Appendix E

Preliminary Hazard Analysis and CFA Response

RED FIRE ENGINEERS

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27 May 2025

Country Fire Authority
8 Lakeside Dr.
BURWOOD EAST, VIC, 3151

Attention: **Jennifer Blyth**

Re: **CFA Fire Safety Response**
Project No: **JV25-00083** **Version:** **3**
Project: **West Mokoan Solar Farm Benalla, VIC 3672**

1 Background

1.1 Red Fire Engineers is currently engaged to provide Fire Safety Engineering support on the West Mokoan Hybrid Solar farm development. RED Fire Engineers has been engaged to develop a new site fire safety strategy and Fire Safety Study (FSS), as well as a Risk Management Plan (RMP).

1.2 This consultant advice notice (CAN) is being provided in relation to the permit approvals stage (Phase 1). We are seeking in-principle approval to the fire strategy provided within. Following 'in-principle' approval, the RMP and FSS will be developed and issued for CFA review and endorsement.

1.3 This CAN starts with an assessment of the hybrid solar farm requirements arising from the Country Fire Authority Renewable Guidelines V4 (CFA guidelines) against the West Mokoan site. Where deviations exist, these will be discussed and preliminary assessment provided.

2 CFA Guidelines

2.1 The CFA Guidelines stipulates the Model Requirements in Table 1. The table also provides an initial assessment of the West Mokoan hybrid solar farm sites against these baseline requirements.

Table 1: Model Requirements as per CFA Guidelines

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
4.11 High Risk Environments	a) An assessment against policy at Clause 13.02-1S (Bushfire Planning) where the facility is located in a Bushfire Prone Area (BPA). b) The impact of any ignitions arising from the infrastructure (solar panels) on nearby communities, infrastructure and assets. c) The impact of bushfire on the infrastructure (e.g., ember attack, radiant heat impact, flame contact). d) Assessment of whether the proposal will lead to an increase in risk to adjacent land and how the proposal will reduce risks on site to an acceptable level.			Site is located within a BPA. These requirements will be met and presented in detail in the RMP and FSS.
4.2.1 Emergency Vehicle (Fire Truck) Access	a) Construction of a minimum four (4) metre wide perimeter road within the perimeter fire break.	Where solar energy facilities are designed over several land parcels separated by private or public roads, overhead powerlines,	At least two access points are to be provided into each section were battery energy storage systems are located. The number and location of vehicle	Generally, these conditions will be met across the site. This includes any power lines across the site being at least 4 m above the

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	b) Roads must be of all-weather construction and capable of accommodating a vehicle of fifteen (15) tonnes (e.g. no compacted earth). c) Constructed roads should be a minimum of four (4) metres in trafficable width with a four (4) metre vertical clearance for the width of the formed road surface. Ensure any fencing along access routes allows for width of fire vehicles. d) The average grade should be no more than 1 in 7 (14.4% or 8.1°) with a maximum of no more than 1 in 5 (20% or 11.3°) for no more than fifty (50) metres. e) Dips in the road should have no more than a 1 in 8 (12.5% or 7.1°) entry and exit angle f) Roads must incorporate passing bays at least every 600 metres, which must be at least twenty (20) metres long and have a minimum trafficable	and/or water courses, vehicle entrances are to be provided into each section. The number and location of vehicle access points must be determined in consultation with CFA.	access points must be determined in consultation with CFA	ground level. On site tracks, which are not associated with access to the BESS / power conversion station (PCS) will be dirt tracks. These dirt tracks will be limited to tracks where there are only solar panels and grass. Preliminary assessment provided in Section 3.

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
	width of six (6) metres. At least one passing bay must be incorporated where roads are less than 600 metres long. g) Road networks must enable responding emergency services to access all areas of the facility, including fire service infrastructure, buildings, battery energy storage systems and related infrastructure, substations and grid connection areas. h) Provision of at least two (2) but preferably more access points to each part of the facility. The number of access points must be informed through.			
4.2.2 Firefighting Water Supply	a) Water access points must be clearly identifiable and unobstructed to ensure efficient access. b) Static water storage tank installations must comply with AS 2419.1-2021: Fire hydrant	a) The fire protection system for solar energy facilities must incorporate at least one (1) x 45,000L static water tank at the primary vehicle entrance to each the part of the facility.	Battery Energy Storage Systems (Decentralised) 1) For facilities with decentralised battery energy storage systems, the fire protection system must include at a minimum:	The intent of these baseline requirements will be met. The only departure will be that a single 45 kL fire water tank will cover up to 9 PCS's, which include BESS units. This will be achieved by having a low

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
	installations – System design, installation and commissioning. c) The static water storage tank(s) must be an above-ground water tank constructed of concrete or steel. d) The static water storage tank(s) must be capable of being completely refilled automatically or manually within 24 hours. e) The static water storage tanks must be located at vehicle access points to the facility and must be positioned at least ten (10) metres from any infrastructure (solar panels, wind turbines, battery energy storage systems, etc.). f) The hard-suction point must be provided, with a 150mm full bore isolation valve (Figure 3) equipped with a Storz connection, sized to comply with the required suction hydraulic performance. Adapters that may be required to match the connection are: 125mm,	b) Additional static fire water tanks of at least 45,000L effective capacity must also be incorporated for every 100ha.	a) Where reticulated water is available, a fire protection system as per Model Requirement (1a) under 'Centralised Battery Energy Storage Systems'. OR b) Where no reticulated water is available, a fire water supply in static storage tanks, where a minimum 45,000L static water tank is provided within 120m of each battery container. The aggregate quantity of fire water supply at the facility must be no less than 288,000L to the satisfaction of CFA.	pressure fire main from a 45 kL tank to feed hydrants that are approx. 110 m from each of the covered PCS (which include BESS units). At each of these hydrants, there shall be fire brigade vehicular hard stand, and the other items called up in the baseline. These 45 kL fire water tanks that feed the low pressure fire main may also be located at main accesses. Preliminary assessment provided in Section 3.

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
	100mm, 90mm, 75mm, 65mm Storz tree adapters (Figure 4) with a matching blank end cap to be provided. g) The hard-suction point must be positioned within four (4) metres to a hardstand area and provide a clear access for emergency services personnel. h) An all-weather road access and hardstand must be provided to the hard-suction point. The hardstand must be maintained to a minimum of 15 tonne GVM, eight (8) metres long and six (6) metres wide or to the satisfaction of the CFA. i) The road access and hardstand must be kept clear at all times. j) The hard-suction point must be protected from mechanical damage (e.g., bollards) where necessary. k) Where the access road has one entrance, an eight (8) metre			

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
	radius turning circle must be provided at the tank. l) An external water level indicator must be provided to the tank and be visible from the hardstand area. m) Signage (Figure 5) indicating 'FIRE WATER' and the tank capacity must be fixed to each tank. n) Signage (Figure 6) must be provided at each vehicle entrance to the facility, indicating the direction to the nearest static water tank(s).			
4.2.3 Fire Detection and Suppression Equipment	Suitable fire detection and suppression equipment must be provided: a) For on-site buildings and structures, according to the requirements of the National Construction Code. b) For storages of dangerous goods, according to the requirements of any Australian			This baseline requirement will be met.

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	Standards for storing and handling of dangerous goods. c) For electrical installations, a minimum of two (2) suitable fire extinguishers must be provided within 3m-20m of each PCU. d) In all vehicles and heavy equipment, each vehicle must carry at least a nine (9)-litre water stored-pressure fire extinguisher with a minimum rating of 3A, or other firefighting equipment as a minimum when on-site during the Fire Danger Period.			
4.2.5 Fire Breaks	A fire break must be established and maintained around: a) The perimeter of the facility, commencing from the boundary of the facility or from the vegetation screening inside the property boundary. b) The perimeter of control rooms, electricity compounds, substations and all other buildings on- site.		A fire break must be established and maintained around battery energy storage systems and related infrastructure.	Perimeter fire breaks will have no vegetation , i.e., dirt, during any fire danger period, as well as two weeks before the standard period. This firebreak will be at least 10 m wide. Rest of the years vegetation within the fire break will have a height

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
	The width of fire breaks must be a minimum of 10m, and at least the distance where radiant heat flux (output) from the vegetation does not create the potential for ignition of on-site infrastructure			limitation, of less than 300 mm. The perimeter road will be part of the perimeter fire break. This road will generally be dirt track, but in some areas, it will be all-weather road. Preliminary assessment provided in Section 3.
4.2.6 Design Specific to Facility Type		Solar energy facilities are to have a minimum six (6) metre separation between solar panel banks	1) The design of the facility must incorporate: a) A separation distance that prevents fire spread between battery containers/enclosures and: • Other battery containers/enclosures. • On-site buildings. Substations. • The site boundary. • Any other site buildings. Vegetation separation must be at least the distance where the radiant	The intent of these baseline requirements will be met. With respect to point 2(a) of BESS specific requirements, as this is a distributed BESS site, it is not practical to locate the BESS units adjacent to the site vehicle entrance. With respect to point 2(i) of BESS specific requirements, the PCS units, which include BESS units are located off the road in such a way

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
			heat flux (output) from a battery energy storage system container/ enclosure fully involved in fire does not create the potential for ignition of these site elements. b) A fire break around the battery energy storage system and related infrastructure, of a width of no less than 10m, or greater were determined in the Risk Management Plan. Fire breaks must be non-combustible, constructed of concrete, mineral earth or non-combustible mulch such as crushed rock. The width must be calculated based on the ignition source being radiant heat of surrounding vegetation, including landscaping. c) A layout of site infrastructure that:	that a vehicle impact is unlikely. Additionally, vehicle speed across the site will be limited to 15 km/hr. Furthermore, guardrails would impede the operations and maintenance activities for the BESS units. This will be further reviewed within FSS, including various methods of providing impact protection. With respect to point 2(k) of BESS specific requirement, the management of fire water run-off is being reviewed but this may include the separation any liquid / solid emissions from the BESS unit undergoing thermal runaway from cooling water to adjacent units and rainwater catch area. Additionally, measures such as portable

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
			i. Considers the safety of emergency responders. ii. Minimises the potential for grassfire and/or bushfire to impact the battery energy storage system. iii. Minimises the potential for fires in battery containers/enclosures to impact on-site and offsite infrastructure. 2) Battery energy storage systems must be: a) Located to be reasonably adjacent to a site vehicle entrance (suitable for emergency vehicles). b) Located so that the site entrance and any fire water tanks are not aligned to the prevailing wind direction (therefore least likely to be impacted by smoke in the event of	bunding and permit environmental emissions will be considered. Preliminary assessment provided in Section 3.

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
			fire at the battery energy storage system.) c) Provided with in-built fire and gas detection systems. Where these systems are not provided, measures to effectively detect fires within containers must be detailed within the Risk Management Plan. d) Provided with explosion prevention via sensing and venting, or explosion mitigation through deflagration panels. e) Provided with suitable ember protection to prevent embers from penetrating battery containers/enclosures. f) Provided with suitable access roads for emergency services vehicles, to and within the site, including to battery energy storage system(s)	

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
			and fire service infrastructure. g) Installed on a non-combustible surface such as concrete. h) Provided with suitable ventilation. i) Provided with impact protection to at least the equivalent of a W guardrail-type barrier, to prevent mechanical damage to battery containers/ enclosures. j) Provided with enclosed wiring and buried cabling, except where required to be above-ground for grid connection. k) Provided with spill containment that includes provision for management of fire water runoff.	
5.1.4 Emergency Management	An Emergency Plan must be developed for the construction			This is proposed.

Section of CFA DGMR Renewable Energy Facilities	CFA Design Baseline Requirement for All Facilities	CFA Design Baseline Requirement for Specifically Solar Energy	CFA Design Baseline Requirement Specifically for BESS's	Project Position
	and commissioning phase, before development starts			
6.1 Fire Management Plan	A Fire Management Plan must be developed for the facility, in consultation with CFA, before development starts.			This is proposed.

3 Assessment

Internal road arrangement

3.1 The roads, marked in red within Figures 1 and 2, will be all-weather roads as they provide access to the BESS units across the site from all the entrances. Located with the BESS units are the PCS's, which include transformers and inverters. The roads marked blue in these figures will be either dirt or crushed rock tracks.

3.2 This arrangement is proposed as aside from fire originating in the BESS units themselves, the main fire hazards are grass fires. A grass fire may have been initiated outside of the site or on-site due to electrical issue with a solar panel, tracking system, or other similar system. We understand that the CFA successfully responds to grass fires elsewhere without all-weather roads being provided, e.g. across farmland and grassland reserves/parks.

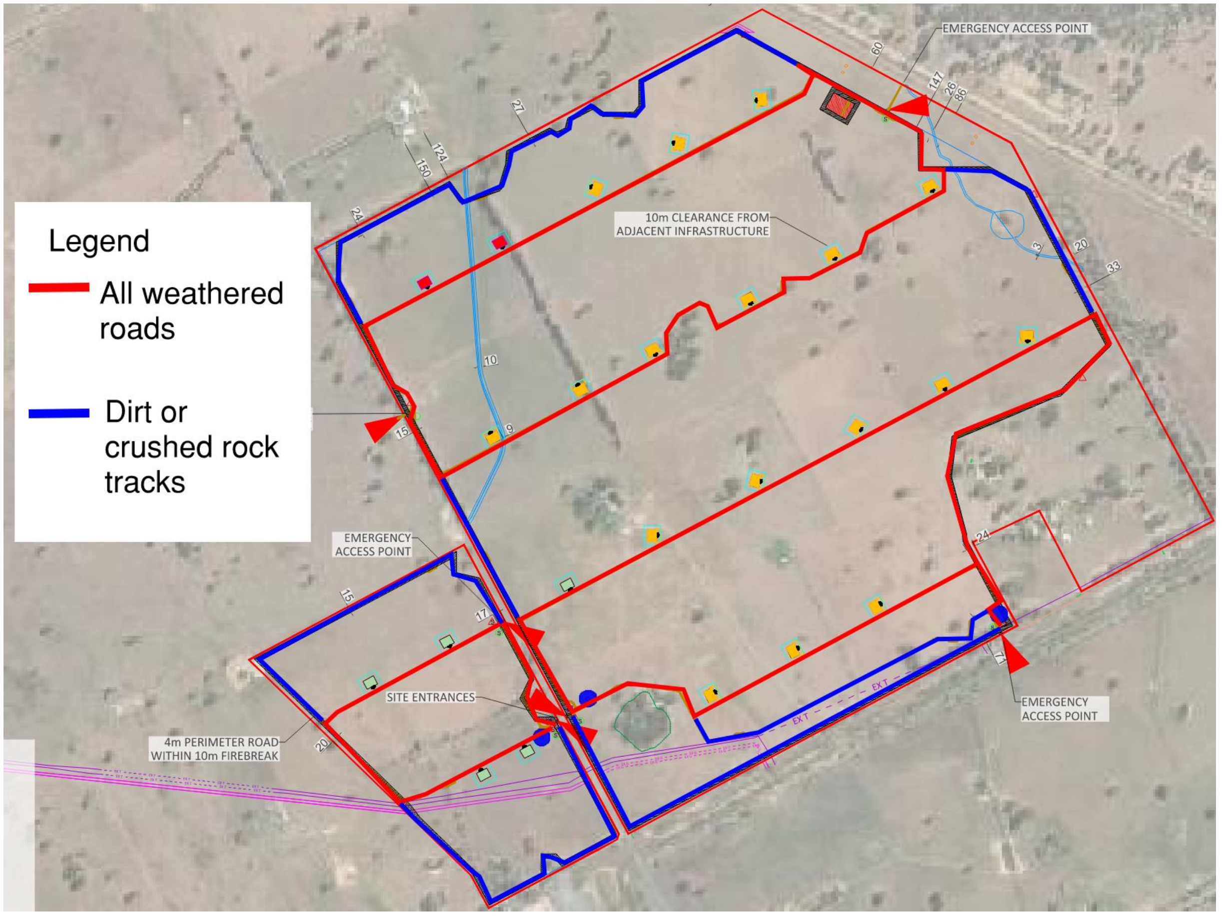

Figure 1: South area, where roads in red are all weathered whilst blue are either dirt or crushed rock tracks

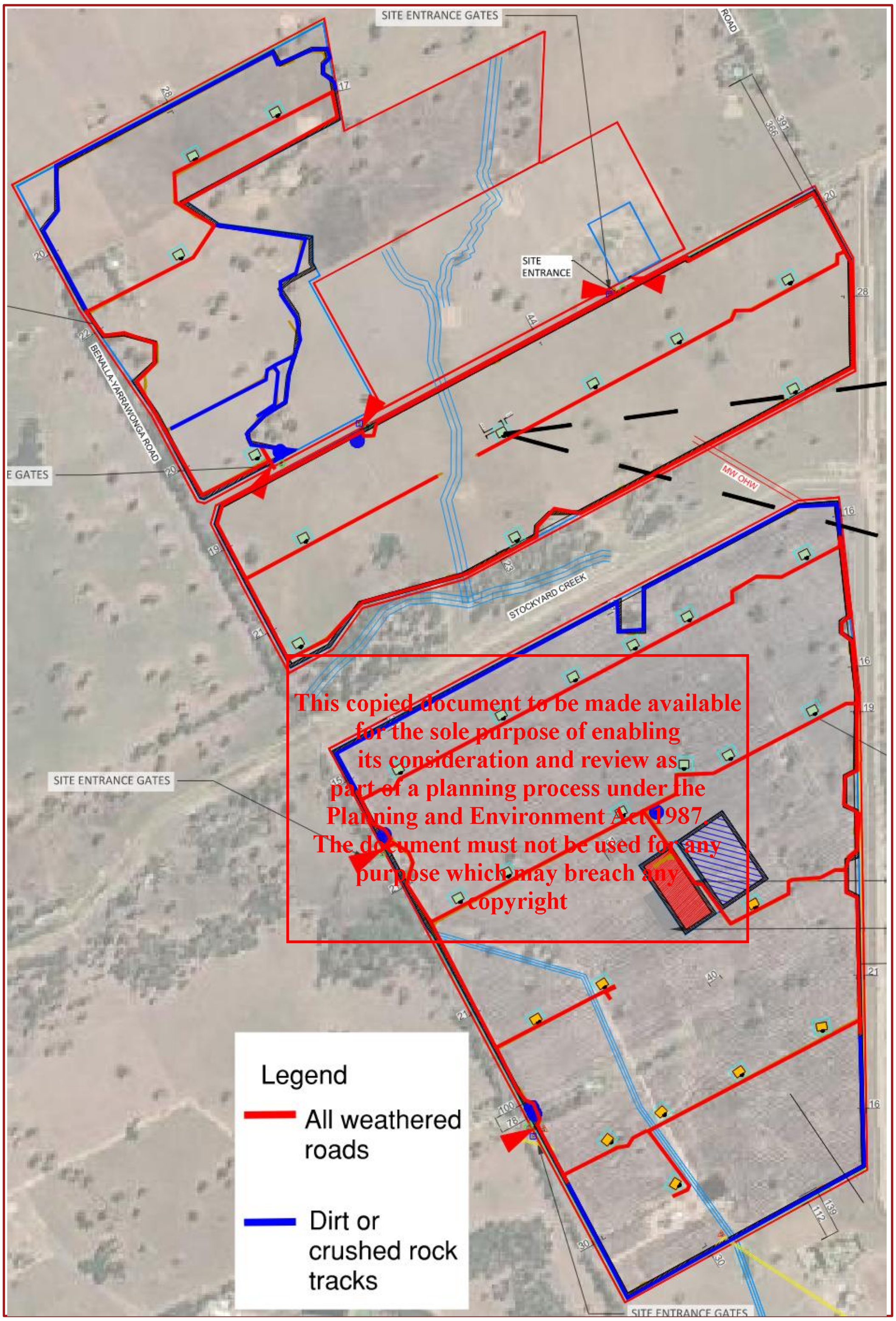

Figure 2: North area, where roads in red are all weathered whilst blue are either dirt or crushed rock tracks

Fire water access

3.3 The site will be supplied by numerous 45 kL fire water tanks. These tanks will not always be located within 120 m of PCS which include BESS units. Instead, each 45 kL fire water tank will cover up to 9 PCS units which include BESS units. Each PCS which includes BESS units will have a feed hydrant that is located within 110 m. Each feed hydrant will have the required associated facilities, such as hard stand and truck connection system. These 45 kL fire water tanks may also be used as the fire water tank at main entrances. The low pressure fire main from each fire water tank may have multiple legs. No low pressure fire main leg is to be greater than 1 km in length.

Fire break

3.4 There will be a fire break around the perimeter of the site. This fire break will be at least 10 m in width and includes the perimeter road, note the arrangements in Figures 1 and 2. There shall be no grass, i.e., dirt, in the fire break during the fire danger periods (plus two weeks before the standard period) and not longer than 300 mm outside of the fire danger period.

3.5 During the fire danger period (including two weeks before) the grass length shall be inspected on a weekly basis whilst for the rest of the year the grass length is to be inspected monthly. The inspection shall be done in each 200 m x 200 m section across the site.

3.6 Outside of the firebreak, once the grass has a height close to 300 mm, then mowing is to be arranged immediately. Instead of mowing grazing may be done with sheep, but goats and cattle will not be used. The grass is to be cut as low as is practical. For tall weeds and the like, they are to be removed by herbicide.

3.7 Outside of the fire danger period high grass could interfere with electrical systems to cause a fire. Therefore, grass under solar arrays is not to exceed a third of the lowest height of the tracking stand at any time. Similarly, vegetation growing near or underneath PCS components are to be appropriately managed before they can interfere with these systems. Outside of these arrangements, grass length is not to ever exceed 300 mm.

3.8 Conducting of the mowing activities and the spraying of herbicide to deal with tall weeds shall be done wearing personnel protective equipment and following safety precautions, as noted within manufacturer's recommendations and the product(s) Safety Data Sheet.

Contaminated containment

3.9 During thermal runaway and fire, BESS units emit solid and liquid by-products which, if mixed with the fire water or rain, generates contaminated water. The BESS units are to be located on crush rock, which can be expected to slow down the spread of these by-products.

3.10 The management of fire water run-off is being reviewed but this may include the separation any liquid / solid by-products from the BESS unit undergoing thermal runaway from cooling water to adjacent units and rainwater catch area. Additionally, measures such as portable bunding and permit environmental emissions will be considered

Yours sincerely,

Prepared by	**Reviewed and approved by**
Raymond	BS Stratton
Dr Ian Raymond	**Blair Stratton**
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Ref: 250617_JV25-00083 West Mokoan Solar Farm_RED FE Minutes of Meeting V2

17 June 2025

ADVERTISED PLAN

Re: **Minutes of meeting**
Project No: **JV25-00083**
Project: **West Mokoan Solar Farm**

Reason for meeting:	Fire Safety Compliance and Infrastructure Planning
Venue:	Microsoft Teams Meeting Online
Date:	20th March 2025.

Present:

Ian Raymond	RED Fire Engineers
Blair Stratton	RED Fire Engineers
Paul Laughlin-Hyde	RED Fire Engineers
Katrina Butler	AECOM
David Nazareth	Lightsource
Jennifer Blythe	CFA
Matthew Allen	CFA
Grace Xu	AECOM
Kristy Zhang	Lightsource

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Minutes:

Item	Discussion	Action
1	Blair provided an overview. Aiming to determine which parts of CFA Guidelines are flexible and which are not, regarding fire water provisions, access etc.	N/A
2	Paul explained the Proposed design includes 6 tanks for West Mokoan and 5 tanks for Kennedys Creek. Fire hydrant provisions:	N/A

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Item	Discussion	Action
	- Positioned along access roads - Low-pressure fire hydrant systems - Aimed at hydrants no more than 120m from each PCS adjoined to a BESS unit - Hardstand at each hydrant point complying with CFA guidelines for emergency services vehicles. This may include sections of dual carriageway within the site, which will be designed to not block traffic flow and within the CFA guidelines - We will provide fire hydrant drawing confirming Fire Water Containment: - BESS fires can release heavy metals which would likely be deposited within the immediate vicinity with water applied. - Proposed exclusion zone around each BESS to avoid fire spread - Relying on the decentralized nature of the site (which means there should only be 1 BESS fire at a time)	
3	Ian discussed the assumed firefighting strategy: - Runoff from burning BESS is contained as no water is applied directly to a BESS unit. - Water on adjacent BESS's is for cooling only. This water would not be contaminated and therefore not require collection/testing/treatment.	No Action
4	Paul noted the all-weather roads from public to PCS, form a loop road with turning circles/passing bays. The dirt tracks elsewhere are more for bushfire response/ maintenance access. Road design will comply with the CFA Guidelines for emergency services vehicles, except for any deviations as agreed by the CFA.	No Action
5	CFA comments: Need further detail to respond to proposal plans Note that solar farms have fires outside of bushfire season and require suitable access to all equipment in potentially wet periods on site. Some access roads to equipment (e.g., solar panels) will need closer access. CFA has concerns with access.	Action: RED to markup and provide: BESS locations, hydrants, water tanks All weather roads extent + distance from solar equipment
6	Application Process & Timing: Can this be made while detail is being prepared? CFA advised yes, this can be done with details provided as part of a secondary consent. CFA expecting at least preliminary Risk Management Plan that clearly states which parts of the CFA Guidelines are to be complied with.	No Action

Minuted by Blair Stratton, blair@redfireengineers.com.au

Preliminary Hazard Analysis

West Mokoan Solar Farm

892 Yarrawonga Development Pty Ltd (Lightsource BP)
Document No. RCE-24035_BP_PHA_Final_12Jun25_Rev(5)
Date 12/06/2025

Preliminary Hazard Analysis

West Mokoan Solar Farm

892 Yarrawonga Development Pty Ltd (Lightsource BP)

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PLAN

892 Yarrawonga Development Pty Ltd (Lightsource BP)
Document No. RCE-24035_BP_PHA_Final_12Jun25_Rev(5)
Date 12/06/2025

Quality Management

Rev	Date	Remarks	Prepared By	Reviewed By
A	21 April 2021	Draft issue for comment	Renton Parker	Steve Sylvester
0	30 April 2021	Issued Final		
1	15 June 2021	Updated drawings		
2	27 March 2024	Updated report for inclusion of AC and DC coupled BESS	Chris Butson	Renton Parker
3	9 May 2024	Updated report based on comments received from Lightsource BP and Aecom		
4	25 June 2024	Finalised layouts added		
5	12June 2025	Updated with current layouts and BESS fire modelling		

Executive Summary

Background

Lightsource BP (Lightsource) has acquired two Solar Photo-Voltaic (PV) projects at Benalla-Yarrawonga Road, Benalla in regional Victoria. These include the West Mokoan Solar Farm and the Kennedys Creek Solar Farm, which Lightsource is intending to deliver as a single development incorporating both sites for the purpose of grid connection and construction, known as the West Mokoan project (the Project). Lightsource is proposing to update the design, including increasing the Battery Energy Storage System (BESS) on the West Mokoan Solar Farm and adding BESS to the Kennedys Creek Solar Farm site. The objective of the Project is to provide support to the existing National Electricity Network by generating energy and providing temporary storage until it is needed and stabilising rapid fluctuation events. Combined, the Project will comprise approximately 380 MW DC of installed PV panels with approximately up to 300 MW BESS along with associated infrastructure. Associated infrastructure would include internal access tracks, operational and maintenance (O&M) facilities, civil works and onsite electrical infrastructure (substation) required to connect to the existing 220 kV transmission line.

A Preliminary Hazards Assessment (PHA) was completed under the previous site ownership, however, due to proposed changes, Lightsource BP has engaged Riskcon Engineering Pty Ltd (Riskcon) to update the PHA for the West Mokoan site in addition to a review of the Fire Protection Quantity (FPQ) requirements as required by the Victorian Dangerous Goods Regulation (VDGR) 2022 (Ref. [1]). This document represents the updated PHA for the West Mokoan Solar Farm site located at Benalla-Yarrawanga Rd, Benalla and does not include any other sites owned or operated by Lightsource.

Conclusions

A hazard identification table was developed for the West Mokoan Solar Farm PV & BESS project to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The consequence analysis showed that a transformer explosion due to surge protection failure would have potential to impact off site. As such, a frequency analysis was conducted on this incident. The frequency analysis estimated the site total fatality risk criteria would be zero 8.9×10^{-7}/year which is within the acceptable risk criteria indicated in HIPAP No.4 (Ref. [2]) of 1×10^{-6}/year.

In addition, incidents exceeding 23 kW/m^2 were reviewed which indicated that, with the recommendation measures implemented, the contours from such incidents would not impact over the site boundary nor create incident propagation within the site and would be below the acceptable criteria.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the facility would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

Recommendations

- Notwithstanding the conclusions drawn, the following recommendations have been made and should be undertaken to cover the battery and inverter equipment as well as common hazards for a mechanical site prior to the commencement of operations at the Solar PV and BESS project to the extent dangerous goods exceed any thresholds:
- BESS must be tested in accordance with UL9540A.
- Testing to demonstrate clearances required to prevent propagation of fires between separated units.
- BESS to be installed in accordance with manufacturer and UL9540A report recommended clearances based on testing.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the facility area whilst meeting the recommended clearances.
- UL testing information shall be made available to the certifying authority. It is noted that a confidentiality agreement may be required.
- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.
- Separation distances between BESS and PCUs should be at least 3 m or in accordance with relevant standards and guidelines, whichever is greater.
- A submission to CFA shall be made for written advice in accordance with the VDGR.
- A Dangerous Goods (DG) risk assessment shall be prepared for the site.

- A DG register shall be prepared for the site.
- A site manifest shall be prepared at the site in accordance with Schedule 3 of the Victorian Dangerous Goods Regulation (VDGR).
- The site shall notify the Regulator (i.e. WorkSafe Victoria) of the presence of DGs.
- A site layout shall be prepared for the site in accordance with Schedule 3 of the VDGR.
- A placard schedule shall be prepared for the site to ensure the correct placards are installed.
- An Emergency Response Plan (ERP) shall be prepared for the site and submitted to the Country Fire Authority (CFA)
- An Emergency Services Information Booklet (ESIB) shall be prepared for the site and submitted to the CFA.
- The substation transformer bunds shall be designed according to the requirements detailed in AS 2067:2017(Ref. [3]), and shall have a volume of 110% of the total volume of the mineral oil within the Transformer to account for any safety risks from a potential fire and or explosion.
- Ensure all site transformers are suitably set back from the site boundary to prevent offsite propagation risk.

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Abbreviations

Abbreviation	Description
ADG	Australian Dangerous Goods Code
AS	Australian Standard
CBD	Central Business District
DGs	Dangerous Goods

ERP	Emergency Response Plan
ESIB	Emergency Services Information Booklet
FCAS	Frequency Control Ancillary Services
FPQ	Fire Protection Quantity
HIPAP	Hazardous Industry Planning Advisory Paper
O&M	Operations & Maintenance
PHA	Preliminary Hazard Analysis
Pmpy	Per million per year
PV	Photovoltaic
SEP	Surface Emissive Power
SEPP	State Environmental Planning Policy
SSC	Spread Sheet Calculator
VDGR	Victorian Dangerous Goods Regulation
VF	View Factor

1.0 Introduction

1.1 Background

Lightsource BP (Lightsource) has acquired two Solar Photo-Voltaic (PV) projects at Benalla-Yarrawonga Road, Benalla in regional Victoria. These include the West Mokoan Solar Farm and the Kennedys Creek Solar Farm, which Lightsource is intending to deliver as a single development incorporating both sites for the purpose of grid connection and construction, known as the West Mokoan project (the Project). Lightsource is proposing to update the design, including increasing the Battery Energy Storage System (BESS) on the West Mokoan Solar Farm and adding BESS to the Kennedys Creek Solar Farm site. The objective of the Project is to provide support to the existing National Electricity Network by generating energy and providing temporary storage until it is needed and stabilising rapid fluctuation events. Combined, the Project will comprise approximately 380 MW DC of installed PV panels with approximately up to 300 MW BESS along with associated infrastructure. Associated infrastructure would include internal access tracks, operational and maintenance (O&M) facilities, civil works and onsite electrical infrastructure (substation) required to connect to the existing 220 kV transmission line.

A Preliminary Hazards Assessment (PHA) was completed under the previous site ownership, however, due to proposed changes, Lightsource BP has engaged Riskcon Engineering Pty Ltd (Riskcon) to update the PHA for the West Mokoan site in addition to a review of the Fire Protection Quantity (FPQ) requirements as required by the Victorian Dangerous Goods Regulation (VDGR) 2022 (Ref. [1]). This document represents the updated PHA for the West Mokoan Solar Farm site located at Benalla-Yarrawonga Rd, Benalla and does not include any other sites owned or operated by Lightsource.

1.2 Objectives

The key objectives of this PHA are to:

- Complete the PHA according to the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis (Ref. [4]);
- Assess the PHA results using the criteria in HIPAP No. 4 – Risk Criteria for Land Use Planning (Ref. [2]); and
- Demonstrate compliance of the site with the relevant codes, standards and regulations (i.e. Planning and Environment Regulation, OHS Regulation, 2017 Ref. [5]).
- Conduct a review of the Fire Protection Quantity (FPQ) under the Victorian Dangerous Goods (Storage and Handling) Regulations 2022 (VDGR, Ref. [1]).

1.3 Scope of Services

The scope of work is to complete a PHA study for the West Mokoan Solar PV and BESS project located at Benalla-Yarrawonga Road, Benalla to assist in evaluating possible dangerous goods and demonstrating the project is safe to operate and compliant with the relevant codes, standards, and regulations. The PHA study aims to support a planning permit application for the West Mokoan Solar Farm and Kennedys Creek Solar Farm (adjacent acquired project) permits to be combined and potential requirement for the application to be referred to WorkSafe in accordance with Clause 66.02 of the Benalla Planning Scheme. The scope does not include any other assessments which may be required as a result of this study nor any other Lightsource BP facilities.

2.0 Methodology

2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach (Ref. [6]), although published by the NSW Department of Planning, Industry and Environment, has been used as the basis for the study to determine the level of risk assessment required. The selection of this framework is due to the absence of a suitable Victorian guideline or policy. The approach considered the development in context of its location, the quantity and type (i.e. hazardous nature) of Dangerous Goods stored and used, and the facility's technical and safety management control. The Multi-Level Risk Assessment Guidelines are intended to assist industry, consultants and the consent authorities to carry out and evaluate risk assessments at an appropriate level for the site being studied.

There are three levels of risk assessment set out in Multi-Level Risk Assessment which may be appropriate for a PHA, as detailed in **Table 2-1**.

Table 2-1: Level of Assessment PHA

Level	Type of Analysis	Appropriate If:
1	Qualitative	No major off-site consequences and societal risk is negligible
2	Partially Quantitative	Off-site consequences but with low frequency of occurrence
3	Quantitative	Where 1 and 2 are exceeded

The Multi-Level Risk Assessment approach is schematically presented in **Figure 2-1**.

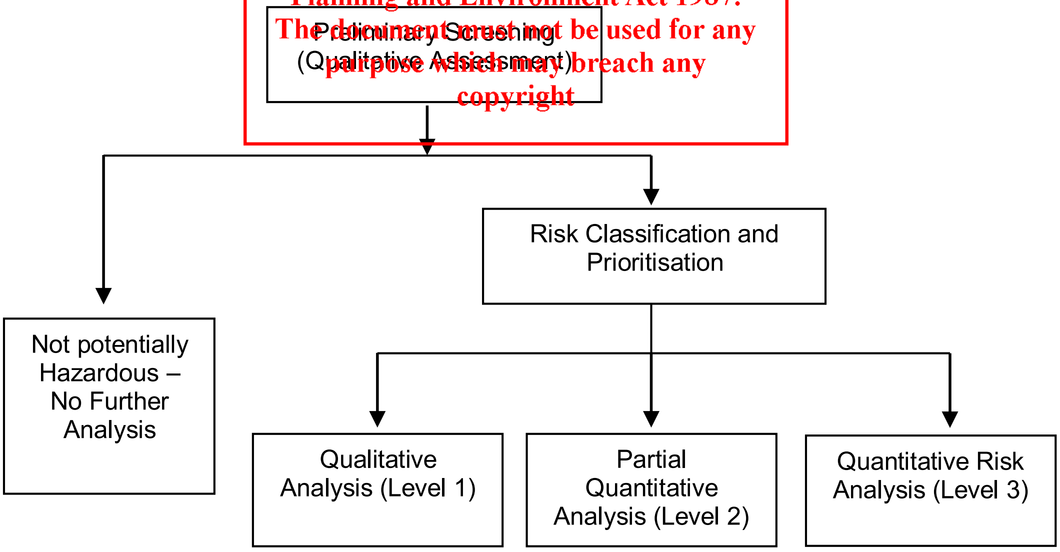


Figure 2-1: The Multi-Level Risk Assessment Approach

Based on the type of DGs to be used and handled at the proposed project, a **Level 2 Assessment** was selected for the Site. This approach provides a qualitative assessment of those DGs of lesser quantities and hazard, and a quantitative approach for the more hazardous materials to be used on-site. This approach is commensurate with the methodologies recommended in "Applying SEPP 33's" Multi Level Risk Assessment approach (DPIE, 2011). The selection of this framework is due to the absence of a suitable Victorian guideline or policy.

2.2 Risk Assessment Study Approach

The methodology used for the PHA is as follows:

Hazard Analysis – A detailed hazard identification was conducted for the site facilities and operations. Where an incident was identified to have a potential off-site impact, it was included in the recorded hazard identification word diagram (**Appendix A**). The hazard identification word diagram lists incident type, causes, consequences and safeguards. This was performed using the word diagram format recommended in HIPAP No. 6 (Ref. [4]).

Each postulated hazardous incident was assessed qualitatively in light of proposed safeguards (technical and management controls). Where a potential offsite impact was identified, the incident was carried into the main report for further analysis. Where the qualitative review in the main report determined that the safeguards were adequate to control the hazard, or that the consequence would obviously have no offsite impact, no further analysis was performed. **Section 3.1** of this report provides details of values used to assist in selecting incidents required to be carried forward for further analysis.

Consequence Analysis – For those incidents qualitatively identified in the hazard analysis to have a potential offsite impact, a detailed consequence analysis was conducted. The analysis modelled the various postulated hazardous incidents and determined impact distances from the incident source. The results were compared to the consequence criteria listed in HIPAP No. 4 (Ref. [2]). The criteria selected for screening incidents is discussed in **Section 3.1**.

Where an incident was identified to result in an offsite impact, it was carried forward for frequency analysis. Where an incident was identified to not have an offsite impact, and a simple solution was evident (i.e. move the proposed equipment further away from the boundary), the solution was recommended, and no further analysis was performed.

Frequency Analysis – In the event a simple solution for managing consequence impacts was not evident, each incident identified to have potential offsite impact was subjected to a frequency analysis. The analysis considered the initiating event and probability of failure of the safeguards (both hardware and software). The results of the frequency analysis were then carried forward to the risk assessment and reduction stage for combination with the consequence analysis results.

Risk Assessment and Reduction – Where incidents were identified to impact offsite and where a consequence and frequency analysis was conducted, the consequence and frequency analysis for each incident were combined to determine the risk and then compared to the risk criteria published in HIPAP No. 4 (Ref. [2]). Where the criteria were exceeded, a review of the major risk contributors was performed, and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

Reporting – On completion of the study, a draft report was developed for review and comment by Lightsource BP. A final report was then developed, incorporating the comments received by Lightsource BP for submission to the regulatory authority.

3.0 Site Description

3.1 Site Location

The site is located at Benalla-Yarrawonga Road, Benalla which is approximately 230 km north of the Melbourne Central Business District (CBD). **Figure 3-1** shows the regional location of the site in relation to the Melbourne CBD.

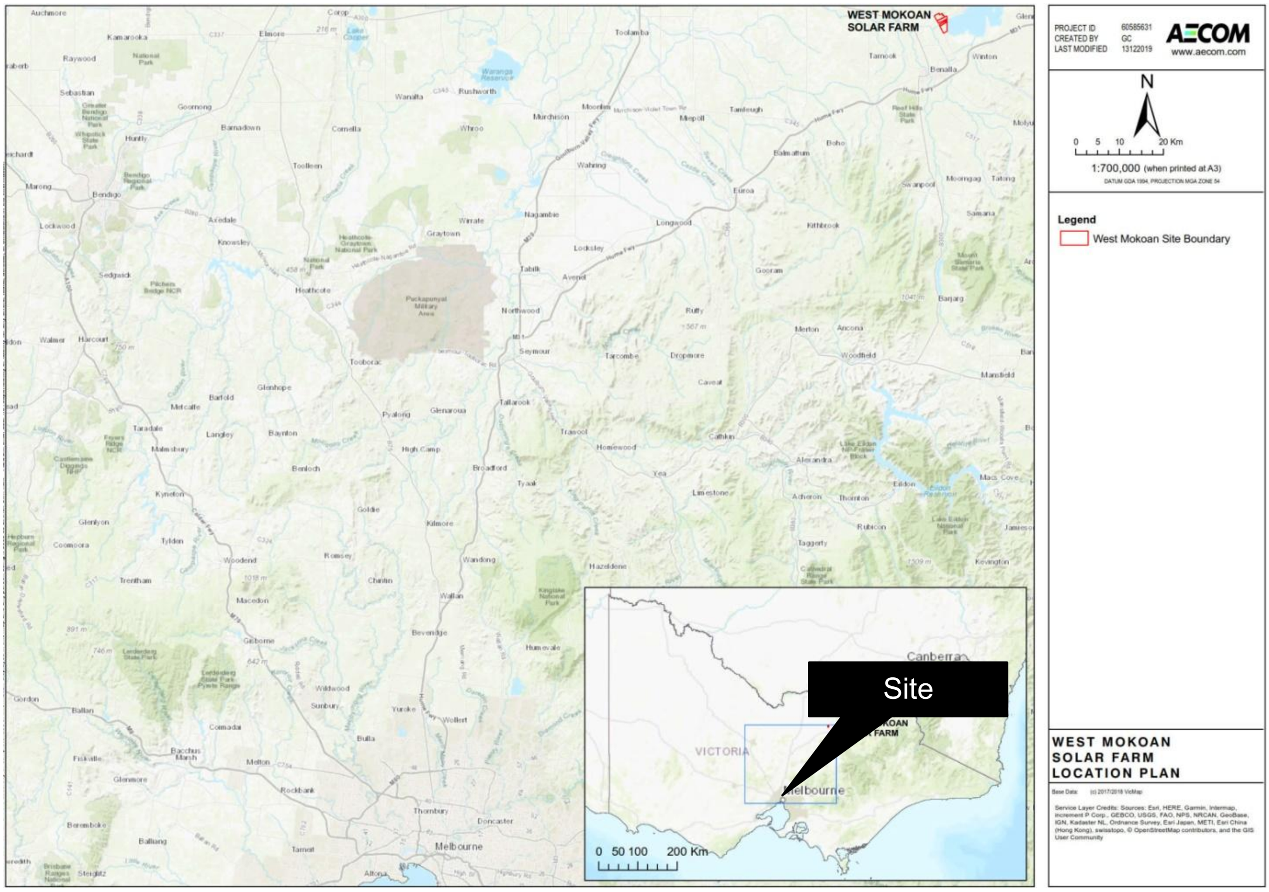


Figure 3-1: Site Location

3.2 Adjacent Land Uses

The land is located in a regional / rural area surrounded by the following land uses, which are adjacent to the site as shown in **Figure 3-2** are:

- North – Farmland (rural)
- South – Farmland (rural)
- East – Public use
- West – Defence munitions site (Thales)

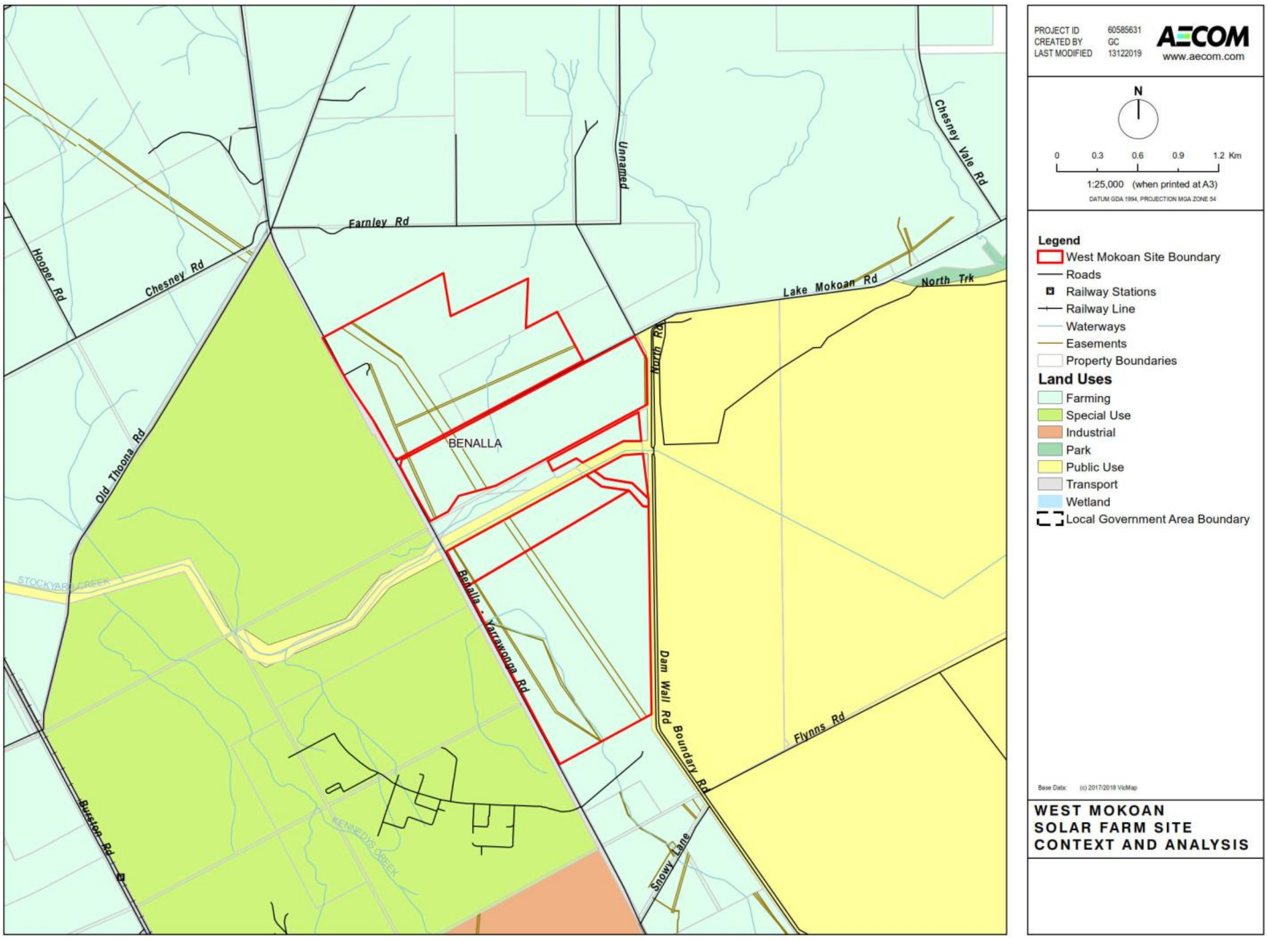


Figure 3-2: Surrounding Land Uses

3.3 Sensitive Receptors

The nearest residential locations are as follows and shown in **Figure 3-3**:

- 18 Farnley Road, the north of the site, approximately 680 metres from the site boundary.
- 286 Farnley Road, to the north of the site, approximately 350 metres from the site boundary.
- 623 Benalla-Yarrawonga Road, to the west of the site, approximately 70 metres from the site boundary.
- 524 Benalla-Yarrawonga Road, to the south of the site, approximately 135 metres from the site boundary.

The receptor at 81 Lake Mokoan Rd, was previously the closest receptor, however this property has been acquired as part of the Project and shall not be treated as a sensitive receptor in this subsequent assessment.

Figure 3-3: Sensitive Receptors

3.4 Detailed Description

The purpose of the facility is to provide energy to and support to the National Electricity Network by generating electricity from the approximately 220 MWp installed capacity of PV panels and 120 MW BESS to arbitrage electricity demand fluctuations by storing electricity during off peak periods or when there is surplus supply and discharging the stored electricity when demand is highest (i.e. generator trips / shutdowns) or in peak periods. This is achievable due to the high response times achieved through lithium-ion battery storage which can fill peak demands due to the quick dispatchability of battery storage.

The site will have capacity to store approximately 120 megawatts (MW) of energy with a duration of 2-4 hours and conceptually comprises the following key components:

- Approximately 349,590 solar PV panels on a single-axis tracking system mounted on aluminium or steel piles with an installed capacity of up to 175 MW Alternating Current (AC) (220 DC Capacity).
- Approximately 32 Power Conversion Units (PCU – two inverters per PCU).
- Direct Current (DC) and AC cabling for electrical reticulation.
- A designated substation.
- Operations and Maintenance (O&M) facility area, control building, office and amenities.
- Individual BESS units of up to 180MW / 370-720 MWh capacity.

- Internal all-weather access tracks and laydown areas.
- Creation of a new access to Benalla-Yarrawonga Road and Lake Mokoan Road.
- Landscaping and revegetation.
- Security fencing, CCTV and Infra-Red lighting.
- Business identification signage including three signs totalling 3 sqm in display area (1 sqm each) located at site entrances along Benalla-Yarrawonga Road and Lake Mokoan Road.
- Realignment of easements.

3.4.1 PCUs

Power Conversion Units, or PCUs, house transformers and inverters which will be sited between the PV Module Arrays, along the solar farm's internal access tracks. There will be approximately 32 PCUs (64 double inverters) across the site which typically comprise:

- PCU transformer
- Inverters
- DC/DC converter

The PCUs convert the Direct Current (DC) to Alternating Current (AC), while the transformers increase the voltage from Low Voltage to a Medium or High Voltage, as required for the electricity grid connection. PCUs are a compact containerised product, with each unit measuring approximately 2.5 metres wide by 2.9 metres high, with a depth of 12.2 metres (equivalent to a 40-foot shipping container for the double inverter units). Due to potential flooding over parts of the subject site, some of the PCUs may be elevated 300 mm above the applicable flood level in accordance with GBCMA requirements (refer to Section 7.2). The exact height of these PCUs will be subject to detailed design. **Figure 3-4** provides an example of the PCUs to be installed on site.

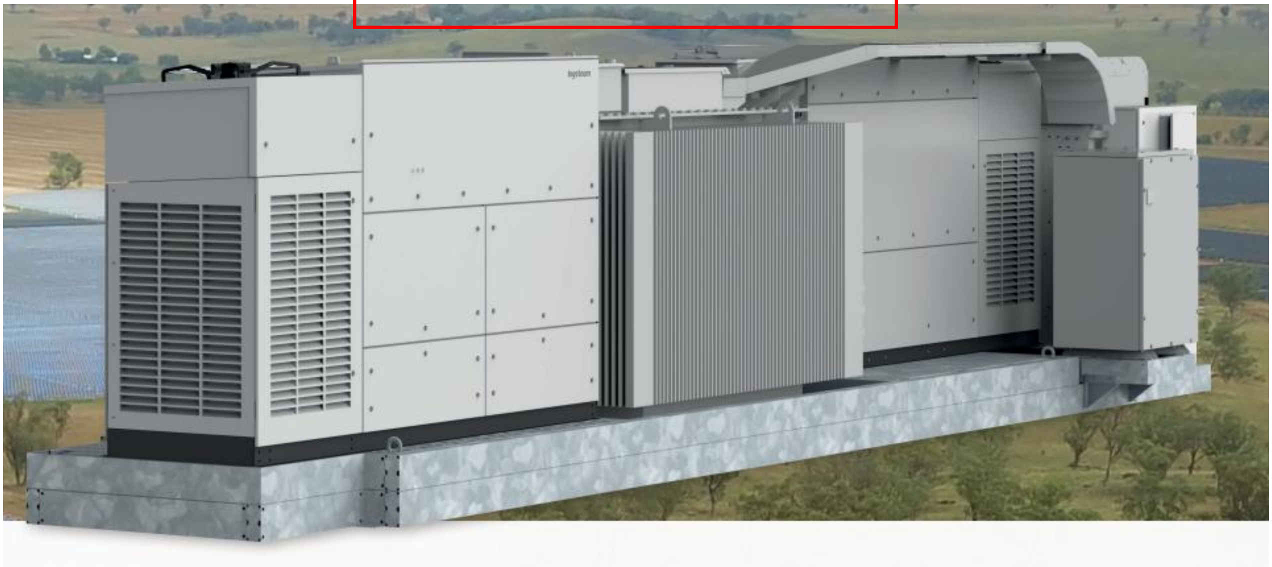


Figure 3-4: Typical Inverter

3.4.2 Battery Energy Storage System and Inverters

The BESS is arrangement to be used is a Direct Current (DC) coupled BESS. DC-coupled BESS is a linear system which includes BESS containers distributed throughout the solar farm to store energy from arrays of PV cells and distribute to the network. Under this arrangement, the BESS containers are typically co-located with the inverters, serving the same array of PV cells. The facility will consist of 32 BESS units with major components of the including Li-ion batteries, inverters, transformers, heating ventilation air conditioning and fire protection. A typical BESS configuration is shown in **Figure 3-5**.

