselves would be combusted in the flame [22]. The duration to spread through a module is estimated to be 240-280 seconds [17]. The lower value was used for conservatism.
- One string assumed to be involved in the overheating, with 416 cells to a string.
- The capacity of a cell is (=314/416) 0.755 Ah (Ampere-hours). Total capacity overheating in a container is 314 Ah.
- Thus, the capacity emitting off gases = [314 Ah] /240 s] = 1.31 Ah/s. The emission, however, would be continuous as the runaway may escalate to other strings.
- Volume of off gases = 4 L/Ah [12].
- Density of off-gases = 1.1 kg/m^3 for 5% H_2 in the gases and 0.9 kg/m^3 for 30% H_2 in the gases.
- Off-gas generation rate: Volume of off-gases per string x Total Ah per string x gas density/ duration per string

The gas generation rates are summarised in Table 11.

Table 11: BESS Thermal Runaway Off-gases Generation Rates

Case	H_2 in off gas, %	Gas generation rate, kg/s	Toxic fraction in gas*	Flammable fraction in gas**
1	5	1.43E-03	5.24	59.6
2	30	1.17E-03	4.23	67.4

*Toxic fraction excludes CO, which is included in the flammable fraction

**Flammables fraction includes CO

6.5.1 Flammable Concentration in Container

The lower flammability limit (LFL) of the gas mixture in the container is calculated using the Le Chatelier principle as follows:

Table 12: Calculation of Lower Flammability Limit of Off Gas Mixture

Gas	LFL,% (v/v)
CO	12
CH_4	4.4
C_2H_6	3
C_2H_4	2.75
H_2	4
C_3H_8	2
C_6H_6	1.2
C_7H_8	1.1
CH_2OH	3.3
CH_3OH	6.7

$$LFL_{mixture} = \frac{\sum y_i}{\sum \frac{y_i}{LFL_i}}$$

Where y_i = mole fraction of component 'I' and LFL_i is the lower flammability limit (volume fraction) of component 'I'.

On a volumetric basis, LFL mixture = 5.64% (for 5% H_2 in off gas) and 4.17% (for 30% H_2 in off gas)

On a stoichiometric basis, the flammable concentrations = 12.56% (for 5% H_2 in off gas) and 9.65% (for 30% H_2 in off gas)

Free volume in container (i.e. volume not occupied by battery modules) = 9.91 m^3.

Mass of stoichiometric concentration of flammable gas = 1.16 kg (for 5% H_2 in off gas) and 0.69 kg (for 30% H_2 in off gas)

6.5.2 Explosion in Container with Exhaust Fan Activated

When 10% LEL hydrogen concentration is detected, the exhaust fan will start automatically. The ventilation fan capacity (v) is 820±15% CFM, which is 0.387±15% m^3/s.

v can also be expressed as an air change rate per hour (ACH) = v/V x 3600

ACH = 0.387x3600/10.69 = 130.3. This is very high degree of ventilation.

Flammables concentration in container is calculated as follows:

$$V\, dc/dt = v.\, c_0 - v.\, c + w$$

Where V = free volume in container; c = concentration in container kg/m^3; v = exhaust fan flow rate m^3/s; w = flammable off gas generation rate; and t = time; c_0 = flammable gas concentration in incoming air = 0.

Solving, c =(w/v) [1- exp(-v.t/V)].

Steady state concentration in the container = w/v.

The flammable concentration in the container with exhaust fan operating are shown in Table 13.

Table 13: Flammable Gas Concentrations in Container

H2 in Off gas	w kg/s (flammable)	C (steady state) = w/v kg/m^3	LFL mixture kg/m^3	Flammable mixture in container?	Max. % LEL in container
5%	7.22E-04	1.86E-03	6.22E-02	No	3.0
30%	6.0E-04	1.56E-03	3.36E-02	No	4.6

The flammable concentration in the container is less than 5% LEL, the fan would stay on as the concentration is > 2% LEL, but explosion is not expected.

