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Fire Safety Study (FSS)

Supernode North – Battery Energy Storage System (BESS)

Issued to: Private Energy Partners

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Abbreviations

AEMO	Australian Energy Market Operator
AFAC	Australian Fire & Emergency Services Authorities Council
AGC	Automatic Generation Control
AHJ	Authority Having Jurisdiction
APZ	Asset protection zone
AS	Australian Standard
ATEX	Atmosphere Explosible (European Union Directive)
BCA	Building Code of Australia
BESS	Battery Energy Storage System
BMP	Bushfire Management Plan
BMS	Battery Management System
CFA	Country Fire Authority (VIC)
CFD	Computation Fluid Dynamics
EDQ	Economic Development Queensland
EMP	Emergency Management Plan
ESIP	Emergency service information package
FDS	Fire Dynamics Simulator
FIP	Fire Indicator Panel
FRNSW	Fire Rescue New South Wales
FSS	Fire Safety Strategy
HAZID	Hazard Identification
LCO	Lithium Cobalt Oxide
LFL	Lower Flammability Limit
LFP	Lithium Iron Phosphate
LOP	Layers of Protection
MSDS	Material Safety Datasheet
NCC	National Construction Code

NFPA	National Fire Protection Association (USA)
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology (USA)
NMC	Nickel Manganese Cobalt
NSP	Network Service Provider
PCU	Power Conditioning Unit
PPE	Personal Protective Equipment
QFD	Queensland Fire Department
QLD	Queensland
RFS	Rural Fire Service (QLD)
SBMU	Slave Battery Management Unit
SFPE	Society of Fire Protection Engineering
STEL	Short Term Exposure Limit
TWA	Time Weighted Average (relating to exposure limit)
UFL	Upper Flammability Limit
UL	Underwriters Laboratory
UPS	Uninterrupted Power Supply
VOC	Volatile Organic Compound
WEL	Work Exposure Limit

1 Executive Summary

1.1 APPOINTMENT

Private Energy Partners has appointed Halliwell Pty Ltd to provide a Fire Safety Study of the fire hazard associated with the BESS yard, transmission line and associated substation, approximately located at 128 Manton Quarry Road, Calcium, QLD, 4816.

1.2 INTENT OF THIS DOCUMENT

This fire safety study has been prepared to outline the credible fire hazard consequence associated with the equipment on site and to outline our fire safety recommendations as a result of the modelling outcomes, facilitating stakeholder consultation, detailed design and management for the development. It is expected that the information, site equipment and associated hazard modelling will be revalidated at detailed design stage.

This Executive Summary provides background information, advice on the layout of the report, a summary of the most pertinent modelling results and the Fire Safety Recommendations.

1.3 BACKGROUND

It is understood that there are three main stages planned as part of this project, with each stage containing approximately 220 m x 125 m of BESS, equating to 390 units with a total storage capacity of 2.201 GWh and discharge power of 275 MW. Additionally, a High-Voltage Substation and water storage are with associated fire-water tanks are also planned to be located on site. All three BESS stages and associated infrastructure will generally be located on land parcel 19SP321818, which is located at approximately located at 128 Manton Quarry Road, Calcium, QLD, 4816. Local access with the BESS yard is via Bidwilli Road, just off the Flinders Highway.

1.3.1 Layout of the Report

Sections 2-3 provide background to the site and relevant information pertaining to the fire safety study.

Section 4 provides identification of relevant onsite hazards, as well as materials associated with the relevant hazard scenarios.

Section 5 details the intent, assumptions and input parameters for the chosen hazard modelling scenarios, as well as a detailed breakdown of the dispersion and heat transfer results. Results are presented in both tabulated and visual image format, providing elevation slices, plot plan views and/or 3D iso-surface representation where applicable, to facilitate contextualisation of results.

Section 6 provides a review of the layers of safety expected to feature in the site's fire strategy.

Section 7 then provides a more detailed review of the fire safety strategy philosophy and Emergency Management approach of the site, based on the current level of schematic design.

Note that relevant equipment specifications and corresponding hazard analyses by others are presented in the Appendices, and additional modelling results visualisations are presented in Appendix D.

1.4 SUMMARY OF MODELLING RESULTS AND FINDINGS

Two (2) primary hazard scenarios have been modelled. The inputs to these models and the modelling outcomes are outlined in detail in Section 6 of this report:

1. BESS battery leak (off-gas)
2. BESS unit fire

Each scenario has been modelled under typical wind conditions (0 m/s, 2.5 m/s) and strong wind conditions (avg. site max = 5.0 m/s) based on historical and more recent measured site data. In most cases maximum dispersion was achieved under the strong wind conditions. (STEL/TWA – please refer Section 4.2.2 for definitions).

Our recommendations are based upon these most onerous outcomes, which are summarised below.

Note: a supplementary assessment investigated the BESS unit exhaust which was successful in mitigating the build-up of a flammable/explosive atmosphere within the unit. Refer Section 5 for full details and results.

Table 1. Off-Gas Dispersion Most Onerous (Case 3)

Material	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	50 m (downwind)	250 m (downwind)	CO STEL may occur up to 50 m downwind. CO 8hr TWA may occur up to 250 m of the BESS plot. Flammable concentration <10 m source
Carbon Dioxide (CO_2)	<10 m from source	30 m (downwind)	
Hydrogen (H)	<10 m from source	<10 m from source	
Methane (CH_4)	<10 m from source	<10 m from source	

This can be visualised as follows:

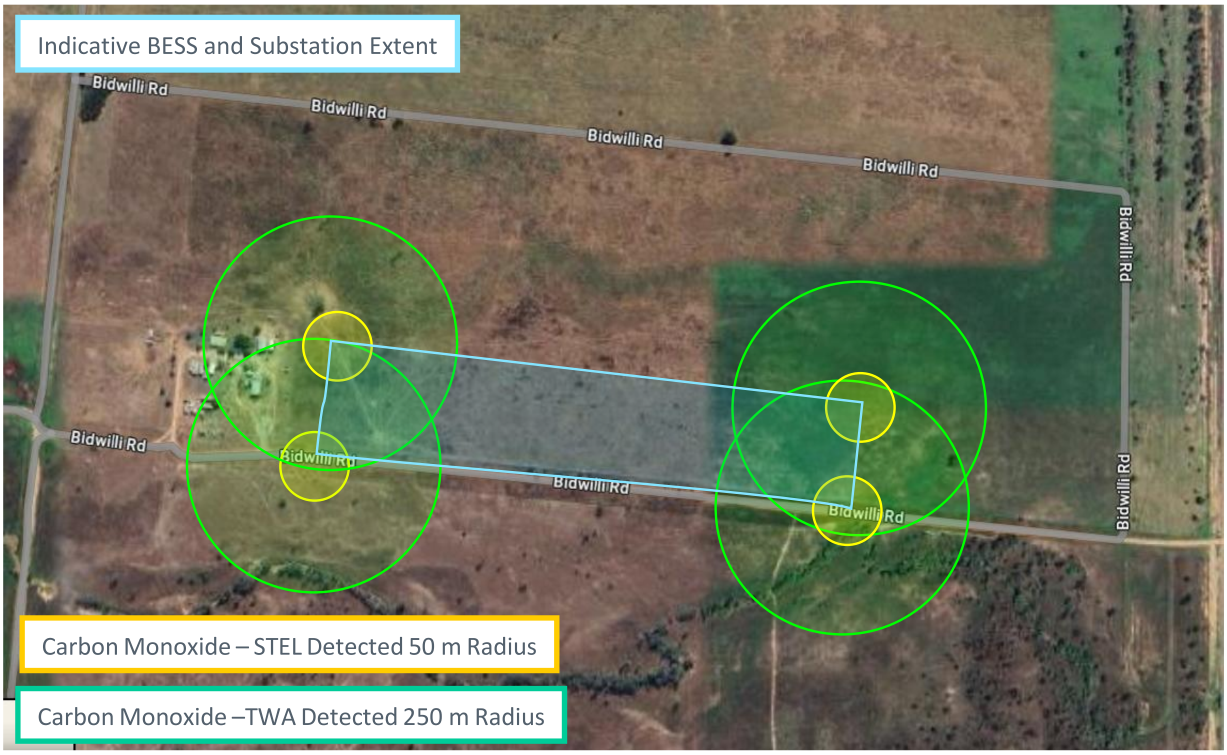

Figure 1. BESS Off-Gas -Dispersion Contours – Case 3

Table 2. BESS Fire Dispersion Most Onerous (Case 9b)

Material	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	At source	At source	5m/s aligns with the reported max avg. annual wind STEL for HCL, HF, NOx and SOx observed 10-40m downwind. TWA for HCL, HF, NOx and SOx observed 30-60m downwind. This higher wind pressure appears to be suitable to migrate gas effectively before significant dilution c. 50m+ downwind. **Recommend STEL considered as 50m downwind.**
Carbon Dioxide (CO_2)	At source	At source	
THC (methane) (CH_4)	At source	At source	
Hydrogen Chloride (HCL)	25 m downwind	45 m downwind	
Hydrogen Fluoride (HF)	45 m downwind	50 m downwind	
Nitric Ox/Nitro Diox (NOx)	20 m downwind	45 m downwind	
Sulphur Dioxide (SOx)	15 m downwind	30 m downwind	

This can be visualised as follows:

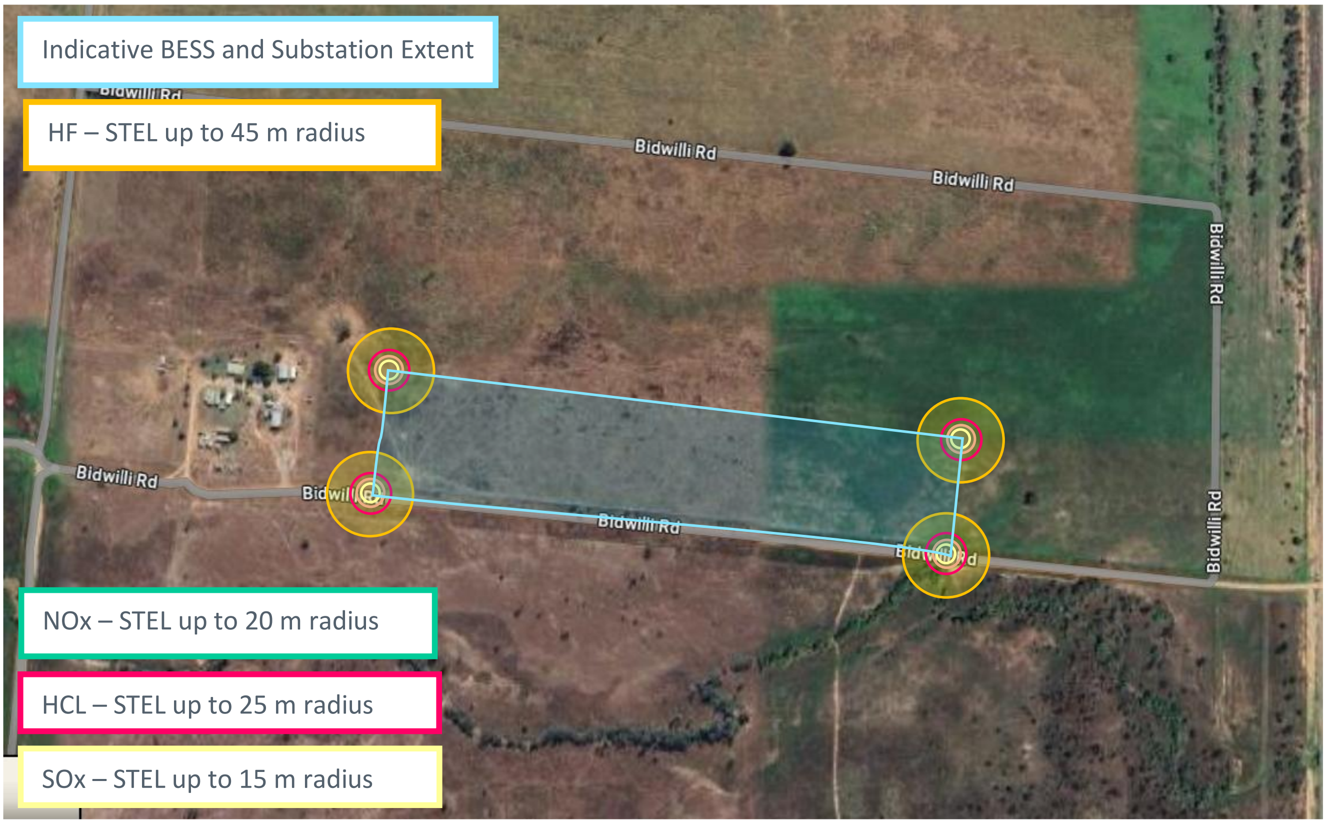

Figure 2. BESS Fire - Dispersion Contours – Case 9b (STEL)

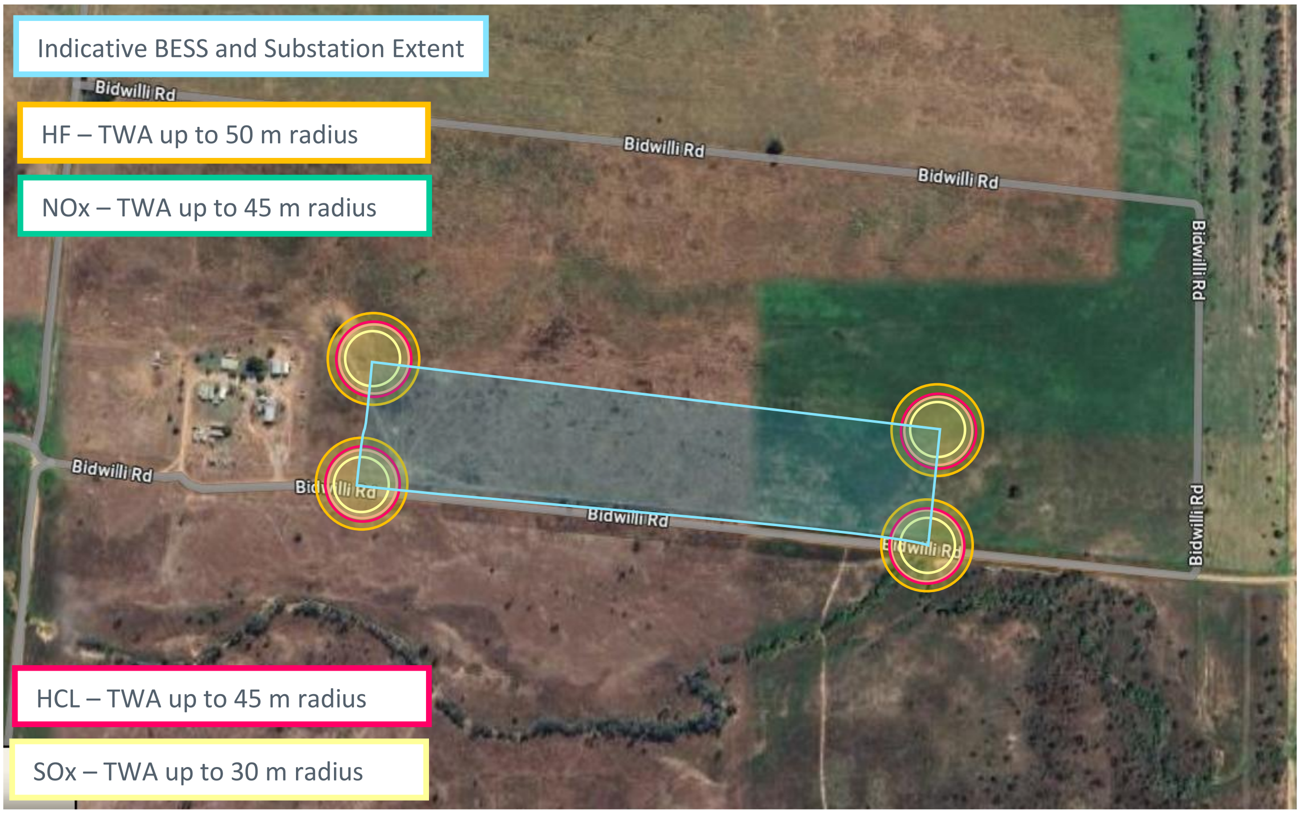

Figure 3. BESS Fire - Dispersion Contours – Case 9b (TWA)

Table 3. Results Data – Case 10a – BESS Unit fire (thermal exposure to surrounding equipment)

BESS fire	Target	Flux (kW/m^2)	Distance (m)	Expected Impact at Target
BESS Unit	Far side of nearest road	~15.0	7.0	< 25 kW/m2, for non-piloted ignition
BESS unit	Nearest BESS unit	21.0	3.0	< 25 kW/m2, for non-piloted ignition / Negligible impact to equipment
BESS unit	Nearest PCU	9.0	6.0	Negligible impact to equipment.

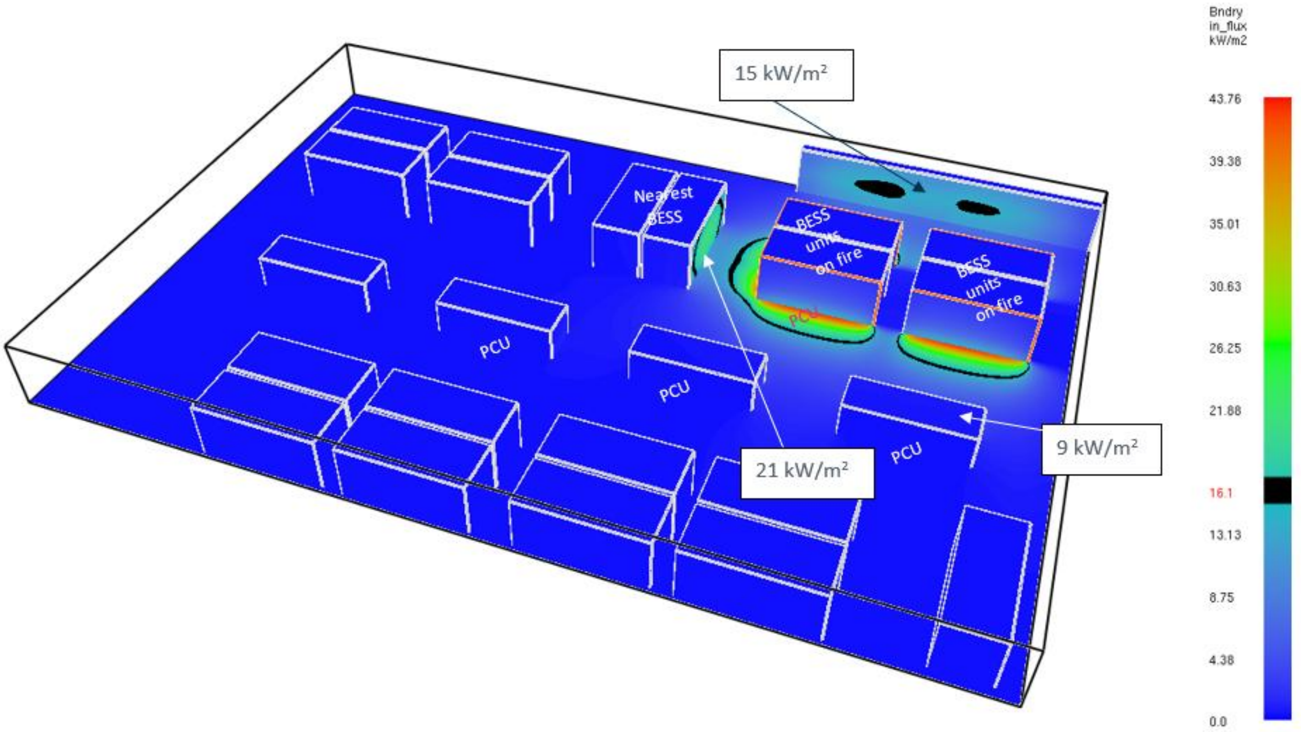

Figure 4. Radiant Heat Flux Analyses between BESS Units and Surrounding Equipment

Table 4. Results Data – Case 10a – BESS Unit fire (thermal exposure to personnel)

BESS side	Flux (kW/m^2)	Distance (m)	Relevance	Exposure Time period	Notes
Long side	2.5	14	Persons with long sleeves and trousers	30 secs +	These time limits for exposure prior to pain are a guide only and real outcomes depend upon on site conditions, weather and individual tolerance levels.
Long side	4.6	11	Fire Brigade in full PPE	Up to 3 min	
Narrow side	2.5	12	Persons with long sleeves and trousers	30 secs +	
Narrow side	4.6	9	Fire Brigade in full PPE	Up to 3 min	

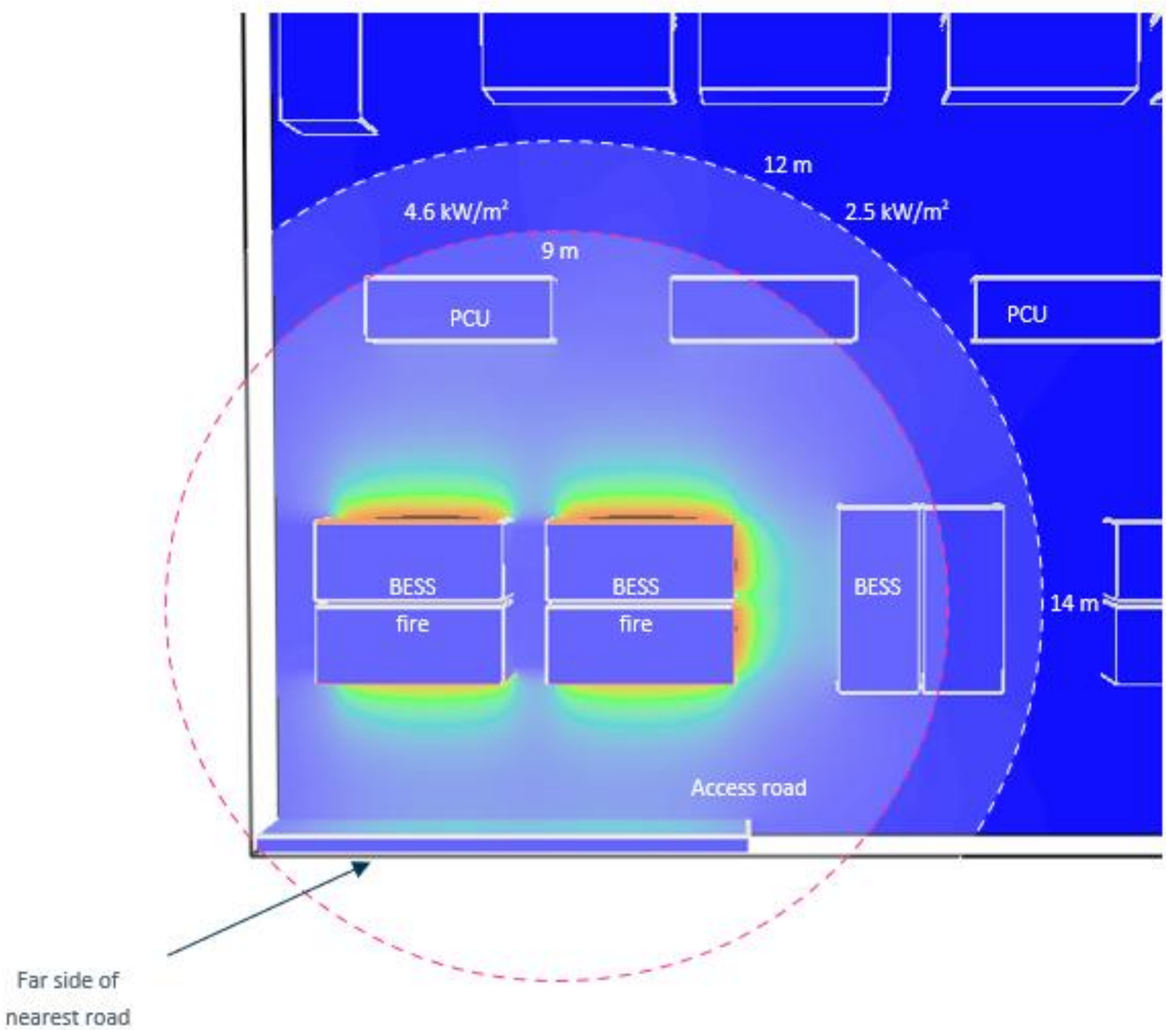

Figure 5. Radiant Heat Flux Analyses for Life Safety

1.5 FIRE SAFETY FINDINGS & REQUIREMENTS

The following recommendations are based on the most onerous (single material) findings from the modelling analyses and results presented above. For tabulated data of those results including the other gases potentially present, please refer back to Section 1.4.

Safety Note: Please be advised that these recommendations are based on the series of credibly foreseeable scenarios detailed within this document, based on the relevant scientific literature available at the time of writing, which is limited on this topic. Moreover, following these recommendations does not guarantee health and life safety and persons must always evaluate the conditions of the environment at the time to determine their best and safest course of action.

1.5.1 BESS Off-Gas Event

During a BESS off-gas event it is advised:

1. Carbon Monoxide (CO) short term exposure limit (STEL – 15 min) may persist for up to 50 m downwind of the leak source.
    a. Site personnel and first responders should remain upwind of the source
    b. BA and PPE should be worn if maintaining a position:
        i. Downwind of the source, or
        ii. Within 50 m upwind of the source for more than 15 min.
2. Carbon Monoxide (CO) time-weighted average (TWA – 8 hour) may persist up to 250 m downwind of the leak source.
    a. Site personnel and first responders should not remain in this zone for more than 8 hours without BA.
3. Flammable/explosive concentrations of CH_4 and H_2 are only credible within a few metres of the source.
4. For the boundary conditions tested, the BESS unit exhaust system was successful in suitably mitigating the build-up of a flammable/explosive concentration of hydrogen within the BESS unit following an off-gas event.

1.5.2 BESS Fire Event (toxic gas dispersion)

5. Hydrogen Fluoride (HF) short term exposure limit (STEL – 15 min) may persist for up to approximately 45 m downwind of the fire source.
    a. Site personnel and first responders should remain upwind of the source
    b. BA and PPE should be worn if maintaining a position:
        i. Downwind of the source, or
        ii. Within 45 m upwind of the source for more than 15 min.
6. Hydrogen Fluoride (HF) time-weighted average (TWA – 8 hour) may persist up to 50 m downwind of the leak source.
    a. Site personnel and first responders should not remain in this zone for more than 8 hours without BA.

Note: HCL, NOx and SOx may also be present and persist for distances less than those stated for HF.

1.5.3 BESS Fire Event (thermal exposure)

7. Given the thermal exposure modelling results, unprotected persons (i.e. without skin protection and BA) should NOT be within approximately 14 m of a BESS fire in any case.

Note: While approaching a fire from upwind may reduce the potential for exposure to toxic materials, radiant heat flux can be considered to be consistent upwind or downwind.

1.5.4 Further Recommendations

8. Based on the modelling results, and generally, BA and PPE should always be worn when approaching a fire. This advice equally applies to the subject site.
9. Local properties are advised to evacuate during a leak or fire event if the property is within the STEL radii of a BESS gas leak or a BESS fire.
    a. There appears to be no neighbour properties positioned within STEL radii of the modelled events.
10. Local properties are advised to consider evacuating during a leak or fire event if the property is within the TWA radii of a BESS gas leak or a BESS fire, as a precautionary measure only.
    a. There appears to be no neighbour properties positioned within TWA radii of the modelled events.

1.5.5 Fire Safety Requirements

11. All buildings classifiable under NCC Vol.1 are understood to be designed, constructed and maintained in accordance with the DtS provisions of the NCC.

1.5.6 Layers of Safety (LOS)

12. A summary of the layers of safety provided by the site's safety equipment and safety features are summarized in Section 6. This advice is based on the information available at the time of writing. Note that the layers of safety documented represent our understanding of what is proposed by the developer and what is provided by the nominated equipment.
13. The safety aspects and protocols detailed in Section 6 are considered to represent the minimum requirements that Halliwell would support, in the context of the consequence outcomes from our detailed modelling analyses.

1.5.7 Broader Fire Safety Strategy (FSS)

14. A detailed discussion of the elements of the site's broader fire safety strategy is provided in Section 7. The Fire Safety Strategy detailed in Section 7 represents the recommended minimum requirements based on the consequence outcomes from our detailed modelling analyses.
15. It is Halliwell's requirement that these will be fully implemented at the completed site, notwithstanding revalidation of the recommendations of this report upon detailed design stage.

1.5.8 Bushfire Water Provisions

16. In addition to the *Layers of Safety* and *Fire Safety Strategy* requirements outlined above, Halliwell recommends that:

    a. Bushfire water tanks are provided in accordance with the Bushfire Management Plan (report). Further context on the Fire Safety Strategy and fire brigade intervention is provided in Section 7.5.4, particularly in Sub-section 7.5.4.2.1.

1.5.9 Clarification

17. We note that the hazard consequence modelling outcomes and the fire safety strategy are fundamentally related, and where the agreed fire safety strategy, and proposed equipment (such as specific BESS units and their required safety features) are not wholly implemented, the results and conclusions of this report pertaining to the modelling outcomes would be invalidated.
18. If any queries or conflicts arise at the time of detailed design/construction with our recommendations, or if compatibility issues are raised by the major equipment manufacturers, Halliwell must be consulted for clarification and agreement.

2 Introduction

2.1 APPOINTMENT

Private Energy Partners has appointed Halliwell Pty Ltd to provide a Fire Safety Study of the fire hazard associated with the BESS yard, transmission line and associated substation, approximately located at 128 Manton Quarry Road, Calcium, QLD, 4816.

2.2 BACKGROUND

It is understood that there are three main stages planned as part of this project, with each stage containing approximately 220 m x 125 m of BESS, equating to 390 units with a total storage capacity of 2.201 GWh and discharge power of 275 MW . Additionally, a High-Voltage Substation and water storage are with associated fire-water tanks are also planned to be located on site. All three BESS stages and associated infrastructure will generally be located on land parcel 19SP321818, which is located at approximately located at 128 Manton Quarry Road, Calcium, QLD, 4816. Local access with the BESS yard is via Bidwilli Road, just off the Flinders Highway.

2.3 SCOPE

The scope is to provide a fire safety study that outlines the credible fire hazard consequence associated with the BESS yard equipment as it pertains to onsite personnel and to the surrounding community, and to outline our recommended fire safety provisions, facilitating stakeholder consultation and detailed design and management for the development.

This report is based on the information available at the time of writing and it is expected that the equipment, hazards and consequence modelling will be revalidated during the detailed design stage.

2.4 INTENT OF THIS REPORT

The intent of the FSS is to provide recommendations and demonstrate that the fire safety strategy at the BESS yard is appropriate for the fire hazards associated with the specific site.

This FSS can be used to inform and support stakeholder consultation, including with Queensland Fire Department (QFD) and the local Rural Fire Service (RFS).

Note that this FSS does not confer compliance of any fire system(s) to any Standard(s) to which they have been installed. This report outlines a series of recommendations intended to deliver an appropriate fire safety strategy resulting from a suitable level of fire hazard and consequence analysis (as recommended by the various guidance documents). Failure to implement the fire safety strategy agreed upon by all stakeholders, and outlined in Section 7 of this report, will result in the conclusions of this report being void.

2.5 STUDY METHODOLOGY

This study can be defined as having two broad aspects:

- Identification and consequence study of fire hazards associated with the specific site and the proposed location and layout.
- Review of the specific fire safety mitigation systems and approaches associated with the equipment proposed to be installed and implemented at the site.

The main principles of the study process can be summarised as follows and are generally referenced from the Hazardous Industry Planning Advisory Paper No. 2 (HIPAP2):

- Hazard Identification (HAZID), materials/quantities, incident/scenarios
- Analysis of consequences of incidents
- Identification/development fire protection strategies and measures
- Analysis of requirements for fire detection and protection measures
- Recommendations of measures to be implemented
- Review of fire-fighting water provision

2.6 LEGISLATION AND REGULATORY FRAMEWORK

The following Queensland Regulatory Framework is applicable:

- Queensland Building Fire Safety Regulation, 2008 and subsequent amendments
- Queensland Fire and Emergency Services Act, 1990 and subsequent amendments
- Queensland Work Health and Safety Act, 2011 and subsequent amendments
- Queensland Building Regulations, 2006 and subsequent amendments
- National Construction Code (NCC) 2022 Volume 1, Building Code of Australia (BCA) Class 2 to Class 9 Buildings
- Queensland Development Code (QDC)

2.7 RELEVANT INFORMATION AND DOCUMENTATION

This document is based on the following:

Site Information:

– Supernode North Concept Design – Electrical Site Plan, prepared by Aurecon, ref. DRG-EL-0091, Rev B, dated 15 July 2025.

– Supernode North BESS Concept Design – BESS Facility Layout, prepared by Aurecon, ref. DRG-EL-0098, Rev B, dated 13 June 2025.

– Supernode North BESS Concept Design – Supernode North BESS QLD Operations HV Substation GA Layout, prepared by Aurecon, ref. DRG-EL-0092, Rev A01.02, dated 4 July 2025.

- Bushfire Hazard Assessment and Management Plan for Northern Quartz Campus and Transmission Line, prepared by Green Tape Solutions, ref. PR25087_BHAMP_Northern Quartz Campus (Package 1)_Ver B, Rev. B, dated 29 August 2025.

BESS Information:

- CATL EnerQB (Tener C8) Liquid Cooling Energy Storage Container Product Specification, ref CATL - EnerQB Product Specification - V0.1Draft - 20250915, dated 15 September 2025.
- EnerQB – Spec Sheet and key features.
- CATL Material Safety Data Sheet for Lithium Ion Battery, prepared by CATL, Doc. No. 2025-A-018, Rev. 1.7. dated 14 January 2025.
- Cell Test Report UL 9540A – Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD) on the CB4V1 model lithium-iron phosphate 3.2V, 565Ah battery manufactured by CATL, dated 4 May 2025.

  Note: This BESS system is understood to be in final development and testing and is subject to change. It is understood that 530 Ah cells will be used for the final design however test reports are not yet available for the specific BESS container unit. Once available, the content and analysis presented within this report must be revalidated.
- Module Test Report UL 9540A – Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD) on the M030301 Module of model lithium-iron phosphate cells (332.8Vdc, 565Ah), manufactured by CATL, dated 15 May 2025.
- Unit Test Report UL 9540A – Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD) on the C070301-R unit of lithium-iron phosphate battery modules (1332.1 V, 1130 Ah), manufactured by CATL, dated 20 May 2025.

2.8 RELEVANT STANDARDS AND GUIDANCE

The following list provides a guide as to the Australian Standards which may be relevant for the fire safety infrastructure and as part of the fire safety strategy on this site. Note that not all documents may be relevant upon detailed design.

Table 5. Applicable Guidance

Provider	Title
AFAC	Large-scale battery energy storage system installations v1.0, 05/02/2025
NFPA	Standard for the installation of stationary energy storage systems
UL	UL9540 Energy storage system requirements
UL	UL9540A Standard for test method for evaluating thermal runaway fire propagation in battery energy storage systems
FM Global	Property loss prevention data sheet 5-33 electrical energy storage systems

Table 6. Associated Australian Standards

Standard Number	Title
AS 1670.1 – 2018 (+A1)	Fire detection, warning, control and intercom systems — System design, installation and commissioning — Fire (incorporating amendment 1)
AS 1670.3 – 2018 (+A1)	Fire detection, warning, control and intercom systems - System design, installation and commissioning Fire alarm monitoring (incorporating amendment 1)
AS 1670.4 – 2018 (+A1)	Fire detection, warning, control and intercom systems — System design, installation and commissioning — Emergency warning and intercom systems (incorporating amendment 1)
AS 1851 – 2012	Routine service of fire protection systems and equipment
AS 2293.1 – 2018 (+A1)	Emergency lighting and exit signs for buildings — System design, installation and operation (incorporating amendment 1)
AS 2419.1 – 2021	Fire hydrant installations — System design, installation and commissioning
AS 2441 – 2005 (+A1)	Installation of fire hose reels (incorporating amendment 1)
AS 2444 – 2001	Portable fire extinguishers and fire blankets — Selection and location
AS 3786 – 2014 (+A1 and 2)	Smoke alarms using scattered light, transmitted light or ionization (incorporating amendments 1 and 2)
AS 1670.1 – 2018 (+A1)	Fire detection, warning, control and intercom systems — System design, installation and commissioning — Fire (incorporating amendment 1)
AS 1319	Safety signs for the occupational environment
AS 1530.4	Methods for fire tests on building materials, components and structures - Fire-resistance test of elements of construction
AS 3011.2	Electrical installations - Secondary batteries installed in buildings - Sealed cells
AS/NZS 4509.1	Stand Alone Power Systems - Installation
AS 4086.2	Secondary batteries for use with stand-alone power systems - Installation and maintenance
AS/NZS 3000	Electrical installations (known as the Australian/New Zealand Wiring Rules)
AS/NZS 5033	Installation and safety requirements for photovoltaic (PV) arrays
AS/NZS 4777.1	Grid connection of energy systems via inverters - Installation requirements
AS/NZS 4777.2	Grid connection of energy systems via inverters - Inverter requirements
AS 62040.1.1	Uninterruptible power systems (UPS) - General and safety requirements for UPS used in operator access areas
AS 62040.1.2	Uninterruptible power systems (UPS) - General and safety requirements for UPS used in restricted access locations
AS/NZS 60529	Degrees of Protection Provided by Enclosures (IP Code)
AS/NZS 60898.2	Circuit-breakers for overcurrent protection for household and similar installations - Circuit-breakers for AC and DC operation

Standard Number	Title
AS/NZS 60947.3	Low-voltage switchgear and control gear - Switches, disconnectors, switch-disconnectors and fuse-combination units
AS/NZS 60950.1	Information technology equipment - Safety - General requirements
IEC 62109-1 Ed. 1.0 (English 2010)	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements
IEC 62109-2 Ed. 1.0 (Bilingual 2011)	Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters

3 Project Description

3.1 LOCATION AND SITE DESCRIPTION

A summary of the facility location and features is presented below. Site location and facility position are depicted in and respectively.

Table 7. Facility Features Summary

Aspect	Summary
Local Government Area	Townsville City Council (TCC)
Location	The site is located approximately 41 kilometres (km) south of Townsville.
Existing Environment	The surrounding area is generally a grazing zone. However, directly west of the location is the Lansdown Motor Sport Facility, zoned for sport and recreation. There are residential neighbours within 500 m of the BESS yard. The Substation for the site is located along the western edge of the perimeter of the site.
Bushfire Assessment	29.1 m wide APZ required around the substation equipment (in accordance with BMP). Site-specific site access road specification Minimum of 3 50,000L bushfire fighting water tanks located at site access points (Refer "Bushfire Hazard Assessment and Management Plan for Northern Quartz Campus and Transmission Line", prepared by Green Tape Solutions Rev B, dated 29 August 2025)
Major equipment (BESS)	Three Bess Stages (220 m x 125 m), with each BESS Stage containing: • 390 BESS Units (total of 2.201 GWh) • 78 PCU 3 x control room 3 x auxiliary transformers 3 x switchrooms 1 x HV Substation and associated infrastructure
Access to and within the site	Access to the site is from Flinders Highway, via Bidwilli Road..
Occupation and operational workforce	The Facility will not be manned continuously, but will be manned remotely. Up to ten (10) personnel could be onsite however during the day. Battery operations and maintenance status will be supervised remotely. The fire indicator panel (FIP) must be readily accessible, located in the Control/switchroom or BESS substation, for example. Routine inspections and maintenance of the BESS will be undertaken on a regular basis in accordance with the manufacturer's recommendations, with repairs, undertaken as required.
Security	A high security fence will be constructed around the perimeter of the BESS yards and the substation. Access to the Site will be controlled by security gates to facilitate authorised access only.