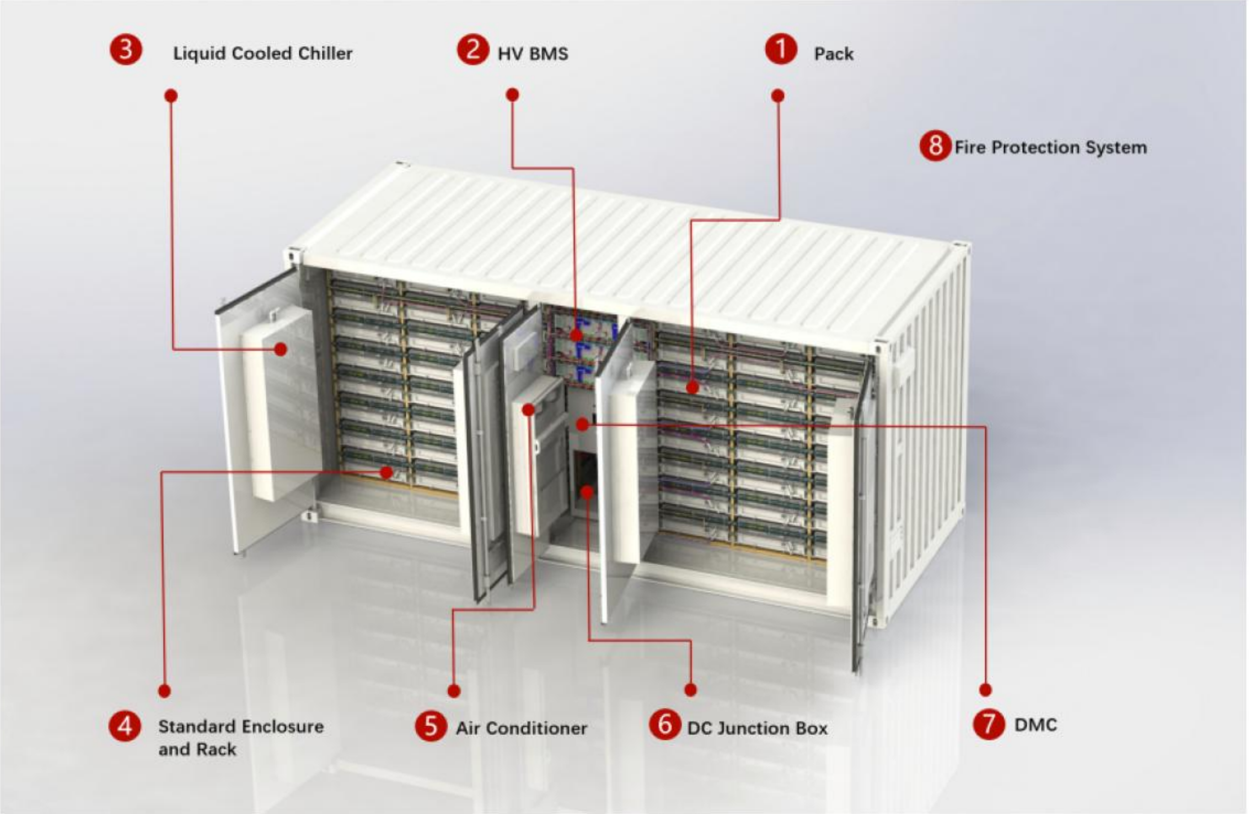


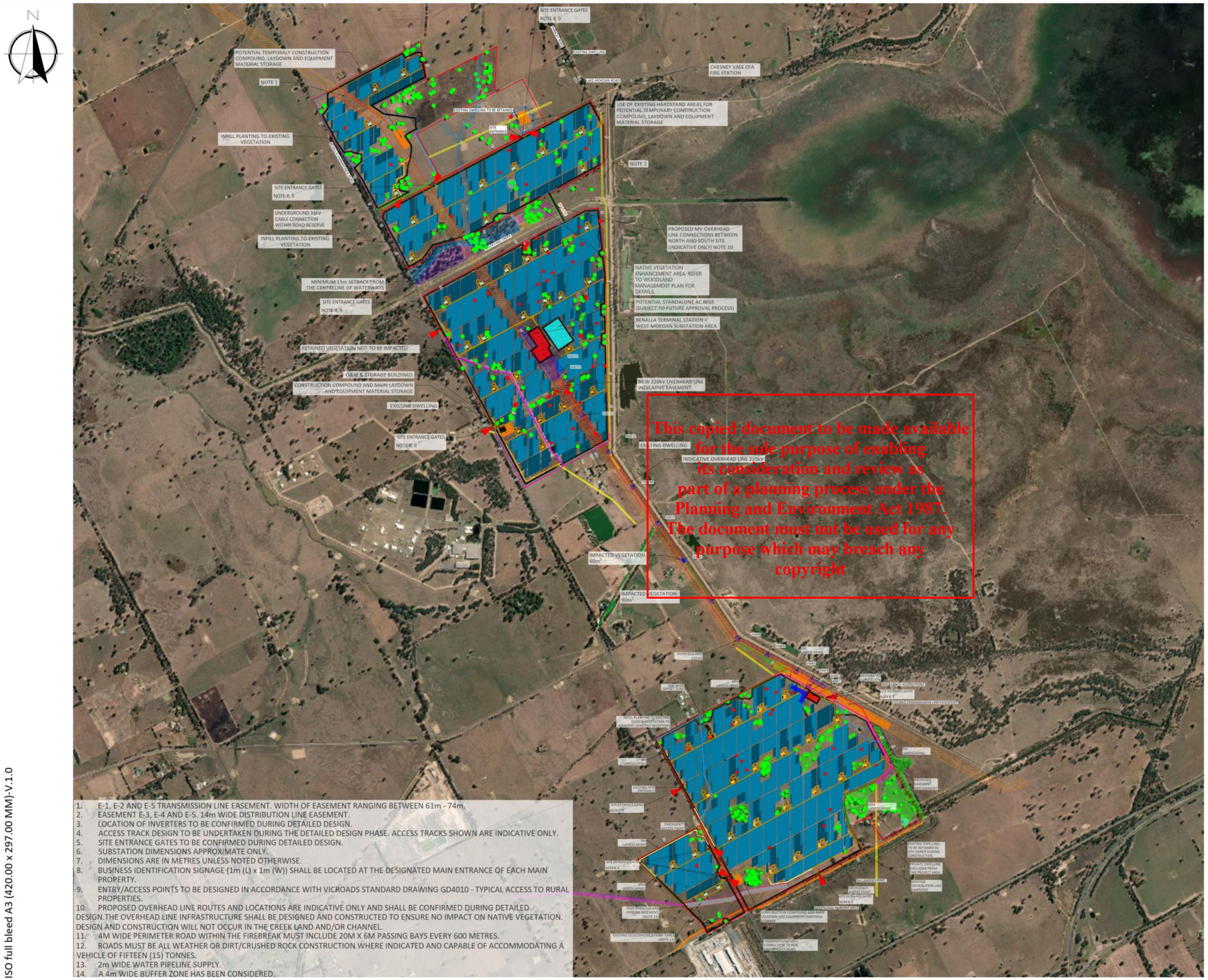
Figure 3-5: Typical BESS unit

The BESS will enable the solar farm to be a flexible energy generation source, providing energy when it is required the most. The BESS converts electrical energy into chemical energy and stores the energy internally. It may also contribute towards network security Frequency Control Ancillary Services (FCAS) in the Region.

Figure 3-6 provides a layout of the site with the proposed inverter and BESS locations. An allowance for a standalone BESS in the centre of site has also been indicated below.

ADVERTISED
PLAN

West Mokoan Solar Farm_LP3-BDL_14 (KC_BDL_04) Planning



1. E-1, E-2 AND E-5 TRANSMISSION LINE EASEMENT. WIDTH OF EASEMENT RANGING BETWEEN 61m - 74m.
2. EASEMENT E-3, E-4 AND E-5. 14m WIDE DISTRIBUTION LINE EASEMENT.
3. LOCATION OF INVERTERS TO BE CONFIRMED DURING DETAILED DESIGN.
4. ACCESS TRACK DESIGN TO BE UNDERTAKEN DURING THE DETAILED DESIGN PHASE. ACCESS TRACKS SHOWN ARE INDICATIVE ONLY.
5. SITE ENTRANCE GATES TO BE CONFIRMED DURING DETAILED DESIGN.
6. SUBSTATION DIMENSIONS APPROXIMATE ONLY.
7. DIMENSIONS ARE IN METRES UNLESS NOTED OTHERWISE.
8. BUSINESS IDENTIFICATION SIGNAGE (1m (L) x 1m (W)) SHALL BE LOCATED AT THE DESIGNATED MAIN ENTRANCE OF EACH MAIN PROPERTY.
9. ENTRY/ACCESS POINTS TO BE DESIGNED IN ACCORDANCE WITH VICROADS STANDARD DRAWING GD4010 - TYPICAL ACCESS TO RURAL PROPERTIES.
10. PROPOSED OVERHEAD LINE ROUTES AND LOCATIONS ARE INDICATIVE ONLY AND SHALL BE CONFIRMED DURING DETAILED DESIGN.THE OVERHEAD LINE INFRASTRUCTURE SHALL BE DESIGNED AND CONSTRUCTED TO ENSURE NO IMPACT ON NATIVE VEGETATION. DESIGN AND CONSTRUCTION WILL NOT OCCUR IN THE CREEK LAND AND/OR CHANNEL.
11. 4M WIDE PERIMETER ROAD WITHIN THE FIREBREAK MUST INCLUDE 20M X 6M PASSING BAYS EVERY 600 METRES.
12. ROADS MUST BE ALL WEATHER OR DIRT/CRUSHED ROCK CONSTRUCTION WHERE INDICATED AND CAPABLE OF ACCOMMODATING A VEHICLE OF FIFTEEN (15) TONNES.
13. 2m WIDE WATER PIPELINE SUPPLY.
14. A 4m WIDE BUFFER ZONE HAS BEEN CONSIDERED.
15. 35m WIDE GAS PIPELINE EASEMENT.

ISO full bleed A3 (420.00 x 297.00 MM)-V.1.0

PV SYSTEM SPECIFICATIONS	
Capacity - DC	375.90 MW_P
Export Capacity - AC	300 MW_{AC}
DC/AC Ratio	1.253
Modules	(616230) 610 W Bifacial
Mods. per string	30
Pitch	5.20 m
GCR	47.40 %
Mounting structure	(7663) NxT Mono-Line SAT
• Full (3 Strings)	5215
• Partial (2 Strings)	2448
• Half	
Inverters	(112) Central Inverter 3575 KVA
• Nominal Power	3575 KVA
Access roads	49545 m
Fenced area	(6273210 m^2) 1550 Ha
• Perimeter	23935 m

Revisions:

Rev	Date	Comments	Dwn	Chkd
09	12.11.24	Layout update (29mod. per string & 620W)	DC	
08	15.07.24	Easement and legend update	EPG	
14	16.05.25	Updated Layout	DC	
13	16.05.25	Update Layout	DC	
12	03.04.24	Substation details added	AG	
11	24.03.25	Updated Layout with 28 Strings	DC	
10	27.11.24	Updated layout	JI	
00	27.11.23	Layout Updated	DC	

DRAWN	CHECKED	APPROVED	DATE
DC			27.11.2023

PROJECT NAME & ADDRESS:
Location: Benalla, Victoria
Australia

NOTES:
- 610 Wp Bifacial modules
-
-
-

Paper Size:	Scale:	Sheet:
A3	1:30	1

CAPACITY:
616230 Modules 375.90 MWp

DRAWING TITLE:
AUS_West Mokoan Solar Farm_LP3-BDL_14 (KC_BDL_04) Planning
Hybrid Project Layout

DRAWING NUMBER:	STATUS:
LP3-BDL	Preliminary

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Figure 3-6: Proposed Layout of West Mokoan (North) and Kennedys Creek (South)

3.5 Quantities of Dangerous Goods Stored and Handled

The DGs stored at the site are for various purposes and primarily contained within other assets (i.e. lithium batteries in BESS units and transformer oils in transformers). The classes and quantities to be approved on the site are summarised **Table 3-1**. The locations of the BESS and transformers are indicated on the drawing provided in **Figure 3-6**.

Table 3-1: Maximum Classes and Quantities of Dangerous Goods Stored

Class	Description	Quantity
2.2	R-134a* / R-410a*	1,000 L*
9	Lithium Batteries	900 T
C1	Transformer oils	196,100 L
C1	Diesel	5,000 L

*Estimated commodity and quantity based upon similar project.

4.0 Fire Protection Quantity Assessment

4.1 Introduction

The Victorian Dangerous Goods (Storage and Handling) Regulations (VDGR, Ref. [1]) covers the storage and handling of materials classified as Dangerous Goods (DGs). This Regulation provides an assessment of the required documentation to be prepared for a site based upon a threshold based approach for each class of DG stored at a site. As shown in **Section 3.5** a range of products will be stored as part of site operations which are classified as DGs; hence, the site is subject to the VDGR. The main purpose of the assessment is to determine whether additional overview is required from a regulatory perspective in terms of WorkSafe Victoria and the Country Fire Authority (CFA).. This is determined by the threshold “Fire Protection Quantity” (FPQ) within the VDGR. Provided in the following section is an assessment of the FPQ and the associated implications for the site approval process.

4.2 Assessment

As noted, the assessment is based upon thresholds provided in the VDGR. The applicable thresholds for the site have been extracted from the Regulation to assess where the site will sit within the regulatory framework for DGs. The results of the assessment are shown in **Table 4-1**.

Table 4-1: Fire Protection Quantity Assessment

Class	Description	Quantity	Placard	Manifest	FPQ	Determination
2.2	R-134a / R-410a	1,000 L	5,000 L	10,000 L	20,000 L	n/a
9	Lithium Batteries	900 T	5 T	10 T	20 T	FPQ
C1	Transformer oils	196,100 L	10,000 L	100,000 L	100,000 L	FPQ
C1	Diesel	5,000 L	10,000 L	100,000 L	100,000 L	n/a

Based upon a review of **Table 4-1** the site would be classified as a FPQ site.

4.3 Implications

The assessment determined that the site would be classified as a FPQ site which requires referral to CFA. Typically, this would require a design assessment of the facility to demonstrate compliance with an applicable DG design standard. However, the site is being triggered by the batteries which are classified as a Class 9 DG which technically only exists during transport and not storage. Nonetheless, the VDGR include this as an assessable quantity; hence, a submission to the CFA for written advice is required under the Regulation.

The design standard for Class 9 batteries, AS/NZS 4681:2000 (Ref. [7]) is extremely dated and only covers DGs stored in buildings as the risks for external storage are relatively minor. Furthermore, the standard was based upon battery designs from the year 2000 which did not include the protection incorporated in modern batteries (i.e. temperature and voltage monitoring, cooling, etc.) and were based upon chemistries more likely to result in thermal decomposition (i.e. lithium metal). Therefore, there is a lack of applicable design guidance available for such battery installation (i.e. West Mokoan BESS) from a DG perspective.

The risks are mitigated via the design of the battery modules themselves and the availability of fire protection at the site. As per the CFA Design Guidelines and Model Requirements For Renewable Energy Facilities v4.2 (Ref. [8]), the facility is also expected to have some abilities (e.g. presence of hydrants, water tanks) to fight a fire at the site should one occur. Discussion with CFA based upon the remoteness of the project site has been initiated and CFA will be actively involved in the review of documentation as the project progresses through design phases.

Additional implications include those relating to the documentation which is required to be prepared by the VDGR. Documentation required for a site exceeding manifest levels is as follows:

- Risk assessment
- Register
- Manifest
- Notification to the Regulator
- Emergency Response Plan
- Emergency Services Information Booklet
- Placard schedule
- Site layout

Each of these items have been discussed further in the following subsections in terms of what they entail and whether they will be submitted to a Regulator (i.e. WorkSafe Victoria) for approval prior to occupation of the site for the proposed use.

4.3.1 Risk Assessment

A risk assessment is required by Clause 27 of the VDGR which requires the risks associated with an activity or storage to be controlled. The DG risk assessment is the documentation prepared to demonstrate the risks have been assessed with the required controls incorporated into the site design / operation to an acceptable level as required by the Regulation. This document is not submitted to a Regulator, however it is a requirement of the operator to demonstrate they have fulfilled their obligations under the VDGR. This document is likely to only be reviewed by a Regulator if they attend the site as part of an inspection or due to an incident at the site requiring their involvement.

4.3.2 Register

A register is required under Clause 58 of the VDGR and is a summary of the DGs stored on site along with the Safety Data Sheets (SDS) for the products stored. The register also links into the findings of the risk assessment closing the loop from the summary document to the risk assessment. The register is not submitted to a Regulator for review but is required to fulfil the operators' obligations under the VDGR.

4.3.3 Manifest

The manifest is required under Clause 44 of the VDGR. The document is another summary document which is submitted along with the notification to the Regulator. The purpose of the manifest is to provide information about the types and quantities of DGs stored to CFA should an incident occur at the site.

While the document is submitted to the Regulator it is typically for information purposes and does not require approval by them.

4.3.4 Notification to the Regulator

The notification is required by Clause 64 of the VDGR and is the driving link between the manifest and the Regulator. It is a form which details the specifics of the DG depots at a site and how they interlink with the manifest. The notification is used to form a database of sites which store DGs exceeding the manifest level. While the notification is not typically reviewed, the operator will receive an acknowledgement from the Regulator which they use to demonstrate they have notified the Regulator as required by the VDGR.

4.3.5 Emergency Response Plan

The Emergency Response Plan (ERP) is required by Clause 53. The purpose is to outline the potential emergencies (i.e. fire, bush fire, natural disaster, etc.) and the associated mitigation and response measures. The document is site specific and is submitted to the CFA for review and approval.

4.3.6 Emergency Services Information Booklet

The Emergency Services Information Booklet (ESIB) is an accompanying document to the ERP and is essentially a summary document of the ERP. This is submitted to the CFA for review and approval.

4.3.7 Placard Schedule

The site is required to be placarded under Clause 47 and the placard schedule is a document which details where the placards are required to achieve compliance with the VDGR. The placard schedule is not submitted to the Regulator but is used to ensure the correct placards have been installed.

4.3.8 Site Layout

The site layout is required by Clause 8 of Schedule 3 of the VDGR and accompanies both the manifest and the notification. The purpose of the layout is to show where the DGs are stored around the site along with other points of interest to CFA including; power isolation points, valve isolation points, drains, etc. to assist them in coordinating a response (i.e. isolate power prior to attacking a fire) or prevent contaminated water from being discharged from the site.

4.3.9 General

The documentation listed above is not required prior to construction but would be required to be in place 2 weeks prior to occupation.

5.0 Hazard Identification

5.1 Introduction

A hazard identification table has been developed and is presented at **Appendix A**. Those hazards identified to have a potential fire or explosion impact are assessed in the following sections of this document.

5.2 Properties of Dangerous Goods

The type of DGs and quantities stored and used at the site has been described in **Section 3**. **Table 5-1** provides a description of the DGs to be stored and handled at the site, including the Class and the hazardous material properties of the DG Class.

Table 5-1: Properties* of the Dangerous Goods and Materials Stored at the Site

Class	Hazardous Properties
2.2 – Non-Flammable, Non-Toxic Gas	Non-flammable, non-toxic gases are those which do not pose a flammable or toxicity risk and are therefore relatively benign. However, such gases may pose asphyxiation risks as they can exclude oxygen at the point of release creating an oxygen deficient environment.
9 – Miscellaneous DGs	Class 9 substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not covered by other classes. Releases to the environment may cause damage to sensitive receptors within the environment. It is noted that the Class 9s stored within this project are lithium-ion batteries which may undergo thermal runaway (i.e. escalating reaction resulting in heat which ultimately leads to failure of the battery and a fire).
Combustible Liquids	Combustible liquids are typically long chain hydrocarbons with flash points exceeding 60.5°C. Combustible liquids are difficult to ignite as the temperature of the liquid must be heated to above the flash point such that vapours are generated which can then ignite. This process requires either sustained heating or a high-energy ignition source.

* The Australian Code for the Transport of Dangerous Goods by Road and Rail (Ref. [9])

5.3 Hazard Identification

Based on the hazard identification table presented in **Appendix A**, the following hazardous scenarios have been developed:

- Li-ion battery fault, thermal runaway and fire.
- Li-ion battery fire, toxic smoke plume
- Electrical equipment failure and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion
- Refrigerant gas release and asphyxiation hazard.
- Diesel release (from tank), ignition and pool fire.
- Electromagnetic field impacts.

Each identified scenario is discussed in further detail in the following sections.

5.4 Li-Ion Battery Fault, Thermal Runaway and Fire

Lithium ion (Li-ion) batteries are composed of a metallic anode and cathode which allows for electrons released from the anode to travel to the cathode where positively charged ions in the solute migrate to the cathode and are reduced. The flow of electrons provides the source of energy which is discharged from a battery and used for work. In a Li-ion battery, the lithium metal composites (a composite of lithium with other metals such as cobalt, manganese, nickel, or any combination of these metals) oxidises (loses an electron) becoming a positively charged ion in solution which migrates through the battery separator to the cathode. At the same time, the lost electron travels through the circuit to the cathode. The lithium ions in solution then recombine with the electron at the cathode forming lithium metal within the cathodic metal composite. This process is shown in **Figure 5-1**.

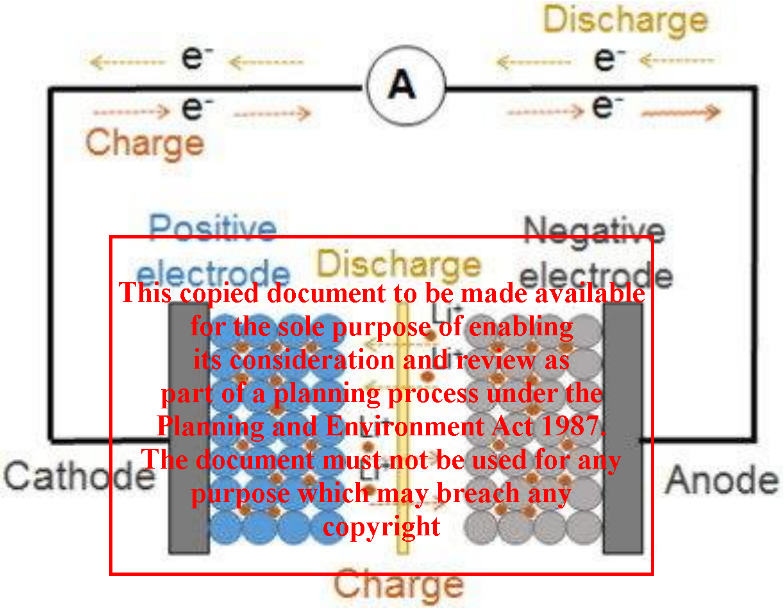

Figure 5-1: Cathode and Anode of a Battery (Source Research Gate)

Initial lithium batteries were designed around lithium metal (i.e. no composite structure) due to the high energy density yielded by the metal. However, when overcharging a battery, lithium ions can begin to plate on the anode in the form of lithium dendrites. Eventually, the dendrites pierce the separator within the battery resulting in a short of the battery which could result in heat, fire, or explosion of the battery. The technology evolved to move away from lithium metal to lithium ions (held within composite materials) which reduced the incidence of lithium dendrites forming resulting in an overall safer battery.

Despite the improvement in battery technology, there are several degradation mechanisms that are still present within the battery which can result in thermal runaway. These include:

- Chemical reduction of the electrolyte at the anode
- Thermal decomposition of the electrolyte
- Chemical reduction of the electrolyte at the cathode
- Thermal decomposition by the cathode and the anode
- Internal short circuit by charge effects

These effects arise primarily as a result of high discharge, overcharging, or water ingress into the battery which results in a host of by-products being formed within the battery during charge and discharge cycles.

As a result, Li-ion batteries are equipped with several safety features to prevent the batteries from charging or discharging at voltages which result in battery degradation, leading to shorting of the battery and thermal runaway. Safety features generally include:

- Shut-down separator (for overheating)
- Tear-away tab (for internal pressure relief)
- Vent (pressure relief in case of severe outgassing)
- Thermal interrupt (overcurrent/overcharging/environmental exposure)
- Battery Management Systems (BMS) – constant monitoring of the voltage, temperature and state of charge of individual cells to aid in early detection of a fault condition. Upon detection of cell fault, the BMS disconnects and isolates the cell to prevent propagation of the incident, and alarms the site EMS.

These features are designed to prevent overcharging or excessive discharge, pressurisation arising from heat generated at the anode or from battery contamination. Protection techniques for Li-ion batteries are standard; hence, the potential for thermal runaway to occur in normal operation is incredibly low with the only exceptions being where batteries are manufactured poorly or due to manufacturing faults, or battery damage (i.e. battery cell is ruptured as this can short circuit the battery resulting in thermal runaway).

The battery chemistry of the BESS units shall be lithium iron phosphate (LiFePO4, or simply LFP), which is one of the safest battery chemistries within the industry. The stability of the batteries is due to the cathode which does not release oxygen therefore preventing violent redox reactions resulting in rapid temperature rise as the oxygen oxides the electrolyte. The stability of LFP batteries has been demonstrated numerous times through appropriate testing.

UL9540A test results from containerised BESS units with LFP battery chemistry typically show that thermal runaway is not propagated to adjacent units, is generally contained to a small quantity of cells and does not result in a BESS unit fire. Testing for shock and damage to batteries (i.e. nail puncture test) has shown that LFP batteries when punctured through membranes typically results in a shorting of the battery, and fire does not result in ignition of the battery demonstrating that the battery chemistry is protected against shock damage.

At the time of assessment, the final selection for the containerised BESS units has not been made. However, the battery manufacturer at minimum is required to comply with the requirements listed in the CFA guidelines including:

- UL9540
- UL9540A
- NFPA855

Although the supplier has not been selected yet, the UL9540A test results from a potential supplier (Hithium) is provided in **Appendix B**. In the report provided, the unit level tests were passes including the following:

- No flaming outside of the unit.

- Surface temperatures of modules within the target units adjacent to the initiating unit was far below the cell venting temperature.
- Surface temperature measurements on wall surface did not exceed the temperature rise above ambient; and
- Explosion hazards were not observed during the test.

As the results are based on cell level tests, further assessment is not conducted as propagation within the module was limited to an acceptable number of cells and therefore a full module or unit fire would not occur. It should be noted that the tests are conducted with no fire suppression and any installed BESS unit would include fire suppression in compliance with NFPA 855.

Based on typical LFP installations and UL9540A testing, the technology does not cause a propagating fire during thermal runaway. Should fire be developed within one BESS enclosure it would not propagate within the unit.

Although the likelihood of both a full unit fire and incident propagation to adjacent BESS units is highly unlikely, consequence modelling has been undertaken to demonstrate the potential heat radiation distances.

5.4.1 Fire Safety Testing and Certifications

Underwriters Laboratories (UL) is a safety certification organisation that performs testing, inspection and certification of products, components, materials and system s to ensure they meet specific safety, quality, and performance standards. UL also develops and maintains standards and testing procedures to support industry in the adoption of new technology. Two key documents which they produce are the UL 9540 Standard for Energy Storage Systems and Equipment and the UL 9540 A Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems.

The first edition of UL 9540 was introduced in 2016, since then it has been a widely adopted requirement that electrochemical ESS be listed to UL 9540. This includes international fire codes and NFPA 1 and 855. The standard defines several system safety tests for energy storage systems. The standard defines the testing requirements for a system, meaning that all components that make up the ESS must be tested together ensuring that safety is retained at the system level. All testing is required to be completed through a nationally recognised testing laboratory (NRTL). In the 2022 updated version of the standard, systems were required to meet the performance criteria of a new test method, UL 9540A

The UL 9540A test method is a systematic evaluation method to evaluate fire safety hazards associated with propagating thermal runaway within battery systems. The test establishes firstly if the storage technology can be driven into thermal runaway, and then if so, what happens? The UL 9540A test method starts at cell level and gradually builds to the installation level over four steps (cell-level, module-level, unit-level, installation-level), if an ESS meets the performance criteria of any of the first three tests, there is no requirements to continue testing the subsequent levels.

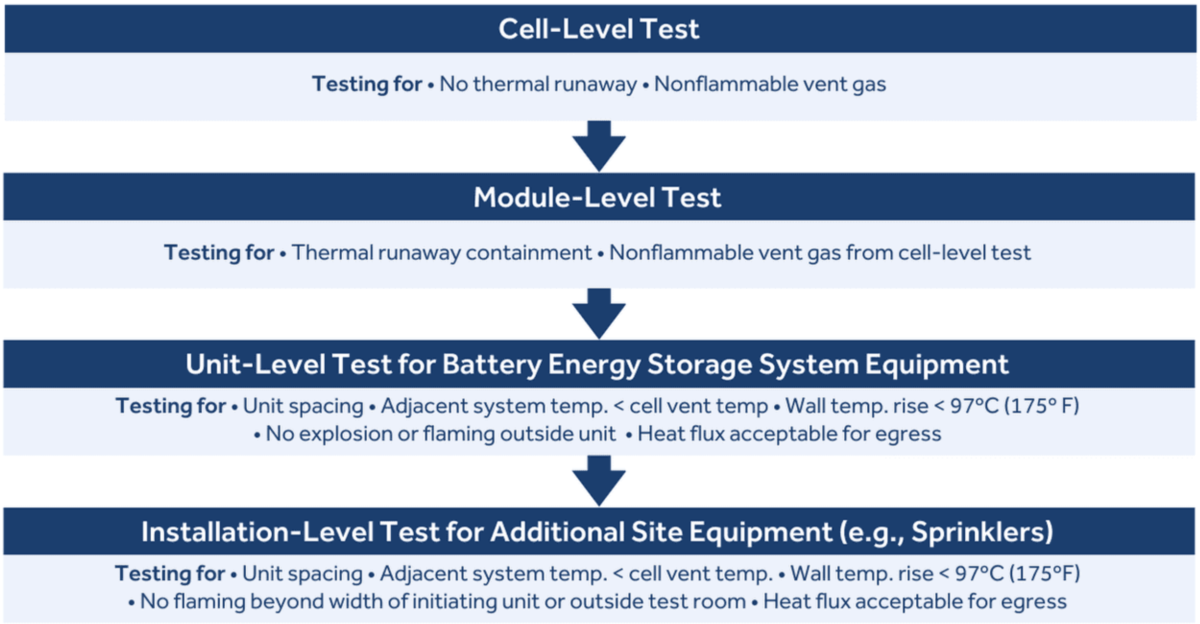

Figure 5-2: UL 9540A Test Sequence

UL 9540A test results from containerised BESS units with LFP battery chemistry typically show that unit-unit propagation does not occur. At the time of assessment, the supplier selection for the BESS units has not been made. However, the battery manufacturer at minimum is required to comply with the requirements listed in the CFA guidelines including UL 9540, UL 9540A and NFPA 855. The passing of the UL 9540A test at cell, module or unit level (all conducted without system suppression) would indicate that the fire risks with the installed system are negligible.

Although the supplier has not been selected yet, the UL 9540A test results from a potential supplier, who has been used at similar sites, is provided in **Appendix B**. In the report provided the unit level tests were passed, including the following:

- No flaming outside of the unit.
- Surface temperatures of modules within the target units adjacent to the initiating unit was far below the cell venting temperature.
- Surface temperature measurements on wall surfaces did not exceed the temperature rise above ambient; and
- Explosion hazards were not observed during the test.

The purpose of the unit-level test is to verify that a fire within a single BESS unit will not spread to other units, nor breach the BESS enclosure, and that there shall be no flying debris or explosive discharge of gases. This sets parameters for distance to surrounding BESS to prevent incident propagation.

It should be noted that unit-level tests are carried out without fire suppression technology that will be included in the final product, therefore the risk of incident propagation is further reduced beyond what is reported in unit-level tests. As the West Mokoan Solar Farm is a decentralised system, the distance between each BESS unit is significant (minimum 95 m and up to 600 m) and unit-to-unit propagation is not a credible fire scenario.

Although the likelihood of both a full unit fire and incident propagation to adjacent BESS units is not considered a credible scenario, consequence modelling has been undertaken to demonstrate the potential heat radiation distances.

5.4.2 Victoria Big Battery Fire Review

Notwithstanding the previous sections, it is necessary to review recent large scale BESS fires to determine whether similar incidents could occur with the present project.

The Victorian Big Battery (VBB) experienced a fire in July 2021 which has a back-to-back layout. According to the independent investigation report on its fire incidence, the back-to-back layout was not the cause for propagation. The main reason for fire propagation was strong wind blowing flames from one Megapack into the unprotected vent atop of an adjacent Megapack which resulted in the ignition of the plastic fan which was able to impact the battery modules directly beneath the fan.

Lessons learnt from the VBB incident results in fire safety precautions on the design of the present project. The vent atop the containers shall be made of metal instead of plastic and covered by a metallic mesh shield. Furthermore, the placement of the fans shall be such that batteries or flammable materials shall not be located directly beneath ventilation openings. To ensure the above are captured the following recommendations have been made:

- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.

Based upon the designs incorporated with the container based upon the VBB fire, the available area and the separation distance assessments, it is considered that the propagation between two units is considered unlikely; hence, this incident has not been carried forward for further analysis.

5.5 Li-ion Battery Fire and Toxic Gas Dispersion

If a BESS failure occurs resulting in a fire, toxic byproducts of combustion may form. A literature review was conducted on lithium-ion battery fires to identify the toxic gases which may be generated in the event of a fire. The review identified the following gases or classes of gases can form:

- Carbon dioxide;
- Carbon monoxide; and
- Fluorine gases.

Each of these have been discussed in further detail in the following subsections.

5.5.1 Carbon Dioxide

Carbon dioxide is a colourless, odourless, dense gas which is naturally forming and is present in the atmosphere at concentrations around 415 ppm (0.0415%). At low concentrations carbon dioxide is physiologically impotent and at low concentrations does not appear to have any toxicological effects. However, as the concentration grows it increases the respiration rate of exposed persons. The Short-Term Exposure Limit (STEL), as noted by SafeWork Australia is 30,000 ppm (3%), above 50,000 ppm (5%) a strong respiration effect is observed along with dizziness, confusion, headaches, and shortness of breath. Concentrations in excess of 100,000 ppm (10%) may result in coma or death.

Carbon dioxide is a by-product of combustion where hydrocarbons or carbon-based materials are involved. A typical combustion reaction producing carbon from a hydrocarbon has been provided in **Equation 5-1**. This reaction proceeds when there is an excess of oxygen to the fuel being consumed and is known as complete combustion as it is the most efficient reaction pathway.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3Co_2(g) + 4H_2O(g) \qquad \textbf{Equation 5-1}$$

The lithium-ion batteries are predominantly composed of metal structures. However, during a fire event ancillary equipment and materials within the batteries will be involved in the fire including wiring, plastics and anodes which will liberate carbon dioxide. However, a review of the toxicological impacts indicates high concentrations would be required to result in injury or fatality. Based upon a review of the sensitive areas, and the similar BESS fires (i.e. Victoria BESS fire), it is not considered that the formation of carbon dioxide in a fire would be sufficient to result in downwind impacts sufficient to cause injury or fatality. Therefore, this incident has not been carried forward for further analysis.

5.5.2 Carbon Monoxide

Carbon monoxide is an odourless, colourless gas which is slightly denser than air and occurs naturally in the atmosphere at concentrations around 80 ppb. Carbon monoxide is a toxic gas as it irreversibly binds with haemoglobin which prevents these molecules from carrying out the function of oxygen / carbon dioxide exchange. The loss of 50% of the haemoglobin may result in seizures, coma or death which can occur at concentration exposures of approximately 600 ppm (0.06%).

Carbon monoxide is by-product of combustion if there is insufficient oxygen to enable complete combustion. The reaction pathway for the formation of carbon monoxide is provided in **Equation 5-2**.

$$2C_3H_8(g) + 7O_2(g) \rightarrow 6CO(g) + 8H_2O(g) \qquad \textbf{Equation 5-2}$$

As noted, in **Section 5.5.1** there is the potential for a fire to occur with the BESS units which could form carbon monoxide if there is insufficient oxygen to sustain complete combustion. However, it is noted that the combustible load within the BESS which could result in the formation of carbon monoxide is relatively low compared to the available oxygen in the surrounding atmosphere. Therefore, it is considered that the formation of carbon monoxide at levels which would result in a substantial downwind impact are not considered credible and subsequent analysis of, this incident is not required.

5.5.3 Fluoride Gases

The electrolyte used in Li-ion batteries typically is lithium hexafluorophosphate ($LiPF_6$) or other li-salts containing fluorine. In the event of a thermal runaway, the electrolyte will expand and be vented from the battery. In the event of a fire, the vented gas and other components such as the polyvinylidene fluoride binders may form gases such as hydrogen fluoride (HF), phosphorous pentafluoride (PF_5) and phosphoryl fluoride (POF_3) (Ref. [10]).

The decomposition of $LiPF_6$ can be promoted by the presence of water / humidity according to reactions **Equation 5-3** to **Equation 5-5**.

$$LiPF_6 \rightarrow LiF + PF_5 \qquad \textbf{Equation 5-3}$$

$$PF_5 + H_2O \rightarrow POF_3 + 2HF \qquad \textbf{Equation 5-4}$$

$$LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF$$ **Equation 5-5**

Of the fluorine gases formed, PF_5 is a short-lived gas while POF_3 is a reactive intermediate. Thermal destruction of several battery chemistry, configurations and State of Charge (SOC) indicated the vast majority of these did not produce observable POF_3 with the only observance occurring in a specific battery chemistry at 0% SOC (Ref. [10]). Therefore, the main fluorine gas of concern in a Li-ion battery fire is HF.

HF gas is hydroscopic readily dissolving into water vapour / humidity or moisture in airways forming hydrofluoric acid. Hydrofluoric acid is a weak acid although is highly corrosive and may result in chemical burns. In addition, it is calcium scavenging. Hence, it will readily bind with calcium in cells and tissues disrupting the nerve signalling. SafeWork Australia nominates a concentration of 30 ppm of HF as being Immediately Dangerous to Life and Health (IDLH). At 170 ppm, HF can be lethal in approximately 10 minutes.

For toxic gas dispersion, a battery container fire is necessary as the initiating event. As discussed in **Section** Error! Reference source not found.**.** The potential for a fire to occur is considered negligible due to the highly stable and safe battery chemistries used. Therefore, toxic gas dispersion impacting sensitive receptors is not deemed a credible scenario and this incident has not been carried forward for further analysis.

5.6 Electrical Equipment Failure and Fire

Electrical equipment is located within the switch room which may fail resulting in overheating, arcing, etc. which could initiate a fire. In the event of a fire, it may begin to propagate to adjacent combustible materials (i.e. wiring). It is noted that electrical equipment fires typically start by smouldering before flame ignition occurs resulting in a slow fire development.

The type of equipment used within the site is ubiquitous throughout the world and across industry segments and is therefore not a unique fire scenario. Based upon fire development within switch rooms the fire would be relatively slow in growth and would be unlikely to result in substantial impacts in terms of impacts to firefighting equipment and incident propagation. Therefore, this incident has not been carried forward for further analysis.

5.7 Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Transformers contain oil which is used to insulate the transformers during operation. If arcing occurs within the transformer (e.g. due to a low oil level), the high energy passing through the coolant vaporises the oil into light hydrocarbons (methane, ethane, acetylene, etc.) resulting in rapid pressurisation within the reservoir. To minimise the likelihood of such occurrence, transformers are fitted with a low oil pressure switch, oil temperature monitoring and switches, gas formation detectors and a pressure surge protection. These devices identify potential oil and pressure events within the transformer, isolating power and alarming operators.

Notwithstanding the protection systems, if the pressure rise exceeds the structural integrity of the reservoir, and the installed pressure relief devices, the reservoir can rupture allowing the release of oil into the bund. The rupture also allows oxygen to enter the reservoir. The temperature of the gases is above the auto ignition point, but this does not occur until oxygen is present. When oxygen enters the reservoir, the gases auto ignite which generates sufficient heat to ignite the oil in the bund.

As there is the potential for a fire to occur within the transformers, this incident has been carried forward for further analysis.

The transformers haven't been subject to detailed design at this stage; hence, the following recommendation has been made:

- The substation transformer bunds shall be designed according to the requirements detailed in AS 2067:2016(Ref. [3]), and shall have a volume of 110% of the total volume of the mineral oil within the Transformer to account for any safety risks from a potential fire and or explosion.

5.8 Transformer Electrical Surge Protection Failure and Explosion

Transformers generate large amounts of heat as a result of the high electrical currents that pass through them; hence, oil is used as an insulating material within the transformers to protect the mechanical components. However, if the transformer gets an extreme surge of energy, such as that which could occur due to a lightning strike, and the electrical surge protection measures fail, the mineral oil may start to decompose and vapourise, resulting in gas bubbles of hydrogen and methane (Ref. [11]) as temperatures above the autoignition of the gases.

The formation of gases will increase the pressure within the transformer which can result in the transformer structure rupturing which allows the ingress of oxygen. As the oxygen enters, the concentration of flammable gases falls within the explosive limits which are above their autoignition temperatures which ignite resulting in increased formation of hot gaseous products resulting in an explosion. The explosion may generate significant overpressure, sparks and fire and would result in a whole transformer fire, as discussed in **Section 5.7**.

To protect against overheating and explosions, transformers generally have surge protection devices which shunt electrical surges safely to ground. However, this surge detection and protection devices are not universally installed nor do they protect against all events such as in the case of a major lightning strike or significant oil deterioration, leakage of water into the transformer, and physical damage such as a fallen tree (Ref. [12]). Therefore, while transformers are ubiquitous units with a low potential for failure, there is the potential for an explosion to occur which may result in offsite impacts. Hence, this incident has been carried forward for further analysis.

5.9 Refrigerant Gas Release and Asphyxiation Hazard

The refrigeration system will be used to providing air conditioning and temperature control in the control room and other areas requiring temperature control. A simplified explanation of how a refrigeration system operates to cool an area is provided below.

A refrigeration system contains four essential components:

1. Compressor
2. Expansion valve
3. Refrigerant
4. Heat exchanging pipework

Figure 5-3 has been provided to aid in the description of how the refrigeration system operates to cool a specific area. The refrigeration system cycles the refrigerant gas through the system.

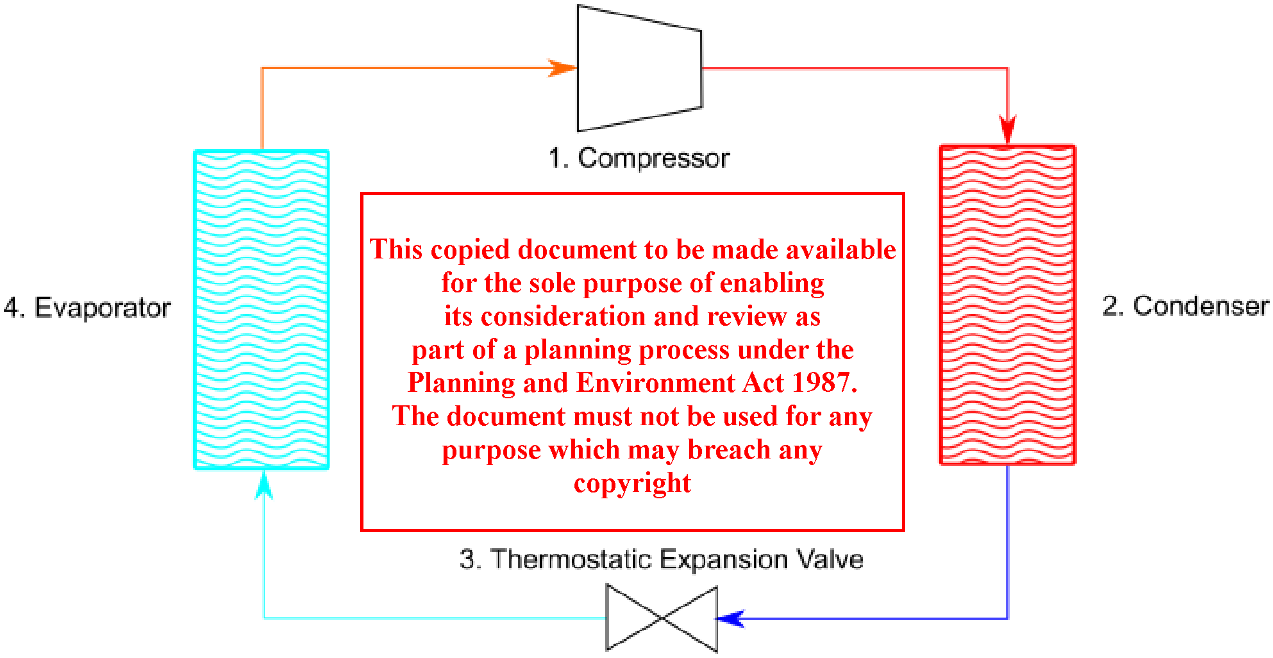

Figure 5-3: Refrigeration Flow Diagram

1. Refrigerant gas from the evaporator enters the compressor where it is pressurised (red) which increases the temperature of the gas. The gas travels along the pipework to the condenser.
2. The condenser is coiled to provide a large surface area to allow the hot gas to dissipate heat. As the gas releases heat through the coils, the gas condenses into a pressurised liquid (dark blue).
3. The pressurised liquid enters the thermostatic expansion valve where it expands across the valve seat, resulting in a sudden drop of pressure of the liquid refrigerant and rapid expansion which cools the liquid (light blue).
4. The cooled refrigerant enters the evaporator which is coiled to provide a large surface area to facilitate exchange of heat from the area to be cooled into the refrigerant. As the refrigerant absorbs heat it boils into a gaseous state.
5. On completion of the cycle, the refrigerant is drawn into the compressor and the cycle repeats.

Refrigeration systems are commonly used in all air conditioning systems which are not subject to frequent releases and if they do occur the leaks are minor resulting in minimal amounts of escaped gas. Therefore, a rupture release would not be a credible scenario given the ubiquitous nature of these systems. In the event a small release occurs it will be dissipated quickly via wind movement around the refrigeration unit prevent accumulation. Furthermore, such a release would be insufficient to impact offsite; hence, this incident has not been carried forward for further analysis.

5.10 Diesel Release, Ignition and Pool Fire

Diesel will be used on site equipment primarily during construction but may be present during operations where equipment needs to be moved / relocated / site vehicles. The diesel will likely be stored in a portable refuelling tank which typically are double skinned (i.e. integrally bunded) tanks complying with AS 1940-2017 (Ref. [13]). The presence of two tanks (i.e. inner and outer tank) results in the potential for external leakage to be incredibly low as this requires the failure of both tanks simultaneously. Therefore, a full release of diesel fuel from the tanks would not be expected to occur.

Nonetheless, if a substantial release did occur, combustible liquids do not emit flammable vapours which results in the ignition probability being incredibly low. To ignite the spill, a sustained ignition source with sufficient energy would be required to be exposed to create sufficient heat to vapourise the liquid to initiate combustion. Should this occur, the fire would grow to the dimensions of the spill which would be unlikely to be sufficient to result in an offsite impact.

Due to the low likelihood of release, ignition and consequences impacts from a diesel pool fire an offsite impact is not considered to be a credible scenario; hence, this incident has not been carried forward for further analysis.

5.11 Electromagnetic Field Impacts

5.11.1 Introduction

Electromagnetic Fields (EMFs) are associated with a wide range of sources and occur both naturally as well as in the built environment. Naturally occurring EMFs, occurring during lightning storms, are generated from Earth’s magnetic field. Non-naturally occurring EMFs are present wherever there is electricity; hence, EMFs are present in almost all built environments where electricity is used.

Extremely low frequency (ELF) EMFs occupy the lower part of the electromagnetic spectrum in the frequency range 0-3,000 Hz which is current that will change direction 0-3,000 times per second. ELF EMFs result from electrically charged particles. Artificial sources are the primary producer of ELF EMFs and are usually associated with the generation, distribution and use of electricity at the frequency of 50 Hz in Australia. The electric field is produced by the voltage whereas the magnetic field is produced by the current.

BESS create EMFs from operational electrical equipment, such as transmission lines, transformers and the electrical components found within BESS units and inverters. This equipment has the potential to produced ELF EMFs in the range of 30 to 300 Hz.

5.11.2 Existing Standards

There are currently no existing standards in Australia for governing the exposure limits to ELF EMFs; however, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has provided some guidelines around exposure limits for prolonged exposure which limits the exposure to 2,000 milligauss (mG) for members of the public in a 24 hour period (Ref. [14]).

Table 5-2 provides typical magnetic field measurements and ranges associated with EMF sources. It is noted that electric fields around devices are generally close to 0 due to the shielding provided around the equipment. In addition, EMF levels drop away quickly with distance; hence, while a value may be measurable at the source, within a short distance the EMF is undetectable.

Table 5-2: EMF Sources and Magnetic Field Strength

Source	Typical Measurement (mG)	Measurement Range (mG)
Television	1	0.2 – 2
Refrigerator	2	2 – 5
Kettle	3	2 – 10

Source	Typical Measurement (mG)	Measurement Range (mG)
Personal computer	5	2 – 20
Electric blanket	20	5 – 30
Hair dryer	25	10 – 70
Distribution powerline (under the line)	10	2 – 20
Transmission power line (under the line)	20	10 – 200
Edge of easement	10	2 – 50

5.11.3 Exposure Discussion

A review of the site indicates there are no residences immediately adjacent to the area where the BESS will be developed providing substantial distance for attenuation of EMFs. Based upon the typical levels which may be generated by transmission equipment the cumulative effect would not exceed the 2,000 mG limit for prolonged exposure.

As the potential for exposure to EMF exceeding the international guidelines is negligible, this incident has not been carried forward for further analysis.

6.0 Consequence Analysis

6.1 Incidents Carried Forward for Consequence Analysis

The following incidents were assessed for consequence analysis:

- Li-ion battery fault, thermal runaway and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion.

Each incident has been assessed in the following sections.

6.2 Li-Ion Battery Fault, Thermal Runaway and Fire

There is potential that a Li-ion battery may fault, resulting in thermal decomposition and a fire. If the fire is not contained or suppressed, there is potential for propagation within the battery container. A detailed analysis has been conducted in **Appendix B** with the modelled radiant heat impact distances shown in **Table 6-1**. Note that the radiant heat contours are measured from the centre of the BESS container to the furthest extent of each contour. The radiant heat contours associated with a Li-ion battery container fire are shown in **Figure 6-1**.

Table 6-1: Radiant Heat from a Li-Ion Battery Fire

Heat Radiation (KW/m^2)	Distance (m)
35	0
28	3
23	6
12.6	6
4.7	10
3.0	13

Figure 6-1 is based upon the BESS unit which is closest to the boundary to determine if there is potential for any off-site impact. The BESS unit is conservatively assumed to have the dimensions of a 40 ft shipping container. The heat radiation contours were assessed at wind speeds of 0.1 m/s and at 2 m/s to assess the effect of wind on the potential for incident propagation (**Figure 6-2**).

