Rushes Creek Poultry Production Farm

Rushes Creek Road, Rushes Creek, NSW 2346

Fire Safety Study

Revision: 2

3 April 2023

Project Number: *12545704*

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Project location	Rushes Creek Road, Rushes Creek, NSW 2346
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Summary of Main Findings and Recommendations

GHD has been appointed by ProTen Tamworth Pty Ltd to undertake a fire safety study for the project located at Rushes Creek Road, Rushes Creek, NSW 2346.

The Rushes Creek Poultry Production Farm was granted Development Consent SSD 7704 on 16 April 2020 by the Minister for Planning and Public Spaces to be established within a rural property approximately 43 km northwest of Tamworth and 33 km northeast of Gunnedah in the New England North West region of New South Wales (NSW).

The development comprises of four individual poultry production units (PPU), where birds are raised for the purpose of producing poultry meat for human consumption. Each farm will contain between 10 to 18 tunnel-ventilated fully enclosed climate controlled poultry sheds, each having the capacity to house 56,500 birds and associated support and servicing infrastructure.

The purpose of the engagement and Fire Safety study is to establish the adequacy of fire safety proposals for the proposed development, ensuring that fire prevention, detection and firefighting measures are appropriate for the specific fire hazards identified at the subject development.

This Fire Safety Study has been developed in accordance with the Hazardous Industry Planning Advisory Paper No.2 – Fire Safety Study Guidelines to a level of detail commensurate with the nature of the project site.

Key Findings

Table 1: Key Findings of Fire Safety Study

Parameter	Finding
Shed Construction	• Dimensions approximately 160.0 m x 18.0 m x 4.7. • BCA Class 8 farm building (subject to performance solution) • Constructed using concrete slab, steel framework, colourbond or zinculume roofing and colourbond steel panel walls insulated with Rigid Polyisocyanurate (PIR) insulation boards. The PIR panels will be encapsulated in aluminium channels. • Sheds will be fully enclosed climate controlled and tunnel ventilated. • Heating provided by wall mounted gas heaters.
Surrounding Residences and Land Use	Surrounding area primarily traditional agricultural production, along with recreational activities associated with Lake Keepit. Low density of surrounding residences with nearest is identified as R25 approximately. 1,025 m from PPU 4. • Nearest populated area, Somerton village to the southeast, approximately 12 km away. • Next nearest populated area, Manilla village to the northeast, approximately 13 km away.

Parameter	Finding
Identified Hazards	• LPG (Class 2.1) – Up to 57,375 L stored at a farm, volume is distributed amongst several tanks in compliance with AS/NZS 1596:2014. • Poultry sheds provided with Polyisocyanurate (PIR)
Prevention / Detection / Protection Required	**LPG Fire** • Installations to comply with AS/NZS 1596:2014 • Outflow of gas to be controlled in accordance with Section 5 of AS/NZS 1596:2014 • Appropriate compliant safety shut down and isolation valves to be installed (Sections 5.3 and 6.7 of AS/NZS 1596:2014) • Inspections, testing and maintenance is to be in accordance with Section 11.5 AS/NZS 1596:2014 • Separation distance between Poultry sheds and LPG tanks is a minimum of 26.5 m apart. Supported by calculations for identified fire scenario and Appendix M of AS/NZS 1596:2014 to not require heat protection at the LPG tanks • Appropriate hazard area classification in accordance with AS/NZS 60079.10.1:2009 • Fire safety systems shall be installed in accordance with Section 13 of AS/NZS 1596:2014
	Solar Panel Fire • Provision of at least one (1) x 45,000 L static water tank for every 100 ha (This can be accounted for in the four (4) zincalume water storage tanks) • Regular maintenance of panels to ensure deterioration kept to a minimal. A maintenance program based upon manufacturer requirements is to be enacted by Proten.
	BESS Fire (If Installed) • Provision of bollards around the perimeter of the BESS for impact protection • The BESS container is to be provided with heat, smoke, H2, CO and VOC combustible gas detectors. Signals from each of the detectors are noted to be linked to the Emergency Management System (EMS). The signal shall then report back to the site office/alarm system, in which Proten is to develop procedures for response to a detection scenario in the BESS, including call out to the fire brigade. • The BESS container shall be provided with a form of automatic suppression system using HFM-227E gaseous suppression, or an

Parameter	Finding

	equivalent system selected by the BESS supplier and agreed with the fire safety engineer.
	• The following are assumptions made in the absence of documentation and should be confirmed with the supplier/manufacturer to validate the study:
	  o In accordance with NFPA 855, Section 4.12.1 the BESS system shall be provided with one of the following;
	    ▪ Explosion prevention systems designed, installed, operated, maintained and tested in accordance with NFPA69; or
	    ▪ Deflagration venting installed and maintained in accordance with NFPA 68
	  o Where the Deflagration Prevention by Combustible Concentration Reduction of NFPA 69 is appropriate, it recommended that upon detection of 10% LFL within the container, that the gas detectors activate and automatically trigger the interlocked emergency ventilation system to ventilate the container.
	  o Following deployment of an extinguishing agent, should gas build-up still occur and a 10% LFL is reached, then the emergency ventilation system to be reinstated.
	  o All batteries and designs used for the BESS must have UL 9540A test reports, for Cell, Module and Unit Level testing.
	• Separation distances of infrastructure and vegetation in proximity to the BESS shall be in accordance with Table 15, and as depicted in Figure 24 and Figure 25
	• Fire hydrants shall be installed in accordance with AS 2419.1-2005, Section 3.3 Open Yard Protection, and Table 3.3: Number of Fire Hydrants Required to Flow Simultaneously for Protected Open Yards.
	Except, that fire hydrants must be provided and located so that every part of the BESS is within reach of a 10 m hose stream issuing from a nozzle at the end of a 60 length of hose connected to a fire hydrant outlet. Indicative location of hydrants is shown in Figure 30.
	• Provision of a non-permeable bund to the BESS for the purpose of contaminated water containment. Design of bunding to accommodate at least 144,000L of water

LPG Preliminary Hazard Analysis	The Development is expected to meet all the requirements stipulated by the Department of Planning, Industry and Environment (DPIE) and hence would not be considered, with suitable engineering and design controls in place, to be an offensive or hazardous development on site or would not be impacted by any other hazardous incidents from adjoining facilities offsite.

Parameter	Finding

LPG tank fire exposure protection	• LPG storage will be separated into four areas, one at each of the PPUs and these areas are a minimum of approximately 870 m apart.
	• The location of the above-ground LPG storage tanks will comply with the following requirements for ventilation, access and set up:
	  ○ Above-ground storage tanks will be in the open air, outside buildings;
	  ○ Nearby buildings, fences and the like will permit free access around the tanks and cross-ventilation for the tanks; and
	  ○ The minimum distance to an adjacent LPG tank is equal to the diameter of the largest tank;
	  ○ Groups of LPG tanks at one PPU will be separated by a minimum of 15 m, unless no tanks in either group exceeds 2m diameter, in which case the distance may be reduced to 10 m.
	• Separation distance between Poultry sheds and LPG tanks is a minimum 26.5 m apart as supported by calculations for the extreme case fire scenario and Appendix M of AS/NZS 1596:2014 to not require heat protection at the LPG tanks
	• At least a hose reel complying with AS/NZS 1221 and installed in accordance with AS 2441 shall be provided.
	• The water supply to the hose reel may be provided by any available on-site reticulated water supply system or from any form of storage system provided that the hose reel is able to deliver at least 0.33 L/s. Where the supply is from a storage system, the duration shall be at least 15 minutes.
	• The number and location of hose reels shall be such as to ensure that a hose nozzle will reach every point in an area bounded by a line around and 5 m distance from any tank and tanker standing area.
	• Maintenance shall be in accordance with AS 1851:2012.

Minor potential hazards	
Arcing/Sparks/Explosion of high voltage transformers (including power poles)	• Annual inspections and maintenance of transformer (where required) • Trees, shrubs, grass and the like shall be kept clear from areas surrounding incoming power lines
Gas heater fire	• Heaters are mounted away from the PIR wall by heater mounts, providing an air gap between the body of the heater and the wall. Penetrations of the PIR panel for the insulated air duct into the sheds are to be capped and protected accordingly.

Parameter	Finding
Fires in chemical store	• Incompatible materials shall be kept separate from each other. • No decanting or mixing of chemicals inside the store. • No ignition sources in store with the exception of lighting. • Provision of fire fighting equipment and appropriate training for staff
Bushfires/ grass fires	• Maintain vegetation to a minimum on site. It is noted that tree/shrub plantings are around the perimeter of each PPU, however grass will be maintained and mowed • No combustible material within 3m of the diesel tanks (Section 2.2.5(d) AS1940) • No Combustible materials within 6m of the LPG facility (Section 6.2.5(e) AS/NZS 1596) • Appropriate firefighting equipment is available, operational and staff are trained to use it
Protection and firefighting	Fighting of fire associated with LPG installations depend upon the nature of the surroundings and any associated structures, hazards and activities that may threaten the LPG facility, rather than solely on the quantity of LPG being stored. Any associated buildings and the like will need to have firefighting equipment to comply with building regulations and should be counted as an important part of the overall protection of the site, including the LPG installation. The following protection measures apply to the LPG tanks; • The following are principles detailed in Clause 13.5 of AS/NZS 1596:2014 which are relevant to the LPG tanks; o When an on-site hydrant system is specified, hydrants shall be provided in accordance with Clause 13.7.1 for the tank. o For all other tank installations, at least a hose reel installation in accordance with Clause 13.7.2 shall be available for the tank. Furthermore, provision of firefighting equipment to the neighbouring poultry shed to comply with the BCA provides protection to the LPG tanks: • Provided fire fighters with a fire hydrant system in accordance with H3.9 or AS 2419.1; • Provided with fire extinguishers throughout the development in accordance with BCA Clause H3.11.
Location and type of fire extinguisher at PPUs	• Location and type of fire extinguishers at each PPU shall be in accordance with BCA Clause H3.10 and is illustrated in Figure 26 through to Figure 29

Parameter	Finding
Firefighting water demand and supply	• Fire hydrants are provided to the poultry sheds in accordance with AS 2419.1, modified where acceptable under the Building Code of Australia for Farm Building Use/Performance Solution. Refer Figure 31 through to Figure 34 for proposed locations. • Fire hydrants are served by a pseudo-ring main which utilises the farms water distribution pump pack to charge the pipes, replacing the requirement for two stand-by pumps. • The hydrant system provides 90 m hose coverage from each hydrant (in lieu of 60 m, subject to a separate performance solution)
Firefighting and PPU water availability	• Each PPU has four water storage tanks, each with a capacity of 375 kL. A combined storage capacity of 1500 kL. • Tanks are automatically filled from pressurised lines to remain near full capacity at all times. • Tanks are fitted with alarms to sound when water levels drop below two-thirds full. • Water tanks at the four PPU's will be interconnected and able to provide additional water to each other as necessary.
Containment of firefighting water	• Water is the primary suppressant use on site, there is no use of foam or other chemical suppressants other than the fire extinguishers provided on site. • A water management system will be installed at each of the farms to mitigate the impact of surface water run-off from the development. • The sheds will be surrounded by a 0.4 m high dwarf concrete nib wall with strategically located seepage holes to convey excess fire fighting water into gassed swales located between sheds. • Excess firefighting water is conveyed via underground pipes into a table drain located around the perimeter of the farms which then convey water to a detention dam, preventing it from entering the environment. • There is limited potential for contaminated water to be generated.
First aid and emergency planning	• In the event of a fire emergency, fire services shall be notified immediately via 000. Fire Rescue NSW, NSW Police and NSW Ambulance being the first responders are responsible for managing the emergency upon arriving on site. • The site evacuation procedure is documented in the Emergency Plan. • The site office located at each PPU will function as an Emergency Control Centre in the event of an emergency • In addition to the fire protection system detailed throughout the study, the provision of fire aid fire protection equipment is

Parameter	Finding
	considered. The development shall be provided with equipment summarised in Table 17 • Site managers shall ensure that all employees and contractors are inducted and trained prior to works being commenced on site. • The Emergency Plan shall be reviewed and tested every 12 months as per the requirements of the POEO(G) Regulation.