Figure 6. Site Location Context (Indicative only)

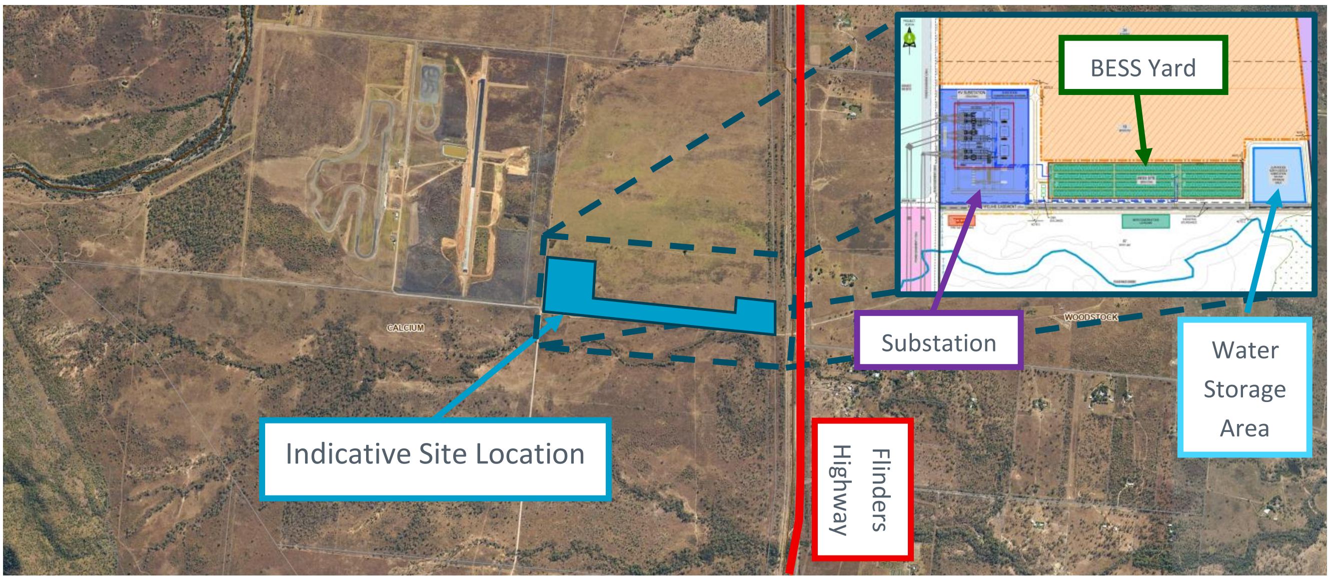

Figure 7. Site Location Detail

3.2 EQUIPMENT AND SITE INFRASTRUCTURE

3.2.1 Overview

The Project's infrastructure comprises of a number of interlinked and integral components for the operation of the equipment and storage of electricity from solar irradiance. These components include:

- Three Bess Stages (220 m x 125 m), with each BESS Stage containing:
    - 390 BESS Units (total of 2.201 GWh)
    - 78 PCU's
- 3 x Control rooms
- 3 x Auxiliary transformers
- 3 x Switchrooms
- 1 x HV Substation and associated infrastructure
- Internal collector lines (underground);
- Telecommunication equipment;
- Security fencing (nominally 2.4 m high) around the BESS/substation yards.

3.2.2 BESS Units

The energy storage system at the facility comprises of discrete energy storage enclosures (referred to hereon as "BESS units", or "units") that house battery modules mounted in racks, battery management system, data acquisition system and the associated equipment intended to maintain safe operation. BESS units are connected via nodes to form clusters. A summary of the specifications and key system design features of the BESS and associated infrastructure is provided below. Manufacturer battery enclosure specifications are discussed throughout Section 6 and Section 7. The BESS yard layout is presented in Figure 8.

Table 8. BESS System Features

Aspect	Summary
Product	EnerQB (TenerC8) , Battery – CB4V1 – 3.2V 565Ah – Lithium Iron Phosphate. **Note:** This system is understood to be in final development and testing and is subject to change. It is understood that 530 Ah cells will be used for the final design, however UL9540A test reports are not yet available for this product.
Configuration	Unit = 4S2P (Module = 104S1P)
Nominal Energy	Design basis system output: 5.644 MWh (per unit)
Primary unit components and connections	Battery Modules, Battery Management System (BMW) and Thermal Management System
Dimensions (w*d*h)	6.06 m x 2.44 m x 3.11 m, Protection Level IP55

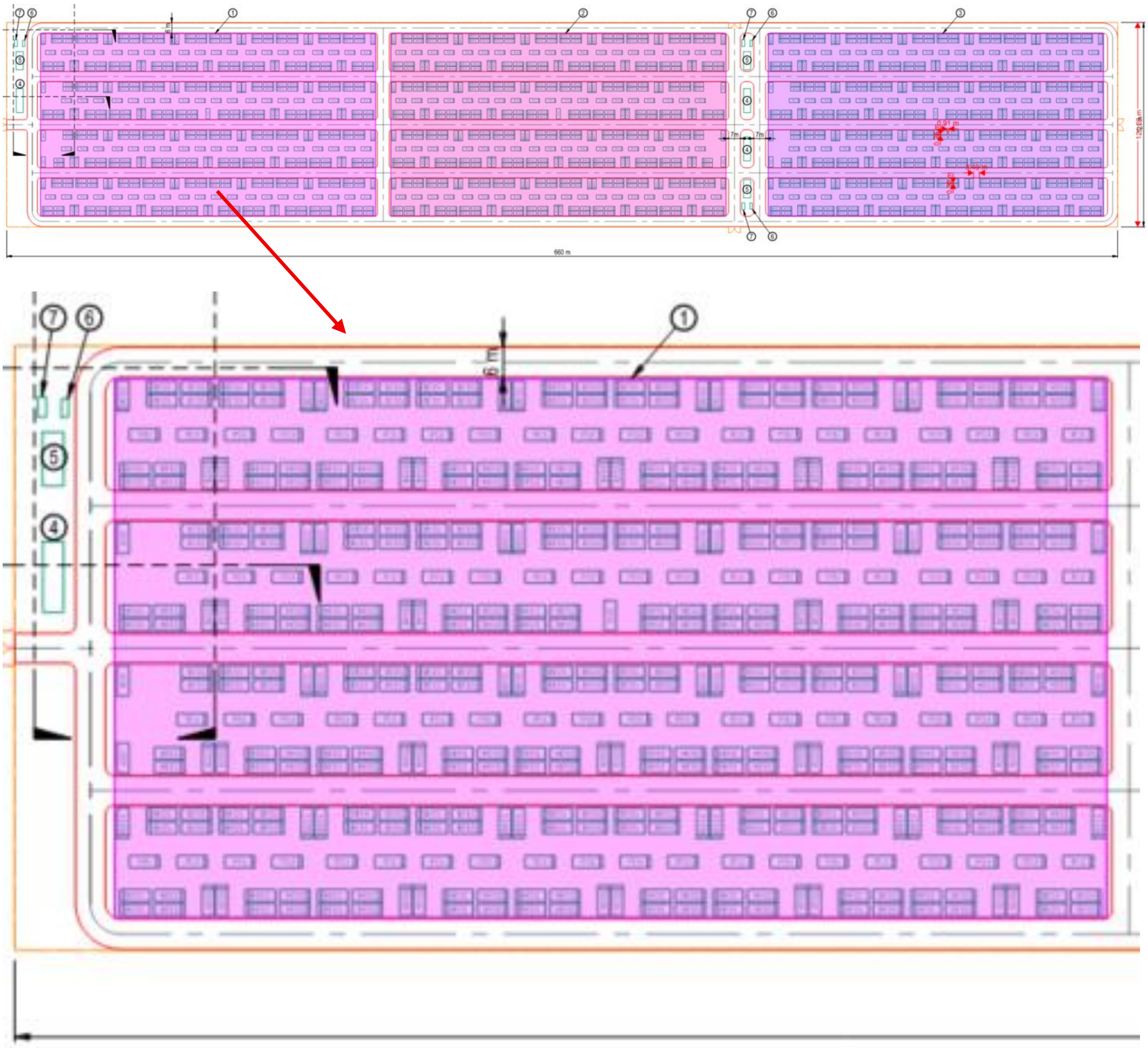

Figure 8. BESS Yard Layout

3.3 CONTROL AND MONITORING

The Facility control and monitoring system enables remote start-up, operation and troubleshooting from the following locations:

1. Local control room at the Facility - when the Site is occupied
2. Offsite (remote) control centre.

The Facility will normally be controlled on site from the control room. The control and monitoring system feature audible and visual alarms and other notifications to guide rectifying action by the operator.

A summary of the BESS key safety features is provided below. Note that the layers of protection and fire safety strategy for the site is discussed in later sections in detail.

Table 9. Key Safety Features - BESS

Layer of Protection	Summary
Battery Management System (BMS)	The system is monitored by a Battery Management System (BMS). The BMS monitors the battery voltage, current, and temperature. A liquid cooling system is built into the system to manage battery temperatures as determined by the BMS monitoring. The BMS utilizes a three-level architecture at unit level (Master Battery Management Unit (MBMU)), rack level (Slave Battery Management Unit (SMBU)), and module level (Cell Supervision Circuit (CSC)) to control the ESS.
Thermal management	The function of the thermal management system (TMS) is to monitor and maintain thermal operating conditions within the BESS unit. The TMS has 4 modes of operation: shutdown, cooling, heating and self-circulation mode.
Fire protection system	The fire protection system within the BESS unit has four (4) levels: detection and alarm, smoke exhaust and ventilation, (optional) aerosol fire suppression and optional dry pipe water suppression capability. Neither aerosol fire suppression nor the optional dry pipe water suppression systems are intended to be utilised for BESS fire mnagement.
Additional safety features	**Venting/Pressure Relief** Explosion/overpressure relief venting, automatic upon gas detection (calibrated to hydrogen) within the BESS unit. **UPS** The unit is provided with an uninterruptable power supply (UPS) to ensure continued operation following a major power cut of the primary supply. Separate UPS's are provided to the fire safety system infrastructure and to the BMS.

3.4 EXISTING FIRE SAFETY PERFORMANCE DATA

3.4.1 UL 9540-A Tests

3.4.1.1 Cell Level Test

UL9540A cell level test report was provided and performed in accordance with UL standards by UL Solutions. The method that was chosen for the test was external heating using thin film with 4°C to 7°C thermal ramp up until thermal runaway was able to be initiated. Cell level testing showed that thermal runaway was able to be initiated at an average temperature of 173°C, and the gasses vented by the cells such as hydrogen and carbon monoxide were flammable, therefore module level testing is required.

3.4.1.2 Module Level Test

UL9540A module level test report was provided and performed in accordance with UL standards by UL Solutions. To test the module, an external heating film was placed on an initiating cell with 4°C to 7°C thermal ramp until thermal runaway was initiated in initiating cell as well as thermal runaway propagation had occurred in neighboring cells. Module level testing showed that thermal runaway was able to be initiated at a temperature of 173°C and a condition of thermal runaway propagation was achieved between one (1) adjacent cell but no flaming occurred, therefore Unit level testing is required.

3.4.1.3 Unit Level Test

UL9540A unit level test report was provided and performed in accordance with UL standards by UL Solutions. To perform unit level testing, one initiating unit sample and two target unit samples were utilized. The following performance criteria for unit level testing was met, rendering installation level testing unnecessary

- Flaming outside the initiating BESS unit was not observed
- Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit did not exceed the temperature at which thermally initiated cell venting occur.
- For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces did not exceed 97°C of temperature rise above ambient.
- Explosion hazards were not observed, including deflagration or detonation.
- Heat flux in the centre of the accessible means of egress did not exceed 1.3 kW/m^2.

4 Hazard Identification (HAZID)

4.1 INPUT INFORMATION AND CONTROLS

The hazard identification in this FSS draws from desktop review of the scientific literature on BESS and photovoltaic fire safety, as well as manufacturer-specific data. The following aspects were considered as part of our review:

- Local area usage external to the site
- Proposed site infrastructure, layout, workforce personnel, manufacturer-specific data received from the operator and the manufacturers of the BESS and BESS safety systems.
- Proposed operation and maintenance activities and potential hazards associated with BESS equipment during long-term operation.
- Liaison with relevant stakeholders including QFD and Queensland RFS.
- Review of Australian Standards, International Codes of practice and global codes or guidance (for example, NFPA, UL, AFAC).
- Review of various research reports into Li-ion battery and photovoltaic safety from across the scientific literature, as well as equipment-specific standardised and ad-hoc fire test reporting.
- Publicly available information relating to BESS fire incidents and accidents.

4.2 POTENTIALLY HAZARDOUS MATERIALS

4.2.1 BESS Unit Materials

The following materials are generally associated with architecture of BESS units and their associated equipment.

Table 10. Hazardous Materials Identification

Hazardous Material	Description	Quantity
Lithium-ion batteries	CATL CB4V1 – 3.2V 565Ah – Lithium Iron Phosphate Li-ion cells use lithium iron phosphate (LiFePO4) as the cathode material and include a volatile hydrocarbon-based liquid and dissolved lithium salt (such as lithium hexafluorophosphate). **Note:** This BESS system is understood to be in final development and testing and is subject to change. It is understood that 530 Ah cells will be used for the final design, and not 565Ah cells. However, test reports have not been provided for this product.	Unit total rated energy 5.644 MWh Unit weight: < 45 tonnes Cell capacity: 3.2 V, 565 Ah Cells in unit: 832 Off-gas released per cell: 288.6 L
Transformer oil	Combustible liquid (HC), contained within transformers	Quantity unconfirmed
Coolant	Assumed 50% ethylene glycol, 50% deionized water (glycol combustible liquid)	50/50 water/glycol mix not considered combustible
Refrigerant gases	Chiller type: Unconfirmed R-134A (tetrafluoroethane)	Normal operating pressure: assumed 140 < x <280 kPa

4.2.2 Impacts and Exposure Limits for Hazardous Gaseous Materials

A work exposure limit (WEL) is a legal limit in Australia for the concentration of hazardous substances in the air at a workplace. WELs are set to protect workers and people from the health risks of exposure to hazardous chemicals. WELs are presented as numerical values that represent the level of exposure to which workers and people can be repeatedly exposed without risk.

These exposure limits can be used to determine when people near a fire are safe from the products of combustion from BESS fires. WELs are described in short and long-term exposure limits:

- Short-term exposure limit (STEL), calculated for a 15-minute period, and
- Time-weighted average (TWA) exposure limits, calculated for an 8-hour period.

A typical BESS fire will produce a number of chemicals during combustion. If damaged, a battery can expel gas prior to burning (known as *off-gassing*). A fire can start if the ignition temperature of the gas is reached. The predominant materials produced during BESS combustion are outlined below, along with the corresponding Australian short-term and long-term work exposure limits.

The exposure limits listed overleaf are intended for repeated exposure in industrial workplaces, and they are used to provide a conservative baseline for hazardous zones near a fire source, and to outline where the safe distance from a fire event begins.

Table 11. Exposure Limits for Off-Gas Materials and Products of BESS Combustion

Material	Source (typical)	STEL	8-hr TWA
Carbon Monoxide (CO)	BESS off-gas BESS fire	200 ppm/15 min 100 ppm/30 min 60 ppm/60 min	30 ppm
Carbon Dioxide (CO_2)	BESS off-gas BESS fire	30,000/15 min	12,500 ppm
Hydrogen Fluoride (HF)	BESS fire	*6 ppm/15 min*	3 ppm
Hydrogen Chloride (HCL)	BESS fire	*5 ppm*	2 ppm
Hydrogen (H_2)	BESS off-gas	N/A - Asphyxiant / Flammable	N/A - Asphyxiant / Flammable
Sulfur Dioxide (SO_2)	BESS fire	5 ppm/15 min	2 ppm
Hydrogen Cyanide (HCN)	BESS fire	*4.7 ppm*	10 ppm
Nitric Oxide (NO)	BESS fire	Refer NO_2	25 ppm
Nitrogen Dioxide (NO_2)	BESS fire	5 ppm/15 min	3 ppm
Methane (CH_4)	BESS fire	N/A - Asphyxiant / Flammable	N/A - Asphyxiant / Flammable

Notes:

1. PPM – parts per million.
2. Materials associated with BESS off-gassing and fire (Conzen et al., 2023).
3. Unless italicised, all data referenced from Safe Work Australia. www.safeworkaustralia.gov.au.
4. *Italicised* data referenced from NIOSH (National Institute for Occupational Safety and Health). www.cdc.gov/niosh.

The following table provides an overview of the hazards for human health of the hazardous gases identified to be associated with photovoltaic and BESS fires and BESS off-gassing.

Table 12. Hazards to Human Health for Off-Gas Materials and Products of BESS/Combustion

<table>
<tr><th>Material</th><th>Hazards</th></tr>
<tr><td>Carbon Monoxide (CO)</td><td>Carbon monoxide is harmful because it binds to hemoglobin in the blood, reducing the ability of blood to carry oxygen. This interferes with oxygen delivery to the body's organs. The most common effects of CO exposure are fatigue, headaches, confusion, and dizziness due to inadequate oxygen delivery to the brain.
Short-term effects
Fatigue: A common effect of CO exposure
Headache: A common effect of CO exposure
Dizziness: A common effect of CO exposure
Chest pain: Can occur in people with heart disease
Angina: Can occur in people with heart disease
Flu-like symptoms: Can include nausea, vomiting, and skin flushing
Long-term effects
Impaired thinking: Can include irritability, impulsiveness, and emotional lability
Heart disease: Can occur from long-term exposure to low levels of CO
Nervous system damage: Can occur from long-term exposure to low levels of CO
Other effects
Loss of consciousness: Can occur at very high levels of CO
Seizures: Can occur at very high levels of CO
Death: Can occur at very high levels of CO
Low birth weights: Can occur in babies whose mothers were exposed to high levels of CO during pregnancy</td></tr>
<tr><td>Carbon Dioxide (CO_2)</td><td>Carbon dioxide (CO_2) can cause health problems when inhaled, including headaches, dizziness, and asphyxiation.

Low to moderate CO_2 exposure
Headache
Drowsiness
Increased blood pressure
Dyspnea
Decreased exercise tolerance
Confusion
High CO_2 exposure
Rapid breathing
Increased cardiac output
Increased arrhythmias
Vomiting
Disorientation
Loss of consciousness
Death by suffocation</td></tr>
</table>

<table>
<tr><th>Material</th><th>Hazards</th></tr>
<tr><td>Hydrogen Fluoride (HF)</td><td>
Hydrogen Fluoride (HF) gas can cause severe irritation to the skin, eyes, and respiratory tract, leading to painful burns, potential vision damage, and death if inhaled at high concentrations.
Exposure can also result in fluid build-up in the lungs (pulmonary edema), irregular heartbeat, and systemic effects like nausea and vomiting due to its corrosive nature.
Importantly, the effects of HF exposure may not be immediately apparent and can be delayed for several hours following contact.
Skin exposure:
Severe burns, pain, redness, and tissue damage, even with minimal contact; delayed onset of symptoms may occur.
Eye exposure:
Irritation, pain, corneal damage, potential vision loss, and permanent eye damage.
Inhalation:
Respiratory irritation, coughing, throat pain, chest tightness, pulmonary edema (fluid in lungs), and potential respiratory failure.
Systemic effects:
Nausea, vomiting, stomach pain, irregular heartbeat (cardiac arrhythmia), low blood calcium levels (hypocalcemia), and potential for seizures in severe cases.
Important points to remember about HF exposure:
Delayed symptoms:
Burns and other symptoms may not appear immediately after exposure, potentially delaying treatment.
Concentration matters:
The severity of effects depends on the concentration of HF gas and duration of exposure.
Immediate action required:
If exposed to HF, seek medical attention immediately, including flushing the affected area with water for skin contact or eye exposure.
</td></tr>
<tr><td>Hydrogen Chloride (HCL)</td><td>
Hydrogen chloride gas can cause irritation of the eyes, skin, and respiratory tract.
Exposure to high levels can result in corrosive damage to the eyes, skin, and respiratory tissues, and could lead to pulmonary edema and even death in extreme cases.
</td></tr>
</table>

Material	Hazards
Hydrogen (H_2)	Hydrogen can have both beneficial and harmful effects on humans. Harmful effects can include: • **Inhalation**: Inhaling hydrogen can be dangerous. • **Burns**: Contact with liquefied hydrogen can cause severe burns and frostbite. **Suffocation**: High levels of hydrogen can decrease the amount of oxygen in the air, which can cause suffocation.
Sulfur Dioxide (SO_2)	Sulfur dioxide (SO2) gas can irritate the respiratory system, causing symptoms like coughing, wheezing, throat irritation, and difficulty breathing, particularly affecting individuals with pre-existing lung conditions like asthma, and can worsen existing heart disease, especially when exposed to high concentrations during physical activity; it can also irritate the eyes and mucous membranes of the nose and throat. Key impacts of SO2 on humans include: • **Respiratory irritation:** Primary impact is irritation to the lining of the nose, throat, and lungs, leading to coughing, wheezing, and chest tightness. • **Asthma aggravation:** People with asthma are particularly vulnerable to SO2 exposure, experiencing worsened asthma attacks and increased symptoms. • **Lung function impairment:** High concentrations can significantly reduce lung function. • **Cardiovascular effects:** Studies link SO2 exposure to increased risk of cardiovascular issues, especially in individuals with pre-existing heart conditions. • **Eye irritation:** Direct contact with SO2 can irritate the eyes.
Hydrogen Cyanide (HCN)	Hydrogen cyanide (HCN) gas, commonly known as cyanide, is highly toxic and can rapidly affect the body by inhibiting cellular oxygen usage, leading to symptoms like dizziness, headache, confusion, nausea, rapid breathing, and in severe cases, seizures, coma, and death within minutes of exposure due to respiratory failure; even small amounts can be fatal if inhaled. Key impacts of HCN gas on humans: • **Rapid onset of symptoms:** Effects can begin within seconds to minutes of exposure, making it a very fast-acting poison. • **Central nervous system effects:** Symptoms like dizziness, confusion, anxiety, weakness, and loss of consciousness can occur due to the impact on the brain. • **Respiratory distress:** Difficulty breathing, rapid breathing, and a feeling of suffocation are common due to the interference with oxygen utilization. • **Cardiovascular effects:** Palpitations, irregular heartbeat, and potential cardiac arrest can occur in severe cases.

Material	Hazards
	• **Potential for rapid death:** High concentrations of HCN can lead to death within minutes due to respiratory failure. **Other potential effects:** Burning sensation in the mouth and throat (if ingested), Eye irritation, Nausea and vomiting, Metallic taste in the mouth, and Skin irritation (with direct contact).
Volatile Organic Compounds (VOCs)	Exposure to Volatile Organic Compounds (VOCs) can cause a range of health impacts on humans, including eye, nose, and throat irritation, headaches, nausea, dizziness, difficulty breathing, and in cases of long-term exposure, potential damage to the liver, kidneys, and central nervous system; some VOCs are even linked to cancer. Key points about VOC impacts on humans: • **Short-term effects:** Primarily irritation to eyes, nose, and throat, along with headaches, nausea, and dizziness. • **Long-term effects:** Potential damage to organs like the liver and kidneys, possible neurological effects, and increased risk of cancer depending on the specific VOC
NOx **Nitrogen Dioxide (NO_2)**	NOx gas, primarily consisting of nitrogen dioxide, can significantly impact human health by causing respiratory irritation, including coughing, shortness of breath, and worsened asthma symptoms, particularly when inhaled at elevated levels; long-term exposure can contribute to chronic lung disease and increased vulnerability to respiratory infections; furthermore, high concentrations can lead to severe throat burns, fluid build-up in the lungs, and even death in extreme cases. Key points about NOx impacts on humans: • **Respiratory irritation:** Even low levels of NOx can irritate the eyes, nose, throat, and lungs, leading to coughing and discomfort. • **Asthma aggravation:** NOx exposure is particularly harmful for people with asthma, causing increased wheezing and attacks. • **Lung function decline:** Chronic exposure to NOx can lead to reduced lung function and increased susceptibility to respiratory infections. • **Increased severity of existing conditions:** People with pre-existing respiratory diseases are more vulnerable to the effects of NOx. • **Acute effects at high concentrations:** Breathing very high levels of NOx can cause rapid burning sensations in the throat, spasms, swelling, and potentially life-threatening pulmonary edema.

Material	Hazards
Methane (CH_4)	Methane (CH4) gas, while not directly toxic, can negatively impact human health primarily by displacing oxygen in enclosed spaces when present in high concentrations, leading to asphyxiation symptoms like dizziness, headaches, fatigue, and in severe cases, unconsciousness and death; additionally, methane can contribute to poor air quality by acting as a precursor to ground-level ozone, which can exacerbate respiratory issues like asthma and other lung diseases. Key points about methane's impact on humans: • **Asphyxiant:** The main danger of methane is its ability to displace oxygen in enclosed spaces, causing asphyxiation when levels are high enough. • **No direct toxicity:** Methane itself is not considered toxic, but its ability to displace oxygen makes it hazardous in high concentrations.

4.2.3 Creating the Conditions for a Fire Event

4.2.3.1 BESS Units

Cells in thermal runaway can cause adjacent cells to also undergo thermal runaway in a phenomenon known as thermal runaway propagation. Cell may cause thermal runaway in adjacent cells through one of several heat transfer mechanisms:

- Conductive heat transfer via direct contact between cells
- Overcurrent caused by damaged circuitry
- Impingement of hot or flaming vent gases.

Cells may also cause thermal runaway in adjacent cells due to the effects of the cell depressurization (thermally from the fireball or mechanically from the force), or due to the original cell swelling and deforming adjacent cells. Sustained cell-to-cell thermal propagation can lead to four primary hazardous scenarios:

- Rapid ignition of flammable gases, sustained propagation, and resultant full-scale fire.
- Multiple cells venting flammable gases without sufficient temperature for ignition.
- Multiple cells venting flammable gases but delayed ignition leading to a deflagration or explosion.
- Multiple cells venting flammable gases without sufficient temperature for ignition until after flammable gas concentrations have exceeded the Upper Flammable Limit (UFL). This condition can create a hazard whereby unburn fuel is present within the unit without sufficient oxygen to burn. Subsequently, opening the container and introducing of fresh oxygen can cause ignition and deflagration of the combustible gas cloud.

4.2.3.2 *Propensity for Fire Occurrence*

Fires on renewable energy sites involving the equipment are reasonably rare, and their occurrence, compared to the number of sites coming online, has decreased significantly over the last decade. This is because lessons learned from historic incidents have been applied to modern sites.

Mitigation of fire risks is in the best interest of all stakeholders including site designers, site operators, governments and the communities supplied by the site, so historical fire event statistics are important.

More than half of BESS fire incidents are linked to operational and integration issues, meaning that there is an opportunity to continually improve BESS facility fire safety through informed design and good working practices.

Only around 10 % of solar site and BESS fires are attributed to battery failures. The graph below from the Electric Power Research Institute (EPRI) Failure Incident Database[1] highlights that BESS fire incidents do not occur because of aging equipment, but more likely due to poor installation practices and circuitry faults. This means that that installation and site management aspects can be targeted to further improve levels of safety.

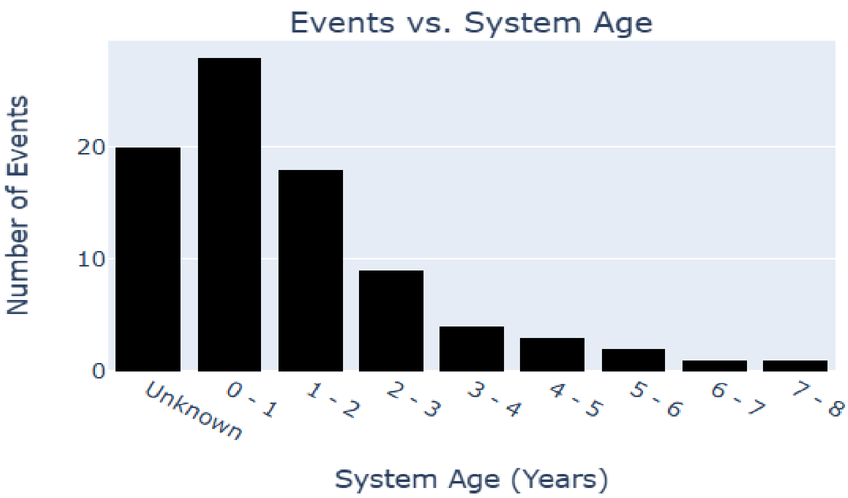

Figure 9. Number of fire events versus system age (Source EPRI Failure Incident Database)

The following graph (also from the EPRI Failure Incident Database) demonstrates that the number of annual BESS incidents are reasonably consistent, while the number of installations has risen rapidly in recent years. This means that, by following the orange trend line, one can observe that *rate of failure* has dropped dramatically since 2018. This means that there are effectively 10 times less solar/BESS fire incidents than there were just eight years ago.

[1] https://storagewiki.epri.com/index.php/BESS_Failure_Incident_Database (Accessed 10/10/25)

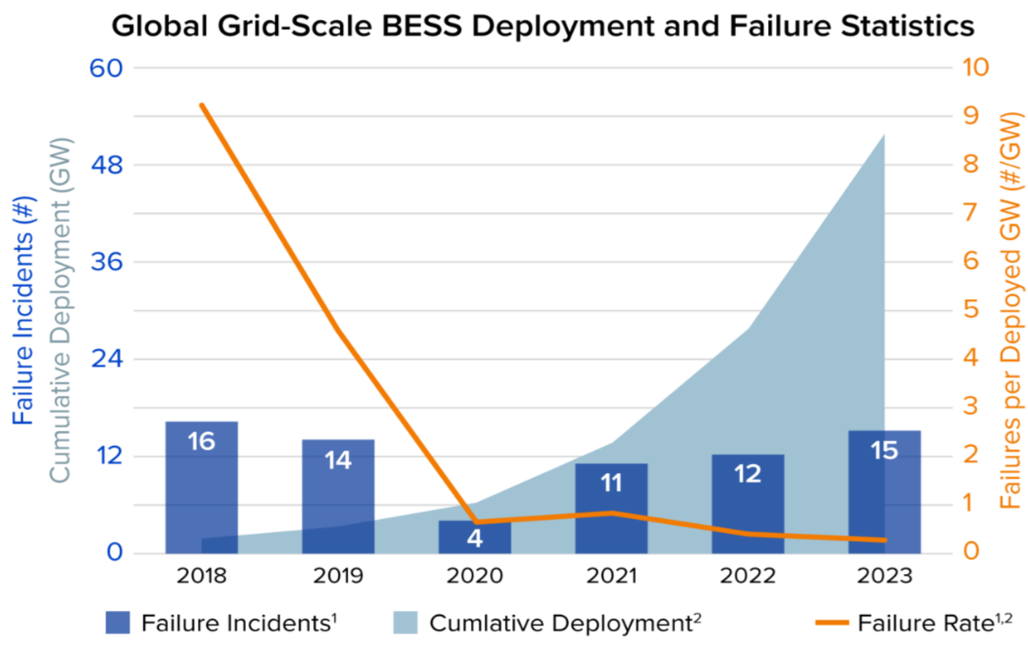

Figure 10. BESS deployment and failure statistics (Source EPRI Failure Incident Database)

5 Fire and Dispersion Modelling

5.1 ASSESSMENT METHODOLOGY

The modelling approach uses computational fluid dynamics (CFD) instead of traditional empirical-based dispersion modelling which does not take account of physical structures and is based on dispersion statistics rather than fundamental modelling. With a CFD approach, we model, from first principles the heat, mass and momentum transfer throughout the modelling domain in discrete volumes. This allows us to focus on a remote area if required during our study.

One of the benefits of CFD modelling is higher resolution of detail compared to empirical-based consequence modelling, especially when assessing relatively small quantities of toxic gaseous products. The modelling results are presented via:

- Elevation slices - to visually, and intuitively articulate the gradient of gas buoyant flow and dilution with both distance and height over long distances downwind. These are primarily presented.
- Three dimensional iso-surface rendering to highlight the approximate volume and position of gases at discrete concentration levels (for example STEL and TWA).
- The dispersion concentration/distance results are also presented via traditional contours plotted on a plan view map of the site/local area for selected scenarios.

5.1.1 Fire Dynamics Simulator (FDS)

FDS is a computational fluid dynamics program developed by the National Institute of Standards and Technology (NIST), Building and Fire Research Laboratory. The suitability of FDS for modelling external dispersion is discussed in in Appendix C.

5.1.2 Radiant Heat Transfer

Radiant heat transfer analyses are carried out using both FDS and first-principle equations, both of which are discussed in in Appendix C.

5.2 MODELLING INTENT

The intent of the modelling presented herein is to analyse the potential for the dispersion of the products of BESS battery off-gassing or the products of combustion during a fire involving the contents of a BESS unit.

5.2.1 Near-field Analysis

Near-field analysis focuses on the area up to around 100 m around the source. The purpose of which is to inform emergency management and first-responder protocols of potential conditions as they approach the event source.

5.2.2 Far-field Analysis

The purpose of the far-field dispersion modelling analysis is to understand the risk of health, if any, to the existing residences that neighbour the site. In this case the focus of the dispersion assessment area is up to 500 m downwind of the leak or fire source.

Note: the distance of 500 m was chosen following preliminary modelling analyses to determine the maximum distance at which target gases (toxic) could be detected – 500 m is in excess of this distance. To track soot particulate the modelling area was extended to 1.5 km downwind.

5.2.3 BESS Unit Internal Leak

The purpose of this assessment is to analyse the capability of the BESS unit's ventilation exhaust system to mitigate the generation of flammable and explosive atmosphere's following BESS cell off-gassing.

5.3 MODEL SCENARIOS

The purpose of this FSS is to detail the consequences of a BESS fire with regard to toxic gas and smoke dispersion and heat transfer to people and surrounding structures. Following our analysis of the available documentation we have developed consequence analysis models based on two (2) equipment failure outcomes:

1. Battery off-gassing prior to ignition (dispersion of gases)
2. BESS unit fire (dispersion of products of combustion and heat transfer)

5.3.1 Modelled Scenarios – CFD Dispersion

The event scenarios modelled are outlined as follows.

Table 13. Modelled Scenarios

Case	Type	No cells	m'' (m^3/s)	Direction	Wind (m/s)	Notes
1	BESS off-gas	5	0.0012	Z	0.1	Far-field dispersion
2		5		Z	2.5	
3		5		Z	5.0	
4		5		-Y	-	BESS internal leak/ventilation
5	BESS fire combustion products (excl. soot)	All cells	0.13	Z	0.1	Fuel release rate for 2-hour fire period. Far-field dispersion
6		All cells		Z	2.5	
7		All cells		Z	5.0	
8		-	-	-	-	Test case – not reported
9		All cells	0.13	X	0.1	Fuel release rate for 2-hour fire period. Near-field dispersion
9a		All cells		X	2.5	
9b		All cells		X	5.0	
10a	BESS fire combustion (soot/smoke)	All cells	10 MW (PHRR)	Z	0.1	Far-field dispersion
10b		All cells		Z	2.5	
10c		All cells		Z	5.0	
10d		All cells		z	20.0	

5.4 ASSUMPTIONS AND INPUTS

5.4.1 Battery Off-Gas Constituents

The products and quantity of off-gassing constituents and the volume that can potentially be released each cell were taken from the UL 9540A report corresponding to the cells used in the subject BESS unit (note alternative CATL BESS unit 9540A test reports have been provided until the proposed unit test reports become available). The data are as follows:

- Cell type: CATL CB4V1– Lithium Iron Phosphate
- Cell voltage: 3.2 V
- Cell Ah: 565
- Cell gas volume: 288.6 L

The measured constituents are outlined below. Note that total hydrocarbons were combined and represented by methane for the purposes of modelling.

Table 14. BESS Battery Off-Gas Measurements – UL 9540A Cell Level Test

Gas	Symbol	Make-up (%)	Modelling simplification (%)
Carbon monoxide	CO	8.66	9
Carbon dioxide	CO2	36.13	37
Hydrogen	H2	36.19	37
Methane	CH4	8.25	17
Acetylene	C2H2	0.22	
Ethylene	C2H4	3.90	
Ethane	C2H6	1.19	
Propadiene (Allene)	C3H4	0.005	
Propylene	C3H6	1.17	
Propane	C3H8	0.52	
na	C4	0.94	
na	C5	0.21	
na	C6	0.07	
1-heptane	C7H14	0.006	
Benzene	C6H6	0.05	
Toluene	C7H8	0.003	
Dimethly Carbonate	C3H6O3	2.26	
Ethyl Methyl Carbonate	C4H8O3	0.19	

5.4.2 Products of Combustion - Philosophy

It is important to note that the purpose of this analysis is not to attempt to model the combustion associated with each BESS/battery cell fires. The combustion associated with batteries is not simple since the internal system provides oxygen and numerous chemical reactions outside of the combustion process occur. CFD and consequence models have also not been validated to model the combustion process with a quantified level of confidence.

What is more important is to accurately represent the products of combustion, since the dispersion concentrations are the focus of the study. The philosophy for modelling the products of combustion has therefore been to take measurement data from the scientific literature and apply those data as inputs to our models. The gases are injected into the model domain with an elevated temperature of approximately 300°C to simulate the buoyancy associated with a fire plume. Noting that buoyancy acts to lift the gases upward and away from ground elevation, and that temperatures near and within the permanent flame zone would be expected to be in excess of 300°C, this approach is considered to be conservative.

5.4.3 Conservatism in Accident Scenario Development

It is further worth noting, that the intent of the modelling is not to "replicate an average event", but to simulate a series of particularly onerous cases, that could perhaps be described as a *credible worst case scenarios*. If the fire safety strategy of the facility can deal with such cases with respect to life safety and property protection, then a desirable level of confidence can be gained regarding the fire safety performance of the site.

5.4.3.1 BESS Fire Products of Combustion

From our review of literature, the following combustion products and quantities are cited for measurements of battery fires where additional materials such as plastics are involved. This is intended to account for the range of additional materials used in the construction and operation of BESS units.

Table 15. BESS Battery Fire – Products of Combustion

Gas	Symbol	Fraction
Carbon monoxide	CO	0.025
Carbon dioxide	CO2	0.950
(THC) Methane	CH4	0.005
Hydrogen chloride	HCL	0.005
Hydrogen fluoride	HF	0.005
Nitrogen dioxide	NOx	0.005
Sulphur dioxide	SOx	0.005

5.4.4 Hazardous Materials - Mass Flux

The rate at which the off-gas and products of combustion are produced (injected into the modelling domain) must be estimated based on the available equipment-specific data where possible, otherwise through review of the scientific literature, with application to the conditions that could be presented on site.

5.4.4.1 BESS Off-Gas Mass Flux

The quantity of off-gas that can potentially be released from a single cell was taken from the UL 9540A cell-level report. The next stage of UL9540A assessment (module-level test) found that following the heating of one primary cell, thermal runaway occurred and subsequently propagated to one (1) additional cell. The process occurred over approximately a one (1) hour period. We note that the heating process is relatively gentle at 4-7 C per minute, and while this might reflect a typical uncontrolled heating process, it does not account for more severe faults or failures where multiple cells become involved in quick succession (due to significant damage, for example).

We have therefore chosen to assume that five (5) cells are simultaneously involved in thermal runaway and release the full available gas over a 20-minute period. It is assumed that following such an abrupt event, flaming combustion and event escalation would occur during or after this.

5.4.4.2 BESS Fire Mass Flux

From our review of the available literature and incident reports it appears that BESS unit fires are reported to last anywhere between approximately 2-8 hours.

In order to test the conditions on site most onerously we have opted to assume that the BESS unit burns for a period of 2-hours, before naturally exhausting its fuel supply. This is considered to be quite conservative since the BESS unit configuration can result in a high energy density.

Each module contains 104 battery cells, and each rack contains four modules in series and two in parallel (4S2P) totaling 832 cells. The unit itself contains eight units and therefore 3,328 battery cells.

The most onerous case to consider is that the entire unit (all cells) is involved in a fire simultaneously. It is perhaps too conservative to assume that all cells discharge their fuel simultaneously, naturally some will begin and exhaust before others begin.

The BESS layout onsite however, positions 4 BESS units together (2 x length to length and 2 x width to width) with separation of 0.3 m and 1.0 m respectively, so it is also reasonable to assume, in the pursuit of a *credible worst-case scenario* that the fire from unit one spreads to the adjacent unit (length to length facing) and we then assume that half the cells from each unit are still fully involved once the second unit ignites. Note that BESS unit external flaming was not observed during the UL 9540A testing series.

While the products of combustion of plastic fuels are considered in the model input parameters, the mass flux associated with plastic fuel is ignored.

We consider this qualitatively derived fire narrative suitable because the mass fuel rates are based on quantitative testing data, and there are simply too many iterations of possible fire progression to model. We believe this approach is suitably conservative for the reasons described, and:

The resulting BESS fire combustion product volumetric flow rate is 130 L/s.