6.5.3 Explosion in Container with Exhaust Fan Failure

If the exhaust fan fails to activate on demand, flammable gas concentration would build inside the container. If ignited, a confined explosion could occur. The maximum impact is expected at stoichiometric concentration of the flammable mixture.

The estimation of explosion effects is complex, and very often a 3-D computational fluid dynamic model is used that takes into account the flammable gas profile inside the container and ignition location. In this instance, for an approximate estimate, the TNT equivalent model has been used to calculate the explosion overpressure for the fan failure case.

Explosion results are summarised in Table 14.

Table 14: BESS Container Explosion Results for Exhaust fan Failure Case

H_2 in off gas	Mass of flammable mixture, kg	Distances (m) to Explosion Overpressure (kPa)			
		7	14	21	35
5%	1.16	10.4	6.6	5.1	3.7
30%	0.69	8.8	5.5	4.3	3.1

The consequences of explosion overpressure impacting on a receiver are summarised in Table 15.

Table 15: Explosion Overpressure Consequences

Explosion overpressure, kPa	Distance from Container, m	Consequences	Offsite Impact?
7	10.4	Damage to battery pack Injury to personnel on site	No
14	6.6	Damage to battery pack Injury to personnel on site	No
21	5.1	Major damage to container Potential for damage to adjacent container	No
35	3.7	Escalation to adjacent BESS container and damage to battery package in adjacent container	No

In all these cases, the explosion effects would be contained within the site.

6.6 Electrical Hazards

6.6.1 Transformer Fire

The BESS output in DC is converted into ultimate grid voltage of 275 kV AC through a series of power transformers.

The transformer oil total volume in the power transformer can be up to 10,000-12,000 L. The transformer is located in a bund. For the current analysis, a conservative value of 12,000L is assumed.

6.6.2 Impairment Criteria

The levels of heat radiation selected to examine the heat effects were 4.7, 12.6, 23, 30, and 37.5 kW/m^2, as given in HIPAP No.4 [23].

The general effects of these levels of heat radiation are summarised in Table 16. These heat flux radiation effects are widely accepted by industry and is appropriate for this analysis.

Table 16: Heat Radiation Effects

Heat Radiation (kW/m^2)	Effect
4.7	Maximum heat radiation level to which fire-fighting personnel may be exposed.
12.6	Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure. 30% chance of fatality for long exposure. High chance of injury.
23	Unprotected steel will reach thermal stress temperatures to cause failure. Pressure vessels need to be relieved, or failure will occur. 100% chance of fatality for long exposure and 10% chance of fatality for instantaneous exposure.
37.5	100% chance of fatality for instantaneous exposure.

6.6.3 Material Modelled

The transformer oil is a mineral oil, comprising of hydro-treated light naphthenic and paraffinic distillates. On this basis, hexadecane (C16) was selected as a representative single component material for the consequence modelling.

PHAST 9.0 models both the luminous and smoky part of the flame for calculating thermal radiation impact distances.

6.6.4 Pool Fire Results

The results in the following table represent the maximum ground level impact distance measured from the centre of the bund in a downwind orientation. The flame height represents the length of the flame from the pool surface to the tip of the flame.

The transformer is to be bunded to contain the contents of the tank, 12000L, and a quantity of fire water applied. An 8m equivalent diameter bund of 300mm height is assumed for the study.

The heat radiation hazard zones are determined using PHAST 9.0. The bund fire was modelled as a circular pool with an equivalent area to that of the area of the rectangular bund (equivalent 8m diameter).