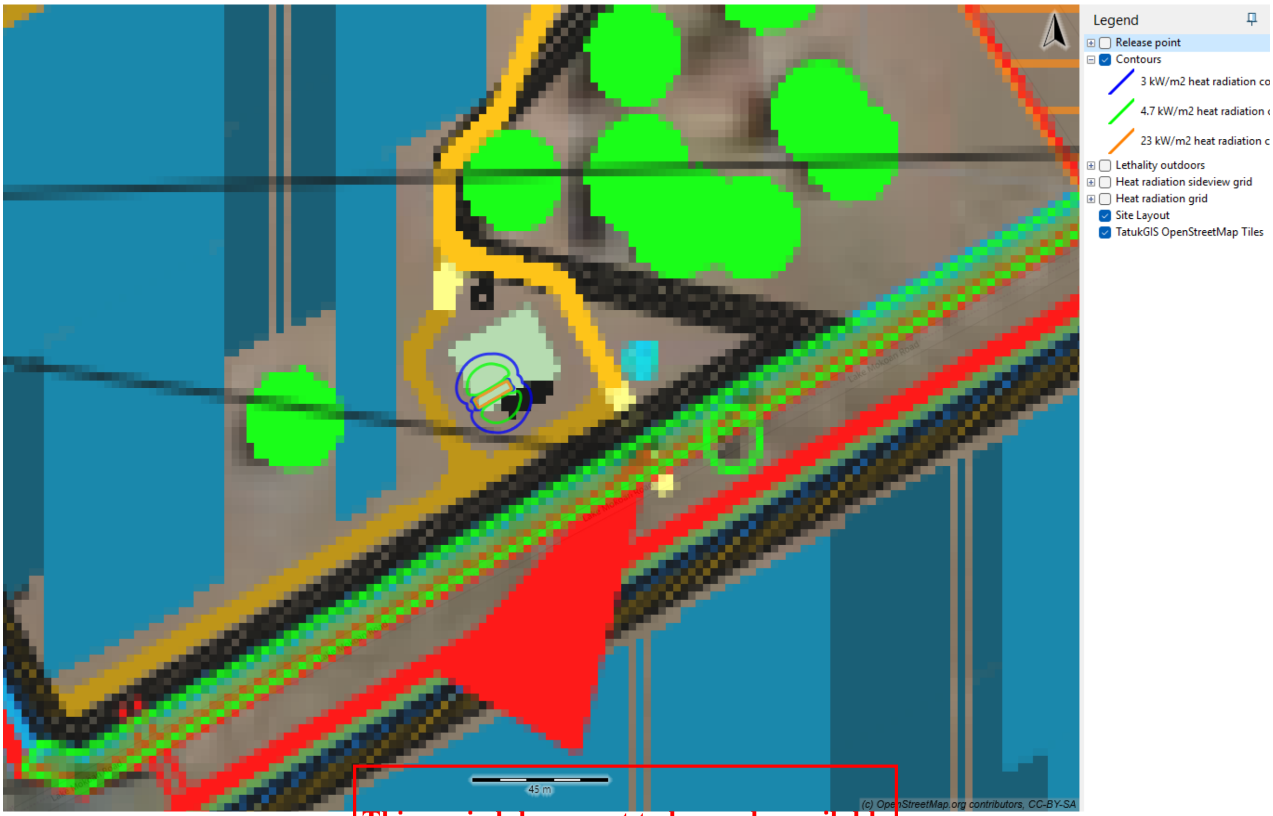

Figure 6-1: BESS Unit Fire Radiant Heat Contours at 0.1 m/s Wind Speed

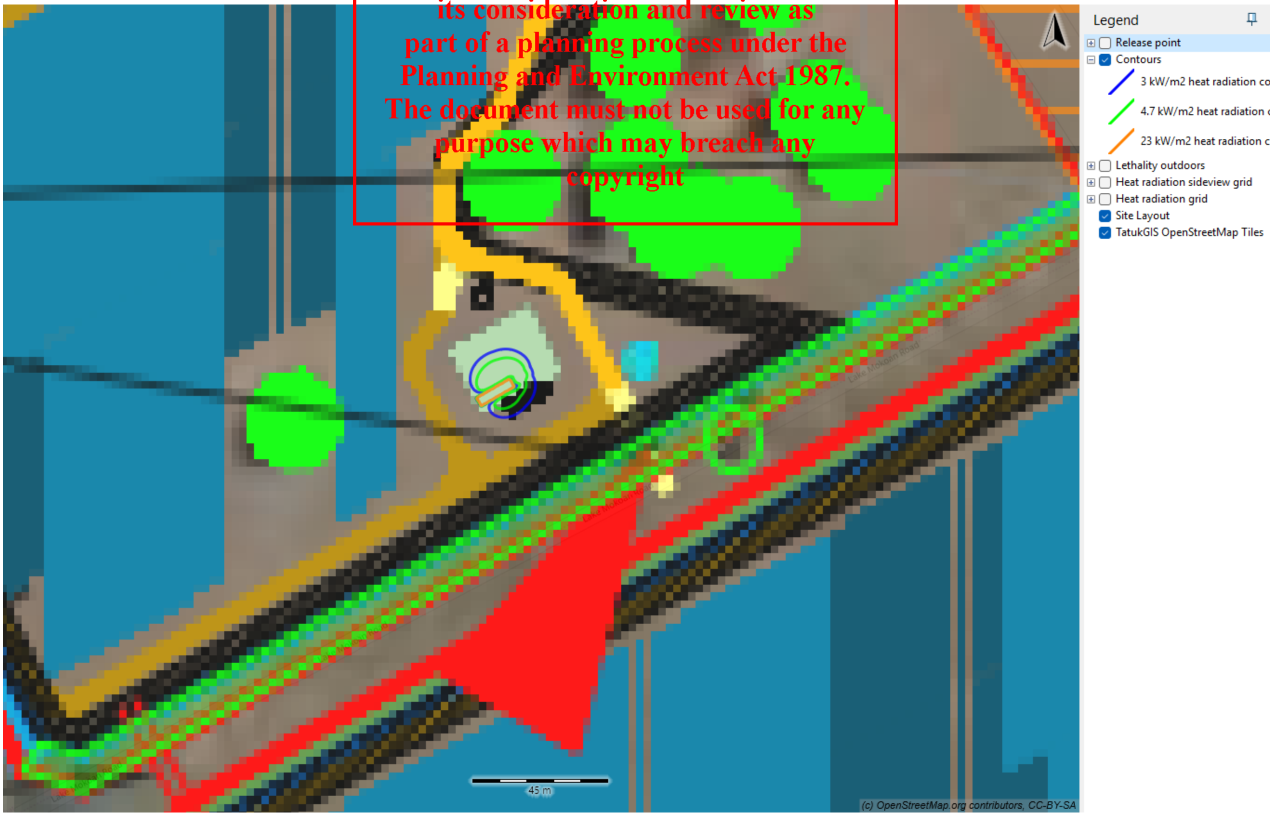

Figure 6-2: BESS Unit Fire Radiant Heat Contours at 2 m/s Wind Speed

The 4.7 kW/m^2 and 23 kW/m^2 heat radiation contours are presented in **Figure 6-1** as these are used to determine if there is any off-site impacts (4.7 kW/m^2) or risk of incident propagation to adjacent infrastructure (23 kW/m^2).

Based on the 4.7 kW/m^2 heat radiation contour, a BESS unit fire would not impact over the site boundary. At a wind speed of 0.1 m/s, the 23 kW/m^2 contour is maintained within approximately a 1 m perimeter around the BESS container. At a wind speed of 2 m/s, the 23 kW/m^2 contour is displaced from the BESS container by approximately 2 m. As the current configuration of the BESS and PCUs is not finalised, the following recommendation has been made:

- Separation distances between BESS and PCUs should be at least 3 m or in accordance with relevant standards and guidelines, whichever is greater.

As this incident does not impact over the site boundary it has not been carried forward for further analysis.

6.3 Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

There is potential that arcing may occur within the transformers which may lead to generation of gases and pressure above the structural integrity of the oil reservoir which may rupture leaking oil into the bund. As a result of the arcing and rupture, the oil may ignite leading to a bund fire within the dimensions of the bund. A detailed analysis has been conducted in **Appendix B** and the radiant heat impact distances estimated for this scenario are shown in **Table 6-2**.

Table 6-2: Radiant Heat from a Transformer Bund Fire

Heat Radiation (KW/m^2)	Distance (m)
35	17
23	19
12.6	24
4.7	37
3.0	45

A review of the site layout was conducted to determine the transformer which is closest to the site boundary and thus has the greatest risk of impacting over the boundary.

Figure 6-3 shows the radiant heat contours for the transformer which is located closest to the boundary (approximately 44 m). The radiant heat contours at 4.7 and 23 kW/m^2 do not impact over the site boundary. The 23 kW/m^2 contour is associated with incident propagation, as can be seen the exclusion area around the transformer would prevent a bund fire form propagating to adjacent infrastructure. As such, this incident has not been carried forward for frequency analysis and no further recommendations have been made.

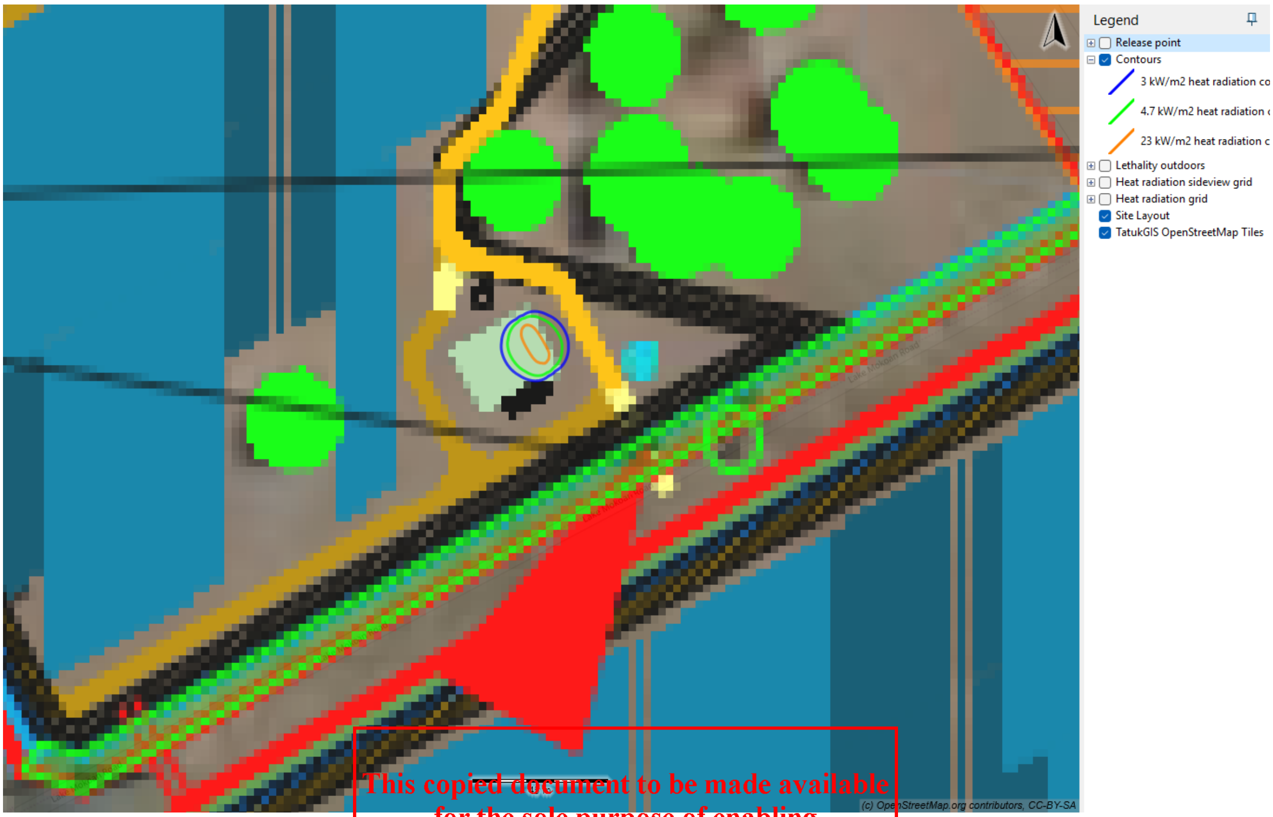

Figure 6-3: Transformer Fire Radiant Heat Contours

As recommended previously, at least 3 m should be maintained between the BESS container and the PCU systems to mitigate the risk of incident propagation between the units.

6.4 Transformer Electrical Surge Protection Failure and Explosion

If a transformer is impacted by an extreme electricity surge, such as in the event of a lightning strike, the ester oil within the transformer may ignite and explode resulting in substantial overpressure impacts. A detailed analysis has been conducted in **Appendix B** with the results summarised in **Table 6-3**.

Table 6-3: Transformer Explosion Overpressures

Overpressure (kPa)	Distance (m)
70	40
35	58
21	81
14	107
7	186

There are several properties which are within close proximity to the site, a review of the transformers was conducted and determined that the property located at 623 Benalla-Yarrawonga Road is located closest to any given transformer. Hence; this transformer was chosen for this assessment to determine the possible impact on local residences.

Provided in **Figure 6-4** is a contour showing the explosion impact distances at 7 kPa and 14 kPa to the surrounding areas for the transformers closest to the site boundary, which represent the potential for injury to personnel and incident propagation, respectively. As can be seen, the 7 kPa contour exceeds over the boundary towards the residence, and there are several other transformers which are closer to boundary which would indicated that in the event of an explosion, there are off-stie risks. Hence, frequency modelling for this event has been completed for this scenario in the following section.

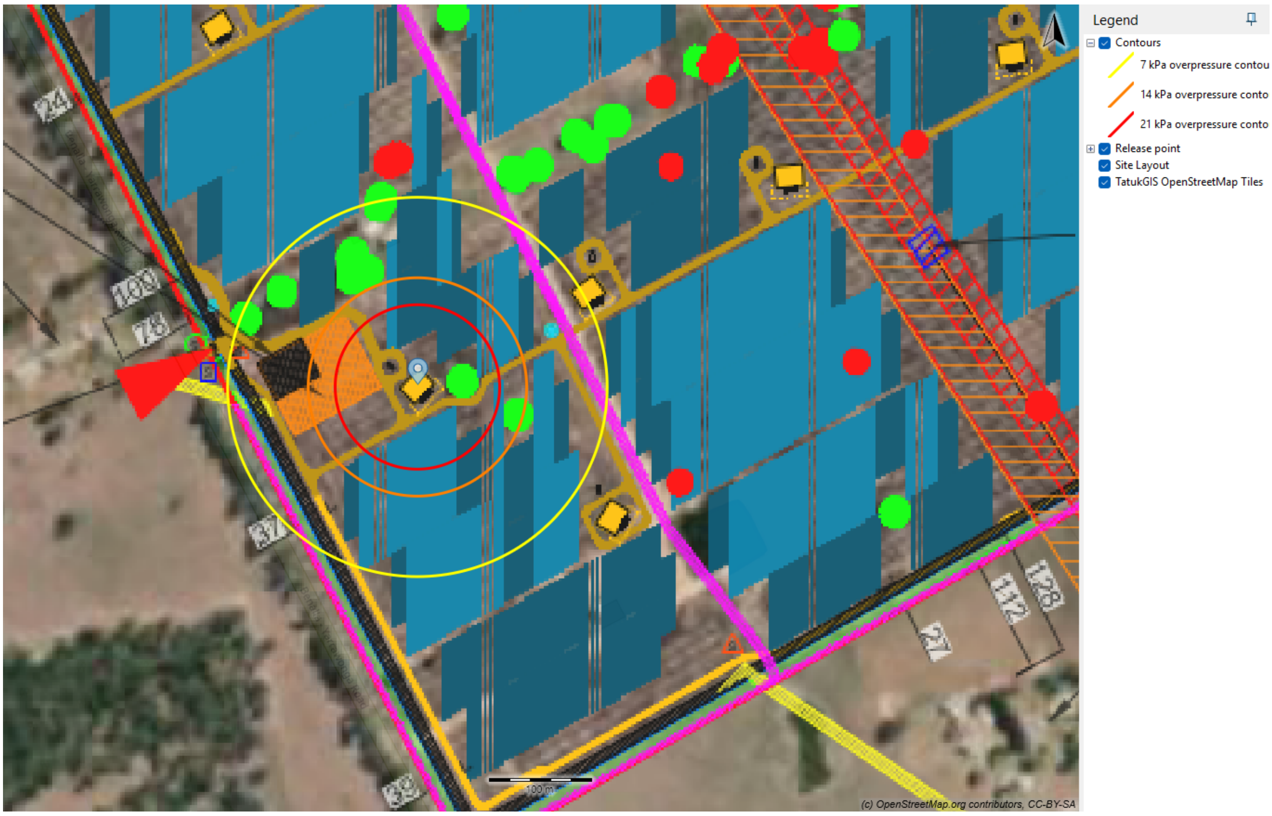

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Figure 6-4: Transformer Explosion Overpressure Contours

7.0 Frequency Analysis

7.1 Incidents Carried Forward for Frequency Analysis

The following incidents have been carried forward for frequency analysis and risk assessment:

- Transformer electrical surge protection failure and explosion.

Each of these incidents have been assessed in the following sections.

7.2 Transformer Electrical Surge Protection Failure and Explosion

The initiating event for a transformer fire is a major oil spill from the transformer casing. This would be classified as a catastrophic failure as all oil contained within the transformer would be released. Failure rate data from the CCPS indicates that the frequency of a catastrophic transformer failure is in the range of 0.125 to 9.26 failures per 10^6 hours (Ref. [15]).

It is noted that this data base was compiled in 1989 and as such is somewhat outdated. It would be expected that more modern equipment would be more reliable due to advances in materials, better understanding of oil management in transformers, better monitoring systems and process safety requirements. Therefore, the lower range of expected failures has been selected for this assessment to reflect the increased safety present in the transformer systems at the site. Hence, the failure frequency would be 0.125 per 10^6 hours, or 1.10×10^{-3} p.a.

Changlong Zhu et al conducted a peer review of several academically accepted methods of calculating ignition probability (Ref. [16]). The study concluded that for flammable liquids with flashpoints greater than 100°C, the probability of direct or delayed ignition was negligible. This data was taken from a number of well-established models including the BEVI Manual (Ref. [17]), the Purple Book (Ref. [18]), and studies conducted on the HIMRS database (Ref. [19]). Furthermore, an assessment of power transformer reliability conducted by Tenbohlen et al which analysed 112 major transformer failures throughout Europe indicates that most major failures do not result in any external effects (Ref. [20]). The Tenbohlen et al study indicates that only 2.7% of major transformer failures result in an explosion (Ref. [20]).

The surrounding land is largely undeveloped farmland and it is not expected for people to be present adjacent to the site boundary / transformers the majority of the time. There are several existing dwellings surrounding the solar farm which have distances greater than 300 m from the nearest proposed transformer. Hence, it has been assumed that personnel may be within the vicinity of the transformers 1 hour per workday or 260 hours/year resulting in an exposure probability of 0.03. Using this exposure potential, the potential for a fatality becomes $1.1 \times 10^{-3} \times 0.027 \times 0.03 = 8.9 \times 10^{-7}$ p.a.

7.3 Comparison Against Risk Criteria

7.3.1 Fatality Risk

The acceptable criteria have been taken from the NSW Department of Planning, Industry and Environment *Hazardous Industry Planning Advisory Paper No. 4 – Risk Criteria for Land Use Safety Planning* (Ref. [2]). The acceptable risk criteria published in the guideline relates to injury, fatality and property damage. The values in the guideline present the maximum levels of risk that are permissible at the land use under assessment as defined in **Table 7-1**.

Table 7-1: Individual Fatality Risk Criteria

Land Use	Suggested Criteria (risk per million per year)
Hospitals, schools, child-care facilities, old age housing	0.5
Residential, hotels motels and tourist resorts	1
Commercial developments including retail centres, offices and entertainment centres	5
Sporting complexes and active open spaces	10
Industrial	50

To be conservative, the private property surrounding the solar farm is to be treated as residential occupancy. Based on **Table 7-2** the individual fatality risk criteria is $1x10^{-6}$/year. Under the guidelines, farmland can often be treated as industrial use and the less stringent risk criteria applied.

The fatality risk estimated for the immediate vicinity was calculated to be $8.9x10^{-7}$/year which is below the allowable individual fatality risk criteria. Therefore, from a fatality risk perspective the development does not result in an exceedance of the criteria and would be considered acceptable for the proposed location.

7.4 Total Fatality Risk

As the transformers are sufficiently set back from the site boundary to prevent the heat radiation contour impacting offsite, the only offsite impacts are due to explosion overpressure from surge protection equipment failure and a subsequent transformer explosion. As such, the total fatality risk from these events is summarised in **Table 7-2**.

Table 7-2: Total Fatality Risk

Incident	Fatality Risk
Transformer Bund Fire	0
Transformer Explosion	$8.9x10^{-7}$
Total	**$8.9x10^{-7}$**

7.5 Comparison Against Risk Criteria

The acceptable criteria have been taken from the NSW Department of Planning, Industry and Environment *Hazardous Industry Planning Advisory Paper No. 4 – Risk Criteria for Land Use Safety Planning* (Ref. [2]) and used for guidance as Victoria does not have any published criteria for offsite risk. The acceptable risk criteria published in the guideline relates to injury, fatality and property damage. The values in the guideline present the maximum levels of risk that are permissible at the land use under assessment.

Under the guidelines the adjacent land use may be considered industrial, however for conservatism the criteria for residential use have been used. For residential use, the maximum permissible fatality risk is $1x10^{-6}$/year. The assessed highest fatality risk is $8.9x10^{-7}$/year at the closest site boundary; hence, the highest risk is within the permissible criteria and therefore all other risk points beyond the boundary would be within the acceptable criteria.

Based on the estimated injury risk, conducted in the analysis above, the risks associated with injury and nuisances at the closest residential area are not considered to be exceeded.

7.6 Incident Propagation

The same guidelines provide acceptable risk criteria (Ref. [2]) for incident propagation as 50 chances pmpy. Based on the recommendations provided, the 23 kW/m^2 contour would not impact offsite; hence, the potential for incident propagation is zero (0) which is less than the acceptable risk criteria for incident propagation.

8.0 Conclusion and Recommendations

8.1 Conclusions

A hazard identification table was developed for the West Mokoan Solar Farm PV & BESS project to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The consequence analysis showed that a transformer explosion due to surge protection failure would have potential to impact off site. As such, a frequency analysis was conducted on this incident. The frequency analysis estimated the site total fatality risk criteria would be zero 8.9x10^{-7}/year which is within the acceptable risk criteria indicated in HIPAP No.4 (Ref. [2]) of 1x10^{-6}/year.

In addition, incidents exceeding 23 kW/m^2 were reviewed which indicated that, with the recommendation measures implemented, the contours from such incidents would not impact over the site boundary nor create incident propagation within the site and would be below the acceptable criteria.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the facility would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

8.2 Recommendations

Notwithstanding the conclusions drawn, the following recommendations have been made and should be undertaken to cover the battery and inverter equipment as well as common hazards for a mechanical site prior to the commencement of operations at the Solar PV and BESS project to the extent dangerous goods exceed any thresholds:

- BESS must be tested in accordance with UL9540A.
- Testing to demonstrate clearances required to prevent propagation of fires between separated units.
- BESS to be installed in accordance with manufacturer and UL9540A report recommended clearances based on testing.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the facility area whilst meeting the recommended clearances.
- UL testing information shall be made available to the certifying authority. It is noted that a confidentiality agreement may be required.
- The vent covers of the BESS shall be constructed of non-combustible material.

- The vents shall not be located above battery packs within the BESS container.
- Separation distances between BESS and PCUs should be at least 3 m or in accordance with relevant standards and guidelines, whichever is greater
- A submission to CFA shall be made for written advice in accordance with the VDGR.
- A Dangerous Goods (DG) risk assessment shall be prepared for the site.
- A DG register shall be prepared for the site.
- A site manifest shall be prepared at the site in accordance with Schedule 3 of the Victorian Dangerous Goods Regulation (VDGR).
- The site shall notify the Regulator (i.e. WorkSafe Victoria) of the presence of DGs.
- A site layout shall be prepared for the site in accordance with Schedule 3 of the VDGR.
- A placard schedule shall be prepared for the site to ensure the correct placards are installed.
- An Emergency Response Plan (ERP) shall be prepared for the site and submitted to the Country Fire Authority (CFA)
- An Emergency Services Information Booklet (ESIB) shall be prepared for the site and submitted to the CFA.
- **Error! Reference source not found.**Ensure all site transformers are suitably set back from the site boundary to prevent offsite propagation risk.

9.0 References

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Appendix A

Hazard Identification Table

Appendix A

A1. Hazard Identification Table

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
1	Battery Storage	• Failure of lithium ion battery protection systems	• Thermal runaway resulting in fire or explosion • Incident propagation through battery cells	• Batteries are tested by manufacturer prior to sale / installation • Overcharging and electrical circuit protection • Battery monitoring systems • Batteries composed of subcomponents (i.e. BBU, cells) reducing risk of substantial component failure • Batteries are not located in areas where damage could easily occur (i.e. within the fenced property) • Electrical systems designed per AS/NZS 3000:2007 (Ref. [21]) • Aerosol fire suppression • UL9540A testing
2	Switch rooms, communications, etc.	• Arcing, overheating, sparking, etc. of electrical systems •	• Ignition of processors and other combustible material within servers and subsequent fire	• Hydrant protection • Fires tend to smoulder rather than burn • Isolated location • Switch room contained within a structure
3	Transformers	• Arcing within transformer, vaporisation of oil and rupture of oil reservoir	• Transformer oil spill into bund and bund fire	• Bunded • Fire protection (hydrants, extinguishers) • Isolated location
4	Transformers	• Power surge to transformers	• Major failure of surge protection in transformer, vapourisation of mineral oil, ignition and explosion	• Transformers have surge protection system to shut down upon detection of extreme energy input • Lightning protection to prevent lightning strikes impacting transformers • Control of ignition sources – no smoking / open flames around the transformers

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
5	BESS Units	• Failure of flanges, valves, compressors, etc. and release of gas	• Non-flammable, non-toxic gases pose no fire issue • Potential oxygen exclusion and asphyxiation risk	• Relatively low volume of gas used • Robust and commonly used systems which are not prone to large leaks • Open outdoor area provides natural ventilation preventing accumulation of gases
6	Diesel Storage	• Release of combustible liquid and ignition	• Pool fire at the point of release	• Combustible liquids do not give off flammable vapours at atmospheric conditions • Low ignition probability • Relatively small release of diesel • AS 1940-2017 compliant storages
7	Electrical Infrastructure	• Electric and magnetic equipment	• Generation of ELF EMF and injury / nuisance to surrounding area	• Large separation distances allow for attenuation of EMFs • Cumulative impacts from equipment below acceptable thresholds. • Low occupancy density within vicinity of the development

Appendix B

Consequence Analysis

B1. Incidents Assessed in Detailed Consequence Analysis

The following incidents are assessed for consequence impacts.

- Li-ion battery fault, thermal runaway and fire

Error! Reference source not found. Each incident has been assessed in the sections below.

B2. Gexcon – Effects

The modelling was prepared using Effects which is proprietary software owned by Gexcon which has been developed based upon the TNO Coloured books and updated based upon CFD modelling tests and physical verification experiments. The software can model a range of incidents including pool fires, flash fires, explosions, jet fires, toxic dispersions, warehouse smoke plumes, etc.

B3. Radiant Heat Physical Impacts

Appendix Table B-1 provides noteworthy heat radiation values and the corresponding physical effects of an observer exposed to these values (Ref. [2]).

Appendix Table B-1: Heat Radiation and Associated Physical Impacts

Heat Radiation (kW/m^2)	Impact
35	• Cellulosic material will pilot ignite within one minute's exposure • Significant chance of a fatality for people exposed instantaneously
23	• Likely fatality for extended exposure and chance of a fatality for instantaneous exposure • Spontaneous ignition of wood after long exposure • Unprotected steel will reach thermal stress temperatures which can cause failure • Pressure vessel needs to be relieved or failure would occur
12.6	• Significant chance of a fatality for extended exposure. High chance of injury • Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure • Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure
4.7	• Will cause pain in 15-20 seconds and injury after 30 seconds exposure (at least second degree burns will occur)

B4. Explosion Overpressure Physical Impacts

Appendix Table B-2 provides noteworthy explosion overpressure values and the corresponding physical effects of an observer exposed to these values (Ref. [2]).

Appendix Table B-2: Effects of Explosion Overpressures

Overpressure (kPa)	Impact
70	• Threshold of lung damage • 100% chance of fatality for a person in a building or in the open • Complete demolition of houses
35	• House uninhabitable

Overpressure (kPa)	Impact
	- Wagons and plants items overturned - Threshold of eardrum damage - 50% chance of fatality for a person in a building and 15% chance of fatality for a person in the open
21	- Reinforced structures distort - Storage tanks fail - 20% chance of fatality to a person in a building
14	- House uninhabitable and badly cracked
7	- Damage to internal partitions and joinery but can be repaired - Probability of injury is 10%. No fatality
3.5	- 90% glass breakage - No fatality and very low probability of injury

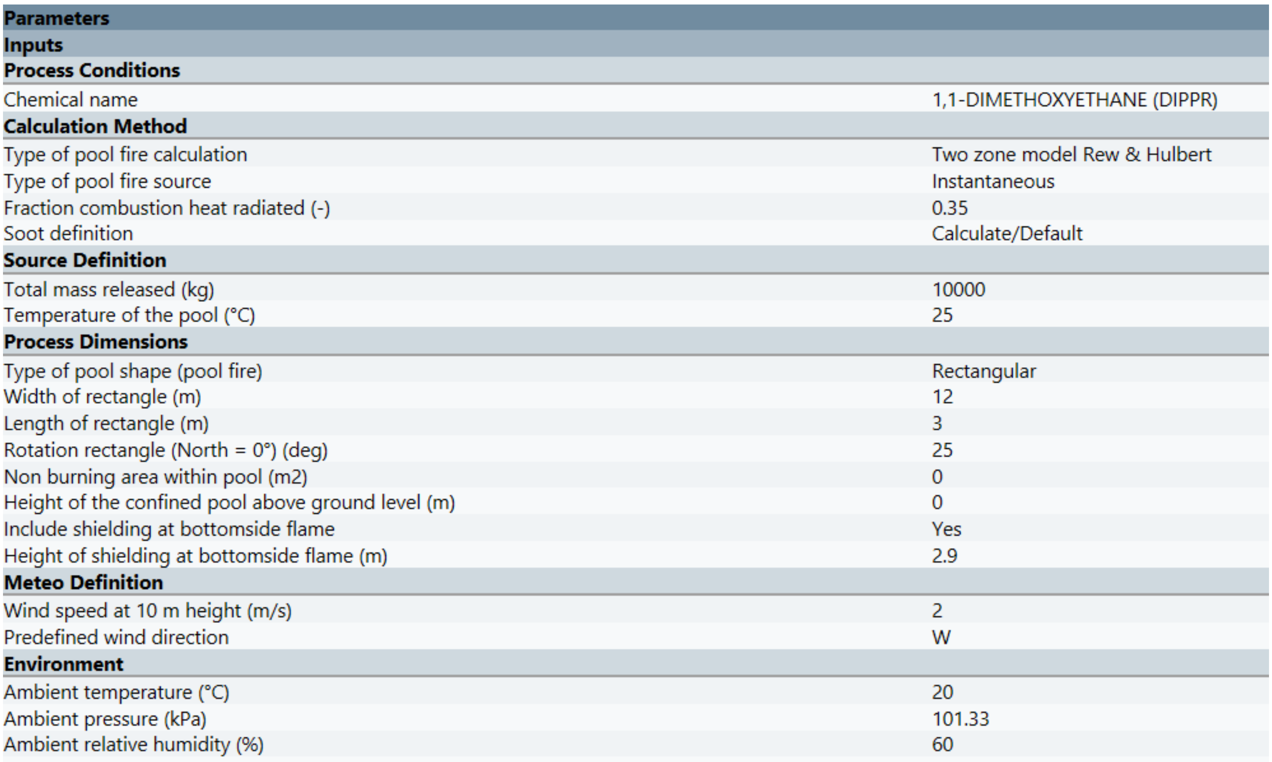
B5. Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

The site has been designed as a decentralized BESS with each battery unit spaced throughout the site with the smallest distance between two battery units being approximately 95 m. Therefore, the assessment has been based on a single full-container fire with any potential incident propagation to adjacent batteries being determined based upon the proximity of the 23 kW/m^2 heat radiation contour. It has been assumed that the maximum dimensions of the battery units will be 12 m x 3 m (40 ft shipping container) resulting in an area of 36 m^2.

The battery fire model has been based upon the properties of the organic solvents used within the battery. A review of typical organic solvents used batteries indicates there is a range including chemicals such as dimethoxyethane and gamma-butyrolacton. For the purposes of this assessment dimethoxyethane has been selected.

It is noted that the BESS units are contained in containerised metal shipping containers which will provide a level of shielding to the fire. A typical 20 ft shipping container has a height of 2.9 m; hence this has been input as a shielding value.

The input file has been provided in **Appendix Figure B-1**.



Parameters	
Inputs	
Process Conditions	
Chemical name	1,1-DIMETHOXYETHANE (DIPPR)
Calculation Method	
Type of pool fire calculation	Two zone model Rew & Hulbert
Type of pool fire source	Instantaneous
Fraction combustion heat radiated (-)	0.35
Soot definition	Calculate/Default
Source Definition	
Total mass released (kg)	10000
Temperature of the pool (°C)	25
Process Dimensions	
Type of pool shape (pool fire)	Rectangular
Width of rectangle (m)	12
Length of rectangle (m)	3
Rotation rectangle (North = 0°) (deg)	25
Non burning area within pool (m2)	0
Height of the confined pool above ground level (m)	0
Include shielding at bottomside flame	Yes
Height of shielding at bottomside flame (m)	2.9
Meteo Definition	
Wind speed at 10 m height (m/s)	2
Predefined wind direction	W
Environment	
Ambient temperature (°C)	20
Ambient pressure (kPa)	101.33
Ambient relative humidity (%)	60
Amount of CO2 in atmosphere (-)	0.0004

Appendix Figure B-1: BESS Fire Input

The above information was input into Effects which calculated the following outputs:

- SEP – 95.8 kW/m^2
- Flame height – 10.2 m

The results of the analysis are shown in **Appendix Table B-3**.

Appendix Table B-3: BESS Fire Heat Radiation Distances

Heat Radiation (KW/m^2)	Distance (m)
35	0
28	3
23	6
12.6	6
4.7	10
3.0	13

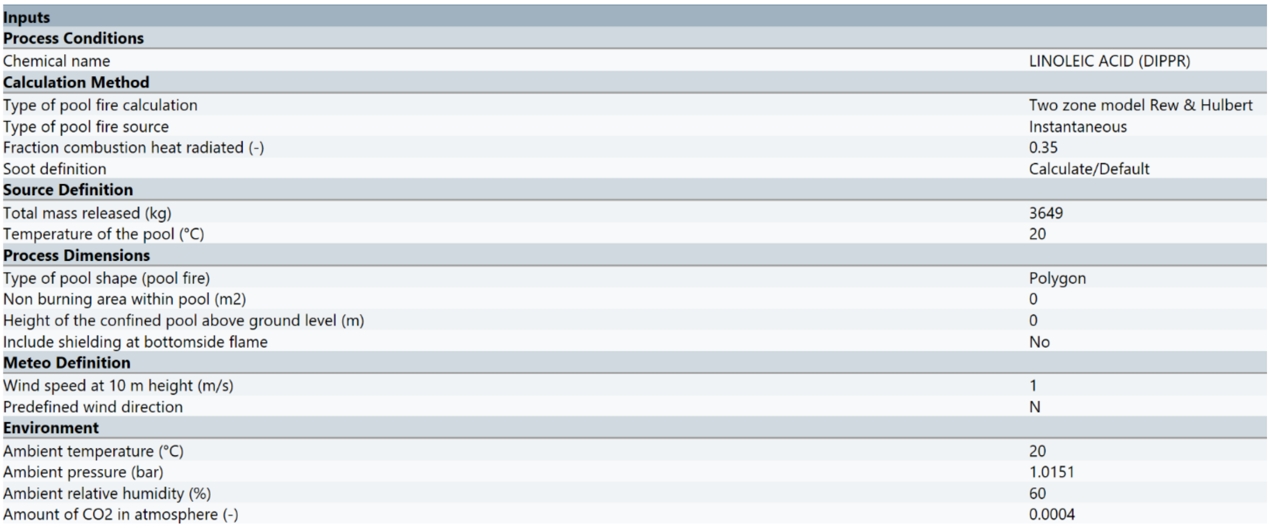
B6. Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Transformers contain oil to provide cooling and insulation. If arcing occurs within the transformer, the oil will rapidly heat generating gases above their auto ignition point. The pressure of the gases may rupture the reservoir allowing oxygen to enter resulting in the gases auto igniting. The oil is released from the reservoir and is ignited by the burning gases.

It has been assumed that the transformer has bund dimensions of approximately 12.5 m x 9 m which is based upon similar projects; hence, if a spill from the transformer was to occur it would fill the base of the bund resulting in a pool fire with the dimensions of the bund.

The exact type of transformer oil to be used in unknown, for the purposes of this assessment, it has been assumed that a natural ester oil such as FR3 will be used which is composed of soybean oil, itself a mixture of triglycerides. These triglycerides are esters of fatty acids, predominantly linoleic acid. Linoleic acid has a flash point of approximately 200 °C, while the FR3 oil itself has a higher flash point of 300 °C. For the purposes of providing a conservative analysis, pure linoleic acid has been selected as the transformer oil. The input file used to model this scenario has been provided in

The results of the analysis are shown in **Appendix Figure B-2**.



Inputs	
Process Conditions	
Chemical name	LINOLEIC ACID (DIPPR)
Calculation Method	
Type of pool fire calculation	Two zone model Rew & Hulbert
Type of pool fire source	Instantaneous
Fraction combustion heat radiated (-)	0.35
Soot definition	Calculate/Default
Source Definition	
Total mass released (kg)	3649
Temperature of the pool (°C)	20
Process Dimensions	
Type of pool shape (pool fire)	Polygon
Non burning area within pool (m2)	0
Height of the confined pool above ground level (m)	0
Include shielding at bottomside flame	No
Meteo Definition	
Wind speed at 10 m height (m/s)	1
Predefined wind direction	N
Environment	
Ambient temperature (°C)	20
Ambient pressure (bar)	1.0151
Ambient relative humidity (%)	60
Amount of CO2 in atmosphere (-)	0.0004

Appendix Figure B-2: BESS Fire Input File

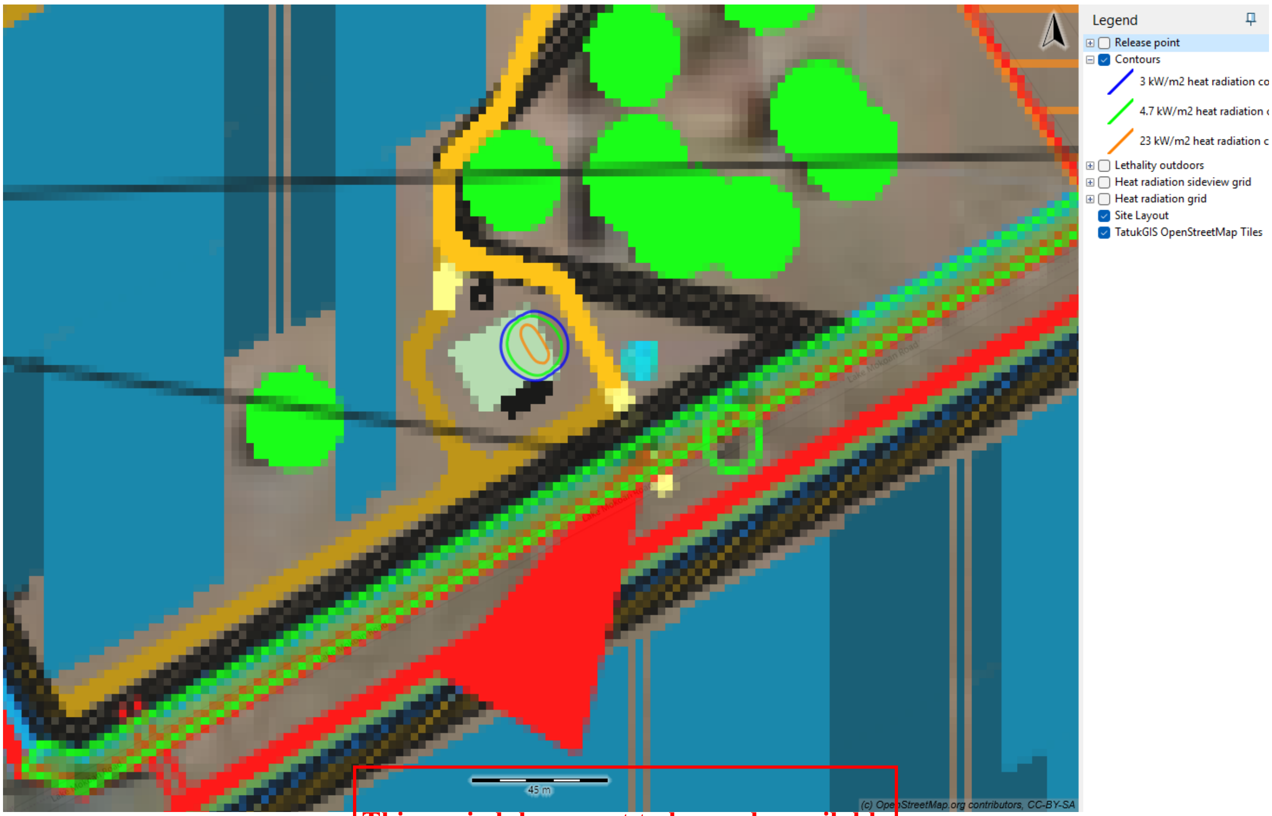
The above information was input into Effects which calculated the following outputs:

- Surface Emissive Power (SEP) – 79.5 kW/m^2
- Flame height – 17.4 m

The results of the analysis are shown in **Appendix Table B-4**, with the heat radiation contours depicted in **Appendix Figure B-3**.

Appendix Table B-4: Heat Radiation Impacts From a Transformer Bund Fire

Heat Radiation (KW/m^2)	Distance (m)
35	17
23	19
12.6	24
4.7	37
3.0	45



Appendix Figure B-3: Transformer Bund Fire Impact Contours

B7. Transformer Electrical Surge Protection Failure and Explosion

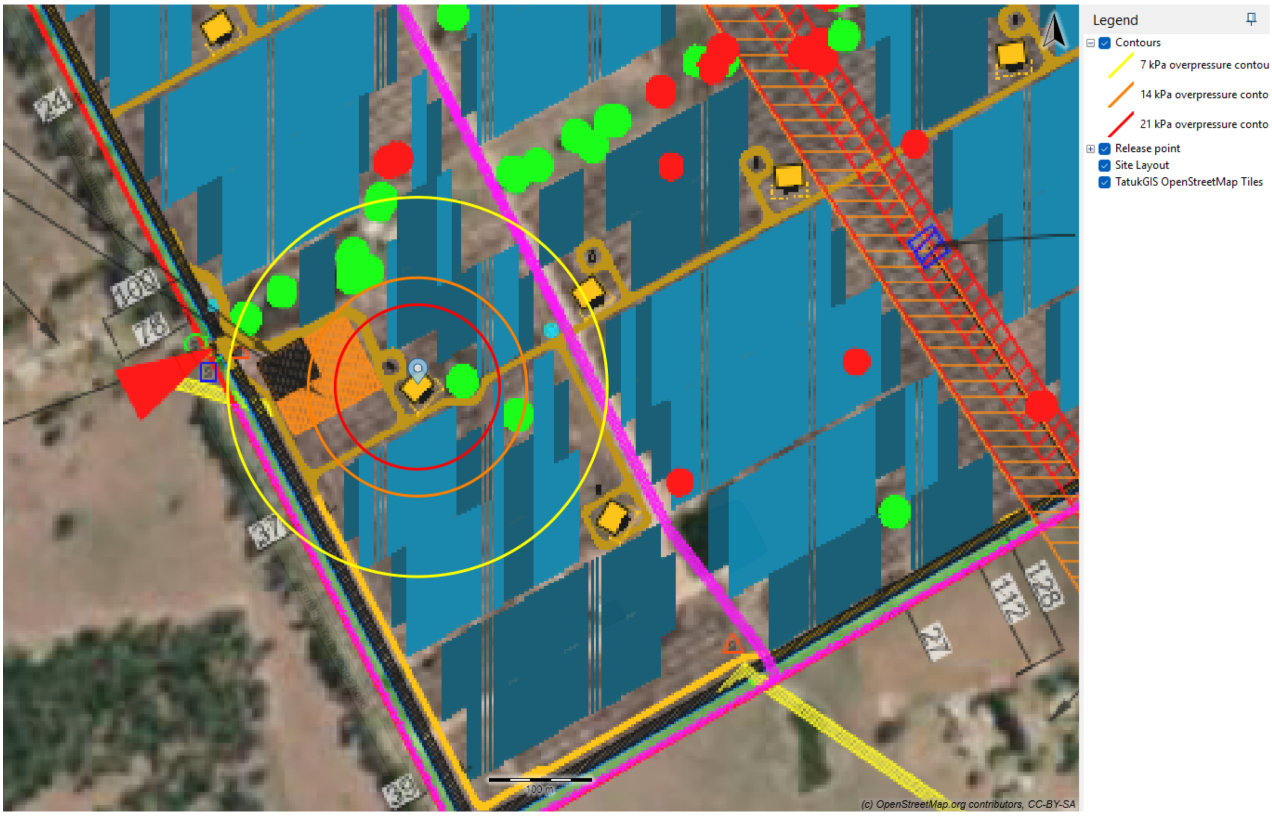
If a transformer is impacted by extreme electricity surge, such as in the event of a lightning strike, the ester oil within the transformer may ignite and explode resulting in substantial overpressure impacts. The following data has been obtained to model a transformer explosion:

- Weight – 3,649 kg (based on 4,100 L of oil contained within a single transformer and an oil density of 890 kg/m^3)
- α – 0.05 for hydrocarbons (Ref. [22])

The above information was input into Gexcon Effects with the results of the explosion calculations provided in **Appendix Table B-5**, with the impact contours depicted in **Appendix Figure B-4**.

Appendix Table B-5: Overpressure from a Transformer Explosion

Overpressure (kPa)	Distance (m)
70	40
35	58
21	81
14	107
7	186



Appendix Figure B-4: Transformer Explosion Overpressure Contours

Appendix C

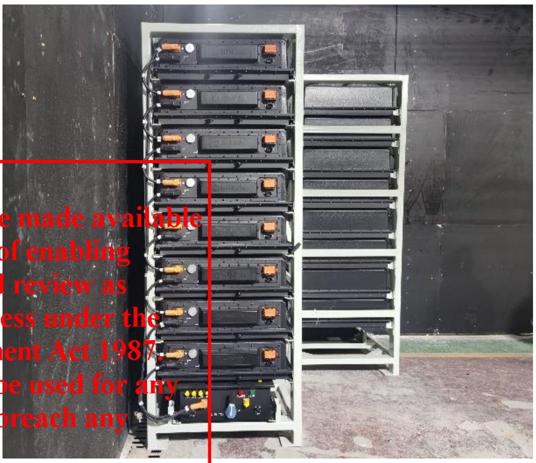
Sample UL9540A Report

Prüfbericht – Produkte
Test report – Products

TÜVRheinland®

Prüfbericht-Nr.: *Test Report No.:*	CN23XPOX 001	**Auftrags-Nr.:** 168418338 *Order No.:*	Seite 1 von 36 *Page 1 of 36*
Kunden-Referenz-Nr.: *Client Reference No.:*	2347845	**Auftragsdatum:** 2023.03.13 *Order date:*	

Auftraggeber: *Client:*	**Xiamen Hithium Energy Storage Technology Co., Ltd.** 201-1, Comprehensive Building 5, No. 11, Butang Middle Road, Industrial Base of Xiamen Torch High Tech zone (Tongxiang), Xiamen, Fujian P.R. China
Prüfgegenstand: *Test item:*	Cluster
Bezeichnung / Typ-Nr.: *Identification / Type No.:*	CL00344U001L
Auftrags-Inhalt: *Order content:*	Test report
Prüfgrundlage: *Test specification:*	UL 9540A: 2019 (Fourth Edition)
Wareneingangsdatum: *Date of sample receipt:*	2023.03.28
Prüfmuster-Nr.: *Test sample No.:*	Engineering sample
Prüfzeitraum: *Testing period:*	2023.03.30 to 2023.04.12
Ort der Prüfung: *Place of testing:*	See to clause 1.1 of main report
Prüflaboratorium: *Testing laboratory:*	See to clause 1.1 of main report
Prüfergebnis*: *Test result*:*	See main report



erstellt von: created by:	Stephen Huang	**genehmigt von:** *authorized by:*	Corney
Datum: *Date:* 2023.05.17	Stephen Huang	**Datum:** *Date:* 2023.05.17	Corney Zhang
Stellung / *Position*	Project Engineer	**Stellung /** *Position*	Reviewer

Sonstiges / *Other:* This report does not evidence compliance of the provided sample with the relevant standards but only with the referred tests. This test report documents the findings of examination conducted on the delivered product mentioned above only. This report does not entitle the applicant to carry any safety mark on this or similar products. Further for sales or other application purposes of the tested product, any reference to TÜV Rheinland or a test through TÜV Rheinland is only permissible with prior written consent of TÜV Rheinland.

Zustand des Prüfgegenstandes bei Anlieferung: *Condition of the test item at delivery:*	Prüfmuster vollständig und unbeschädigt *Test item complete and undamaged*

* Legende:	P(ass) = entspricht o.g. Prüfgrundlage(n)	F(ail) = entspricht nicht o.g. Prüf grundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
**Legend:*	*P(ass) = passed a.m. test specification(s)*	*F(ail) = failed a.m. test specification(s)*	*N/A = not applicable*	*N/T = not tested*

Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens.

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INTRODUCTION

Model fire codes and energy storage system standards require energy storage systems to comply with UL 9540, which in turn requires battery cells and modules to comply with UL 1973. Compliance with these standards reduces the risk of batteries and battery energy storage systems (BESS) creating fire, shock or personal injury hazards. However, they don't evaluate the ability of the BESS installed as intended and with fire suppression mechanisms in place if necessary, from contributing to a fire or explosion in the end use installations.

To address these fire and explosion hazards associated with the installation of a BESS, the fire and other codes require energy storage systems to meet certain location, separation, fire suppression and other criteria. Those codes also provide a means to provide an equivalent level of safety based on large scale fire testing of anticipated BESS installations.

UL 9540A is intended to provide a test method that can be used as a basis for validating the safety of a BESS installation in lieu of meeting the specific criteria provided in those codes. The data generated can be used to determine the fire and explosion protection required for installation of a BESS.

The test method is initiated through the establishment of a thermal runaway condition that leads to combustion within the BESS. The test method outlined in UL 9540A consists of several steps – cell level testing, module level testing, unit level testing and installation level testing. The cell and module level testing steps are information gathering steps to inform the unit and installation level testing.

The following outlines the information that may be gathered as part of the testing:

a) Cell level – An individual cell fails in a manner that leads to thermal runaway and fire through a suitable method such as external heating. Data such as off-gassing contents, temperatures at venting and temperatures at thermal runaway are recorded.

b) Module level – One or more cells within a BESS module fail in the manner determined during the cell level testing. Data such as fire propagation in the module, temperatures on the failed cells and surrounding cells, off-gassing contents and heat release data are gathered.

c) Unit level – A complete BESS is installed surrounded by target (e.g. dummy) BESS and walls separated at a distance as intended in its installation. The module level test is repeated on a module located in the BESS in the most unfavorable location. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; observation of fire propagation from BESS to target units and walls as well as observance of explosions or evidence of re-ignition within the BESS; and heat release and off-gassing contents are gathered.

d) Installation level – This test is a repeat of the unit level test with the test conducted within a test room and with the intended fire suppression system installed as well as any overhead cables (that can lead to fire propagation) installed. This test is intended to validate the fire suppression system for the BESS installation. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; fire propagation from the BESS to target units, walls or overhead cables and any observable explosion incidents or re-ignition within the BESS; and off-gassing contents (if needed) and heat release are gathered.

Contents

1 General information

1.1 Test specification

Standard: ANSI/CAN/UL 9540A: 2019 (Fourth Edition)

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

This report presents the result of unit level tests of UL 9540A: 2019.

All tests were conducted at TUV Rheinland (Shenzhen) Co., Ltd. and TUV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer.

Testing period: March 30, 2023 to April 11, 2023

Refer to Clause 4 for test and measurement instruments.

1.2 General remarks

This report is descriptive and provide the test data only.

The test results presented in this report relate only to the object tested.

This report shall not be reproduced, except in full, without the written approval of the testing laboratory.

Throughout this report a ☐ comma / ☒ point is used as the decimal separator.

1.3 Revision information

New report, not applicable.

1.4 Definitions

CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

MODULE – A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

UNIT – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such as cells, modules, battery management systems, ventilation devices and other ancillary equipment.

BATTERY SYSTEM (BS) – Is a component of a BESS and consists of one or more modules typically in a rack configuration, controls such as the BMS and components that make up the system such as cooling systems, disconnects and protection devices.

BATTERY ENERGY STORAGE SYSTEM (BESS) – Stationary equipment that receives electrical energy and then utilizes batteries to store that energy to supply electrical energy at a future time. The BESS, at a minimum consists of one or more modules, a power conditioning system (PCS), battery management system (BMS) and balance of plant components.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test.

b) TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS) – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

Note: Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), the unit level test can be done at battery system level. In such case, the BESS is be read as BS throughout this report.

NON-RESIDENTIAL USE – Intended for use in commercial, industrial or utility owned locations.

RESIDENTIAL USE – In accordance with this standard, intended for use in one or two family homes and town homes and individual dwelling units of multi-family dwellings.

THERMAL RUNAWAY- The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

STATE OF CHARGE (SOC) – The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

2 General Product Information

The product information and parameters were provided by the client as below.