1. Glossary & Abbreviations

Table 2: Abbreviations and Acronyms

Abbreviations / Acronym	Description
AS & AS/NZS	Australian Standards / New Zealand Standards
BESS	Battery Energy Storage System
BCA	Building Code of Australia
DGs	Dangerous Goods
DPIE	Department of Planning, Industry and Environment
DtS	Deemed to Satisfy
ECC	Emergency Control Centre
EIS	Environmental Impact Statement
FHA	FHA Final Hazard Analysis
FRNSW	Fire and Rescue NSW
FSS	Fire Safety Study
HRR	Heat Release Rate
HIPAP	Hazardous Industry Planning Advisory Paper
ISO	International Organization for Standardization
LGA	Local Government Area
LPG	Liquid petroleum gas
L/s	Litres per second
ML	Mega-litres
NSW	New South Wales
PCS	Power Conversion System
PHA	Preliminary Hazard Analysis
PIR	Polyisocyanurate
PPE	Personal Protective Equipment
PRS	Preliminary Risk Screening
PPU	Poultry Production Unit
ProTen	ProTen Tamworth Pty Ltd

Abbreviations / Acronym	Description
PV	Photovoltaic
SDS	Safety Data Sheets
SEPP	State Environmental Planning Policy
SLR	SLR Consulting Australia Pty Ltd
SSD	State Significant Development
STS	Static Transfer System

2. Introduction

2.1 Purpose of this Report

GHD has been appointed by ProTen Tamworth Pty Ltd to undertake a fire safety study for the project located at Rushes Creek Road, Rushes Creek, NSW 2346.

The purpose of the engagement and Fire Safety Study is to establish the adequacy of fire safety proposals for the proposed development, ensuring that fire prevention, detection and firefighting measures are appropriate for the specific fire hazards identified at the subject development.

This Fire Safety Study has been developed in accordance with the Hazardous Industry Planning Advisory Paper No.2 – Fire Safety Study Guidelines (Department of Planning, 2011) to a level of detail commensurate with the nature of the project site.

2.2 Scope and Limitations

This report has been prepared by GHD for ProTen Tamworth Pty Ltd and may only be used and relied on by ProTen Tamworth Pty Ltd for the purpose agreed between GHD and ProTen Tamworth Pty Ltd, as set out in section 2.1 of this report.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

2.3 Terms of Reference

2.3.1 Regulatory Framework

The Fire Safety Study has been prepared to satisfy condition B40(a) of Development Consent SSD 7704.

> *At least one month prior to the commencement of construction of the development (except for construction of those preliminary works that are outside the scope of the hazard studies), or within such further period as the Planning Secretary may agree, the Applicant must prepare and submit for the approval of the Planning Secretary the studies set out under subsections (a) to (b) below (the pre-construction studies). Construction, other than of preliminary works, must not commence until approval has been given by the Planning Secretary*
>
> *(a) A Fire Safety Study for the development. This study must cover the relevant aspects of the Department's Hazardous Industry Planning Advisory Paper No. 2, 'Fire Safety Study Guidelines' and the New South Wales Government's Best Practice Guidelines for Contaminated Water Retention and Treatment Systems (NSW HMPCC, 1994). The study must meet the requirements of Fire and Rescue NSW.*

This Fire Safety Study has been developed in accordance with the Hazardous Industry Planning Advisory Paper No.2 – Fire Safety Study Guidelines (Department of Planning, 2011) to a level of detail commensurate with the nature of the project site.

2.3.2 Other Relevant Studies

The Fire Safety Study shall be read in conjunction with the following relevant studies;

- The Environmental Impact Statement (EIS) – Volumes 1-3 (SLR, 2018)
- The Response to Submissions (RTS) (EME Advisory, 2019)
- Preliminary Risk Screening (SLR, 2018) (Contained within EIS Volume 3)
- Preliminary Hazard Analysis (SLR, 2018) (Contained within EIS Volume 3)
- Final Hazard Analysis (GHD Pty Ltd, 2021)

2.3.3 Stakeholders

Table 3: Relevant Stakeholders

Role	Stakeholder (organisation)	Named representative
Client	ProTen Tamworth Pty Ltd	Bill Williams
Fire Engineering	GHD Pty Ltd	Mark Tsai Colin Thomson

3. Description of the Facility

3.1 Site Location

The Development Site is located within an area known as Rushes Creek approximately 43 kilometres (km) northwest of Tamworth and 33 km northeast of Gunnedah in the New England North West region of New South Wales (NSW) (see Figure 1) and the Tamworth local government area (LGA).

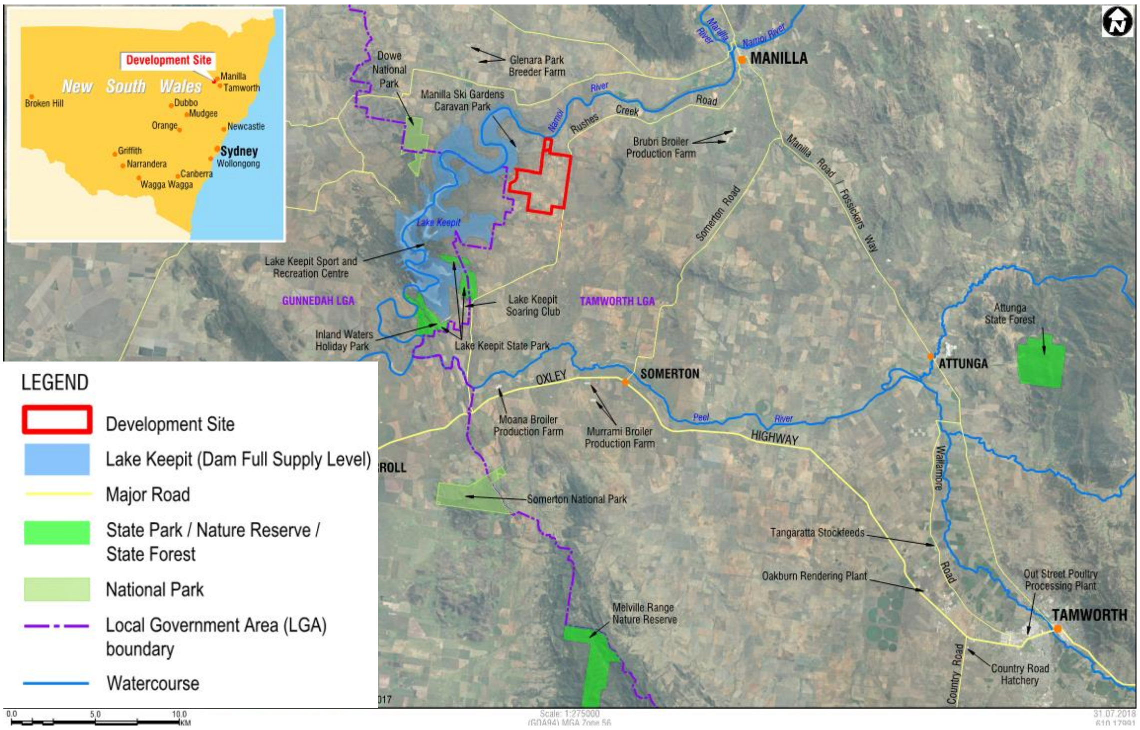

Figure 1: Site Location (SLR, 2018)

3.1.1 Development Overview

The below is from the Environmental Impact Statement developed by SLR, summarised for the purpose of this document. Please see the full Environmental Impact Statement, Volumes 1-3, dated August 2018 for full details (SLR, 2018).

The Rushes Creek Production Farm was granted Development Consent SSD 7704 on 16 April 2020. The long-standing and existing use of the Development Site is traditional agricultural production, including both livestock grazing and cropping. The Development Site comprises approximately 1,016 hectares of land, including cleared grassland with paddock trees and areas of woodland.

The Development will comprise four individual farms or poultry production units (PPUs), each including between 10 and 18 tunnel-ventilated fully-enclosed climate-controlled poultry sheds (54 sheds in total), along with associated support infrastructure and staff amenities.

The Development will have the capacity to house a total population of 3.051 million birds. The proposed numbers of sheds for each farm are as follows:

Table 4: Proposed number of sheds per farm

Farm Number	Number of Sheds
1	10
2	18
3	10
4	16
Total	**54**

The proposed layout of the Development is shown in Figure 2.

In addition to the poultry shedding, the Development will comprise various support/servicing infrastructure, including:

- Eight new residences to house the farm managers;
- Water supply infrastructure to extract, transfer, treat and store water from the Namoi River;
- Electricity supply infrastructure and solar panels at each farm;
- Two new access driveways from Rushes Creek Road and internal access roads;
- A staff amenities and workshop facility at each farm (office space, toilets, change rooms, workshop, chemical store and pump room);
- Dead bird freezers adjacent to the internal access roads near Rushes Creek Road;
- One poultry bedding material storage shed;
- Bulk liquid petroleum gas (LPG) tanks at each farm;
- Generators and generator enclosures/sheds at each farm (emergency use only);
- Vehicle wheel wash facilities;
- Feed silos at each farm;
- Water storage tanks at each farm; and
- Surface water management system at each farm (swale drains, table drains, detention dam and upstream diversions).

The total disturbance footprint is approximately 92.81 ha (Refer Figure 2) and the commercial activities associated with the poultry operation will be largely confined to the individual farm sites and access roads.

It is intended to continue using the land outside of the disturbance footprint within the Development Site for continued agricultural production purposes under some form of lease or share farming arrangement.