A schematic of the BESS unit is provided as follows:

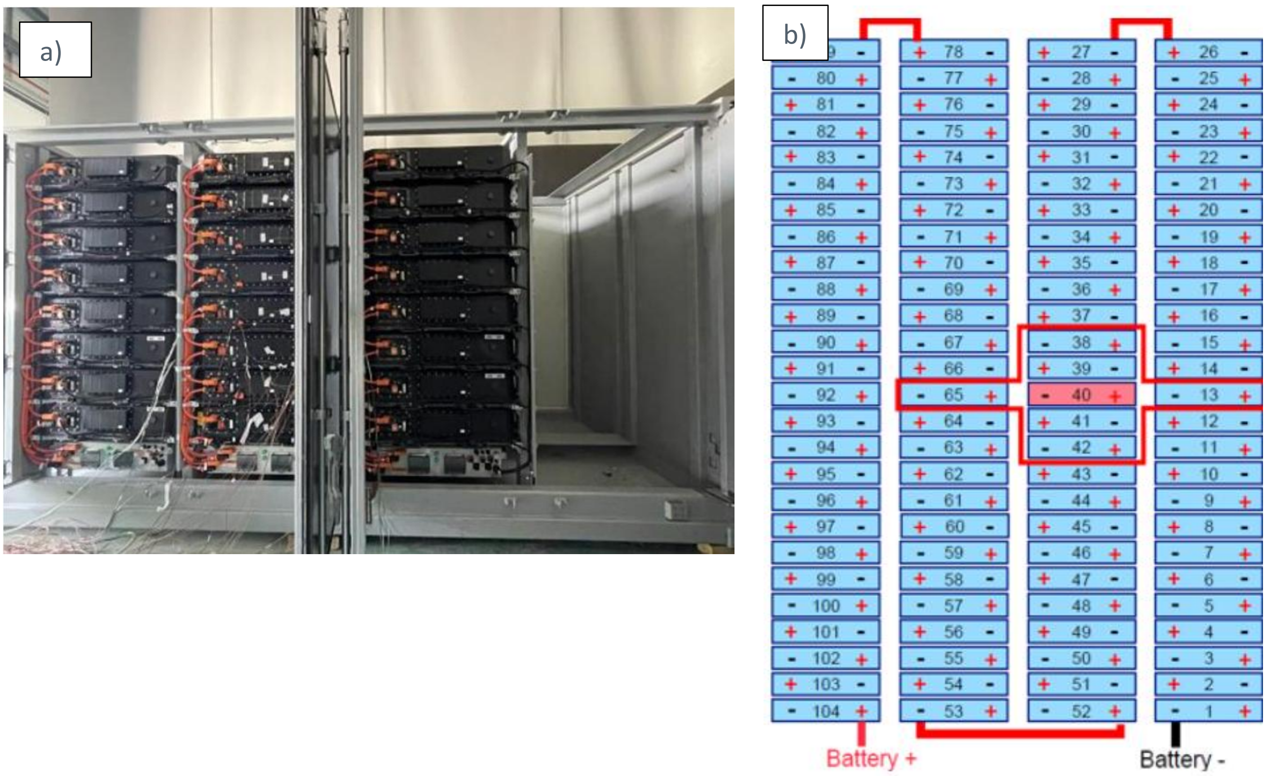

Figure 11. a) Indicative BESS Unit Photo and b) Battery Module Schematic[2]:

[2] Reproduced from: *Unit Test Report UL 9540A by UL (Changzhou) Quality Technical Service Co. Ltd*, dated 20-04-2025.

5.4.5 Site Parameters and Modelling Design

5.4.5.1 Weather

Statistical local wind pressure data has been sourced to incorporate condition variants into the modelling series.

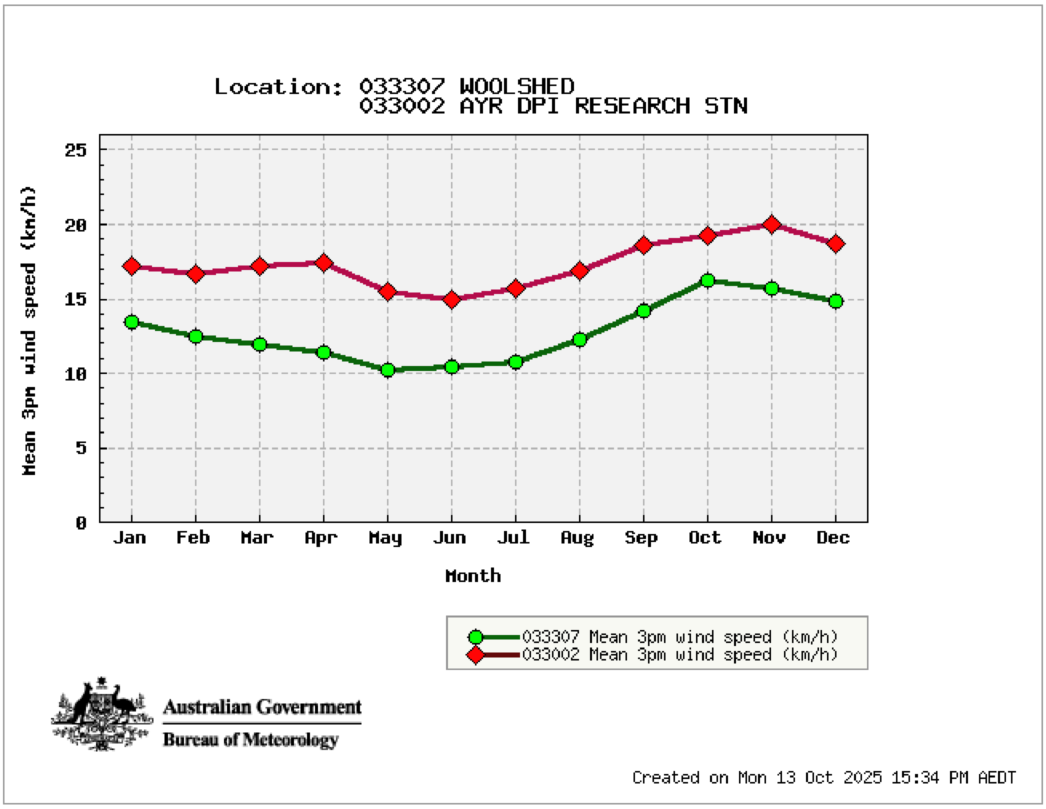

Figure 12. Mean 3pm Wind Speed (km/h) for 1998-2010 at Woolshed and Ayr DPI Research Station[3].

Note: these locations are chosen as they are the closet stations operated by the BOM to the subject site. Woolshed is located ~39 km North East of the subject site, whilst the Ayr DPI research station is located ~ 58 km east.

Figure 12 presents the mean 3pm wind velocities across the two BOM operated weather stations within the closest proximity to the subject site, being Woolshed and Ayr DPI Research Station. Consequently, we have chosen to model the following range of wind speeds for each leak/fire scenario:

Modelled wind speeds: 0 m/s, 2.5 m/s and 5 m/s (one sensitivity case, analysing smoke with >20 m/s gales).

Increasing the wind pressure has the effect, in the first instance, of increasing the downstream distance over which toxic materials may be observed at concentrations of interest. As the pressure is continually increased, at some point the turbulent mixing associated with higher pressures begins to more significantly and rapidly dilute the products of combustion. We note additionally that despite the common wind directions, our modelling

[3] Data gathered from the BOM Climate Statistics for Australia, https://www.bom.gov.au/climate/data/ (Accessed 13 October 2025).

assumes that wind could head in any direction momentarily and the downstream dispersion concentration results reflect this.

5.4.5.2 Environment Modelling Configuration

5.4.5.2.1 Surface Roughness

Surface roughness describes the degree of ground turbulence caused by the passage of winds across surface structures. Ground turbulence is greater in urban areas than in rural areas, for example, due to the presence of tall buildings.

The development site is situated on a plain adjacent mostly to agricultural land with significant land contours arising approximately 3.5 km to the west (Mingela State Forest), and 11km to the north-east (Mount Elliot) of the BESS yard, as indicatively illustrated within Figure 13.

A surface roughness of 0.3m, corresponding to parkland and generally open environment has been selected to represent the local terrain in our modelling.

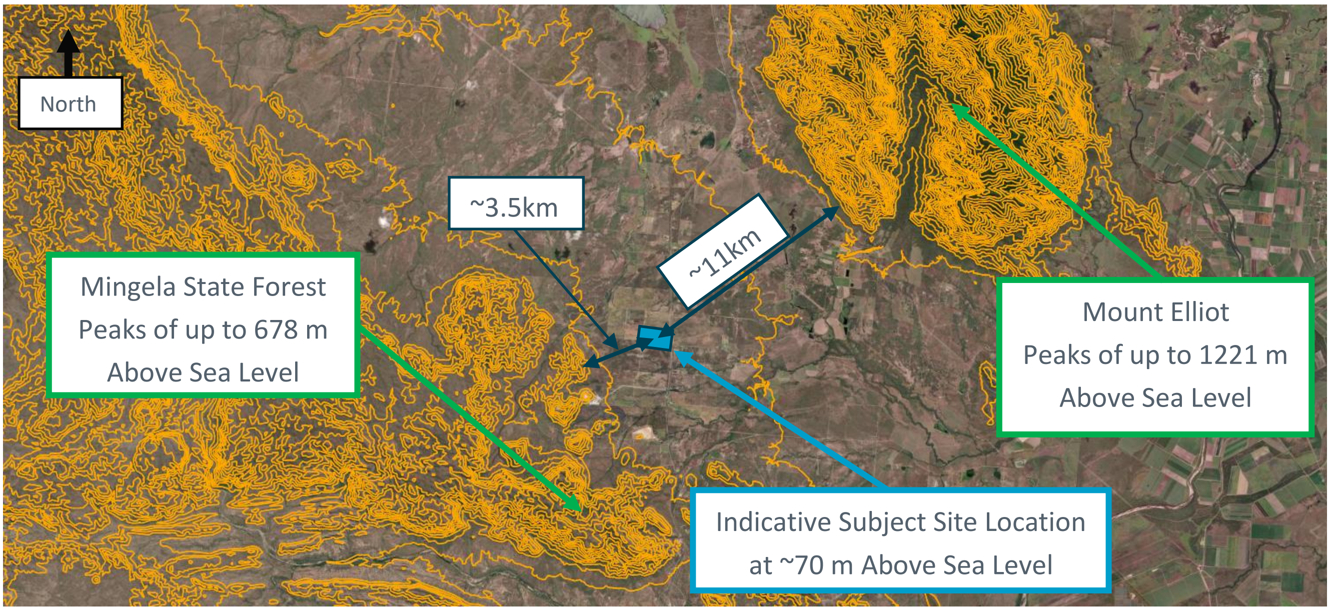

Figure 13. Subject Site Location with Surrounding Contours[4]

5.4.5.2.2 Random Wind Fluctuations

Random wind fluctuations were not included in our modelling. It is considered that additional and random wind flows, increasing shear stress, only serves to increase turbulence and hence, turbulent mixing and increasing air entrainment, which has the effect of increasing dilution. By excluding random wind fluctuations we believe that the dispersion/concentration results tend toward conservatism.

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[4] Data gathered from the QLD Globehttps://qldglobe.information.qld.gov.au/ (Accessed 13 October 2025).

5.4.6 Thermal Exposure – Fire Spread and Life Safety

A series of CFD models were performed to assess radiant heat flux from a BESS fire to surrounding equipment and for the purposes of life safety. First-principle hand calculations were performed as an internal check for the CFD model results.

Table 16. Modelled Scenario – Thermal Exposure

Case	Type	Fire	Emitter surface temp	Emitter surface emissivity
11	BESS unit	Unit(s) fully involved	900 C	0.9

The following assumptions and input parameters were used:

- Emissivity – a value of 0.9 has been assumed for the flame/emitting surface. This is considered to be a conservative assumption. [1].
- Temperature of the emitting surface, T_e – a surface temperature of 900°C will be used. Peak external plume temperatures of 900°C, maintained for short periods of time, are reported by Fire Code Reform Centre [2] and Babrauskas [3].
- Temperature of the receiving surface, T_r – a surface temperature of 24 °C will be used.

Clarification notes:

- We have assumed that the BESS unit(s) are fully involved in a fire. There is no point modelling a small or partial fire if there is a *possibility* of a fully involved fire occurring. The goal is to understand the credible worst-case conditions for heat transfer to remote equipment.
- We have the reviewed the literature, media reports and typical industry approach to applying a temperature to the emitting surface when modelling radiant heat transfer from a BESS container fire. We have noticed that often, a comparison is made between a fully involved BESS unit and the conditions in a compartment (room) fire at the onset of flashover, typically taken as 600 C. Given that compartment fire conditions are generally ventilation controlled post flashover, we do not believe this is a suitable comparison to draw since:
    i. the battery cells will provide their own oxygen for combustion, to some degree, and
    ii. the battery cells will produce high pressure jet flames which can impinge on the container surface heating it directly
    iii. the battery cells will produce high pressure jet flames that may project further outside of the unit that a buoyant flame at the window of a ventilation-controlled compartment fire
    iv. Doors or openings may fail, and the steel unit may suffer localised structural failure during a fully involved fire. It is therefore not possible to predict what portion of the BESS unit surface should be considered as flame (temperature), as opposed to heated external wall (temperature).
    v. We have therefore applied a surface temperature of 900 C to the BESS unit external surface (as the “emitter”). This temperature is referenced by various researchers (noted above) as it pertains to flame temperature within fully-developed compartment fires.

5.4.7 Off-Gas – BESS Internal – Mitigation of Flammable Atmosphere

A series of CFD models were performed to assess the build-up of flammable concentrations within a BESS unit during an off-gassing event, with the leak rate parameters as described in Section 5.4.4.1. Since hydrogen constitutes almost half of the combustible gas make-up, and has the widest combustible concentration limits of the gases given off, hydrogen is the gas of focus.

To analyse the development of the environment 25% and 50% lower flammable limits (LFL) were tracked (1% and 2% respectively), as was the hydrogen upper flammable limit (UFL), taken as 75%.

Note: for the modelling assessment gas detectors are assumed to be set to 25% LFL.

5.5 ANALYSES RESULTS

5.5.1 Case List

For convenience the list of model cases (from Table 13) is reproduced here. Results are presented in tabulated form and then followed by a series of image results of the most pertinent outcomes. A full presentation of all modelling image results are provided in Appendix D.

Table 17. Modelled Scenarios (Dispersion)

Case	Type	No cells	m'' (m^3/s)	Direction	Wind (m/s)	Notes
1	BESS off-gas	5	0.0012	Z	0.1	Far-field dispersion
2		5		Z	2.5	
3		5		Z	5.0	
4		5		-Y	-	BESS internal leak/ventilation
5	BESS fire combustion products (excl. soot)	All cells	0.13	Z	0.1	Fuel release rate for 2-hour fire period. Far-field dispersion
6		All cells		Z	2.5	
7		All cells		Z	5.0	
8		-	-	-	-	Test case – not reported
9		All cells	0.13	X	0.1	Fuel release rate for 2-hour fire period. Near-field dispersion
9a		All cells		X	2.5	
9b		All cells		X	5.0	
10a	BESS fire combustion (soot/smoke)	All cells	10 MW (PHRR)	Z	0.1	Far-field dispersion
10b		All cells		Z	2.5	
10c		All cells		Z	5.0	
10d		All cells		z	20.0	

Table 18. Modelled Scenario (Rad Flux)

Case	Type	Fire	Emitter surface temp	Emitter surface emissivity
11	BESS unit	Unit(s) fully involved	900 C	0.9

Results Presentation – Notes:

1. All results are presented in tabulated form
2. Where the scenario did not result in dispersion *laterally away* from the source, images of those outcomes are generally not presented.
3. Dispersion models are applicable to a BESS leak/fire in any location within the site, however the dispersion contour plot plans are plotted only in the extreme locations (for example, each of the 4 corners of the BESS area).

5.5.2 Description of BESS Internal Leak Analysis Visual Observations

The gas detection was assumed to occur when the 25 % LFL contour reached across approximately half of the ceiling length, to account for gas detector positioning. The exhaust fan was then assumed to run at 50% of the capacity (i.e. taken as 12 m^3/min) speed after a 30 second system activation and ramp up time.

The following section presents visual representation of the results. Generally, a small combustible gas cloud was observed to form near the leak source and a plume of 25 % LFL concentration was generally constantly observed between the leak source and the ceiling.

Upon activation of the exhaust fan, the hydrogen concentration was generally kept below combustible limits throughout the unit volume, other than very near to the source.

For the assumed boundary conditions, the exhaust system appears to be effective to mitigate flammable and explosive atmospheres within the BESS unit.

5.5.3 Off-Gass Dispersion

Table 19. Results Data – Case 1

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	<10 m from source	<10 m from source	Because of the gas make-up (low toxicity) and the comparatively gas flow rate (compared to fire), off-gassing dispersion cases are reasonably benign compared to the fire cases presented later.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	<10 m from source	<10 m from source	
Hydrogen (H)	N/A. LFL – 40,000 ppm	N/A. UFL – 750,000 ppm	<10 m from source	<10 m from source	
Methane (CH_4)	N/A. LFL – 50,000 ppm	N/A. UFL – 150,000 ppm	<10 m from source	<10 m from source	

Table 20. Results Data – Case 2

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	20 m (downwind)	230 m (downwind)	As above. Except that CO 8hr TWA is notable within ~230 m of the BESS plot.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	<10 m from source	<10 m from source	
Hydrogen (H)	N/A. LFL – 40,000 ppm	N/A. UFL – 750,000 ppm	<10 m from source	<10 m from source	
Methane (CH_4)	N/A. LFL – 50,000 ppm	N/A. UFL – 150,000 ppm	<10 m from source	<10 m from source	

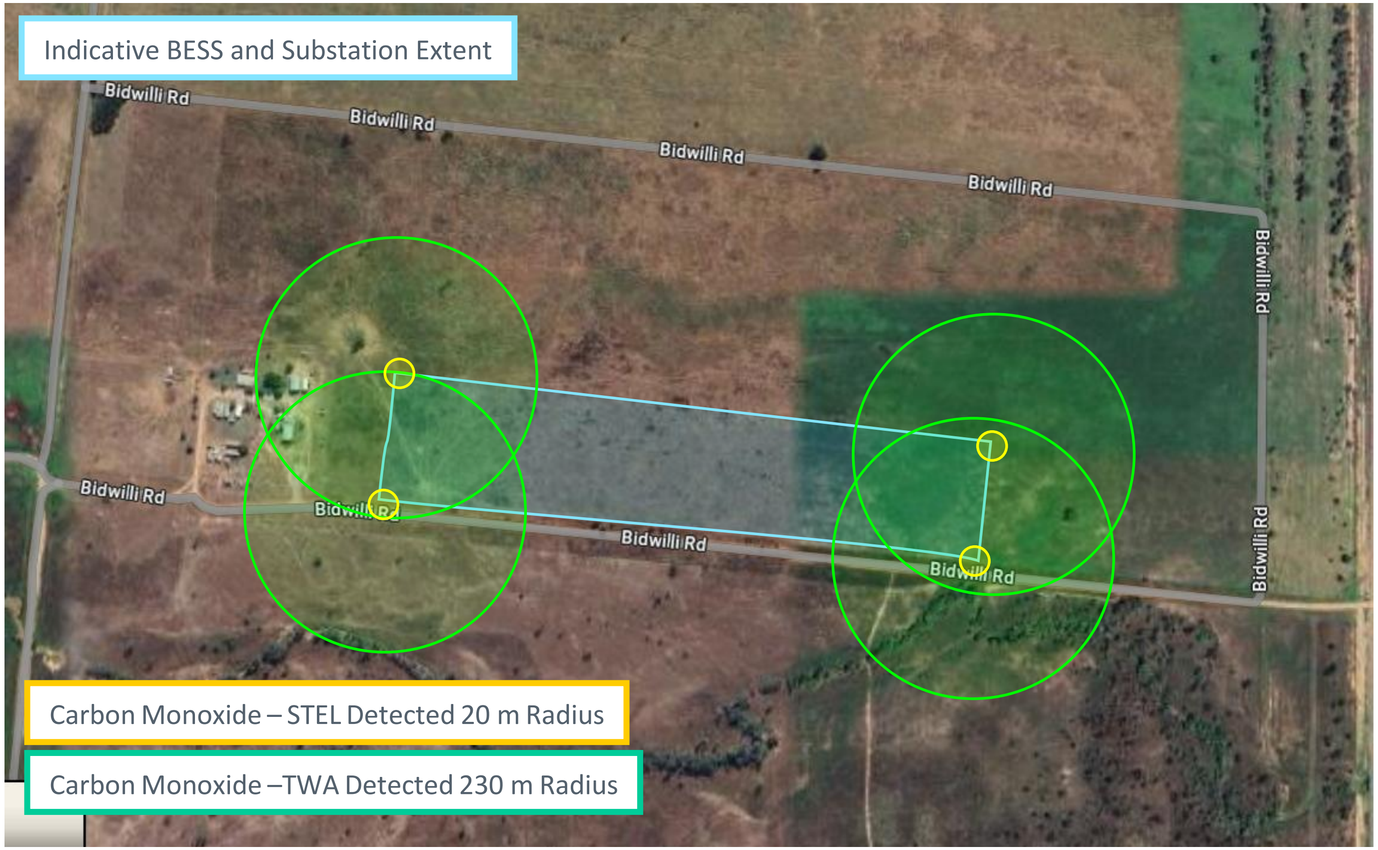
Table 21. Results Data – Case 3

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	50 m (downwind)	250 m (downwind)	As above. Except that CO 8hr TWA is notable within ~250 m of the BESS plot.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	<10 m from source	30 m (downwind)	
Hydrogen (H)	N/A. LFL – 40,000 ppm	N/A. UFL – 750,000 ppm	<10 m from source	<10 m from source	
Methane (CH_4)	N/A. LFL – 50,000 ppm	N/A. UFL – 150,000 ppm	<10 m from source	<10 m from source	

Table 22. Results Data – Case 4 (TBC – Internal BESS units).

Material	Flammable limits		25% LEL	50% LEL	Notes
Hydrogen (H)	LFL – 40,000 ppm	UFL – 750,000 ppm	Tracked	Tracked	Effective dilution and ventilation is demonstrated where the exhaust fan runs at assumed 50% of max capacity , i.e. runs at 12 m^3/min exhaust. 5 cells off-gas simultaneously 2 minute delay detection exhaust ramp-up assumed.

Table 23. Dispersion Contours – Case 2

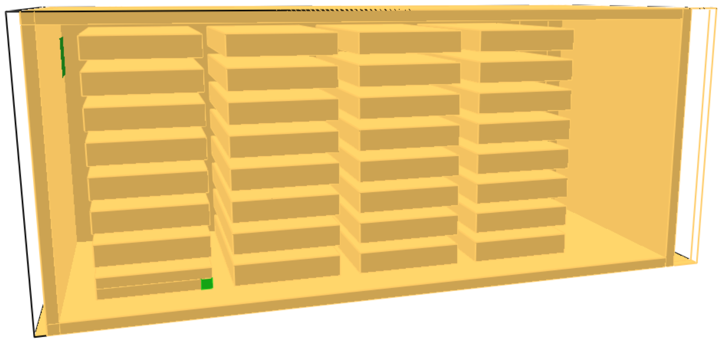
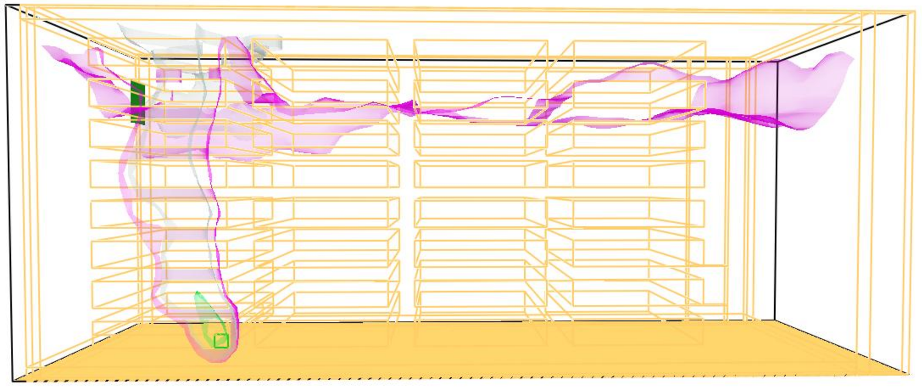
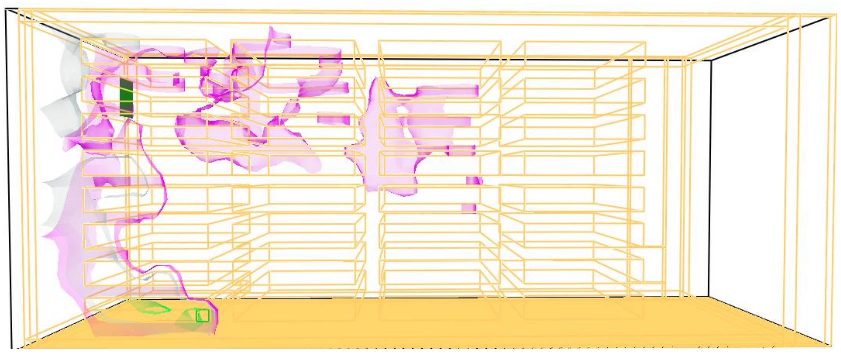
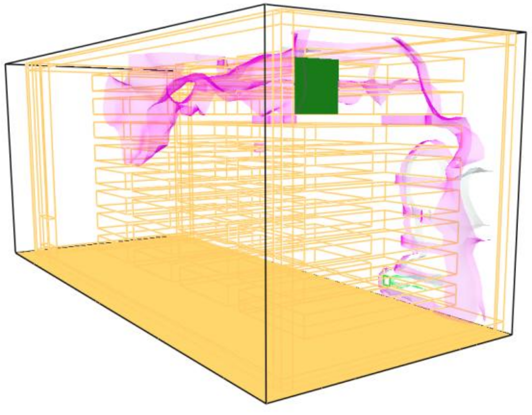


Case 2: Carbon Monoxide – 20 m STEL, and 230 m TWA

Table 24. Dispersion Contours – Case 3

Case 3: Carbon Monoxide – 50 m STEL, and 250 m TWA Radius

Table 25. Dispersion Contours – Case 4

BESS internal w modules	150 seconds (as exhaust comes online) (battery modules shown outline)
	
Constant concentration achieved with fan at 12m^3/min	Alternative view showing 50% LFL confined so small column above leak point
	

5.5.4 BESS Fire – Combustion Products Dispersion

Table 26. Results Data – Case 5 – BESS fire - wind 0.1 m/s

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source/plume above	At source/plume above	Low wind (<0.2 m/s) / i.e. "calm" environment Turbulent mixing from obscure air currents in an otherwise calm environment are not modelled here and could increase gas migration. **Assume STEL occurs not less than 30 m perimeter around source.** Further factor of safety should be added re intervention.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source/plume above	At source/plume above	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source/plume above	At source/plume above	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	At source/plume above	At source/plume above	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	At source/plume above	At source/plume above	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	At source/plume above	At source/plume above	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	At source/plume above	At source/plume above	

Table 27. Results Data – Case 6 – BESS fire - wind 2.5 m/s

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source/plume above	At source/plume above	Gentle wind case (2.5 m/s) STEL and TWA observed 10-15m downwind but at elevation of source +10 m. **Assume STEL occurs at not less than 30 m downwind of source.** Further factor of safety should be considered re intervention protocols.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source/plume above	At source/plume above	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source/plume above	At source/plume above	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	At source/plume above	At source/plume above	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	At source/plume above	At source/plume above	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	At source/plume above	At source/plume above	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	At source/plume above	At source/plume above	

Table 28. Results Data – Case 7 – BESS fire - wind 5 m/s

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source	At source	5m/s aligns with the reported max avg. annual wind
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source	At source	STEL for HCL, HF, NOx and SOx observed 10-30m downwind.
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source	At source	TWA for HCL, HF, NOx and SOx observed 30-40m downwind.
Hydrogen Chloride (HCL)	5 ppm	2 ppm	20 m downwind	40 m downwind	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	30 m downwind	45 m downwind	This higher wind pressure appears to be suitable to migrate gas
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	20 m downwind	40 m downwind	effectively before significant dilution c. 50m+ downwind.
Sulphur Dioxide (SOx)	5 ppm	2 ppm	15 m downwind	30 m downwind	**Recommend STEL considered as 50m downwind.**

Table 29. Results Data – Case 9 – BESS fire - wind 0.1 m/s (obstructed flame)

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source	At source	
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source	At source	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source	At source	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	At source	At source	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	At source	At source	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	At source	At source	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	At source	At source	

Table 30. Results Data – Case 9a – BESS fire - wind 2.5 m/s (obstructed flame)

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source	10 m downwind	
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source	At source	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source	At source	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	25 m downwind	40 m downwind	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	30 m downwind	50 m downwind	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	20 m downwind	40 m downwind	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	10 m downwind	15 m downwind	

Table 31. Results Data – Case 9b – BESS fire - wind 5.0 m/s (obstructed flame)

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source	At source	5m/s aligns with the reported max avg. annual wind
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source	At source	STEL for HCL, HF, NOx and SOx observed 10-45 m downwind.
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source	At source	TWA for HCL, HF, NOx and SOx observed 30-50 m downwind.
Hydrogen Chloride (HCL)	5 ppm	2 ppm	25 m downwind	45 m downwind	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	45 m downwind	50 m downwind	This higher wind pressure appears to be suitable to migrate gas
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	20 m downwind	45 m downwind	effectively before significant dilution c. 50m+ downwind.
Sulphur Dioxide (SOx)	5 ppm	2 ppm	15 m downwind	30 m downwind	**Recommend STEL considered as 50m downwind.**

Table 32. Results Data – Case 10(a-d) – BESS fire

Case	Wind	Case Type	PHRR	Visible Plume*	Plume Olfactory**
10a	0.1 m/s	Primary	10 MW	~ 100 m downwind	< 500 m
10b	2.5 m/s	Primary	10 MW	~ 1,000 m downwind	> 1,000 m
10c	5.0 m/s	Primary	10 MW	~ 2,000 m downwind	> 2,000 m
10d	20.0 m/s	Sensitivity	10 MW	< 1,000 m downwind	< 2,000 m

* Note that distances are approximate. Nuances in weather/wind conditions will impact the nature of the smoke plume and whether smoke can be detected in the air through visual or olfactory means. Toxicity of combustion products are reviewed in case 1-9.
** Olfactory – meaning that the smell of smoke in the air may be credible.

Table 33. BESS Fire - Dispersion Contours – Case 9b (STEL)

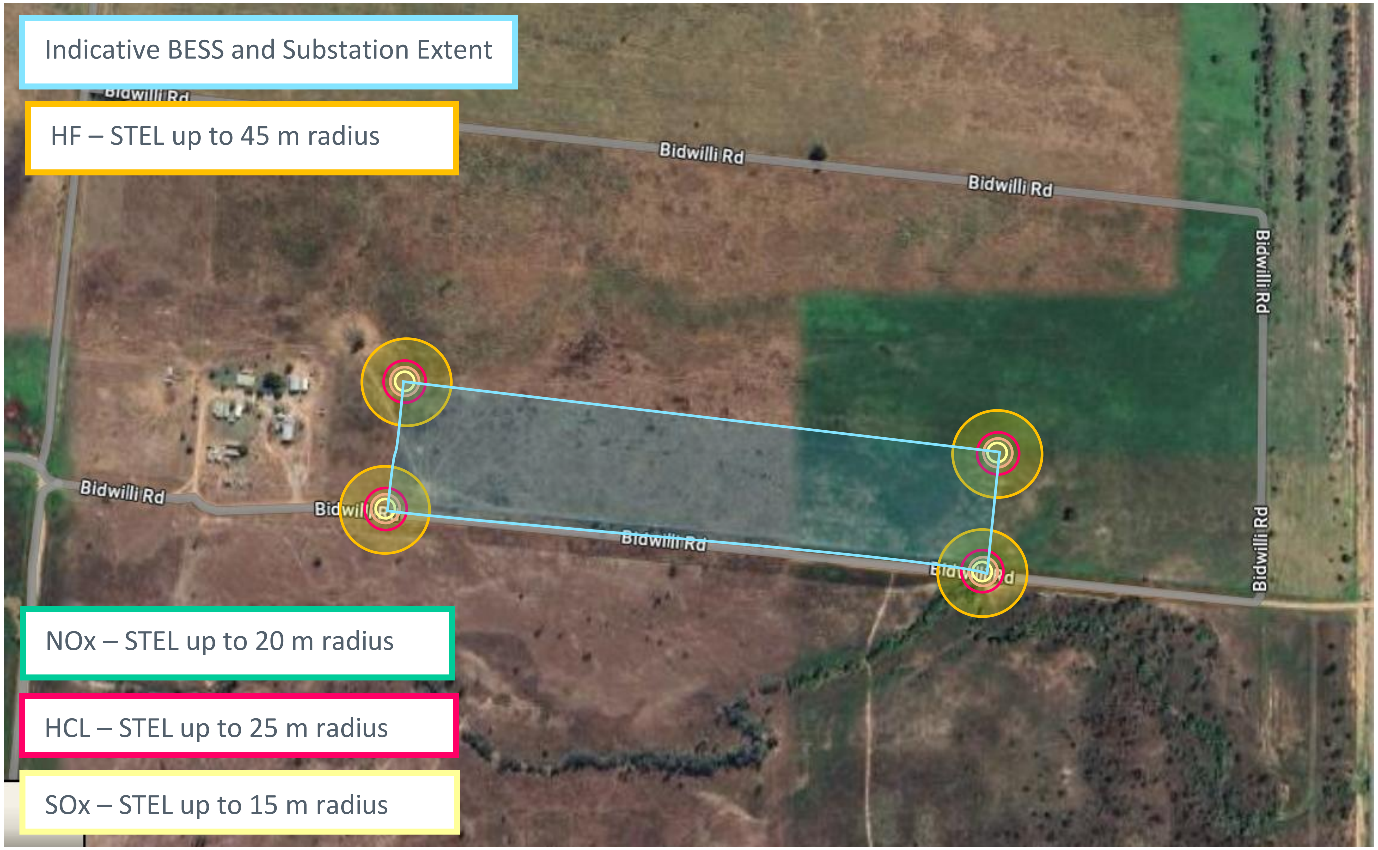


Table 34. BESS Fire - Dispersion Contours – Case 9b (TWA)

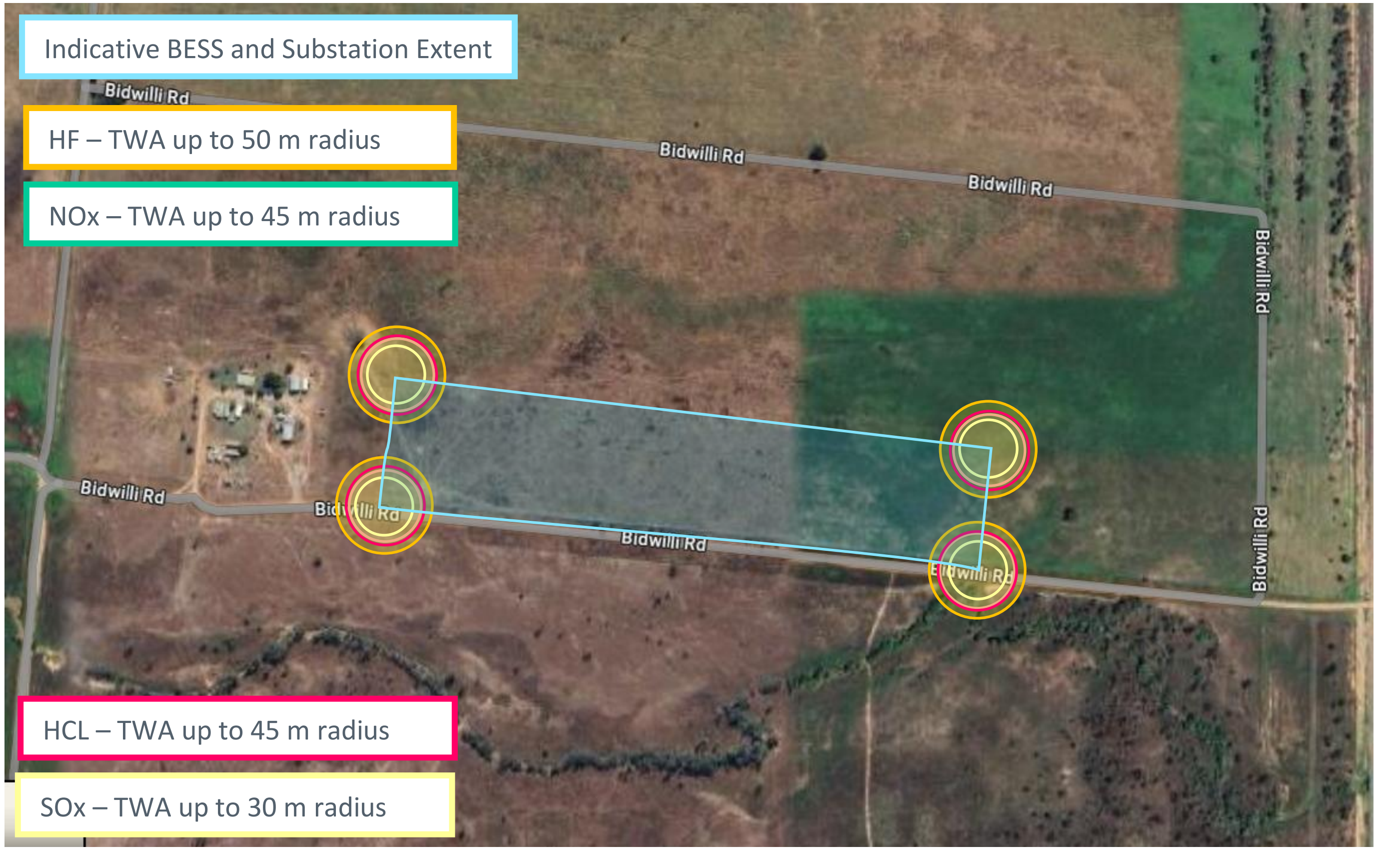


Table 35. BESS Fire - Dispersion Iso-surfaces – Case 9

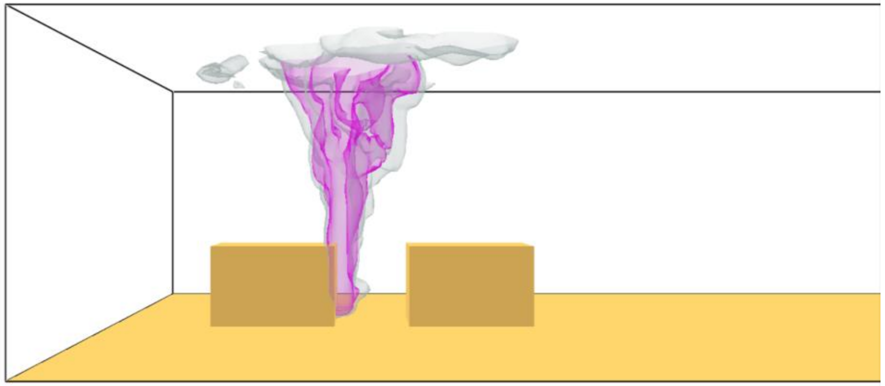
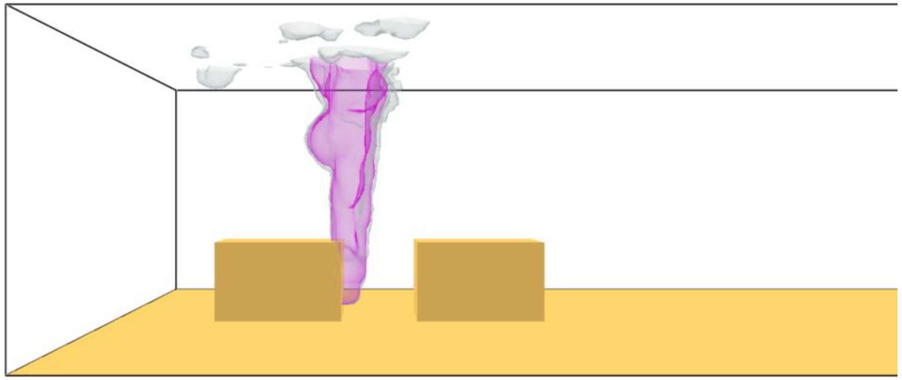
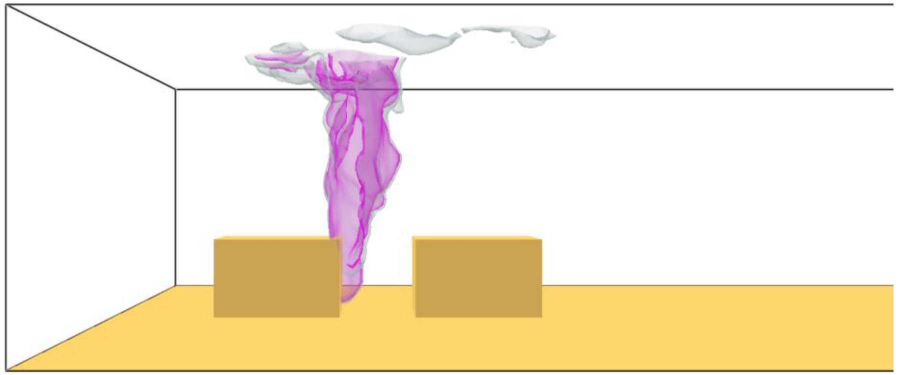
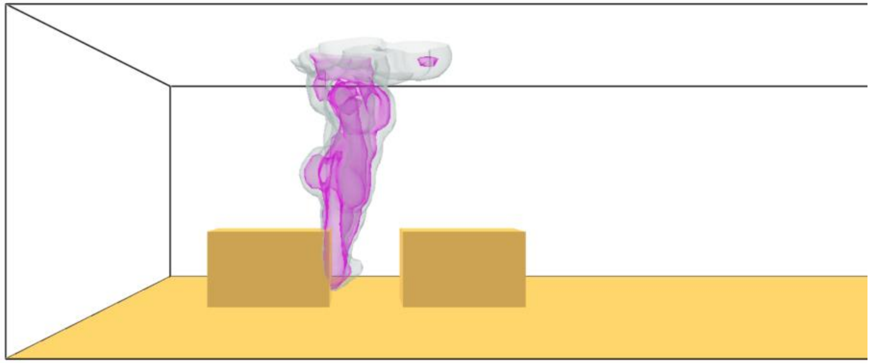
	