2.1 Cell

Manufacturer:	**Xiamen Hithium Energy Storage Technology Co., Ltd.** 201-1, Comprehensive Building 5, No. 11, Butang Middle Road, Industrial Base Of Xiamen Torch High Tech Zone (Tongxiang), Xiamen, Fujian P.R. China	
Model number:	LFP71173207/280Ah	
Chemistry:	☒ $LiFePO_4$ ☐ NMC ☐ NCA ☐ LTO ☐ Other:	
Physical configuration:	☒ Prismatic ☐ Cylindrical ☐ Pouch	
	Weight(kg):	5.43±0.2kg
Electrical rating :	Rated capacity (Ah):	280
	Nominal voltage (V):	3.2
Standard charge method:	Charge current (A):	140
	Standard Charge Voltage (V):	3.65
	Cut off current (A):	14
Standard discharge method:	Discharge current (A):	140
	End of discharge voltage (V):	2.5
Maximum continuous charge current (A):	280	
Maximum continuous discharge current (A):	280	
Compliance with UL 1973:	☒ Yes TUV Rheinlad TUVus Certification: US 72228053 0001, Report No.: CN22YQLL 001 ☐ No	

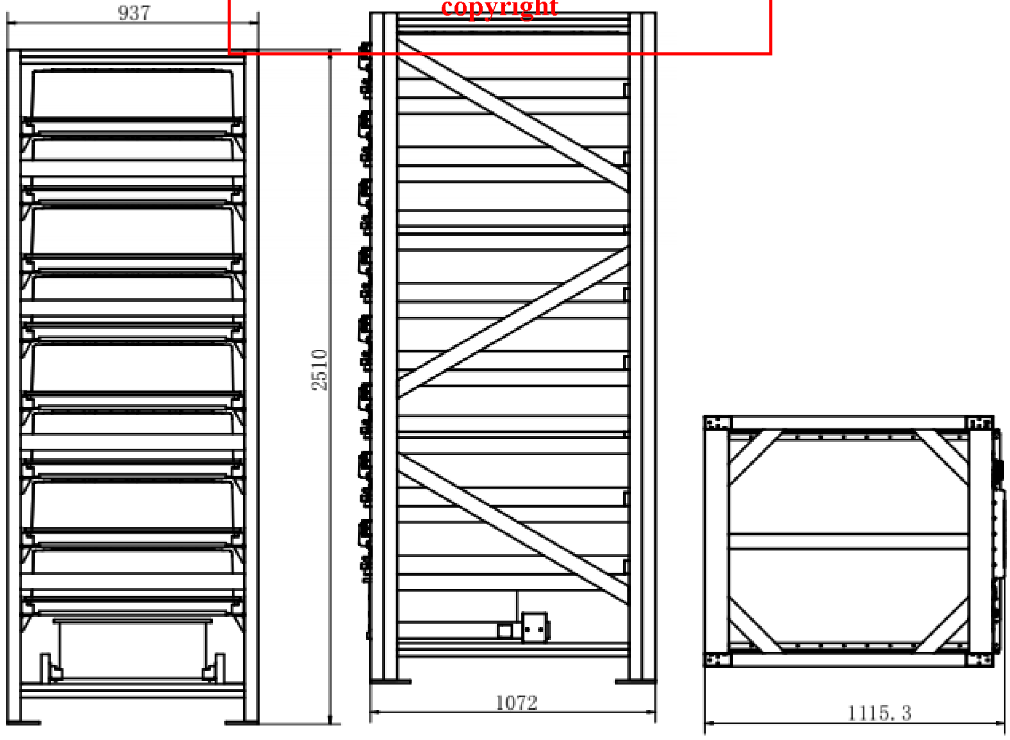
2.2 Module

Manufacturer:	**Xiamen Hithium Energy Storage Technology Co., Ltd.** 201-1, Comprehensive Building 5, No. 11, Butang Middle Road, Industrial Base Of Xiamen Torch High Tech Zone (Tongxiang), Xiamen, Fujian, P.R. China	
Model number:	ML00043U001L	
Physical configuration:	Metal base, the other sides are non-metallic material. A mica plate is installed under the top enclosure.	
	Weight:	310 ±10 kg
	Cells in series/parallel:	48S1P
Cooling method:	Liquid cooling	
Separation between cells:	Thermal insulation sheet: Aerogel Heat insulation pad and Polyurethane foam, see Figure 4 for install location details.	
Electrical rating:	Rated capacity:	280 Ah
	Nominal voltage:	153.6 Vdc
Standard charge method:	Charge power:	21504 W
	End of charge:	The highest cell voltage reaches 3.65 V
Standard discharge method:	Discharge power:	21504 W
	End of discharge:	The lowest cell voltage reaches 2.5 V
Compliance with UL 1973:	☐ Yes	☒ No

2.3 Unit

Product name	Cluster
Model	CL00344U001L
Voltage range	960V-1401.6V
Nominal voltage	1228.8V
Maximum charge and discharge Current	170A(within one minute)
Rated capacity	280Ah
Operating Temperature	0-50°C(Cell)(Charge), -30-50°C(Cell)(Discharge)
Storage Temperature	-20°C to 45°C (within one month)
Recommend charging method declared by the manufacturer	Charged with constant power 172kW till cell voltage reaches 3.65V, at 25±2°C.
Recommend discharging method declared by the manufacturer	Discharged with constant power 172kW till cell voltage reaches 2.5V, at 25±2°C.
Nominal mass	About 2.9t
External dimensions (mm)	L*W*H:937*1116*2510

Unit diagram with overall dimension



Unit: mm

2.4 Photo

Module

Unit

3 Unit level test (section 9 of UL 9540A)

3.1 General

Unit level testing corresponds with the testing anticipated by fire codes and other codes impacting energy storage system installations to evaluate the large scale fire performance of BESS units installed in, on or adjacent to buildings or in other areas and their resultant performance to qualify for exceptions to limits in the codes imposed on these installations. The limitations where exceptions may be sought are limitations on the size of the individual BESS units, the total number of BESS units installed within a room, and the separation distances between BESS units and between BESS units and walls of the building.

In this test the initiating BESS unit is placed a set distance from target BESS units simulating BESS units identical to the initiating BESS unit, and from simulated walls representative on the installation. A thermal runaway is induced in cells, using the same approach as used in the module level testing within one of the modules in the initiating BESS, and a variety of measurements are taken. The results are intended to be used to verify that a fire within a single BESS unit will not spread to other units, nor breach the walls or the BESS enclosure (if provided), and there shall be no flying debris or explosive discharge of gases.

The test arrangement include the largest (energy) BESS unit for the installation to be represented by the test, and minimum spacing to adjacent walls and BESS units. The BESS may be tested with an internal fire suppression system provided by the manufacturer if that fire suppression system is required to be installed in the BESS. Optional internal fire suppression systems are not included in the unit level testing.

The test monitors the fire behavior of the BESS unit and measures heat release rates (convective and chemical); gas generation and composition; smoke release rate; maximum heat flux on the target BESS units, wall surfaces and within the accessible means of egress; maximum surface temperatures of the walls and modules within the target BESS units; and documents any explosions, deflagrations and flying debris from the BESS under test.

3.2 Unit sample preparation

The battery rack is constructed with 8 modules that was considered as a unit for purposes of the test.

All 8 modules samples through 3 charge/discharge cycles per the manufacturer's instructions to verify that the module was functional. Each cycle was defined as a charge to 100% SOC and allowed to rest 30 minutes and then discharged to an end of discharge voltage (EODV) determined by the module specification. Refer to 2.2 for the end of condition of charge and discharge.

3.3 Setup of the test

3.3.1 Battery system installation information

The installation information was provided by the client as below.

Intended use location.........................:	☐ Residential	☒ Non-residential
	☐ Non-residential rooftop	
	☐ Non-residential open garage use	
Type of installation ....:	☒ Indoor	☐ Outdoor
	☒ Floor/ground mounted	☐ Wall mounted
Row(s) of installation	☐ Single	☒ Multiple

3.3.2 Test site setup

Two instrumented wall with 3.66 m height, 4.1 m length. Walls were constructed of 116-mm (5/8-in) gypsum wall board and painted flat black.

Three units were used for the purpose of the test.

The initiating unit was positioned adjacent to the two instrumented wall sections.

Minimum separation distance from the unit to wall and between unit were provided by the client, separation distance: A=B=38.2mm, C=D=G=130mm, E=12.5mm.

Unit’s layout can be seen in Figure 1.

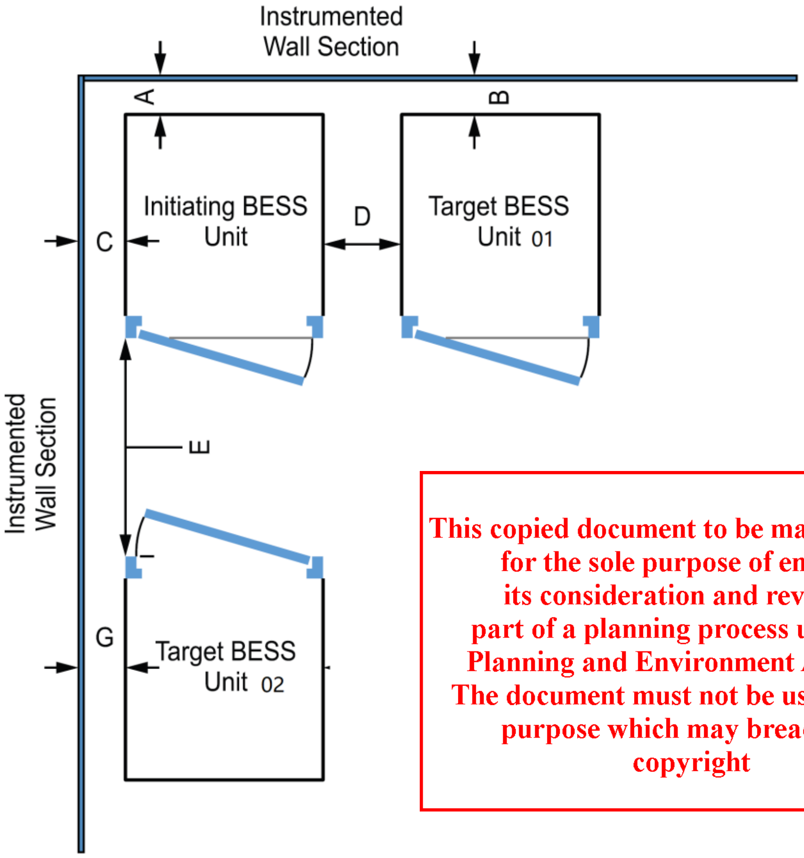


Figure 1. Layout of BESS units

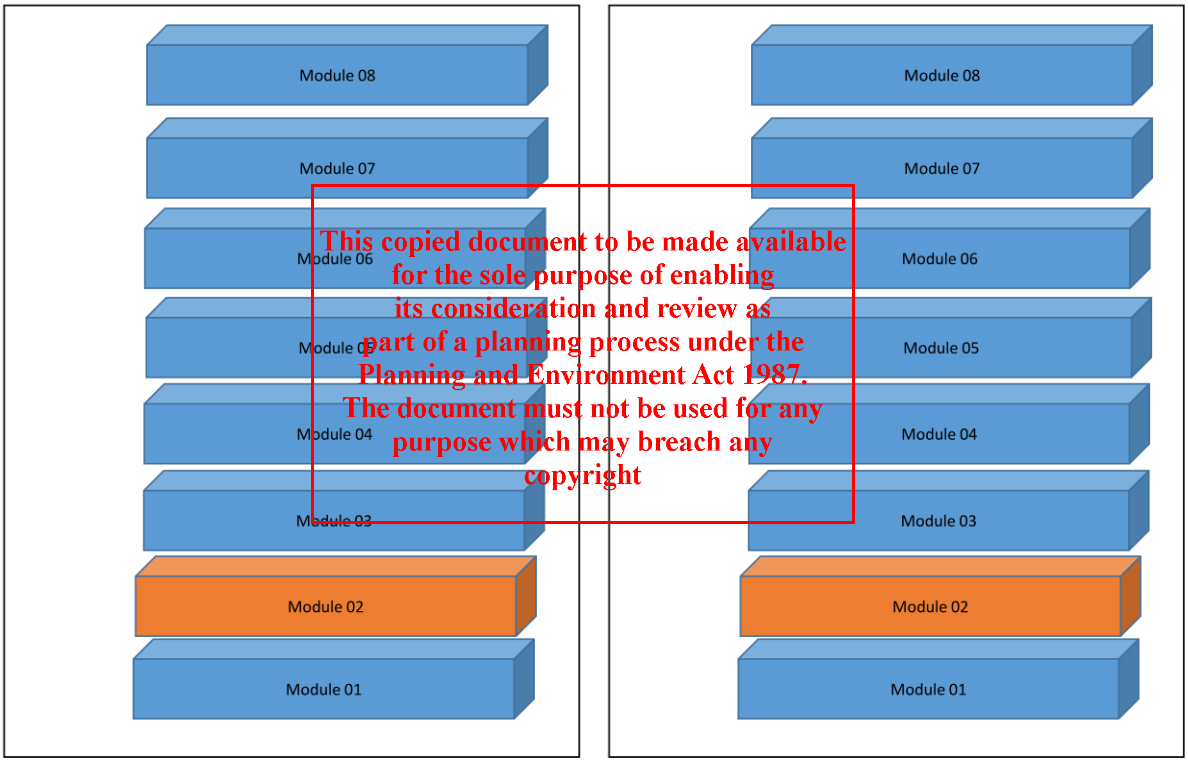
3.3.3 Thermal runaway setup

Setup of Unit:

There were three units were marked as initiating unit and target unit, one was initiating unit, and the others were target units. Each unit had been installed 8 modules.

Module **02** in initiating unit was selected as “initiating module” for the test.

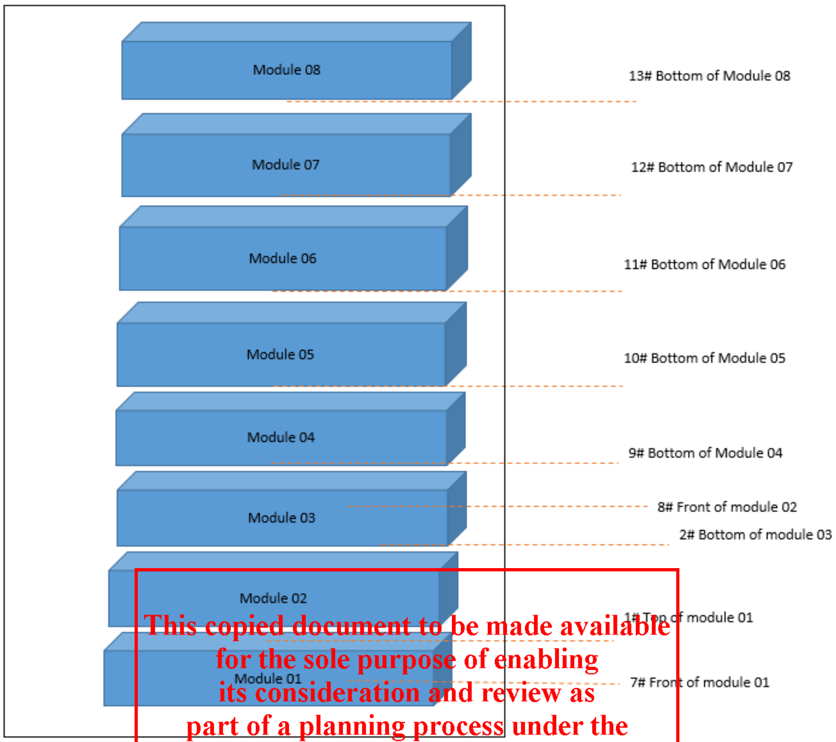
Modules **01, 03** in initiating unit and modules in target unit 01 and target unit 02 were used to check the possible propagation between modules in initiating unit and target unit. Figure 2 show the details.



Initiating Unit

Target Unit 01

Figure 2. Module numbering in unit



PS: #3 to #6 is on the front, back, left and right surface side of module 02

Figure 3. Thermocouple in initiating unit

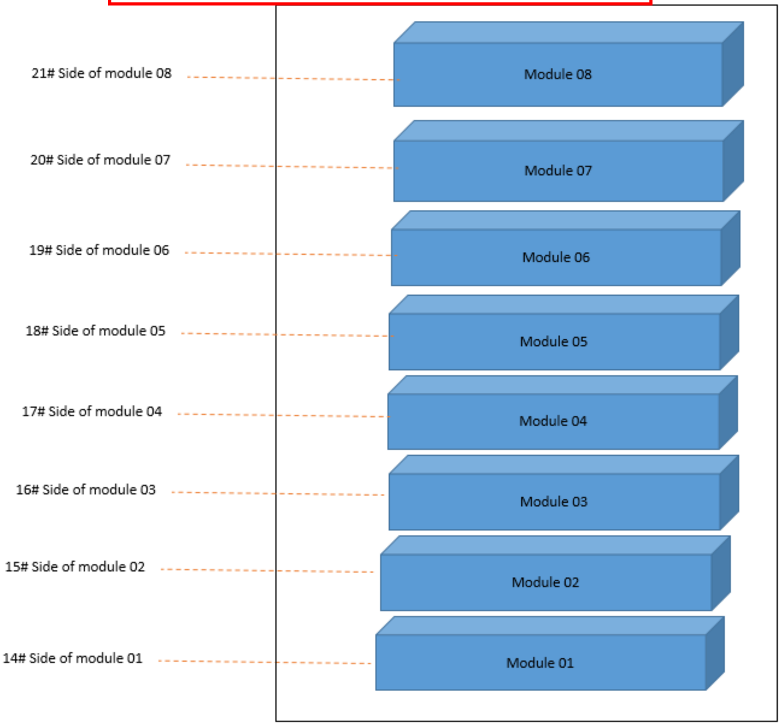


Figure 4. Thermocouple in target unit 01

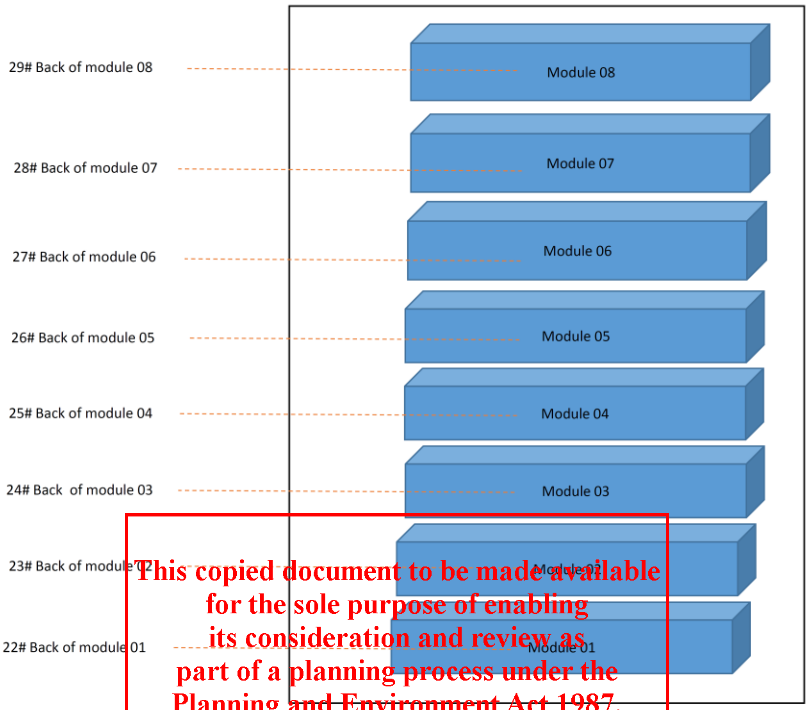


Figure 5: Thermocouple in target unit 02

Setup of module:

The module was consisted of 48 cells (1P48S). All cells in the module were numbered as below picture.

External heating method was used to initiate thermal runaway in the module. One PI sheet heater, rated 220V ac/650 W, size 160*140*3.0 mm, was fitted on cell #1-7.

A surface heating rate of 4° C (7.2° F) to 7° C (12.6° F) per minute was applied to the cell by a PID heating controller. The PID controller maintain the heating rate by controlling the voltage supply.

The heater was de-energized immediately and independently as the thermal runaway observed on the target cell.

Multiple thermocouples, Type K, 24AWG, were attached between the cells and under the heating surface. See Figure 6 for the detail locations.

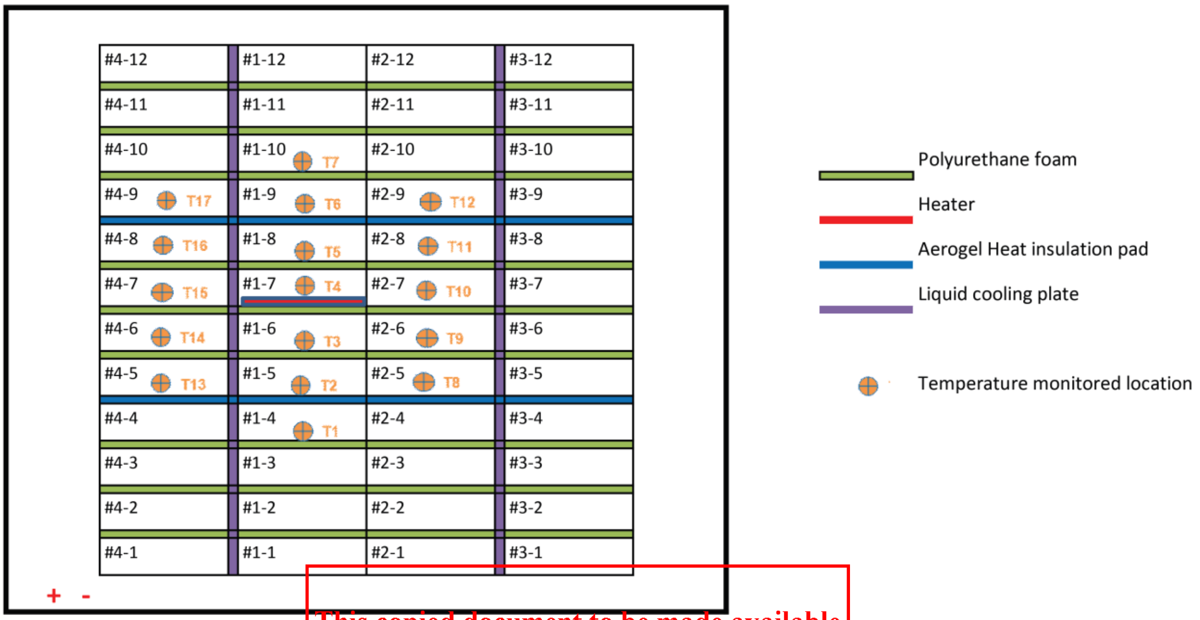


Figure 6. Cell number, location of heater, thermal insulation sheet (Aerogel Heat insulation pad and Polyurethane foam) and thermocouple

3.4 Observations and records

Before test:

The initiating module was charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

Ambient condition at the initiation of the test was 22°C, 50% R.H.

Test was performed on 2023.04.10, started at 16:44 PM.

Before the test, Module 2 in Initiating unit	
OCV (V)	161.4
Weight (kg)	311.5

Observations during test:

Time	1	2	3	4
Vent time	17:50:55	17:52:00	18:04:08	18:06:16
Thermal runaway	17:59:50	18:01:00	18:04:36	18:37:00

No flying debris or explosive discharge of gases during test.

No sparks, electrical arcs, or other electrical events during test.

No external flaming was observed.

Observations after test:

No damage on target walls.

No damage on target units.

The initiating cells (#1-5 to #1-8) were damaged (thermal runway) after the test. Cell #1-5 and cell #1-8 were damaged because of the cell to cell propagation.

After the test, Module 2 in Initiating unit	
OCV (V)	147.1
Weight (kg)	310.0
Weight loss (kg)	1.5

3.5 Temperature measurement

3.5.1 Temperature measurement of initiating module

Multiple thermocouples, Type K, 24AWG, were attached on all module and unit. See Figure 3 to Figure 6 for the detailed locations.

The thermocouple temperature of the module 2 in initiating unit was shown in the figure 7 as below.

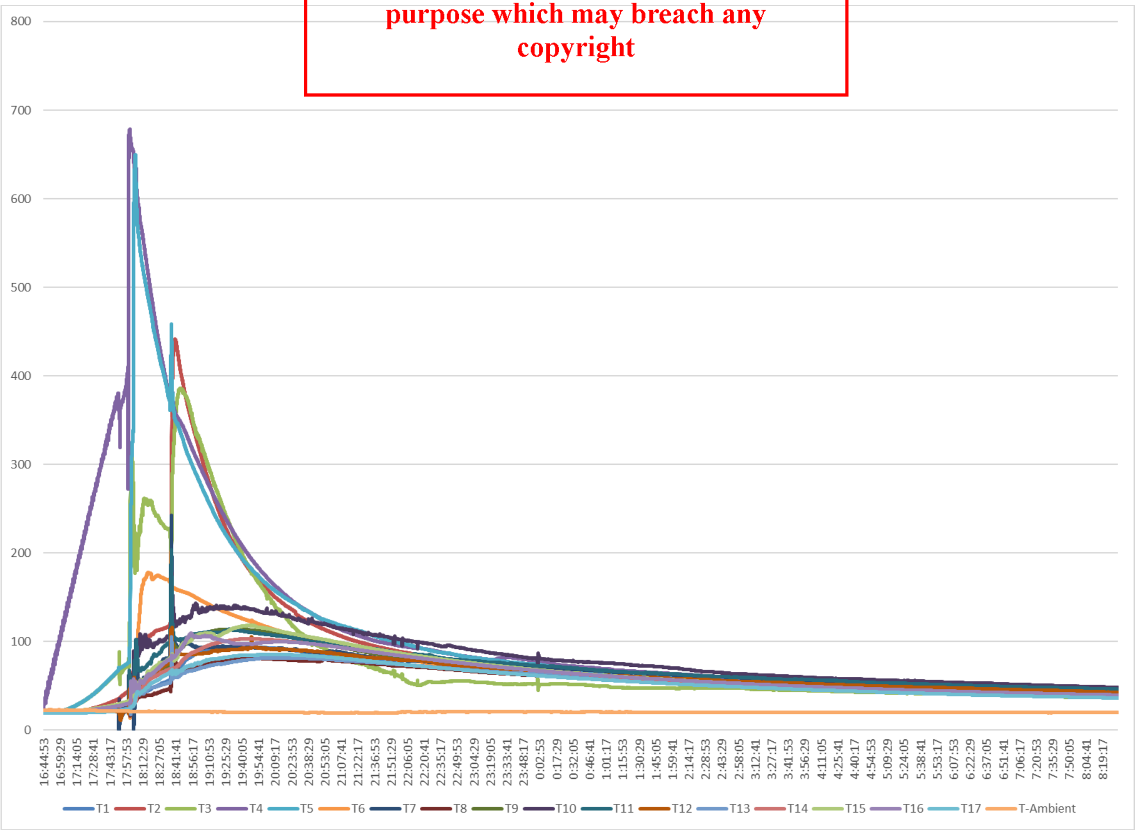


Figure 7. Temperature vs time curve of module 2 in initiating unit.

Thermocouple no.	Location	Maximum temp. °C
T1	Surface of cell #1-4	94.5
T2	Surface of cell #1-5	441.5
T3	Surface of cell #1-6	386.2
T4	Surface of cell #1-7	678.3
T5	Surface of cell #1-8	649.8
T6	Surface of cell #1-9	239.6
T7	Surface of cell #1-10	242.7
T8	Surface of cell #2-5	81.7
T9	Surface of cell #2-6	123.3
T10	Surface of cell #2-7	182.9
T11	Surface of cell #2-8	203.5
T12	Surface of cell #2-9	116.0
T13	Surface of cell #4-5	105.3
T14	Surface of cell #4-6	103.4
T15	Surface of cell #4-7	118.2
T16	Surface of cell #4-8	109.5
T17	Surface of cell #4-9	85.5
T_Ambient	Ambient temperature	23.9

3.5.2 Temperature measurement of moduless surface in unit

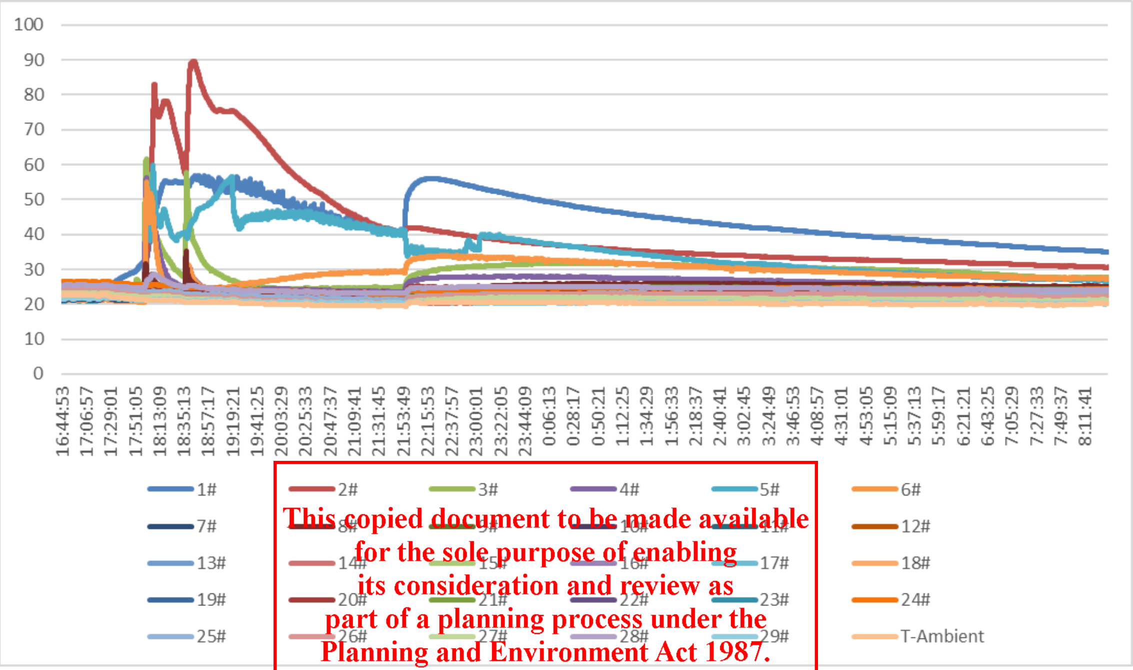


Figure 8: Surface temperatures of module in units

Unit	Channel Number	Location	Max Temp. (°C)
Initiating Unit	1#	Top of module 01 (near the heated cell)	57.0
	2#	Bottom of module 03 (near the heated cell)	89.7
	3#	Front of module 02	61.8
	4#	Back of module 02	56.3
	5#	Left of module 02	60.0
	6#	Right of module 02	55.0
	7#	Front of module 01	31.0
	8#	Front of module 02	35.2
	9#	Bottom of Module 04	24.9
	10#	Bottom of Module 05	22.9
	11#	Bottom of Module 06	23.7
	12#	Bottom of Module 07	24.3
	13#	Bottom of Module 08	23.3
Target unit 01	14#	Front of module 01	23.1
	15#	Front of module 02	23.7
	16#	Front of module 03	25.9
	17#	Front of module 04	23.7
	18#	Front of module 05	23.3
	19#	Front of module 06	23.2
	20#	Front of module 07	25.4
	21#	Front of module 08	23.8
Target unit 02	22#	Front of module 01	23.9

	23#	Front of module 02	23.9
	24#	Front of module 03	26.6
	25#	Front of module 04	25.2
	26#	Front of module 05	24.2
	27#	Front of module 06	23.3
	28#	Front of module 07	28.8
	29#	Front of module 08	22.2

3.5.3 Temperature measurement of instrumented wall

Wall surface temperatures were measured in vertical array at 152 mm intervals for the full height of the instrumented wall sections using Type K, 24 AWG thermocouple. The thermocouple array were collinear with the center line of initiating unit and target unit.

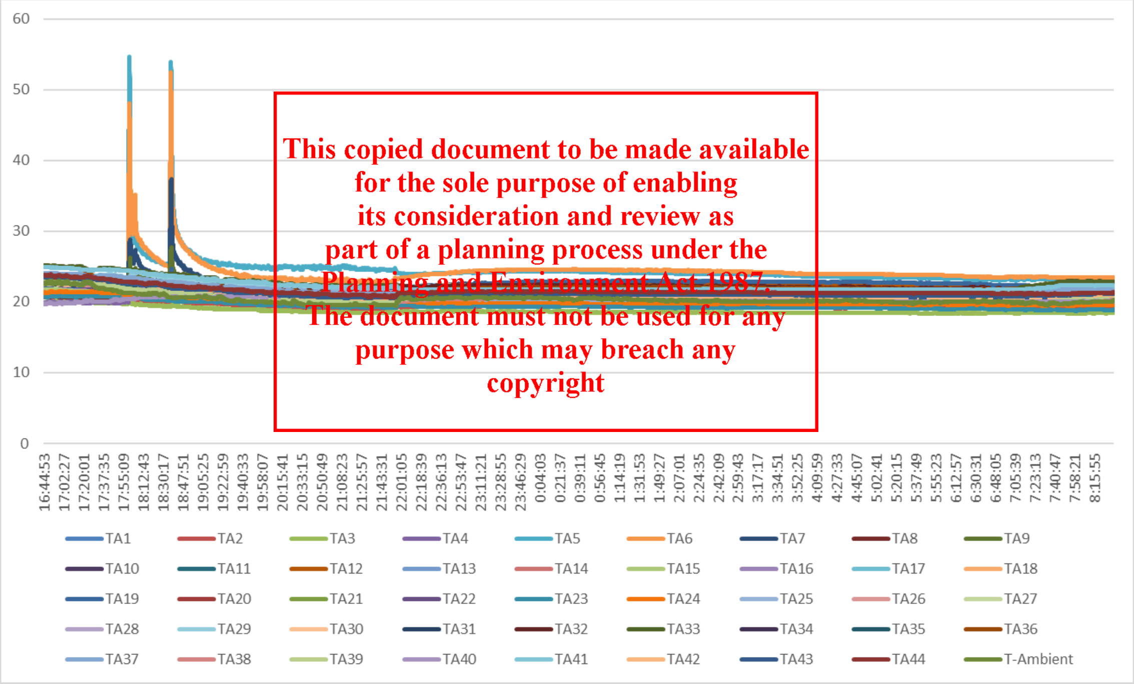


Figure 9. Temperature of instrumented wall A and B

Number	Location	Channel	Max Temp. (°C)
1	Wall A. Vertical array at 152 mm intervals. Left side of Unit1_sub-unitA in the horizontal direction.	TA1-TA22	54.7
2	Wall C. Vertical array at 152 mm intervals. In front of Unit1_sub-unitA in the horizontal direction.	TA23-TA44	

3.6 Heat flux measurement

Eight sensors were placed on the instrument wall A, wall C and target units to measure the heat flux, see below table and figure 10 for details.

Channel Number	Location
HF7, HF8	on the surface of instrumented wall A
HF9, HF10	on the surface of instrumented wall C
HF3, HF4	on target unit 01 surface that facing initiating unit
HF5, HF6	on target unit 02 surface that facing initiating unit

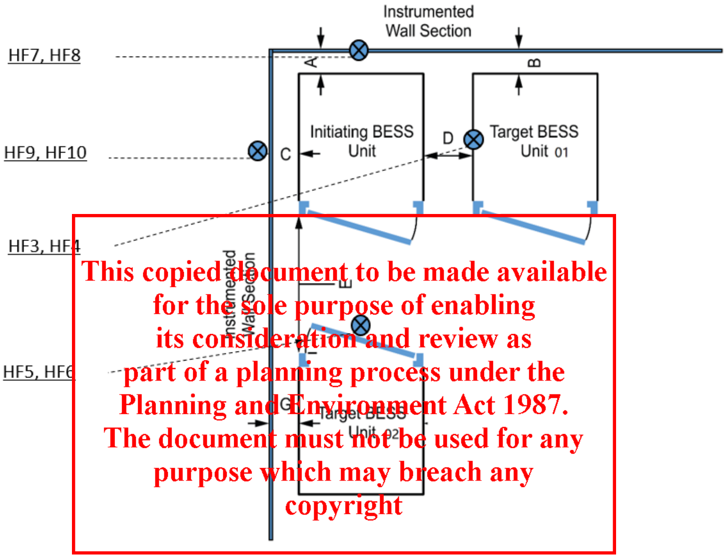


Figure 10. Layout of Heat flux sensor

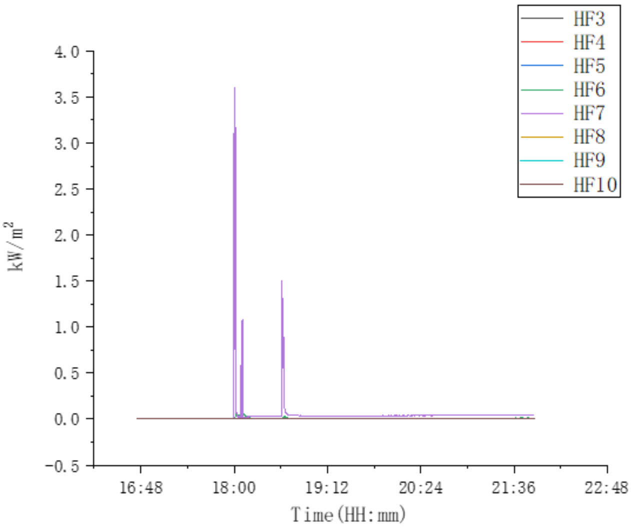


Figure 11. The measured heat flux of target walls and target unit

3.7 Chemical heat release rate measurement

The chemical heat release rates were measured by an oxygen consumption calorimeter measurement system consisting of a paramagnetic oxygen analyzer, non-dispersive infrared carbon dioxide and carbon monoxide analyzer, velocity probe, and a Type K thermocouple.
The instrumentations are located in the exhaust duct of the heat release rate calorimeter. The chemical heat release rate was calculated at each of the flows as follows:

$$HRR_1 = \left[E \times \varphi - (E_{co} - E) \times \frac{1-\varphi}{2} \times \frac{X_{co}}{X_{O_2}}\right] \times \frac{\dot{m}_e}{1 + \varphi \times (\alpha - 1)} \times \frac{M_{O_2}}{M_a} \times (1 - X^o_{H_2O}) \times X^o_{O_2}$$

In which:

HRR_t = total heat release rate, as a function of time (kW)

E = Net heat released for complete combustion per unit of oxygen consumed (adjusted for oxygen contained within cell chemistry, 13,100 kJ/kg)

E_{CO} = Net heat released for complete combustion per unit of oxygen consumed, for CO (adjusted for oxygen contained within cell chemistry, 17,600 kJ/kg)

φ = Oxygen depletion factor (non-dimensional), where:

$$\varphi = \frac{X^o_{O_2} \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X^o_{CO_2}]}{X^o_{O_2} \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

X_{CO} = Measured mole fraction of CO in exhaust flow (non-dimensional)

X_{CO_2} Measured mole fraction of CO_2 in exhaust flow (non-dimensional)

$X°_{CO_2}$ = Measured mole fraction of CO_2 in incoming air (non-dimensional)

$X°_{H_2O}$ = Measured mole fraction of H_2O in incoming air (non-dimensional)

X_{O_2} = Measured mole fraction of O_2 in exhaust flow (non-dimensional)

$X°_{O_2}$ = Measured mole fraction of O_2 in incoming air (non-dimensional)

α = Combustion expansion factor (non-dimensional; normally a value of 1.105)

M_a = Molecular weight of incoming and exhaust air (29 kg/kmol)

M_{O_2} = Molecular weight of oxygen (32 kg/kmol)

$\dot{m}_e$ = Mass flow rate in exhaust duct (kg/s), in which:

$$\dot{m}_e = C \times \sqrt{\frac{\Delta p}{T_e}}$$

or

$$\dot{m}_e = 26.54 \times \frac{A \times k_c}{f(\mathrm{Re})} \times \sqrt{\frac{\Delta p}{T_e}}$$

C = Orifice plate coefficient (in $kg^{1/2}m^{1/2}K^{1/2}$)

Δp = Pressure drop across orifice plate or bidirectional probe (Pa)

T_e = Combustion gas temperature at orifice plate or bidirectional probe (K)

A = Cross sectional area of the duct (m^2)

k_c = Velocity profile shape factor (non-dimensional)

$f(Re)$ = Reynolds number correction (non-dimensional)

Measured peak chemical heat release rate HRRt was 28.11kW

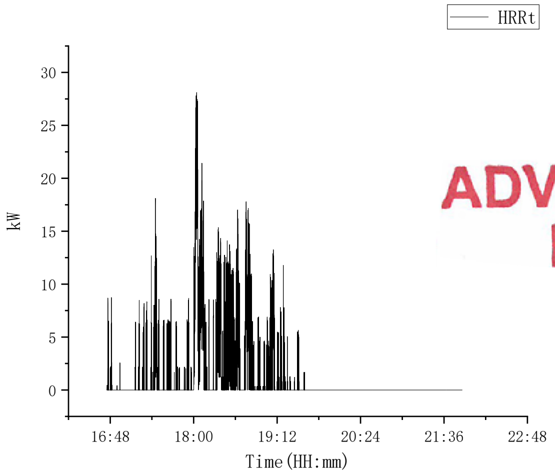


Figure 12. HRRt curve

Measured total heat release THR through the test was 18.455 MJ

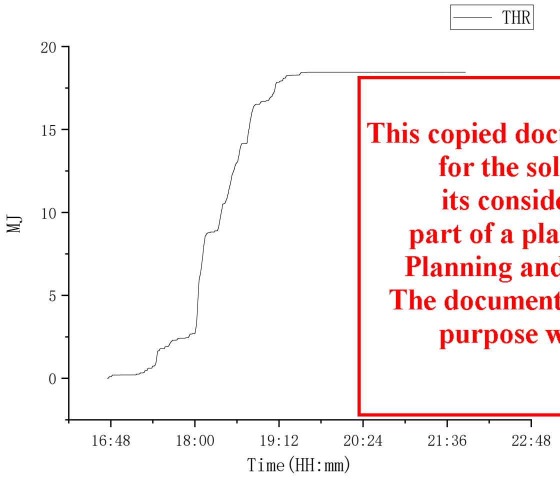


Figure 13. THR curve

3.8 Convective heat release rate measurement

The convective heat release rate were measured using thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct.

The convective heat release rate was calculated at each of the flows as follows:

$$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$

Where:

HRR_c = The convective heat release rate (kW)

V_e = The exhaust velocity (m/s)

A = The exhaust duct cross sectional area (m^2)

T_e = The temperature at the location where exhaust velocity is measured (K)

$353.22/T_e$ = The density of air at the velocity measurement location (kg/m^3)

T_o = The ambient temperature (K) in the test room

T = The thermopile temperature (K)

$$\int_{T_o}^{T} C_p dT = A_0(T - T_o) + A_1/2(T^2 - T_o^2) + A_2/3(T^3 - T_o^3) + A_3/4(T^4 - T_o^4)$$

Cp = Specific heat of air (kJ/kg-K), given as $\boldsymbol{C_p = A_0 + A_1T + A_2T^2 + A_3T^3}$, where:

A_0 = 0.9950

A_1 = -5.29933E-05

A_2 = 3.21022E-07

A_3 = -1.22004E-10

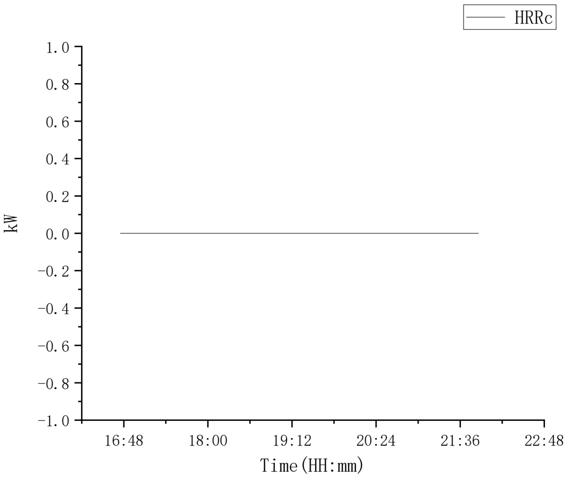


Figure 14. HRRc curve

3.9 Smoke release rate measurement

3.9.1 Test method

The light transmission in the calorimeter's exhaust duct was measured using a white light source and photo detector for the duration of the test.
The smoke release rate was calculated as follows:

The whole smoke release rate measurement system were self-checked using calibrated light filter before test. The self-check were performed at 100%, 79%, 50%, 32%, 16%, 10%, 1% and 0% light transmittance.

3.9.2 Test result

Peak smoke release rate SRR: 0.4124 m^2/s

Total smoke release TSR: 69.57 m^2

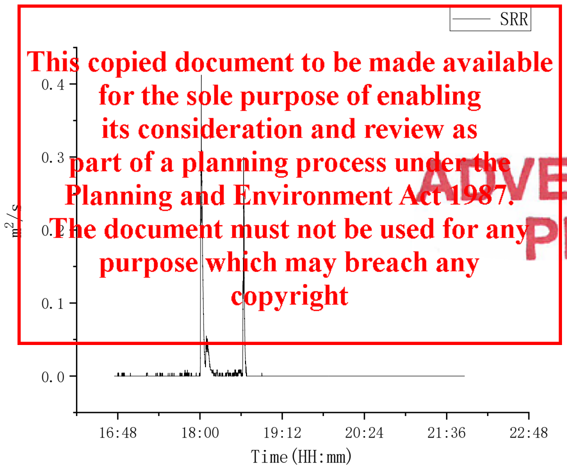


Figure 15. SRR curve

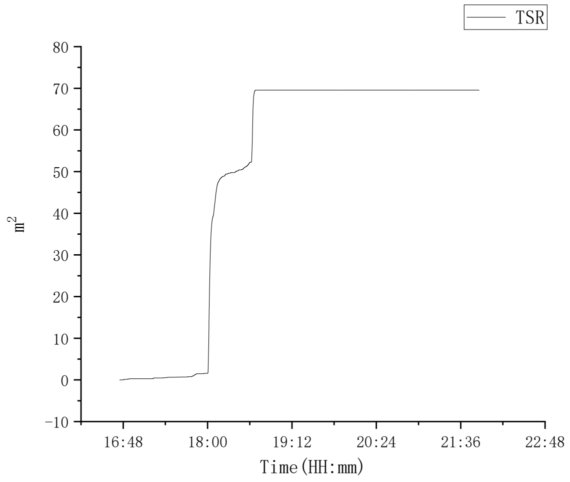


Figure 16. TSR curve

3.10 Gas generation measurement

3.10.1 Test method

The composition, velocity and temperature of the vent gases were measured within the calorimeter's exhaust duct.

Gas composition were measured using a Fourier-Transform Infrared Spectrometer with a resolution of 1 cm^{-1} and a path length of 4.2 m within the calorimeter's exhaust duct.

The hydrocarbon content of the vent gas was measured using flame ionization detection.

Hydrogen gas was measured with a palladium-nickel thin-film solid state sensor.

Composition, velocity and temperature instrumentation were collocated with heat release rate calorimetry instrumentation

3.10.2 Total gas release

Gas type	Gas components		Total volume of gas (L)
Hydrocarbon species	Methane	CH_4	37.5
	Ethylene	C_2H_4	19.4
	Ethane	C_2H_6	7.3
	Propylene	C_3H_6	26.8
	Propane	C_3H_8	11.2
Others	Carbon Monoxide	CO	55.7
	Carbon Dioxide	CO_2	214.8
	Hydrogen	H_2	299.1
	Ethylmethyl carbonate	C_4H_8O	41.7
	Dimethyl carbonate	$C_3H_6O_3$	83.2
Total Hydrocarbons (equivalent to C_3H_8, measured by FID)			220.7

3.10.3 Gas components

Concentration of different gas components were present according to gas species classification in Figures 17 to 20. Average flow rate was 9.77 m³/s during test.

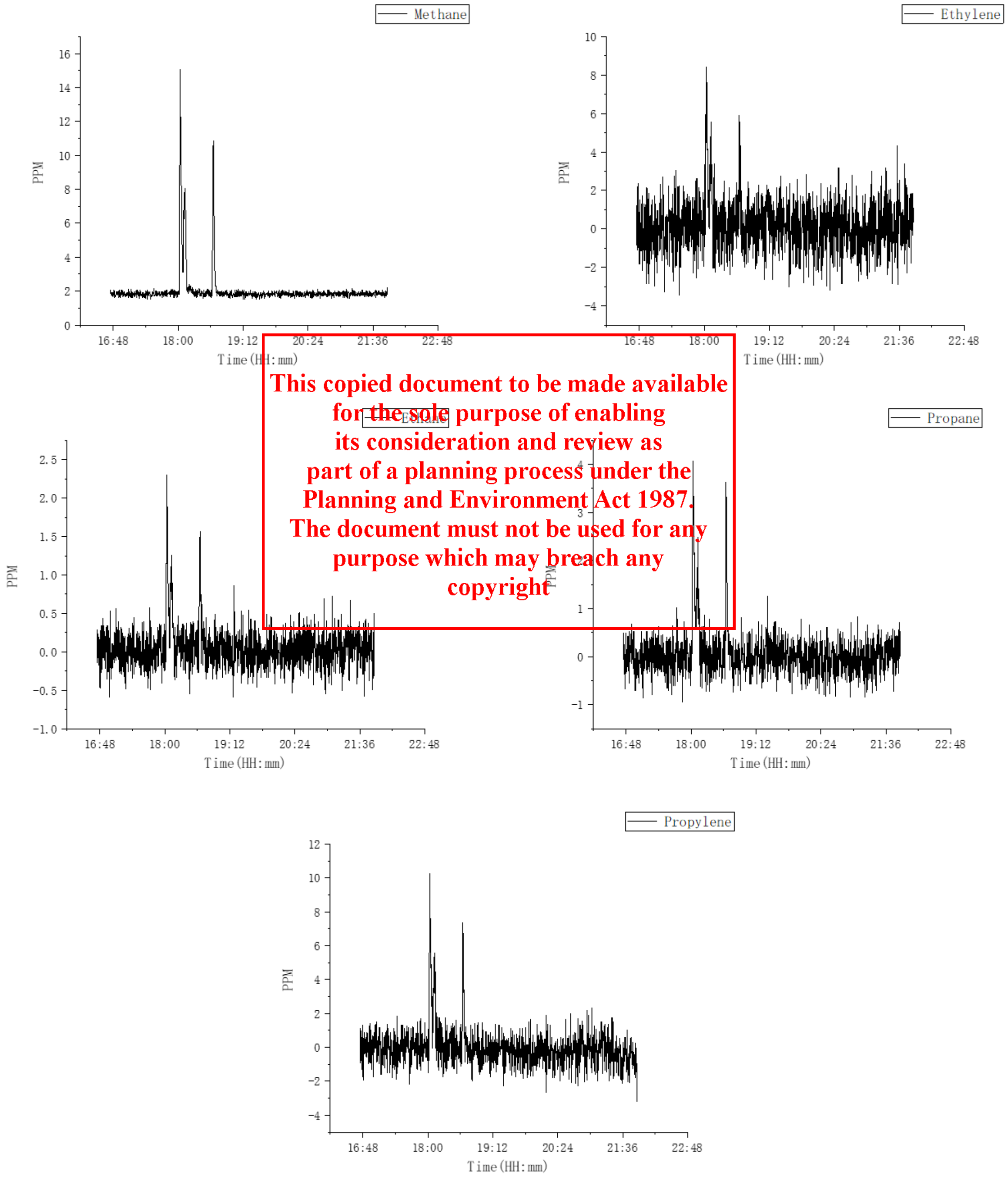


Figure 17 Hydrocarbon species

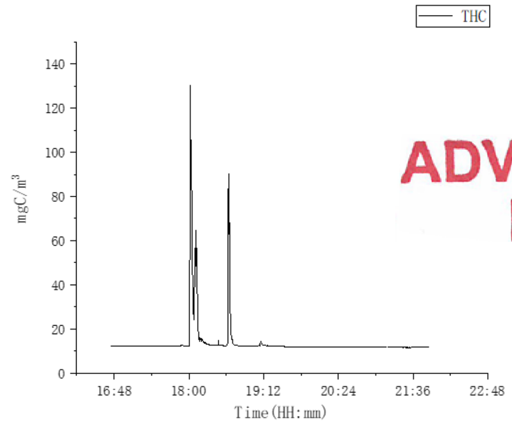


Figure 18 Total Hydrocarbons

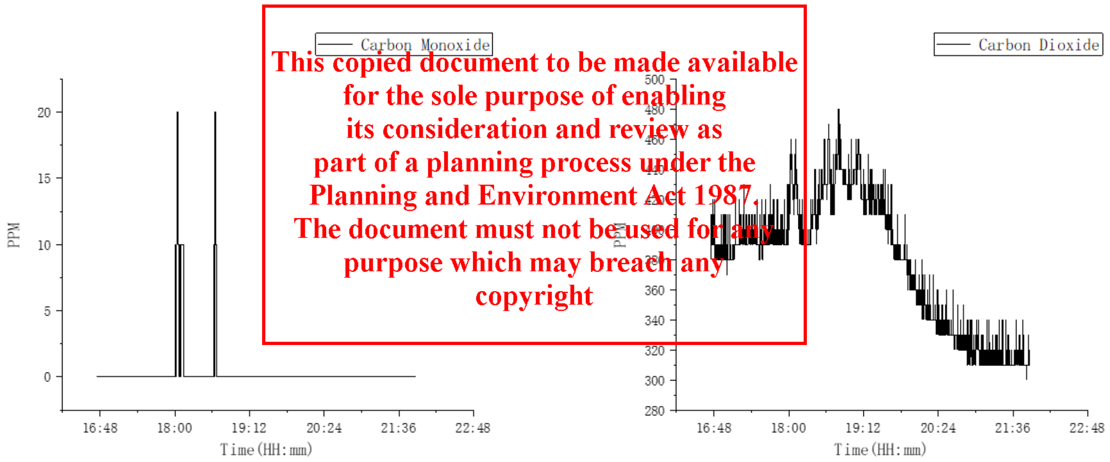


Figure 19 CO and CO2 concentration

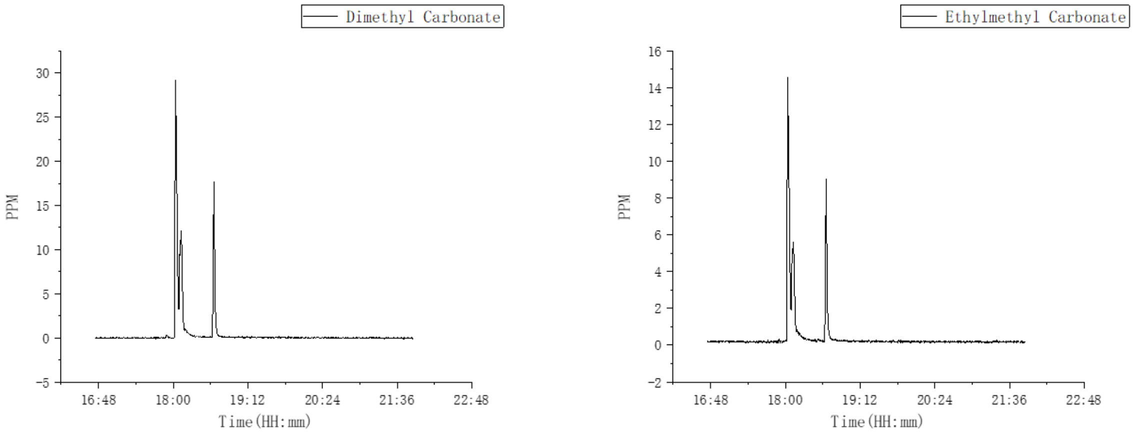


Figure 20 Others

3.11 Performance Summary Remark Against Criteria

Installation level testing was not required as the following performance conditions were met during the unit level test.