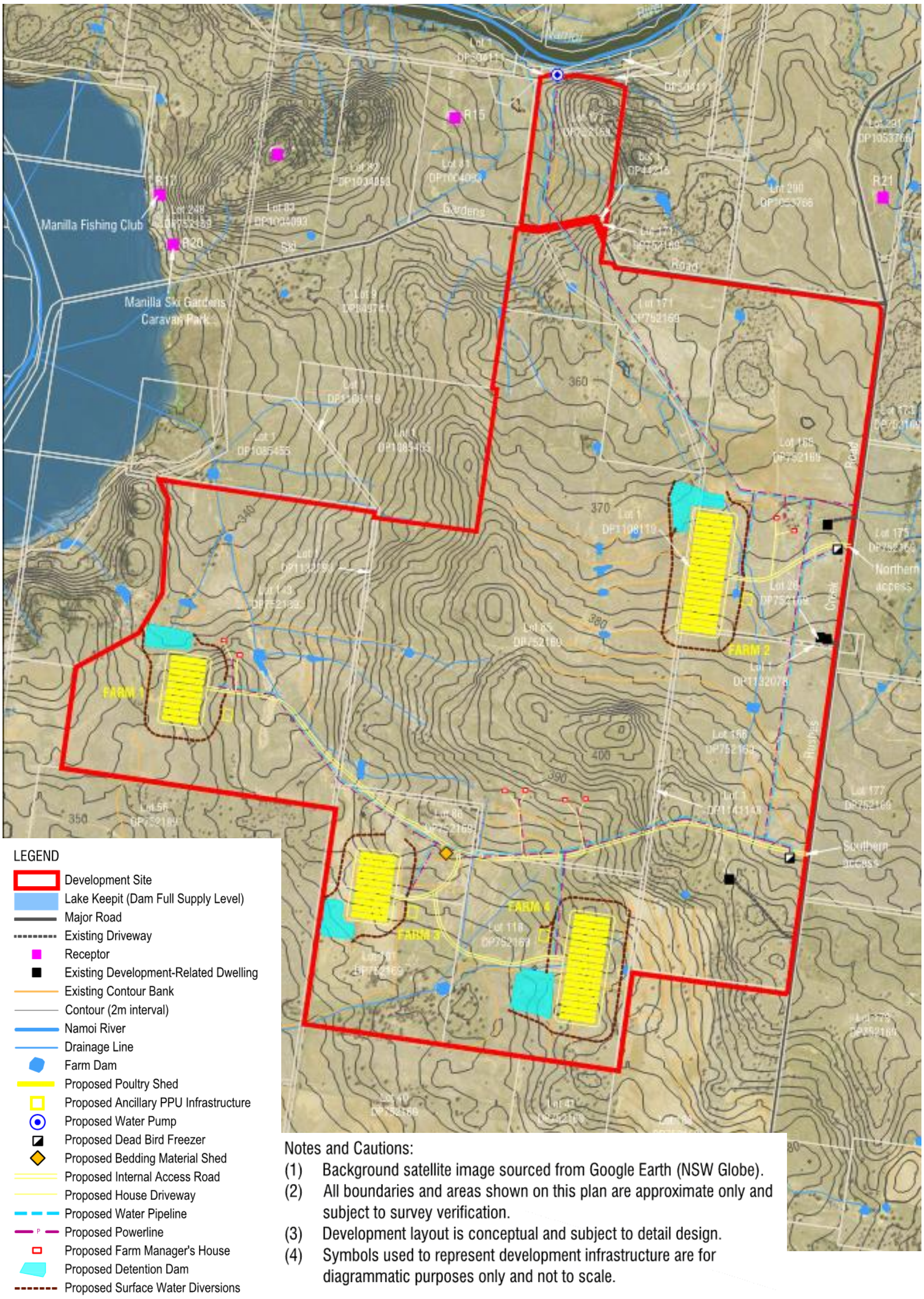

Figure 2: Development Layout (EME Advisory, 2019)

3.1.2 Poultry Sheds

Each of the farms will consist of 10 to 18 poultry sheds, with a total of 54 sheds on the Development Site. The sheds will be distributed laterally and achieve a separation distance of approximately 15 m between sheds.

Each farm will also be provided with a one-way circulation road around the perimeter of the farm to enable entering, exiting and manoeuvring of vehicles.

Based on the civil drawings set, issued by Lance Ryan Consulting Engineers Pty Ltd on 26 March 2019, Rev 4, the individual sheds will measure approximately 160 m in length and 18.0 m wide, equating to a footprint of approximately 2,880 m^2. They are understood to measure approximately 4.7 m to the ridge of the roof and 2.6 m under the eaves.

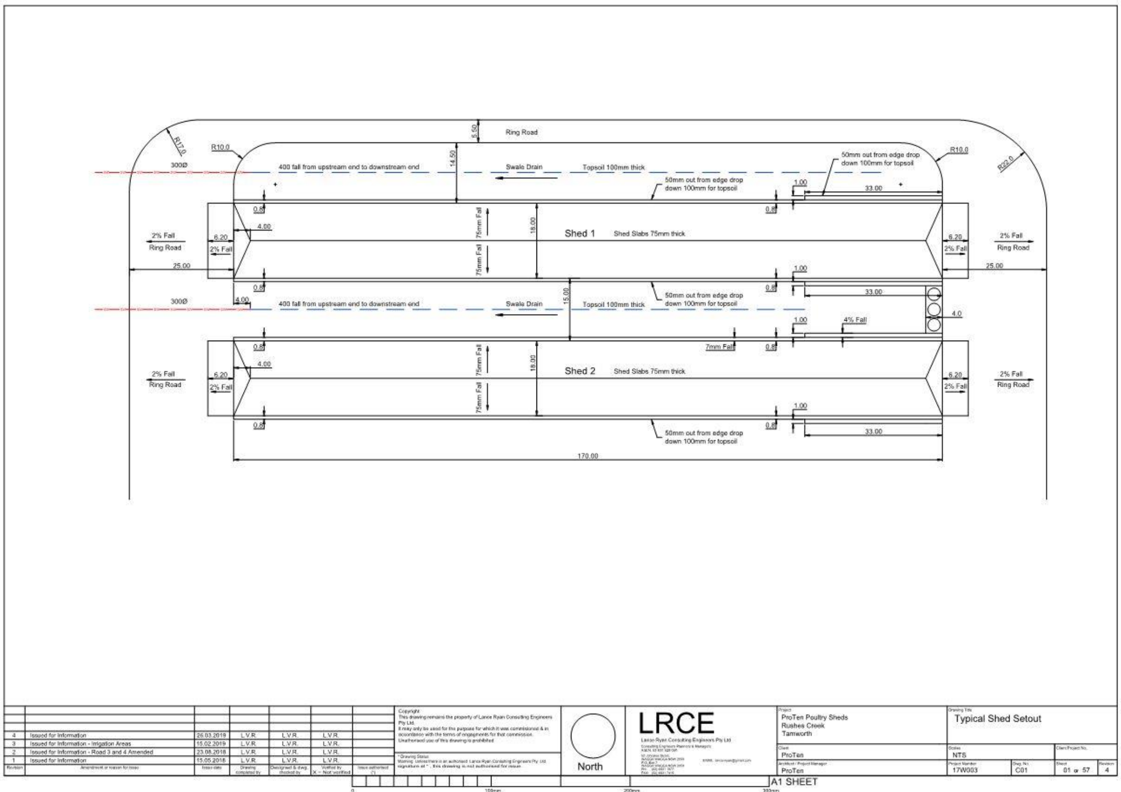

Figure 3: Typical shed layout (Lance Ryan Consulting Engineers Pty Ltd, 2019)

The poultry sheds are considered as “farm buildings” under the BCA and therefore are identified as either a Class 7 or 8 building. The building is understood to be subject to a performance solution to treat the building as a Class 8 farm building in lieu of a large isolated building. The Performance Solution process is separate to this Fire Safety Study, and not discussed further here.

Each shed will be constructed on a concrete slab utilising steel framework, colourbond or zincalume roofing and colourbond steel panel walls insulated with Rigid Polyisocyanurate (PIR) insulation boards. PIR panels will be encapsulated in aluminium channels.

The floor bedding material is understood to consist of soft wood shavings, rice hulls or chopped straw. The flooring will be raw cured concrete and surrounded by a 0.4 m high dwarf concrete nib wall. All expansion gaps and saw cuts are understood to be Sikaflex filled. An image from one of ProTen’s existing sites (Bective Poultry Production Complex) which is built to a similar specification is shown for reference in Figure 4.

Figure 4: ProTen's Bective Poultry Production Complex (SLR, 2018)

3.1.2.1 Tunnel Ventilation

The sheds are to be fully enclosed climate controlled and tunnel ventilated. The temperature sensors located within the sheds allow ventilation to be adjusted as required.

Heating is anticipated to be required for up to 21 days of each production cycle will be provided by wall mounted LPG heater. The LPG for the heaters is supplied by LPG tanks onsite.

Tunnel ventilation systems will be completely computer controlled and alarm monitored. Back up power is available via emergency diesel standby generators.

3.1.3 Modification Proposed – Potential Installation of BESS and Solar Panels

A Modification to the facility has been proposed to potentially encompass an off-grid power solution containing the following infrastructure:

- Solar Panels,
- Battery Energy Storage System (BESS) container containing lithium ion batteries, and
- Backup Generators.

The solar panels are proposed to be mounted on a number of poultry sheds (approx. 183 panels per shed), with the BESS and supporting infrastructure located east of the sheds as indicated in Figure 5. Figure 6 provides a plan layout of the BESS area to the east.

Access to both the BESS area and poultry sheds is via a sealed road accessed from Rushes Creek Road.