Case 9 – Iso-surface: Hydrogen Chloride (STEL- Purple, TWA – Grey)	**Case 9 – Iso-surface: Hydrogen Fluoride (STEL- Purple, TWA – Grey)**
	
Case 9 – Iso-surface: NOx (STEL- Purple, TWA – Grey)	**Case 9 – Iso-surface: Sulphur Dioxide (STEL- Purple, TWA – Grey)**

Table 36. BESS Fire - Dispersion Iso-surfaces – Case 9a (HCL, HF)

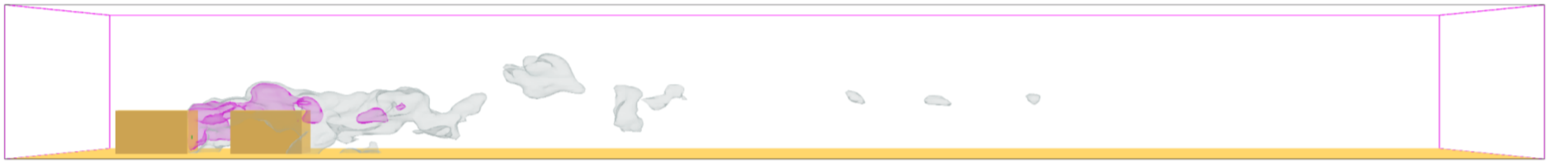
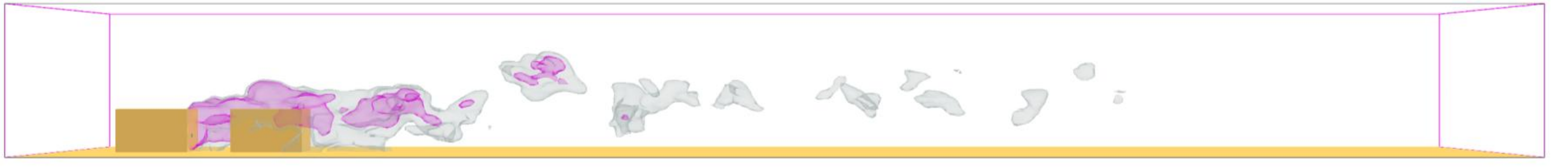
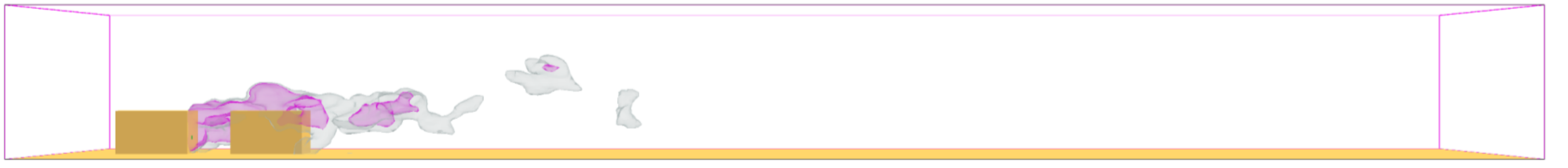
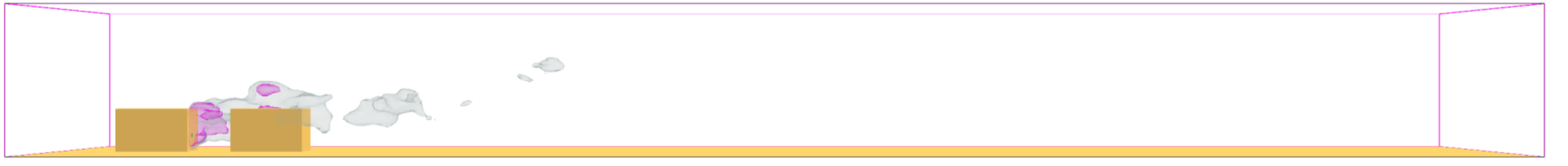
	
Case 9a – Iso-surface: Hydrogen Chloride (STEL- Purple, TWA – Grey)	100 m
	
Case 9a – Iso-surface: Hydrogen Fluoride (STEL- Purple, TWA – Grey)	

Table 37. BESS Fire - Dispersion Iso-surfaces – Case 9a (NOx, SOx)

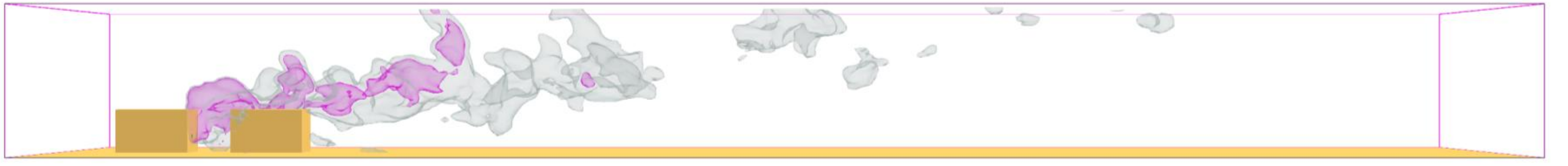


Case 9a – Iso-surface: NOx (STEL- Purple, TWA – Grey)	100 m



Case 9a – Iso-surface: Sulphur Dioxide (STEL- Purple, TWA – Grey)

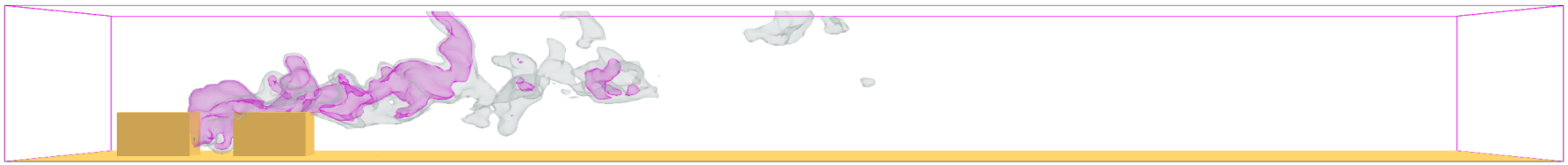
Table 38. BESS Fire - Dispersion Iso-surfaces – Case 9b (HCL, HF)



Case 9b – Iso-surface: Hydrogen Chloride (STEL- Purple, TWA – Grey) 100 m

Case 9b – Iso-surface: Hydrogen Fluoride (STEL- Purple, TWA – Grey)

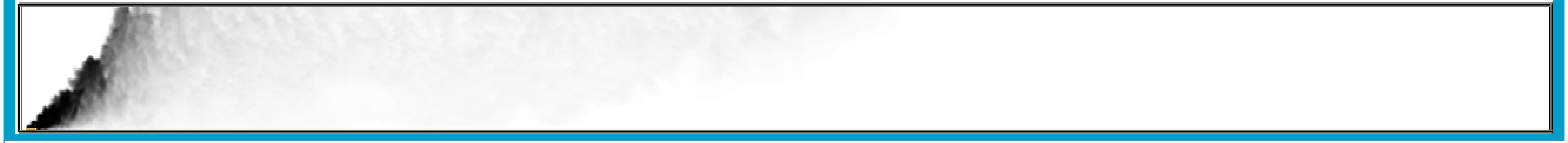
Table 39. BESS Fire - Dispersion Iso-surfaces – Case 9b (NOx, SOx)



Case 9b – Iso-surface: NOx (STEL- Purple, TWA – Grey)	100 m

Case 9b – Iso-surface: Sulphur Dioxide (STEL- Purple, TWA – Grey)

Table 40. BESS Fire – Approximate visible identification of smoke – Case 10


Case 10b – Visible smoke plume (2.5 m/s) **1500 m**

Case 10c – Visible smoke plume (5.0 m/s)

Case 10d – Visible smoke plume (20.0 m/s) (sensitivity study)

5.5.5 BESS Fire – Thermal Exposure

Table 41. Results Data – Case 10a – BESS Unit fire (thermal exposure to surrounding equipment)

BESS fire	Target	Flux (kW/m²)	Distance (m)	Expected Impact at Target
BESS Unit	Far side of nearest road	~15.0	7.0	< 25 kW/m2, for non-piloted ignition
BESS unit	Nearest BESS unit	21.0	3.0	< 25 kW/m2, for non-piloted ignition / Negligible impact to equipment
BESS unit	Nearest PCU	9.0	6.0	Negligible impact to equipment.

Table 42. Results Data – Case 10a – BESS Unit fire (thermal exposure to personnel)

BESS side	Flux (kW/m²)	Distance (m)	Relevance	Time period	Notes
Long side	2.5	14	Persons with long sleeves and trousers	30 secs +	These time limits for exposure prior to pain are a guide only and real outcomes depend upon on site conditions, weather and individual tolerance levels.
Long side	4.6	11	Fire Brigade in full PPE	Up to 3 min	
Narrow side	2.5	12	Persons with long sleeves and trousers	30 secs +	
Narrow side	4.6	9	Fire Brigade in full PPE	Up to 3 min	

Notes:

Given the dispersion modelling results, unprotected persons (i.e. with skin protection and BA) should NOT be within 14 m of a BESS fire in any case. While approaching a fire from upwind may reduce the potential for exposure to toxic materials, radiant heat flux can be considered to be consistent upwind or downwind.

Figure 14. Radiant Heat Flux Analyses between BESS Units and Surrounding Equipment

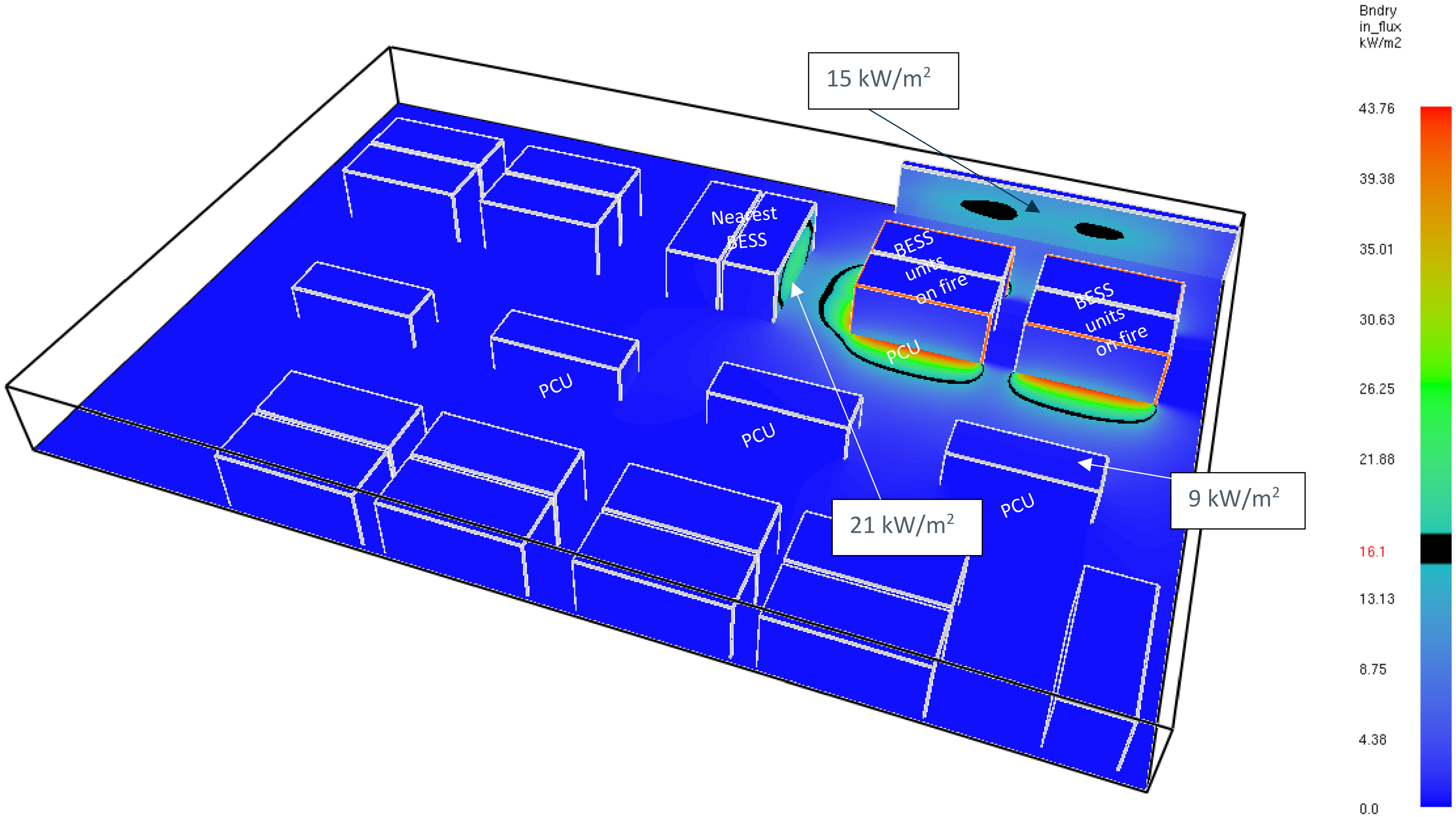
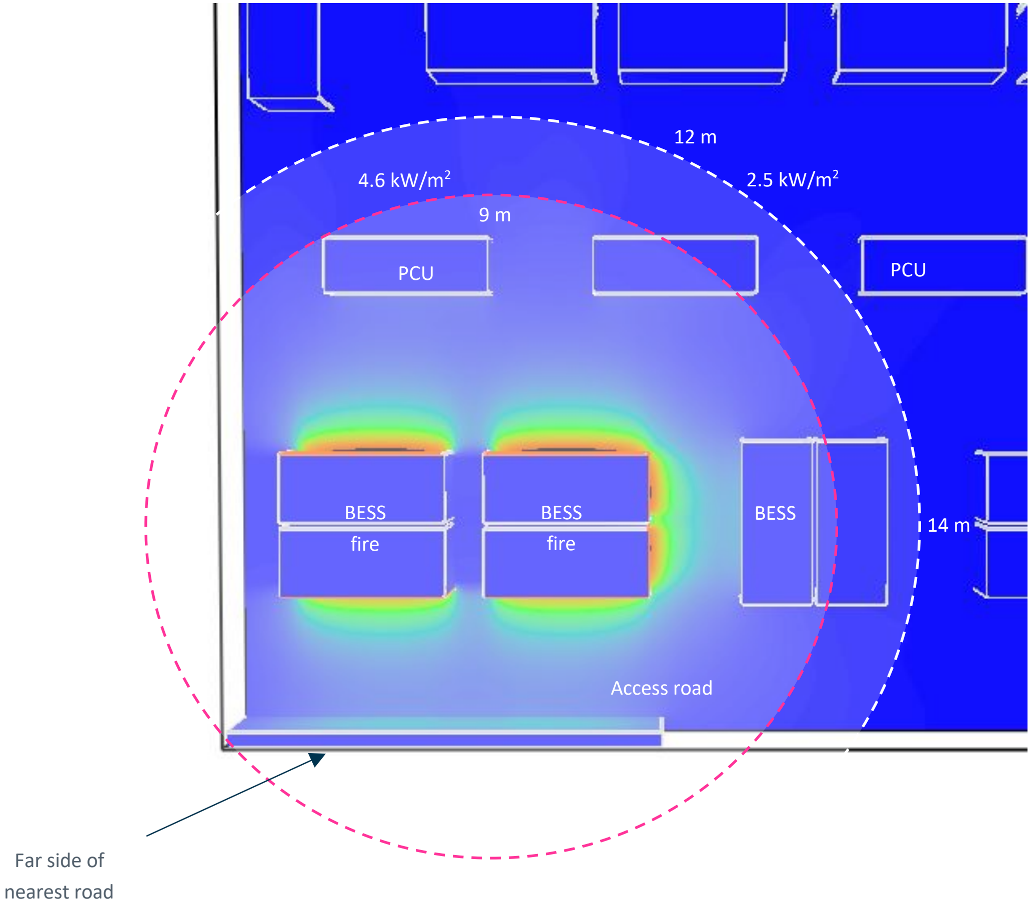


Figure 15. Radiant Heat Flux Analyses for Life Safety



6 Layers of Safety (LOS) Summary

6.1 OVERVIEW

The fire safety strategy will be composed of various levels of event prevention and consequence mitigation ranging from product choice/design to active/passive fire protection systems and emergency response/intervention. The levels of protection can be considered as follows:

1. Battery characteristics
2. BMS, monitoring and process control
3. Inherent safe design, compliance with relevant codes and standards
4. Automatic Control Measures
5. Physical Protection
6. Site layout and design
7. Facility emergency response, fire brigade intervention and emergency responders.

6.2 LAYERS OF SAFETY

6.2.1 Layer of Safety 1: Battery Characteristics

The risk of fire and thermal runaway in battery cells and modules is minimised through the choice of cell chemistry, and cell, module and rack design and construction.

Key Controls:

Battery Cell:

- Li-ion chemistry is lithium iron phosphate (LFP), which is the most stable in terms of thermal runaway potential under normal and abnormal operating conditions.
- Prismatic metal casing (aluminium) resists deformation and provides heat sink mechanism.
- The cell vent provides direct pressure relief, as shown.

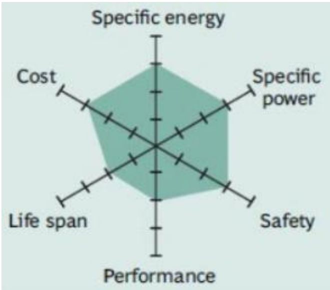
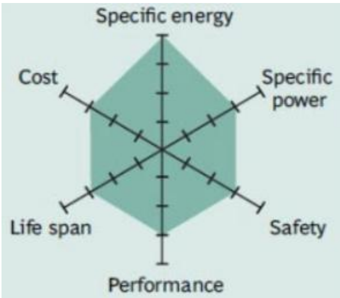
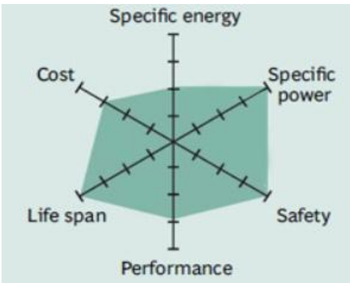
Battery rack:

- Isolation switch at control panel
- Thermal management system applying liquid cooling of cells and modules.

A damaged or overcharged battery carries a risk of inducing fire. Thermal runaway is the onset of the chain reaction that occurs when a battery's temperature begins a sequence of uncontrollable temperature rise, generally leading to the emission of internal fire. Some batteries are more prone to thermal runaway than others, depending on the chemistry of the battery and how it is used.

The Battery Energy Storage System (BESS) technology and chemistry proposed for the Project is LFP (Lithium, Ferrous and Phosphate), sometimes known as Lithium Iron Phosphate. LFP batteries are inherently safer and less prone to thermal runaway than other lithium-ion battery chemistries, such as Lithium Nickel Manganese Cobalt (NMC) and Lithium Cobalt Oxide (LCO) batteries, for example. LFP batteries can be forced to shut down if damaged to help prevent thermal runaway and support safety throughout shipping, transit, and operation. Table 43 provides a visual depiction of the strengths and weaknesses of these common lithium-ion battery options.

Table 43. Battery chemistry summary

Battery Chemistry	Safety limit	Summary	Safety Snapshot
Lithium Cobalt Oxide (LCO)	150 C	All round battery, average safety, low performance and life span. Uses: Power tools, medical devices	
(Lithium) Nickel Manganese Cobalt Oxide (NMC)	210 C	High power and high energy, sensitivity to overcharging and potential thermal runaway, meaning a higher burden for safety management. Uses: Automotive, energy storage	
Lithium Ferrous Phosphate (LFP)	270 C	Lower energy density but able to self-discharge, excellent lifespan and operational stability, one of the safest Li-ion batteries. Use: energy storage.	

Visuals ref: https://batteryuniversity.com

Figure 16 provides a comparison of typical volume (quantity) of gases emitted from damaged battery cells of the types discussed in Table 43 (LCO, NMC and LFP). The LFP battery type chosen for this project was demonstrated to emit significantly less than other battery chemistries LCO (approximately half) and NMC (approximately one third).

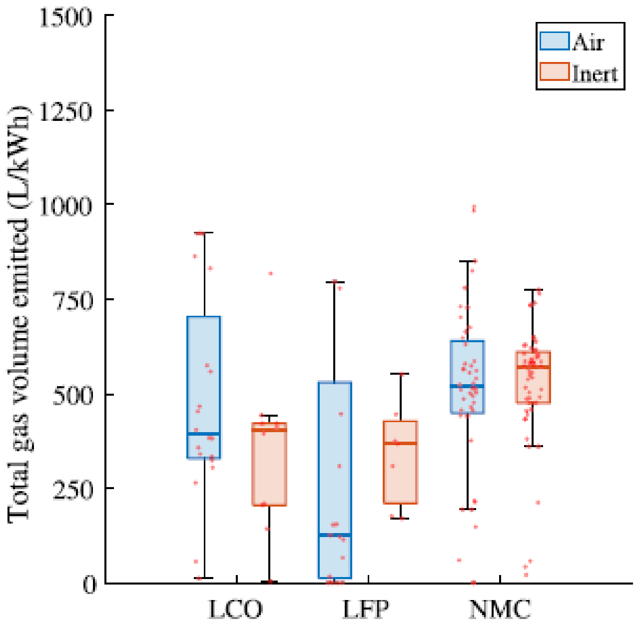


Figure 16. Quantity of gas emitted by various battery types (Ref. Bugryniec et al. 2024)

6.2.2 Layer of Safety 2: Battery Management and Thermal Management Systems (BMS, TMS)

Process monitoring through the BMS is integrated across all levels from battery cell to Core. The BMS monitors and controls parameters such as temperature, current and voltage to ensure batteries are operating optimally and within design specifications. It also detects and manages faults and potential operational upset conditions that could otherwise lead to problems such as thermal runaways and/or fire.

The unit utilises liquid cooling to keep the battery system running within an optimal operating temperature range. This enables the battery to perform at high efficiency, maximizing energy storage and release, minimizing State of Health (SOH) degradation, and extending its lifespan to the fullest.

The TMS is composed of a liquid cooling unit (including a PTC heater), liquid cooling pipes located beneath battery modules. Controlled by the BMS, the TMS operates as the BMS sends startup or shutdown signals to the cooling unit. In response, the cooling unit works to adjust the circulating coolant's temperature, facilitating heat exchange within the cooling pipes. This circulating coolant transfers heat to or from the battery through the pipe, thereby maintaining the battery's temperature within the optimal range.

For example, when the BMS detects that the battery temperature exceeds the preset value, the cooling unit activates, lowering the temperature of the circulating liquid until it reaches the preset value. Conversely, if the

BMS detects that the temperature falls below the preset value, the heating mode will engage, raising the circulating liquid's temperature to the desired level.

Key Controls

- Battery operations are maintained within design specifications through cell balancing, thermal management and the like. A liquid cooling system is built into the system to manage battery temperatures as determined by the BMS monitoring.
- Battery racks can be disconnected remotely from the control room/by operators.
- Performance and condition is constantly monitored and information is sent to, and distributed as required via the fire indicator panel.
- The BMS is integrated with the facility-wide control and monitoring systems. Remote shutdown, start-up and troubleshooting is possible.

6.2.3 Layer of Safety 3: Inherent Safe Design

The subject BESS unit systems are designed to contain a fire within the unit of origin.

Large-scale fire testing of the battery racks conducted in accordance with the UL 9540A Test Method confirmed that the batteries meet the associated criteria for non-propagation, i.e. if a fire was to occur within a battery cell, module or rack, provided the fire does not compromise the integrity of adjacent equipment or structures, the fire would not spread to other areas within the unit or to adjacent units.

Key Controls

No propagation between modules, racks or units observed throughout the UL9540A testing of the chosen units.

6.2.4 Layer of Safety 4: Automatic Control Measures

Layers of protection 1-3 are provided with the intent that an accidental fire event is avoided. However, should a fire occur, spread from a battery cell, module, rack or unit is mitigated by ensuring that conditions supporting fire development are shut down rapidly.

Key Controls

- Multi-criteria detectors monitor for pre-thermal runaway conditions (smoke, gas and heat detection, for example).
- The BMS and control systems include an emergency stop function which can be triggered at different infrastructure levels (rack, unit, cluster etc) depending on the nature of the event.
- A flashing strobe identifies the affected unit for external responders.
- Automatic safety shutdown is triggered at the inverters and transformers if safe operating conditions are breached.

6.2.4.1 Automatic Fire Detection and Alarm

Should a fire occur, early detection and alarm is critical to alert the remote monitor site (and if applicable, onsite personnel) and to initiate exhaust venting.

Unit Level

BESS containers are provided with automatic detection for fire and combustible gas depending on the specific battery chemistry and local hazards. For the LFP batteries used on site, the most effective gas detection is considered to be hydrogen detection, since hydrogen constitutes over one third of the gas given off from battery cells in the case of damage or overheating off-gassing.

The detection systems will have direct alarm monitoring to the fire control panel and the detection of smoke and or gas (hydrogen) will automatically activate the container ventilation louvres.

6.2.4.2 Venting and Overpressure Protection

BESS containers are provided with automatic ventilation to allow displacement of gas/smoke following a leak/fire and to mitigate the build-up of combustible/explosive atmospheres. Explosion overpressure venting is not provided.

If a battery is damaged and off-gassing occurs, the gas will be composed of a number of different chemicals. The site-specific battery cells have been tested and the gas composition analysed. The primary constituents are (approximately) as follows:

- Hydrogen ~ 36%
- Carbon dioxide ~36%
- Carbon monoxide ~9 %
- Methane/THC 17%

Therefore, the quickest detection following off-gassing is likely to be achieved by monitoring for hydrogen within the BESS container. If hydrogen is detected at a predetermined set point, the vent louvres will automatically open and the extraction fan will start-up to draw gas out of the container. The intent of this approach is to ensure that combustible or explosive air-gas mixtures cannot occur within the container.

The lower combustible limit (LCL) of hydrogen is 4 %, and so a predefined detector set point of 20 %LEL would be detected when the sampled air is composed of at least 0.8 % hydrogen by volume.

Apart from equipment components required to be made of plastic and the like, the materials within the container are generally non-combustible, and electrical equipment is required to be ATEX-rated, meaning that they are airtight and cannot act as an ignition source. The containers are made of steel which is non-combustible and retains its integrity at high temperature, and so provides a physical barrier to fire spread in the case of a fire within a container.

Figure 17 is borrowed from the manual for a similar CATL BESS unit and is used (as a placeholder) to demonstrate the gas/smoke exhaust system concept. The exhaust fan is positioned at high elevation since hydrogen, methane and the like present as lighter, buoyant gases compared to air.

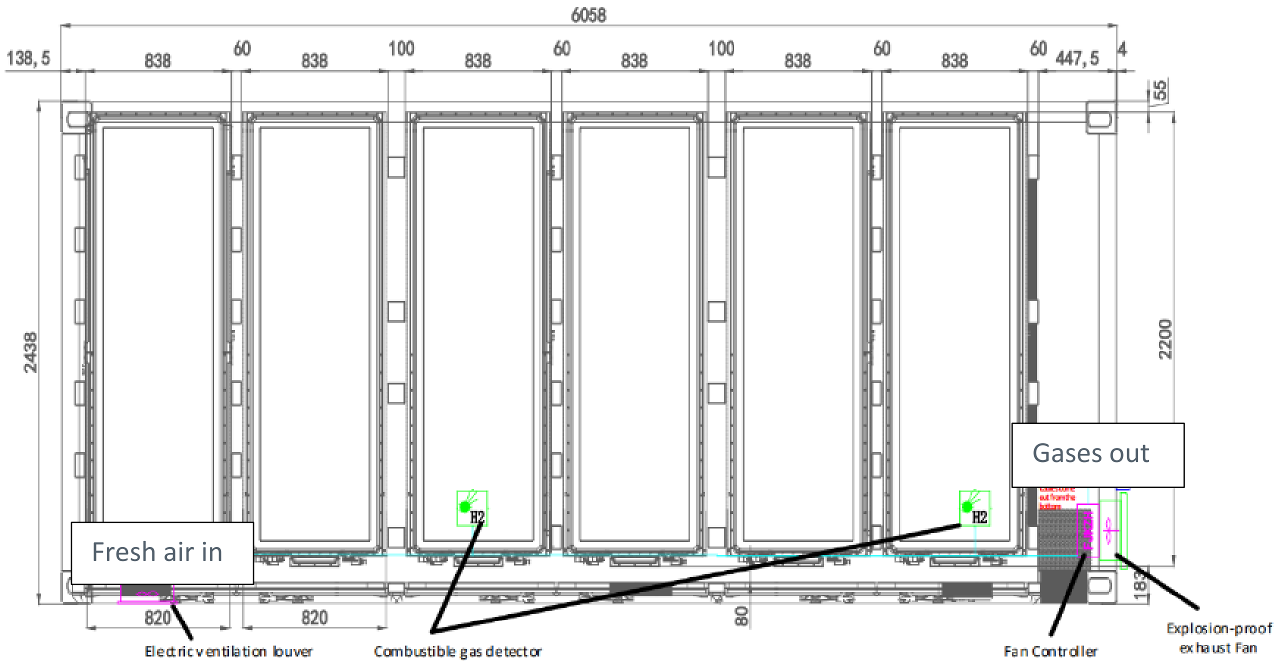


Figure 17. Depressurisation strategy (plan view)

6.2.5 Layer of Safety 5: Physical Protection

If a breach did occur at the module and rack level, allowing further combustible material within the enclosure to be exposed, an extensive fire may develop. If a flammable gas mixture accumulates, ignition (e.g. from faulty or exposed electrics) may cause a deflagration or explosion with significant overpressure and ejected material followed by a fire. Provided the explosion does not compromise the integrity of the unit, the fire would, in principle, remain confined to the source enclosure and propagation to other areas would not be expected.

Key Controls

- The units act as discrete battery enclosures which are sealed and independently controlled.
- The vent on each battery cell provides direct pressure relief for that cell.
- Venting/exhaust panels are fitted in the walls of each unit to allow the mechanical, fan-assisted exhaust of combustible gases prior to the occurrence of combustible concentrations and the opportunity for ignition.
- The walls of the units are thermally insulated with non-combustible insulation (rock wool).
- Horizontal separation at least in accordance with AS2067:2016 must be maintained between buildings and storage of flammable materials.
- Lightning masts are installed on site, designed and installed in accordance with AS 1768:2021. We assume a Lightning Protection System Level (PL) of PL II or PL III is appropriate, however this determination should be undertaken by an Electrical specialist through detailed assessment in accordance with AS 1768 / IEC 62305.
- Arc flash restricted approach boundaries and arc flash personal protective equipment (PPE) are required to minimise the potential consequence following occurrence of an arc flash event.

6.2.6 Layer of Safety 6: Site Layout and Fire Break Strategy

Fire spread (heat transfer) and the impact of a pressure event between equipment and the environment around fire or explosion-involved equipment are mitigated by the site layout/design.

Key Controls

- BESS units are arranged such that fire spread between equipment is suitably mitigated. It is accepted that if one BESS unit becomes fully involved in a fire, there is a possibility that the immediate neighbour unit could also become involved in the fire.
- In this way it is noted that the BESS units are not positioned in typical rows (that effectively form corridors) and instead the rows that do exist utilise a ~10 m separation between each set of four (4) units. PCUs are located approximately 3 m east and west of the BESS units.
- These separation distances are understood to exceed the minimum prescriptive requirements outlined in:
    - NFPA 855 (being approx. 3 m to adjacent equipment)
    - AS 5139 provides advice on the principles and intent of risk assessment for battery systems. The suitability of the BESS cluster spacing proposed has been assessed in detail and the nature of credible fire growth within and between BESS units was discussed in Section 5. This forms the basis for safety at this site, as opposed to prescriptive separation distances.
- The BESS and sub-station yards are arranged such that personnel have at least two direction-of-travel options following fire involving equipment or other emergency situation.
- Protection against thermal attack/ignition of site equipment from the threat of bushfire has been assessed and addressed in a site-specific bushfire assessment report, by others. The resulting asset protection zone (APZ) and fire break requirements are reproduced overleaf.
- The BESS yard , including substation and transmissions lines requires an asset protection zone (APZ) of not less than 29.1 around the perimeter, in accordance with the findings of the site's Fire Management Plan

(FMP) report. The FMP report contains details of the separation required during construction and during normal operation for each area of the site.

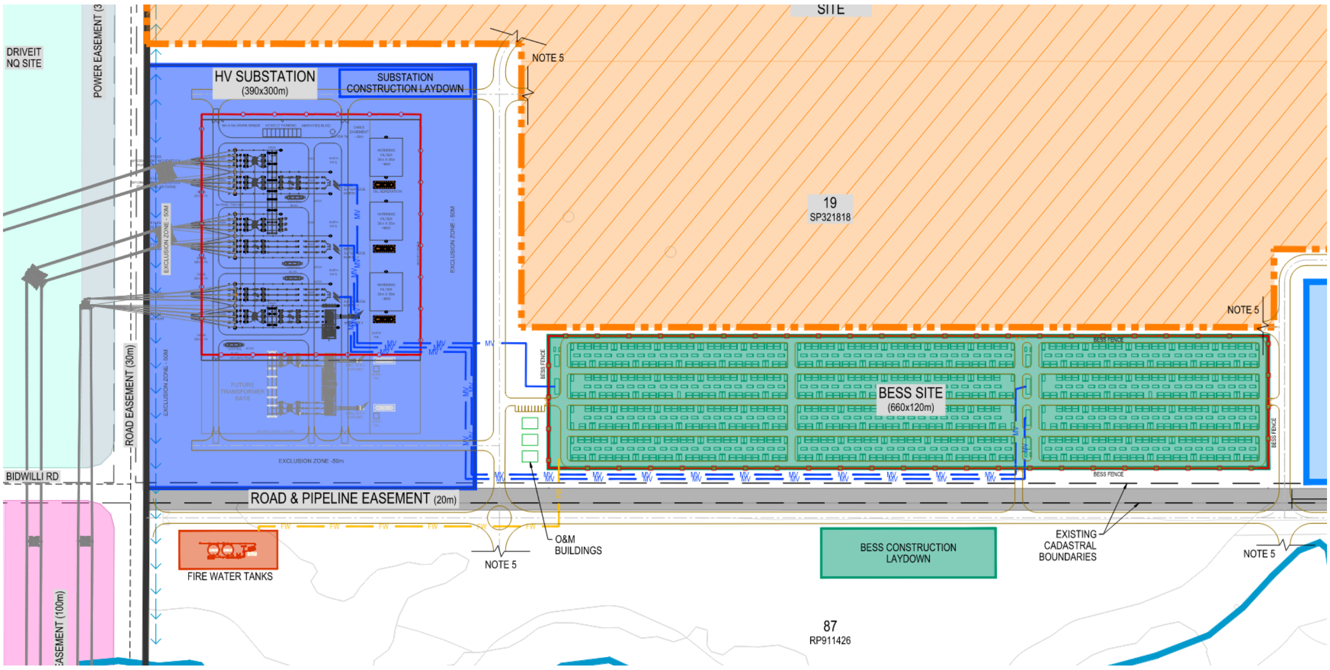


Figure 18. Substation and BESS Layout – General Arrangement

6.2.7 Layer of Safety 7: Emergency Response and Fire Brigade Intervention

Some of the key aspects of the emergency response are as follows:

Key Controls

- The control system includes thermal management system (TMS) and an emergency shutdown triggered upon detection of pre-thermal runaway in a BESS by the BMS.
- BESS units are provided manual shutdown buttons, with connected alarm and strobe.
- Fire Indicator Panels are provided in the external access cabinets in each BESS unit with relay and addressable function in the on-site control room and remote monitor centre(s).
- BESS units are provided with UPS to support continued operation and maintain safety system functions.
- Transformers are provided circuit breakers, earth switches and disconnectors.
- 3 x 50,000L bushfire-water tanks are positioned in accordance with the BMP
- All buildings, including switchrooms must be provided with hand held fire extinguishers and emergency exit signage and lighting, and any other items as required by the NCC DtS provisions.
- An Emergency Management Plan will be developed specifically for the site.

7 Fire Safety Strategy & Emergency Management

The purpose of this section to is to summarise the Fire Safety Strategy elements of the site in so far as they have been developed for schematic design. Note that this explanatory narrative is in addition to the Layers of Safety (LOS) summary provided in Section 6), and to detail the intent of the Emergency Management Plan.

7.1 EMERGENCY MANAGEMENT PLAN (EMP)

An Emergency Management Plan (EMP) will be developed for the site. The basic principles and background information are presented here as it relates to the fire safety study outcomes. The EMP document addresses the following items (this list is not exhaustive) and will be informed by the findings of this FSS:

- Procedures for safe shutdown
- Procedures for inspection and testing
- Procedures in response to system alarms and out-of-range notifications
- Emergency procedures for the case of fire, explosion, release of liquids/vapours, or damage to critical moving parts:
    - For onsite personnel (where applicable)
    - For onsite personnel (management/responsible persons)
    - For offsite (remote) monitor staff
    - For first-responders, an Emergency Services Information Pack (ESIP)
- Response considerations for surrounding public areas
- Material safety data sheets (MSDS)
- Procedures for dealing with BESS equipment damaged from an emergency
- Other procedures determined as necessary by the AHJ
- Environmental Impact Response and Management (for example mitigation measures and processes for minimization of environmental impacts)
- Procedures and schedules for conducting drills
- Appropriate planning and training:
    - Engagement, planning and training with the relevant Fire Brigade
    - Equipment usage under normal operation training, typically delivered by the system(s) integrator.

7.2 FIRE SAFETY STRATEGY OVERVIEW

7.2.1 Construction

Fire risks will be identified and effectively managed during the construction and commissioning of the facility by the trained installation teams. Fire Detection systems for the facility will be installed and commissioned prior to site operation.

7.2.2 Battery Management System

The battery management system (BMS) monitors the system for electrical shorts, faults, and equipment failures and increases in temperature outside of the defined operating parameters of the manufacturer. These conditions are immediately intercepted, and the BMS disconnects and isolates the battery from the system with the intent to avoid temperature rise within the battery cells that could induce thermal runaway. Off-gassing, smoke, fire or fault is immediately notified to the operator and emergency services.

7.2.3 Leak and Fire Detection

If thermal runaway cannot be prevented by the BMS smoke/heat/gas detectors located within the BESS unit will detect the presence of heat/smoke from a fire or gas from a release.

Detection Logic

The system of single and multiple detector activation is intended to minimise false alarms and:

- A fault signal is referred to hereon as “fault”
- “Initial detection” is detection by one single detector, referred hereon as: **1ooN**
- “Confirmed detection” is detection by two (2) detector units simultaneously, referred hereon as: **2ooN**.
- Detector set points (e.g. for CH_4 or H_2) will likely be set at 25% LFL, 50% LFL).

Detector Allocation

Detectors and infrastructure are recommended to be positioned with numbers at least as follows:

- 2 x heat detectors in the battery compartment
- 2 x optical smoke detectors in battery compartment
- 2 x gas detectors in the battery compartment (recommended to be calibrated for hydrogen detection)
- 1 x fire control panel (FIP) located in the electrical compartment

7.2.3.1 BESS Fire Detection, Automatic Actions and Alarm Raising Process

The BESS unit undergoes an automatic process to mitigate heat damage, fire spread and explosion control. Precise operating logic across all detection scenarios is yet to be confirmed, and Halliwell makes the following in-principle strategy recommendations:

Following detection of a fault within the infrastructure system, the FIP logic is recommended as follows:

1. Displays detailed fault information (status) for onsite and remote control centres.
2. Activate BESS external strobe.

Following 1ooN detection, the fire indicator panel logic is directed to:

3. Send Level I alarm to BMS
4. Displays status information for onsite and remote control centres.
5. Activate BESS alarm bell (if applicable).