Performance conditions	Remark
a) If flaming outside of the unit observed, separation distances to exposures shall be determine by greatest flame extension observed during test. *(No flaming)*	No flaming observed in both external and internal of unit during the test.
b) Surface temperatures of modules within the target units adjacent to the initiating unit do not exceed the temperature at which thermally initiated cell venting occurs.	Surface temperatures of modules within the target units adjacent to the initiating unit was 28. 8°C, which is far below the cell venting temperature 274.3°C (From TUV RH cell 9540A report No.: CN22Y93I 001).
c) For units intended for intended for near exposures, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient installation.	Surface temperature measurements on wall surfaces was 54.7°C, below the 97°C of temperature rise above ambient.
d) Explosion hazards are not observed, including deflagration, detonation or accumulation of battery vent gases; *(The explosion shall not be observed)*	Explosion hazards were not observed during the test.
e) Heat flux in the center of the accessible means of egress shall not exceed 1.3kW/m²	There are no means of egress in this test. During the installation process, the distance shall be controlled to prevent the heat flux in the center of the accessible means of egress exceed 1.3kW/m²
f) The concentration of flammable gas does not exceed 25% LFL in air for the smallest specified room installation size.	Based on final installation conditions

3.12 Photos

Before the test:

Before covered with a single layer of cheese cloth ignition indicator

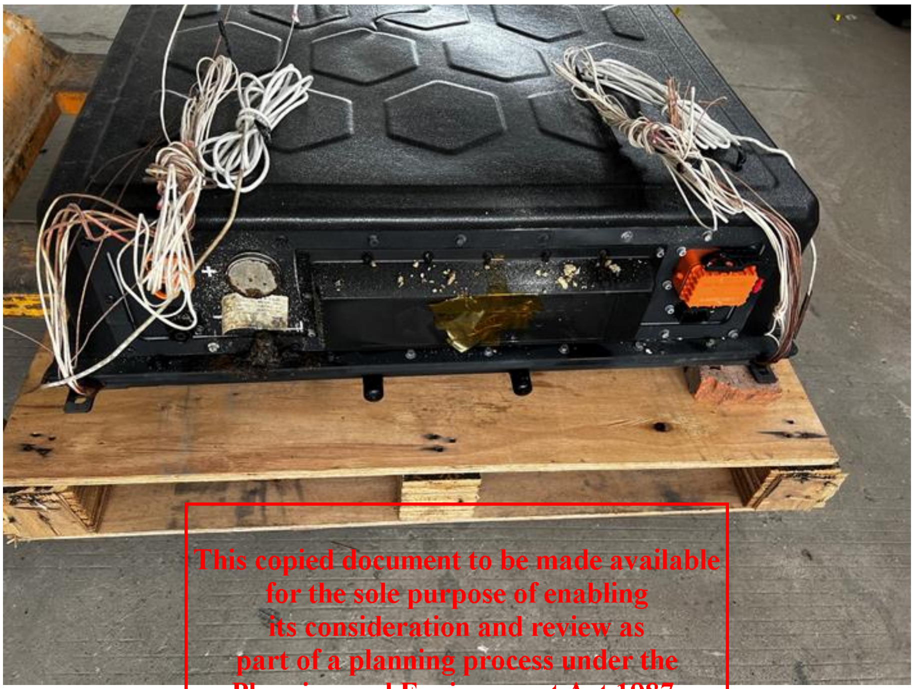
After covered with a single layer of cheese cloth ignition indicator

Three units

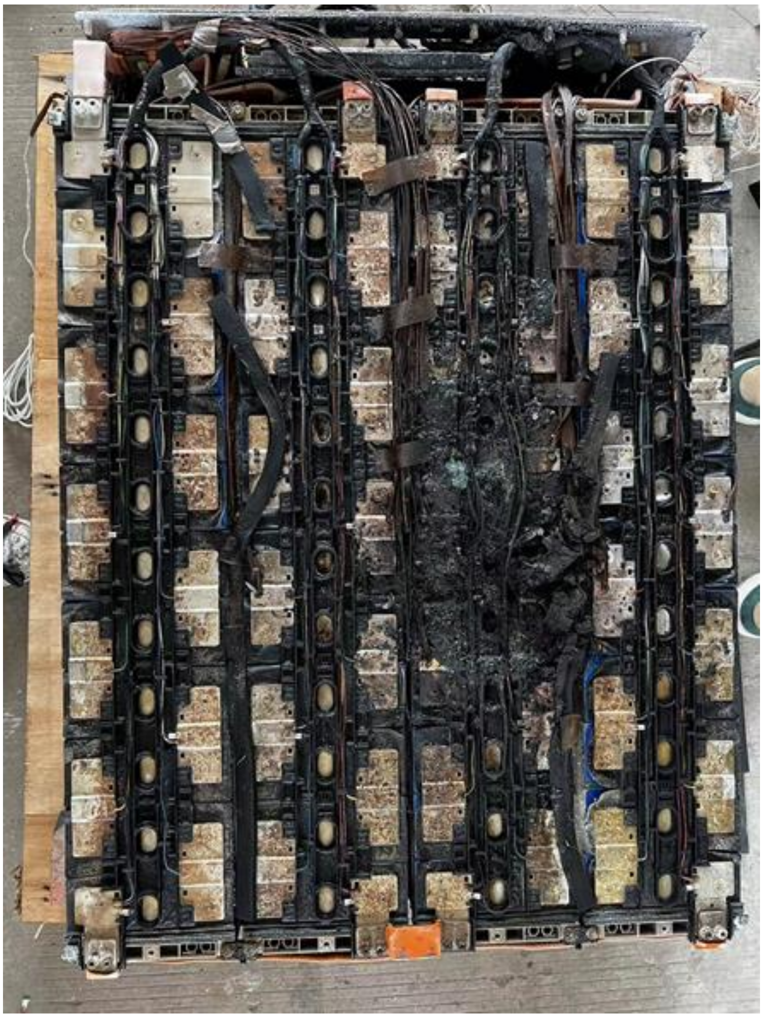
During the test:

After the test:

Initiating module



Damage of the internal components



3.13 List of Test and Measurement Instruments

No.	Equipment		Model	Rating	Inventory no.	Last Cal. date
1	Ambient monitor		WSB-2-H1	0-40°C, 10-90%RH	S-055	2022.07.11
2	Ambient monitor		WSB-2-H1	0-40°C, 10-90%RH	S-050	2023.01.03
3	Ambient monitor		WSB-2-H1	0-40°C, 10-90%RH	S-044	2023.01.03
4	Digital multi-meter		FLUKE101	0-600V	S-038	2023.02.08
5	Tape		1000mm 5000mm	0-1000mm 0-5000mm	S-040 S-042	2022.12.19 2022.12.19
6	Electronic scale		TCS-500	0-500kg	S-039	2023.02.09
7	Charge /discharge equipment		CE-7002-200V300A-R28GC	200V/300A	T-003	2023.03.20
8	Heating control equipment		DTB4824	0-1000°C	S-046-2	2022.07.11
9	Data acquisition equipment		ADAM-4117 ADAM-4118 MT4W MT4W DTM	0-10V 0-1000°C 0-100V 0-500V 0-1000°C	S-060-1 S-060-2 S-060-4~5 S-060-6~7 S-061	2022.07.11 2022.07.11 2022.07.11 2022.07.11 2022.07.11
10	Oxygen consumption calorimeter measurement system	Paramagnetic oxygen analyzer	OXYMAT 61	O2: 0-21%	S-024-09	2022.08.11
		CO and CO2 sensor	ULTRAMAT 23	CO2:0-10% CO:0-1%	S-024-08	2022.08.11
		Light filter	0.25 0.5 0.75	25% 50% 75%	S-024-5 S-024-6 S-024-7	2023.03.31
		Micro-differential pressure transmitter (20MW)	DP101MD	-100~100Pa	S-024-4	2023.02.08
		Thermopile (20MW)	TT I 20-CAXL-I I 6U-10-SPW-M	0~200°C	S-024-1~3	2023.01.03
11	Palladium-nickel thin-film solid state sensor		710B	0.05%~100%	S-023-1	2022.08.11
13	Electrochemical hydrogen sensors		H240000/H21000	0-4%/0-0.1%	S-023-2~3	2022.08.11
14	Fourier-Transform Infrared Spectrometer		MG6000	0.01ppm-100%	S-019	2023.01.30

15	Flame Ionization Detector	AO2040	0-2700mgC/m³	S-025-1	2022.08.11
16	Heat flux measurement equipment	64-5-20	0-50kW	S-031-1 S-031-2 S-031-3 S-031-4 S-031-5 S-031-6 S-031-7 S-031-8	2022.06.10 2022.06.10 2022.06.10 2022.09.09 2022.06.10 2022.06.10 2022.09.09 2022.09.09

End of Test Report

Riskcon engineering

Preliminary Hazard Analysis

Kennedys Creek Solar Farm

433 Link Development Pty Ltd (Lightsource BP)
Document No. RCE-24036_BP_PHA_Final_12Jun25_Rev(2)
Date 12/06/2025

Preliminary Hazard Analysis

Kennedys Creek Solar Farm

433 Link Development Pty Ltd (Lightsource BP)

Prepared by

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433 Link Development Pty Ltd (Lightsource BP)
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Date 12/06/2025

Quality Management

Rev	Date	Remarks	Prepared By	Reviewed By
A	27th March 2024	Draft issue for comment	Chris Butson	Renton Parker
0	9th May 2024	Updated to final		
1	25th June 2024	Finalised layouts added		
2	12th June 2025	Updated with current layouts and BESS fire modelling		

Executive Summary

Background

Lightsource BP (Lightsource) has acquired two Solar Photo-Voltaic (PV) projects at Benalla-Yarrawonga Road, Benalla in regional Victoria. These include the West Mokoan Solar Farm and the Kennedys Creek Solar Farm, which Lightsource is intending to deliver as a single development incorporating both sites for the purpose of grid connection and construction, known as the West Mokoan project (the Project). Lightsource is proposing to update the design, including increasing the Battery Energy Storage System (BESS) on the West Mokoan Solar Farm site and adding BESS to the Kennedys Creek Solar Farm. The objective of the Project is to provide support to the existing National Electricity Network by generating energy and providing temporary storage until it is needed and stabilising rapid fluctuation events. Combined, the Project will comprise approximately 380 MW DC of installed PV panels with approximately up to 300 MW BESS along with associated infrastructure. Associated infrastructure would include internal access tracks, operational and maintenance (O&M) facilities, civil works and onsite electrical infrastructure (substation) required to connect to the new 220 kV transmission line.

Lightsource BP has engaged Riskcon Engineering Pty Ltd (Riskcon) to prepare this PHA for the Kennedys Creek Solar Farm in addition to a review of the Fire Protection Quantity (FPQ) requirements as required by the Victorian Dangerous Goods (Storage and Handling) Regulation (VDGR) 2022 (Ref. (Victoria State Government, 2022)). This document represents the study for the Kennedys Creek Solar Farm site and does not include any other sites owned or operated by Lightsource.

Conclusions

A hazard identification table was developed for the Kennedys Creek Solar Farm site to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The consequence analysis showed that a transformer explosion due to surge protection failure would have potential to impact off site. As such, a frequency analysis was conducted on this incident. The frequency analysis estimated the site total fatality risk criteria would be zero 8.9×10^{-7}/year which is within the acceptable risk criteria indicated in HIPAP No.4 (Ref. (Department of Planning, Industry and Environment, 2011)) of 1×10^{-6}/year.

In addition, incidents exceeding 23 kW/m^2 were reviewed which indicated that, with the recommendation measures implemented, the contours from such incidents would not impact over the site boundary nor create incident propagation within the site and would be below the acceptable criteria.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the facility would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

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Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the facility would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

Recommendations

Notwithstanding the conclusions drawn, the following recommendations have been made and should be undertaken to cover the battery and inverter equipment as well as common hazards for a mechanical site prior to the commencement of operations of the Solar PV and BESS site to the extent dangerous goods exceed any thresholds:

- BESS must be tested in accordance with UL9540A.
- Testing to demonstrate clearances required to prevent propagation of fires between separated units.
- BESS to be installed in accordance with manufacturer and UL9540A report recommended clearances based on testing.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the facility area whilst meeting the recommended clearances.
- UL testing information shall be made available to the certifying authority. It is noted that a confidentiality agreement may be required.
- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.
- Separation distances between BESS and PCUs should be at least 3 m or in accordance with relevant standards and guidelines, whichever is greater.

- A submission to CFA shall be made for written advice in accordance with the VDGR.
- A Dangerous Goods (DG) risk assessment shall be prepared for the site.
- A DG register shall be prepared for the site.
- A site manifest shall be prepared at the site in accordance with Schedule 3 of the Victorian Dangerous Goods Regulation (VDGR).
- The site shall notify the Regulator (i.e. WorkSafe Victoria) of the presence of DGs.
- A site layout shall be prepared for the site in accordance with Schedule 3 of the VDGR.
- A placard schedule shall be prepared for the site to ensure the correct placards are installed.
- An Emergency Response Plan (ERP) shall be prepared for the site and submitted to the Fire & Rescue Victoria (CFA).
- An Emergency Services Information Booklet (ESIB) shall be prepared for the site and submitted to the CFA.
- The substation transformer bunds shall be designed according to the requirements detailed in AS 2067:2016(Ref. (Standards Australia, 2016)), and shall have a volume of 110% of the total volume of the mineral oil within the Transformer to account for any safety risks from a potential fire and or explosion.

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Abbreviations

Abbreviation	Description
ADG	Australian Dangerous Goods Code
AS	Australian Standard
CBD	Central Business District
DGs	Dangerous Goods
ERP	Emergency Response Plan
ESIB	Emergency Services Information Booklet
FCAS	Frequency Control Ancillary Services
FPQ	Fire Protection Quantity
HIPAP	Hazardous Industry Planning Advisory Paper
O&M	Operations & Maintenance
PHA	Preliminary Hazard Analysis
Pmpy	Per million per year
PV	Photovoltaic
SEP	Surface Emissive Power

SEPP	State Environmental Planning Policy
SSC	Spread Sheet Calculator
VDGR	Victorian Dangerous Goods Regulation
VF	View Factor

1.0 Introduction

1.1 Background

Lightsource BP (Lightsource) has acquired two Solar Photo-Voltaic (PV) projects at Benalla-Yarrawonga Road, Benalla in regional Victoria. These include the West Mokoan Solar Farm and the Kennedys Creek Solar Farm, which Lightsource is intending to deliver as a single development incorporating both sites for the purpose of grid connection and construction, known as the West Mokoan project (the Project). Lightsource is proposing to update the design, including increasing the Battery Energy Storage System (BESS) on the West Mokoan Solar Farm site and adding BESS to the Kennedys Creek Solar Farm. The objective of the Project is to provide support to the existing National Electricity Network by generating energy and providing temporary storage until it is needed and stabilising rapid fluctuation events. Combined, the Project will comprise approximately 380 MW DC of installed PV panels with approximately up to 300 MW BESS along with associated infrastructure. Associated infrastructure would include internal access tracks, operational and maintenance (O&M) facilities, civil works and onsite electrical infrastructure (substation) required to connect to the new 220 kV transmission line.

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1.2 Objectives

The key objectives of this PHA are to:

- Complete the PHA according to the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis (Ref. (Department of Planning, Industry and Environment, 2011));
- Assess the PHA results using the criteria in HIPAP No. 4 – Risk Criteria for Land Use Planning (Ref. (Department of Planning, Industry and Environment, 2011)); and
- Demonstrate compliance of the site with the relevant codes, standards and regulations (i.e. Planning and Environment Regulation, OHS Regulation, 2017 Ref. (WorkSafe Victoria, 2017)).
- Conduct a review of the Fire Protection Quantity (FPQ) under the Victorian Dangerous Goods (Storage and Handling) Regulations 2022 (VDGR, Ref. (Victoria State Government, 2022)).

1.3 Scope of Services

The scope of work is to complete a PHA study for the Kennedys Creek Solar Farm site located at Benalla-Yarrawonga Road, Benalla to assist in evaluating possible dangerous goods and demonstrating the facility is safe to operate and compliant with the relevant codes, standards, and regulations. The PHA study aims to support a new planning permit application to combine the Kennedys Creek Solar Farm Permit with the West Mokoan Solar Farm permit and the potential requirement for the application to be referred to WorkSafe in accordance with Clause 66.02 of the Benalla Planning Scheme. The scope does not include any other assessments which may be required as a result of this study nor any other Lightsource BP facilities.

2.0 Methodology

2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach (Ref. (Department of Planning, Industry and Environment, 2011)), although published by the NSW Department of Planning, Industry and Environment, has been used as the basis for the study to determine the level of risk assessment required. The selection of this framework is due to the absence of a suitable Victorian guideline or policy. The approach considered the development in context of its location, the quantity and type (i.e. hazardous nature) of Dangerous Goods stored and used, and the facility's technical and safety management control. The Multi-Level Risk Assessment Guidelines are intended to assist industry, consultants and the consent authorities to carry out and evaluate risk assessments at an appropriate level for the site being studied.

There are three levels of risk assessment set out in Multi-Level Risk Assessment which may be appropriate for a PHA, as detailed in **Table 2-1**.

Table 2-1: Level of Assessment PHA

Level	Type of Analysis	Appropriate If:
1	Qualitative	No major off-site consequences and societal risk is negligible
2	Partially Quantitative	Off-site consequences but with low frequency of occurrence
3	Quantitative	Where 1 and 2 are exceeded

The Multi-Level Risk Assessment approach is schematically presented in **Figure 2-1**.

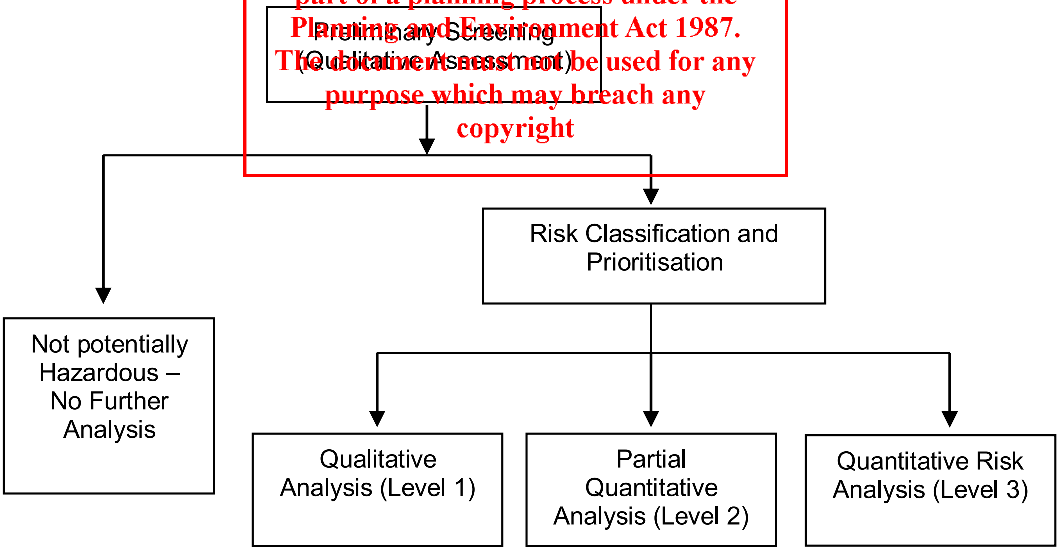


Figure 2-1: The Multi-Level Risk Assessment Approach

Based on the type of DGs to be used and handled at the proposed site, a **Level 2 Assessment** was selected for the Site. This approach provides a qualitative assessment of those DGs of lesser quantities and hazard, and a quantitative approach for the more hazardous materials to be used on-site. This approach is commensurate with the methodologies recommended in "Applying SEPP 33's" Multi Level Risk Assessment approach (DPIE, 2011). The selection of this framework is due to the absence of a suitable Victorian guideline or policy.

2.2 Risk Assessment Study Approach

The methodology used for the PHA is as follows;

Hazard Analysis – A detailed hazard identification was conducted for the site facilities and operations. Where an incident was identified to have a potential off-site impact, it was included in the recorded hazard identification word diagram (**Appendix A**). The hazard identification word diagram lists incident type, causes, consequences and safeguards. This was performed using the word diagram format recommended in HIPAP No. 6 (Ref. (Department of Planning, Industry and Environment, 2011)).

Each postulated hazardous incident was assessed qualitatively in light of proposed safeguards (technical and management controls). Where a potential offsite impact was identified, the incident was carried into the main report for further analysis. Where the qualitative review in the main report determined that the safeguards were adequate to control the hazard, or that the consequence would obviously have no offsite impact, no further analysis was performed. **Section 3.1** of this report provides details of values used to assist in selecting incidents required to be carried forward for further analysis.

Consequence Analysis – For those incidents qualitatively identified in the hazard analysis to have a potential offsite impact, a detailed consequence analysis was conducted. The analysis modelled the various postulated hazardous incidents and determined impact distances from the incident source. The results were compared to the consequence criteria listed in HIPAP No. 4 (Ref. (Department of Planning, Industry and Environment, 2011)). The criteria selected for screening incidents is discussed in **Section 3.1**.

Where an incident was identified to result in an offsite impact, it was carried forward for frequency analysis. Where an incident was identified to not have an offsite impact, and a simple solution was evident (i.e. move the proposed equipment further away from the boundary), the solution was recommended, and no further analysis was performed.

Frequency Analysis – In the event a simple solution for managing consequence impacts was not evident, each incident identified to have potential offsite impact was subjected to a frequency analysis. The analysis considered the initiating event and probability of failure of the safeguards (both hardware and software). The results of the frequency analysis were then carried forward to the risk assessment and reduction stage for combination with the consequence analysis results.

Risk Assessment and Reduction – Where incidents were identified to impact offsite and where a consequence and frequency analysis was conducted, the consequence and frequency analysis for each incident were combined to determine the risk and then compared to the risk criteria published in HIPAP No. 4 (Ref. (Department of Planning, Industry and Environment, 2011)). Where the criteria were exceeded, a review of the major risk contributors was performed, and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

Reporting – On completion of the study, a draft report was developed for review and comment by Lightsource BP. A final report was then developed, incorporating the comments received by Lightsource BP for submission to the regulatory authority.

3.0 Site Description

3.1 Site Location

The site is located at Benalla-Yarrawonga Road, Benalla which is approximately 230 km north of the Melbourne Central Business District (CBD). **Figure 3-1** shows the regional location of the site in relation to the Melbourne CBD.

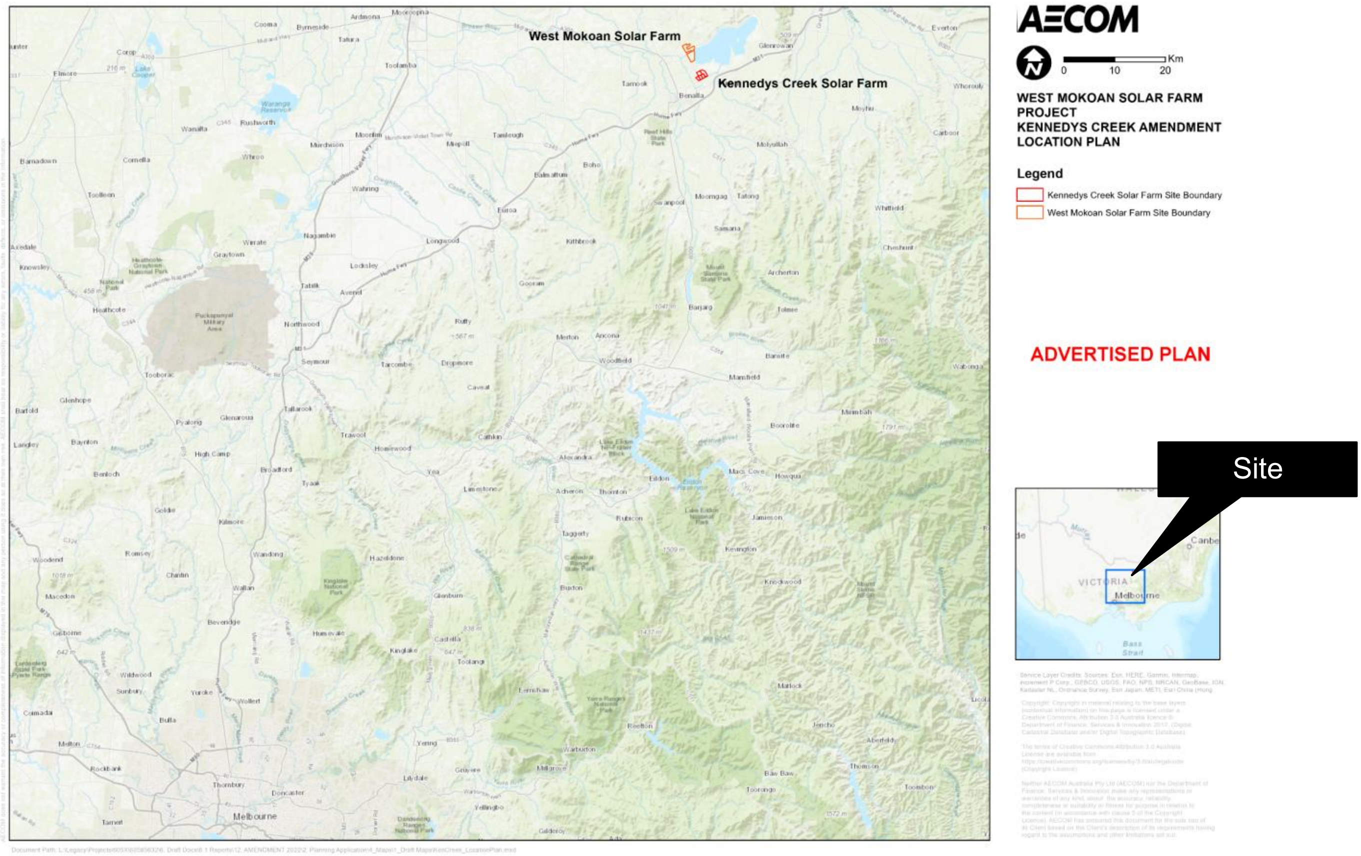


Figure 3-1: Site Location

3.2 Adjacent Land Uses

The land is located in a regional / rural area surrounded by the following land uses, which are adjacent to the site as shown in **Figure 3-2** are:

- North – Single residential property and associated outbuildings, defence and agricultural industries
- South – Public use
- East – Public use (wetlands)
- West – Industrial use

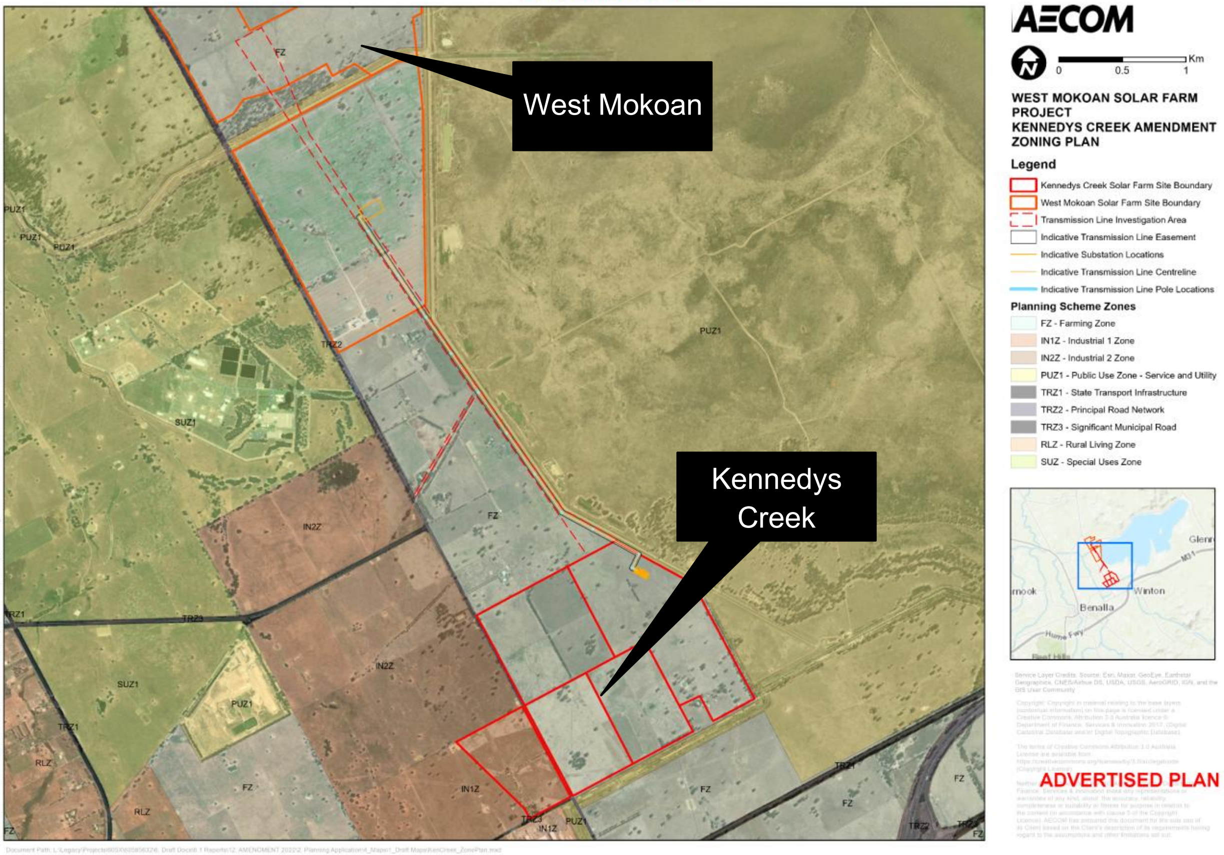


Figure 3-2: Surrounding Land Uses

3.3 Sensitive Receptors

The nearest residential locations are as follows and shown in **Figure 3-3**:

- 368 Benalla-Yarrawonga Road, approximately 120 metres from the north-western site boundary.
- 130 Benalla-Yarrawonga Road, approximately 750 metres from the south-eastern site boundary.
- 226 Murray Road, approximately 700 metres from the south-western site boundary.
- Nelson Road, approximately 200 metres from the south-eastern corner of the site.

Figure 3-3: Sensitive Receptors

3.4 Detailed Description

The purpose of the facility is to provide energy to and support to the National Electricity Network by generating electricity from the approximately 160 MW installed capacity of PV panels and the 120 MW BESS to arbitrage electricity demand fluctuations by storing electricity during off peak periods or when there is surplus supply and discharging the stored electricity when demand is highest (i.e. generator trips / shutdowns) or in peak periods. This is achievable due to the high response times achieved through lithium-ion battery storage which can fill peak demands due to the quick dispatchability of battery storage.

The site will have capacity to store up to 120 MW of energy with a duration of 2-4 hours and conceptually comprises the following key components:

- Approximately 262,439 solar PV panels on a single-axis tracking system mounted on aluminium or steel piles with an installed capacity of up to 125 MW Alternating Current (AC) (160 MW DC Capacity).
- Approximately 24 Power Conversion Units (PCU – two inverters per PCU).
- Direct Current (DC) and AC cabling for electrical reticulation.
- A designated substation.
- Operations and Maintenance (O&M) facility area, control building, office and amenities.

- Approximately 22 DC-coupled BESS units (co-located with PCUs)
- Internal all-weather access tracks and a laydown areas.
- Landscaping and revegetation.
- Security fencing, CCTV and Infra-Red lighting.
- Business identification signage (location to be determined).
- Realignment of easements.

3.4.1 PCUs

Power Conversion Units, or PCUs, house transformers and inverters which will be sited between the PV Module Arrays, along the solar farm's internal access tracks. There will be approximately 24 PCUs across the site which typically comprise:

- PCU transformer
- Inverters
- DC/DC converter

The PCUs convert the Direct Current (DC) to Alternating Current (AC), while the transformers increase the voltage from Low Voltage to a Medium or High Voltage, as required for the electricity grid connection. PCUs are a compact, containerised product, with each unit measuring approximately 2.5 metres wide by 2.9 metres high, with a depth of 12.2 metres (equivalent to a 40-foot shipping container for the double inverter units). Due to potential flooding over parts of the subject site, some of the PCUs will be elevated 300 mm above the applicable flood level in accordance with GBCMA requirements (refer to Section 7.2). The exact height of these PCUs will be subject to detailed design. **Figure 3-4** provides an example of the PCUs to be installed on site.

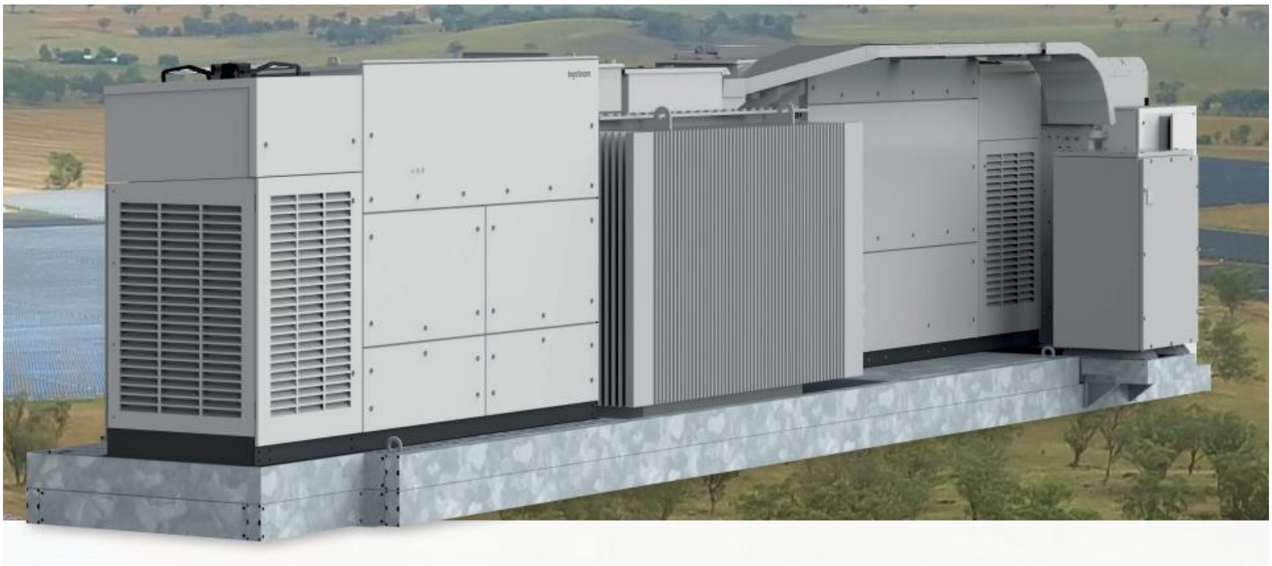


Figure 3-4: Typical Single Inverter

3.4.2 Battery Energy Storage System and Inverters

The proposed BESS configuration is for DC-coupled BESS units co-located with 22 of the 24 PCUs throughout the site. The major components of the BESS units include Li-ion batteries, inverters, transformers, heating ventilation air conditioning and fire protection. A typical BESS configuration is shown in **Figure 3-5**.

The layout provided in **Figure 3-6** shows the proposed locations of the PCUs and collocated BESS units throughout the site.

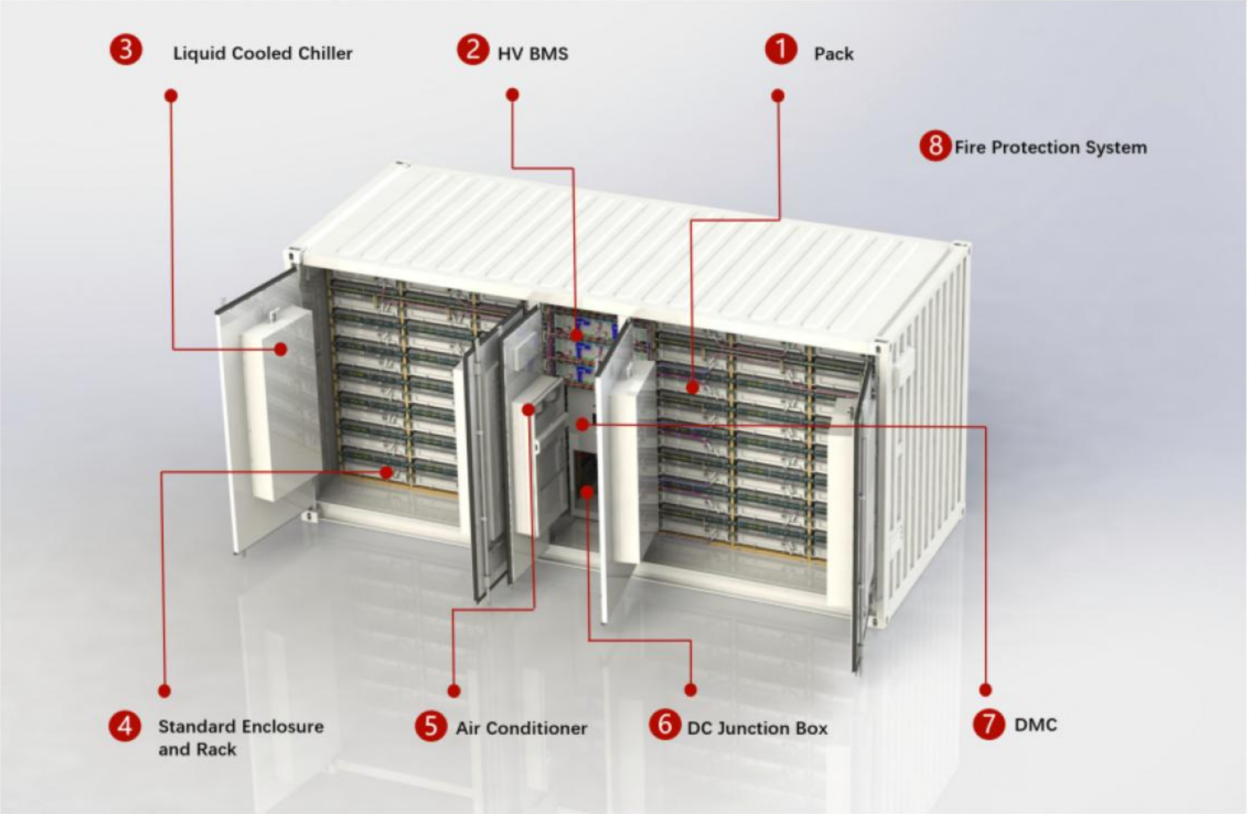
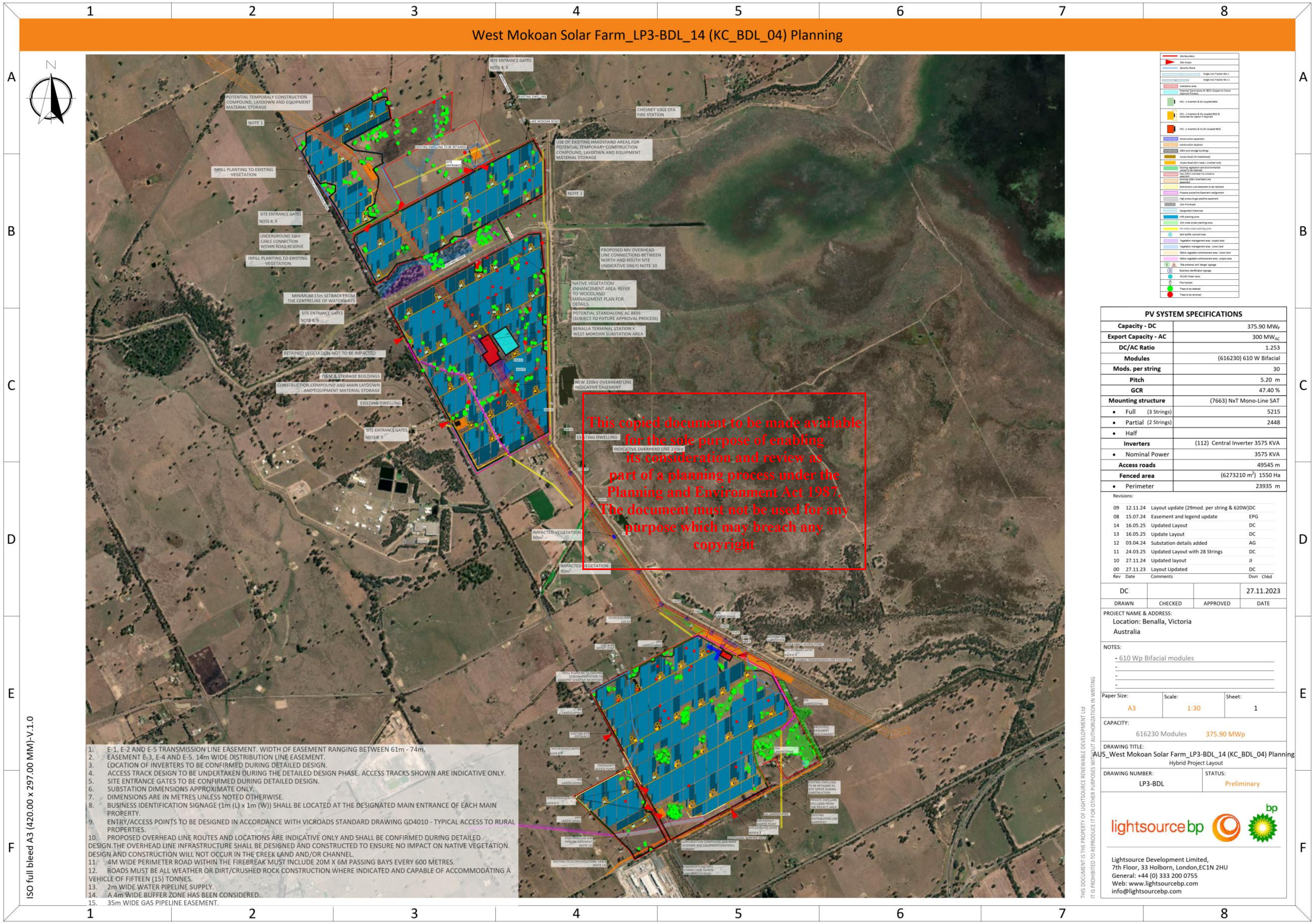


Figure 3-5: Typical BESS unit



1. E-1, E-2 AND E-5 TRANSMISSION LINE EASEMENT. WIDTH OF EASEMENT RANGING BETWEEN 61m - 74m.
2. EASEMENT E-3, E-4 AND E-5. 14m WIDE DISTRIBUTION LINE EASEMENT.
3. LOCATION OF INVERTERS TO BE CONFIRMED DURING DETAILED DESIGN.
4. ACCESS TRACK DESIGN TO BE UNDERTAKEN DURING THE DETAILED DESIGN PHASE. ACCESS TRACKS SHOWN ARE INDICATIVE ONLY.
5. SITE ENTRANCE GATES TO BE CONFIRMED DURING DETAILED DESIGN.
6. SUBSTATION DIMENSIONS APPROXIMATE ONLY.
7. DIMENSIONS ARE IN METRES UNLESS NOTED OTHERWISE.
8. BUSINESS IDENTIFICATION SIGNAGE (1m (L) x 1m (W)) SHALL BE LOCATED AT THE DESIGNATED MAIN ENTRANCE OF EACH MAIN PROPERTY.
9. ENTRY/ACCESS POINTS TO BE DESIGNED IN ACCORDANCE WITH VICROADS STANDARD DRAWING GD4010 - TYPICAL ACCESS TO RURAL PROPERTIES.
10. PROPOSED OVERHEAD LINE ROUTES AND LOCATIONS ARE INDICATIVE ONLY AND SHALL BE CONFIRMED DURING DETAILED DESIGN.THE OVERHEAD LINE INFRASTRUCTURE SHALL BE DESIGNED AND CONSTRUCTED TO ENSURE NO IMPACT ON NATIVE VEGETATION. DESIGN AND CONSTRUCTION WILL NOT OCCUR IN THE CREEK LAND AND/OR CHANNEL.
11. 4M WIDE PERIMETER ROAD WITHIN THE FIREBREAK MUST INCLUDE 20M X 6M PASSING BAYS EVERY 600 METRES.
12. ROADS MUST BE ALL WEATHER OR DIRT/CRUSHED ROCK CONSTRUCTION WHERE INDICATED AND CAPABLE OF ACCOMMODATING A VEHICLE OF FIFTEEN (15) TONNES.
13. 2m WIDE WATER PIPELINE SUPPLY.
14. A 4m WIDE BUFFER ZONE HAS BEEN CONSIDERED.
15. 35m WIDE GAS PIPELINE EASEMENT.

PV SYSTEM SPECIFICATIONS	
Capacity - DC	375.90 MW_P
Export Capacity - AC	300 MW_{AC}
DC/AC Ratio	1.253
Modules	(616230) 610 W Bifacial
Mods. per string	30
Pitch	5.20 m
GCR	47.40 %
Mounting structure	(7663) NxT Mono-Line SAT
• Full (3 Strings)	5215
• Partial (2 Strings)	2448
• Half	
Inverters	(112) Central Inverter 3575 KVA
• Nominal Power	3575 KVA
Access roads	49545 m
Fenced area	(6273210 m^2) 1550 Ha
• Perimeter	23935 m

Revisions:

Rev	Date	Comments	Dwn	Chkd
09	12.11.24	Layout update (29mod. per string & 620W)	DC	
08	15.07.24	Easement and legend update	EPG	
14	16.05.25	Updated Layout	DC	
13	16.05.25	Update Layout	DC	
12	03.04.24	Substation details added	AG	
11	24.03.25	Updated Layout with 28 Strings	DC	
10	27.11.24	Updated layout	JI	
00	27.11.23	Layout Updated	DC	

DRAWN	CHECKED	APPROVED	DATE
DC			27.11.2023

PROJECT NAME & ADDRESS:
Location: Benalla, Victoria
Australia

NOTES:
- 610 Wp Bifacial modules
-
-
-

Paper Size:	Scale:	Sheet:
A3	1:30	1

CAPACITY:
616230 Modules 375.90 MWp

DRAWING TITLE:
AUS_West Mokoan Solar Farm_LP3-BDL_14 (KC_BDL_04) Planning
Hybrid Project Layout

DRAWING NUMBER: LP3-BDL
STATUS: Preliminary

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Figure 3-6: Proposed Layout of West Mokoan (North) and Kennedys Creek (South)

3.5 Quantities of Dangerous Goods Stored and Handled

The DGs stored at the site are for various purposes and primarily contained within other assets (i.e. lithium batteries in BESS units and transformer oils in transformers). The classes and quantities to be approved on the site are summarised **Table 3-1**. The locations of the BESS and transformers are indicated on the drawing provided in **Figure 3-6**.

Table 3-1: Maximum Classes and Quantities of Dangerous Goods Stored

Class	Description	Quantity
2.2	R-134a* / R-410a*	1,000 L*
9	Lithium Batteries	620 T
C1	Transformer oils	163,300 L
C1	Diesel	5,000 L

*Estimated commodity and quantity based upon similar project.

4.0 Fire Protection Quantity Assessment

4.1 Introduction

The Victorian Dangerous Goods (Storage and Handling) Regulations (VDGR, Ref. (Victoria State Government, 2022)) covers the storage and handling of materials classified as Dangerous Goods (DGs). This Regulation provides an assessment of the required documentation to be prepared for a site based upon a threshold based approach for each class of DG stored at a site. As shown in **Section 3.5** a range of products will be stored as part of site operations which are classified as DGs; hence, the site is subject to the VDGR. The main purpose of the assessment is to determine whether additional overview is required from a regulatory perspective in terms of WorkSafe Victoria and Country Fire Authority (CFA) involvement. This is determined by the threshold “Fire Protection Quantity” (FPQ) within the VDGR. Provided in the following section is an assessment of the FPQ and the associated implications for the site approval process.

4.2 Assessment

As noted, the assessment is based upon thresholds provided in the VDGR. The applicable thresholds for the site have been extracted from the Regulation to assess where the site will sit within the regulatory framework for DGs. The results of the assessment are shown in **Table 4-1**.

Table 4-1: Fire Protection Quantity Assessment

Class	Description	Quantity	Placard	Manifest	FPQ	Determination
2.2	R-134a / R-410a	1,000 L	5,000 L	10,000 L	20,000 L	n/a
9	Lithium Batteries	620 T	5 T	10 T	20 T	FPQ
C1	Transformer oils	163,300 L	10,000 L	100,000 L	100,000 L	FPQ
C1	Diesel	5,000 L	10,000 L	100,000 L	100,000 L	n/a

Based upon a review of **Table 4-1** the site would be classified as a FPQ site.

4.3 Implications

The assessment determined that the site would be classified as a FPQ site which requires referral to CFA. Typically, this would require a design assessment of the facility to demonstrate compliance with an applicable DG design standard. However, the site is being triggered by the batteries which are classified as a Class 9 DG which technically only exists during transport and not storage. Nonetheless, the VDGR include this as an assessable quantity; hence, a submission to the CFA for written advice is required under the Regulation.

The design standard for Class 9 batteries, AS/NZS 4681:2000 (Ref. (Standards Australia, 2000)) is extremely dated and only covers DGs stored in buildings as the risks for external storage are relatively minor. Furthermore, the standard was based upon battery designs from the year 2000 which did not include the protection incorporated in modern batteries (i.e. temperature and voltage monitoring, cooling, etc.) and were based upon chemistries more likely to result in thermal decomposition (i.e. lithium metal). Therefore, there is a lack of applicable design guidance available for such battery installation (i.e. Kennedys Creek BESS) from a DG perspective.