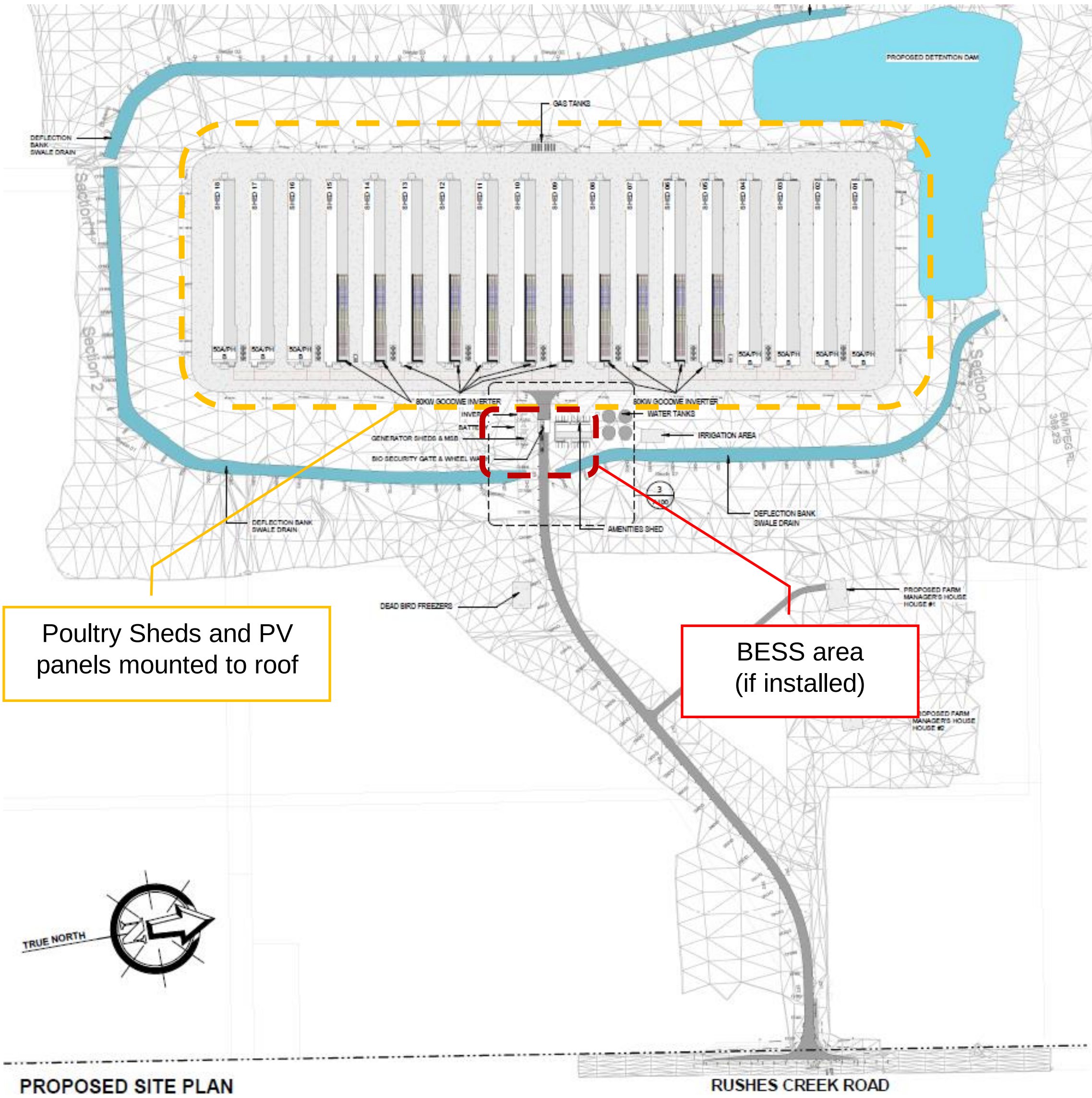

Figure 5: Proposed Site Plan

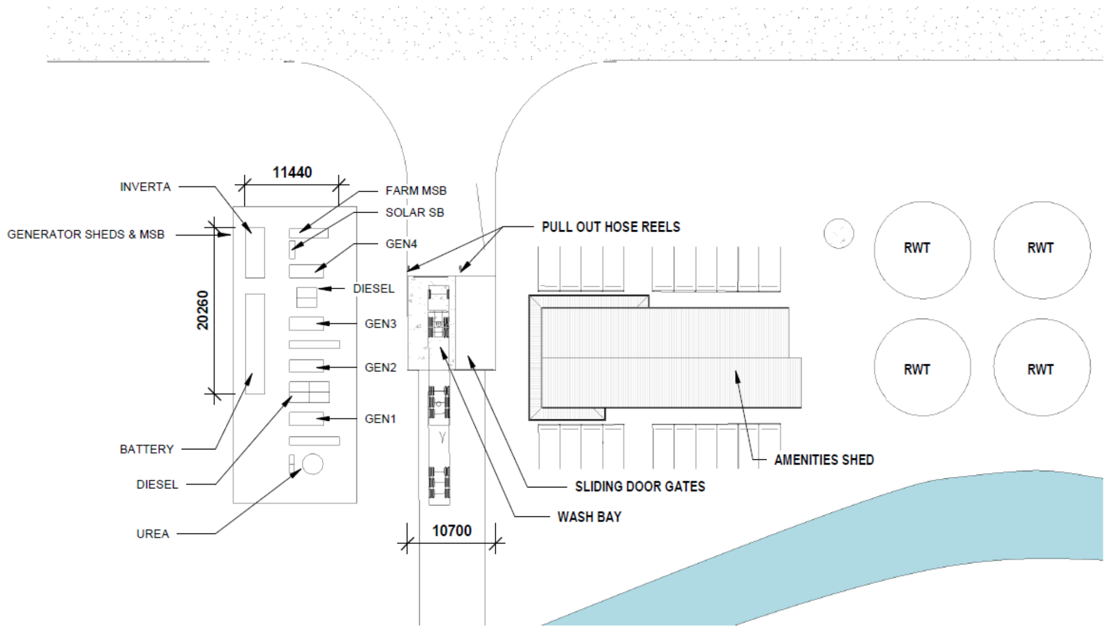

Figure 6: Close-up plan view of BESS area (If Installed)

3.1.3.1 BESS Container (If Installed)

The proposed BESS container measures 40 ft (approx. 12.2 m) and has a nameplate capacity of 1.28 MWh. Supporting infrastructure to the BESS, including the Power Conversion System (PCS), Transformer and Static Transfer System (STS) are all installed in a separate 20 ft container.

Indicative arrangement for the BESS and supporting infrastructure is shown in Figure 7 and Figure 8 respectively.

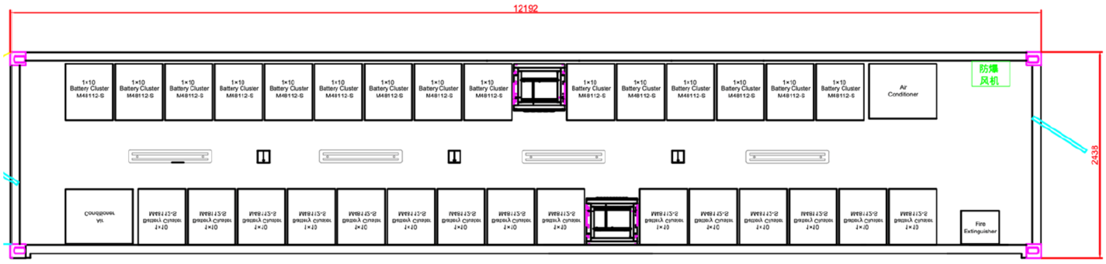

Figure 7: Indicative Layout of BESS (40 ft container)

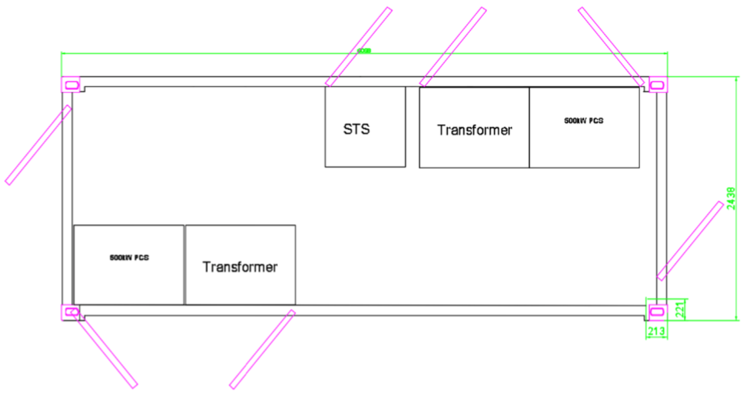

Figure 8: Indicative Layout of Supporting BESS Infrastructure (20 ft container)

The BESS container comprises of lithium-ion batteries manufactured by EVE Energy Co Ltd, Model M48112-S, with the container design developed by Alpha ESS. The batteries are of lithium iron phosphate chemistry. Further details of the battery are provided in Appendix C.

It is understood that BESS does not come pre-assembled with all the relative components to operate as a 'turn-key' system. The BESS is assembled and commissioned on site by contractors, including the fire extinguishing system, in accordance with the technical requirements provided by the supplier, Alpha ESS. The design specification is also attached in Appendix C.

The project includes the potential installation of a BESS as detailed above. The Fire Safety Study has been developed based upon the potential that a BESS, with battery cells manufactured by EVE Energy Co Ltd (Model M48112-S) and container design by Alpha ESS may be installed in the approximate location shown in Figure 5 and Figure 6, subject to controls and recommendations of this report.

In the event that the BESS location changes, or the BESS is of different make/manufacturer than documented, a re-assessment will be necessary.

3.1.3.2 Photovoltaic (PV) Modules

The PV modules proposed to be installed are crystalline silicon terrestrial photovoltaic modules manufactured by Rise Energy Co., Ltd. The modules are certified to IEC 61730-1:2016 and IEC61730-2:2016 by TÜV SÜD Certification and Testing (China) Co., Ltd Shanghai branch.

As part of the certification, the panels are tested to *UL 790 - Standard Test Methods for Fire Tests of Roof Coverings.* UL 790 exposes the panels which are used as roof coverings to a simulated fire based on fuel sources from outside a building on which the panels are installed. The subject panels are classified as Class C coverings which are;

"effective against light fire test exposures. Under such exposure, panels of this class afford a light degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands."

3.1.4 Supporting Infrastructure

3.1.4.1 Residential Dwellings

As a result of the scale and 24 hour nature of operation, eight homes are proposed to be constructed on the development to accommodate the farm managers. These buildings are ancillary to the proposed development.

3.1.5 Surrounding Residences and Land Use

The surrounding area is primarily characterised by traditional agricultural production, along with recreational activities around Lake Keepit.

Key surrounding receptors to the Development is summarised in Table 5

Table 5: Key Residences

Name	Description	Distance
Manilla Ski Gardens Caravan Park and Manilla Fishing Club	Caravan park and camping ground	Approximately 2 km from nearest PPU
Lake Keepit Sport and Recreation Centre	Cabins, conference centre, recreational facilities	Approximately 7 km from nearest PPU
Lake Keepit Soaring Club	Gliding facilities, clubhouse, cabins	> 8 km from nearest PPU
Inland Waters Holiday Park	Caravan park, cabins, camping ground, recreational facilities	> 9 km from nearest PPU
Somerton	Populated	Approximately 12 km South East of the Development
Manilla	Populated	Approximately 13 km North East of the Development

Three foreshore locations exist around Lake Keepit. These three locations have been designated as a State Park.

The development has a relatively low density of surrounding privately owned residences. The nearest identified is located off Rushes Creek Road, approximately 1,025 m southeast of the nearest PPU (Refer Figure 10)

3.1.6 Distance to Receptors

Figure 9, an excerpt from the EIS, lists the distances between the PPUs and notable surrounding features in the natural and built environments. It is noted that the distances are approximate and were been scaled from satellite imagery and topographic mapping (See Figure 10).

Receptor	Location	Distance from Nearest PPU (m) (nearest PPU)
R1	Dwelling, Rushes Creek Road	4,715 (Farm 2)
R2	Dwelling, Rushes Creek Road	4,585 (Farm 2)
R3	Dwelling, Rushes Creek Road	5,745 (Farm 2)
R4	Dwelling, Rushes Creek Road	5,885 (Farm 2)
R5	Dwelling, Rushes Creek Road	5,395 (Farm 2)
R6	Dwelling, Rushes Creek Road	5,855 (Farm 2)
R7	Dwelling, Moys Lane	5,025 (Farm 2)
R8	Dwelling, Moys Lane	4,225 (Farm 2)
R9	Dwelling, Corella Road	4,385 (Farm 2)
R10	Dwelling, Corella Road	3,890 (Farm 2)
R11	Dwelling, Rushes Creek Road	4,395 (Farm 2)
R12	Dwelling, Rushes Creek Road	4,185 (Farm 2)
R13	Dwelling and small piggery, Rushes Creek Road	3,145 (Farm 2)
R14	Dwelling, Rushes Creek Road	3,625 (Farm 2)
R15	Dwelling, Ski Gardens Road	2,255 (Farm 2)
R16 (potential)	Potential future dwelling, Rushes Creek Road	2,585 (Farm 2)
R17	Manilla Fishing Club, Ski Gardens Road	2,250 (Farm 1)
R18	Dwelling, Ski Gardens Road	2,460 (Farm 1)
R19	Dwelling, Moys Lane	3,775 (Farm 2)
R20	Manilla Ski Gardens Caravan Park, Ski Gardens Road	2,005 (Farm 1)
R21	Dwelling, Rushes Creek Road	1,720 (Farm 2)
R22	Dwelling, Moys Lane	2,765 (Farm 2)
R23	Dwelling, Moys Lane	2,750 (Farm 2)
R24	Dwelling, Rushes Creek Road	1,335 (Farm 2)
R25	Dwelling, Rushes Creek Road	1,025 (Farm 4)
R26	Dwelling, Perrings Road	4,160 (Farm 4)
R27	Dwelling, Perrings Road	4,305 (Farm 4)
R28	Dwelling, Rushes Creek Road	2,480 (Farm 4)
R29	Dwelling, Boundary Road	3,465 (Farm 4)
R30	Dwelling, Boundary Road	3,515 (Farm 4)
R31	Dwelling, Glenbrook Road	5,015 (Farm 4)
R32	Lake Keepit Sport and Recreation Centre, National Fitness Road	6,835 (Farm 1)
R33	Dwelling, National Fitness Road	5,255 (Farm 3)
R34	Dwelling, Rushes Creek Road	3,365 (Farm 4)
R35 (potential)	Potential future dwelling, Bidford Access	3,265 (Farm 4)
R36	Dwelling, Glenbrook Road	4,510 (Farm 2)
Road Traffic Noise Sensitive Receptors		
R37	Dwelling, Rushes Creek Road	12,775 (Farm 4)
R38	Dwelling, Rushes Creek Road	13,495 (Farm 4)