Note: 1ooN logic – ventilation fan start is noted to initiate upon gas detector low set point on 1ooN at 25% LFL (refer flow chart overleaf).

Following 1ooN heat or smoke detection, the fire indicator panel logic is directed to:

6. Level I alarm to BMS
7. EMS cuts power to affected PCS
8. Activate BESS external strobe (and alarm bell if not already)
9. Displays detailed fault information (status) for onsite and remote control centres.

   Note 1: it may be advantageous to keep the BESS smoke/gas exhaust running during a fire to ensure that high pressure does not accumulate within the unit. Unlike solid fuel or liquid fires, battery fires do not rely on the availability of oxygen in the atmosphere to sustain combustion.

   Note 2: the precise detection action logic will be confirmed once the BESS unit is confirmed as part of detailed design stage.

For clarity, the logic control processes from the BESS manufacturer are reproduced below. Note that this flow chart diagram is borrowed from a similar BESS unit literature as a placeholder until the precise unit is confirmed at detailed design.

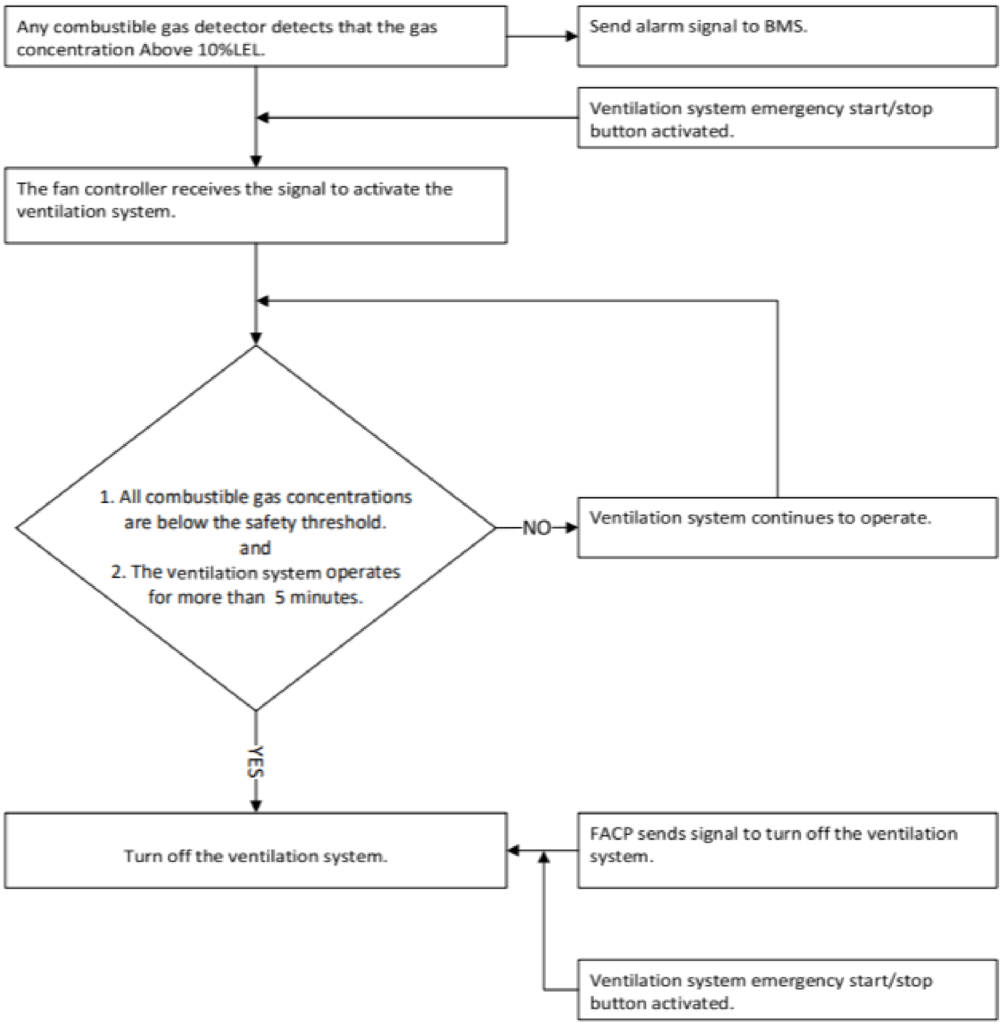


Figure 19. Logic Control of Air Inlet and Exhaust System

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7.2.4 Alarm and Annunciation

7.2.4.1 Site-wide Alarm

It is understood that this site will not be managed by on site-staff and instead, will be managed remotely. However, a maximum of up to 10 personnel will be on site on any given day. These staff, if present during these events, may also communicate via personal radio or mobile phone to convey fault investigation and/or evolving emergency conditions. The site alarm should be delivered by sounder/strobe as applicable, with the following actions recommended:

Table 44. Onsite Alarm Actions

Event	Action
Monitor system fault signal or BESS 1ooN detection	Investigation/standby tone (if applicable). BESS external strobe activation (if detection is within BESS unit).
Operator manual confirmed detection	Confirmed detection and evacuate/muster tone. Staff training must include familiarity with, and actions upon, all alarm tones.
2ooN (confirmed) detection in BESS	
Manual alarm call point activation	

7.2.4.2 Community Contact and Evacuation

Based on the fire and leak dispersion modelling results presented in Section 5, evacuation of local residents is not anticipated to be required as a result of a BESS unit fire.

7.2.5 Fire Suppression

7.2.5.1 Automatic Fire Suppression - Water

Note that battery fires cannot generally be extinguished and the purpose of the water is to cool the BESS unit and minimise potential for heat-induced structural failure and subsequent fire spread. Therefore the site will use physical spacing separation (clusters of 2-4 BESS containers) as the primary mode to mitigate fire spread to other BESS units. This approach is incorporated into our analyses and the fire safety strategy as detailed in this report.

7.2.5.2 Aerosol Suppression - Aerosol

There is little evidence to demonstrate that aerosol suppression carries any significant benefit in the case of battery fires, in particular, in an Li-Ion thermal runaway event. On the contrary, various potential hazards could be introduced by the conditions associated with the use of aerosol suppressant use in a confined space.

Even if an aerosol agent is able to temporarily suppress flaming combustion, this will most likely result in the build-up of unburnt, combustible gases, increasing the likelihood of deflagration, or explosion if gas cloud ignition occurs within the confinement of the metal container.

7.2.5.3 Manual Fire Suppression

All buildings (where provided) must be provided with handheld fire extinguishers.

All NCC-classified buildings must be provided with fire extinguishers and exit signs/lighting and all NCC Deemed-to-Satisfy (DtS) provisions.

BESS fire manual suppression: Battery fires cannot be extinguished, the extent to which suppression can be utilised is to cool the surrounding structure(s) and adjacent fuel packets by application of water, however **risk of electrocution exists**. Manual fire suppression of BESS fires using handheld fire extinguishers is ineffective, puts the user at risk, and is recommended **NOT** be attempted.

7.2.6 Operator Control and First Responders

7.2.6.1 Operator/Personnel Response

The FIP will relay the status (normal/fault/alarm) to the onsite control centre (if provided) and to the remote control centre. The operator will then follow the company procedure to contact the required personnel.

A confirmed fire alarm will be either manually or automatically conveyed to the Queensland Fire Department (QFD) control centre, to be confirmed upon consultation with local QFD.

If the site is manned during an alarm, noting that the site is intended to primarily be managed remotely, the responsible person(s) will lead the personnel response which requires as a minimum:

- Account for all personnel on site
- Make safe work site(s) and return to the designated muster point immediately
- Ensure that all personnel are relocated to at least a 50 m perimeter of a BESS unit fire. If a presence must be maintained, the perimeter location should be UPWIND of the fire.
- Ensure that breathing apparatus (BA) and PPE is fitted if personnel cannot relocate away from a fire source.

7.2.6.2 Automatic System Response

A confirmed (2ooN) alarm should:

- Be automatically conveyed to the Queensland Fire Department (QFD) control centre.
- Trigger shutdown of all building ventilation air in-take systems in buildings positioned within 200 m of a BESS fire.

7.2.7 Emergency Evacuation Plans

Fire protection layouts will be available in the site O&M building and in an external location highlighting:

- Egress and fire safety access routes.
- Evacuation routes and fire safety access routes will be clearly highlighted on site, including reflective, visible signage.
- Entry/access points for first responders, including fire water access locations for the Fire Brigade.
- Delineation of hazards and non-hazardous areas.

7.3 FIRE RISK MANAGEMENT

Working ban/restriction exclusions must be managed between the operator and local authority for any significant works scheduled during fire danger periods and/or days of elevated danger.

Routine fire drills will be undertaken onsite.

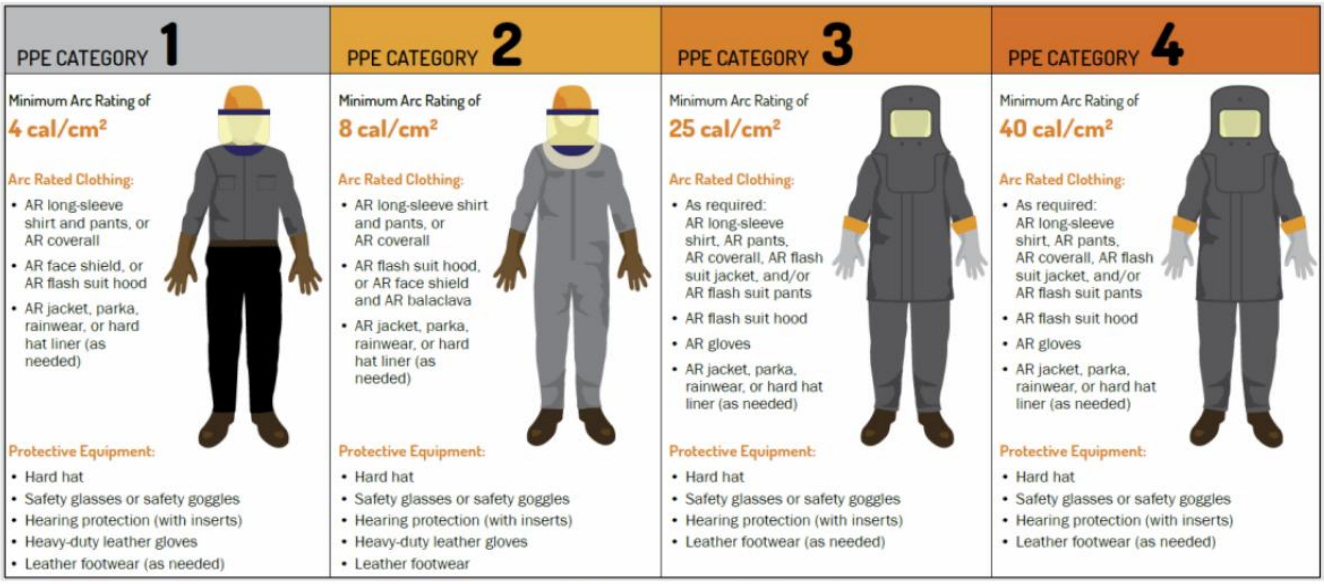
The QFD and RFS should be notified at least one week prior to the commissioning of any high-risk infrastructure at the facility (switchyard, substation, BESS, for example).

Control of ignition sources and hot works management must be covered in a safe work protocol.

7.4 OCCUPATIONAL HEALTH & SAFETY

A safe work procedure for the facility, addressing at least the following must be prepared:

- Electricity and chemical management
- Site security
- Infrastructure, equipment and vehicle maintenance
- Emergency management, including PPE (personal protective equipment) requirements in emergency conditions.
- Provide the required fire protection equipment for any future storages of dangerous goods as per the relevant Australian Standards.
- For the purpose of BESS maintenance and protection from arc flash hazard, at least PPE Category 3 should be utilized.



PPE Category Definition (Refer to NFPA 70E)

Figure 20. Arc Flash-Rated PPE

7.4.1 Key Fire Safety Systems

Table 45. Key Fire Safety Systems in Buildings/BESS Yard

System	Provided	System	Provided
Facilities for Emergency Services		**Detection Systems**	
Fire mains	☐	AS 3786 Smoke Alarms	☐
Emergency lifts	☐	AS 1670.1 Smoke detection (in accordance with AS where applicable for BESS site)	☒
Fire control centre or room	☐	Gas Detection (within BESS unit package)	☒
Perimeter vehicular access	☒	Heat Detection (within BESS unit package)	☒
Standby power supply system	☒	**Smoke Hazard Management**	
Building Act Section 79 (Hazardous Building)	☒	Zone smoke control	☐
NCC Clause E1.10 (Special Hazard)	☐	Smoke and heat vents	☐
Fire Fighting Equipment		Smoke exhaust (BESS unit smoke and gas exhaust ventilation)	☒
Portable fire extinguishers (buildings)	☒	Smoke baffles	☐
Fire hose reels	☐	Ridge vents	☐
Fire hydrant system	☐	Stair pressurisation	☐
Fire sprinkler system (other than wall-wetting)	☐	Impulse / jet fans	☐
Bushfire water tanks (in accordance with BMP)	☒	**Signage and Lighting**	
Special automatic fire suppression	☐	Emergency lighting	☒
Occupant Warning		Exit and directional signs	☒
Building Occupant Warning (BOWS)	☒	Prohibitive signs	☐
Sound System and Intercom System for Emergency Purposes (SSIEP)	☐	Warning and operational signs (e.g. strobes)	☒

7.5 FIRE BRIGADE INTERVENTION

7.5.1 Emergency Services Information Package (ESIP)

The Emergency Services Information Package (ESIP) is to provide firefighters and other emergency services with specific information that can be used during operations and develop effective strategies and tactics to manage a fire or emergency incident.

An Emergency Services Information Package (ESIP) should be provided to the local fire department and as part of the Emergency Management Plan (EMP) to assist first responders upon arrival in a secure location, signposted accordingly, at the site entrance.

Note that the ESIP is intended for use by emergency services only and supplements the Emergency Management Plan (EMP) for occupants.

7.5.2 Fire Brigade Details

Upon confirmation of a fire event the Fire Brigade will attend site and will evaluate the conditions prior to intervention.

The location and approximate travel times for the closest Queensland Fire Department (QFD) and Rural Fire Service (RFS) stations to the site are as follows:

Table 46. Fire Station Details

Station	Address	Approx. distance	Approx. travel time
QFD Wulguru (Permanent)	171 Stuart Drive, Wulguru, QLD, 4811	46 km	36 mins
QFD Giru (Auxiliary)	12 Brookes Street, Giru. QLD,4809	49 km	38 mins
RFS Lime Hill Elliot (Rural)	Lot 138, Glenn Road, Woodstock, 4816	13 km	15 mins

7.5.2.1 Queensland Fire Department (QFD)

Queensland Fire Department (QFD) corporate objectives include attendance to 90th percentile of all fires within 14 minutes from the time of notification [4].

Address:

Wulguru Fire Station
171 Stuart Drive,
Wulguru,
QLD, 4811
Opening times: 7 days
Contact no. 07 4778 4313 (Emergency 000)

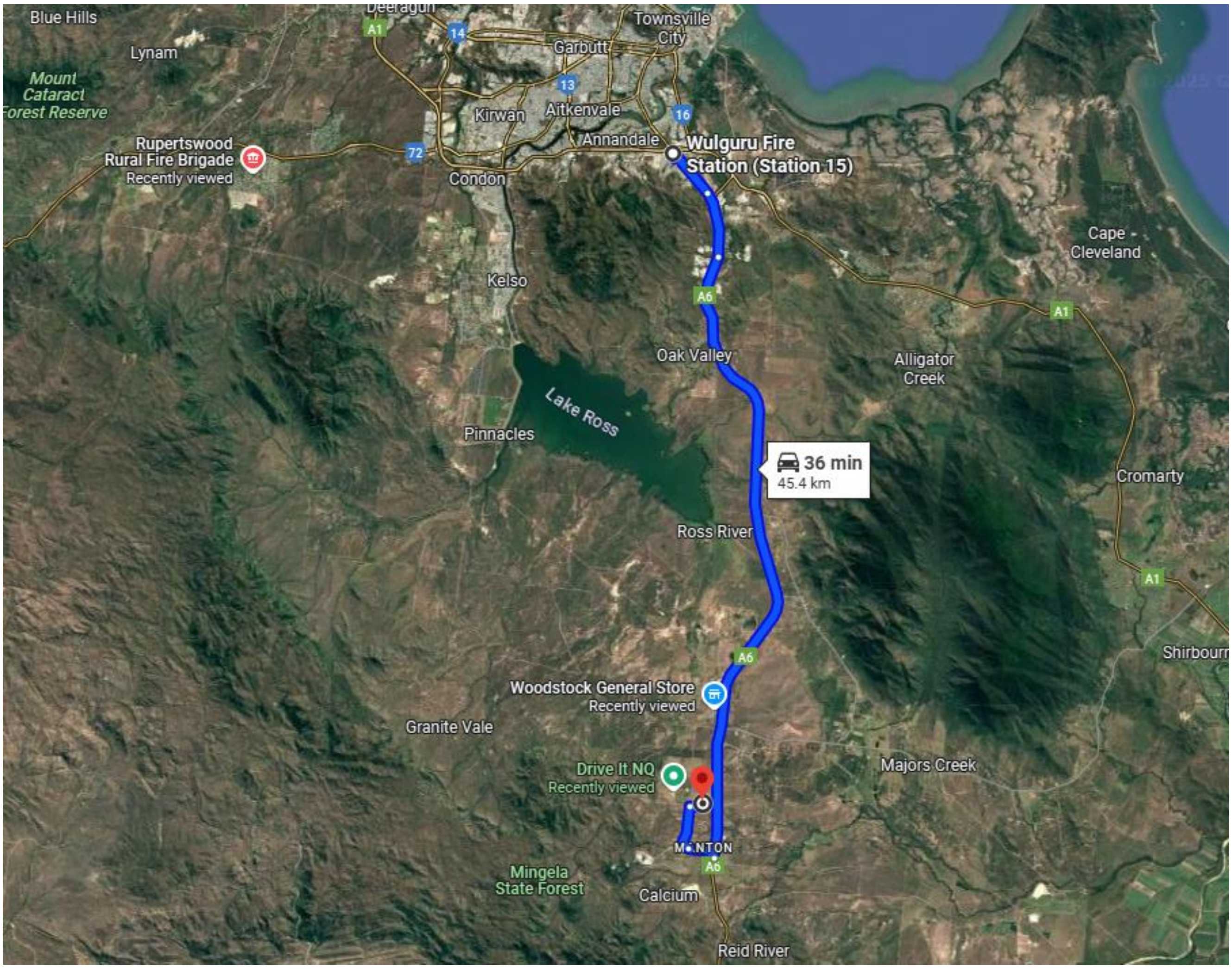


Figure 21. Primary travel from QFD to site

Address:

Giru Fire Station
12 Brookes Street,
Giru.
QLD,4809
Opening times: On Call
Contact no. 07 4796 7404 (Emergency 000)

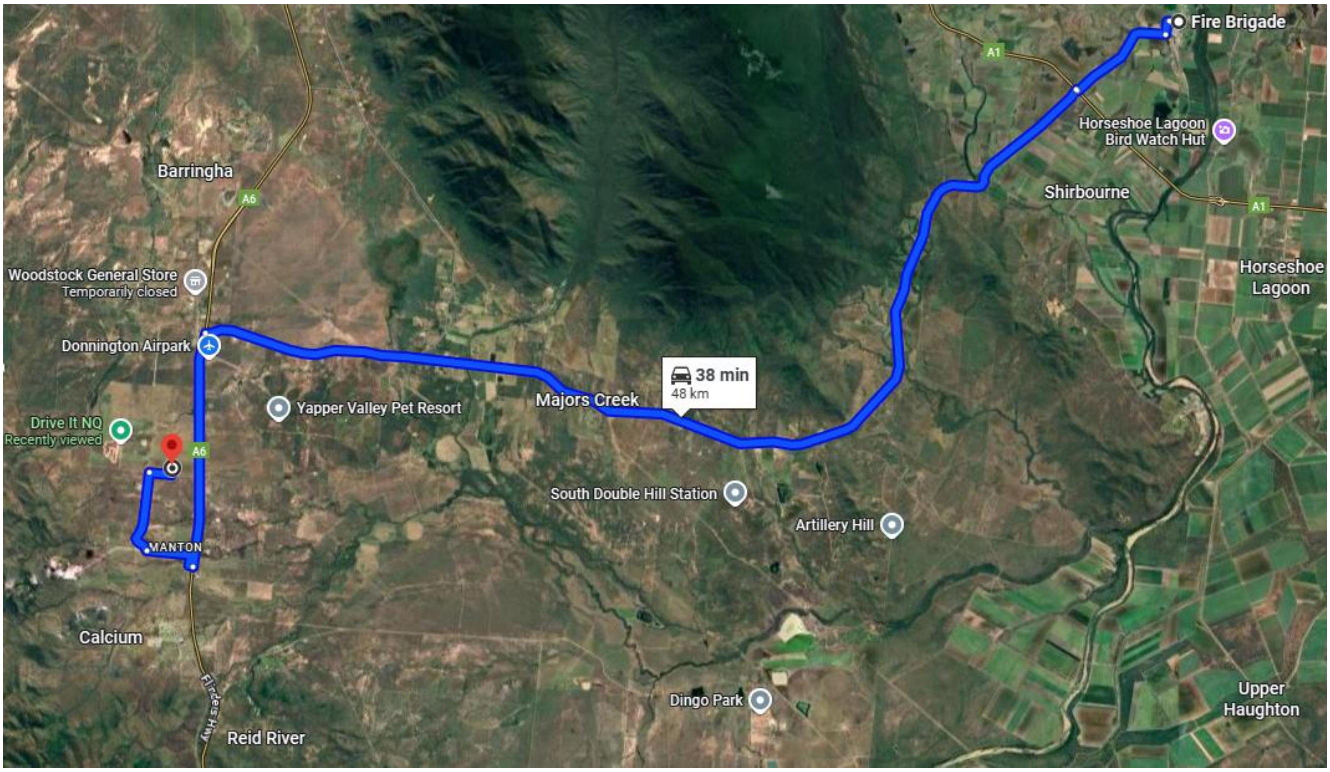


Figure 22. Primary travel from QFD (Auxiliary) to site

7.5.2.2 Rural Fire Service (RFS)

The local Rural Fire Service is a voluntary primary producer brigades and have limited resources to respond to a fire ignition within the site. They are unlikely to have any training or experience operating around electrical infrastructure, ie the BESS, switching station or the substation, and have limited capability to respond to structural fires.

Address:
Lime Hills Elliot Rural
Lot 138, Glenn Road,
Woodstock,
QLD, 4816
Opening times: On Call
Contact no. 0432 774 776 (Emergency 000)

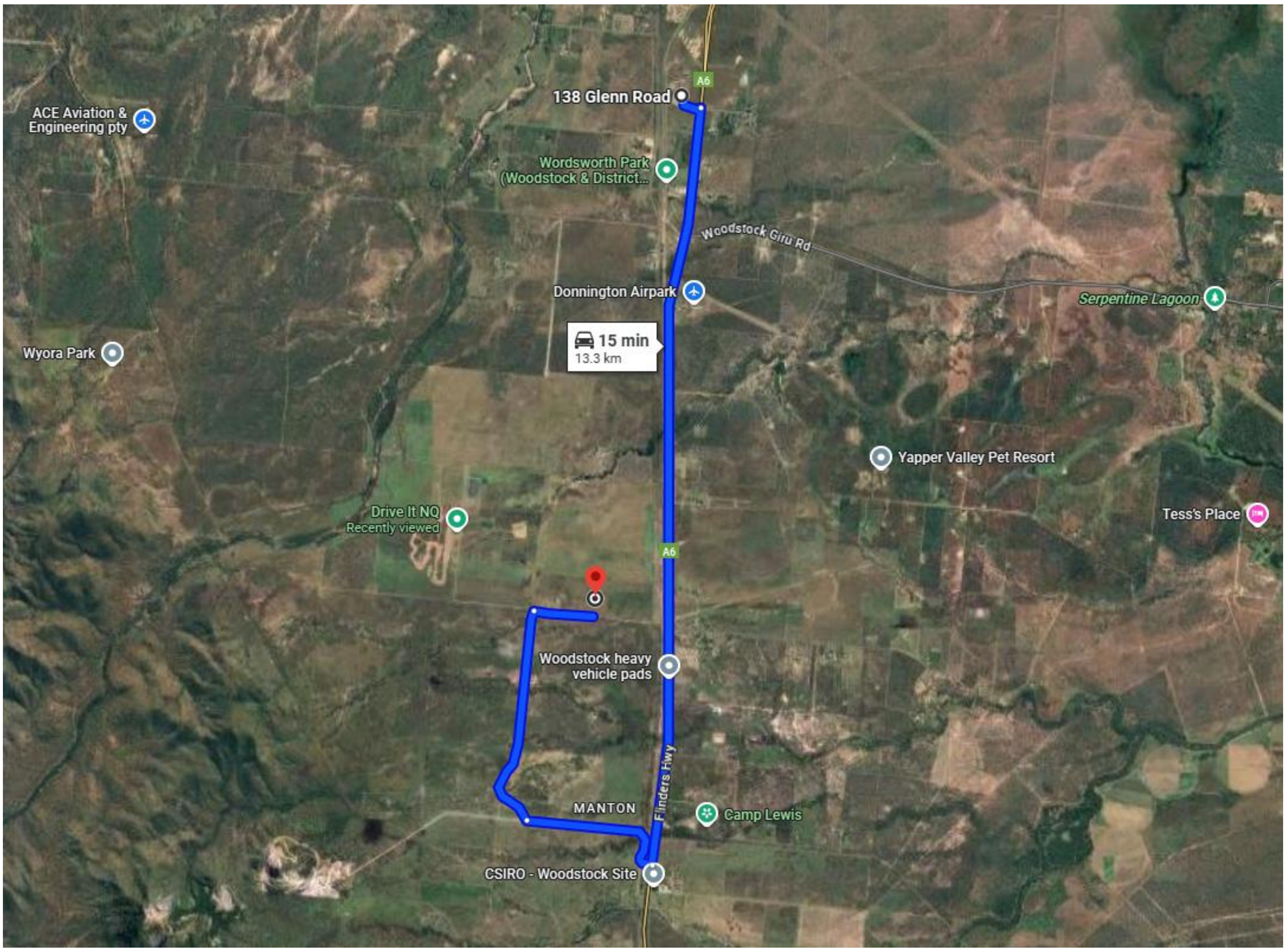


Figure 23. Primary travel from Rural Fire Service to site

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7.5.3 Notification, Equipment and Access

7.5.3.1 Notification

It is anticipated that the responding Fire Brigade (i.e. trained personnel) will arrive to this site on receipt of an automated alert following confirmed fire detection by smoke or heat detectors, or by activation of the BESS unit confirmed alarm, or by manual call.

An Emergency Services Information Package (ESIP) will be provided (accessible on arrival) to assist first responders upon arrival. Refer Section 7.5.1.

7.5.3.2 Equipment

Consistent with Standard Operational Procedures, it is expected that responding Fire Brigade personnel will be wearing appropriate turnout attire in accordance with occupational health and safety requirements.

Note: Breathing apparatus and appropriate PPE is required prior to approach of BESS leak or fire.

7.5.3.3 Access

Fire fighter access to the BESS yard is via Bidwilli Road off Flinders Highway from the north or the south.

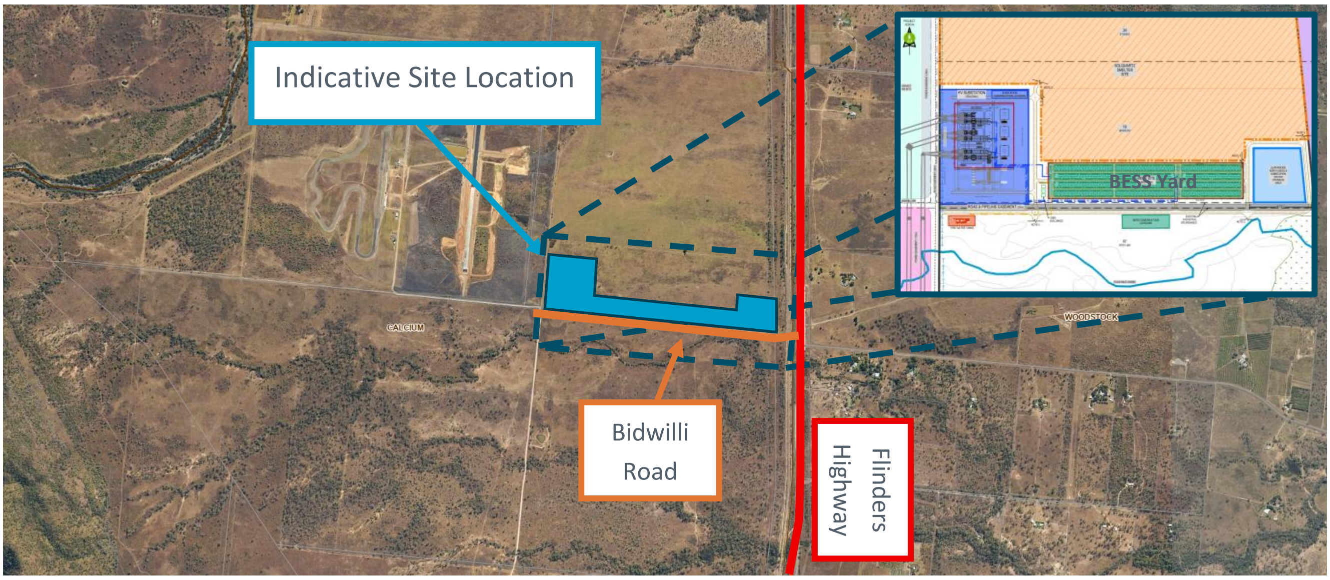

Figure 24. Fire Brigade Access

7.5.4 Firefighting Water

7.5.4.1 BESS Fire Fighting Strategy

We acknowledge that the Fire Brigade will assess each event as they find it once onsite, and will determine the best course of action considering fire suppression and the safety of on-site personnel, the community and the firefighters. We also acknowledge that for the cases of BESS/battery fires, application of water may not be the most appropriate action to take.

7.5.4.1.1 Battery Fires Likely Cannot Be Extinguished

BESS/battery fire suppression: Battery fires generally cannot be extinguished. The extent to which suppression can be utilised, is only to cool the surrounding structure(s) and adjacent fuel packets by application of water.

7.5.4.1.2 Risk of Electrocution

We note however that **risk of electrocution could exist** with the application of water to a BESS unit. Even a unit that has been isolated from the power grid and discharged is likely to hold some residual charge in its batteries and the application of water must be applied with extreme caution – BESS unit batteries may still be subject to high voltage even after emergency shut down. This applies to BESS units involved in a fire, or adjacent BESS units that are the targets of water to cool the outer container surface to mitigate remote fire spread.

7.5.4.1.3 Fire Is Not Expected to Spread Between 4-Unit Clusters

Our analysis of radiant heat transfer from a BESS unit involved in a fire to surrounding equipment demonstrated that without pilot ignition, fire spread to surrounding equipment (remote of each 4-BESS cluster) is not expected, due to the configuration and separation distance between equipment in the BESS yard. Hence, separation distance of high fuel load equipment is an intentional aspect of the fire safety strategy for the site.

7.5.4.2 BESS Fire Fighting Strategy

An asset protection zone (APZ) is provided around the perimeter of the BESS yard[5] and our radiant heat transfer analysis further demonstrates that, in terms of *potential to support ignition*, an insignificant radiant flux is expected at the BESS yard boundary a result of a fully involved BESS unit fire.

Considering the expected conditions outlined above, since BESS fire extinguishment is not considered to be a viable endeavour and since fire spread between 4-unit clusters is not considered credible based on our analyses, fire hydrant coverage for external, manual water suppression of BESS unit fires will not be provided. A BESS unit fire is intended to be left to burn out.

7.5.4.2.1 Active Mitigation of Bushfire Ignition

BESS units are generally composed of non-combustible materials and small quantities of plastic components, and so hot embers discharged in the products of combustion are generally not expected. Should hot embers (which could present as pilot sources for ignition) be discharged from a BESS fire and carried to the surrounding area, the perimeter of the BESS yard is serviced by an access road via which a fire truck can traverse to allow localised water discharge if required. We note that this is combined with the provision of bushfire water tanks in accordance with the BMP report.

Our analysis demonstrated that heat fluxes from a BESS fire, received at the perimeter of the BESS yard, are not expected to be large enough to support non-piloted ignition.

[5] APZ of 29.1 m along the entire boundary of Package 1 (BESS, transmission line and substation) refer - refer *Bushfire Hazard Assessment and Management Plan – Northern Quartz Campus* report, Version B, dated 29/08/25.

7.5.4.3 Guidance on Fire Water Availability

We note that in Queensland, the QFD has not as yet issued a detailed Guide regarding their expectations for firefighting infrastructure to be provided at BESS sites. The AFAC Guide “Large-scale battery energy storage system installations” version 1 was issued in February 2025. The AFAC guide *recommends* provision of a minimum of a fire hydrant system be provided in accordance with the requirements of AS2419.1, noting that BESS installations are considered a special hazard to be considered under Appendix D of the Standard.

The AFAC Guide also nominates that where AS2419.1 specifications are not achieved, the developer does not propose to install firefighting infrastructure, or the nominated site does not have reliable water resources in practical proximity, the Fire Safety Study should assess and demonstrate that in the case of a fire event, without fire and emergency service intervention, the fire will be contained within the site boundaries.

The toxic and thermal consequences of a BESS fire on the site have been assessed as part of this report and we find that a fire involving multiple BESS units is expected to be contained within the BESS yard boundary, without manual fire suppression intervention. Please refer back to Section 7.5.4.2 for additional context.

7.5.4.4 Bushfire Firefighting Water Requirements

Bushfire water tanks must be provided in accordance with the BMP.

7.5.4.5 Emergency Vehicle Access

Heavy vehicle access must be provided in accordance with the BMP [6].

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[6] *Bushfire Hazard Assessment and Management Plan – Northern Quartz Campus* report, Version B, dated 29/08/25

8 Conclusions

8.1 MODELLING ANALYSES

A series of fire and off-gas scenarios have been derived and analysed based on the specific equipment and related test reports intended for this site (modelling to be revalidated once available). The findings of those analyses are discussed in the Executive Summary of this report. Justification and background of the analyses, along with presentation of tabulated and visual results are provided in Section 5.

A summary of the layers of safety provided by the site equipment and safety features are summarized in Section 6. It is intended that these will be fully implemented at the completed site.

A detailed discussion of the elements of the site's broader fire safety strategy is provided in Section 7. It is intended that once agreed upon by all stakeholders, these will be fully implemented at the completed site.

Please refer Section 1.5 for the full suite of findings and fire safety requirements.

8.2 OPINION

It is our opinion that this document provides an appropriate assessment of the fire risk associated with the BESS yard and associated equipment and that the risk is reduced So Far As Is Reasonably Practicable (SFAIRP) to be confirmed upon revalidation.

This is primarily achieved through the detailed fire consequence modelling contained within, and the review of the Layers of Safety (LOS) and Fire Safety Strategy (FSS). The recommendations provided in Section 1.5 are intended to assist with emergency planning to manage the residual risk in an operation context.

8.3 CLARIFICATION

We note that the hazard consequence modelling outcomes and the fire safety strategy are fundamentally related, and where the agreed fire safety strategy, and proposed equipment (such as specific BESS units and their required safety features) are not wholly implemented, the results and conclusions of this report pertaining to the modelling outcomes would be invalidated.

If any queries or conflicts arise at the time of detailed design/construction with our recommendations, or if compatibility issues are raised by the major equipment manufacturers, Halliwell must be consulted for clarification and agreement.

Bibliography

[1] M. Spearpoint, Fire Engineering Design Guide, Christchurch: New Zealand Centre for Advanced Engineering, University of Canterbury, NZ, Third Edition, 2008.

[2] T. Alam and P. Beever, “Flashover Fires – An Experimental Program,” Centre for Environmental Safety and Risk Engineering, October 1996.

[3] D. V. Babrauskas, “Temperatures in flames and fires,” February 2006. [Online]. Available: http://www.doctorfire.com/flametmp.html.

[4] Queensland Fire and Emergency Services, “2016-17 Annual Report - Performance,” Queensland Fire and Emergency Services, 2017.

[5] NFPA, SFPE Handbook of Fire Protection Engineering (5th Ed.), Quincy, Massachusetts: National Fire Protection Association, 2016.

Appendix A Assumptions and Limitations

A.1 Assumptions

The following assumptions apply to the fire engineering assessments contained in this document:

1. Except where explicitly noted herein, all standards and other documentation that are referred to within this document are assumed to be:
   a. For a standard or other document referenced by the NCC, the version or edition listed by the NCC revision applicable to the project, as determined by the Authority Having Jurisdiction (AHJ) and cited in this document.
   b. For all other codes, standards, and documentation not referenced by the NCC, the current version or edition at the time of design, or an alternative approved edition, and includes the use of any international documents having been approved by the AHJ.
2. All Fire Safety Installations will be commissioned and maintained in accordance with the manufacturer's details.
3. All Fire Safety Installations will be maintained to the operational capacity to which they were designed, installed, commissioned and certified.
4. Except where explicitly noted herein, all Fire Safety Installations discussed within this document are assumed to be functioning correctly during a fire situation.
5. Occupants will become aware of the fire through fire cues, respond to the cue, cope with the cue and attempt to avoid the fire, as intended by the NCC for safe evacuation.
6. The analyses contained herein are derived making all reasonable assumptions regarding Disability Discrimination Act (DDA) issues. That is, all physically and intellectually handicapped occupants within the building are capable of evacuating to the fire exit of their own accord or are assisted by colleagues/others.

A.2 Limitations

The following limitations apply to the fire engineering assessment contained in this document:

1. This document incorporates all reasonable and practical efforts into producing a Fire Safety Strategy commensurate with the client's objectives, expectations, and operations. Guarantees cannot be provided, in producing a fire engineering documentation, that ignition or fire will not occur. Moreover, no amount of advice can guarantee that ignition or fire will not occur.
2. Requirements by others to achieve compliance with provisions not covered by the Building Act 1975 must supersede any requirements noted herein.
3. The report will not include for building and contents damage, stock loss, goodwill impact, environmental impact (in a fire situation) or any loss of trade or business interruption associated directly or indirectly with a fire in these premises.

4. Stipulated design criteria/parameters for engineering assessment to meet the relevant Performance Requirements of the NCC for buildings are set out herein. Where not specifically mentioned, the design, with respect to fire engineering, is expected to meet the NCC DtS provisions of all relevant codes and legislation at the time of construction and/or at the time of production of this document.
5. No liability is accepted for the application or use of the Fire Engineering Provisions or the design criteria/parameters contained within this report by any party not engaged to undertake design, construction or commissioning work associated with this development.
6. No liability is accepted for the accuracy of the documents and professional advice provided by others which form the basis of the analysis.
7. Changes to the documents and professional advice provided by others may require further fire engineering assessment to determine compliance implications.
8. Liability for re-installation and costs of any damages caused by fire is beyond our scope of responsibility.
9. Drawings, figures, sketches, photographs, etc. referred to or incorporated in this document:
    a. provide indicative supporting information and are for illustrative purposes only; and
    b. may change due to design variations. Where changes occur, readers of all fire engineering documentation must ensure that they observe the latest project related drawings and relate these to the Fire Engineering Provisions outlined in this document.
10. Future changes to the development, occupant, or fuel conditions outside those considered by this document may invalidate the findings of this document. If the design changes, those changes must be referred to the Building Certifier and/or an appropriately qualified Fire Safety Engineer, for review and clarification on the compliance implications.
11. The concepts outlined in this report assume a complete and operational building/site, and do not address protection of the building/site during construction, renovation, or demolition, unless otherwise stated.
12. The assessment of deliberate fires through acts of malicious intent, arson or acts of terrorism are outside the scope of this report.
13. It is not a fire engineering responsibility to detail specific design components of individual installations. This is a function of each relevant specific services designer and/or the installing contractors concerned.
14. The assessment and analyses as provided herein are intended to address aspects as they relate to fire safety and are not intended to address other requirements that may relate to the Equitable Access or Workplace Health and Safety.