Table 17: Transformer Bund Fire Characteristics

Parameter	Value
Material	Hexadecane
Pool diameter	8m
Flame height	10.9m
Burn rate	2 kg/s
Surface emissive power (luminous part of flame)	86.4 kW/m^2
Surface emissive power (smoky part of flame)	64.6 kW/m^2

Table 18: Transformer Bund Pool Fire Heat Radiation Impact Distances

Stability Class /Wind Speed	Flame Tilt by Wind (deg)	Distance to heat radiation kW/m^2 (m)			
		4.7	12.6	23	35
B3	43.7	22.2	15.6	12.0	8.3
D 1.5	30.3	21.4	14.3	10.4	7.5
D 5	52.7	22.4	16.1	13.2	8.9
D 9	61.4	22.2	16.7	14.2	9.6
E3	43.7	22.2	15.6	12.0	8.3
F1.5	30.3	21.4	14.3	10.4	7.5

The maximum distance to 4.7 kW/m2 is 22-23m and lies within the site boundary with no potentially injurious offsite effects. The separation distances between transformers and to protected works on site is specified in AS-2067 (2016) [24].

The transformers must be either physically separated or separated by fire rated walls to prevent escalation of one transformer fire to an adjacent transformer.

From fire hydrants available, the fire can be fought with fire water and foam.

It is necessary that that all bund penetrations, including conduits, are sealed with a suitable fire-resistant packing or sealant.

6.7 Natural hazards

PO 10 specifies the following natural hazards to be addressed.

a. flood;
b. bushfire;
c. erosion;
d. storm tide inundation;
e. landslide;
f. earthquake;
g. wind action.

6.7.1 Flood and Storm Tide Inundation

A flood assessment with hydrological modelling was conducted by WMS Engineering [2]. The flood maps generated are provided in Appendix C of Ref. [2] and not repeated here.

The study found that stormwater flows are contained within the natural channel traversing through the site (north-to-south), with the channel banks breached near the southern boundary of the site. Flows from the watercourse traversing the site do not encroach any of the battery stations for the 0.5% Annual Exceedance Probability (AEP) storm event (defined flood event).

The modelling of overland flows from rains indicated that flow depths traversing the site are collected and conveyed via the natural channels, with modelled flow depths in the channels typically in the range of 0.5 m to 1.5 m for the 1% AEP and 0.5% AEP events.

The study concluded that the switchyard and key electrical components are immune to stormwater and riverine flooding up to and including the 0.1% AEP storm event.

6.8 Bushfire

A bushfire assessment and management report for the site and development has been prepared by Eldon Bottcher Architect Pty Ltd [7].

The study found the following:

The predominant vegetation in the area, which is located approximately 500m to the east/west of the proposed development, consists of two types: (a) Moist to dry eucalypt woodland on coastal lowlands and ranges, and (b) spotted gum dominated woodlands.

The bushfire modelling indicated that thermal radiation from a bushfire on the electrical infrastructure on the site would be less than 1 kW/m^2. This is less than the solar radiation on a summer day.

Buildings constructed to the National Construction Code would be sufficient to withstand the impact of a potential bushfire.

The bushfire management plan recommends a number of actions for mitigating the potential effects of an external bushfire.

6.9 Seismic and Earthquake Hazards

Geoscience Australia data, Nov 2023 [25], the National Earthquake Hazard Map of Australia was reviewed as part of this study. The map is a research product that can inform the hazard component of Australia's earthquake loading code AS1170.4 – 2024 along with other uses.

Geoscience Australia has developed the National Seismic Hazard Assessment (NSHA) for Australia [25]. The NSHA defines the level of earthquake ground shaking across Australia that has a likelihood of being exceeded in a given time period. Ground shaking is represented by 'g' (gravity, 981 cm^2/s). Figure 16 shows NSHA 18 peak ground acceleration(PGA) with a 10% chance of exceedance in 50 years.

Two major parameters are essential for a qualitative estimate of earthquake damage potential.