Figure 9: Receptor Distances (Excerpt from Environment Impact Statement Volume 1) (SLR, 2018)

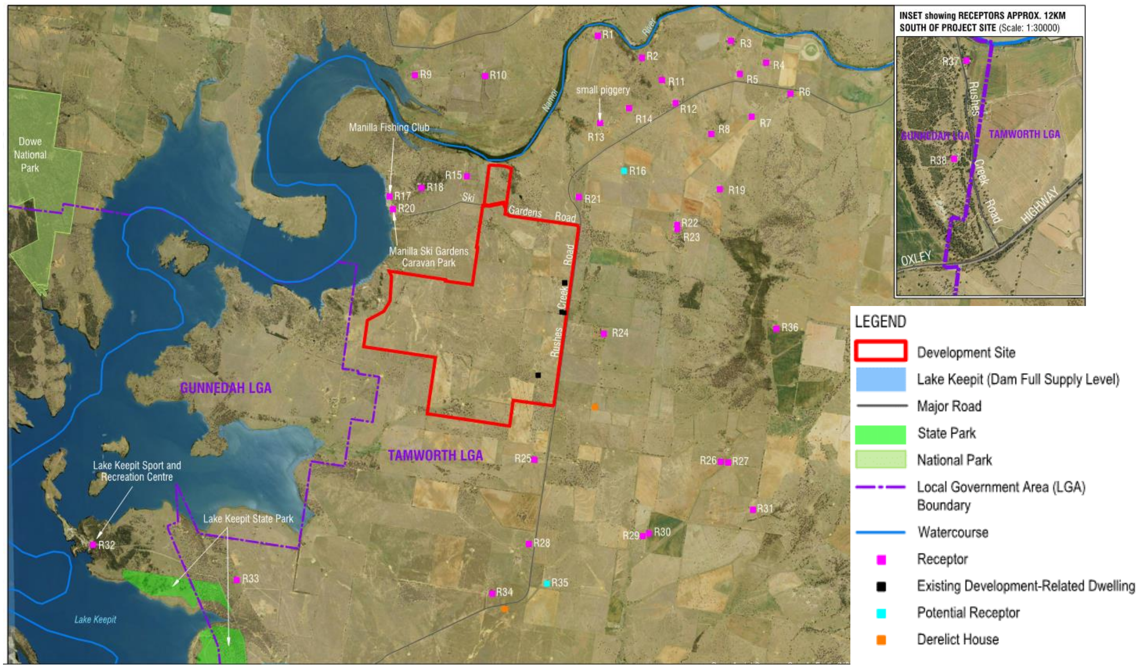

Figure 10: Sensitive Receptors (SLR, 2018)

From the above, the nearest residential receptors are R25 and R24 located off Rushes Creek Road at approximate distances of 1,025 and 1,335 m, respectively, from the development (nearest PPU).

4. Hazards Identified

The identification of fire hazards at the subject development has considered the likes of hazardous materials, process and incidents; in particular those associated with flammables and combustible materials. The likelihood of internal and external causes of incidents are also identified as required.

The site layout is such that PPU's are located at least 870 m away from each other. Therefore, for the purpose of this study, each PPU is considered a separate area. As the design of each PPU is exactly the same (barring the number of sheds, but including the construction direction, only 1 PPU is described in a generic term and considered the same for all 4 PPUs.

4.1 Inventory of Hazardous Materials, Chemical and Fuels

This section of the report provides information in relation to the inventory of hazardous materials, chemical and fuels at the proposed development. This data is based on the Preliminary Risk Screening and Hazard Assessment conducted by SLR, and can be found in Appendix J of the EIS (SLR, 2018).

4.1.1 Storage of Substances

Figure 11 provides a summary of the developments inventory of hazardous materials, chemicals and fuels, extracted from the abovementioned study.

Substance	Hazardous Class	UN No.	HAZCHEM Code	Total Storage at each PPU	Threshold Quantity	SEPP 33 Threshold Screening
LPG	Class 2.1	1075	2YE	Farm 1 – 38,250 L (38.25 m^3) Farm 2 – 57,375 L (57.38 m^3) Farm 3 – 38,250 L (38.25 m^3) Farm 4 – 51,000 L (51.00 m^3)	16 m^3 (above ground storage)	**Above**
Diesel	Class C1	3082	3Z	Each PPU - 4,000 L (2 x 2,000 L tanks)	100,000 L	Below
Petrol	Class 3 (PG II)	1203	3YE	Each PPU – 700 L (1 x 700 L tank) (0.52 tonnes)	4 tonnes	Below
Sodium Hypochlorite (10-30%) (bleach, disinfectant)	Class 8 (PG III)	1791	2X	Each PPU – 400 L (2 x 200 L drums)	25 tonnes (PG II)	Below
Chlorine dioxide (water supply treatment)	Class 8 (PG II)	1789	2R	Each PPU – 240 L (8 x 30 L drums)		
Microgard 755N or Micro-4 (sanitiser)	Class 9	3082	-	Each PPPU – 25 L (1 x 25 L drum)	10,000 L or kg	Below
Goal (herbicide)	Class 9	3082	2X	Each PPU - 10 L (1 x 10 L drum)		
Agri-Quat (disinfectant, sanitiser)	N/A	-	-	Each PPU – 50 L (2 x 25 L drums)	N/A	N/A
Ditrac (rodenticide)	N/A	-	-	Each PPU - 20 kg (1 x 20 kg container)	N/A	N/A
Glister (herbicide)	N/A	1950	-	Each PPU – 20 kg (1 x 20 kg container)	N/A	N/A
Unicide (sanitiser)	N/A	-	-	Each PPU – 100 L (1 x 100 L drum)	N/A	N/A
Unicide d (sanitizer)	N/A	-	-	Each PPU - 100 L (1 x 100 L drum)	N/A	N/A
Roundup (Glyphosate, herbicide)	N/A	-	-	Each PPU - 25 L (1 x 25 L drum)	N/A	N/A

- Denotes normal fire extinguishing procedures and equipment are appropriate and chemical will not react with the firefighting material.

* Each PPU is located a minimum of 870 m apart therefore the storage for each PPU has been considered on their own and not as one facility.

Figure 11: Inventory of hazardous materials, chemical and fuels (SLR, 2018)

It is noted that chemicals without a hazard classification are not considered hazardous and therefore did not form part of the assessment study.

4.1.2 Dangerous Goods Transport

The dangerous goods transported to the proposed development (maximum per week) is summarised in Figure 12.

ADG Class	Materials	Maximum DGs Vehicle Movements (per week)	Load Type (relevant to the facility)	SEPP 33 Threshold Vehicle Movements (per week)	SEPP 33 Threshold Minimum Quantity (per load)	SEPP 33 Threshold Level Findings
2.1	LPG	1-2	Bulk	>30	2 tonnes	**Above** (in regards to quantity per load only)
3	Petrol	<1	Bulk	>45	3 tonnes	Below
C1	Diesel	< 1	Bulk	N/A	N/A	Below
8	Sodium hypochorite & chlorine dioxide	<1	Packages	>30	5 tonnes	Below

Note: Assumes each dangerous good class is transported separately. Note that LPG is only used at each PPU for a period of up to 21 days during each production cycle. Outside this time LPG will not be used at that PPU.

Figure 12: Dangerous Goods Vehicle Movements (SLR, 2018)

It is noted that the while the number of vehicle movements for the delivery of LPG are well below the SLR screening threshold study, the quantity of LPG delivered per load will likely exceed the screening threshold of 2 tonnes and may be considered potentially hazardous with respect to the transport of LPG.

The vehicle movements for transport of other DG's are well below the respective screening thresholds.

4.2 Identification of fire hazards

The fire safety study is primarily focused on chemicals that pose a fire hazard, propagate a fire or impact fire brigade intervention activities. Therefore, chemicals which do not hold a hazard class are not considered hazardous and do not form the scope of this study.

4.2.1 Storage of Substances

The following substances are only stored in minor quantities, well below thresholds of the SLR screening study and therefore are not considered to present a hazard risk:

- Diesel;
- Petrol;
- Sodium hypochlorite;
- Chlorine dioxide;
- Microgard; and
- Goal

The above substances will be located in dedicated storage areas in appropriately secured, sealed and bunded facilities at each PPU. LPG, diesel and petrol will be stored separately and away from other materials as well as each other. As a result, these substances were not further considered in the Risk Screening study by SLR.

Applying SEPP 33, clearly states *"If combustible liquids of class C1 are present on site and are stored in a separate bund or within a storage area where there are no flammable materials stored they are not considered to be potentially hazardous*." Diesel, which is a Class C1 material, will be stored within bunded areas with a minimum bund volume of 110% of the volume stored and there will be no flammable materials stored in the vicinity.

The total quantities of LPG to be stored at each PPU are above the 16 m^3 (~16,000L water capacity) screening threshold set in Applying SEPP 33 and above the Safe Work Australia manifest quantity of 5,000 L. As a result, the Development may be considered potentially hazardous with respect to the quantity of LPG to be stored at each PPU. LPG therefore has been considered in detail as part of the study.

4.2.2 Dangerous Goods Transport

With reference to Figure 12 where the movement of DG vehicles are summarised, it is noted that whilst the number of vehicle movements for delivery of LPG is well below the screening threshold, the quantity of LPG delivered per load will likely be greater than the screening threshold of 2 tonnes.

The Preliminary Hazard Analysis by SLR acknowledges that whilst the quantity of LPG transported per load to the site will likely exceed the SEPP 33 threshold of 2 tonnes, the number of deliveries will be one to two per week and deliveries are undertaken in a sparsely populated area by rigid vehicles which will limit the capacity of LPG transported. The PHA concludes that on this basis, further consequence analysis for transport risks were not considered necessary.

4.2.3 Hazard Incident Identification

Detailed assessment of potential hazards which could not be eliminated through the SLR Preliminary Risk Screening review is covered in this section of the report. The following substances are treated as a potential hazard after considering the surrounding land uses and potential receptors that may be affected in a hazard event:

- LPG Fire

In addition to an LPG Fire, the hazards associated with a fire occurring at the poultry shed is considered. This is due to a significant amount of PIR panels being installed onto each building and the proximity to the LPG tanks. Furthermore, risks relating to the PV panels and potential BESS under the modification are also reviewed.

Potential Hazardous Incidents identified through the SLR PHA study and the poultry shed fire scenarios are summarised in Table 6. The same table presents controls required to reduce risks to an acceptable level.

..