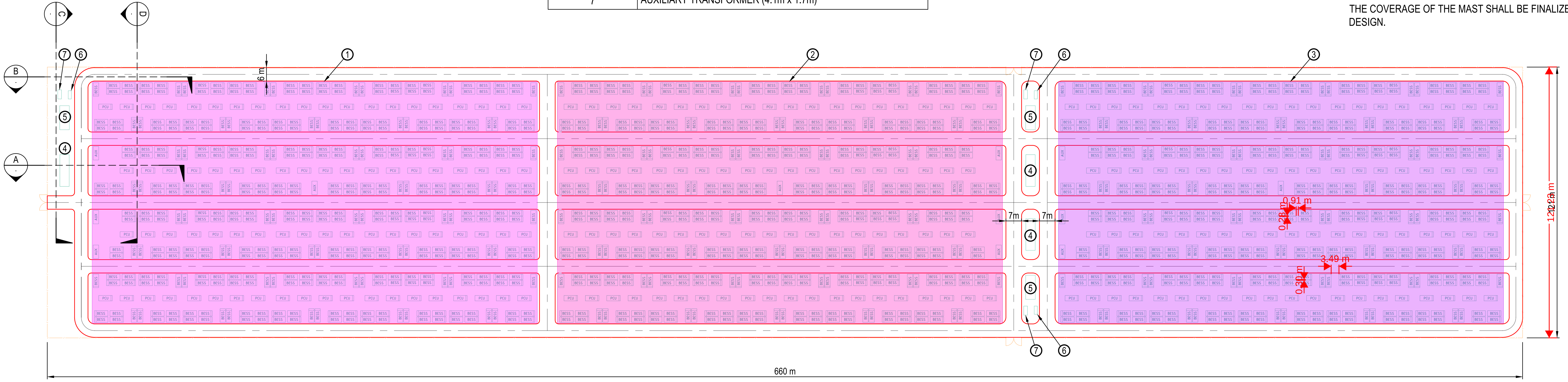
Appendix B BESS Yard Layout

EQUIPMENT RATINGS (APPLICABLE TO EACH STAGES)				
EQUIPMENT	MAKE/MODEL	NAMEPLATE RATING	QTY.	TOTAL
BESS	CATL EnerQB	5.644 (MWh)	390	2.201 (GWh)
PCU	TBC	4.6 (MVA)	78	358.8 (MVA)

EQUIPMENT	DESCRIPTION
1	STAGE 1 BESS AREA (220m x 125m)
2	STAGE 2 BESS AREA (220m x 125m)
3	STAGE 3 BESS AREA (220m x 125m)
4	SWITCHROOM (21m x 5m)
5	CONTROL ROOM (13m x 5m)
6	DIESEL GENERATOR (3.7m x 1.4m)
7	AUXILIARY TRANSFORMER (4.1m x 1.7m)

NOTES:

1. CONCEPT DESIGN ONLY AND THE LAYOUT SHALL BE FINALISED DURING DETAILED DESIGN.
2. EQUIPMENT RATING AND THE NUMBER BATTERY MODULES/PCS ARE SUBJECTED TO CHANGE BASED ON THE DETAILED DESIGN.
3. BESS EQUIPMENTS SHALL BE INSTALLED ABOVE FROM THE IDENTIFIED FLOOD LEVELS.
4. BESS LAYOUT SUBJECT TO DESIGN INPUT FROM OEM FOR ACCESS/CLEARANCE REQUIREMENTS.
5. THE REQUIREMENTS FOR FIRE FIGHTING SYSTEM SHALL BE DETERMINED DURING FIRE SAFETY STUDY.
6. LIGHTNING MAST SHOWN ARE THE ONLY FOR THE PURPOSE OF THE DA. THE COVERAGE OF THE MAST SHALL BE FINALIZED DURING DETAILED DESIGN.



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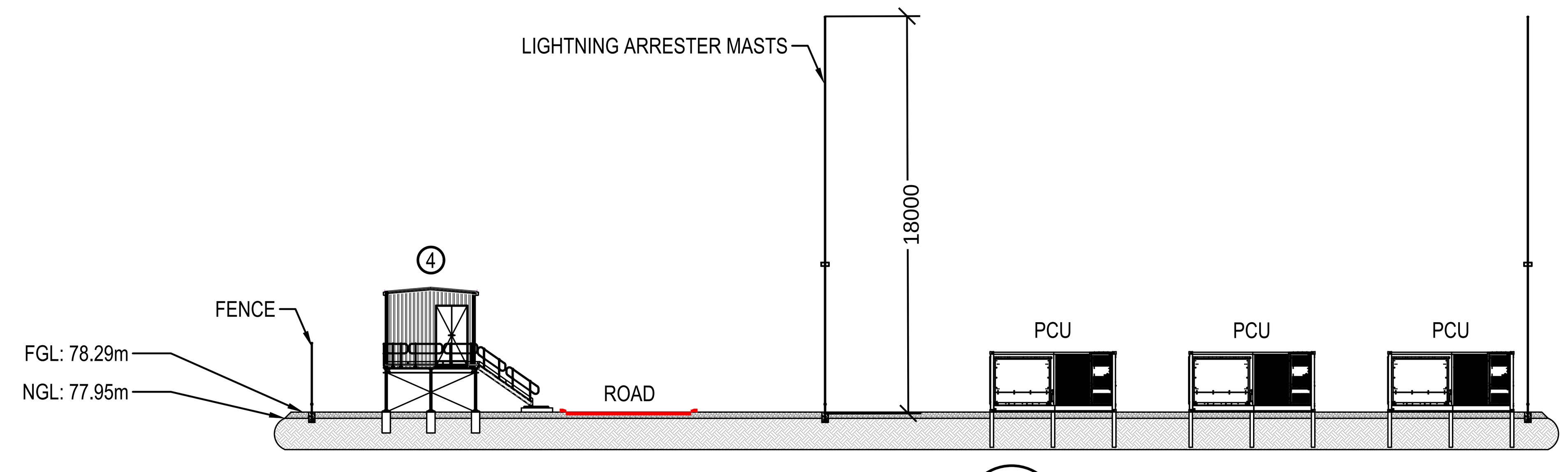

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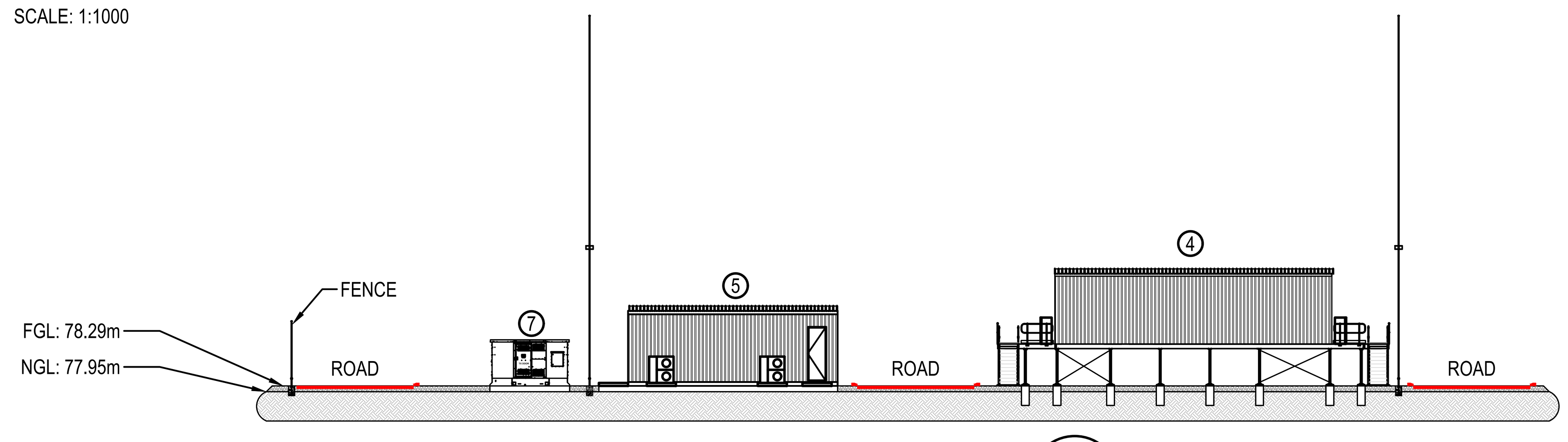

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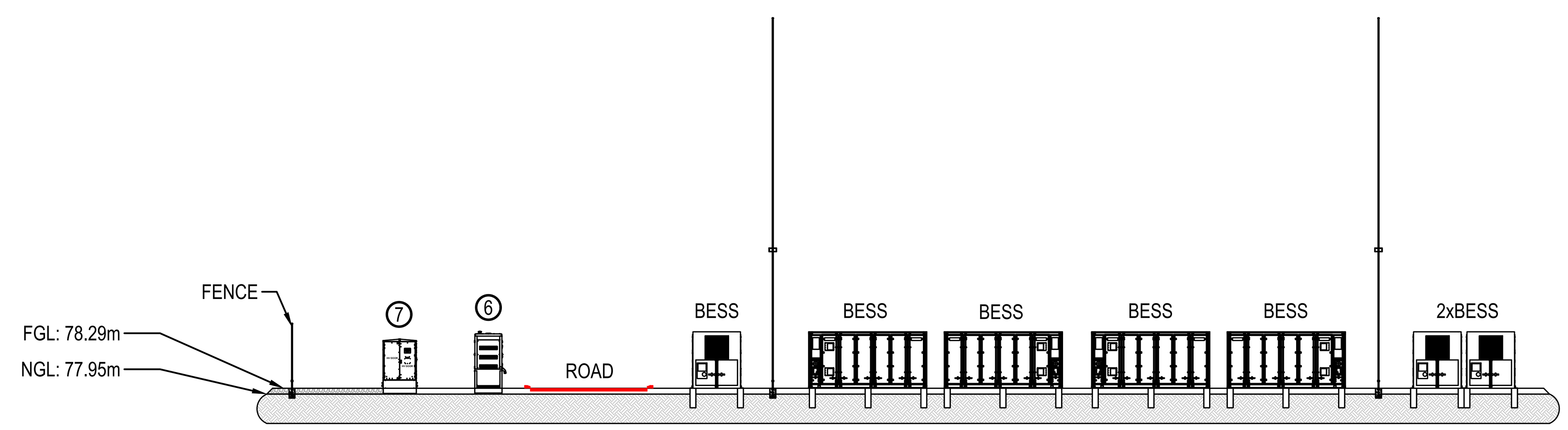

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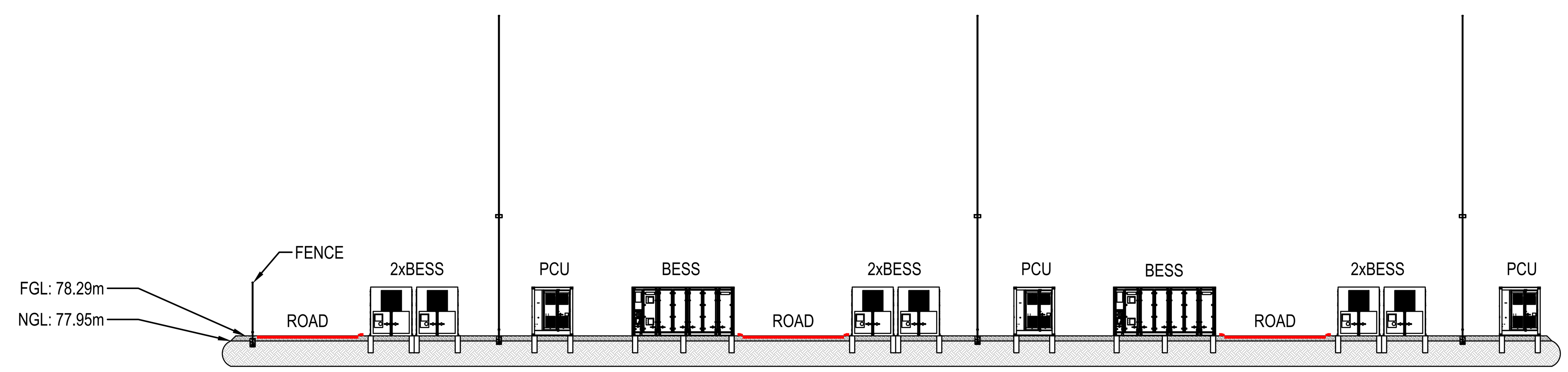

SECTION D

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REFERENCE DRAWINGS

REFERENCE MODELS

REV	DATE	REVISION DETAILS
A	2024-06-10	FOR REVIEW
B	2025-06-13	UPDATED SITE LAYOUT

REV	DRAWN	DESIGNED	VERIFIED	APPROVED
A	B.JOSEPH	B.JOSEPH		
B	T.NGUYEN	A.JAMES	B.JOSEPH	S.KERR

1:1000 10 0 20 40 m

All written dimensions take precedence over scaled dimensions.

PREPARED BY

aurecon

www.aurecongroup.com

CERTIFICATION | No. | CERTIFIER | DATE

CLIENT

Solquartz

CLIENT DOCUMENT NUMBER | REV

Coordinate system MGA

Height datum AHD

PRINT ALL COPIES IN COLOUR

CONSTRUCTION STATUS: NOT FOR CONSTRUCTION

DRAWN BY: T.NGUYEN

DESIGNED BY: A.JAMES

STATUS: REVISED

CODE: W1

DOCUMENT STATE: WORK IN PROGRESS

PROJECT: SUPER NODE NORTH BESS CONCEPT DESIGN

TITLE: BESS FACILITY LAYOUT

DOCUMENT CODE: 529130-W00001-DRG-EL-0098

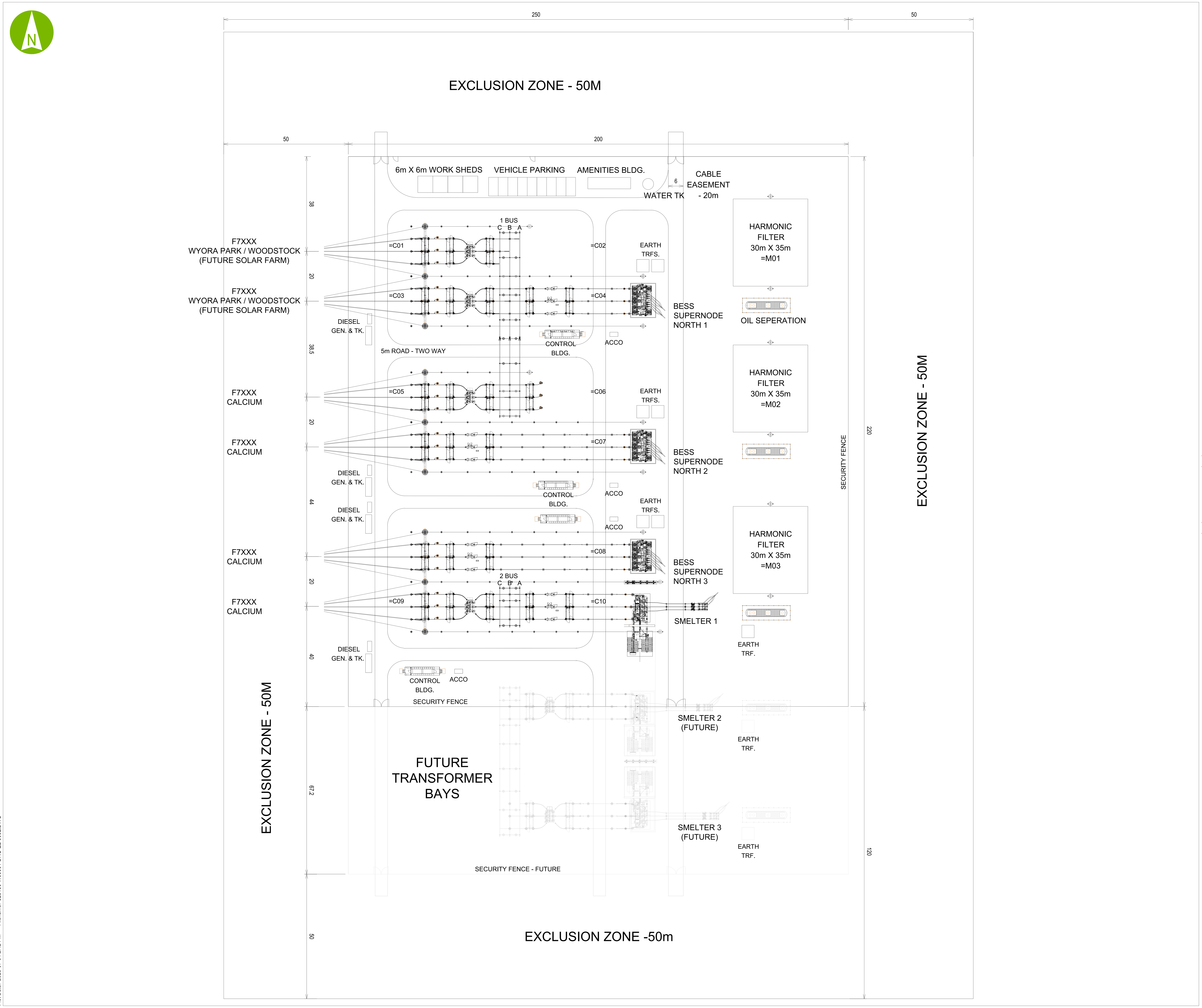
SCALE: 1:1000

SIZE: A1

REFERENCE No.: DRG-EL-0098

REV: B

Plot Date: 2025-07-03 12:33 PM Filename: 529130-W00001-DRG-GA-0098.DWG



PRINT ALL COPIES IN COLOUR

Coordinate system MGA

Height datum AHD

All written dimensions take precedence over scaled dimensions.

REFERENCE DRAWINGS

REFERENCE MODELS

REV	DATE	REVISION DETAILS
A01.01	2025-06-27	ISSUED FOR CLIENT REVIEW
A01.02	2025-07-04	ISSUED FOR USE

REV	DRAWN	DESIGNED	VERIFIED	APPROVED
A01.01	K.CHILDS	K.JANSEN VAN RENSBURG		
A01.02	K.CHILDS	K.JANSEN VAN RENSBURG	M.NURCOMBE	B.JOSEPH

PREPARED BY

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CERTIFICATION	No.	CERTIFIER	DATE

CLIENT

Solquartz

CLIENT DOCUMENT NUMBER	REV

CONSTRUCTION STATUS	DRAWN BY
NOT FOR CONSTRUCTION	K.CHILDS
	DESIGNED BY: K.JANSEN VAN RENSBURG

STATUS	CODE	DOCUMENT STATE
STARTED	W1	WORK IN PROGRESS

PROJECT
SUPERNODE NORTH BESS TECHNICAL SUPPORT

TITLE
SUPERNODE NORTH BESS QLD OPERATIONS
HV SUBSTATION GA LAYOUT

DOCUMENT CODE
529130-W00001-DRG-EL-0092

SCALE	SIZE	REFERENCE No.	REV
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Plot Date: 2025-07-04 2:42 PM Filename: 529130-W00001-DRG-EL-0092.DWG

Appendix C Assessment Tools and Methodologies

C.1 Fire dynamics simulator (FDS)

FDS is a numerical computer program developed by the National Institute of Standards and Technology (NIST), Building and Fire Research Laboratory. FDS is a Computational Fluid Dynamics (CFD) model of fire-driven fluid flow. The model solves numerically a form of the Navier-Stokes equations appropriate for low-speed (i.e. thermally-driven flow) with an emphasis on smoke and heat transport from fires.

Because FDS requires high computing power to undertake the analysis, model simplifications are implemented. These simplifications include, but are not limited to the following:

- Obstructions (i.e. walls, floors, ceilings and equipment) are smooth and inert (i.e. do not interact with the combustion or allow for soot deposits), but do allow for heat transfer though the obstruction.
- The fire is assumed to be in the same location throughout the analysis (i.e. no fire spread). However, fire spread across the fire seat will be modelled, where required.
- The combustible material is homogeneous in its geometry and make-up.

FDS models have been constructed within the software program *PyroSim* produced by Thunderhead Engineering. Pyrosim is a preprocessor for FDS Version 6.7.5 and later.

Pyrosim Version 2023.3.1312, which interfaces with FDS Version 6.8.0, was used throughout this analysis.

C.2 Radiant Heat Transfer

The radiant heat flux received (q_r) at and beyond the site boundary, caused by a fire in the subject building, will be determined using radiation calculations detailed in Section 7.5 of the Fire Engineering Design Guide [1].

$$q_r = k_1 \Phi \varepsilon \sigma [(T_e + 273)^4 - (T_r + 273)^4]$$

Where:

k_1	is the radiation reduction (or attenuation) factor
Φ	is the configuration (or view) factor
ε	is the emissivity of the emitter and absorptivity of the receiving surface
σ	is the Stefan Boltzman Constant (5.67 x 10^{-11} kW/m² K⁴)
T_e	is the temperature of the emitting surface (°C)
T_r	is the temperature of the receiving surface (°C)

The following assumptions have been made for the above values:

- Emissivity – a value of 0.9 has been assumed for the flame/emitting surface. This is considered to be a conservative assumption. [1].
- Temperature of the emitting surface, T_e – a surface temperature of 900°C will be used. Peak external plume temperatures of 900°C, maintained for short periods of time, are reported by Fire Code Reform Centre [2] and Babrauskas [3].
- Temperature of the receiving surface, T_r – a surface temperature of 24 °C will be used.

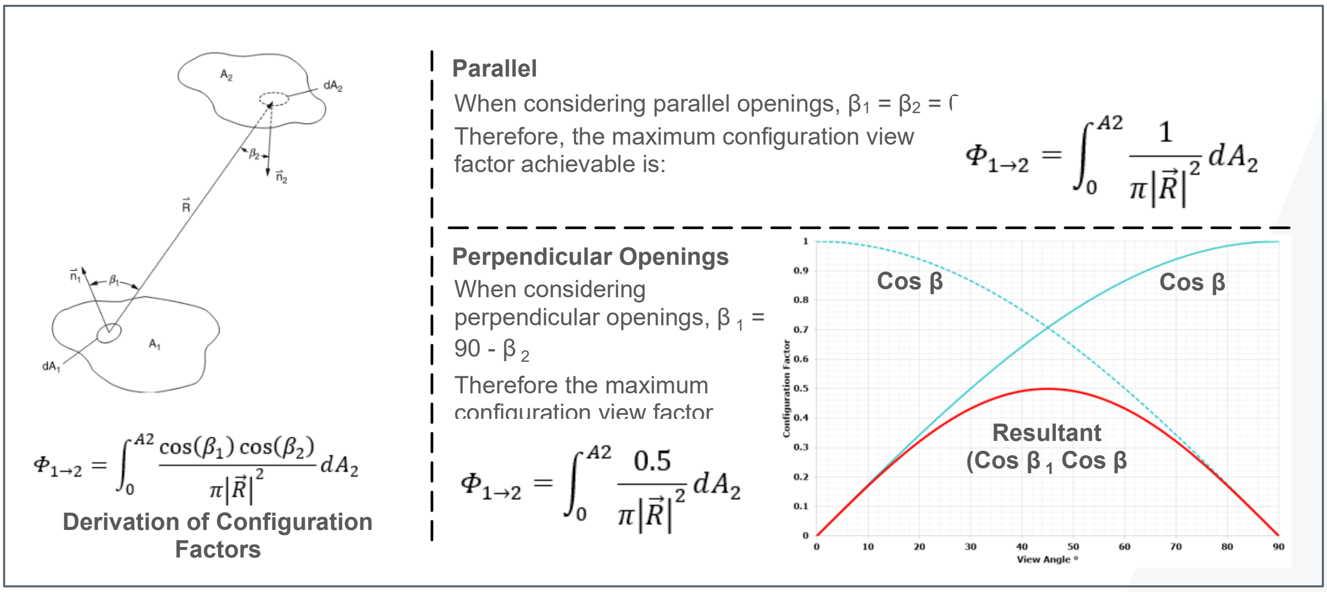

Figure Appendix D.1 Configuration factors

Received Radiant Heat Flux

Conditions are determined by assessing the heat flux received at various locations within the allotment boundary (q_R).

Critical Heat Flux

The critical heat flux (q_{cr}) causing ignition of fuels is based on Appendix G3 of AS 3959-2009 and Table A3 of AS 1530.4-2014, and is as follows:

- 13 kW/m² for piloted ignition (i.e. where a spark is present to ignite the material (e.g. the glazing of the window has failed or a window is operable)).
- 25 kW/m² for non-piloted ignition (i.e. where a spark is absent to ignite the material—the glazing of the window remains intact or the window is fixed closed).

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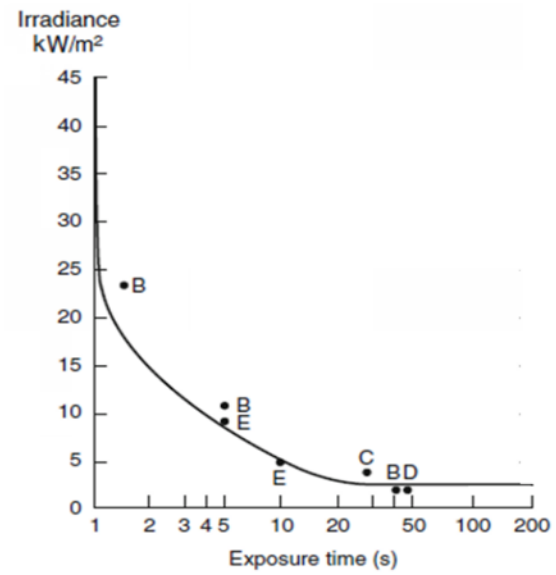
C.3 Exposure to paths of Egress

Assessment of the exposure to paths of egress is carried out using an absolute quantitative analysis using deterministic data. The objective of exposure of paths of egress is to safeguard occupants from illness or injury while evacuating in an emergency. A fire in the subject building must not cause conditions such that these paths become unusable.

Conditions are determined by assessing the heat flux received in the path of travel (q_R) calculated as detailed in Appendix C.2.

Acceptance for whether an egress path remains usable is demonstrated if the heat flux received (q_R) does not exceed the critical heat flux for safe human exposure (q_{CR}).

The critical heat flux (q_{CR}) is defined as the human tolerance to radiant heat on exposed skin as provided in Chapter 63 of the SFPE Handbook of Fire Protection Engineering, 5th Ed [5], as reproduced below, accompanied by a table of some key values and the best-fit equation.



Irradiance, I_R (kW/m²)	Exposure Time, t_e (s)
25	1
14.5	2
12	3
10	4
8.5	5
5	10
3	20
2.5	30 and above
Equation: $t_e = 100\ I_R^{(-1.425)}$	

Appendix D Modelling Results

1.1 CASE BREAKDOWN

Cases 1-4 model the off-gassing from cells prior to ignition and fire. These cases are of interest for the following reasons:

- Minimal heating limits buoyancy (and vertical inertia upon release) and therefore the gases are more strongly influenced by crosswind (compared to fire case).
- The gas mixture is less toxic before undergoing combustion and where composed of hydrogen almost 50%, flammable and explosion potential must be assessed.

We note that:

- Case 4 studies the BESS unit internal environment.
- The gas make-up is taken from the UL9540A cell level test report which provides constituents and quantity for cell. Total HCs are simplified as CH_4 for modelling.
- Conservatively, 5 cells are assumed to off-gas simultaneously, which is a greater number than observed across the UL9540A testing.

Table 1. Case Details (1-3)

Case	Type	No cells	m'' (m^3/s)	Direction	Wind (m/s)
1	Off gassing	5	0.0012	Z	0.1
2	Off gassing	5	0.0012	Z	2.5
3	Off gassing	5	0.0012	Z	4.9
4	Off gassing	5	0.0012	Z	N/A

Table 2. Battery off-gas composition

Constituents	Symbol	%	New %
Carbon monoxide	CO	8.66	09
Carbon dioxide	CO_2	36.13	37
Hydrogen	H_2	36.19	37
Methane	CH_4	8.25	17

1.2 RESULTS SUMMARY

Table 3. Results Data – Case 1

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	<10 m from source	<10 m from source	Because of the gas make-up (low toxicity) and the comparatively gas flow rate (compared to fire), off-gassing dispersion cases are reasonably benign compared to the fire cases presented later.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	<10 m from source	<10 m from source	
Hydrogen (H)	N/A. LFL – 40,000 ppm	N/A. UFL – 750,000 ppm	<10 m from source	<10 m from source	
Methane (CH_4)	N/A. LFL – 50,000 ppm	N/A. UFL – 150,000 ppm	<10 m from source	<10 m from source	

Table 4. Results Data – Case 2

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	20 m (downwind)	230 m (downwind)	As above. Except that CO 8hr TWA is notable within ~250 m of the BESS plot.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	<10 m from source	<10 m from source	
Hydrogen (H)	N/A. LFL – 40,000 ppm	N/A. UFL – 750,000 ppm	<10 m from source	<10 m from source	
Methane (CH_4)	N/A. LFL – 50,000 ppm	N/A. UFL – 150,000 ppm	<10 m from source	<10 m from source	

Table 5. Results Data – Case 3

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	50 m (downwind)	250 m (downwind)	As above. Except that CO 8hr TWA is notable within ~250 m of the BESS plot.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	<10 m from source	30 m (downwind)	
Hydrogen (H)	N/A. LFL – 40,000 ppm	N/A. UFL – 750,000 ppm	<10 m from source	<10 m from source	
Methane (CH_4)	N/A. LFL – 50,000 ppm	N/A. UFL – 150,000 ppm	<10 m from source	<10 m from source	

Table 6. Results Data – Case 4 (Internal BESS units).

Material	Flammable limits		25% LEL	50% LEL	Notes
Hydrogen (H)	LFL – 40,000 ppm	UFL – 750,000 ppm	Tracked	Tracked	Effective dilution and ventilation is demonstrated where the exhaust fan runs at assumed 50% of max capacity , i.e. runs at 12 m^3/min exhaust. 5 cells off-gas simultaneously 2 minute delay detection exhaust ramp-up assumed.

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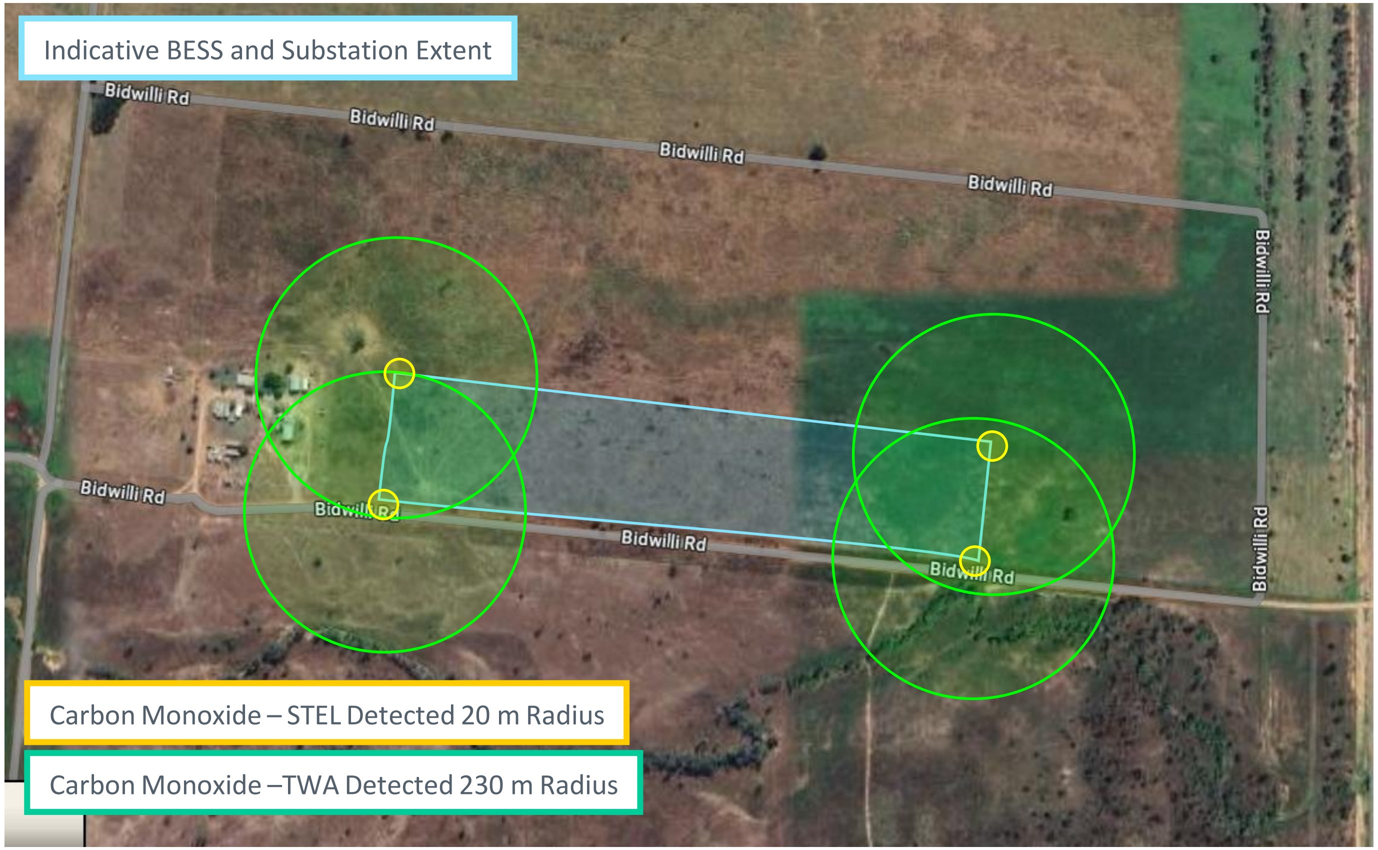

Case 2: Carbon Monoxide – 20 m STEL, and 230 m TWA

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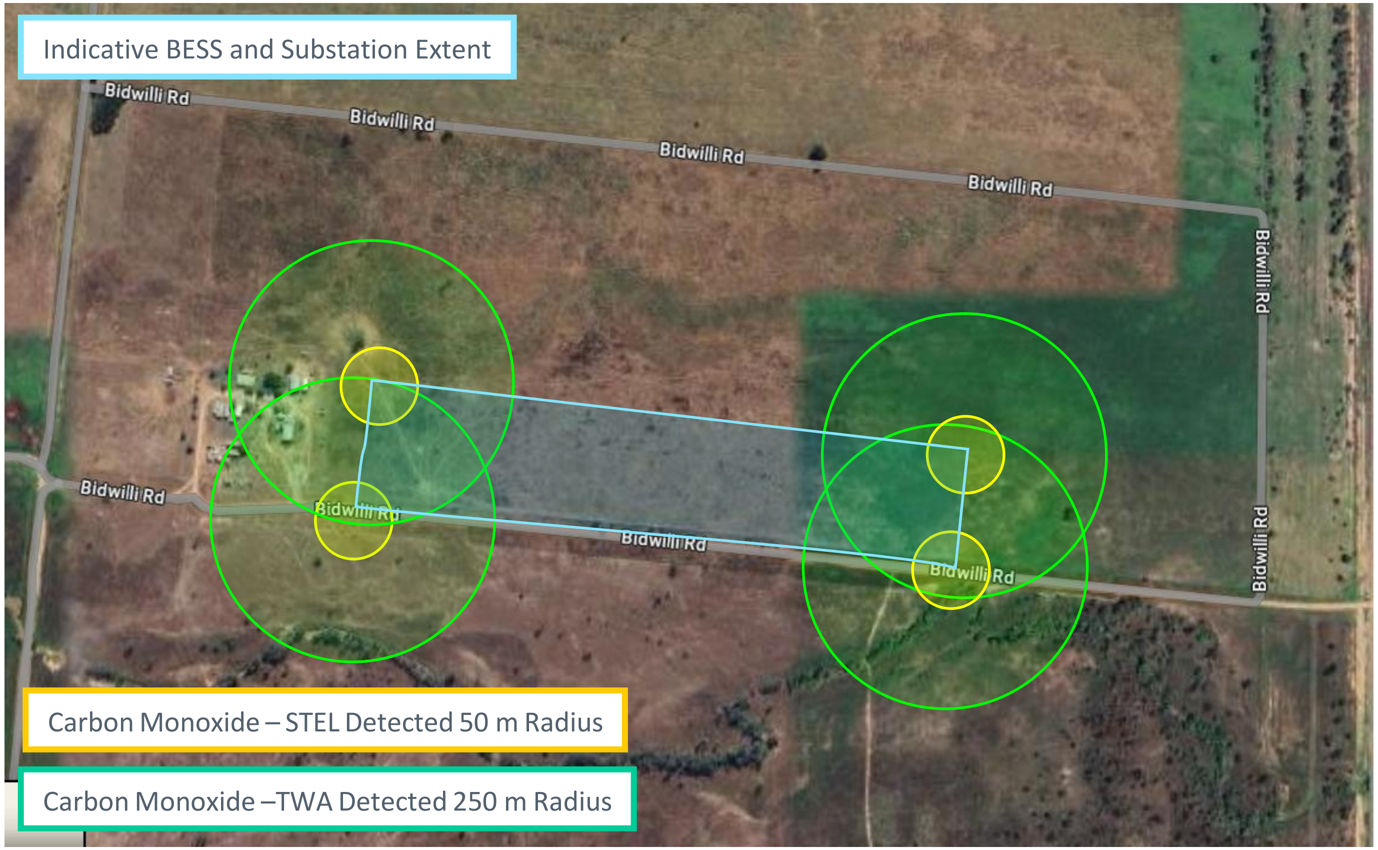