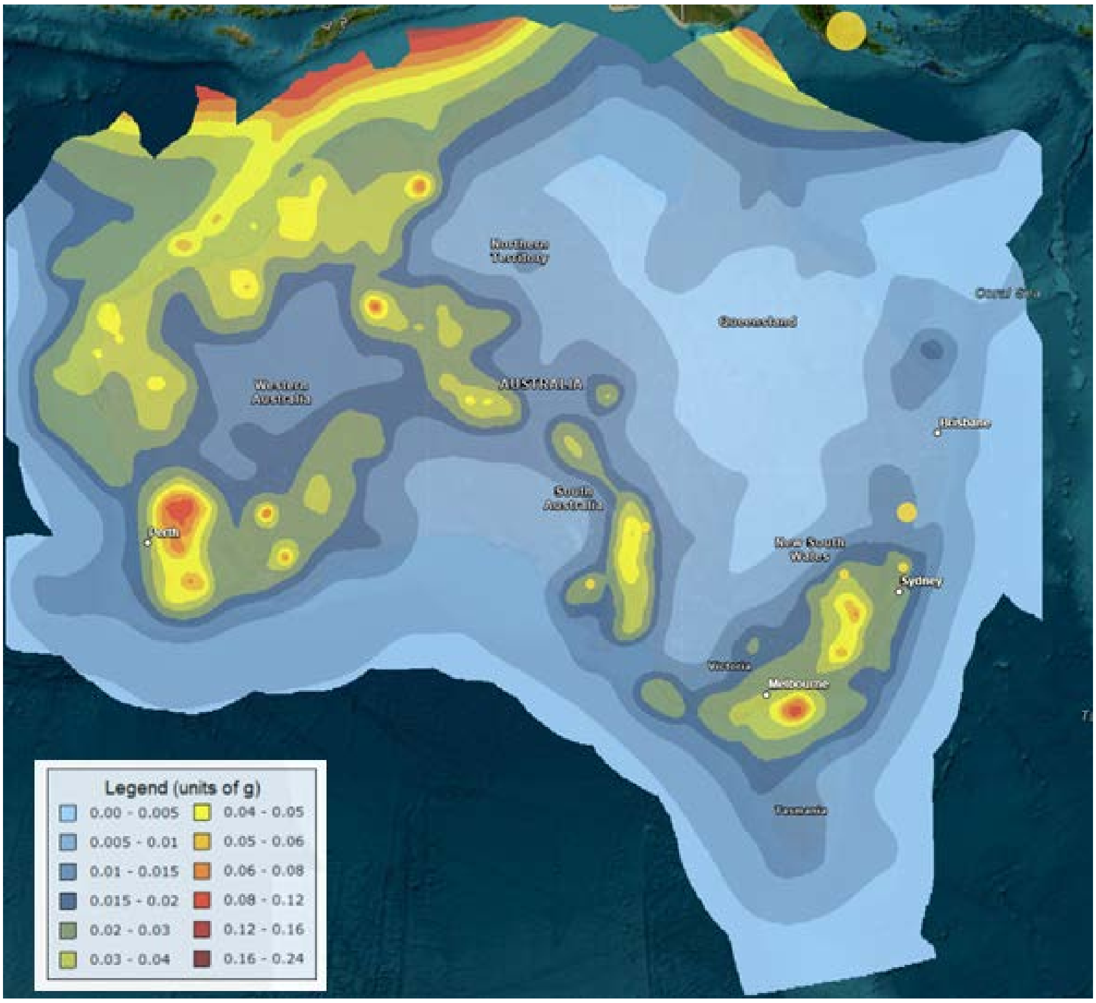
(a) The peak ground acceleration (PGA), expressed in 'g's.

(b) The Modified Mercalli Index (MMI), which is a measure of the extent of perception of the shaking and potential damage.

Based on the above Geoscience Australia data, the current Earthquake hazard map of Queensland (in AS1170.4 - 2024) suggests that the state has low levels of seismicity and earthquake hazard, sufficient for earthquake loading, like wind loading, to be taken into account in normal structural design (See Figure 16).