Table 6: Potential Hazardous Incidents

Event	Cause	Potential Consequences	Prevention/Protection Requirements to Reduce Risks to Acceptable Level
Rupture of gas line	Failure of pipe or connection	Leak/release of LPG to atmosphere resulting in ignition	Installations must comply with AS/NZS 1596:2014, specifically Sections 3, 5, 6, 8, 11, 12 & 13. The following sections/clauses are highlighted from AS/NZS 1596:2014, given their relevance to the specific event, noting all relevant sections/clauses must be complied with: • The outflow of gas must be controlled in accordance with Section 5 AS/NZS 1596:2014 • Appropriate compliant safety shut down and isolation valves will be installed (Sections 5.3 and 6.7 AS/NZS 1596:2014). • Ensure that all inspections, testing and maintenance is in accordance with Section 11.5 AS/NZS 1596:2014. • Separation distances are to be maintained as identified in AS/NZS 1596:2014, more specifically separation distances between LPG tanks and any protected place, including poultry sheds, to be at least 26.5 m • Appropriate hazard area classification is accordance with AS 60079.10.1 (Zone 2 hazard area within the space from ground level to 1m vertically above the tank and laterally to a distance of 6m for an 8kL tank (Table ZA.6.5.2.1 AS 60079.10.1:2009)). All electrical equipment used as part of the installation will comply with AS3000. • Fire safety systems will be installed and/or available in accordance with Section 13 AS/NZS 1596:2014 Ensure appropriate staff are trained in how to use firefighting equipment. Appropriate fire drills are conducted to ensure the emergency plan works.

Event	Cause	Potential Consequences	Prevention/Protection Requirements to Reduce Risks to Acceptable Level
Leak during tank filling	Rupture of filling pipe, overfilling tanks, over pressure of lines.	Leak of LPG to atmosphere resulting in ignition	Installations must comply with AS/NZS 1596:2014, specifically Sections 3, 5, 6, 8, 11, 12 & 13. The following sections/clauses are highlighted from AS/NZS 1596:2014, given their relevance to the specific event, noting all relevant sections/clauses must be complied with: • Tank filling requirement must comply with Section 6.6 AS/NZS 1596:2014 • Appropriate compliant safety shut down and isolation valves will be installed (Sections 5.3 and 6.7 AS/NZS 1596:2014). If direct connection filling hose and coupling must be of the type which prevents the escape of more than 0.1L if liquid during disconnection • Fire-sensing elements of the emergency shutdown system shall be located so as to sense and respond to a fire at the filling or loading connection in accordance with Clause 6.7.2 of AS/NZS 1596:2014. • Ensure that all inspections, testing and maintenance is in accordance with Section 11.5 of AS/NZS 1596:2014. • Separation distances are to be maintained as identified in AS/NZS 1596:2014, more specifically separation distances between LPG tanks and any protected place, including poultry sheds, to be at least 26.5 m • Appropriate hazard area classification is accordance with AS 60079.10.1 (Zone 2 hazard area within the space from ground level to 1m vertically above the tank and laterally to a distance of 6m for an 8kL tank (Table ZA.6.5.2.1 AS 60079.10.1:2009)). All electrical equipment used as part of the installation will comply with AS3000.

Event	Cause	Potential Consequences	Prevention/Protection Requirements to Reduce Risks to Acceptable Level
			• Fire safety systems will be installed and/or available in accordance with Section 13 of AS/NZS 1596:2014. Ensure appropriate staff are trained in how to use firefighting equipment. Appropriate fire drills are conducted to ensure the emergency plan works.
Tank failure	Overpressure of tank, due to adjacent fire Tank failure due to corrosion	Leak of LPG to atmosphere resulting in ignition	Installations must comply with AS/NZS 1596:2014, specifically Sections 3, 5, 6, 8, 11, 12 & 13. The following sections/clauses are highlighted from AS/NZS 1596:2014, given their relevance to the specific event, noting all relevant sections/clauses must be complied with: • The tank must be made of steel and comply with the requirements AS 1200 in accordance with Section 5.2.1 of AS/NZS 1596:2014. • Ensure that all inspections, testing and maintenance is in accordance with Section 11.5 of AS/NZS 1596:2014. • Separation distances are to be maintained as identified in AS/NZS 1596:2014, more specifically the separation distance between LPG tank and poultry sheds are proposed to be 26.5 m apart. • Automatic fill shutoff when tank has reached capacity in accordance with Section 6.6 of AS/NZS 1596:2014. • Appropriate hazard area classification is accordance with AS 60079.10.1 (Zone 2 hazard area within the space from ground level to 1m vertically above the tank and laterally to a distance of 6m for an 8kL tank (Table ZA.6.5.2.1 AS 60079.10.1:2009)

Event	Cause	Potential Consequences	Prevention/Protection Requirements to Reduce Risks to Acceptable Level
			• Fire safety systems will be installed and/or available in accordance with Section 13 of AS/NZS 1596:2014. Ensure appropriate staff are trained in how to use firefighting equipment. Appropriate fire drills are conducted to ensure the emergency plan works.
Poultry shed fire (Scenario 1 – Section 5.3.1)	Fire event arising from tunnel fan malfunction, causing a nearby combustible load to be ignited and spreading to PIR panels.	The building dimensions are relatively large in that a building wide flashover event is not expected to occur after an extended duration. Therefore, the fire is assumed to spread to consume ¼ of the buildings PIR panels running parallel to neighbouring poultry sheds. Potential spread of fire to adjacent poultry sheds or LPG storage tanks to be examined.	A fire hydrant system in accordance with AS 2419.1 and/or any approved performance solution shall be provided to service the poultry sheds. Water storage tanks with suitable firefighting water capacity to be provided to serve the pseudo ring main at each poultry shed cluster. Water storage tanks shall be maintained at near capacity at all times and fitted with low level alarms to sound when tanks reach a capacity of two thirds full. Tanks shall automatically be filled from pressurised lines. LPG tank storage shall comply with separation distances as identified in AS/NZS 1596:2014, more specifically the separation distance between LPG tank and poultry sheds are proposed to be a minimum of 26.5 m apart. Ensure appropriate staff are trained in how to use firefighting equipment. Appropriate fire drills are conducted to ensure the emergency plan works. Fire extinguishers shall be provided in accordance with BCA Clause H3.11.

Event	Cause	Potential Consequences	Prevention/Protection Requirements to Reduce Risks to Acceptable Level
BESS Fire (Scenario detailed in Section 5.4) – (If Installed)	Thermal runaway of batteries within BESS	Fire spread to adjacent infrastructure and vegetation.	Bollards be erected around the BESS for impact protection. The BESS container is to be provided with heat, smoke, H2, CO and VOC combustible gas detectors. Signals from each of the detectors are noted to be linked to the Emergency Management System (EMS). The signal shall then report back to the site office/alarm system, in which Proten is to develop procedures for response to a detection scenario in the BESS, including call out to the fire brigade The BESS container shall be provided with a form of automatic suppression system using HFM-227E gaseous suppression, or an equivalent system selected by the BESS supplier and agreed with the fire safety engineer. In accordance with NFPA 855, Section 4.12.1, it is recommended that the BESS system to be provided with one of the following; (1) Explosion prevention systems designed, installed, operated, maintained and tested in accordance with NFPA69; or (2) Deflagration venting installed and maintained in accordance with NFPA 68 Where the Deflagration Prevention by Combustible Concentration Reduction of NFPA 69 is appropriate, it recommended that upon detection of 10% LFL within the container that the gas detectors activate and automatically trigger the interlocked emergency ventilation system to ventilate the container Separation distances to be achieved in accordance with Table 13 and Figure 24 to mitigate the risk of fire spread from a BESS fire.

Event	Cause	Potential Consequences	Prevention/Protection Requirements to Reduce Risks to Acceptable Level
			Following deployment of the gaseous extinguishing agent, should gas build-up still occur and 25% LFL is reached, emergency ventilation system shall be reinstated. Fire hydrants installed in accordance with AS 2419.1-2005, Section 3.3 Open Yard Protection, and Table 3.3: Number of Fire Hydrants Required to Flow Simultaneously for Protected Open Yards. That is 10 L/s for a duration of four (4) hours. Fire hydrants must be provided and located so that every part of the BESS is within reach of a 10 m hose stream issuing from a nozzle at the end of a 60 length of hose connected to a fire hydrant outlet.
Fire originating from PV panels located on the roof of poultry sheds	Faulty installation, lightning strike, power surge	Fire spreading to adjacent poultry sheds as a result of a PV array fire limited to the roof.	Regular maintenance of panels to ensure deterioration kept to a minimal. A maintenance program based upon manufacturer requirements is to be enacted by Proten. Minimise the use of any combustible material as part of the solar array installation, including support fixings, framing etc.

5. Consequence of Incidents

The consequence of the incidents detailed in Table 6 are further assessed in this section of the report.

5.1 Preliminary Hazard Analysis

The potential consequences of incident scenarios assessed in the SLR Preliminary Hazards Analysis are summarised below;

- The operation of the Development will meet the criteria laid down in HIPAP 4 and would be unlikely to cause any risk, significant or minor, to the community.

  Note that this fire safety study further elaborates on various fire scenarios at the development, highlighting the expected impacts.

- There is a requirement to ensure that LPG is stored and used correctly on site, and with compliance with *AS/NZS 1596:2014 The storage and Handling of LP Gas* there is considered to be a low risk to the site users.

- Other spill, fire and incident events are not likely to extend beyond the boundary of the Development Site, with the exception of a major facility fire where, regardless of the type of operation, there will always be a risk of potentially harmful smoke plumes downwind. In the majority of large fires the buoyant nature of a smoke plume means any potentially harmful materials are rapidly dispersed. Any firefighting water can be managed on site without release into the wider environment.

- It is considered that the operations of the Development with the safeguards stipulated would not cause significant off site risks. Whilst the Development is considered to be a hazardous development given the quantity of LPG stored at each PPU, this is easily managed with compliant construction and availability of incident management strategies.

  The surrounding area is lightly populated with the closest residence approximately 1,025 m from the nearest PPU and the nearest population centre, Somerton, approximately 12 km from the nearest PPU.

- The PHA concludes that the Development is expected to meet all the requirements stipulated by the DPIE and hence would not be considered, with suitable engineering and design controls in place, to be an offensive or hazardous development on site or would not be impacted by any other hazardous incidents from adjoining facilities offsite. This Fire Safety Study shall further detail other potential fire hazards in relation to the development.

The PHA has concluded that the risk associated with the use of LPG tanks on the development, when stored and used correctly and with compliance with AS/NZS 1596:2014, there is only a low risk to the site users. Further to this, the fire safety study shall assess the relationship between LPG tanks and poultry sheds given the proposed separation distance when considering worst case fire scenarios at the latter.

The study shall further identify whether the proposed separation distance between LPG tanks and poultry sheds are sufficient such that a fire at the latter should unlikely result in a cascading fire event at the LPG tank. A detailed assessment, including calculations, will be presented in the following sub-sections for the respective hazards identified.

5.2 Fire exposure protection of LPG Tanks

It is understood that each LPG storage location contains a total capacity ranging from 38,250 L to 57,375 L. The assessment shall consider the maximum total capacity of 57,375 L located at farm 2 (Refer Figure 11). The total capacity at any storage location is distributed across several tanks. Tank installations are to comply with requirements of AS/NZS 1596:2014 under Clause 6.2.2:

> *Tanks may be arranged in groups of up to six tanks, with each tank in the group separated in accordance with Table 6.1, Column 2. The following requirements and recommendations apply to tanks in groups:*
>
> *(a) The distance from one such group to another tank or group shall be not less than 15 m except that, where no tank in either group exceeds 2 m diameter, the distance may be reduced to 10 m.*
>
> *(b) Tanks shall not be stacked above one another.*
>
> *(c) The longitudinal axes of thanks in a group should be parallel and should be directed away from any adjacent storages of hazardous, flammable or combustible liquids or gases. Where another arrangement is unavoidable, whereby a tank could be in line with the axis of another tank, the distance between the end of any tank and the end or shell of another tank shall not be less than 3 m or twice the diameter of the larger tank, whichever is greater.*

Furthermore, as indicated in Figure 6, Table 6.1 of AS/NZS 1596:2014, it is required that a minimum distance between adjacent LPG tanks to be the diameter of the largest tank irrespective of tank capacity.