The risks are mitigated via the design of the battery modules themselves and the availability of fire protection at the site. As per the Country Fire Authority (CFA) Design Guidelines and Model Requirements For Renewable Energy Facilities v4.2 (Ref. (Country Fire Authority, 2024)), the facility is also expected to have some abilities (e.g. presence of hydrants, water tanks) to fight a fire at the site should one occur. Discussion with CFA based upon the remoteness of the proposed site (i.e. if a site is not within the immediate turnout area of a fire station) is recommended prior to construction.

Additional implications include those relating to the documentation which is required to be prepared by the VDGR. Documentation required for a site exceeding manifest levels is as follows:

- Risk assessment
- Register
- Manifest
- Notification to the Regulator
- Emergency Response Plan
- Emergency Services Information Booklet
- Placard schedule
- Site layout

Each of these items have been discussed further in the following subsections in terms of what they entail and whether they will be submitted to a Regulator (i.e. WorkSafe Victoria) for approval prior to occupation of the site for the proposed use.

4.3.1 Risk Assessment

A risk assessment is required by Clause 27 of the VDGR which requires the risks associated with an activity or storage to be controlled. The DG risk assessment is the documentation prepared to demonstrate the risks have been assessed with the required controls incorporated into the site design / operation to an acceptable level as required by the Regulation. This document is not submitted to a Regulator, however it is a requirement of the operator to demonstrate they have fulfilled their obligations under the VDGR. This document is likely to only be reviewed by a Regulator if they attend the site as part of an inspection or due to an incident at the site requiring their involvement.

4.3.2 Register

A register is required under Clause 58 of the VDGR and is a summary of the DGs stored on site along with the Safety Data Sheets (SDS) for the products stored. The register also links into the findings of the risk assessment closing the loop from the summary document to the risk assessment. The register is not submitted to a Regulator for review but is required to fulfil the operators’ obligations under the VDGR.

4.3.3 Manifest

The manifest is required under Clause 44 of the VDGR. The document is another summary document which is submitted along with the notification to the Regulator. The purpose of the manifest is to provide information about the types and quantities of DGs stored to CFA should an incident occur at the site.

While the document is submitted to the Regulator it is typically for information purposes and does not require approval by them.

4.3.4 Notification to the Regulator

The notification is required by Clause 64 of the VDGR and is the driving link between the manifest and the Regulator. It is a form which details the specifics of the DG depots at a site and how they interlink with the manifest. The notification is used to form a database of sites which store DGs exceeding the manifest level. While the notification is not typically reviewed, the operator will receive an acknowledgement from the Regulator which they use to demonstrate they have notified the Regulator as required by the VDGR.

4.3.5 Emergency Response Plan

The Emergency Response Plan (ERP) is required by Clause 53. The purpose is to outline the potential emergencies (i.e. fire, bush fire, natural disaster, etc.) and the associated mitigation and response measures. The document is site specific and is submitted to the CFA for review and approval.

4.3.6 Emergency Services Information Booklet

The Emergency Services Information Booklet (ESIB) is an accompanying document to the ERP and is essentially a summary document of the ERP. This is submitted to the CFA for review and approval.

4.3.7 Placard Schedule

The site is required to be placarded under Clause 47 and the placard schedule is a document which details where the placards are required to achieve compliance with the VDGR. The placard schedule is not submitted to the Regulator but is used to ensure the correct placards have been installed.

4.3.8 Site Layout

The site layout is required by Clause 8 of Schedule 3 of the VDGR and accompanies both the manifest and the notification. The purpose of the layout is to show where the DGs are stored around the site along with other points of interest to CFA or the appropriate combat agency including; power isolation points, valve isolation points, drains, etc. to assist them in coordinating a response (i.e. isolate power prior to attacking a fire) or prevent contaminated water from being discharged from the site.

4.3.9 General

The documentation listed above is not required prior to construction but would be required to be in place 2 weeks prior to occupation.

5.0 Hazard Identification

5.1 Introduction

A hazard identification table has been developed and is presented at **Appendix A**. This table has been developed following the recommended approach in Hazardous Industry Planning Advisory Paper No .6, Hazard Analysis Guidelines (Ref. (Department of Planning, Industry and Environment, 2011)). The Hazard Identification Table provides a summary of the potential hazards, consequences and safeguards at the site. The table has been used to identify the hazards for further assessment in this section of the study. Each hazard is identified in detail and no hazards have been eliminated from assessment by qualitative risk assessment prior to detailed hazard assessment in this section of the study.

In order to determine acceptable impact criteria for incidents that would not be considered for further analysis, due to limited impact offsite, the following approach has been applied:

- *Fire Impacts* - It is noted in Hazardous Industry Planning Advisory Paper (HIPAP) No. 4 (Ref. (Department of Planning, Industry and Environment, 2011)) that a criterion is provided for the maximum permissible heat radiation at the site boundary (4.7 kW/m^2) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in a heat radiation less that at 4.7 kW/m^2, at the site boundary, are screened from further assessment.

  Those incidents exceeding 4.7 kW/m^2 at the site boundary are carried forward for further assessment (i.e. frequency and risk). This is a conservative approach, as HIPAP No. 4 (Ref. (Department of Planning, Industry and Environment, 2011)) indicates that values of heat radiation of 4.7 kW/m^2 should not exceed 50 chances per million per year at sensitive land uses (e.g. residential). It is noted that the closest residential area is approximately 70 m from the site, hence, by selecting 4.7 kW/m^2 as the consequence impact criteria (at the adjacent industrial site boundary) the assessment is considered conservative.

- *Explosion* - It is noted in HIPAP No. 4 (Ref. (Department of Planning, Industry and Environment, 2011)) that a criterion is provided for the maximum permissible explosion over pressure at the site boundary (7 kPa) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in an explosion overpressure less than 7 kPa, at the site boundary, are screened from further assessment.

  Those incidents exceeding 7 kPa, at the site boundary, are carried forward for further assessment (i.e. frequency and risk). Similarly, to the heat radiation impact discussed above, this is conservative as the 7 kPa value listed in HIPAP No. 4 relates to residential areas, which are approximately 1 km from the site.

- *Toxicity* – Toxic by-products of combustion may be generated by a BESS fire; hence, toxicity has been assessed with criteria based upon the Emergency Response Planning Guidelines (ERPG)

- *Property Damage and Accident Propagation* - It is noted in HIPAP No. 4 (Ref. (Department of Planning, Industry and Environment, 2011)) that a criterion is provided for the maximum permissible heat radiation/explosion overpressure at the site boundary (23 kW/m^2/14 kPa) above which the risk of property damage and accident propagation to neighbouring sites must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk to incident propagation, for this study, incidents that result in a heat radiation heat radiation less than 23 kW/m^2 and explosion over pressure less than 14 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 23 kW/m^2 at the site boundary are carried forward for further assessment with respect to incident propagation (i.e. frequency and risk).

- *Societal Risk* – HIPAP No. 4 (Ref. (Department of Planning, Industry and Environment, 2011)) discusses the application of societal risk to populations surrounding the proposed site. It is noted that HIPAP No. 4 indicates that where a development proposal involves a significant intensification of population, in the vicinity of such a site, the change in societal risk needs to be taken into account. In the case of the proposed facility, there is currently no significant intensification of population around the proposed site; hence, societal risk has not been considered in this assessment.

5.2 Properties of Dangerous Goods

The type of DGs and quantities stored and used at the site has been described in **Section 3**. **Table 5-1** provides a description of the DGs to be stored and handled at the site, including the Class and the hazardous material properties of the DG Class.

Table 5-1: Properties* of the Dangerous Goods and Materials Stored at the Site

Class	Hazardous Properties
2.2 – Non-Flammable, Non-Toxic Gas	Non-flammable, non-toxic gases are those which do not pose a flammable or toxicity risk and are therefore relatively benign. However, such gases may pose asphyxiation risks as they can exclude oxygen at the point of release creating an oxygen deficient environment.
9 – Miscellaneous DGs	Class 9 substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not covered by other classes. Releases to the environment may cause damage to sensitive receptors within the environment. It is noted that the Class 9s stored within this site are lithium ion batteries which may undergo thermal runaway (i.e. escalating reaction resulting in heat which ultimately leads to failure of the battery and a fire).
Combustible Liquids	Combustible liquids are typically long chain hydrocarbons with flash points exceeding 60.5^{o}C. Combustible liquids are difficult to ignite as the temperature of the liquid must be heated to above the flash point such that vapours are generated which can then ignite. This process requires either sustained heating or a high-energy ignition source.

* The Australian Code for the Transport of Dangerous Goods by Road and Rail (Ref. (National Transport Commission (NTC), 2011)

5.3 Hazard Identification

Based on the hazard identification table presented in **Appendix A**, the following hazardous scenarios have been developed:

- Li-ion battery fault, thermal runaway and fire.
- Li-ion battery fire and toxic gas dispersion.
- Electrical equipment failure and fire.

- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion.
- Refrigerant gas release and asphyxiation hazard.
- Release of diesel, ignition and pool fire.
- Electromagnetic field impacts.
- Gas pipeline impacts.

Each identified scenario is discussed in further detail in the following sections.

5.4 Li-Ion Battery Fault, Thermal Runaway and Fire

Lithium ion (Li-ion) batteries are composed of a metallic anode and cathode which allows for electrons released from the anode to travel to the cathode where positively charged ions in the solute migrate to the cathode and are reduced. The flow of electrons provides the source of energy which is discharged from a battery and used for work. In a Li-ion battery, the lithium metal composites (a composite of lithium with other metals such as cobalt, manganese, nickel, or any combination of these metals) oxidises (loses an electron) becoming a positively charged ion in solution which migrates through the battery separator to the cathode. At the same time, the lost electron travels through the circuit to the cathode. The lithium ions in solution then recombine with the electron at the cathode forming lithium metal within the cathodic metal composite. This process is shown in **Figure 5-1**.

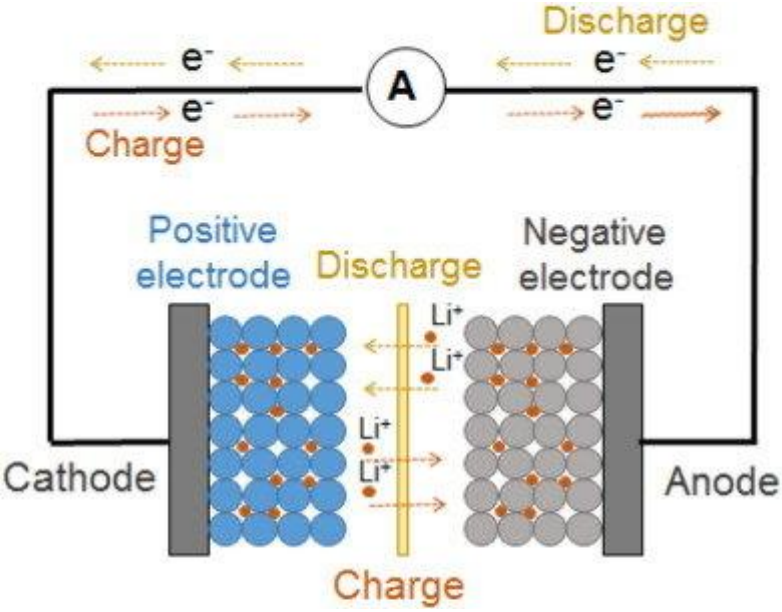

Figure 5-1: Cathode and Anode of a Battery (Source Research Gate)

Initial lithium batteries were designed around lithium metal (i.e. no composite structure) due to the high energy density yielded by the metal. However, when overcharging a battery, lithium ions can begin to plate on the anode in the form of lithium dendrites. Eventually, the dendrites pierce the separator within the battery resulting in a short of the battery which could result in heat, fire, or explosion of the battery. The technology evolved to move away from lithium metal to lithium ions (held within composite materials) which reduced the incidence of lithium dendrites forming resulting in an overall safer battery.

Despite the improvement in battery technology, there are several degradation mechanisms that are still present within the battery which can result in thermal runaway. These include:

- Chemical reduction of the electrolyte at the anode
- Thermal decomposition of the electrolyte
- Chemical reduction of the electrolyte at the cathode
- Thermal decomposition by the cathode and the anode
- Internal short circuit by charge effects

These effects arise primarily as a result of high discharge, overcharging, or water ingress into the battery which results in a host of by-products being formed within the battery during charge and discharge cycles.

As a result, Li-ion batteries are equipped with several safety features to prevent the batteries from charging or discharging at voltages which result in battery degradation, leading to shorting of the battery and thermal runaway. Safety features generally include:

- Shut-down separator (for overheating)
- Tear-away tab (for internal pressure relief)
- Vent (pressure relief in case of severe outgassing)
- Thermal interrupt (overcurrent/overcharging/environmental exposure)
- Battery Management Systems (BMS) – constant monitoring of the voltage, temperature and state of charge of individual cells to aid in early detection of a fault condition. Upon detection of cell fault, the BMS disconnects and isolates the cell to prevent propagation of the incident, and alarms the site EMS.

These features are designed to prevent overcharging or excessive discharge, pressurisation arising from heat generated at the anode or from battery contamination. Protection techniques for Li-ion batteries are standard; hence, the potential for thermal runaway to occur in normal operation is incredibly low with the only exceptions being where batteries are manufactured poorly or due to manufacturing faults, or battery damage (i.e. battery cell is ruptured as this can short circuit the battery resulting in thermal runaway).

The battery chemistry of the BESS units shall be lithium iron phosphate (LiFePO4, or simply LFP), which is one of the safest battery chemistries within the industry. The stability of the batteries is due to the cathode which does not release oxygen therefore preventing violent redox reactions resulting in rapid temperature rise as the oxygen oxides the electrolyte. The stability of LFP batteries has been demonstrated numerous times through appropriate testing.

UL9540A test results from containerised BESS units with LFP battery chemistry typically show that thermal runaway is not propagated to adjacent units, is generally contained to a small quantity of cells and does not result in a BESS unit fire. Testing for shock and damage to batteries (i.e. nail puncture test) has shown that LFP batteries when punctured through membranes typically results in a shorting of the battery, and fire does not result in ignition of the battery demonstrating that the battery chemistry is protected against shock damage.

At the time of assessment, the final selection for the containerised BESS units has not been made. However, the battery manufacturer at minimum is required to comply with the requirements listed in the CFA guidelines including:

- UL9540
- UL9540A
- NFPA855

Although the supplier has not been selected yet, the UL9540A test results from a potential supplier (Hithium) is provided in **Appendix C**. In the report provided, the unit level tests were passes including the following:

- No flaming outside of the unit.
- Surface temperatures of modules within the target units adjacent to the initiating unit was far below the cell venting temperature.
- Surface temperature measurements on wall surface did not exceed the temperature rise above ambient; and
- Explosion hazards were not observed during the test.

As the results are based on cell level tests, further assessment is not conducted as propagation within the module was limited to an acceptable number of cells and therefore a full module or unit fire would not occur. It should be noted that the tests are conducted with no fire suppression and any installed BESS unit would include fire suppression in compliance with NFPA 855.

Based on typical LFP installations and UL9540A testing, the technology does not cause a propagating fire during thermal runaway. Should fire be developed within one BESS enclosure it would not propagate within the unit.

Although the likelihood of both a full unit fire and incident propagation to adjacent BESS units is highly unlikely, consequence modelling has been undertaken to demonstrate the potential heat radiation distances.

5.4.1 Fire Safety Testing and Certifications

Underwriters Laboratories (UL) is a safety certification organisation that performs testing, inspection and certification of products, components, materials and system s to ensure they meet specific safety, quality, and performance standards. UL also develops and maintains standards and testing procedures to support industry in the adoption of new technology. Two key documents which they produce are the UL 9540 Standard for Energy Storage Systems and Equipment and the UL 9540 A Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems.

The first edition of UL 9540 was introduced in 2016, since then it has been a widely adopted requirement that electrochemical ESS be listed to UL 9540. This includes international fire codes and NFPA 1 and 855. The standard defines several system safety tests for energy storage systems. The standard defines the testing requirements for a system, meaning that all components that make up the ESS must be tested together ensuring that safety is retained at the system level. All testing is required to be completed through a nationally recognised testing laboratory (NRTL). In the 2022 updated version of the standard, systems were required to meet the performance criteria of a new test method, UL 9540A

The UL 9540A test method is a systematic evaluation method to evaluate fire safety hazards associated with propagating thermal runaway within battery systems. The test establishes firstly if the storage technology can be driven into thermal runaway, and then if so, what happens? The UL

9540A test method starts at cell level and gradually builds to the installation level over four steps (cell-level, module-level, unit-level, installation-level), if an ESS meets the performance criteria of any of the first three tests, there is no requirements to continue testing the subsequent levels.

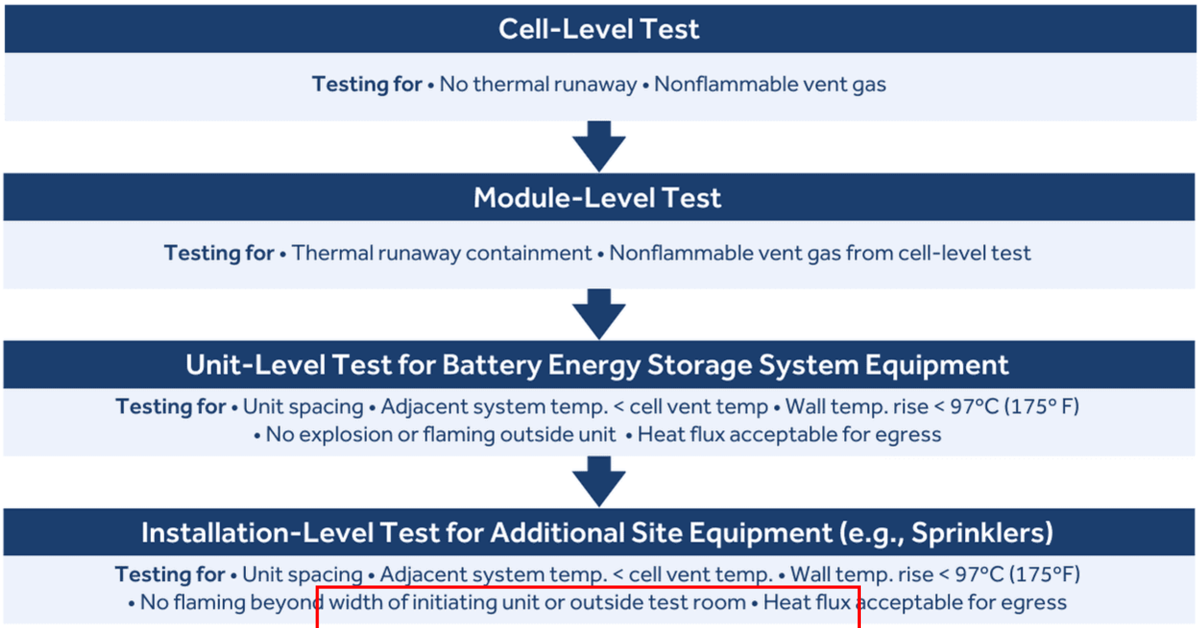

Figure 5-2: UL 9540A Test Sequence

UL 9540A test results from containerised BESS units with LFP battery chemistry typically show that unit-unit propagation does not occur. At the time of assessment, the supplier selection for the BESS units has not been made. However, the battery manufacturer at minimum is required to comply with the requirements listed in the CFA guidelines including UL 9540, UL 9540A and NFPA 855. The passing of the UL 9540A test at cell, module or unit level (all conducted without system suppression) would indicate that the fire risks with the installed system are negligible.

Although the supplier has not been selected yet, the UL 9540A test results from a potential supplier, who has been used at similar sites, is provided in **Appendix C**. In the report provided the unit level tests were passed, including the following:

- No flaming outside of the unit.
- Surface temperatures of modules within the target units adjacent to the initiating unit was far below the cell venting temperature.
- Surface temperature measurements on wall surfaces did not exceed the temperature rise above ambient; and
- Explosion hazards were not observed during the test.

The purpose of the unit-level test is to verify that a fire within a single BESS unit will not spread to other units, nor breach the BESS enclosure, and that there shall be no flying debris or explosive discharge of gases. This sets parameters for distance to surrounding BESS to prevent incident propagation.

It should be noted that unit-level tests are carried out without fire suppression technology that will be included in the final product, therefore the risk of incident propagation is further reduced beyond what is reported in unit-level tests. As the Kennedys Creek Solar Farm is a decentralised system, the distance between each BESS unit is significant (minimum 95 m and up to 600 m) and unit-to-unit propagation is not a credible fire scenario.

Although the likelihood of both a full unit fire and incident propagation to adjacent BESS units is not considered a credible scenario, consequence modelling has been undertaken to demonstrate the potential heat radiation distances.

5.4.2 Victoria Big Battery Fire Review

Notwithstanding the previous sections, it is necessary to review recent large scale BESS fires to determine whether similar incidents could occur with the present project.

The Victorian Big Battery (VBB) experienced a fire in July 2021 which has a back-to-back layout. According to the independent investigation report on its fire incidence, the back-to-back layout was not the cause for propagation. The main reason for fire propagation was strong wind blowing flames from one Megapack into the unprotected vent atop of an adjacent Megapack which resulted in the ignition of the plastic fan which was able to impact the battery modules directly beneath the fan.

Lessons learnt from the VBB incident results in fire safety precautions on the design of the present project. The vent atop the containers shall be made of metal instead of plastic and covered by a metallic mesh shield. Furthermore, the placement of the fans shall be such that batteries or flammable materials shall not be located directly beneath ventilation openings. To ensure the above are captured the following recommendations have been made:

- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.

Based upon the designs incorporated with the container based upon the VBB fire, the available area and the separation distance assessments, it is considered that the propagation between two units is considered unlikely; hence, this incident has not been carried forward for further analysis.

5.5 Li-Ion Battery Fire and Toxic Gas Dispersion

If a BESS failure occurs resulting in a fire, toxic byproducts of combustion may form. A literature review was conducted on lithium-ion battery fires to identify the toxic gases which may be generated in the event of a fire. The review identified the following gases or classes of gases can form:

- Carbon dioxide;
- Carbon monoxide; and
- Fluorine gases.

Each of these have been discussed in further detail in the following subsections.

5.5.1 Carbon Dioxide

Carbon dioxide is a colourless, odourless, dense gas which is naturally forming and is present in the atmosphere at concentrations around 415 ppm (0.0415%). At low concentrations carbon dioxide is physiologically impotent and at low concentrations does not appear to have any toxicological effects. However, as the concentration grows it increases the respiration rate of exposed persons. The Short-Term Exposure Limit (STEL), as noted by SafeWork Australia is 30,000 ppm (3%), above 50,000 ppm (5%) a strong respiration effect is observed along with dizziness, confusion, headaches, and shortness of breath. Concentrations in excess of 100,000 ppm (10%) may result in coma or death.

Carbon dioxide is a by-product of combustion where hydrocarbons or carbon-based materials are involved. A typical combustion reaction producing carbon from a hydrocarbon has been provided in **Equation 5-1**. This reaction proceeds when there is an excess of oxygen to the fuel being consumed and is known as complete combustion as it is the most efficient reaction pathway.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3Co_2(g) + 4H_2O(g) \qquad \textbf{Equation 5-1}$$

The lithium-ion batteries are predominantly composed of metal structures. However, during a fire event ancillary equipment and materials within the batteries will be involved in the fire including wiring, plastics and anodes which will liberate carbon dioxide. However, a review of the toxicological impacts indicates high concentrations would be required to result in injury or fatality. Based upon a review of the sensitive areas, and the similar BESS fires (i.e. Victoria BESS fire), it is not considered that the formation of carbon dioxide in a fire would be sufficient to result in downwind impacts sufficient to cause injury or fatality. Therefore, this incident has not been carried forward for further analysis.

5.5.2 Carbon Monoxide

Carbon monoxide is an odourless, colourless gas which is slightly denser than air and occurs naturally in the atmosphere at concentrations around 80 ppb. Carbon monoxide is a toxic gas as it irreversibly binds with haemoglobin which prevents these molecules from carrying out the function of oxygen / carbon dioxide exchange. The loss of 50% of the haemoglobin may result in seizures, coma or death which can occur at concentration exposures of approximately 600 ppm (0.06%).

Carbon monoxide is by-product of combustion if there is insufficient oxygen to enable complete combustion. The reaction pathway for the formation of carbon monoxide is provided in **Equation 5-2**.

$$2C_3H_8(g) + 7O_2(g) \rightarrow 6CO(g) + 8H_2O(g) \qquad \textbf{Equation 5-2}$$

As noted, in **Section 5.5.1** there is the potential for a fire to occur with the BESS units which could form carbon monoxide if there is insufficient oxygen to sustain complete combustion. However, it is noted that the combustible load within the BESS which could result in the formation of carbon monoxide is relatively low compared to the available oxygen in the surrounding atmosphere. Therefore, it is considered that the formation of carbon monoxide at levels which would result in a substantial downwind impact are not considered credible and subsequent analysis of, this incident is not required.

5.5.3 Fluoride Gases

The electrolyte used in Li-ion batteries typically is lithium hexafluorophosphate ($LiPF_6$) or other li-salts containing fluorine. In the event of a thermal runaway, the electrolyte will expand and be vented from the battery. In the event of a fire, the vented gas and other components such as the polyvinylidene fluoride binders may form gases such as hydrogen fluoride (HF), phosphorous pentafluoride (PF_5) and phosphoryl fluoride (POF_3) (Ref. (Larson, Andersson, Blomqvist, & Mellander, 2017)).

The decomposition of $LiPF_6$ can be promoted by the presence of water / humidity according to reactions **Equation 5-3** to **Equation 5-5**.

$$LiPF_6 \rightarrow LiF + PF_5$$ **Equation 5-3**

$$PF_5 + H_2O \rightarrow POF_3 + 2HF$$ **Equation 5-4**

$$LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF$$ **Equation 5-5**

Of the fluorine gases formed, PF_5 is a short-lived gas while POF_3 is a reactive intermediate. Thermal destruction of several battery chemistry, configurations and State of Charge (SOC) indicated the vast majority of these did not produce observable POF_3 with the only observance occurring in a specific battery chemistry at 0% SOC (Ref. (Larson, Andersson, Blomqvist, & Mellander, 2017)). Therefore, the main fluorine gas of concern in a Li-ion battery fire is HF.

HF gas is hydroscopic readily dissolving into water vapour / humidity or moisture in airways forming hydrofluoric acid. Hydrofluoric acid is a weak acid although is highly corrosive and may result in chemical burns. In addition, it is calcium scavenging. Hence, it will readily bind with calcium in cells and tissues disrupting the nerve signalling. SafeWork Australia nominates a concentration of 30 ppm of HF as being Immediately Dangerous to Life and Health (IDLH). At 170 ppm, HF can be lethal in approximately 10 minutes.

For toxic gas dispersion, a battery container fire is necessary as the initiating event. As discussed in **Section 5.4.** The potential for a fire to occur is considered negligible due to the highly stable and safe battery chemistries used. Therefore, toxic gas dispersion impacting sensitive receptors is not deemed a credible scenario and this incident has not been carried forward for further analysis.

5.6 Electrical Equipment Failure and Fire

Electrical equipment is located within the switch room which may fail resulting in overheating, arcing, etc. which could initiate a fire. In the event of a fire, it may begin to propagate to adjacent combustible materials (i.e. wiring). It is noted that electrical equipment fires typically start by smouldering before flame ignition occurs resulting in a slow fire development.

The type of equipment used within the site is ubiquitous throughout the world and across industry segments and is therefore not a unique fire scenario. Based upon fire development within switch rooms the fire would be relatively slow in growth and would be unlikely to result in substantial impacts in terms of offsite impact or incident propagation. Therefore, this incident has not been carried forward for further analysis.

5.7 Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Transformers contain oil which is used to cool the units during operation. If arcing occurs within the transformer (e.g. due to a low oil level), the high energy passing through the coolant vaporises the oil into light hydrocarbons (methane, ethane, acetylene, etc.) resulting in rapid pressurisation within the reservoir. To minimise the likelihood of such occurrence, transformers are fitted with a low oil pressure switches and a pressure surge switch (Buckholtz relay). These devices identify potential oil and pressure events within the transformer, isolating power and alarming operators.

Notwithstanding the protection systems, if the pressure rise exceeds the structural integrity of the reservoir, and the installed pressure relief devices, the reservoir can rupture allowing the release of oil into the bund. The rupture also allows oxygen to enter the reservoir. The temperature of the gases is above the auto ignition point, but this does not occur until oxygen is present. When oxygen enters the reservoir, the gases auto ignite which generates sufficient heat to ignite the oil in the bund.

As there is the potential for a fire to occur within the substation transformers, this incident has been carried forward for further analysis.

The transformers haven't been subject to detailed design at this stage; hence, the following recommendation has been made:

- The substation transformer bunds shall be designed according to the requirements detailed in AS 2067:2017(Ref. (Standards Australia, 2016)), and shall have a volume of 110% of the total volume of the mineral oil within the Transformer to account for any safety risks from a potential fire and or explosion.

5.8 Transformer Electrical Surge Protection Failure and Explosion

Transformers generate large amounts of heat as a result of the high electrical currents that pass through them; hence, as described in **Section 5.7**, oil is used as an insulating material within the transformers to protect the mechanical components. However, if the transformer receives an extreme surge of energy, such as that which could occur due to a lightning strike, and the electrical surge protection measures fail, the ester oil may start to decompose and vapourise, resulting in flammable gas bubbles including hydrogen and methane (Ref. (Bo Gao, 2023)) at temperatures above the autoignition of the gases.

The formation of gases will increase the pressure within the transformer which can result in the transformer structure rupturing which allows the ingress of oxygen. As the oxygen enters, the concentration of flammable gases falls within the explosive limits which are above their autoignition temperatures which ignite resulting in increased formation of hot gaseous products resulting in an explosion. The explosion may generate significant overpressure, sparks and fire and would result in a whole transformer fire, as discussed in **Section 5.7**.

To protect against overheating and explosions, transformers generally have surge protection devices which shunt electrical surges safely to ground. However, this surge detection and protection devices are not universally installed nor do they protect against all events such as in the case of a major lightning strike or significant oil deterioration, leakage of water into the transformer, and physical damage such as a fallen tree (Ref. (Hoole, et al., 2017)). Therefore, while transformers are ubiquitous units with a low potential for failure, there is the potential for an explosion to occur which may result in offsite impacts. Hence, this incident has been carried forward for further analysis.

5.9 Refrigerant Gas Release and Asphyxiation Hazard

The refrigeration system will be used to providing air conditioning and temperature control in the control room and other areas requiring temperature control. A simplified explanation of how a refrigeration system operates to cool an area is provided below.

A refrigeration system contains four essential components:

1. Compressor
2. Expansion valve
3. Refrigerant
4. Heat exchanging pipework

Figure 5-3 has been provided to aid in the description of how the refrigeration system operates to cool a specific area. The refrigeration system cycles the refrigerant gas through the system.

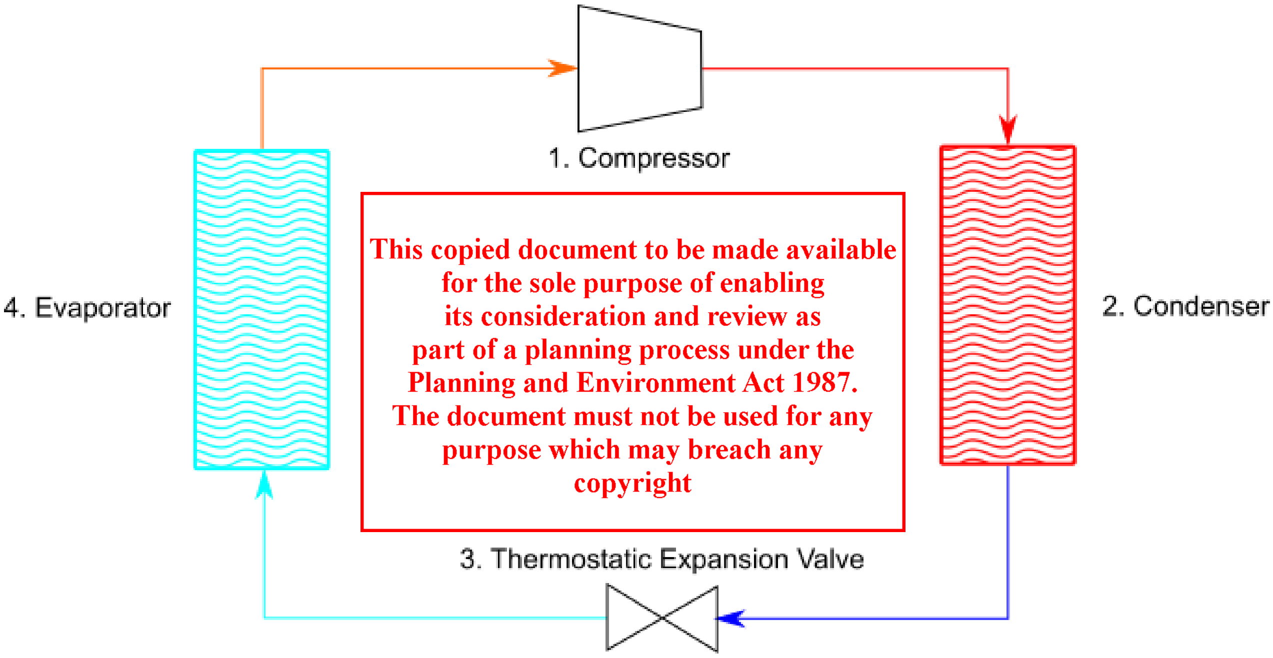

Figure 5-3: Refrigeration Flow Diagram

1. Refrigerant gas from the evaporator enters the compressor where it is pressurised (red) which increases the temperature of the gas. The gas travels along the pipework to the condenser.
2. The condenser is coiled to provide a large surface area to allow the hot gas to dissipate heat. As the gas releases heat through the coils, the gas condenses into a pressurised liquid (dark blue).
3. The pressurised liquid enters the thermostatic expansion valve where it expands across the valve seat, resulting in a sudden drop of pressure of the liquid refrigerant and rapid expansion which cools the liquid (light blue).
4. The cooled refrigerant enters the evaporator which is coiled to provide a large surface area to facilitate exchange of heat from the area to be cooled into the refrigerant. As the refrigerant absorbs heat it boils into a gaseous state.
5. On completion of the cycle, the refrigerant is drawn into the compressor and the cycle repeats.

Refrigeration systems are commonly used in all air conditioning systems which are not subject to frequent releases and if they do occur the leaks are minor resulting in minimal amounts of escaped gas. Therefore, a rupture release would not be a credible scenario given the ubiquitous nature of these systems. In the event a small release occurs it will be dissipated quickly via wind movement around the refrigeration unit prevent accumulation. Furthermore, such a release would be insufficient to impact offsite; hence, this incident has not been carried forward for further analysis.

5.10 Release of Diesel, Ignition and Pool Fire

Diesel will be used on site equipment primarily during construction but may be present during operations where equipment needs to be moved / relocated / site vehicles. The diesel will likely be stored in a portable refuelling tank which typically are double skinned (i.e. integrally bunded) tanks complying with AS 1940-2017 (Ref. (Standards Australia, 2017)). The presence of two tanks (i.e. inner and outer tank) results in the potential for external leakage to be incredibly low as this requires the failure of both tanks simultaneously. Therefore, a full release of diesel fuel from the tanks would not be expected to occur.

Nonetheless, if a substantial release did occur, combustible liquids do not emit flammable vapours which results in the ignition probability being incredibly. To ignite the spill, a sustained ignition source with sufficient energy would be required to be exposed to create sufficient heat to vapourise the liquid to initiate combustion. Should this occur, the fire would grow to the dimensions of the spill which would be unlikely to be sufficient to result in an offsite impact.

Due to the low likelihood of release, ignition and consequences impacts from a diesel pool fire an offsite impact is not considered to be a credible scenario; hence, this incident has not been carried forward for further analysis.

5.11 Electromagnetic Field Impacts

5.11.1 Introduction

Electromagnetic Fields (EMFs) are associated with a wide range of sources and occur both naturally as well as in the built environment. Naturally occurring EMFs, occurring during lightning storms, are generated from Earth’s magnetic field. Non-naturally occurring EMFs are present wherever there is electricity; hence, EMFs are present in almost all built environments where electricity is used.

Extremely low frequency (ELF) EMFs occupy the lower part of the electromagnetic spectrum in the frequency range 0-3,000 Hz which is current that will change direction 0-3,000 times per second. ELF EMFs result from electrically charged particles. Artificial sources are the primary producer of ELF EMFs and are usually associated with the generation, distribution and use of electricity at the frequency of 50 Hz in Australia. The electric field is produced by the voltage whereas the magnetic field is produced by the current.

BESS create EMFs from operational electrical equipment, such as transmission lines, transformers and the electrical components found within BESS units and inverters. This equipment has the potential to produced ELF EMFs in the range of 30 to 300 Hz.

5.11.2 Existing Standards

There are currently no existing standards in Australia for governing the exposure limits to ELF EMFs; however, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has provided some guidelines around exposure limits for prolonged exposure which limits the exposure to 2,000 milligauss (mG) for members of the public in a 24 hour period (Ref. (International Commission on Non-Ionizing Radiation Protection, 2010)).

Table 5-2 provides typical magnetic field measurements and ranges associated with EMF sources. It is noted that electric fields around devices are generally close to 0 due to the shielding provided around the equipment. In addition, EMF levels drop away quickly with distance; hence, while a value may be measurable at the source, within a short distance the EMF is undetectable.

Table 5-2: EMF Sources and Magnetic Field Strength

Source	Typical Measurement (mG)	Measurement Range (mG)
Television	1	0.2 – 2
Refrigerator	2	2 – 5

Source	Typical Measurement (mG)	Measurement Range (mG)
Kettle	3	2 – 10
Personal computer	5	2 – 20
Electric blanket	20	5 – 30
Hair dryer	25	10 – 70
Distribution powerline (under the line)	10	2 – 20
Transmission power line (under the line)	20	10 – 200
Edge of easement	10	2 – 50

5.11.3 Exposure Discussion

A review of the site indicates there are no residences immediately adjacent to the area where the BESS will be developed providing substantial distance for attenuation of EMFs. Based upon the typical levels which may be generated by transmission equipment the cumulative effect would not exceed the 2,000 mG limit for prolonged exposure.

As the potential for exposure to EMF exceeding the international guidelines is negligible, this incident has not been carried forward for further analysis.

5.12 Gas Pipeline Impacts

A review of the surrounding area indicates there is a buried gas pipeline running through the site. Incidents arising from the BESS and transformers have potential to impact upon the gas pipeline which could result in a loss of containment and associated incidents (i.e. jet fire, flash fire, explosions, etc.).

Based upon the hazard identification conducted, the only real threats to the gas pipeline during operation are from BESS / transformer fires and explosions which will emit radiant heat and overpressure effects. The pipeline running through the site is located within a 35 m wide easement and is buried 0.9 – 1.2 m below the ground, the earth above the pipeline provides shielding from the radiant preventing heating or thermal damage to the pipeline and limits pressure wave translation through the ground.

The only other threats to the pipeline occur during the construction of the BESS and solar farm whereby any excavation works may result in the pipeline being impacted and damaged and subsequent loss of containment or create a point where corrosion can take hold resulting in an eventual failure as the metal pipework is corroded. Typical protection systems around pipelines include “dial before you dig” to identify the location of pipelines, marker signs and marker tape. As the pipeline is a major gas network assets and located in an existing easement, the pipeline is already made visible via signage and landscaping. Notwithstanding, prior to construction, due diligence should be completed to ensure the exact location and extent of the pipeline is known and the appropriate operational authorities are notified of works occurring near the asset.

In the event of a site error resulting in excavation along the pipeline, the marker tape should be identified prior to impact; however, this may only be the case if the operator is aware of what the marker tape means. Assuming, the protection systems work as intended, the potential damage to the gas pipeline should be minimised preventing damage and potential incident escalation.

It is noted, the protection of the gas pipeline relies on personnel working in the area to be aware of the gas pipeline and the protections associated with it. Therefore, to improve site personnel knowledge, the following recommendations have been made:

- The site induction shall include information regarding the gas pipeline including location and protections to identify the gas pipeline (i.e., marker tape, etc.).
- All personnel working at the site shall be inducted prior to commencing any work.
- Appropriate marking shall be provided along the length of the gas pipeline as required to minimise the potential for unauthorised works occurring within the vicinity of the gas pipeline, in conjunction with the Site Induction and relevant site-specific construction management plans.

Based upon the low risk of interaction with the gas pipeline based upon the protection systems incorporated and the recommendation induction, training and markings, it is considered that the potential for an offsite incident to occur as a result of the gas pipeline is negligible; hence, this incident has not been carried forward for further analysis.

6.0 Consequence Analysis

6.1 Incidents Carried Forward for Consequence Analysis

The following incidents were identified to have potential to impact off site:

- Li-ion battery fault, thermal runaway and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion.

Each incident has been assessed in the following sections.

6.2 Li-Ion Battery Fault, Thermal Runaway and Fire

There is potential that a Li-ion battery may fault, resulting in thermal decomposition and a fire. If the fire is not contained or suppressed, there is potential for propagation within the battery container. A detailed analysis has been conducted in **Appendix B** with the modelled radiant heat impact distances shown in **Table 6-1**. Note that the radiant heat contours are measured from the centre of the BESS container to the furthest extent of each contour. The radiant heat contours associated with a Li-ion battery container fire are shown in **Figure 6-1**.

Table 6-1: Radiant Heat from a Li-ion Battery Fire

Heat Radiation (kW/m^2)	Distance (m)
35	0
28	3
23	6
12.6	6
4.7	10
3.0	13

Figure 6-1 is based upon the BESS unit which is closest to the boundary to determine if there is potential for any off-site impact. The BESS unit is conservatively assumed to have the dimensions of a 40 ft shipping container. The heat radiation contours were assessed at wind speeds of 0.1 m/s and at 2 m/s to assess the effect of wind on the potential for incident propagation (**Figure 6-2**).

The 4.7 kW/m^2 and 23 kW/m^2 heat radiation contours are presented in **Figure 6-1** as these are used to determine if there is any off-site impacts (4.7 kW/m^2) or risk of incident propagation to adjacent infrastructure (23 kW/m^2).

Based on the 4.7 kW/m^2 heat radiation contour, a BESS unit fire would not impact over the site boundary. At a wind speed of 0.1 m/s, the 23 kW/m^2 contour is maintained within approximately a 1 m perimeter around the BESS container. At a wind speed of 2 m/s, the 23 kW/m^2 contour is displaced from the BESS container by approximately 2 m. As the current configuration of the BESS and PCUs is not finalised, the following recommendation has been made:

- Separation distances between BESS and PCUs should be at least 3 m or in accordance with relevant standards and guidelines, whichever is greater.

As this incident does not impact over the site boundary it has not been carried forward for further analysis.

Figure 6-1: BESS Unit Fire Radiant Heat Contours at 0.1 m/s Wind Speed

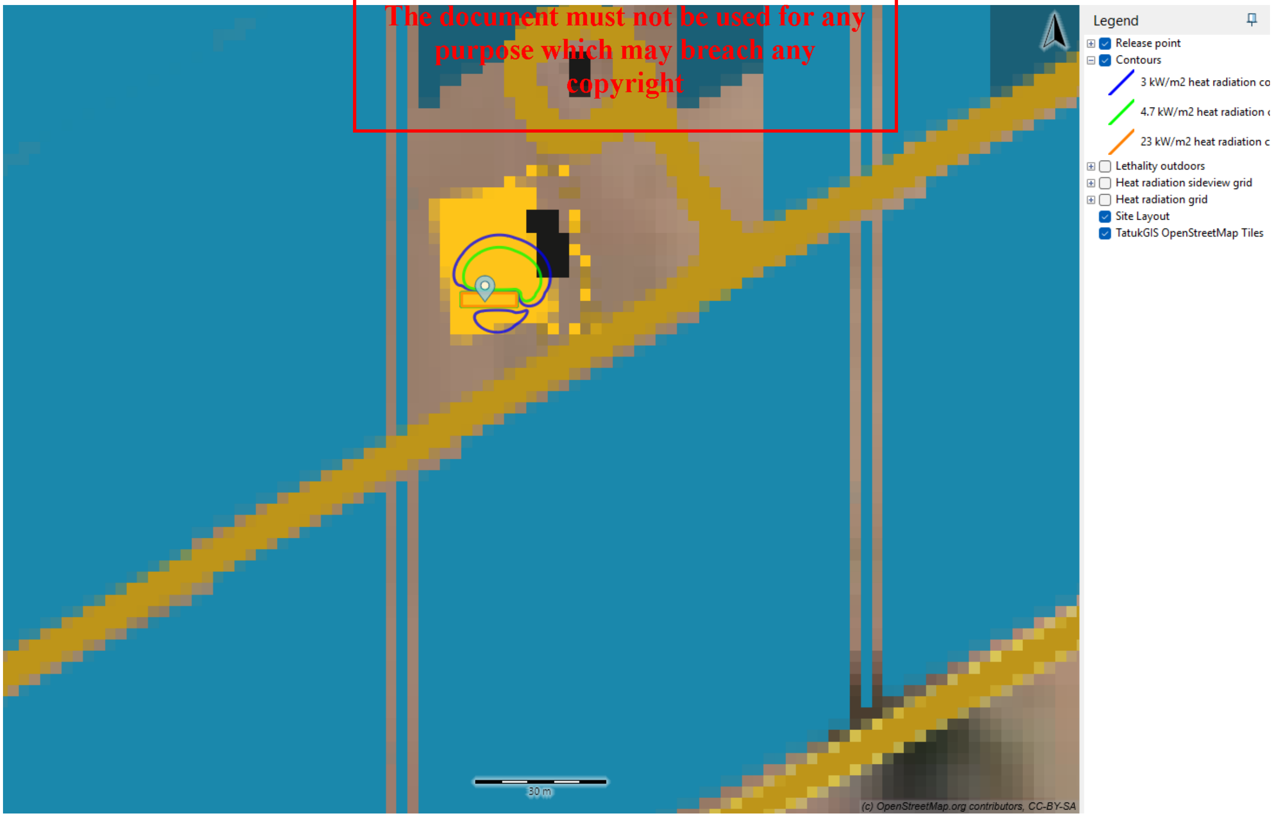

Figure 6-2: BESS Unit Fire Radiant Heat Contours at 2 m/s Wind Speed

6.3 Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

There is potential that arcing may occur within the transformers which may lead to generation of gases and pressure above the structural integrity of the oil reservoir which may rupture leaking oil into the bund. As a result of the arcing and rupture, the oil may ignite leading to a bund fire within the dimensions of the bund. A detailed analysis has been conducted in **Appendix B** and the radiant heat impact distances estimated for this scenario are shown in **Table 6-2**. The radiant heat contours associated with a fire occurring within a transformer bund are shown in **Figure 6-3**. It is noted the contours are located at the worst-case location within the solar farm with respect to the site boundary and assets.

Table 6-2: Radiant Heat from a Transformer Bund Fire

Heat Radiation (KW/m^2)	Distance (m)
35	17
23	19
12.6	24
4.7	37
3.0	45

A review of the site layout was conducted to determine the transformer which is closest to the site boundary and thus has the greatest risk of impacting over the boundary.

Figure 6-3 is based on a transformer which is approximately 100 m from the boundary as this was determined to be the most conservative. As can be seen in **Figure 6-3** the radiant heat contours at 4.7 and 23 kW/m^2 do not impact over the site boundary. The 23 kW/m^2 contour is associated with incident propagation, as can be seen the exclusion area around the transformer would prevent a bund fire form propagating to adjacent infrastructure. As such, this incident has not been carried forward for frequency analysis and no further recommendations have been made.

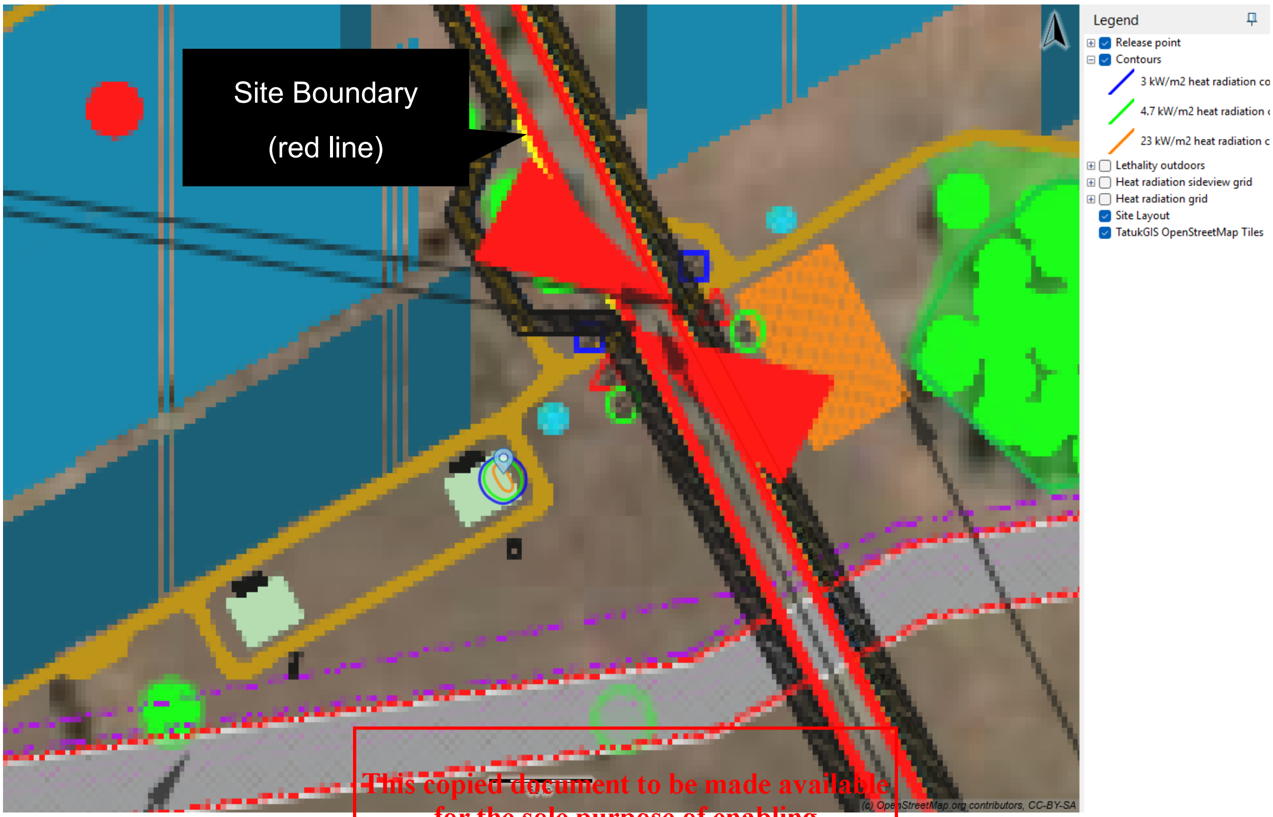

Figure 6-3: Transformer Bund Fire Radiant Heat Contours

6.4 Transformer Electrical Surge Protection Failure and Explosion

If a transformer is impacted by an extreme electricity surge, such as in the event of a lightning strike, the ester oil within the transformer may ignite and explode resulting in substantial overpressure impacts. A detailed analysis has been conducted in **Appendix B** with the results summarised in **Table 6-3**.

Table 6-3: Transformer Explosion Overpressures

Overpressure (kPa)	Distance (m)
70	40
35	58
21	81
14	107
7	186

There are no properties which are in close proximity to any of the transformers on site. However, Benalla-Yarrawonga Road runs through the site which means the boundary is split between two adjacent lots. Hence; the transformer closest to Benalla-Yarrawonga Road and the O&M building in the adjacent lot was chosen for this assessment to determine the possible impact on assets and public spaces.

Provided in **Figure 6-4** is a contour showing the explosion impact distances at 7 kPa, 14 kPa and 21 kPa which represent the potential for injury to personnel, incident propagation and damage to assets. As can be seen, neither the 7 kPa contour extends over the boundary towards Benalla-Yarrawonga Road and onto the O&M facility. The 14 kPa contour reaches the site boundary as well. As the consequence is shown to exceed the site boundary, frequency modelling has been completed in the following section to quantify the potential impact.