The Rutherglen site falls in the area of 'g' ranging from 0.005-0.01, indicating very low ground acceleration from seismic activity.

Figure 16: Peak ground acceleration with a 10% chance of exceedance in 50 years



There is no correlation between PGA and MMI, and any relationship is empirical and has to be derived from seismic data for a specific region. An approximate correlation has been developed by US Geological Survey (USGS) [26], [27], and shown in Figure 17.

Figure 17: Relationship between MMI and PGA

Standard USGS Conversion of MMI to PGA (%g) Values									
Near-Source Modified Mercalli Intensity (MMI)	I	II-III	IV	V	VI	VII	VIII	IX	X
Maximum Peak Ground Acceleration. (PGA) in %g	< .17	.17 – 1.4	1.4 - 3.9	3.9 - 9.2	9.2 - 18	18 - 34	34 - 65	65 - 124	> 124
Perceived shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential Damage	None	None	None	Very Light	Light	Moderate	Moderate / Heavy	Heavy	Very Heavy

It is seen that for 1%g, the MMI is II-III , indicating that perceived shaking is “weak” and potential damage is “None”. USGS reports the following [27]:

MMI II: Shaking is weak, and felt only by a few persons at rest in upper floors of buildings.

MMI III: Shaking is weak and felt noticeably by people on upper floors of buildings. Many people do not recognise it as an earthquake. Vibration similar to the passing of a truck.

It is concluded that the proposed BESS facility is in a very low intensity earthquake impact region.

6.10 Extreme Weather

While there have been many tropical cyclones (TCs) along the cost of Queensland over the years, most of them have been to the north of Gladstone. There have been only 3 cyclones south of Gladstone: Marcia in February 2015 (near Rockhampton) [28], Oma in February 2019 (Queensland coast) and Alfred (South East Queensland).

A review of past tropical cyclones was conducted [29]. From 2000 to 2025 (25 years), twenty eight (18) cyclones have crossed the coast of Queensland. Of these only 3 of them have to the south of Gladstone. There have been no cyclones reported in the Gladstone region during this period.

The risk of cyclone damage for the site is considered low.

7 EVALUATION AGAINST PERFORMANCE OUTCOMES IN STATE CODE 21

This section discusses the hazard evaluation against performance outcomes (POs) in State Code 21 [1].

The State Code 21 Version 3 has removed a risk criteria for fatality risk in sensitive (residential) and vulnerable (schools, childcare, hospitals, aged care facilities etc), and commercial land uses, and instead based on dangerous dose consequences alone.

7.1 Off-site impacts—vulnerable land use or land zoned for a vulnerable land use

PO1 The hazardous chemical facility does not create a dangerous dose to human health

To meet the above Outcome, the following criteria need to be met.

7.1.1 Thermal radiation

Areas outside the facility boundary shall not be exposed to heat radiation exceeding 4.7 kW/m^2

The longest distance of impact for 4.7 kW/m^2 is 23 m for a transformer fire. This radiation level does not reach offsite.

Therefore PO1 for thermal radiation is met.

7.1.2 Explosion

Areas outside the facility boundary shall not be exposed to an overpressure greater than 7 kPa, except industrial land use which shall not exceed 14 kPa.

The ventilation of BESS containers can maintain the flammable gas concentration of off gases from thermal runaway to 2% of LEL and hence an explosion is prevented.

Therefore PO1 for explosion is met.

7.1.3 Toxic Gas Exposure

For toxic or corrosive gases – an effect that equals or exceeds the following:

a. AEGL-2 (60 minutes).

b. where a corresponding AEGL is not available – ERPG-2; or

c. where a corresponding ERGP-2 is not available – a concentration that is likely to produce the following effects:

i. severe distress to almost all people; or

ii. a substantial proportion of people require medical attention; or

iii. some people are seriously injured, requiring prolonged treatment; or iv. highly susceptible people might be fatally injured.