TABLE 6.1

LOCATION OF ABOVE-GROUND STORAGE TANKS

1	2	3	4
Capacity of the tank kL	**Minimum distance to an adjacent LP Gas tank** m	**Minimum distance from the tank to a public place, or a railway line** m	**Minimum distance from the tank to a protected place** m
≥0.5	Diameter of the largest tank	1.5	1.5
1		2	3
2		4 (3)	6 (4.5)
5		5 (3.5)	8 (5)
8		6 (4)	10 (6)
10		7	11
15		8	14
20		9	15
50		10	17
100		11	20
200		12	25
500		22	45

Figure 13: Excerpt from AS/NZS 1596:2014

A fire exposure assessment in accordance with Appendix M of AS/NZS 1596:2014 has also been undertaken to determine the potential effect of a fire in the poultry shed (nearest structure) and its impacts on the LPG storage facility. The assessment determines whether the LPG storage facilities require protection from such fire event.

Parameters utilised in the assessment and the resultant distance ‘D’ (minimum separation distance required) is summarised in Table 7. The typical layout of LPG tank to poultry sheds is shown in Figure 14.

Table 7: Input parameters and calculation results

Parameter	Comments/Results
Required distance between LPG tank and protected place (as required by Table 6.1) *Note that the max total capacity of LPG stored is at Farm 2, 57,375 L.*	17.45 m *Interpolated from data points in Table 6.1*
Distance at which fire source can be ignored	3 x 17.45 = 52.35 m
Actual distance between protected place and LPG tanks	26.5 m (same for all 4 farms)
Assessment Required	Actual Separation Distance < Distance permitted to be ignored; 26.5 m < 52.35 m Yes, further assessment required (per below)
Dimensions of poultry shed *B equals the width of one poultry shed since, shed to shed fire spread is not expected given the 15 m separation. Therefore, worst case is one shed involved in a fire.*	B = 18.0 m H = 4.7 m (to the ridge of the roof)
Net fire area	B x H = 18.0 m x 4.7 m = 84.6 m^2
Distance	D = 2.2 x √A = 2.2 x √84.6 = 20.24 m

TABLE 6.1

LOCATION OF ABOVE-GROUND STORAGE TANKS

1	2	3	4
Capacity of the tank kL	Minimum distance to an adjacent LP Gas tank m	Minimum distance from the tank to a public place, or a railway line m	Minimum distance from the tank to a protected place m
≥0.5	Diameter of the largest tank	1.5	1.5
1		2	3
2		4 (3)	6 (4.5)
5		5 (3.5)	8 (5)
8		6 (4)	10 (6)
10		7	11
15		8	14
20		9	15
50		10	17
100		11	20
200		12	25
500		22	45

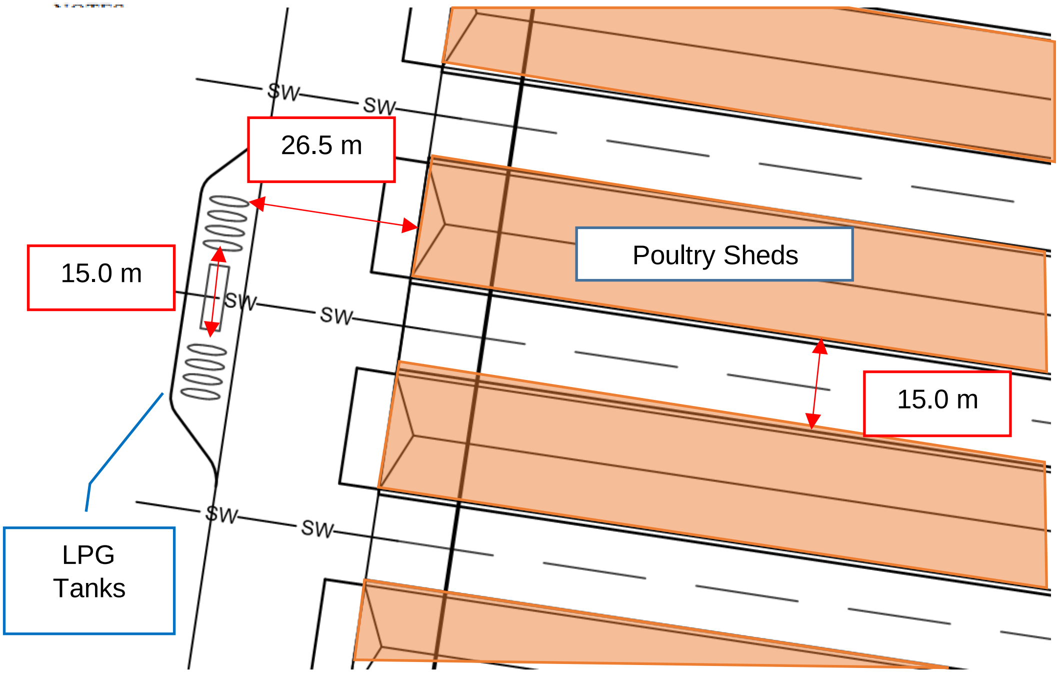

Figure 14: Typical Layout of LPG tanks to poultry sheds

Appendix M of AS/NZS 1596:2014 notes that where distance 'D' is greater than the actual separation distance, additional protection is required to be provided to the LPG tanks to ensure that the tank shell does not exceed 300 °C after 45 minutes of exposure to heat radiation. The temperature of the tank shell will not exceed such temperature if the heat radiation received at the shell's surface does not exceed 10 kW/m^2 as noted in the standard. This estimate is based on a worst case, ie. the tank being effectively empty of LPG liquid and the tanks surface having deteriorated to the point where it cannot reflect heat.

Calculations from Table 7 indicate that the minimum distance D is less than distance of separation (20.24m < 26.5 m), therefore no additional protection is required to the LPG storage tanks.

It is noted that the calculation above assumes that the adjacent building fire will be at 1000°C so the emission from the structure will be 150 kW/m^2. Whilst this is conservative, it does not account for high hazard scenarios whereby a fire at the adjacent building may exceed such assumptions.

As the nearest structure, the poultry shed is clad with PIR, a combustible product, a detailed study of fire scenarios at the poultry shed is considered to validate the findings of the above calculations.

The following section of the report shall assess the extreme fire scenarios that may impact the LPG tanks.

5.3 Poultry Shed Fires

5.3.1 Fire scenario

The fire scenario identified in Table 6 for the poultry shed is further assessed in this section.

The radiant heat levels exhibited in a poultry shed fire will be assessed to determine the likelihood of secondary structures being involved. This study will provide further clarity as to whether the separation distances between structures, particularly LPG storage tanks is sufficient when calculated in accordance with Appendix M of AS/NZS 1596:2014 detailed in Section 5.2.

The poultry sheds are cladded with PIR throughout the building, including the wall directly facing the LPG gas tanks. As with most insulating materials, there are different types of PIR foam, each with differing characteristics and therefore fire behaviour.

As the specific product specifications have not been stipulated for the design at this point, reliance on studies of PIR panels are required to determine their general behaviour in a fire.

While the fire properties may vary, experiments conducted by (Juan P.Hiadlgo, 2017) on the fire performance of PIR found that the results of three PIR specimens sought from various manufacturers yielded very similar results when exposed to radiant heat. Therefore, while the exact product is unknown at this point in time, reliance on results from the experiment is considered acceptable as the fire behaviour of the PIR was demonstrated to behave relatively similar. It was identified that the critical temperature for the onset of pyrolsis of rigid PIR was between 300°C to 370°C.

During the study, when the specimen (100 mm thick) was exposed to a constant irradiance level of 65 kW/m^2, the HRRPUA of the panel (without protective layer at surface) peaked at 160 kW/m^2. This occurred within the first few minutes of exposure (during the flaming combustion stage) as shown in Figure 14, after which it decayed below 60 kW/m^2 represented by the formation of a char layer and transition of the pyrolysis front towards the inner depths.

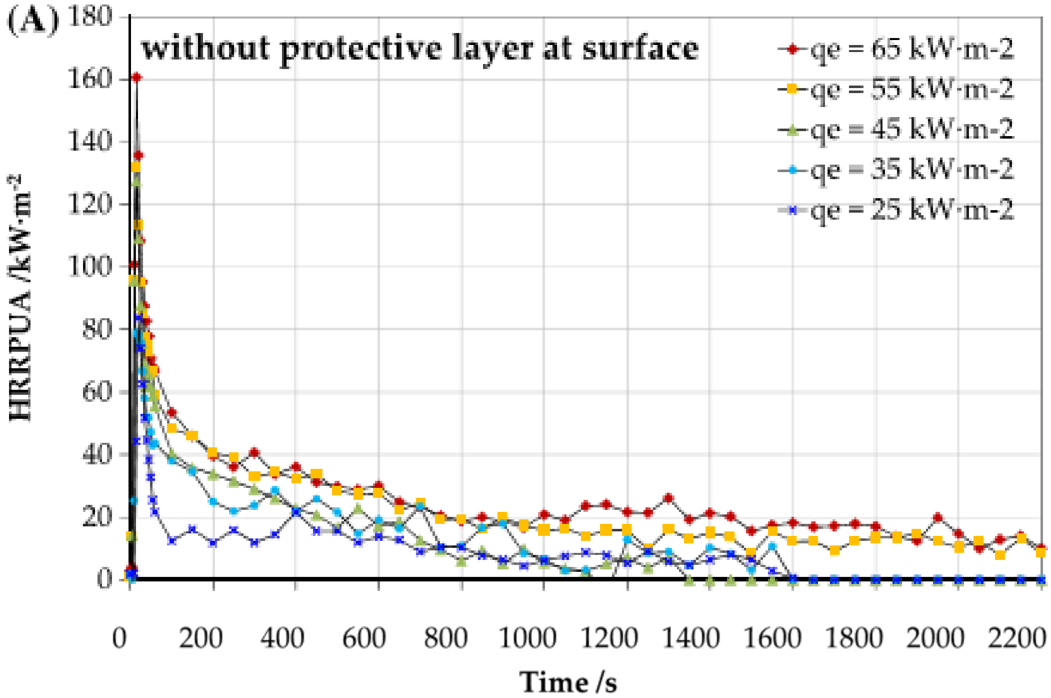

Figure 15: Heat release rate per unit area of 100-mm-thick PIR (Juan P.Hiadlgo, 2017)

It is further noted that under irradiance exposure levels above 55 kW/m^2, the PIR was consumed by the end of the experiment. Under lower levels of exposure, this was not the case. Refer Figure 16 illustrating normalised mass of PIR over time (Juan P.Hiadlgo, 2017).

Details of the study can be found in Appendix B.