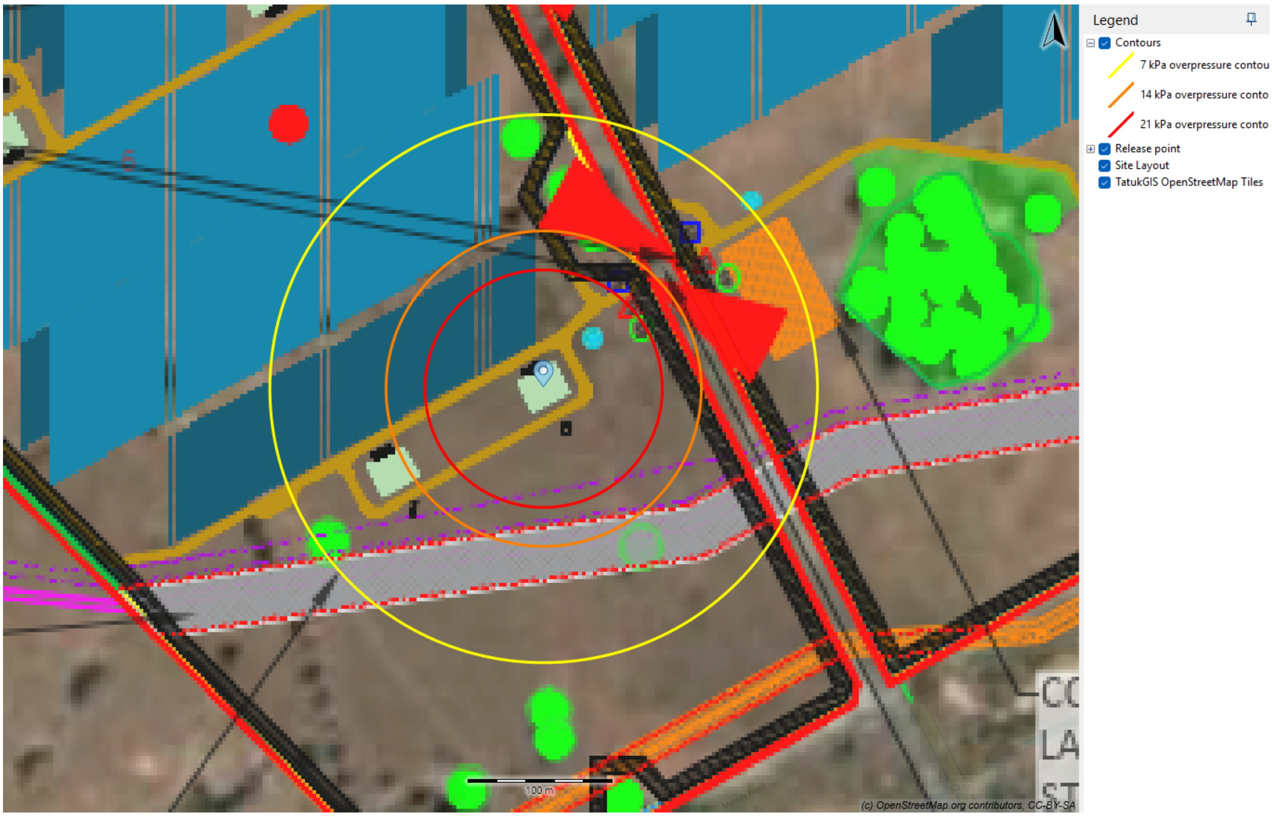

Figure 6-4: Transformer Explosion Overpressure Contours

It should be noted that the contours shown do not represent the underground explosion overpressure impacts. Surface level explosions translate into the ground at the point of the explosion with the majority of the energy being reflected outwards and deflection and peak pressure within the soil layer dissipating rapidly.

7.0 Frequency Analysis

7.1 Incidents Carried Forward for Frequency Analysis

The following incidents have been carried forward for frequency analysis and risk assessment:

- Transformer electrical surge protection failure and explosion.

Each of these incidents have been assessed in the following sections.

7.2 Transformer Electrical Surge Protection Failure and Explosion

The initiating event for a transformer fire is a major oil spill from the transformer casing. This would be classified as a catastrophic failure as all oil contained within the transformer would be released. Failure rate data from the CCPS indicates that the frequency of a catastrophic transformer failure is in the range of 0.125 to 9.26 failures per 10^6 hours (Ref. (Centre for Chemical Process Safety, 1989)).

It is noted that this data base was compiled in 1989 and as such is somewhat outdated. It would be expected that more modern equipment would be more reliable due to advances in materials, better understanding of oil management in transformers, better monitoring systems and process safety requirements. Therefore, the lower range of expected failures has been selected for this assessment to reflect the increased safety present in the transformer systems at the site. Hence, the failure frequency would be 0.125 per 10^6 hours, or 1.10×10^{-3} p.a.

Changlong Zhu et al conducted a peer review of several academically accepted methods of calculating ignition probability (Ref. (Zhu, Jiang, & Yuan, 2012)). The study concluded that for flammable liquids with flashpoints greater than 100°C, the probability of direct or delayed ignition was negligible. This data was taken from a number of well-established models including the BEVI Manual (Ref. (BEVI, 2009)), the Purple Book (Ref. (Committee for the Prevention of Disasters, 2005)), and studies conducted on the HMIRS database (Ref. (Ronza, Vilchez, & Casal, 2007)). Furthermore, an assessment of power transformer reliability conducted by Tenbohlen et al which analysed 112 major transformer failures throughout Europe indicates that most major failures do not result in any external effects (Ref. (Tenbohlen, Vahidi, Gebaur, Kruger, & Muller, 2011)). The Tenbohlen et al study indicates that only 2.7% of major transformer failures result in an explosion (Ref. (Tenbohlen, Vahidi, Gebaur, Kruger, & Muller, 2011)).

The impacted area outside of the site boundary is Benalla-Yarrawonga Road, which is a single-lane, two-way arterial road with no built public access. As such, it is very unlikely that a member of the public or multiple members of the public frequent the area. Hence, it has been assumed that personnel may be within the vicinity of the transformers 1 hour per workday or 260 hours/year resulting in an exposure probability of 0.03. Using this exposure potential, the potential for a fatality becomes $1.1 \times 10^{-3} \times 0.027 \times 0.03 = 8.9 \times 10^{-7}$ p.a.

7.3 Comparison Against Risk Criteria

7.3.1 Fatality Risk

The acceptable criteria have been taken from the NSW Department of Planning, Industry and Environment *Hazardous Industry Planning Advisory Paper No. 4 – Risk Criteria for Land Use Safety Planning* (Ref. (Department of Planning, Industry and Environment, 2011)). The acceptable risk criteria published in the guideline relates to injury, fatality and property damage. The values in the guideline present the maximum levels of risk that are permissible at the land use under assessment as defined in **Table 7-1**.

Table 7-1: Individual Fatality Risk Criteria

Land Use	Suggested Criteria (risk per million per year)
Hospitals, schools, child-care facilities, old age housing	0.5
Residential, hotels motels and tourist resorts	1
Commercial developments including retail centres, offices and entertainment centres	5
Sporting complexes and active open spaces	10
Industrial	50

Based on **Table 7-2**, as the surrounding area is zoned as industrial use, the individual fatality risk criteria is 50x10^{-6}/year.

The fatality risk estimated for the immediate vicinity was calculated to be 8.9x10^{-7}/year which is below the allowable individual fatality risk criteria. Therefore, from a fatality risk perspective the development does not result in an exceedance of the criteria and would be considered acceptable for the proposed location.

7.4 Total Fatality Risk

As the transformers are sufficiently set back from the site boundary to prevent the heat radiation contour impacting offsite, the only offsite impacts are due to explosion overpressure from surge protection equipment failure and a subsequent transformer explosion. As such, the total fatality risk from these events is summarised in **Table 7-2**.

Table 7-2: Total Fatality Risk

Incident	Fatality Risk
Transformer Bund Fire	0
Transformer Explosion	8.9x10^{-7}
Total	**8.9x10^{-7}**

7.5 Comparison Against Risk Criteria

The acceptable criteria have been taken from the NSW Department of Planning, Industry and Environment *Hazardous Industry Planning Advisory Paper No. 4 – Risk Criteria for Land Use Safety Planning* (Ref. (Department of Planning, Industry and Environment, 2011)) and used for guidance as Victoria does not have any published criteria for offsite risk. The acceptable risk criteria published in the guideline relates to injury, fatality and property damage. The values in the guideline present the maximum levels of risk that are permissible at the land use under assessment.

The adjacent land use is classified as an industrial site (under the guidelines). For industrial facilities, the maximum permissible fatality risk is 50x10^{-6}/year. The assessed highest fatality risk is 8.9x10^{-7}/year at the closest site boundary; hence, the highest risk is within the permissible criteria and therefore all other risk points beyond the boundary would be within the acceptable criteria.

Based on the estimated injury risk, conducted in the analysis above, the risks associated with injury and nuisances at the closest residential area are not considered to be exceeded.

7.6 Incident Propagation

The same guidelines provide acceptable risk criteria (Ref. (Department of Planning, Industry and Environment, 2011)) for incident propagation as 50 chances pmpy. Based on the recommendations provided, the 23 kW/m^2 contour would not impact offsite; hence, the potential for incident propagation is zero (0) which is less than the acceptable risk criteria for incident propagation.

8.0 Conclusion and Recommendations

8.1 Conclusions

A hazard identification table was developed for the Kennedys Creek Solar Farm site to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with a potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

Incidents carried forward for consequence analysis were assessed in detail to estimate the impact distances. Impact distances were developed into scenario contours and overlaid onto the site layout diagram to determine if an offsite impact would occur. The consequence analysis showed that a transformer explosion due to surge protection failure would have potential to impact off site. As such, a frequency analysis was conducted on this incident. The frequency analysis estimated the site total fatality risk criteria would be zero 8.9×10^{-7}/year which is within the acceptable risk criteria indicated in HIPAP No.4 (Ref. (Department of Planning, Industry and Environment, 2011)) of 1×10^{-6}/year.

In addition, incidents exceeding 23 kW/m^2 were reviewed which indicated that, with the recommendation measures implemented, the contours from such incidents would not impact over the site boundary nor create incident propagation within the site and would be below the acceptable criteria.

Based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the facility would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

8.2 Recommendations

Notwithstanding the conclusions drawn, the following recommendations have been made and should be undertaken to cover the battery and inverter equipment as well as common hazards for a mechanical site prior to the commencement of operations of the Solar PV and BESS site to the extent dangerous goods exceed any thresholds:

- BESS must be tested in accordance with UL9540A.
- Testing to demonstrate clearances required to prevent propagation of fires between separated units.
- BESS to be installed in accordance with manufacturer and UL9540A report recommended clearances based on testing.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the facility area whilst meeting the recommended clearances.
- UL testing information shall be made available to the certifying authority. It is noted that a confidentiality agreement may be required.
- The vent covers of the BESS shall be constructed of non-combustible material.

- The vents shall not be located above battery packs within the BESS container.
- Separation distances between BESS and PCUs should be at least 3 m or in accordance with relevant standards and guidelines, whichever is greater.
- A submission to CFA shall be made for written advice in accordance with the VDGR.
- A Dangerous Goods (DG) risk assessment shall be prepared for the site.
- A DG register shall be prepared for the site.
- A site manifest shall be prepared at the site in accordance with Schedule 3 of the Victorian Dangerous Goods Regulation (VDGR).
- The site shall notify the Regulator (i.e. WorkSafe Victoria) of the presence of DGs.
- A site layout shall be prepared for the site in accordance with Schedule 3 of the VDGR.
- A placard schedule shall be prepared for the site to ensure the correct placards are installed.
- An Emergency Response Plan (ERP) shall be prepared for the site and submitted to the Fire & Rescue Victoria (CFA).
- An Emergency Services Information Booklet (ESIB) shall be prepared for the site and submitted to the CFA.
- The substation transformer bunds shall be designed according to the requirements detailed in AS 2067:2016(Ref. (Standards Australia, 2016)), and shall have a volume of 110% of the total volume of the mineral oil within the Transformer to account for any safety risks from a potential fire and or explosion.

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Appendix A

Hazard Identification Table

Appendix A

A1. Hazard Identification Table

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
1	Battery Storage	• Failure of lithium ion battery protection systems	• Thermal runaway resulting in fire or explosion • Incident propagation through battery cells	• Batteries are tested by manufacturer prior to sale / installation • Overcharging and electrical circuit protection • Battery monitoring systems • Batteries composed of subcomponents (i.e. BBU, cells) reducing risk of substantial component failure • Batteries are not located in areas where damage could easily occur (i.e. within the fenced property) • Electrical systems designed per AS/NZS 3000:2007 (Ref. (Standards Australia, 2018)) • Aerosol fire suppression • UL9540A testing
2	Switch rooms, communications, etc.	• Arcing, overheating, sparking, etc. of electrical systems •	• Ignition of processors and other combustible material within servers and subsequent fire	• Hydrant protection • Fires tend to smoulder rather than burn • Isolated location • Switch room contained within a structure
3	Transformers	• Arcing within transformer, vaporisation of oil and rupture of oil reservoir	• Transformer oil spill into bund and bund fire	• Bunded • Fire protection (hydrants, extinguishers) • Isolated location
4	Transformers	• Power surge to transformers	• Major failure of surge protection in transformer, vapourisation of mineral oil, ignition and explosion	• Transformers have surge protection system to shut down upon detection of extreme energy input • Lightning protection to prevent lightning strikes impacting transformers • Control of ignition sources – no smoking / open flames around the transformers

ID	Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
5	BESS Units	• Failure of flanges, valves, compressors, etc. and release of gas	• Non-flammable, non-toxic gases pose no fire issue • Potential oxygen exclusion and asphyxiation risk	• Relatively low volume of gas used • Robust and commonly used systems which are not prone to large leaks • Open outdoor area provides natural ventilation preventing accumulation of gases
6	Diesel Storage	• Release of combustible liquid and ignition	• Pool fire at the point of release	• Combustible liquids do not give off flammable vapours at atmospheric conditions • Low ignition probability • Relatively small release of diesel • AS 1940-2017 compliant storages
7	Electrical Infrastructure	• Electric and magnetic equipment	• Generation of ELF EMF and injury / nuisance to surrounding area	• Large separation distances allow for attenuation of EMFs • Cumulative impacts from equipment below acceptable thresholds. • Low occupancy density within vicinity of the development
8	Gas Pipeline Impacts	• Damage to pipeline during construction • Fire and explosion from solar farm equipment impacts pipeline	• Failure of pipeline and loss of containment and fire, vapour cloud explosion, jet fire, flash fire	• Underground pipeline protects against damage / radiant heat • Marker tape, marker signs • Dial before you dig • Known location of pipeline

Appendix B

Consequence Analysis

Appendix B

B1. Incidents Assessed in Detailed Consequence Analysis

The following incidents are assessed for consequence impacts.

- Li-ion battery fault, thermal runaway and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion.

Each incident has been assessed in the sections below.

B2. Gexcon – Effects

The modelling was prepared using Effects which is proprietary software owned by Gexcon which has been developed based upon the TNO Coloured books and updated based upon CFD modelling tests and physical verification experiments. The software can model a range of incidents including pool fires, flash fires, explosions, jet fires, toxic dispersions, warehouse smoke plumes, etc.

B3. Radiant Heat Physical Impacts

Appendix Table B-1 provides noteworthy heat radiation values and the corresponding physical effects of an observer exposed to these values (Ref. (Department of Planning, Industry and Environment, 2011)).

Appendix Table B-1: Heat Radiation and Associated Physical Impacts

Heat Radiation (kW/m^2)	Impact
35	• Cellulosic material will pilot ignite within one minute's exposure • Significant chance of a fatality for people exposed instantaneously
23	• Likely fatality for extended exposure and chance of a fatality for instantaneous exposure • Spontaneous ignition of wood after long exposure • Unprotected steel will reach thermal stress temperatures which can cause failure • Pressure vessel needs to be relieved or failure would occur
12.6	• Significant chance of a fatality for extended exposure. High chance of injury • Causes the temperature of wood to rise to a point where it can be ignited by a naked flame after long exposure • Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure
4.7	• Will cause pain in 15-20 seconds and injury after 30 seconds exposure (at least second degree burns will occur)

B4. Explosion Overpressure Physical Impacts

Appendix Table B-2 Appendix Table B-1 provides noteworthy explosion overpressure values and the corresponding physical effects of an observer exposed to these values (Ref. (Department of Planning, Industry and Environment, 2011)).

Appendix Table B-2: Effects of Explosion Overpressures

Overpressure (kPa)	Impact
70	• Threshold of lung damage • 100% chance of fatality for a person in a building or in the open • Complete demolition of houses
35	• House uninhabitable • Wagons and plants items overturned • Threshold of eardrum damage • 50% chance of fatality for a person in a building and 15% chance of fatality for a person in the open
21	• Reinforced structures distort • Storage tanks fail • 20% chance of fatality to a person in a building
14	• House uninhabitable and badly cracked
7	• Damage to internal partitions and joinery but can be repaired • Probability of injury is 10%. No fatality
3.5	• 90% glass breakage • No fatality and very low probability of injury

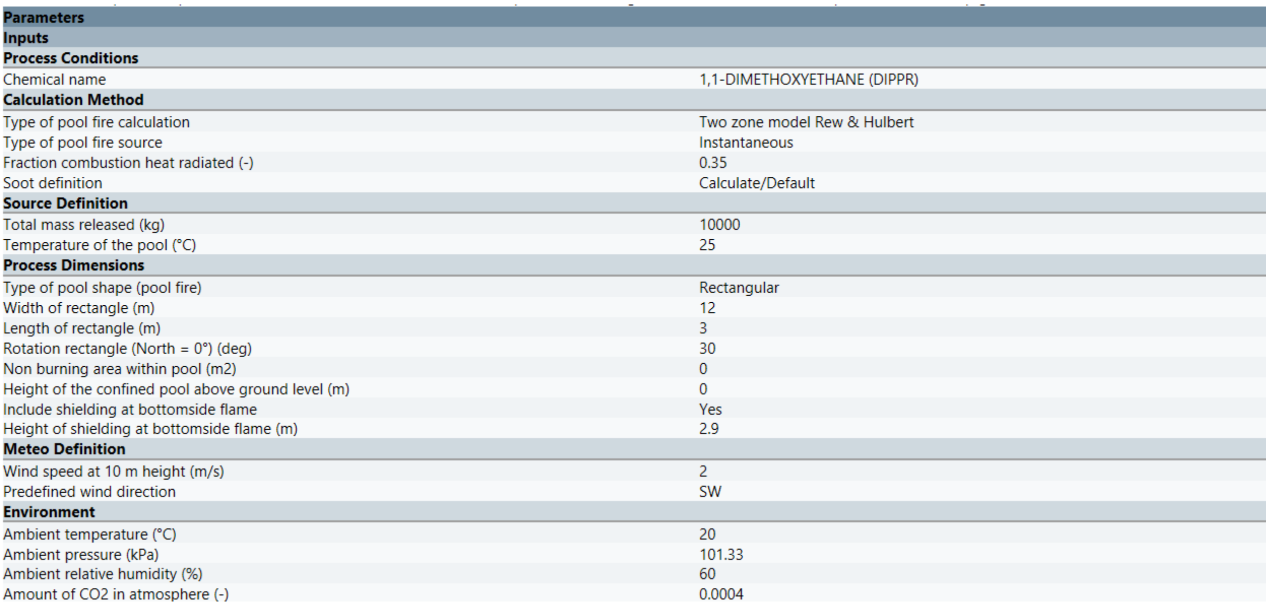
B5. Li-Ion Battery Fault, Thermal Runaway and Fire

The site has been designed as a decentralized BESS with each battery unit spaced throughout the site with the smallest distance between two battery units being approximately 90 m. Therefore, the assessment has been based on a single full-container fire with any potential incident propagation to adjacent batteries being determined based upon the proximity of the 23 kW/m^2 heat radiation contour. It has been assumed that the maximum dimensions of the battery units will be 12 m x 3 m (40 ft shipping container) resulting in an area of 36 m^2.

The battery fire model has been based upon the properties of the organic solvents used within the battery. A review of typical organic solvents used in batteries indicates there is a range including chemicals such as dimethoxyethane and γ-butyrolactone. For this assessment, dimethoxyethane has been selected.

It is noted that the BESS units are contained in containerized metal shipping containers which will provide a level of shielding to the fire. A typical 20 ft shipping container has a height of 2.9 m; hence this has been input as a shielding value.

The input file has been provided in **Appendix Figure B-1**.



Parameters	
Inputs	
Process Conditions	
Chemical name	1,1-DIMETHOXYETHANE (DIPPR)
Calculation Method	
Type of pool fire calculation	Two zone model Rew & Hulbert
Type of pool fire source	Instantaneous
Fraction combustion heat radiated (-)	0.35
Soot definition	Calculate/Default
Source Definition	
Total mass released (kg)	10000
Temperature of the pool (°C)	25
Process Dimensions	
Type of pool shape (pool fire)	Rectangular
Width of rectangle (m)	12
Length of rectangle (m)	3
Rotation rectangle (North = 0°) (deg)	30
Non burning area within pool (m2)	0
Height of the confined pool above ground level (m)	0
Include shielding at bottomside flame	Yes
Height of shielding at bottomside flame (m)	2.9
Meteo Definition	
Wind speed at 10 m height (m/s)	2
Predefined wind direction	SW
Environment	
Ambient temperature (°C)	20
Ambient pressure (kPa)	101.33
Ambient relative humidity (%)	60
Amount of CO2 in atmosphere (-)	0.0004

Appendix Figure B-1: BESS Fire Input

The above information was input into Effects which calculated the following outputs:

- SEP – 95.8 kW/m^2
- Flame height – 10.2 m

The results of the analysis are shown in **Appendix Table B-3**.

Appendix Table B-3: BESS Fire Heat Radiation Distances

Heat Radiation (KW/m^2)	Distance (m)
35	0
28	3
23	6
12.6	6
4.7	10
3.0	13

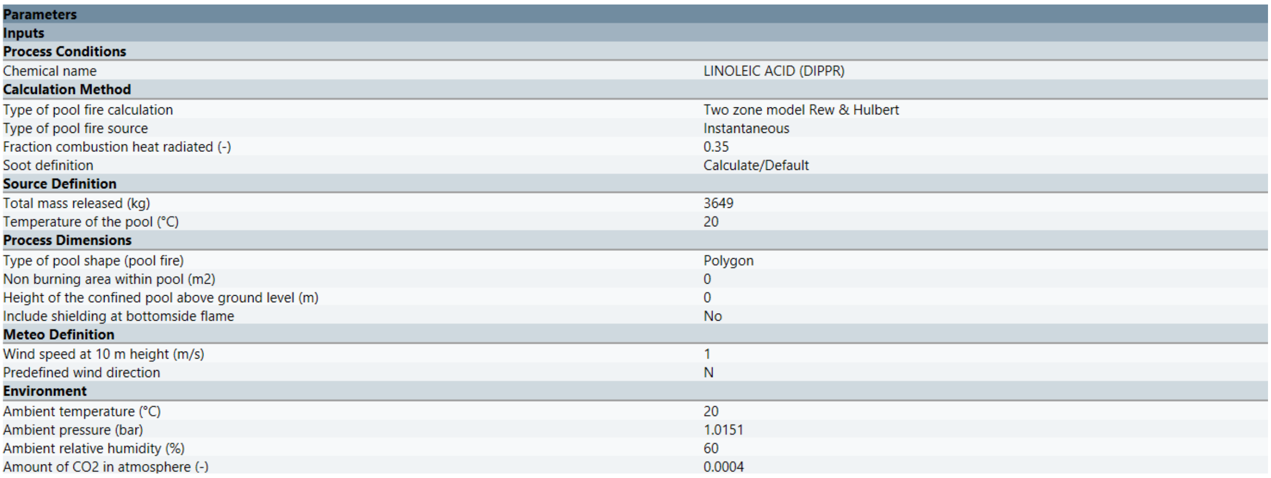
B6. Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Transformers contain oil to provide cooling and insulation. If arcing occurs within the transformer, the oil will rapidly heat generating gases above their auto ignition point. The pressure of the gases may rupture the reservoir allowing oxygen to enter resulting in the gases auto igniting. The oil is released from the reservoir and is ignited by the burning gases.

It has been assumed that the transformer has bund dimensions of approximately 12.5 m x 9 m which is based upon similar projects; hence, if a spill from the transformer was to occur it would fill the base of the bund resulting in a pool fire with the dimensions of the bund.

The exact type of transformer oil to be used in unknown, for the purposes of this assessment, it has been assumed that a natural ester oil such as FR3 will be used which is composed of soybean oil, itself a mixture of triglycerides. These triglycerides are esters of fatty acids, predominantly linoleic acid. Linoleic acid has a flash point of approximately 200 °C, while the FR3 oil itself has a higher flash point of 300 ^{O}C. For the purposes of providing a conservative analysis, pure linoleic acid has been selected as the transformer oil. The input file used to model this scenario has been provided in

The results of the analysis are shown in **Appendix Figure B-2**.



Parameters	
Inputs	
Process Conditions	
Chemical name	LINOLEIC ACID (DIPPR)
Calculation Method	
Type of pool fire calculation	Two zone model Rew & Hulbert
Type of pool fire source	Instantaneous
Fraction combustion heat radiated (-)	0.35
Soot definition	Calculate/Default
Source Definition	
Total mass released (kg)	3649
Temperature of the pool (°C)	20
Process Dimensions	
Type of pool shape (pool fire)	Polygon
Non burning area within pool (m2)	0
Height of the confined pool above ground level (m)	0
Include shielding at bottomside flame	No
Meteo Definition	
Wind speed at 10 m height (m/s)	1
Predefined wind direction	N
Environment	
Ambient temperature (°C)	20
Ambient pressure (bar)	1.0151
Ambient relative humidity (%)	60
Amount of CO2 in atmosphere (-)	0.0004

Appendix Figure B-2: BESS Fire Input File

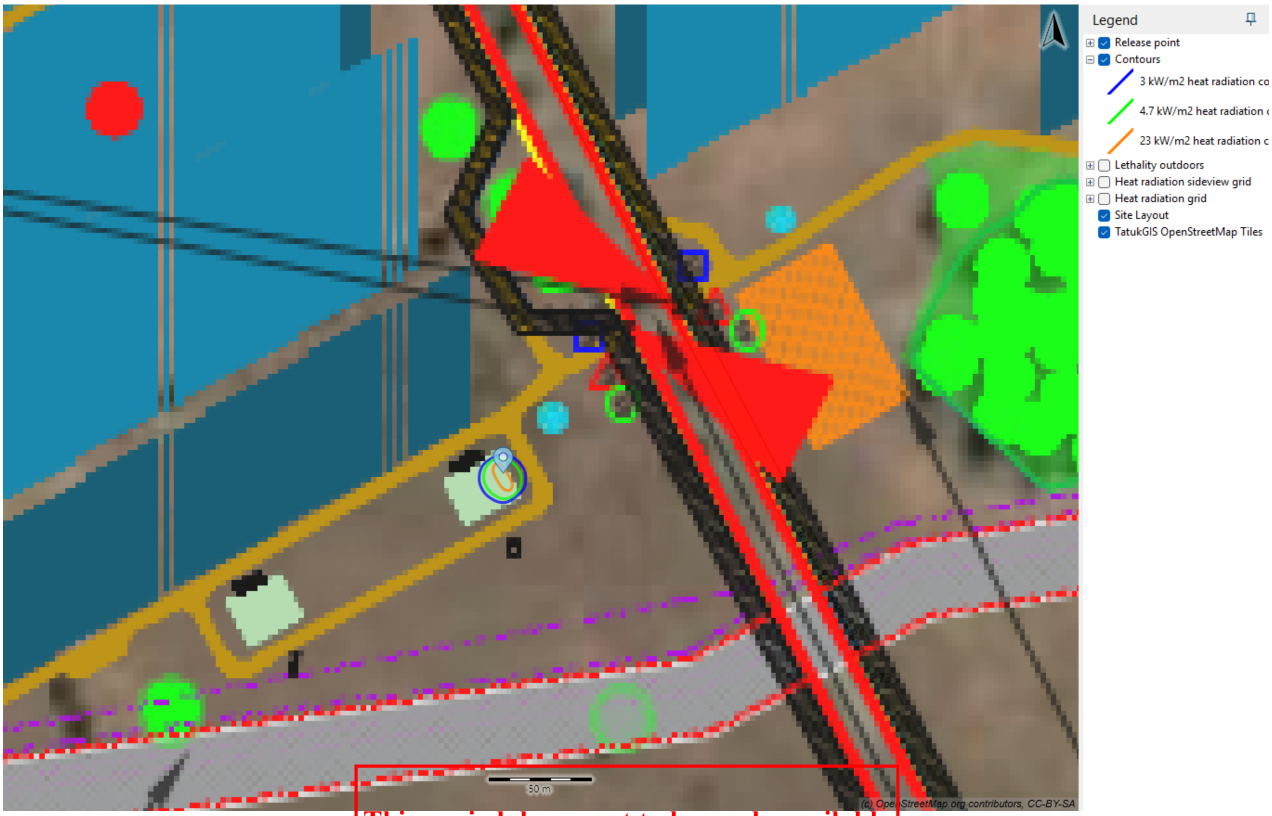
The above information was input into Effects which calculated the following outputs:

- Surface Emissive Power (SEP) – 85.4 kW/m^2
- Flame height – 21.6 m

The results of the analysis are shown in **Appendix Table B-4**, with the heat radiation contours depicted in **Appendix Figure B-3**.

Appendix Table B-4: Heat Radiation Impacts From a Transformer Bund Fire

Heat Radiation (KW/m^2)	Distance (m)
35	18
23	20
12.6	27
4.7	42
3.0	51



Appendix Figure B-3: Transformer Bund Fire Impact Contours

B7. Transformer Electrical Surge Protection Failure and Explosion

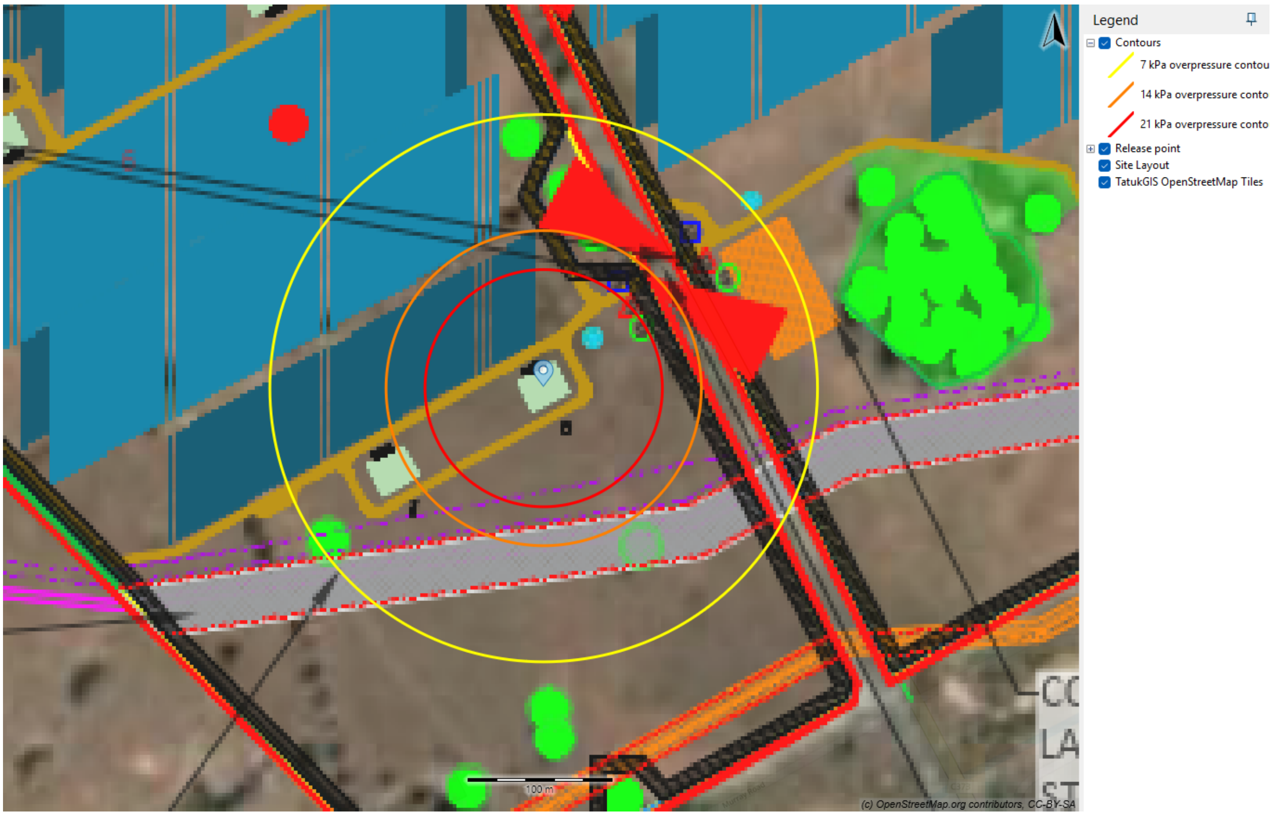
If a transformer is impacted by extreme electricity surge, such as in the event of a lightning strike, the ester oil within the transformer may ignite and explode resulting in substantial overpressure impacts. The following data has been obtained to model a transformer explosion:

- Weight – 3,649 kg (based on 4,100 L of oil contained within a single transformer and an oil density of 890 kg/m^3)
- α – 0.05 for hydrocarbons (Ref. (Orica))

The above information was input into Gexcon Effects with the results of the explosion calculations provided in **Appendix Table B-5**, with the impact contours depicted in **Appendix Figure B-4**.

Appendix Table B-5: Overpressure from a Transformer Explosion

Overpressure (kPa)	Distance (m)
70	40
35	58
21	81
14	107
7	186



Appendix Figure B-4: Transformer Explosion Overpressure Contours

Appendix C

Sample UL9540A Report

Appendix C

Prüfbericht-Nr.: *Test Report No.:* CN23XPOX 001
Auftrags-Nr.: *Order No.:* 168418338
Seite 1 von 36 *Page 1 of 36*

Kunden-Referenz-Nr.: *Client Reference No.:* 2347845
Auftragsdatum: *Order date:* 2023.03.13

Auftraggeber: *Client:*
Xiamen Hithium Energy Storage Technology Co., Ltd.
201-1, Comprehensive Building 5, No. 11, Butang Middle Road, Industrial Base
of Xiamen Torch High Tech zone (Tongxiang), Xiamen, Fujian P.R. China

Prüfgegenstand: *Test item:* Cluster

Bezeichnung / Typ-Nr.: *Identification / Type No.:* CL00344U001L

Auftrags-Inhalt: *Order content:* Test report

Prüfgrundlage: *Test specification:* UL 9540A: 2019 (Fourth Edition)

Wareneingangsdatum: *Date of sample receipt:* 2023.03.28

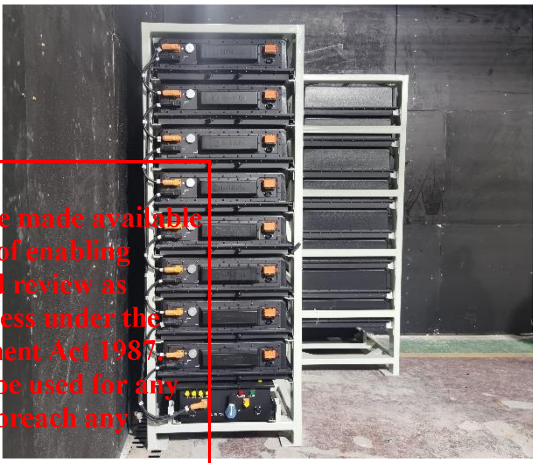
Prüfmuster-Nr.: *Test sample No.:* Engineering sample

Prüfzeitraum: *Testing period:* 2023.03.30 to 2023.04.12

Ort der Prüfung: *Place of testing:* See to clause 1.1 of main report

Prüflaboratorium: *Testing laboratory:* See to clause 1.1 of main report

Prüfergebnis*: *Test result*:* See main report



erstellt von: created by: Stephen Huang
Datum: *Date:* 2023.05.17 Stephen Huang
Stellung / *Position* Project Engineer

genehmigt von: *authorized by:* Corney
Datum: *Date:* 2023.05.17 Corney Zhang
Stellung / *Position* Reviewer

Sonstiges / *Other:* This report does not evidence compliance of the provided sample with the relevant standards but only with the referred tests. This test report documents the findings of examination conducted on the delivered product mentioned above only. This report does not entitle the applicant to carry any safety mark on this or similar products. Further for sales or other application purposes of the tested product, any reference to TÜV Rheinland or a test through TÜV Rheinland is only permissible with prior written consent of TÜV Rheinland.

Zustand des Prüfgegenstandes bei Anlieferung: Prüfmuster vollständig und unbeschädigt
Condition of the test item at delivery: *Test item complete and undamaged*

* Legende:	P(ass) = entspricht o.g. Prüfgrundlage(n)	F(ail) = entspricht nicht o.g. Prüf grundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
**Legend:*	*P(ass) = passed a.m. test specification(s)*	*F(ail) = failed a.m. test specification(s)*	*N/A = not applicable*	*N/T = not tested*

Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens.

This test report only relates to the a. m. test sample. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.

INTRODUCTION

Model fire codes and energy storage system standards require energy storage systems to comply with UL 9540, which in turn requires battery cells and modules to comply with UL 1973. Compliance with these standards reduces the risk of batteries and battery energy storage systems (BESS) creating fire, shock or personal injury hazards. However, they don't evaluate the ability of the BESS installed as intended and with fire suppression mechanisms in place if necessary, from contributing to a fire or explosion in the end use installations.

To address these fire and explosion hazards associated with the installation of a BESS, the fire and other codes require energy storage systems to meet certain location, separation, fire suppression and other criteria. Those codes also provide a means to provide an equivalent level of safety based on large scale fire testing of anticipated BESS installations.

UL 9540A is intended to provide a test method that can be used as a basis for validating the safety of a BESS installation in lieu of meeting the specific criteria provided in those codes. The data generated can be used to determine the fire and explosion protection required for installation of a BESS.

The test method is initiated through the establishment of a thermal runaway condition that leads to combustion within the BESS. The test method outlined in UL 9540A consists of several steps – cell level testing, module level testing, unit level testing and installation level testing. The cell and module level testing steps are information gathering steps to inform the unit and installation level testing.

The following outlines the information that may be gathered as part of the testing:

a) Cell level – An individual cell fails in a manner that leads to thermal runaway and fire through a suitable method such as external heating. Data such as off-gassing contents, temperatures at venting and temperatures at thermal runaway are recorded.

b) Module level – One or more cells within a BESS module fail in the manner determined during the cell level testing. Data such as fire propagation in the module, temperatures on the failed cells and surrounding cells, off-gassing contents and heat release data are gathered.

c) Unit level – A complete BESS is installed surrounded by target (e.g. dummy) BESS and walls separated at a distance as intended in its installation. The module level test is repeated on a module located in the BESS in the most unfavorable location. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; observation of fire propagation from BESS to target units and walls as well as observance of explosions or evidence of re-ignition within the BESS; and heat release and off-gassing contents are gathered.

d) Installation level – This test is a repeat of the unit level test with the test conducted within a test room and with the intended fire suppression system installed as well as any overhead cables (that can lead to fire propagation) installed. This test is intended to validate the fire suppression system for the BESS installation. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; fire propagation from the BESS to target units, walls or overhead cables and any observable explosion incidents or re-ignition within the BESS; and off-gassing contents (if needed) and heat release are gathered.

Contents

1 General information

1.1 Test specification

Standard: ANSI/CAN/UL 9540A: 2019 (Fourth Edition)

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

This report presents the result of unit level tests of UL 9540A: 2019.

All tests were conducted at TUV Rheinland (Shenzhen) Co., Ltd. and TUV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer.

Testing period: March 30, 2023 to April 11, 2023

Refer to Clause 4 for test and measurement instruments.

1.2 General remarks

This report is descriptive and provide the test data only.

The test results presented in this report relate only to the object tested.

This report shall not be reproduced, except in full, without the written approval of the testing laboratory.

Throughout this report a ☐ comma / ☒ point is used as the decimal separator.

1.3 Revision information

New report, not applicable.

1.4 Definitions

CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

MODULE – A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

UNIT – A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such as cells, modules, battery management systems, ventilation devices and other ancillary equipment.

BATTERY SYSTEM (BS) – Is a component of a BESS and consists of one or more modules typically in a rack configuration, controls such as the BMS and components that make up the system such as cooling systems, disconnects and protection devices.

BATTERY ENERGY STORAGE SYSTEM (BESS) – Stationary equipment that receives electrical energy and then utilizes batteries to store that energy to supply electrical energy at a future time. The BESS, at a minimum consists of one or more modules, a power conditioning system (PCS), battery management system (BMS) and balance of plant components.

a) INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS) – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test.

b) TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS) – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

Note: Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), the unit level test can be done at battery system level. In such case, the BESS is be read as BS throughout this report.

NON-RESIDENTIAL USE – Intended for use in commercial, industrial or utility owned locations.

RESIDENTIAL USE – In accordance with this standard, intended for use in one or two family homes and town homes and individual dwelling units of multi-family dwellings.

THERMAL RUNAWAY- The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

STATE OF CHARGE (SOC) – The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

2 General Product Information

The product information and parameters were provided by the client as below.

2.1 Cell

Manufacturer:	**Xiamen Hithium Energy Storage Technology Co., Ltd.** 201-1, Comprehensive Building 5, No. 11, Butang Middle Road, Industrial Base Of Xiamen Torch High Tech Zone (Tongxiang), Xiamen, Fujian P.R. China	
Model number:	LFP71173207/280Ah	
Chemistry:	☒ $LiFePO_4$ ☐ NMC ☐ NCA ☐ LTO ☐ Other:	
Physical configuration:	☒ Prismatic ☐ Cylindrical ☐ Pouch	
	Weight(kg):	5.43±0.2kg
Electrical rating :	Rated capacity (Ah):	280
	Nominal voltage (V):	3.2
Standard charge method:	Charge current (A):	140
	Standard Charge Voltage (V):	3.65
	Cut off current (A):	14
Standard discharge method:	Discharge current (A):	140
	End of discharge voltage (V):	2.5
Maximum continuous charge current (A):	280	
Maximum continuous discharge current (A):	280	
Compliance with UL 1973:	☒ Yes TUV Rheinlad TUVus Certification: US 72228053 0001, Report No.: CN22YQLL 001 ☐ No	

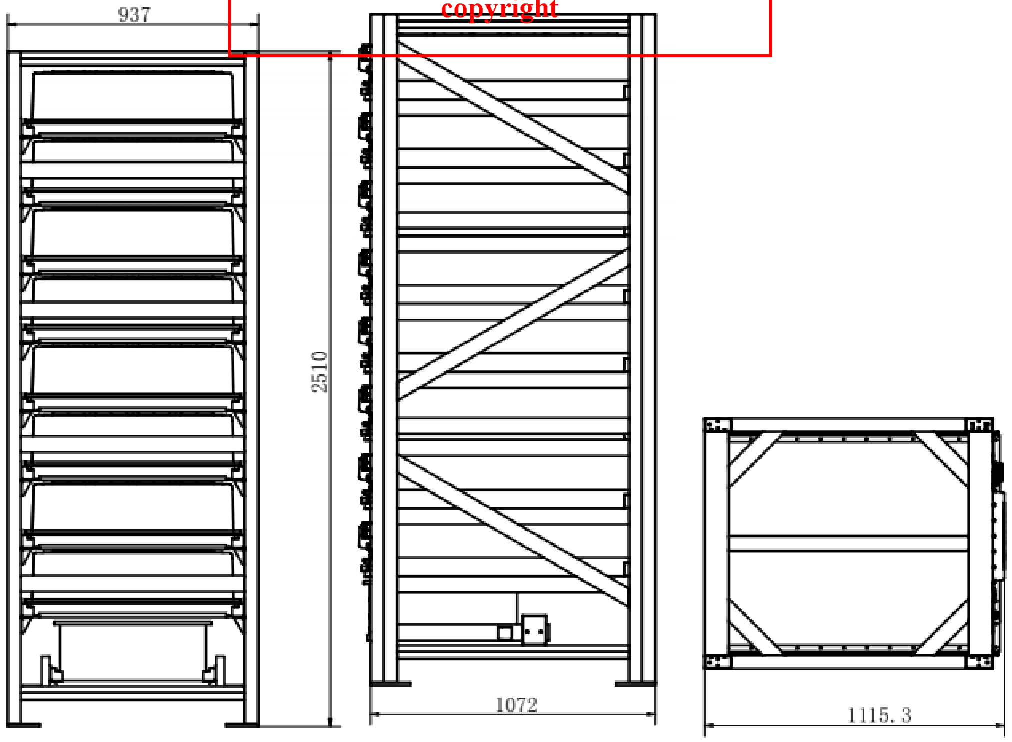
2.2 Module

Manufacturer:	**Xiamen Hithium Energy Storage Technology Co., Ltd.** 201-1, Comprehensive Building 5, No. 11, Butang Middle Road, Industrial Base Of Xiamen Torch High Tech Zone (Tongxiang), Xiamen, Fujian, P.R. China	
Model number:	ML00043U001L	
Physical configuration:	Metal base, the other sides are non-metallic material. A mica plate is installed under the top enclosure.	
	Weight:	310 ±10 kg
	Cells in series/parallel:	48S1P
Cooling method:	Liquid cooling	
Separation between cells:	Thermal insulation sheet: Aerogel Heat insulation pad and Polyurethane foam, see Figure 4 for install location details.	
Electrical rating:	Rated capacity:	280 Ah
	Nominal voltage:	153.6 Vdc
Standard charge method:	Charge power:	21504 W
	End of charge:	The highest cell voltage reaches 3.65 V
Standard discharge method:	Discharge power:	21504 W
	End of discharge:	The lowest cell voltage reaches 2.5 V
Compliance with UL 1973:	☐ Yes	☒ No

2.3 Unit

Product name	Cluster
Model	CL00344U001L
Voltage range	960V-1401.6V
Nominal voltage	1228.8V
Maximum charge and discharge Current	170A(within one minute)
Rated capacity	280Ah
Operating Temperature	0-50°C(Cell)(Charge), -30-50°C(Cell)(Discharge)
Storage Temperature	-20°C to 45°C (within one month)
Recommend charging method declared by the manufacturer	Charged with constant power 172kW till cell voltage reaches 3.65V, at 25±2°C.
Recommend discharging method declared by the manufacturer	Discharged with constant power 172kW till cell voltage reaches 2.5V, at 25±2°C.
Nominal mass	About 2.9t
External dimensions (mm)	L*W*H:937*1116*2510

Unit diagram with overall dimension



Unit: mm

2.4 Photo

Module

Unit

3 Unit level test (section 9 of UL 9540A)

3.1 General

Unit level testing corresponds with the testing anticipated by fire codes and other codes impacting energy storage system installations to evaluate the large scale fire performance of BESS units installed in, on or adjacent to buildings or in other areas and their resultant performance to qualify for exceptions to limits in the codes imposed on these installations. The limitations where exceptions may be sought are limitations on the size of the individual BESS units, the total number of BESS units installed within a room, and the separation distances between BESS units and between BESS units and walls of the building.

In this test the initiating BESS unit is placed a set distance from target BESS units simulating BESS units identical to the initiating BESS unit, and from simulated walls representative on the installation. A thermal runaway is induced in cells, using the same approach as used in the module level testing within one of the modules in the initiating BESS, and a variety of measurements are taken. The results are intended to be used to verify that a fire within a single BESS unit will not spread to other units, nor breach the walls or the BESS enclosure (if provided), and there shall be no flying debris or explosive discharge of gases.

The test arrangement include the largest (energy) BESS unit for the installation to be represented by the test, and minimum spacing to adjacent walls and BESS units. The BESS may be tested with an internal fire suppression system provided by the manufacturer if that fire suppression system is required to be installed in the BESS. Optional internal fire suppression systems are not included in the unit level testing.

The test monitors the fire behavior of the BESS unit and measures heat release rates (convective and chemical); gas generation and composition; smoke release rate; maximum heat flux on the target BESS units, wall surfaces and within the accessible means of egress; maximum surface temperatures of the walls and modules within the target BESS units; and documents any explosions, deflagrations and flying debris from the BESS under test.

3.2 Unit sample preparation

The battery rack is constructed with 8 modules that was considered as a unit for purposes of the test.

All 8 modules samples through 3 charge/discharge cycles per the manufacturer's instructions to verify that the module was functional. Each cycle was defined as a charge to 100% SOC and allowed to rest 30 minutes and then discharged to an end of discharge voltage (EODV) determined by the module specification. Refer to 2.2 for the end of condition of charge and discharge.

3.3 Setup of the test

3.3.1 Battery system installation information

The installation information was provided by the client as below.

Intended use location.........................:	☐ Residential	☒ Non-residential
	☐ Non-residential rooftop	
	☐ Non-residential open garage use	
Type of installation ....:	☒ Indoor	☐ Outdoor
	☒ Floor/ground mounted	☐ Wall mounted
Row(s) of installation	☐ Single	☒ Multiple

3.3.2 Test site setup

Two instrumented wall with 3.66 m height, 4.1 m length. Walls were constructed of 116-mm (5/8-in) gypsum wall board and painted flat black.

Three units were used for the purpose of the test.

The initiating unit was positioned adjacent to the two instrumented wall sections.

Minimum separation distance from the unit to wall and between unit were provided by the client, separation distance: A=B=38.2mm, C=D=G=130mm, E=12.5mm.

Unit's layout can be seen in Figure 1.

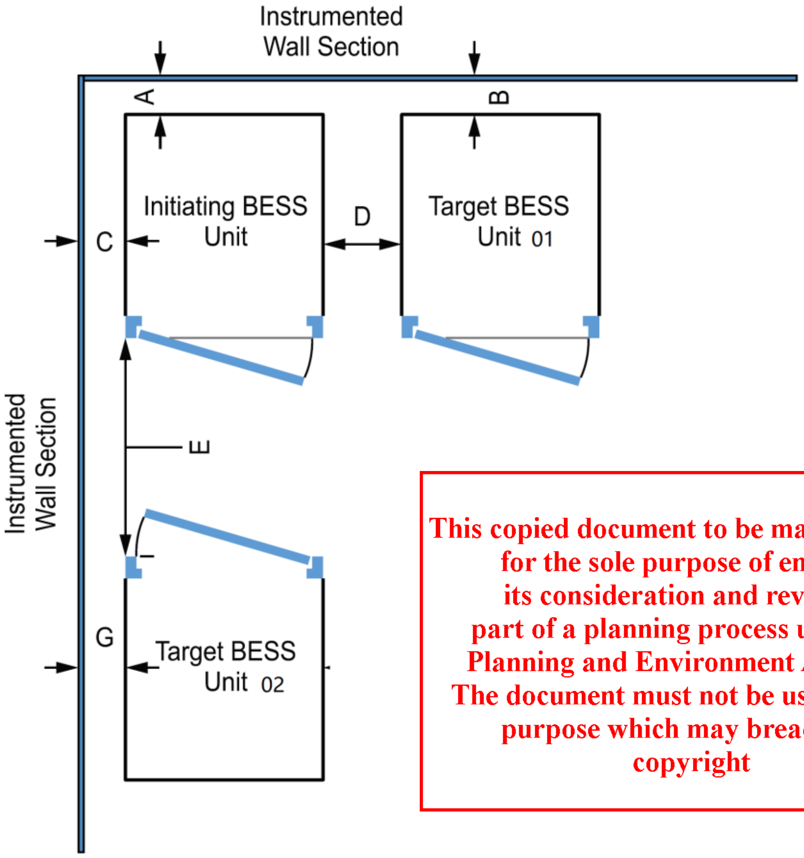


Figure 1. Layout of BESS units

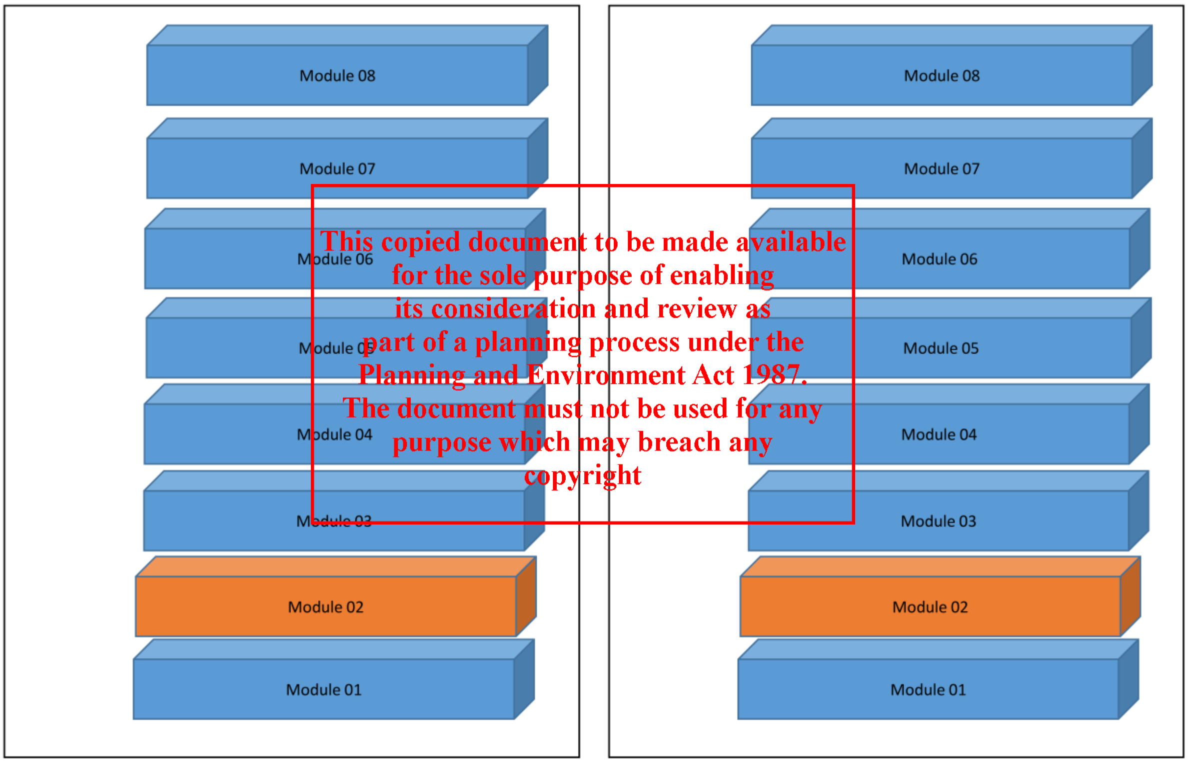
3.3.3 Thermal runaway setup

Setup of Unit:

There were three units were marked as initiating unit and target unit, one was initiating unit, and the others were target units. Each unit had been installed 8 modules.