The toxic gases present in the thermal runaway off-gases are HCl, HF, HCN and CO. It also contains carbon dioxide (CO_2).

It was found that the AEGL-2 distances for toxic gas concentrations are contained entirely within the site. There are no AEGL or ERPG values defined for CO_2. A 3% exposure concentration was adopted as criterion for impairment.

It was found the 3% CO_2 concentration plume was localised near the point of discharge and does not reach ground levels. Therefore PO1 for toxic exposure is met.

7.2 Off-site impacts—sensitive land use or land zoned for a sensitive land use

PO2 The hazardous chemical facility does not create a dangerous dose to human health

7.2.1 Thermal radiation

The longest distance of impact for 4.7 kW/m^2 is 23m for maximum wind tilt angle from vertical. This distance lies within the site.

Therefore PO2 for thermal radiation is met.

7.2.2 Explosion

There are no explosion consequences as the ventilation fan keeps flammable gas concentrations in container at 2% LEL.

Therefore, PO2 in terms of explosion is met.

7.2.3 Toxic Exposure

The same arguments as in Section 7.1.3 equally apply here, and hence PO2 in terms of toxic exposure is met.

7.3 Off-site Impacts - Commercial or community activity land use

PO3 - The hazardous chemical facility does not create a dangerous dose to human health

7.3.1 Toxic exposure

The arguments put forward for PO1 and PO2 equally apply to PO3 in this instance, and not repeated here.

Therefore PO3 for toxic exposure is met.

7.4 Off-site impacts—open space land use or land zoned for an open space land use

PO4 - The hazardous chemical facility, does not create:

a. a dangerous dose to human health; or

b. where (a) cannot be achieved, an individual fatality risk level of 10x10^{-6}/year and the societal risk criteria in figure 21.1

The Erimbula National Park abuts the eastern boundary of the site. The park boundary is 2.3 km from the nearest BESS container. A thermal radiation of 4.7 kW/m^2 does not reach the national park boundary.

The maximum distance from the container to AEGL-2 concentration of any of the toxic or corrosive gases is less than 15m which lies entirely within the site boundary. The CO_2 concentration is localised near the point of discharge.

Therefore PO4 is satisfied.

7.5 Off-site impacts—industrial land use or land zoned for an industrial land use

PO5 - The hazardous chemical facility, does not create either of the following:

a. a dangerous dose to the built environment; and

b. an individual fatality risk level of 50x10^{-6}/year.

Dangerous dose to the built environment means an effect from fire or explosion that equals or exceeds the following:

1. 12.6 kilowatts per square metre for heat radiation; or

2. 14 kilopascals for explosion overpressure

7.5.1 Thermal Radiation

The maximum distance to 12.6 kW/m^2 is 17 m from a transformer fire. This would reach outside the site boundary.

Therefore PO5 is met for thermal radiation consequences.

7.5.2 Explosion

As discussed above, no explosion consequences are expected from BESS unless a thermal runaway occurs with generation of flammable gases with simultaneous failure of the ventilation system. The safeguards proposed ensure that such a situation is extremely unlikely.

7.5.3 Toxic exposure

The distances to AEGL-2 remain within the site boundary. There for PO 5 is met for toxic exposures.

Since toxic impact is contained within the site boundary, the risk criteria for fatality in (a) above in PO 5 is satisfied.

7.6 Storage and Handling Areas for fire risk hazardous Chemicals

PO6 - Storage and handling areas for fire risk hazardous chemicals are provided with a 24-hour monitored fire detection system that has the ability to detect a fire in its early stages and notify an emergency responder at all times.

There are no fire risk hazardous materials other than the BESS battery packs. Fire detection and suppression system is provided. Therefore PO6 is met.

7.7 Storage and Handling Areas for Packages

PO7 Storage and handling areas for packages of liquid or solid fire risk hazardous chemicals are provided with a spill containment system with a working volume capable of containing a minimum of 100 percent of all packages (prescribed hazardous chemicals and/or non-hazardous chemicals) within the area plus the output of any fixed firefighting system provided for the area over a minimum of 90 minutes.