Case 3: Carbon Monoxide – 50 m STEL, and 250 m TWA Radius

Figure 1. Farfield Dispersion – Off-gas – Case 1

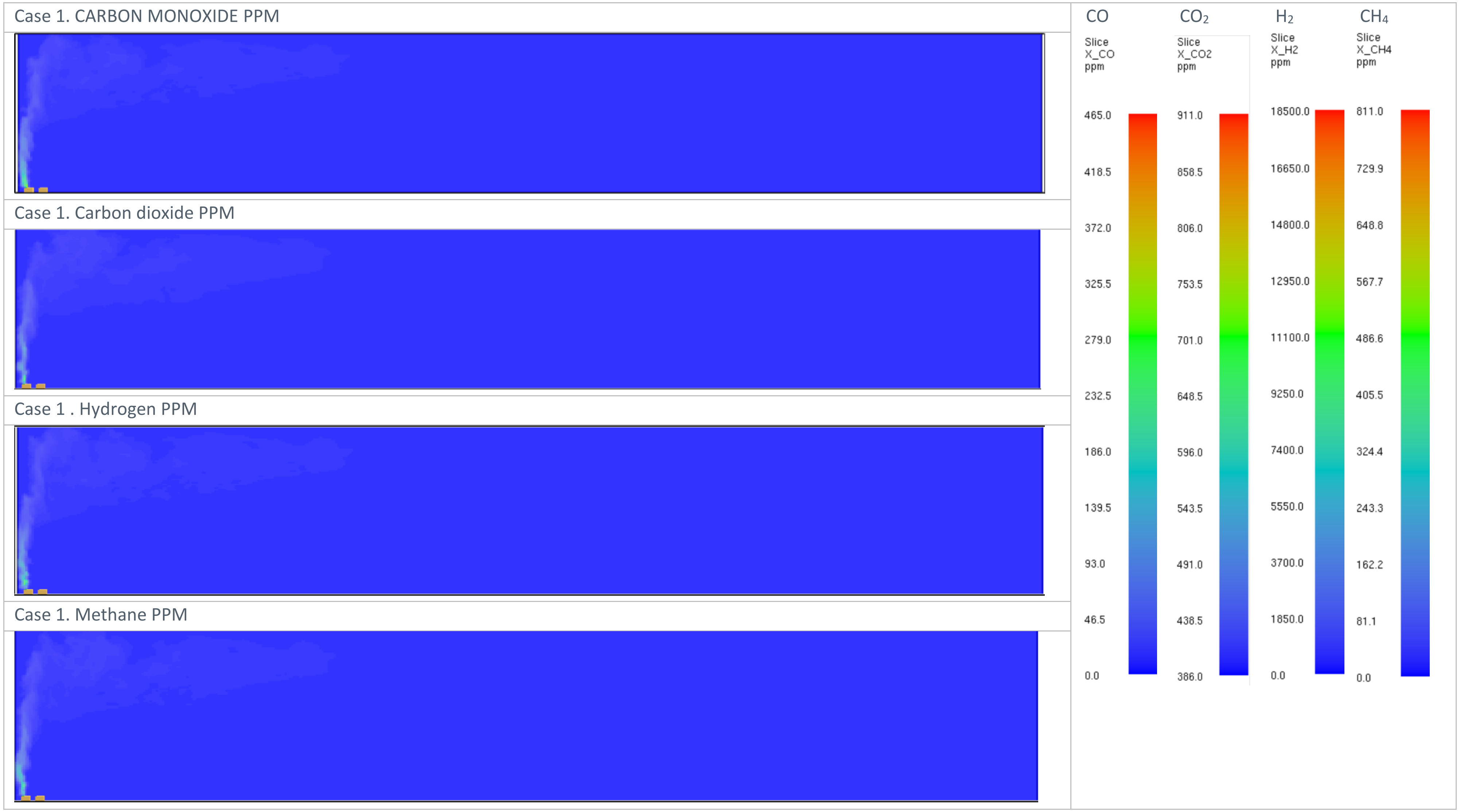


Figure 2. Farfield Dispersion – Off-gas – Case 2 – CO and CO_2

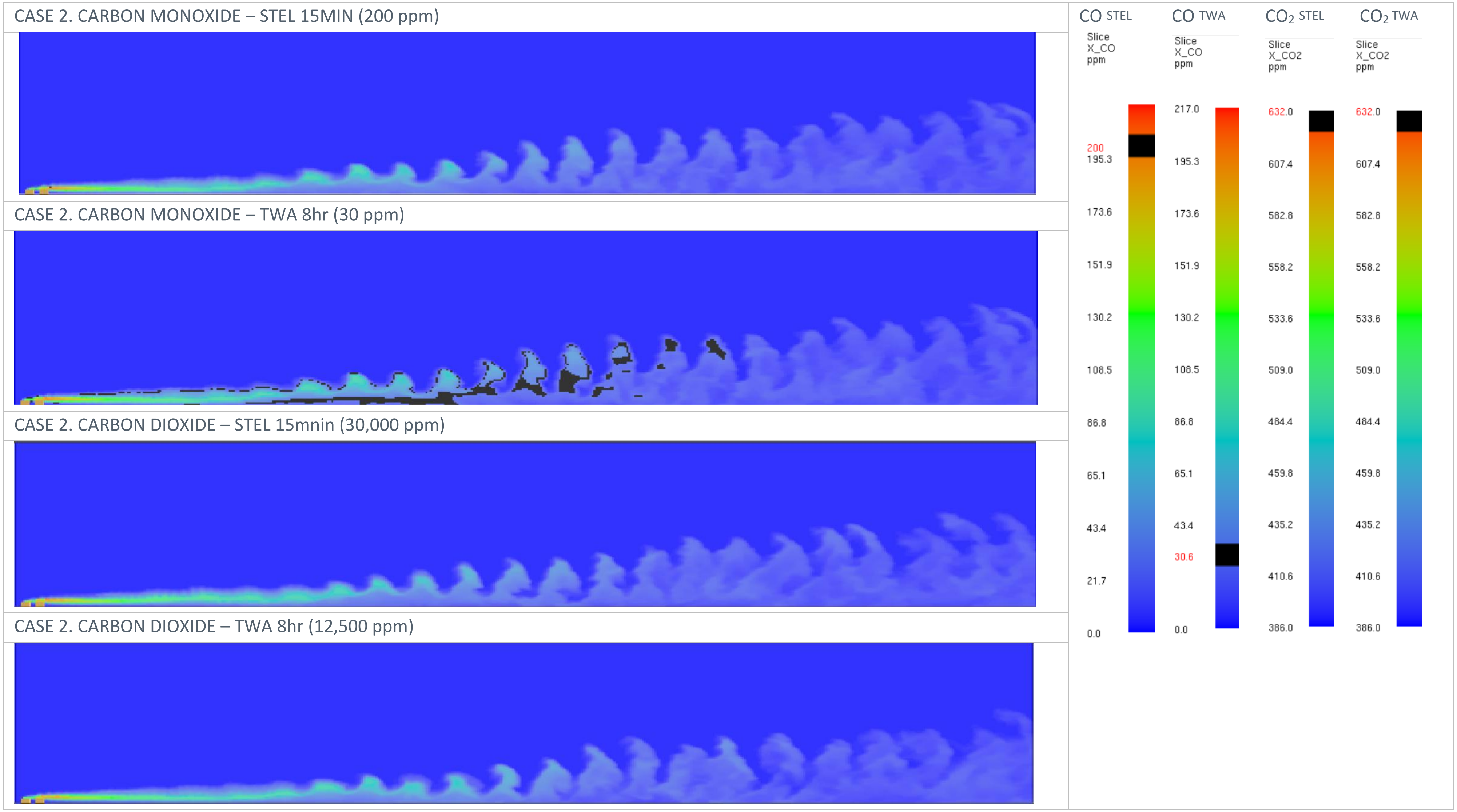


Figure 3. Farfield Dispersion – Off-gas – Case 2 – H_2 and CH_4

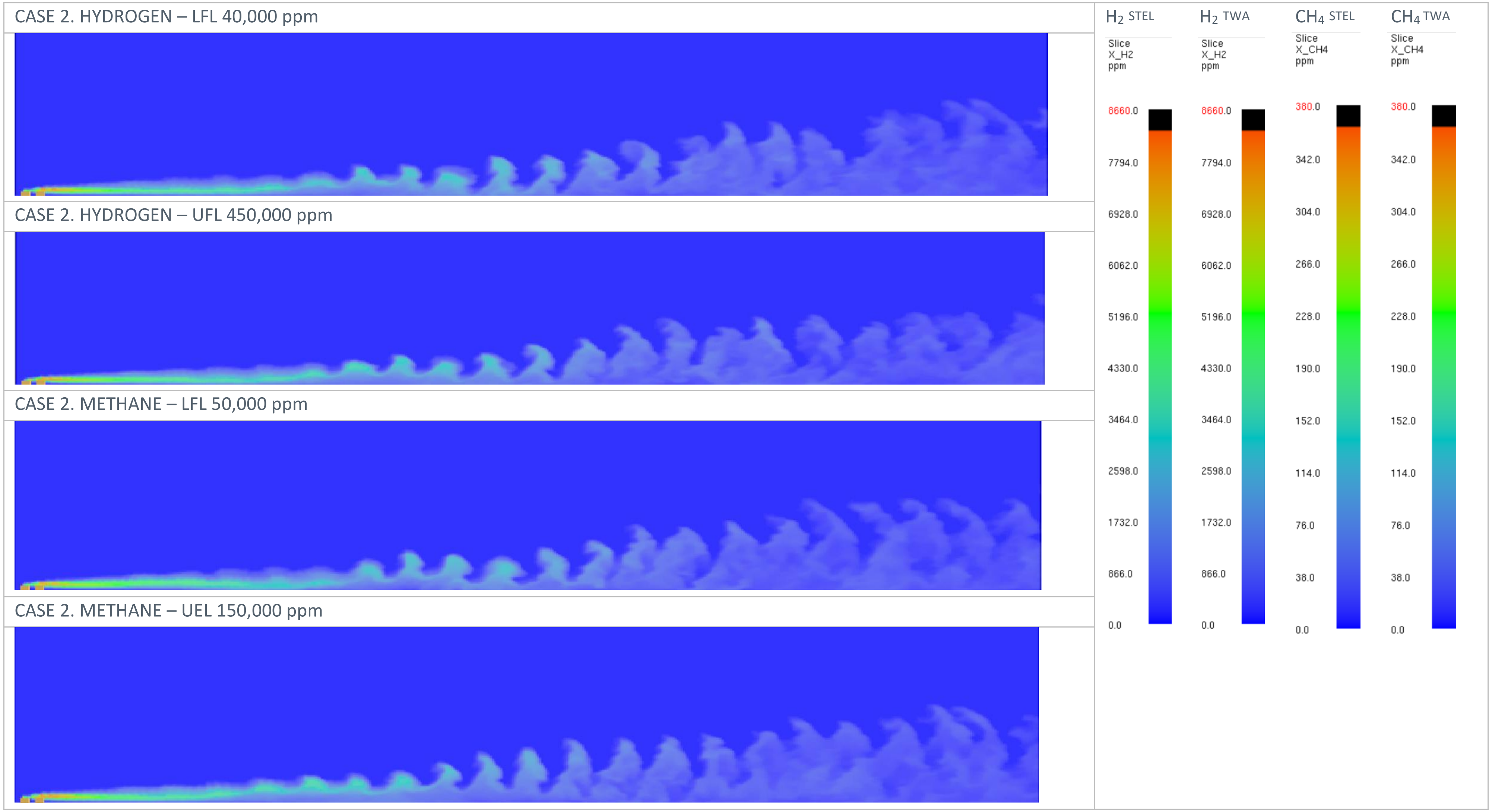


Figure 4. Farfield Dispersion – Off-gas – Case 3 – CO and CO_2

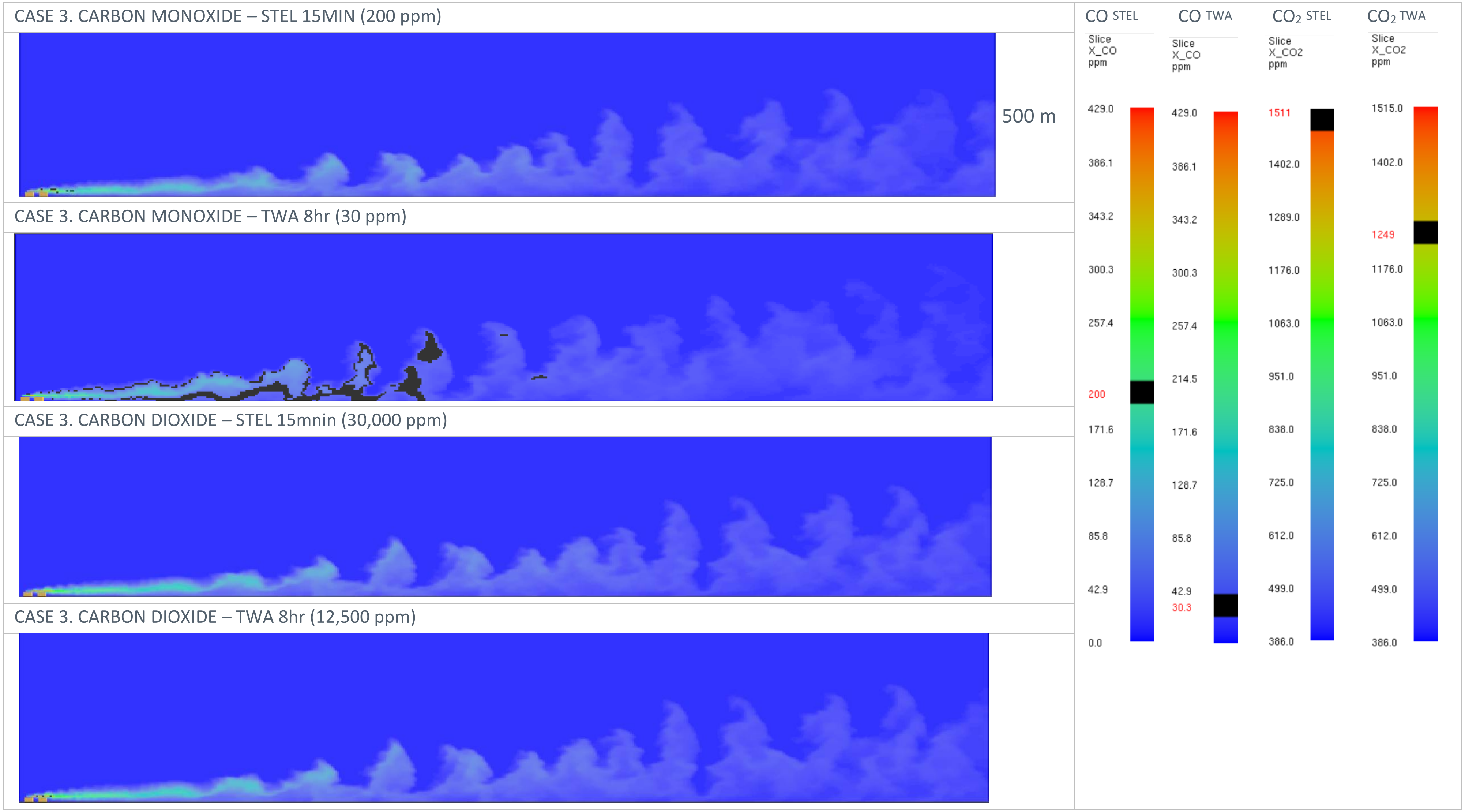
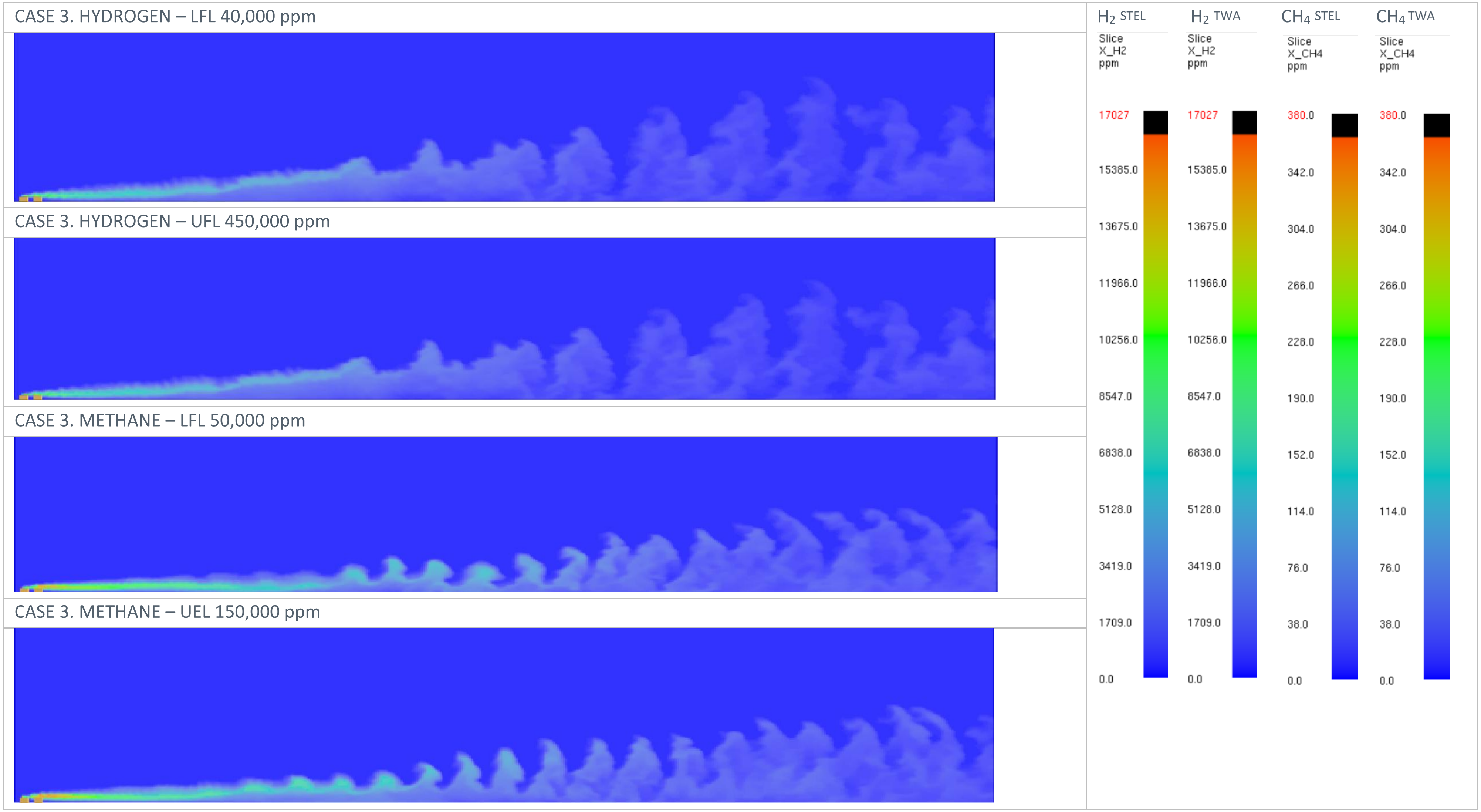
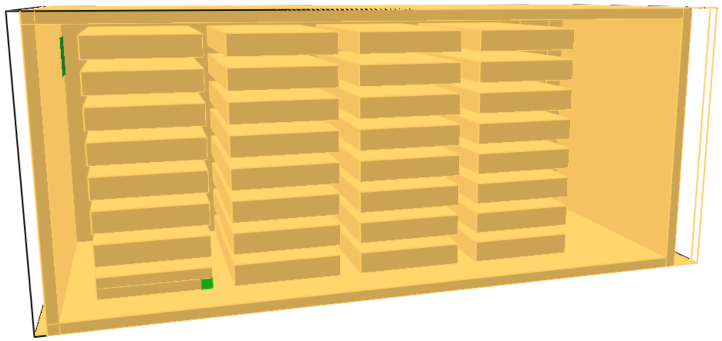
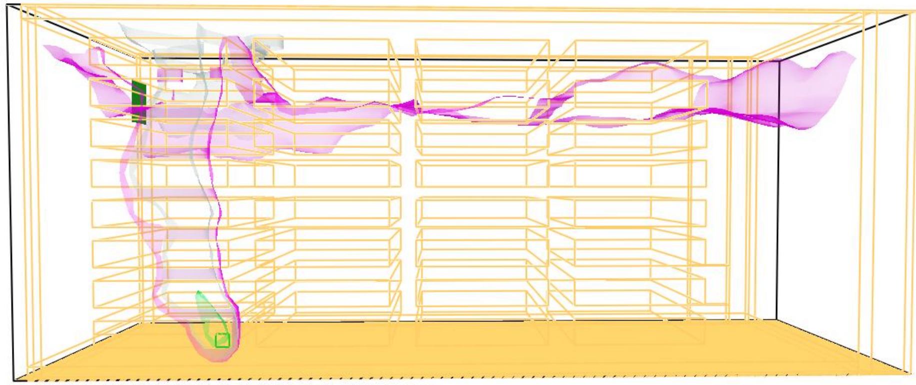
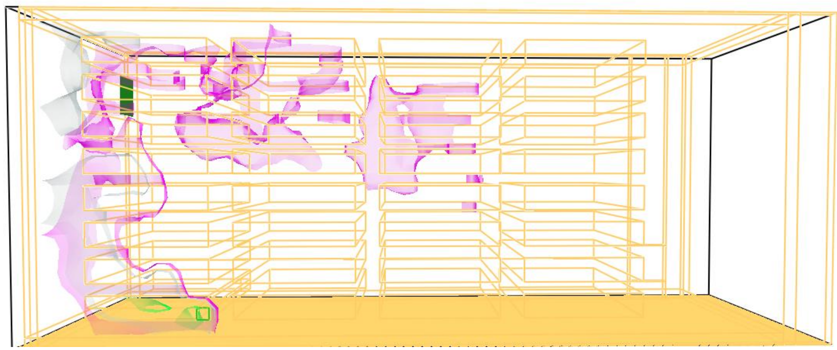
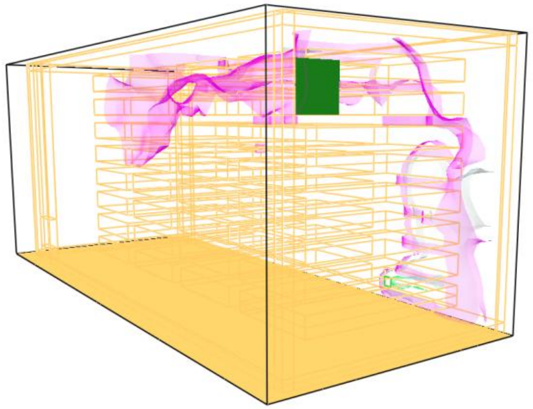


Figure 5. Farfield Dispersion – Off-gas – Case 3 – H_2 and CH_4



1.3 BESS INTERNAL OFF-GASS / EXHAUST

Figure 6. Farfield Dispersion – Off-gas – Case 4 – CO and CO_2 - CASE 4. Iso-surface: HYDROGEN (25% LEL purple, 50% LEL grey) – Leak location 1

BESS internal w modules	150 seconds (as exhaust comes online) (battery modules shown outline)
	
Constant concentration achieved with fan at 12m^3/min	Alternative view showing 50% LFL confined so small column above leak point
	

2 Combustion Products Dispersion (fire)

2.1 CASE BREAKDOWN

Cases 5-10(d) model a BESS unit-scale fire (1 unit, all cells). These cases are of interest for the following reasons:

- Significant heating supports buoyancy and therefore the gases are less strongly influenced by crosswind (compared to dispersions cases).
- The products of combustion are taken from the various literature sources on battery combustion product measurements, since modelling of battery combustion processes is not yet possible, and is also not important for this study.

We note that:

- Conservatively, all cells in the unit are assumed to be involved in fire simultaneously, and we have limited to total burn time to 2 hours, utilising the total gas per cell reported in the UL9540A cell level test report over this time period. This is intended to give a more onerous (conservative) rate of production of combustion products than generally observed in BESS and battery burn reports (where BESS fires have been observed to last between 2-8 hours generally).
- Cases 5-9(b) show the toxic products of combustion (where human health may be of concern) and cases 10(a) – 10(d) show visibly observable smoke.

Table 7. Case Details (5-10)

Case	Type	No cells	m'' (m^3/s)	Direction	Wind (m/s)	Notes
5	BESS fire combustion products (excl. soot)	All cells	0.13	Z	0.1	Fuel release rate for 2-hour fire period. Far-field dispersion
6		All cells		Z	2.5	
7		All cells		Z	5.0	
8		-	-	-	-	Test case – not reported
9		All cells	0.13	X	0.1	Fuel release rate for 2-hour fire period. Near-field dispersion
9a		All cells		X	2.5	
9b		All cells		X	5.0	
10a	BESS fire combustion (soot/smoke)	All cells	10 MW (PHRR)	Z	0.1	Far-field dispersion
10b		All cells		Z	2.5	
10c		All cells		Z	5.0	
10d		All cells		z	20.0	

Table 8. Battery unit smoke products composition

Constituents	Symbol	%
Carbon Dioxide	CO_2	0.95
Carbon Monoxide	CO	0.025
THC (Methane)	CH_4	0.005
Hydrogen Chloride	HCL	0.005
Hydrogen Fluoride	HF	0.005
Nitric ox/Nitro dioxide	NOx	0.005
Sulphur Dioxide	SOx	0.005

2.2 RESULTS SUMMARY

BESS Fires

Table 9. Results Data – Case 5 – BESS fire - wind 0.1 m/s

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source/plume above	At source/plume above	<u>Low wind (<0.2 m/s) / i.e. "calm" environment</u> Turbulent mixing from obscure air currents in an otherwise calm environment are not modelled here and could increase gas migration. **Assume STEL occurs not less than 30 m perimeter around source.** Further factor of safety should be added re intervention.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source/plume above	At source/plume above	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source/plume above	At source/plume above	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	At source/plume above	At source/plume above	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	At source/plume above	At source/plume above	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	At source/plume above	At source/plume above	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	At source/plume above	At source/plume above	

Table 10. Results Data – Case 6 – BESS fire - wind 2.5 m/s

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source/plume above	At source/plume above	<u>Gentle wind case (2.5 m/s)</u> STEL and TWA observed 10-15m downwind but at elevation of source +10 m. **Assume STEL occurs at not less than 30 m downwind of source.** Further factor of safety should be considered re intervention protocols.
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source/plume above	At source/plume above	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source/plume above	At source/plume above	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	At source/plume above	At source/plume above	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	At source/plume above	At source/plume above	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	At source/plume above	At source/plume above	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	At source/plume above	At source/plume above	

Table 11. Results Data – Case 7 – BESS fire - wind 5 m/s

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source	At source	<u>5m/s aligns with the reported max avg. annual wind</u> STEL for HCL, HF, NOx and SOx observed 10-30m downwind. TWA for HCL, HF, NOx and SOx observed 30-40m downwind. This higher wind pressure appears to be suitable to migrate gas effectively before significant dilution c. 50m+ downwind. **Recommend STEL considered as 50m downwind.**
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source	At source	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source	At source	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	20 m downwind	40 m downwind	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	30 m downwind	45 m downwind	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	20 m downwind	40 m downwind	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	15 m downwind	30 m downwind	

Table 12. Results Data – Case 9 – BESS fire - wind 0.1 m/s (obstructed flame)

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source	At source	
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source	At source	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source	At source	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	At source	At source	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	At source	At source	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	At source	At source	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	At source	At source	

Table 13. Results Data – Case 9a – BESS fire - wind 2.5 m/s (obstructed flame)

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source	10 m downwind	
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source	At source	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source	At source	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	25 m downwind	40 m downwind	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	30 m downwind	50 m downwind	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	20 m downwind	40 m downwind	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	10 m downwind	15 m downwind	

Table 14. Results Data – Case 9b – BESS fire - wind 5.0 m/s (obstructed flame)

Material	STEL (15min)	8-hr TWA	STEL detected	TWA detected	Notes
Carbon Monoxide (CO)	200 ppm	30 ppm	At source	At source	5m/s aligns with the reported max avg. annual wind STEL for HCL, HF, NOx and SOx observed 10-40m downwind. TWA for HCL, HF, NOx and SOx observed 30-50m downwind. This higher wind pressure appears to be suitable to migrate gas effectively before significant dilution c. 50m+ downwind. **Recommend STEL considered as 50m downwind.**
Carbon Dioxide (CO_2)	30,000	12,500 ppm	At source	At source	
THC (methane) (CH_4)	N/A. LEL – 50,000 ppm	N/A. UEL – 150,000 ppm	At source	At source	
Hydrogen Chloride (HCL)	5 ppm	2 ppm	25 m downwind	45 m downwind	
Hydrogen Fluoride (HF)	6 ppm	3 ppm	45 m downwind	50 m downwind	
Nitric Ox/Nitro Diox (NOx)	5 ppm (NO_2)	3 ppm (NO_2)	20 m downwind	45 m downwind	
Sulphur Dioxide (SOx)	5 ppm	2 ppm	15 m downwind	30 m downwind	

Table 15. Results Data – Cases 10(a-d) – BESS fire

Case	Wind	Case Type	PHRR	Visible Plume*	Plume Olfactory**
10a	0.1 m/s	Primary	10 MW	~ 100 m downwind	< 500 m
10b	2.5 m/s	Primary	10 MW	~ 1,000 m downwind	> 1,000 m
10c	5.0 m/s	Primary	10 MW	~ 2,000 m downwind	> 2,000 m
10d	20.0 m/s	Sensitivity	10 MW	< 1,000 m downwind	< 2,000 m

* Note that distances are approximate. Nuances in weather/wind conditions will impact the nature of the smoke plume and whether smoke can be detected in the air through visual or olfactory means. Toxicity of combustion products are reviewed in case 1-9.
** Olfactory – meaning that the smell of smoke in the air may be credible.

Figure 7. Farfield Dispersion – BESS Combustion Products (fire) – Case 5 – CO and CO_2

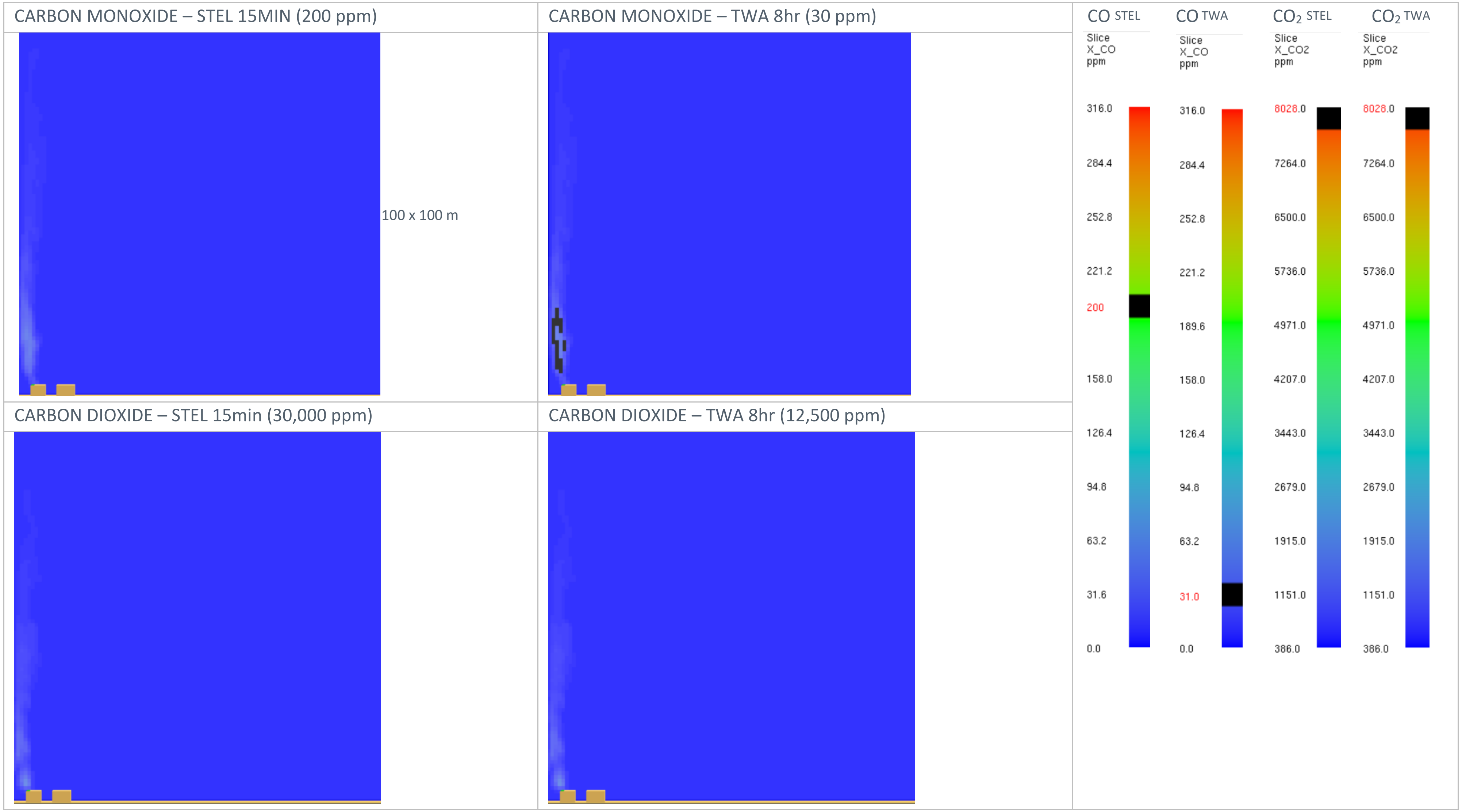


Figure 8. Farfield Dispersion – BESS Combustion Products (fire) – Case 5 – CH_4 and HCL

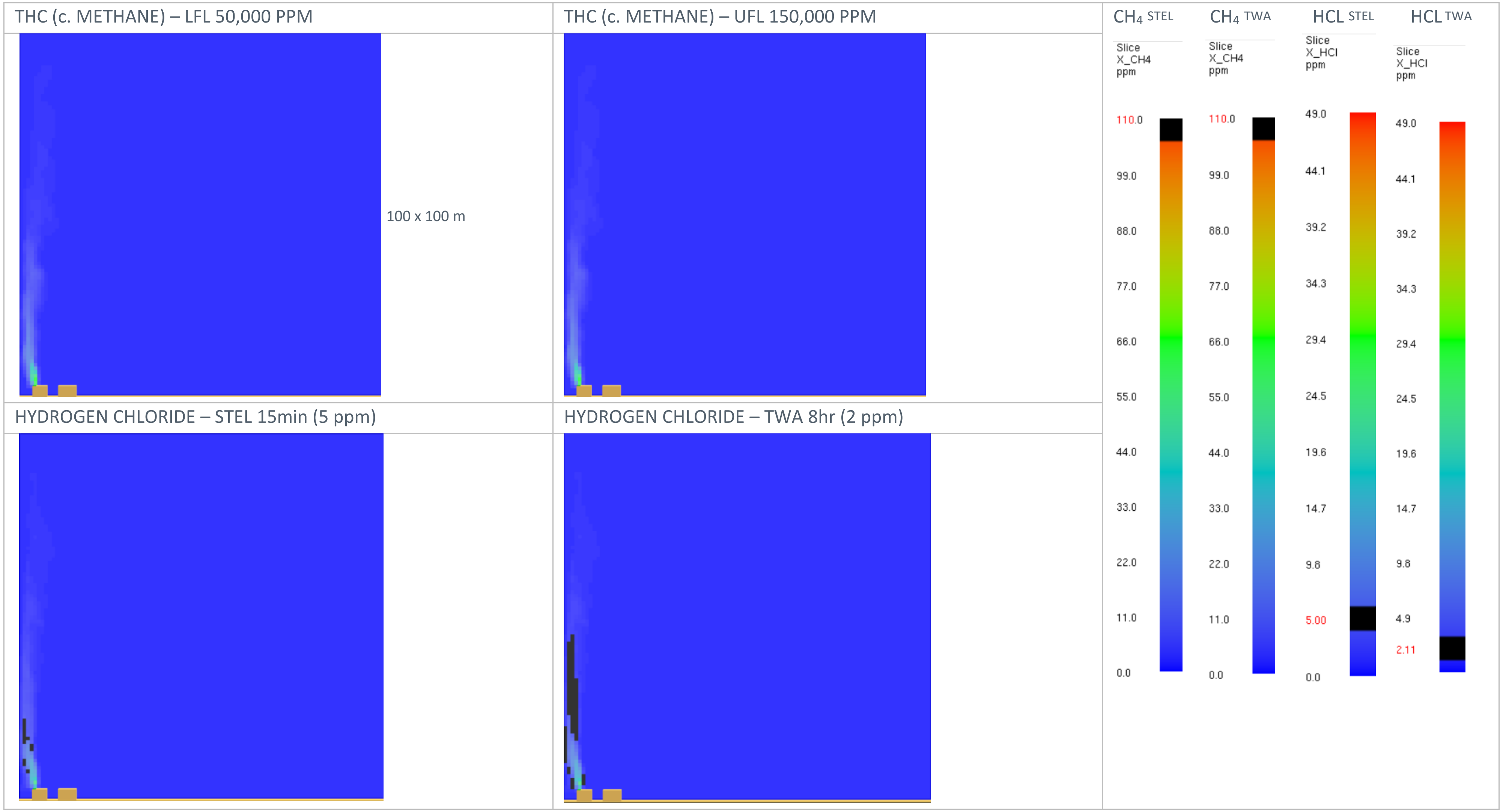


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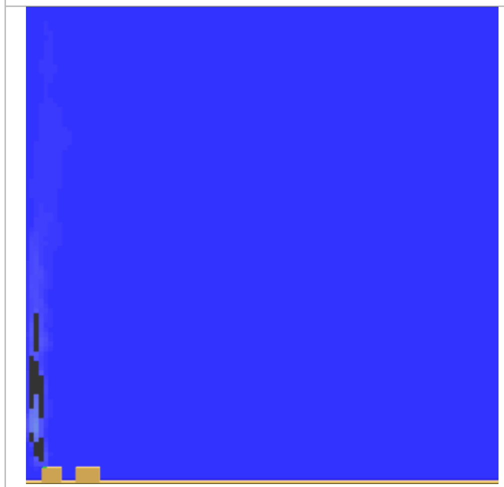
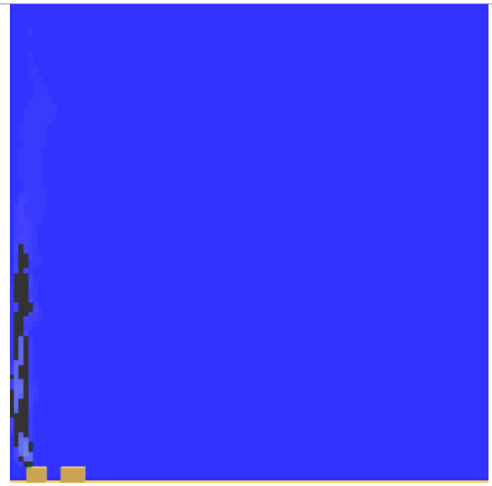
Figure 9. Farfield Dispersion – BESS Combustion Products (fire) – Case 5 – HF and Nox

HYDROGEN FLUORIDE – STEL 15MIN (6 ppm)



100 x 100 m

HYDROGEN FLUORIDE – TWA 8hr (3 ppm)



NO_X – STEL 15mnin (5 ppm)

NOx – TWA 8hr (3 ppm)

CH_4 STEL | CH_4 TWA | HCL STEL | HCL TWA

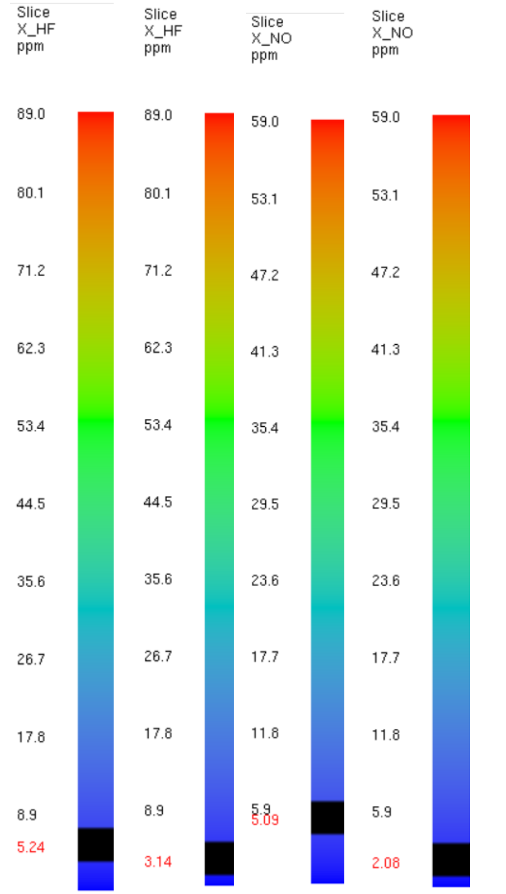


Figure 10. Farfield Dispersion – BESS Combustion Products (fire) – Case 5 – SOx

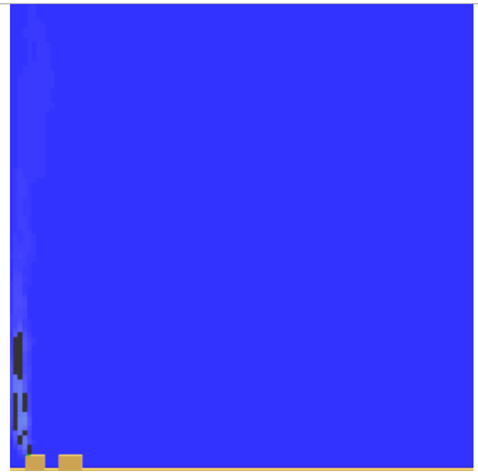
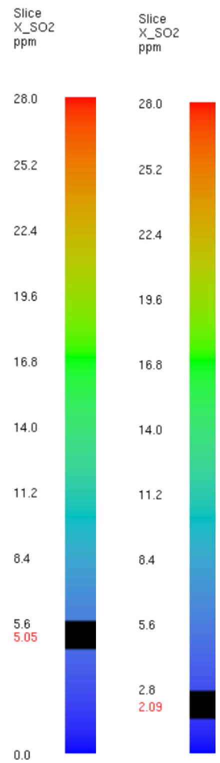
SOx (c. SO_2) – STEL 15MIN (5 ppm)	SOx (c. SO_2) – TWA 8hr (2 ppm)	SO_X STEL SO_X TWA
		

Figure 11. Farfield Dispersion – BESS Combustion Products (fire) – Case 6 – CO and CO_2