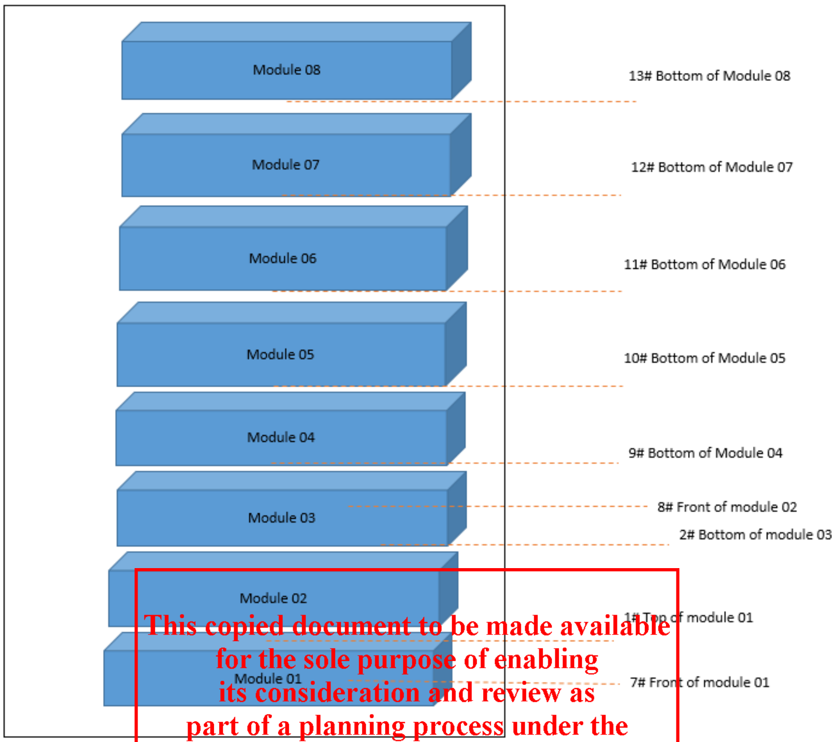
Module **02** in initiating unit was selected as "initiating module" for the test.

Modules **01, 03** in initiating unit and modules in target unit 01 and target unit 02 were used to check the possible propagation between modules in initiating unit and target unit. Figure 2 show the details.



Initiating Unit Target Unit 01

Figure 2. Module numbering in unit



PS: #3 to #6 is on the front, back, left and right surface side of module 02

Figure 3. Thermocouple in initiating unit

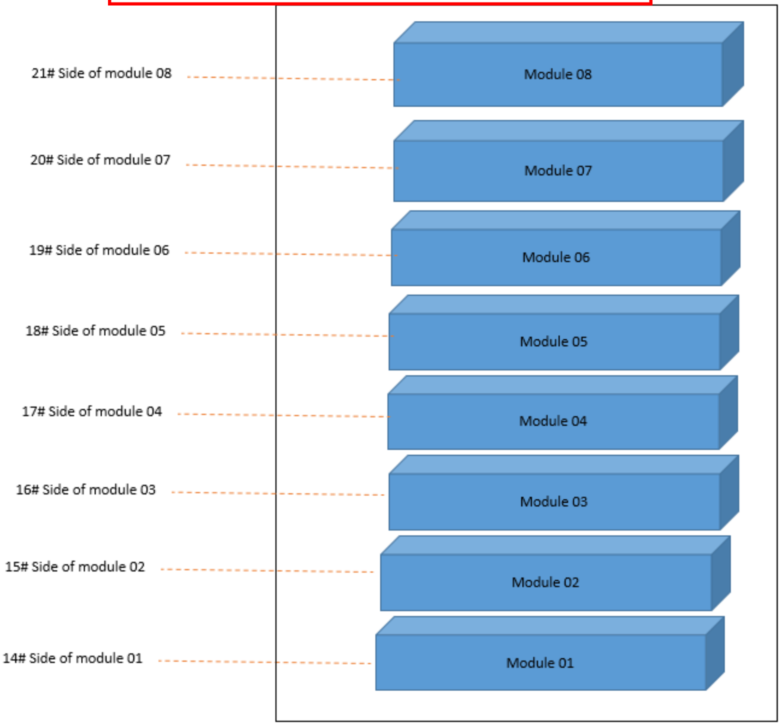


Figure 4. Thermocouple in target unit 01

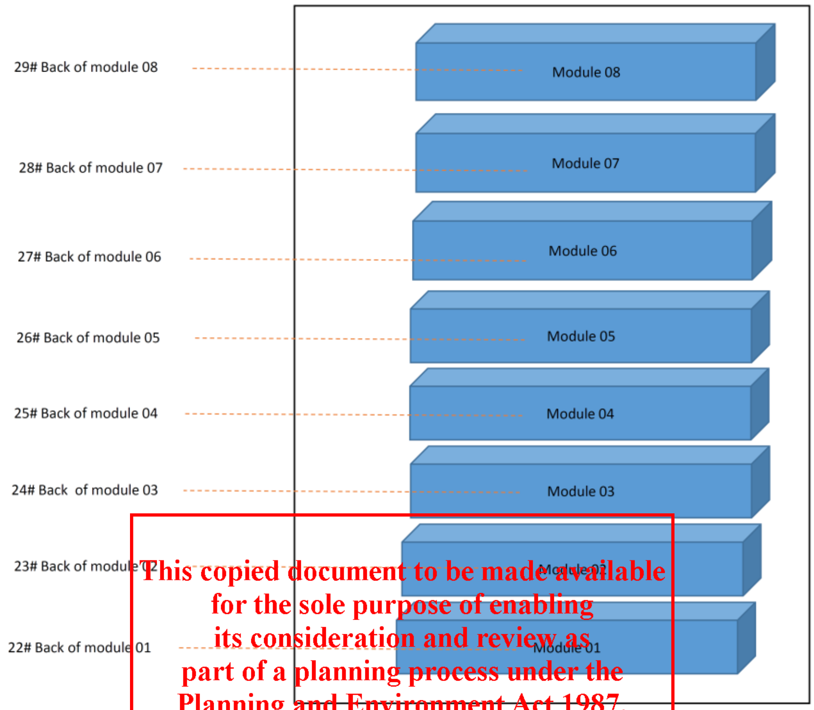


Figure 5: Thermocouple in target unit 02

Setup of module:

The module was consisted of 48 cells (1P48S). All cells in the module were numbered as below picture.

External heating method was used to initiate thermal runaway in the module. One PI sheet heater, rated 220V ac/650 W, size 160*140*3.0 mm, was fitted on cell #1-7.

A surface heating rate of 4° C (7.2° F) to 7° C (12.6° F) per minute was applied to the cell by a PID heating controller. The PID controller maintain the heating rate by controlling the voltage supply.

The heater was de-energized immediately and independently as the thermal runaway observed on the target cell.

Multiple thermocouples, Type K, 24AWG, were attached between the cells and under the heating surface. See Figure 6 for the detail locations.

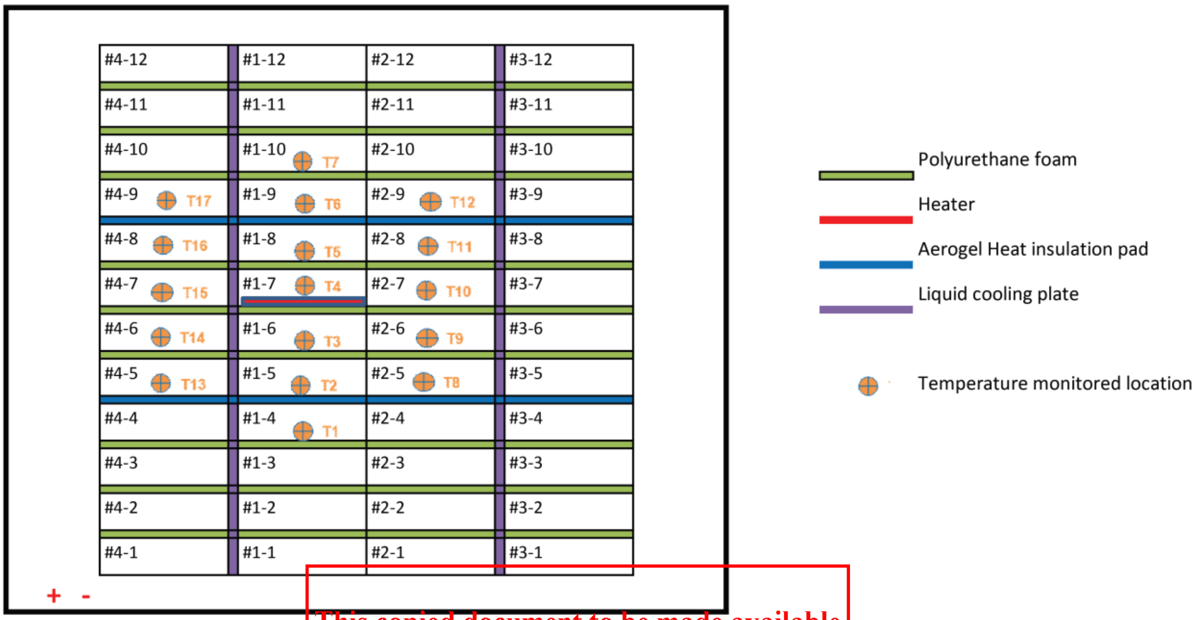


Figure 6. Cell number, location of heater, thermal insulation sheet (Aerogel Heat insulation pad and Polyurethane foam) and thermocouple

3.4 Observations and records

Before test:

The initiating module was charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

Ambient condition at the initiation of the test was 22°C, 50% R.H.

Test was performed on 2023.04.10, started at 16:44 PM.

Before the test, Module 2 in Initiating unit	
OCV (V)	161.4
Weight (kg)	311.5

Observations during test:

Time	1	2	3	4
Vent time	17:50:55	17:52:00	18:04:08	18:06:16
Thermal runaway	17:59:50	18:01:00	18:04:36	18:37:00

No flying debris or explosive discharge of gases during test.

No sparks, electrical arcs, or other electrical events during test.

No external flaming was observed.

Observations after test:

No damage on target walls.

No damage on target units.

The initiating cells (#1-5 to #1-8) were damaged (thermal runway) after the test. Cell #1-5 and cell #1-8 were damaged because of the cell to cell propagation.

After the test, Module 2 in Initiating unit	
OCV (V)	147.1
Weight (kg)	310.0
Weight loss (kg)	1.5

3.5 Temperature measurement

3.5.1 Temperature measurement of initiating module

Multiple thermocouples, Type K, 24AWG, were attached on all module and unit. See Figure 3 to Figure 6 for the detailed locations.

The thermocouple temperature of the module 2 in initiating unit was shown in the figure 7 as below.

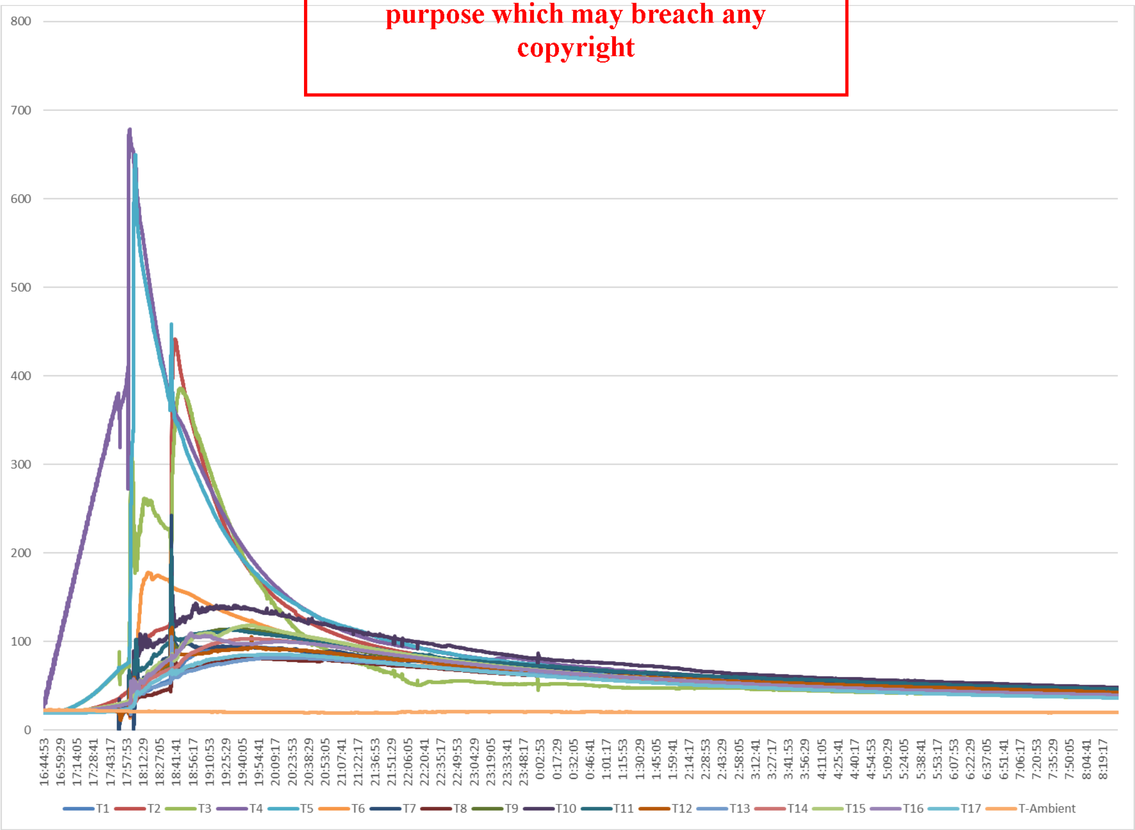


Figure 7. Temperature vs time curve of module 2 in initiating unit.

Thermocouple no.	Location	Maximum temp. °C
T1	Surface of cell #1-4	94.5
T2	Surface of cell #1-5	441.5
T3	Surface of cell #1-6	386.2
T4	Surface of cell #1-7	678.3
T5	Surface of cell #1-8	649.8
T6	Surface of cell #1-9	239.6
T7	Surface of cell #1-10	242.7
T8	Surface of cell #2-5	81.7
T9	Surface of cell #2-6	123.3
T10	Surface of cell #2-7	182.9
T11	Surface of cell #2-8	203.5
T12	Surface of cell #2-9	116.0
T13	Surface of cell #4-5	105.3
T14	Surface of cell #4-6	103.4
T15	Surface of cell #4-7	118.2
T16	Surface of cell #4-8	109.5
T17	Surface of cell #4-9	85.5
T_Ambient	Ambient temperature	23.9

3.5.2 Temperature measurement of moduless surface in unit

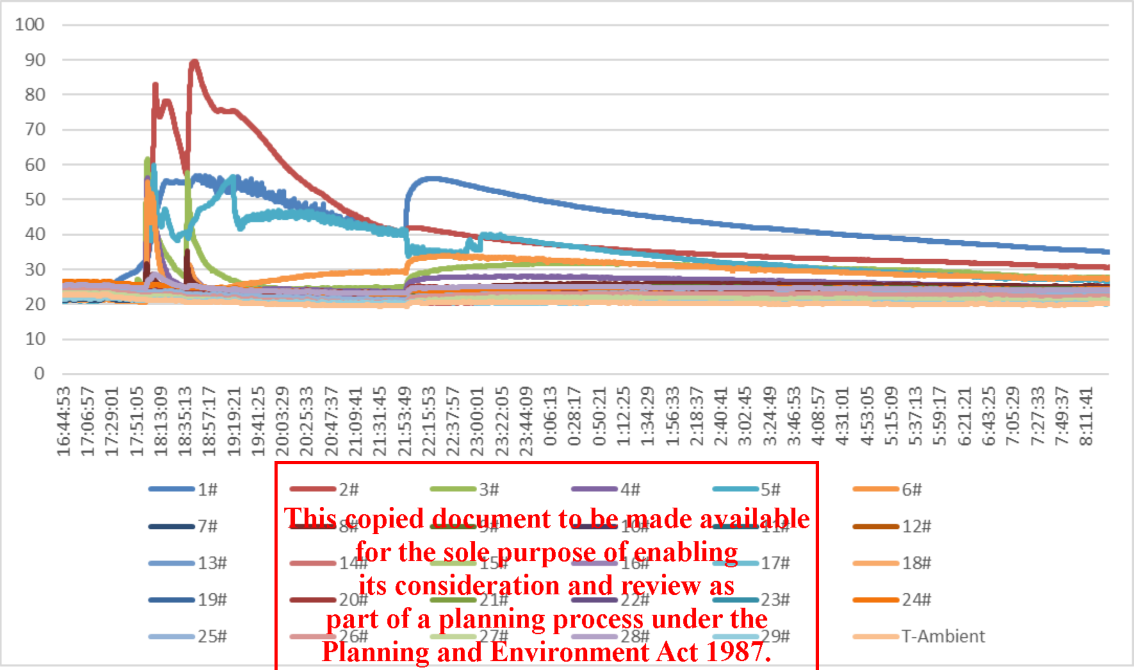


Figure 8: Surface temperatures of module in units

Unit	Channel Number	Location	Max Temp. (°C)
Initiating Unit	1#	Top of module 01 (near the heated cell)	57.0
	2#	Bottom of module 03 (near the heated cell)	89.7
	3#	Front of module 02	61.8
	4#	Back of module 02	56.3
	5#	Left of module 02	60.0
	6#	Right of module 02	55.0
	7#	Front of module 01	31.0
	8#	Front of module 02	35.2
	9#	Bottom of Module 04	24.9
	10#	Bottom of Module 05	22.9
	11#	Bottom of Module 06	23.7
	12#	Bottom of Module 07	24.3
	13#	Bottom of Module 08	23.3
Target unit 01	14#	Front of module 01	23.1
	15#	Front of module 02	23.7
	16#	Front of module 03	25.9
	17#	Front of module 04	23.7
	18#	Front of module 05	23.3
	19#	Front of module 06	23.2
	20#	Front of module 07	25.4
	21#	Front of module 08	23.8
Target unit 02	22#	Front of module 01	23.9

	23#	Front of module 02	23.9
	24#	Front of module 03	26.6
	25#	Front of module 04	25.2
	26#	Front of module 05	24.2
	27#	Front of module 06	23.3
	28#	Front of module 07	28.8
	29#	Front of module 08	22.2

3.5.3 Temperature measurement of instrumented wall

Wall surface temperatures were measured in vertical array at 152 mm intervals for the full height of the instrumented wall sections using Type K, 24 AWG thermocouple. The thermocouple array were collinear with the center line of initiating unit and target unit.

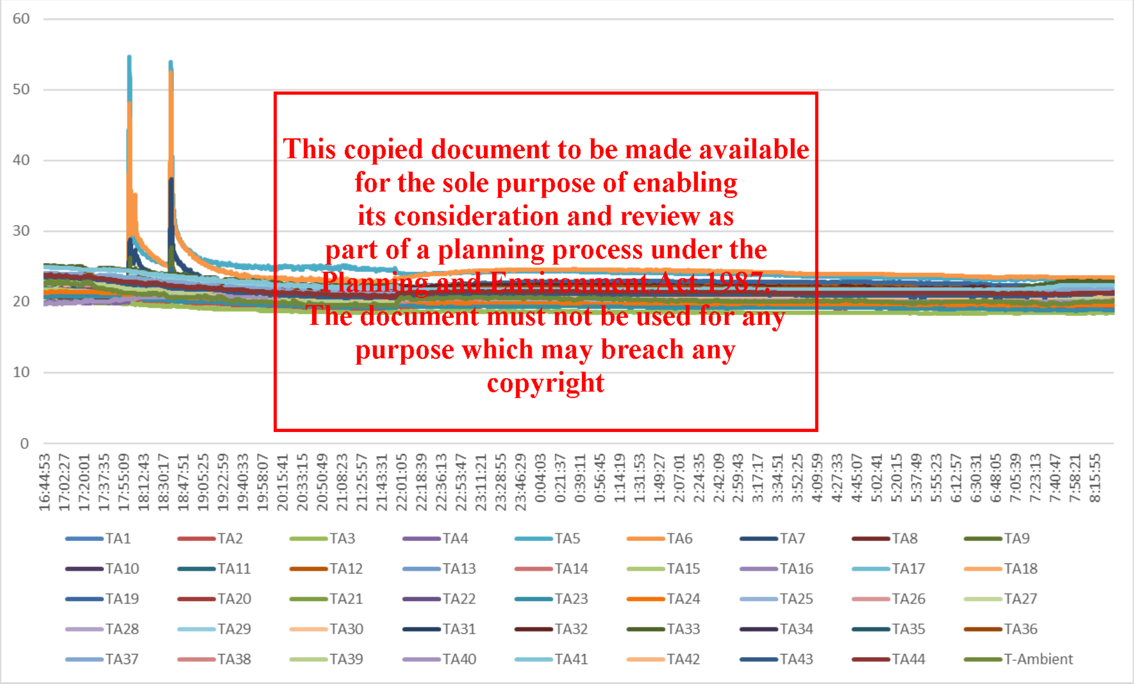


Figure 9. Temperature of instrumented wall A and B

Number	Location	Channel	Max Temp. (°C)
1	Wall A. Vertical array at 152 mm intervals. Left side of Unit1_sub-unitA in the horizontal direction.	TA1-TA22	54.7
2	Wall C. Vertical array at 152 mm intervals. In front of Unit1_sub-unitA in the horizontal direction.	TA23-TA44	

3.6 Heat flux measurement

Eight sensors were placed on the instrument wall A, wall C and target units to measure the heat flux, see below table and figure 10 for details.

Channel Number	Location
HF7, HF8	on the surface of instrumented wall A
HF9, HF10	on the surface of instrumented wall C
HF3, HF4	on target unit 01 surface that facing initiating unit
HF5, HF6	on target unit 02 surface that facing initiating unit

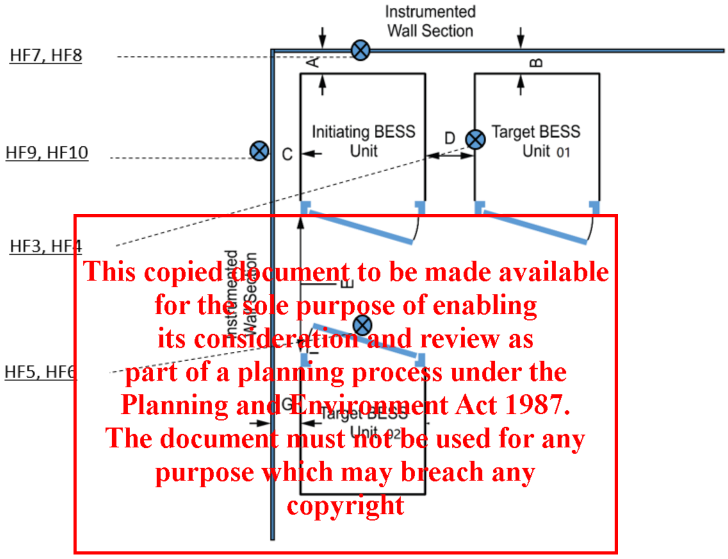


Figure 10. Layout of Heat flux sensor

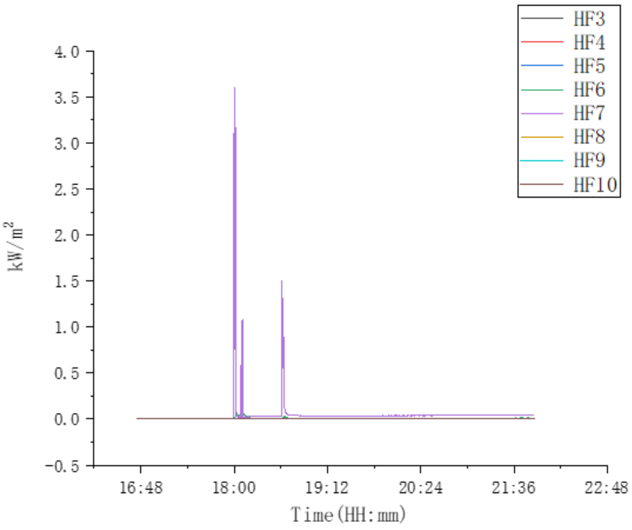


Figure 11. The measured heat flux of target walls and target unit

3.7 Chemical heat release rate measurement

The chemical heat release rates were measured by an oxygen consumption calorimeter measurement system consisting of a paramagnetic oxygen analyzer, non-dispersive infrared carbon dioxide and carbon monoxide analyzer, velocity probe, and a Type K thermocouple.

The instrumentations are located in the exhaust duct of the heat release rate calorimeter. The chemical heat release rate was calculated at each of the flows as follows:

$$HRR_1 = \left[E \times \varphi - (E_{co} - E) \times \frac{1-\varphi}{2} \times \frac{X_{co}}{X_{O_2}}\right] \times \frac{\dot{m}_e}{1 + \varphi \times (\alpha - 1)} \times \frac{M_{O_2}}{M_a} \times (1 - X^o_{H_2O}) \times X^o_{O_2}$$

In which:

HRR_t = total heat release rate, as a function of time (kW)

E = Net heat released for complete combustion per unit of oxygen consumed (adjusted for oxygen contained within cell chemistry, 13,100 kJ/kg)

E_{CO} = Net heat released for complete combustion per unit of oxygen consumed, for CO (adjusted for oxygen contained within cell chemistry, 17,600 kJ/kg)

φ = Oxygen depletion factor (non-dimensional), where:

$$\varphi = \frac{X^o_{O_2} \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X^o_{CO_2}]}{X^o_{O_2} \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

X_{CO} = Measured mole fraction of CO in exhaust flow (non-dimensional)

X_{CO_2} Measured mole fraction of CO_2 in exhaust flow (non-dimensional)

$X°_{CO_2}$ = Measured mole fraction of CO_2 in incoming air (non-dimensional)

$X°_{H_2O}$ = Measured mole fraction of H_2O in incoming air (non-dimensional)

X_{O_2} = Measured mole fraction of O_2 in exhaust flow (non-dimensional)

$X°_{O_2}$ = Measured mole fraction of O_2 in incoming air (non-dimensional)

α = Combustion expansion factor (non-dimensional; normally a value of 1.105)

M_a = Molecular weight of incoming and exhaust air (29 kg/kmol)

M_{O_2} = Molecular weight of oxygen (32 kg/kmol)

$\dot{m}_e$ = Mass flow rate in exhaust duct (kg/s), in which:

$$\dot{m}_e = C \times \sqrt{\frac{\Delta p}{T_e}}$$

or

$$\dot{m}_e = 26.54 \times \frac{A \times k_c}{f(\mathrm{Re})} \times \sqrt{\frac{\Delta p}{T_e}}$$

C = Orifice plate coefficient (in $kg^{1/2}m^{1/2}K^{1/2}$*)*

Δp *= Pressure drop across orifice plate or bidirectional probe (Pa)*

T_e *= Combustion gas temperature at orifice plate or bidirectional probe (K)*

A = Cross sectional area of the duct (m^2*)*

k_c *= Velocity profile shape factor (non-dimensional)*

$f(Re)$ *= Reynolds number correction (non-dimensional)*

Measured peak chemical heat release rate HRR_t was 28.11kW

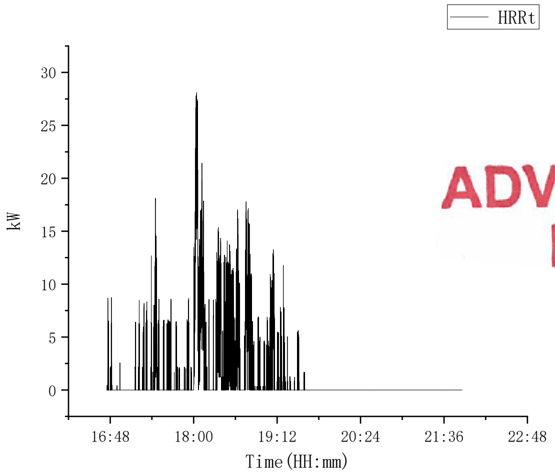


Figure 12. HRR_t curve

Measured total heat release THR through the test was 18.455 MJ

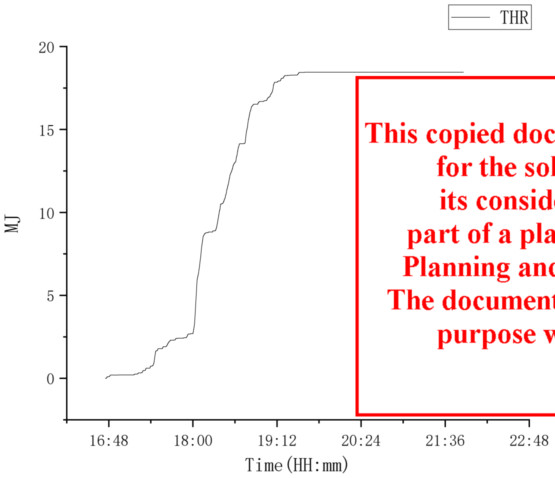


Figure 13. THR curve

3.8 Convective heat release rate measurement

The convective heat release rate were measured using thermopile, a velocity probe, and a Type K thermocouple, located in the exhaust system of the exhaust duct.

The convective heat release rate was calculated at each of the flows as follows:

$$HRR_c = V_e A \frac{353.22}{T_e} \int_{T_o}^{T} C_p dT$$

Where:

HRR_c = The convective heat release rate (kW)

V_e = The exhaust velocity (m/s)

A = The exhaust duct cross sectional area (m^2)

T_e = The temperature at the location where exhaust velocity is measured (K)

$353.22/T_e$ = The density of air at the velocity measurement location (kg/m^3)

T_o = The ambient temperature (K) in the test room

T = The thermopile temperature (K)

$$\int_{T_o}^{T} C_p dT = A_0(T - T_o) + A_1/2(T^2 - T_o^2) + A_2/3(T^3 - T_o^3) + A_3/4(T^4 - T_o^4)$$

Cp = Specific heat of air (kJ/kg-K), given as $C_p = A_0 + A_1T + A_2T^2 + A_3T^3$, where:

A_0 = 0.9950

A_1 = -5.29933E-05

A_2 = 3.21022E-07

A_3 = -1.22004E-10

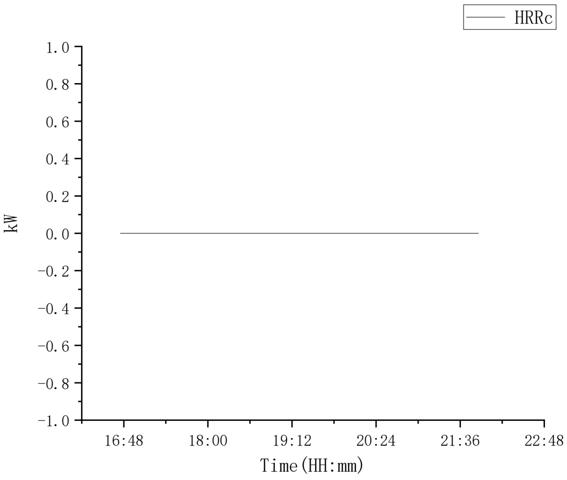


Figure 14. HRRc curve

3.9 Smoke release rate measurement

3.9.1 Test method

The light transmission in the calorimeter's exhaust duct was measured using a white light source and photo detector for the duration of the test.
The smoke release rate was calculated as follows:

The whole smoke release rate measurement system were self-checked using calibrated light filter before test. The self-check were performed at 100%, 79%, 50%, 32%, 16%, 10%, 1% and 0% light transmittance.

3.9.2 Test result

Peak smoke release rate SRR: 0.4124 m²/s

Total smoke release TSR: 69.57 m²

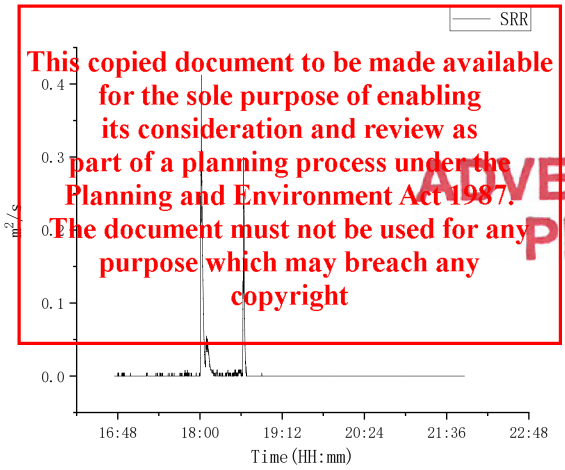


Figure 15. SRR curve

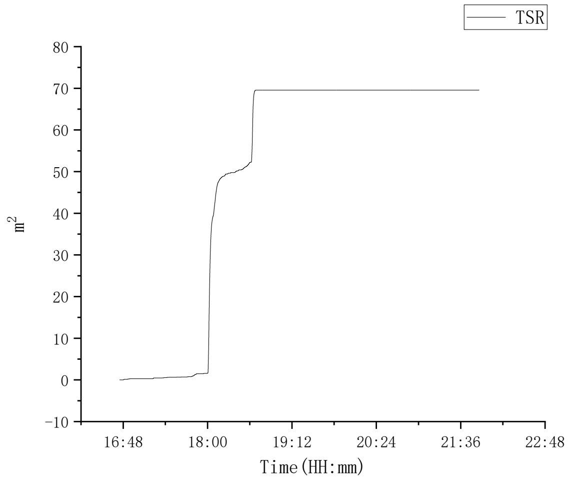


Figure 16. TSR curve

3.10 Gas generation measurement

3.10.1 Test method

The composition, velocity and temperature of the vent gases were measured within the calorimeter's exhaust duct.

Gas composition were measured using a Fourier-Transform Infrared Spectrometer with a resolution of 1 cm^{-1} and a path length of 4.2 m within the calorimeter's exhaust duct.

The hydrocarbon content of the vent gas was measured using flame ionization detection.

Hydrogen gas was measured with a palladium-nickel thin-film solid state sensor.

Composition, velocity and temperature instrumentation were collocated with heat release rate calorimetry instrumentation

3.10.2 Total gas release

Gas type	Gas components		Total volume of gas (L)
Hydrocarbon species	Methane	CH_4	37.5
	Ethylene	C_2H_4	19.4
	Ethane	C_2H_6	7.3
	Propylene	C_3H_6	26.8
	Propane	C_3H_8	11.2
Others	Carbon Monoxide	CO	55.7
	Carbon Dioxide	CO_2	214.8
	Hydrogen	H_2	299.1
	Ethylmethyl carbonate	C_4H_8O	41.7
	Dimethyl carbonate	$C_3H_6O_3$	83.2
Total Hydrocarbons (equivalent to C_3H_8, measured by FID)			220.7

3.10.3 Gas components

Concentration of different gas components were present according to gas species classification in Figures 17 to 20. Average flow rate was 9.77 m³/s during test.

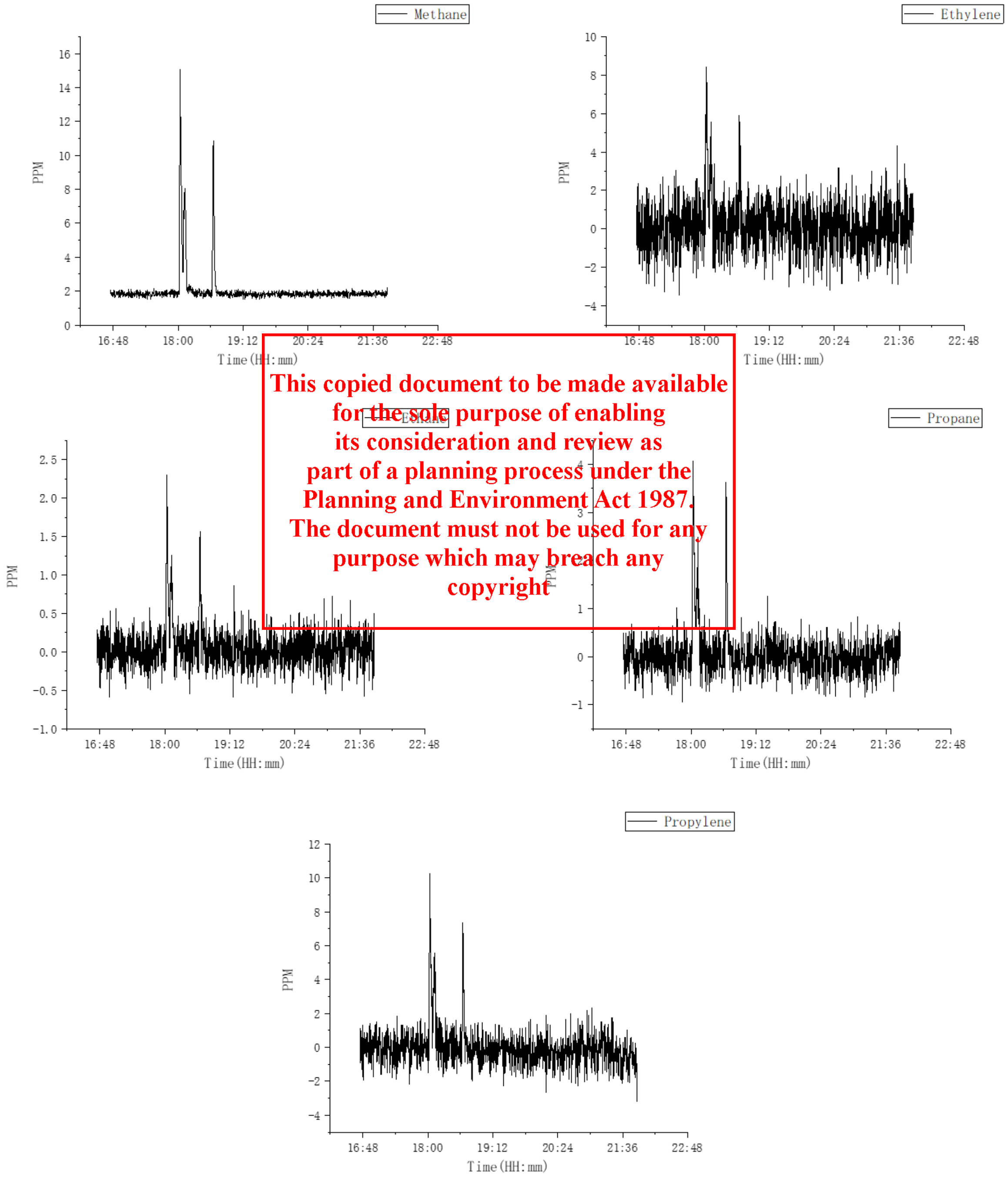


Figure 17 Hydrocarbon species

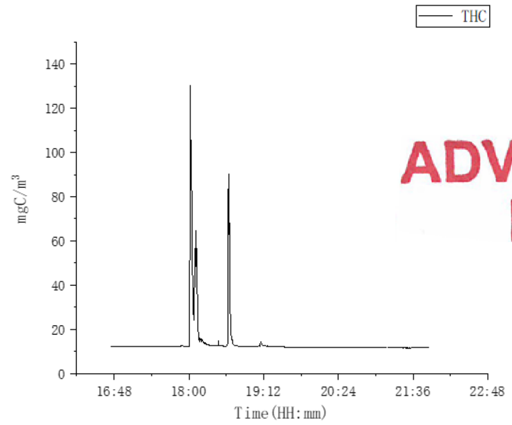


Figure 18 Total Hydrocarbons

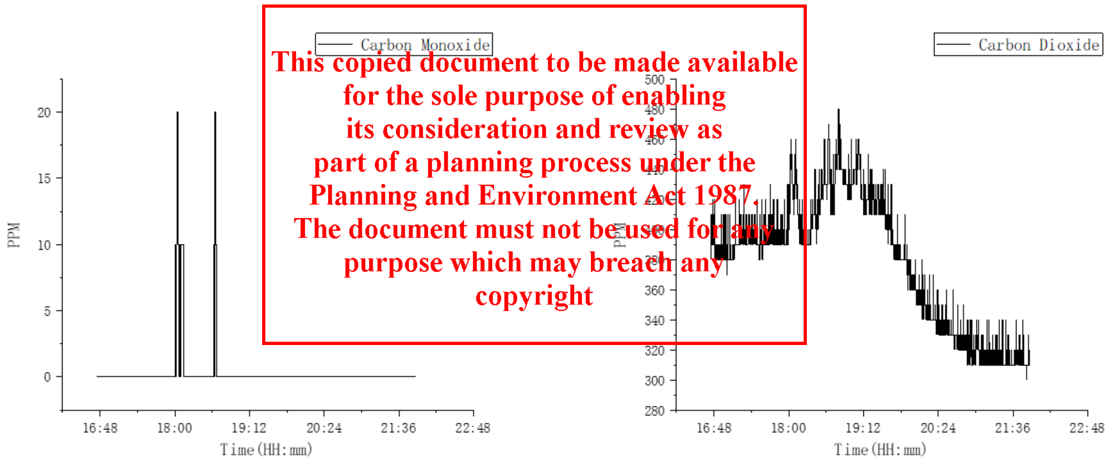


Figure 19 CO and CO2 concentration

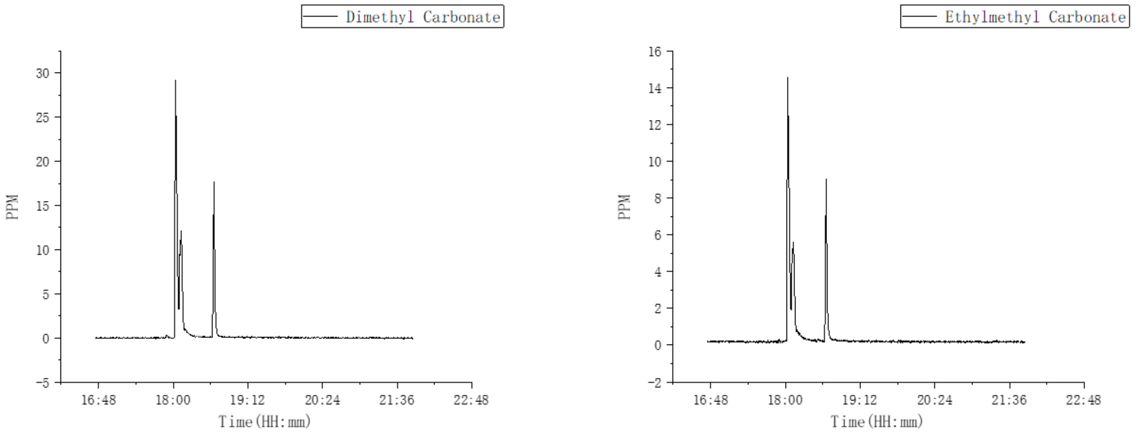


Figure 20 Others

3.11 Performance Summary Remark Against Criteria

Installation level testing was not required as the following performance conditions were met during the unit level test.

Performance conditions	Remark
a) If flaming outside of the unit observed, separation distances to exposures shall be determine by greatest flame extension observed during test. *(No flaming)*	No flaming observed in both external and internal of unit during the test.
b) Surface temperatures of modules within the target units adjacent to the initiating unit do not exceed the temperature at which thermally initiated cell venting occurs.	Surface temperatures of modules within the target units adjacent to the initiating unit was 28. 8°C, which is far below the cell venting temperature 274.3°C (From TUV RH cell 9540A report No.: CN22Y93I 001).
c) For units intended for intended for near exposures, surface temperature measurements on wall surfaces do not exceed 97°C (175°F) of temperature rise above ambient installation.	Surface temperature measurements on wall surfaces was 54.7°C, below the 97°C of temperature rise above ambient.
d) Explosion hazards are not observed, including deflagration, detonation or accumulation of battery vent gases; *(The explosion shall not be observed)*	Explosion hazards were not observed during the test.
e) Heat flux in the center of the accessible means of egress shall not exceed 1.3kW/m^2	There are no means of egress in this test. During the installation process, the distance shall be controlled to prevent the heat flux in the center of the accessible means of egress exceed 1.3kW/m^2
f) The concentration of flammable gas does not exceed 25% LFL in air for the smallest specified room installation size.	Based on final installation conditions

3.12 Photos

Before the test:

Before covered with a single layer of cheese cloth ignition indicator

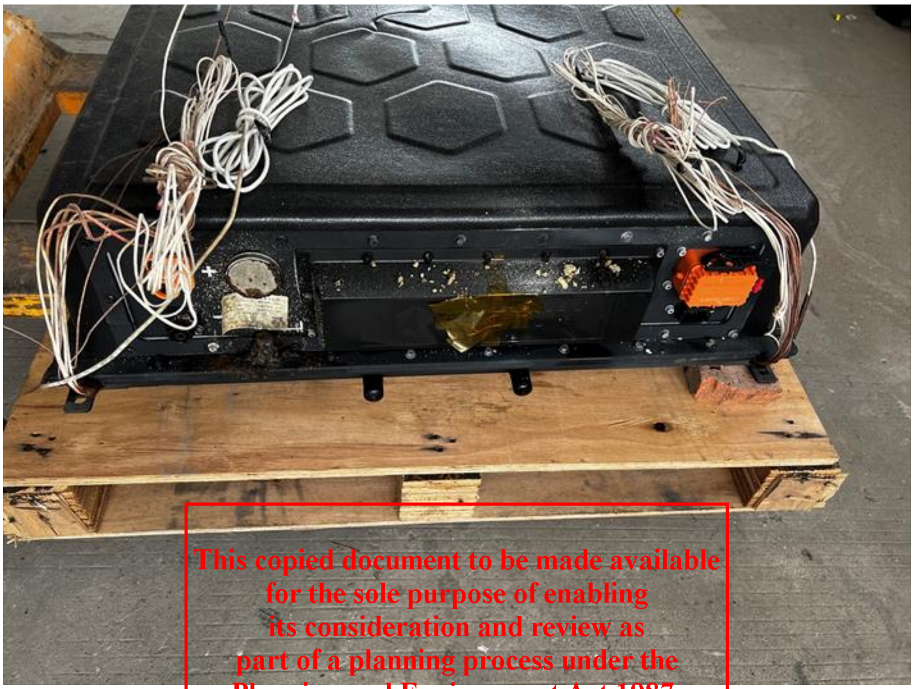
After covered with a single layer of cheese cloth ignition indicator

Three units

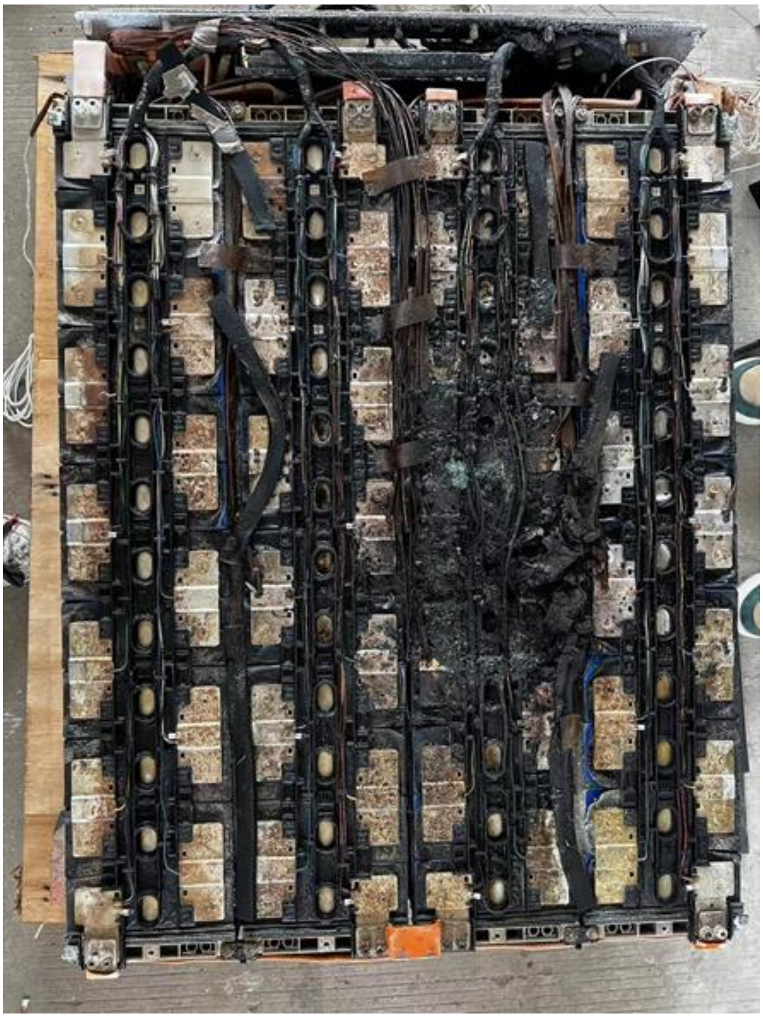
During the test:

After the test:

Initiating module



Damage of the internal components



3.13 List of Test and Measurement Instruments

No.	Equipment		Model	Rating	Inventory no.	Last Cal. date
1	Ambient monitor		WSB-2-H1	0-40°C, 10-90%RH	S-055	2022.07.11
2	Ambient monitor		WSB-2-H1	0-40°C, 10-90%RH	S-050	2023.01.03
3	Ambient monitor		WSB-2-H1	0-40°C, 10-90%RH	S-044	2023.01.03
4	Digital multi-meter		FLUKE101	0-600V	S-038	2023.02.08
5	Tape		1000mm 5000mm	0-1000mm 0-5000mm	S-040 S-042	2022.12.19 2022.12.19
6	Electronic scale		TCS-500	0-500kg	S-039	2023.02.09
7	Charge /discharge equipment		CE-7002-200V300A-R28GC	200V/300A	T-003	2023.03.20
8	Heating control equipment		DTB4824	0-1000°C	S-046-2	2022.07.11
9	Data acquisition equipment		ADAM-4117 ADAM-4118 MT4W MT4W DTM	0-10V 0-1000°C 0-100V 0-500V 0-1000°C	S-060-1 S-060-2 S-060-4~5 S-060-6~7 S-061	2022.07.11 2022.07.11 2022.07.11 2022.07.11 2022.07.11
10	Oxygen consumption calorimeter measurement system	Paramagnetic oxygen analyzer	OXYMAT 61	O2: 0-21%	S-024-09	2022.08.11
		CO and CO2 sensor	ULTRAMAT 23	CO2:0-10% CO:0-1%	S-024-08	2022.08.11
		Light filter	0.25 0.5 0.75	25% 50% 75%	S-024-5 S-024-6 S-024-7	2023.03.31
		Micro-differential pressure transmitter (20MW)	DP101MD	-100~100Pa	S-024-4	2023.02.08
		Thermopile (20MW)	TT I 20-CAXL-I I 6U-10-SPW-M	0~200°C	S-024-1~3	2023.01.03
11	Palladium-nickel thin-film solid state sensor		710B	0.05%~100%	S-023-1	2022.08.11
13	Electrochemical hydrogen sensors		H240000/H21000	0-4%/0-0.1%	S-023-2~3	2022.08.11
14	Fourier-Transform Infrared Spectrometer		MG6000	0.01ppm-100%	S-019	2023.01.30

15	Flame Ionization Detector	AO2040	0-2700mgC/m³	S-025-1	2022.08.11
16	Heat flux measurement equipment	64-5-20	0-50kW	S-031-1 S-031-2 S-031-3 S-031-4 S-031-5 S-031-6 S-031-7 S-031-8	2022.06.10 2022.06.10 2022.06.10 2022.09.09 2022.06.10 2022.06.10 2022.09.09 2022.09.09

End of Test Report