There is no packaged chemicals storage. Therefore PO7 is not applicable.

7.8 Storage and handling areas for liquid or solid fire risk hazardous chemicals in tanks

PO8 Storage and handling areas for liquid or solid fire risk hazardous chemicals in tanks are provided with a spill containment system with a working volume capable of containing a minimum of:

a. 110 percent of the largest tank within a spill compound or 25 percent of the aggregate where multiple tanks are located within a spill compound, whichever is the greater; and

b. the output of any fixed firefighting system provided for any bulk tank within a spill compound over a minimum of 90 minutes.

There are no fire risk substances in tanks. Therefore, PO8 is not applicable.

7.9 Storage and handling areas for prescribed hazardous chemicals

PO9 ***Storage and handling areas*** *for* ***prescribed hazardous chemicals*** *that, if in contact with each other, may react to produce a fire, explosion or other harmful reaction, or a flammable, toxic or corrosive vapour are designed to prevent contact between the* ***prescribed hazardous chemicals****.*

There are no chemicals stored or handled on the site. Therefore, PO 9 is not applicable.

7.10 Natural Hazards

PO 10 Development is designed and sited to mitigate impacts on ***storage and handling areas*** *from* ***natural hazard*** *including, but not limited to:*

a. flood;

b. bushfire;

c. erosion;

d. storm tide inundation;

e. landslide;

f. earthquake;

g. wind action.

The hydrological study for the site [2] has concluded that the electrical integrity on the site would not be affected by stormwater flows or inundation.

The bushfire study for the site [7] has found that the thermal radiation on site infrastructure is < 1 kW/m2, indicating no adverse impact from bushfires. A bushfire management plan has been prepared.

The site is located in low seismic activity area.

Extreme weather event potential is low for the Gladstone region, from a review of historical cyclone events in Queensland in the last 25 years.

PO 10 is considered to be satisfied.

7.11 All Development

PO 11 Development is designed and sited to mitigate the risks from ***hazard scenarios*** *occurring at existing* ***hazardous chemical facilities****.*

The proposed development is a new facility and not an existing facility. Therefore, PO 11 is not applicable.

8 FINDINGS AND RECOMMENDATIONS

8.1 Findings

The key findings of the assessment include:

- The thermal radiation, explosion and toxic gas effects of BESS fires would be confined within the site and there would be no potentially injurious offsite effects. The separation distance between containers should enable approach of the fire by firefighting personnel; however, if entry into a container is required for firefighting this will require self-contained breathing apparatus due to toxic fumes.
- Toxic gas concentrations that produce injury or irritation level are confined entirely within the site boundary.
- The thermal radiation impacts from transformer fires are confined within the site boundary with no potentially injurious offsite effects.
- The Rutherglen BESS development complies with the performance outcomes specified in Queensland State Code 21.

8.2 Recommendations

Recommendations based on the key findings of the assessment include:

1. The transformers in separate bunds should be protected by firewalls if a separation distance of 10m from each other cannot be achieved.
2. Calibration of the combustible gas detector and function testing of the exhaust fan start on gas detection must be carried out at schedule intervals to ensure reliability. Half-yearly testing is recommended.
3. An alarm should be installed to indicate failure of exhaust fan in the containers when operational.
4. The Emergency Response Plan for the proposed development should address the specific hazards identified in the hazard analysis (e.g. battery overheating, fires, explosions etc.) and ensure emergency response personnel take appropriate precautions to protect themselves from the hazards and escalating events.
5. Design the transformer bund to contain 110% of the oil volume in the transformer tank and firewater applied as per NFPA 855-2020.
6. Develop a schedule for function testing of the electrical protection and fire protection safeguards (alarm and trip systems) to ensure reliability and integrity, at specified intervals.

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