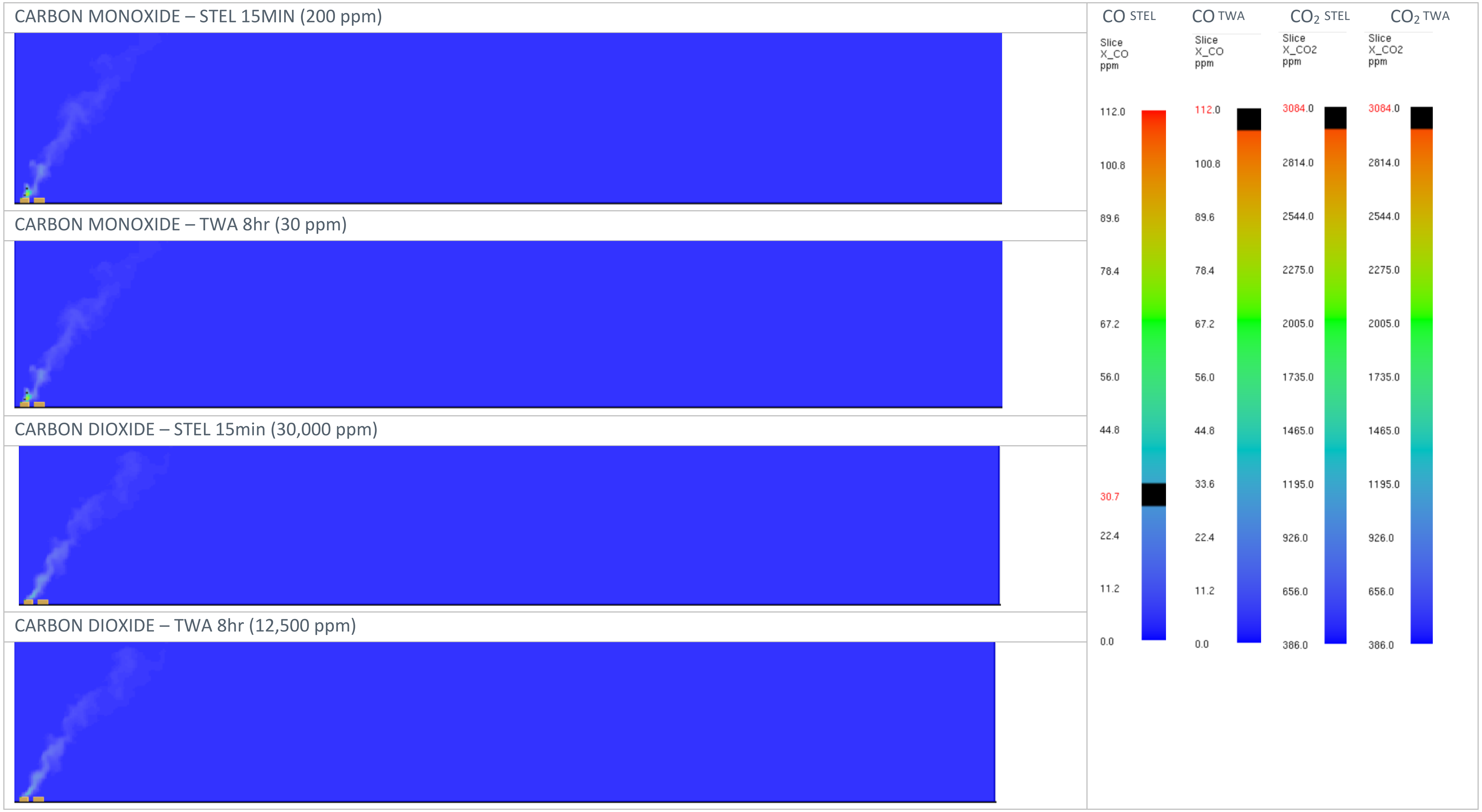


Figure 12. Farfield Dispersion – BESS Combustion Products (fire) – Case 6 – CH_4 and HCL

Figure 13. Farfield Dispersion – BESS Combustion Products (fire) – Case 6 – HF and NOx

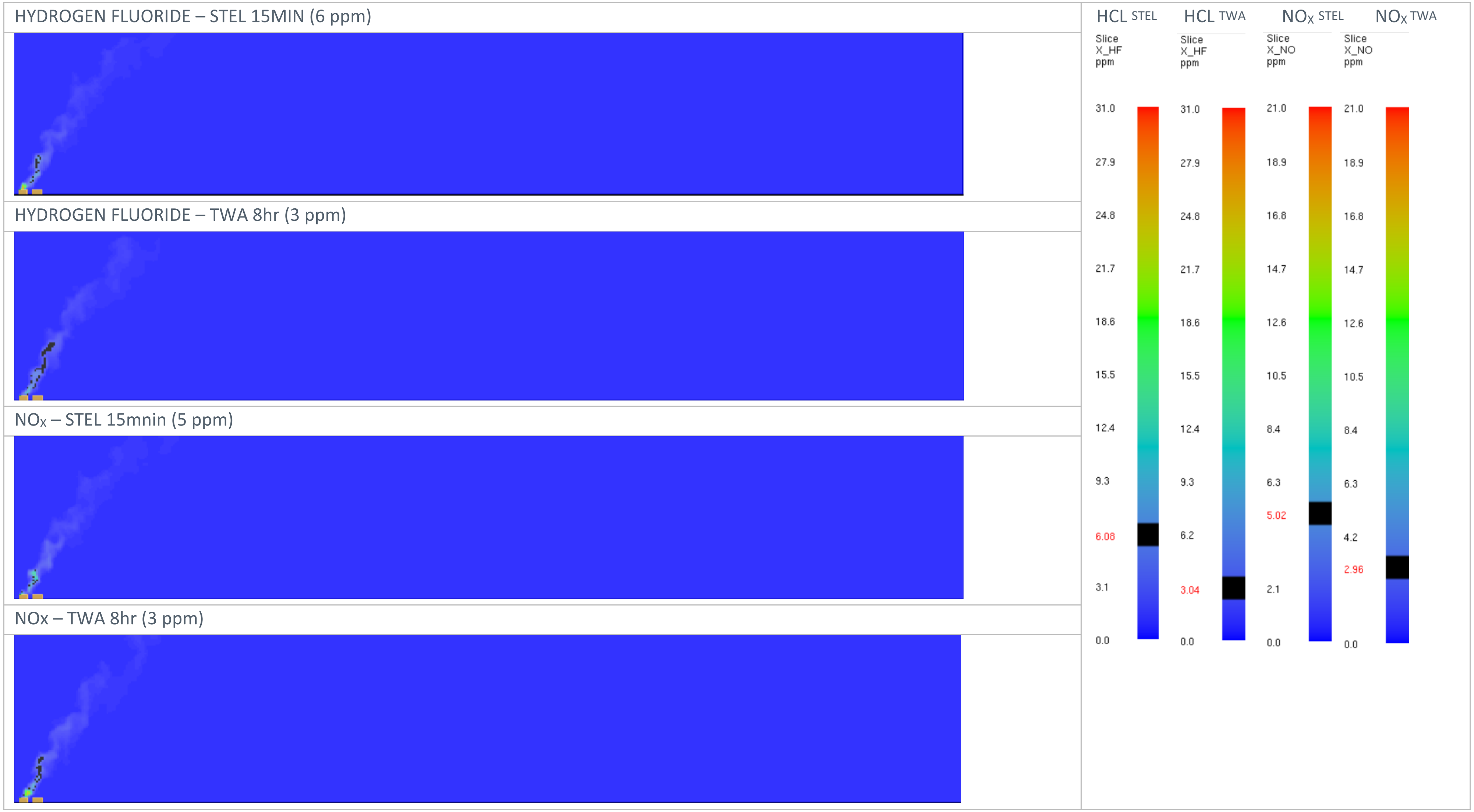


Figure 14. Farfield Dispersion – BESS Combustion Products (fire) – Case 6 – SOx

SOx (c. SO_2) – STEL 15MIN (5 ppm)

SOx (c. SO_2) – TWA 8hr (2 ppm)

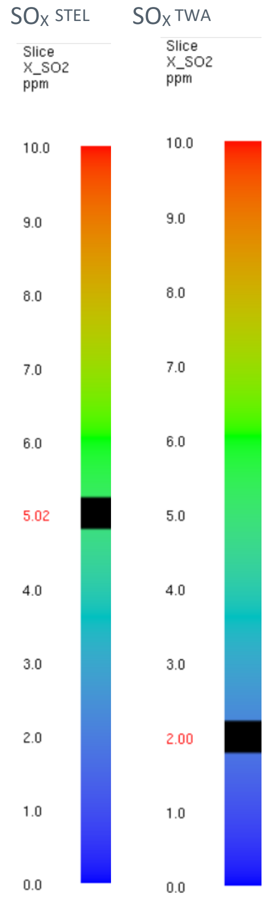


Figure 15. Farfield Dispersion – BESS Combustion Products (fire) – Case 7 – CO and CO_2

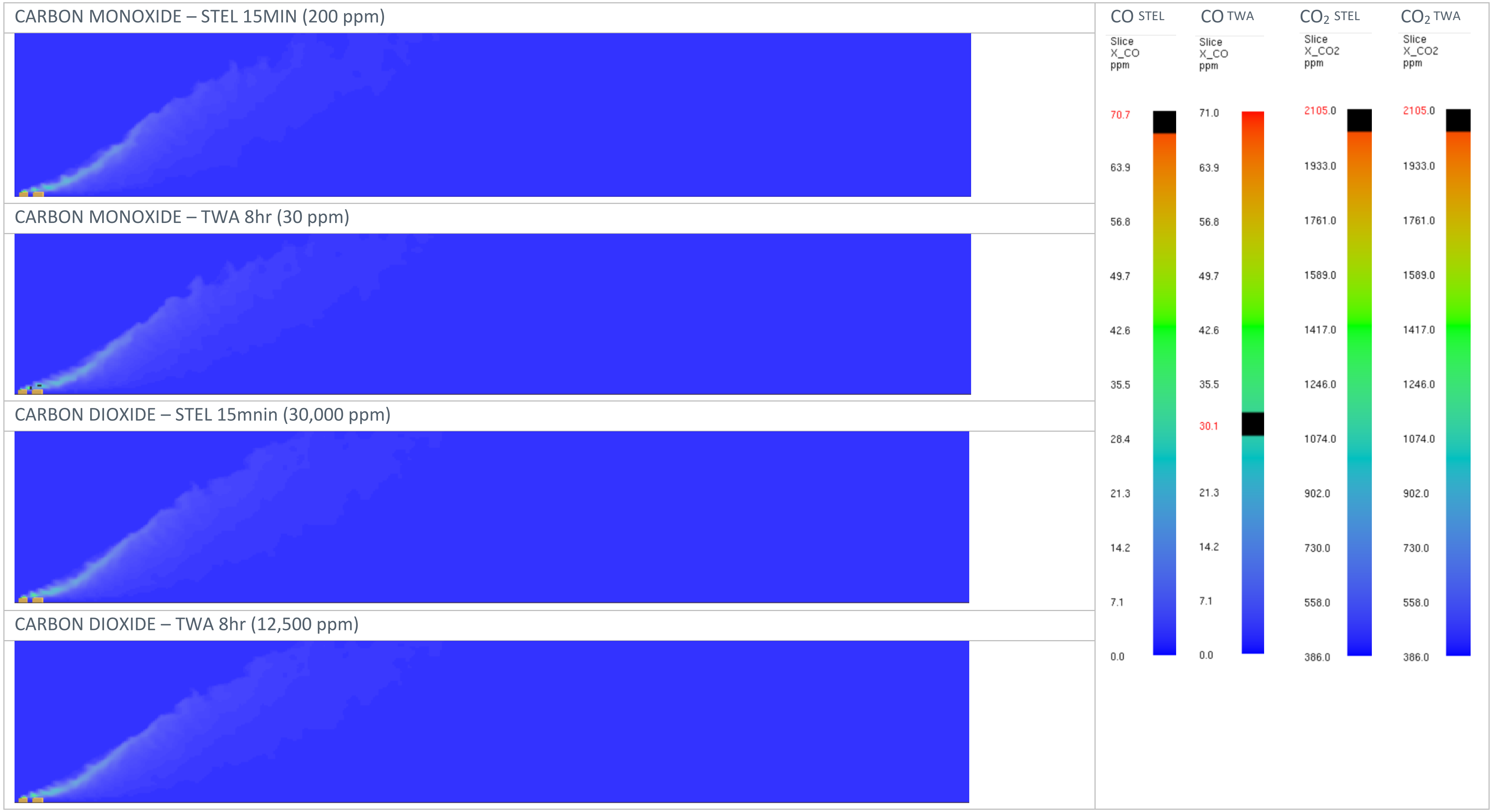
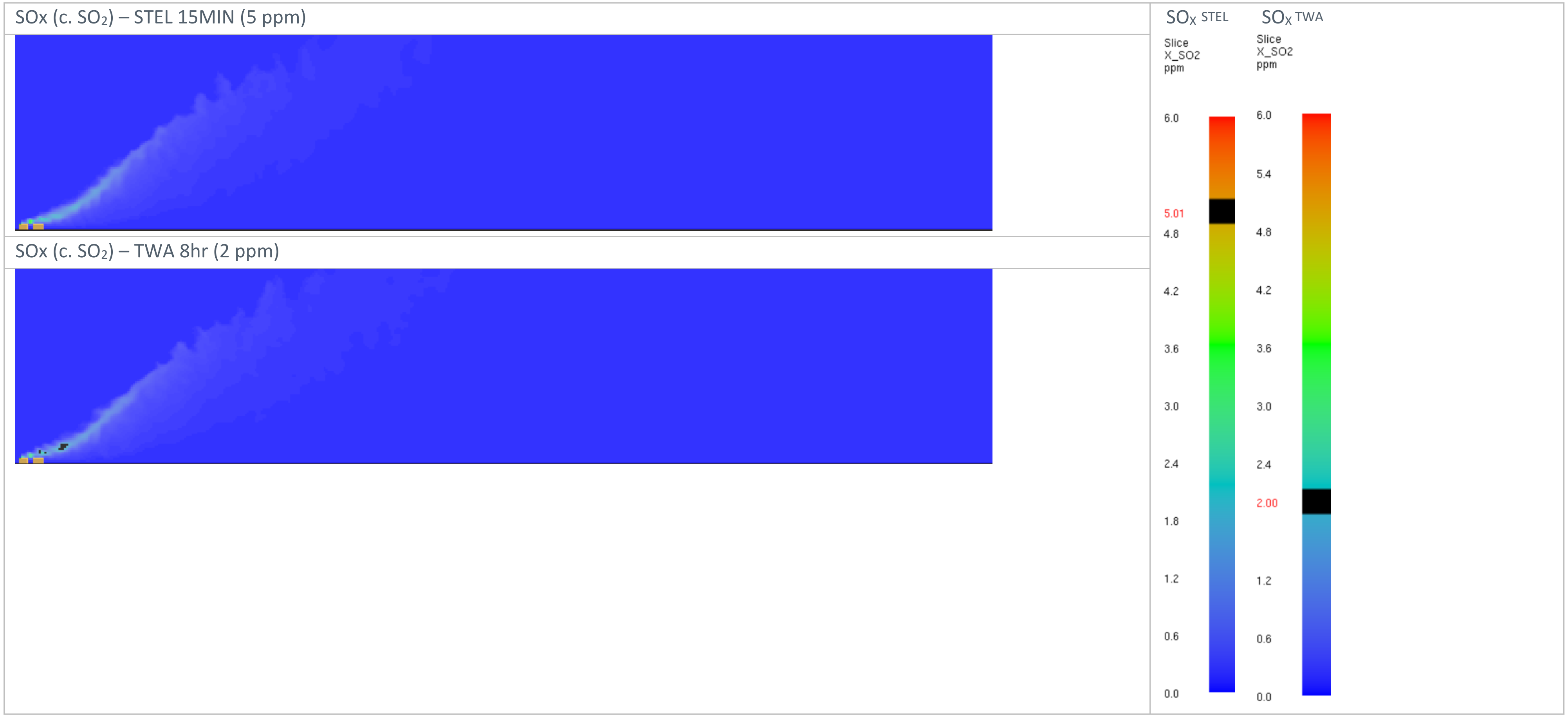


Figure 16. Farfield Dispersion – BESS Combustion Products (fire) – Case 7 – CH_4 and HCL

Figure 17. Farfield Dispersion – BESS Combustion Products (fire) – Case 7 – HF and NOx

Figure 18. Farfield Dispersion – BESS Combustion Products (fire) – Case 7 – SOx



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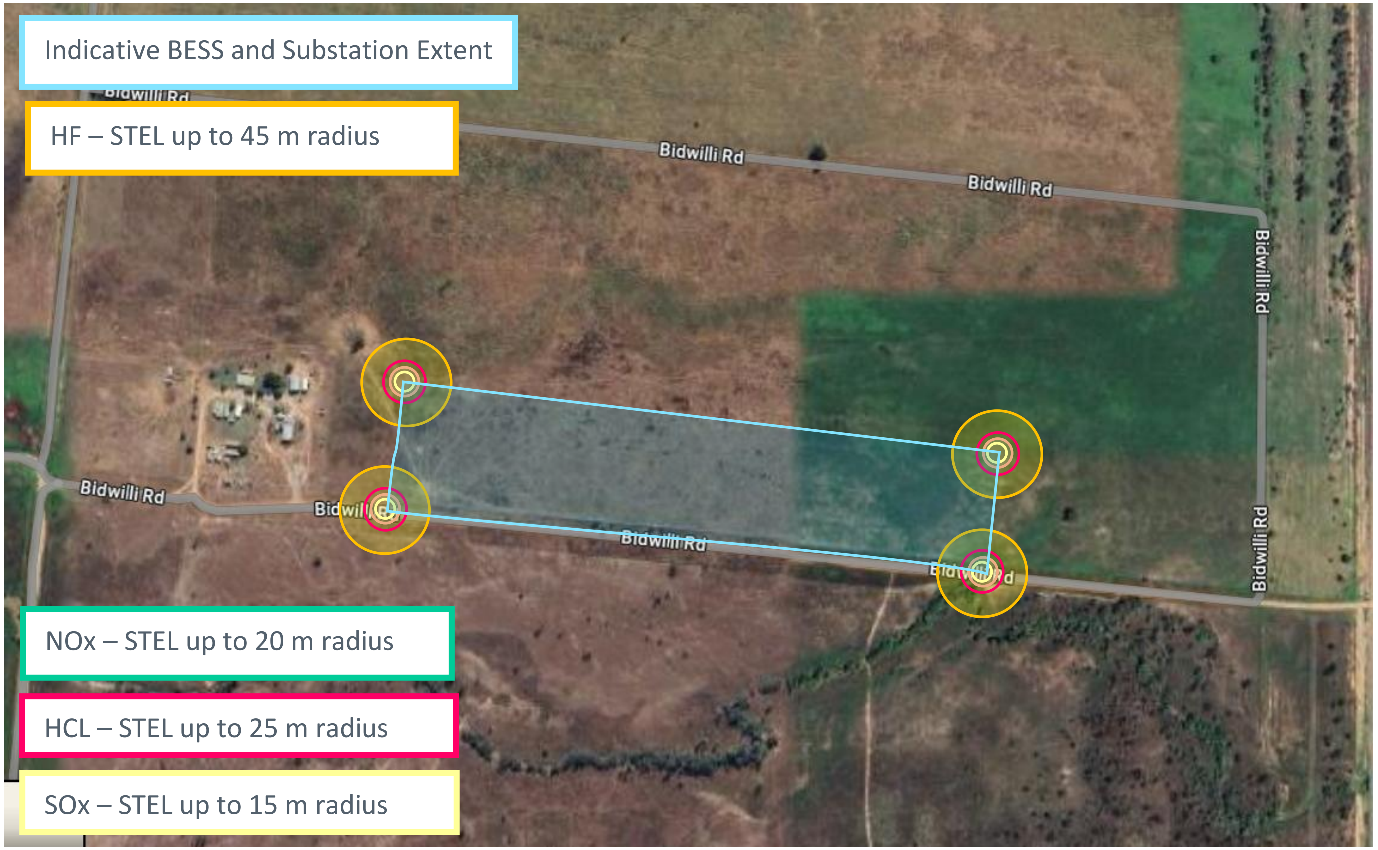

Case 9b- BESS dispersion contours (STEL)

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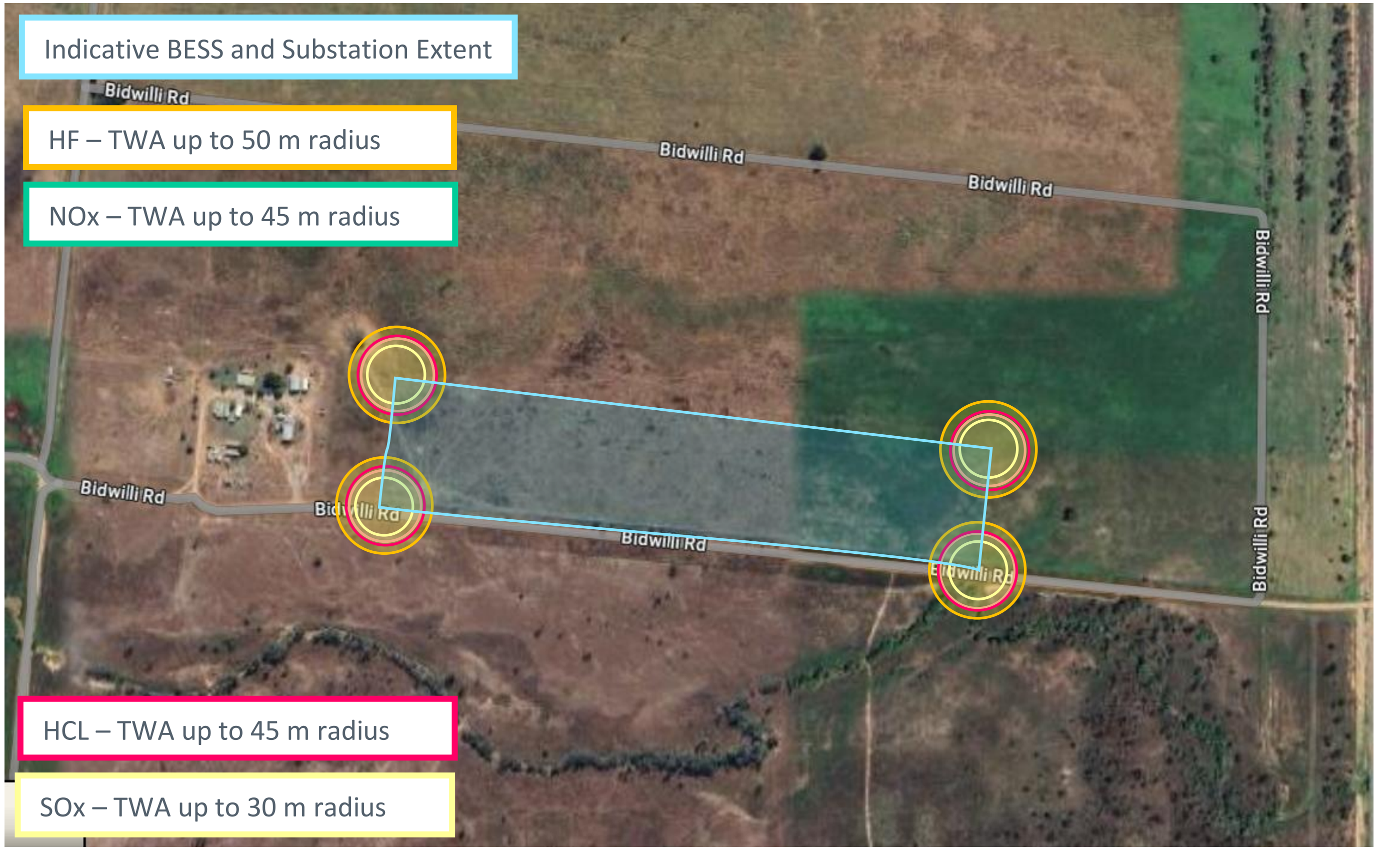
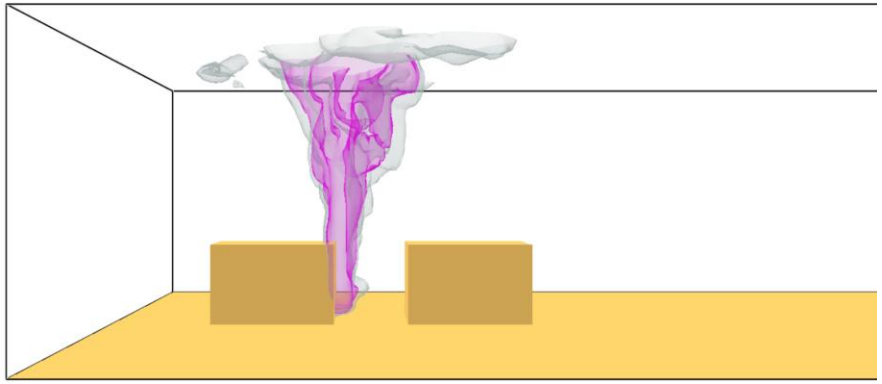
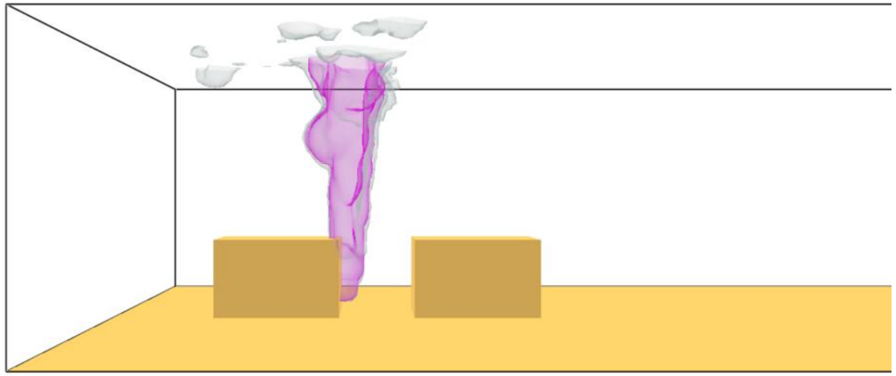


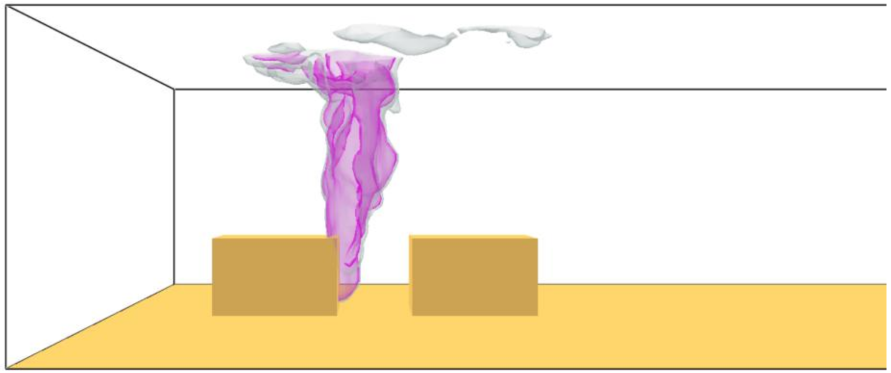
Case 9b- BESS dispersion contours (TWA)



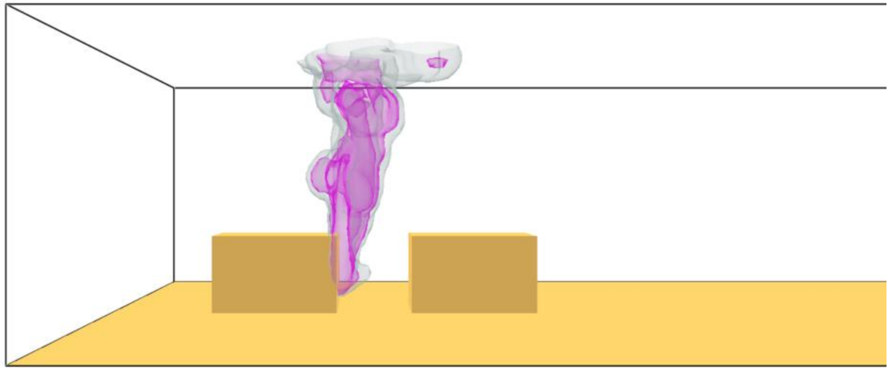
Case 9 – Iso-surface: Hydrogen Chloride (STEL- Purple, TWA – Grey)



Case 9 – Iso-surface: Hydrogen Fluoride (STEL- Purple, TWA – Grey)

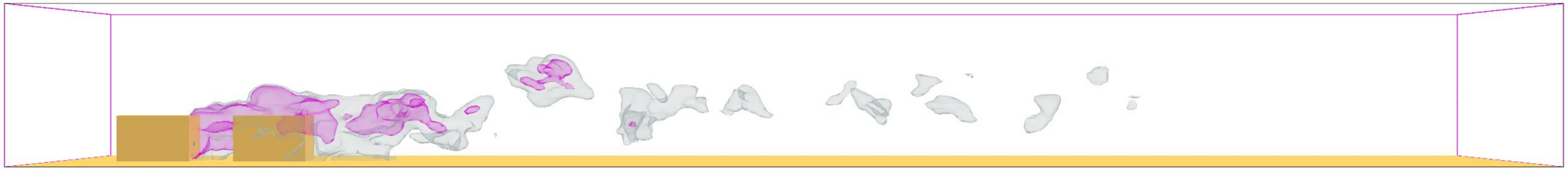


Case 9 – Iso-surface: NOx (STEL- Purple, TWA – Grey)

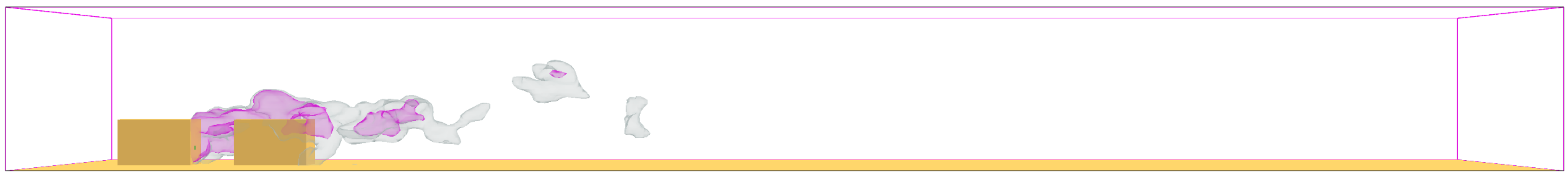


Case 9 – Iso-surface: Sulphur Dioxide (STEL- Purple, TWA – Grey)

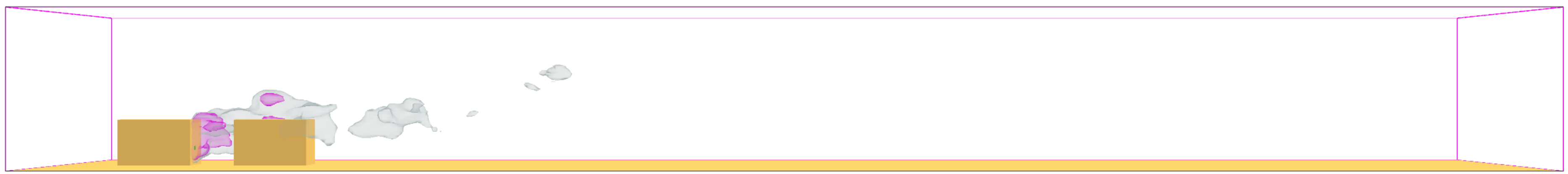
Case 9a – Iso-surface: Hydrogen Chloride (STEL- Purple, TWA – Grey) 100 m



Case 9a – Iso-surface: Hydrogen Fluoride (STEL- Purple, TWA – Grey)

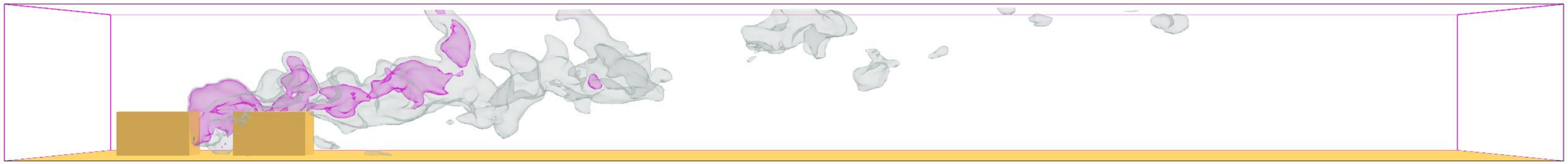


Case 9a – Iso-surface: NOx (STEL- Purple, TWA – Grey)



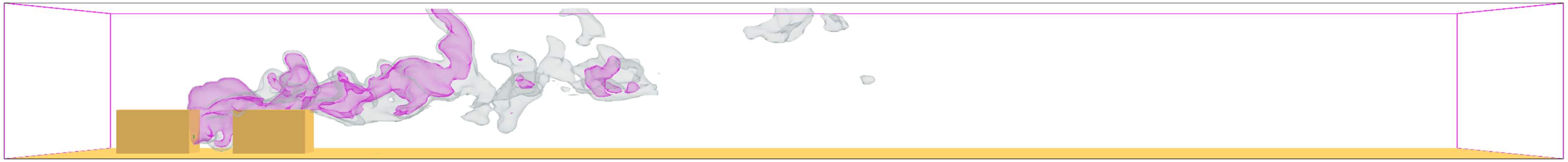
Case 9a – Iso-surface: Sulphur Dioxide (STEL- Purple, TWA – Grey) 100 m

HALLIWELL

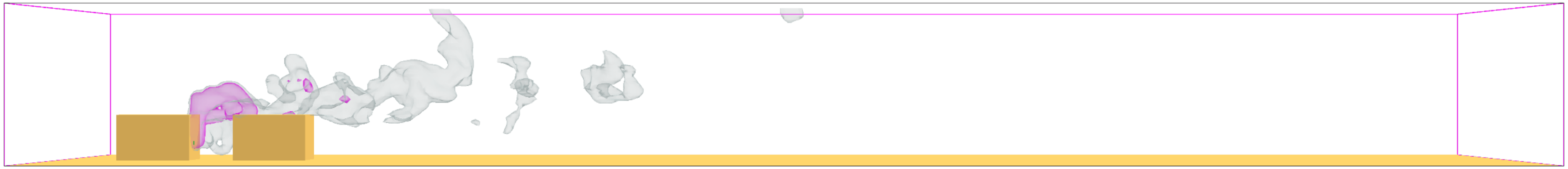


Case 9b – Iso-surface: Hydrogen Chloride (STEL- Purple, TWA – Grey) 100 m

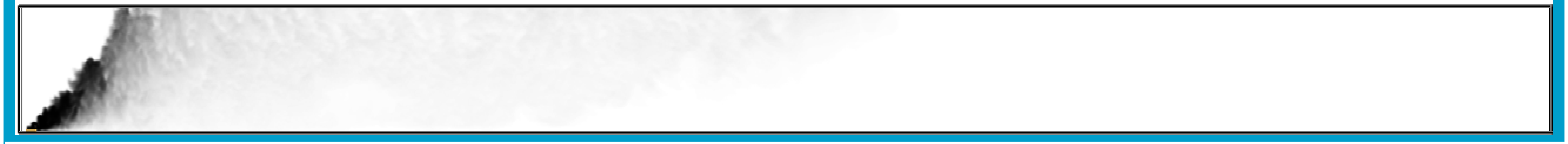
Case 9b – Iso-surface: Hydrogen Fluoride (STEL- Purple, TWA – Grey)



Case 9b – Iso-surface: NOx (STEL- Purple, TWA – Grey) 100 m

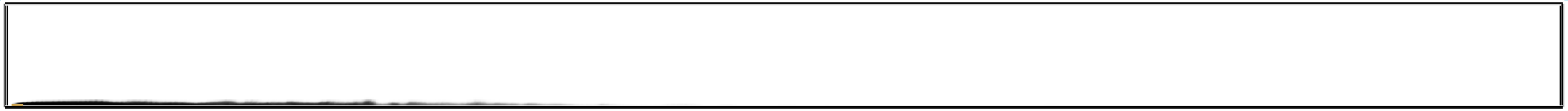


Case 9b – Iso-surface: Sulphur Dioxide (STEL- Purple, TWA – Grey)



Case 10b – Visible smoke plume (2.5 m/s) 1500 m

Case 10c – Visible smoke plume (5.0 m/s)



Case 10d – Visible smoke plume (20.0 m/s) (sensitivity study)

3 BESS Fire – Thermal Exposure

Table 16. Results Data – Case 11 – BESS unit fire - wind 0.1 m/s (thermal exposure to surrounding equipment)

BESS fire	Target	Flux (kW/m^2)	Distance (m)	Expected Impact at Target
BESS Unit	Far side of nearest road	~15.0	7.0	< 25 kW/m2, for non-piloted ignition
BESS unit	Nearest BESS unit	21.0	3.0	< 25 kW/m2, for non-piloted ignition / Negligible impact to equipment
BESS unit	Nearest PCU	9.0	6.0	Negligible impact to equipment.

Table 17. Results Data – Case 11 – PV BESS unit fire - wind 0.1 m/s (thermal exposure to personnel)

BESS side	Flux (kW/m^2)	Distance (m)	Relevance	Time period	Notes
Long side	2.5	14	Persons with long sleeves and trousers	30 secs +	These time limits for exposure prior to pain are a guide only and real outcomes depend upon on site conditions, weather and individual tolerance levels.
Long side	4.6	11	Fire Brigade in full PPE	Up to 3 min	
Narrow side	2.5	12	Persons with long sleeves and trousers	30 secs +	
Narrow side	4.6	9	Fire Brigade in full PPE	Up to 3 min	

Notes:

Given the thermal exposure modelling results, unprotected persons (i.e. with skin protection and BA) should NOT be within 14 m of a BESS fire in any case.

While approaching a fire from upwind may reduce the potential for exposure to toxic materials, radiant heat flux can be considered to be consistent upwind or downwind.

Figure 19. Radiant Heat Flux Analyses between BESS Units and Surrounding Equipment

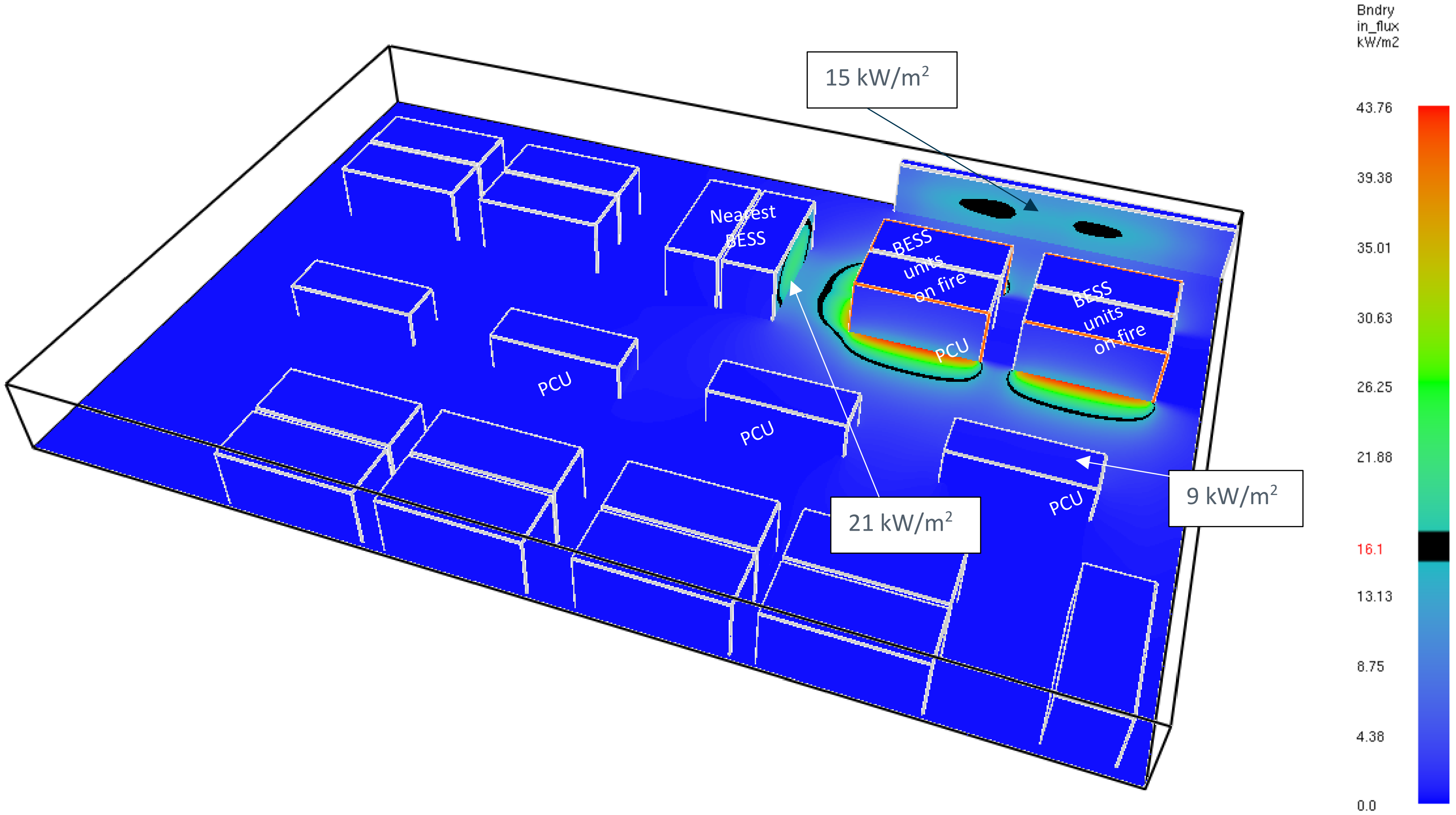


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Figure 20. Radiant Heat Flux Analyses for Lide Safety