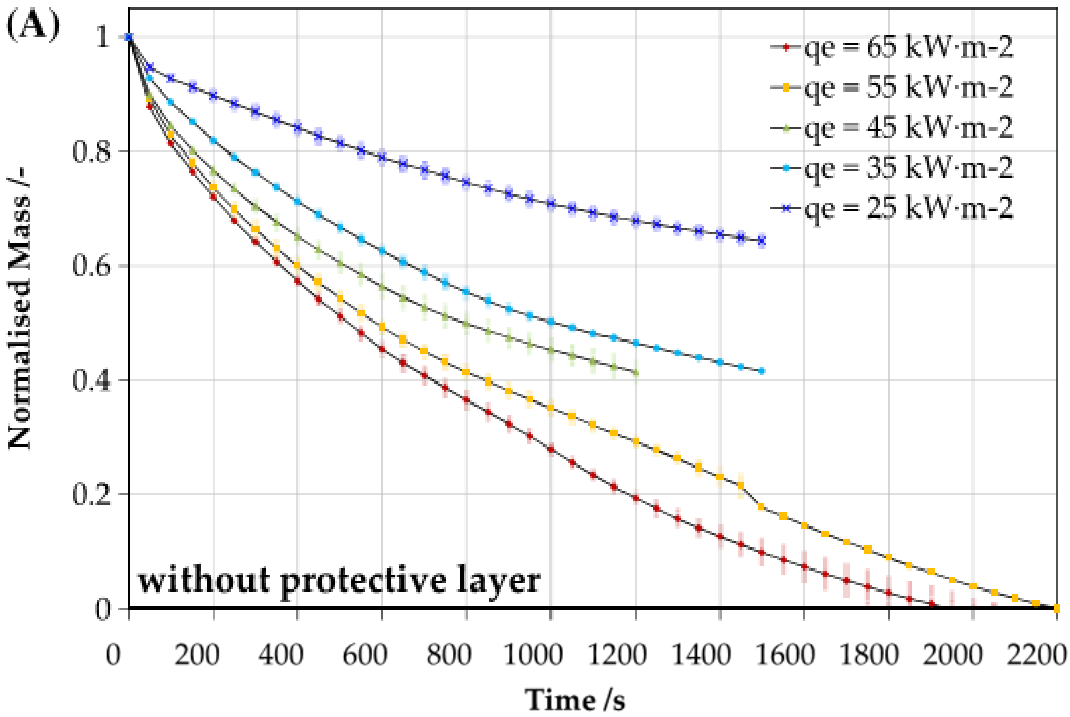

Figure 16: Normalised mass of PIR over time (Juan P.Hiadlgo, 2017)

The risk of ignition and a fully involved fire at the development is relatively low as a result of the operational nature of the facility, local response and material used. However, for sensitivity, the following fire scenario at the poultry shed is assessed.

Details for the fire scenarios are summarised in Table 8.

Table 8: Fire Scenarios

Fire Scenario	Comments
Fire event arising from tunnel fan malfunction, causing a nearby combustible load to be ignited and spreading to PIR panels at the closest face to the LPG tanks. The building dimensions are relatively large in that a building wide flashover event is not expected to occur after an extended duration. Therefore, the fire is assumed to spread to consume ¼ of the buildings PIR panels running parallel to neighbouring poultry sheds. Refer Figure 17.	A malfunction in the fan unit results in fire whereby a combustible load located against the internal face of the building is ignited, resulting in the PIR panels being involved. It is assumed that the entire internal and external face of the wall closest to the LPG tank is involved in the fire as a result of openings in the fan units. The entire surface area of the wall will be radiating heat towards the LPG tanks. Area = 18 x 2.2 = 39.6 m^2 W = 18 m, H = 2.2 (wall from topside of dwarf wall to the eaves). It is assumed that the panels involved have an irradiance level of 160 kW/m^2 and is constant for the duration. This is conservative considering the study indicates such levels of radiant heat is only exhibited during the flaming phase and is reduced as char begins to form. Furthermore, the study was conducted on exposed PIR panels without a protective covering which is not the case for the subject buildings. The panels are understood to be encapsulated in aluminium channels. However, the higher level of irradiance may account for other potential combustible loads within the vicinity of the panels. The wall running parallel to the neighbouring poultry sheds are also assumed to be involved in the fire. However due to the large footprint of the building, a building wide flashover is not expected to occur until after a significant time has lapsed. It is assumed that a quarter of the buildings PIR along the wall running parallel to the neighbouring poultry shed (160.0 m / 4 = 40.0 m) is involved based on the location of fire origin.

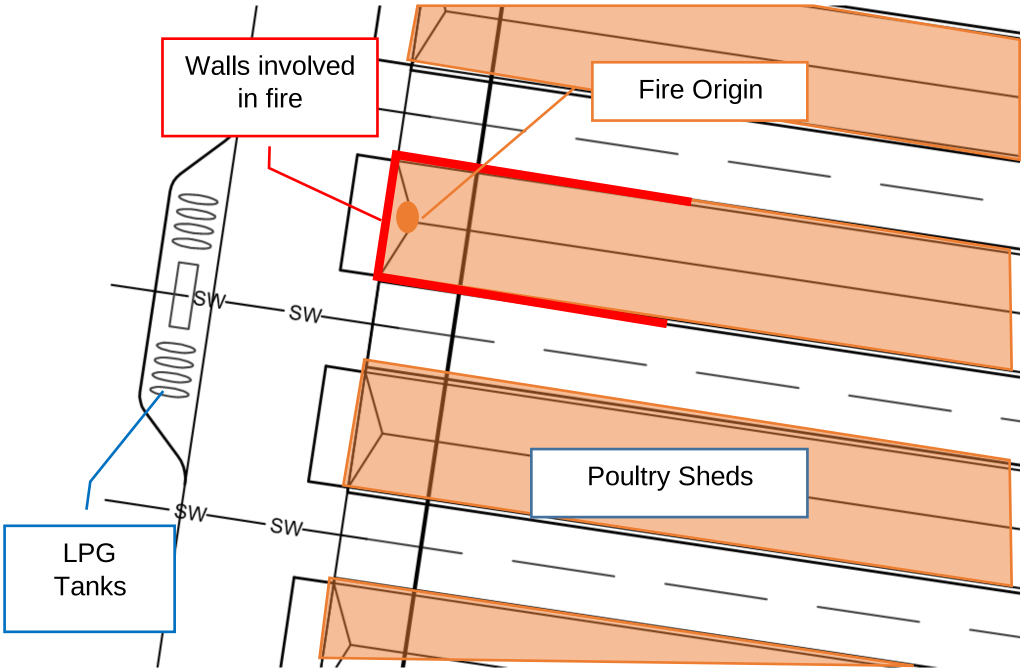

Figure 17: Typical Layout of LPG tanks to poultry sheds

The radiant heat flux received at nearby structures are summarised in Table 9.

Calculations and assumptions are available in Appendix A.

Table 9: Radiant heat flux received from fire scenario 1

Surrounding Infrastructure	Heat radiating surface dimensions	Radiant Heat Flux Received
Poultry shed located 15 m away	Poultry Shed (Side Wall) 40.0 m x 2.2 m (Parallel to adjacent shed)	10.6 kW/m^2
LPG storage tanks located 26.5 m away	Poultry Shed (End Wall) 18.0 m x 2.2 m (Parallel to LPG Tanks) Poultry Shed (Side Wall) 40.0 m x 2.2 m (Perpendicular to LPG Tanks)	3.4 kW/m^2

Table A3 of AS 1530.4-2014 provides typical radiant heat intensities for various phenomena and suggests that piloted ignition occurs at approximately 13 kW/m^2.

As the poultry shed located 15 m away received a radiant heat flux below this threshold, fire spread between the PPU's are not expected.

When determining an acceptable radiant heat flux received at the LPG tanks, reference to the assumptions made under AS/NZS 1596:2014 is applicable. As noted earlier, the standard stipulates that radiant heat flux received at the tank should not exceed 10 kW/m^2 for 45 minutes to maintain the temperature of the tank below 300 °C.

The radiant heat flux received at the LPG tank under the detailed fire scenario is 3.4 kW/m^2 and therefore below the threshold acceptable under AS/NZS 1596:2014. As both the calculation methods; for the fire scenario detailed above, and that in Appendix M of AS/NZS 1596:2014 are deemed acceptable, poultry sheds located 26.5 m from the LPG are acceptable and not expected to promote fire spread.

As the nearest structure, the poultry shed, is considered to exhibit radiant heat flux commensurate with that permitted in AS/NZS 1596:2014 (Refer Section 5.3 for detailed calculations), the LPG tanks are not considered to be exposed to high levels of radiant heat to trigger a secondary fire. As such further catastrophic events such as a Boiling Liquid Expanding Vapor Explosion (BLEVE) events are considered highly unlikely, especially when no other fuel or ignition sources are in the vicinity and fire protection measures provided (Refer Section 7 for fire protection measures).

5.4 Solar Panel Fire

The solar panel fire identified in Table 6 is assessed in detail in this section.

Based on past solar panel rooftop fires, a large number of occurrences in Australia can be related back to the rooftop DC isolators (Regen Power, 2021) (Fire + Rescue NSW, 2020). These isolators improve safety through shutting off DC current in cabling which runs along the roof cavity and down to the solar inverter, however due to faulty installations, defects and the like, they have proven to be fire hazards.

While the cause of a fire event may vary, the assessment considers that a fire event has already occurred, originating from the solar installation to assess the level of potential impact to the site.

The PV arrays are proposed to be installed to the roofing of several poultry sheds as shown in Figure 18.

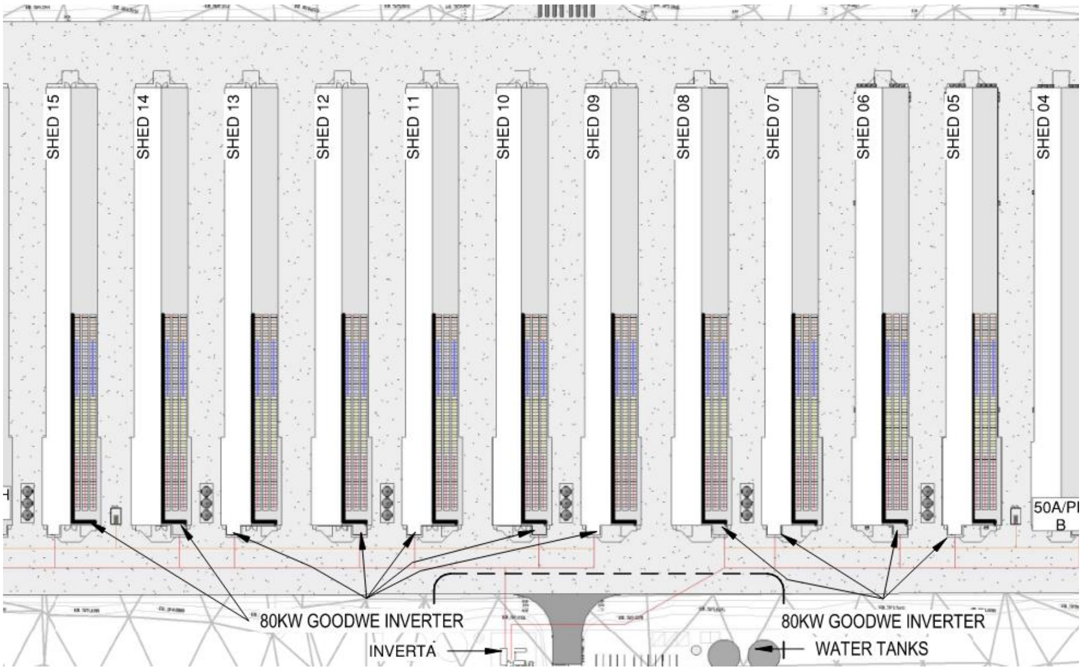

Figure 18: Proposed installation of PV arrays on roof of poultry sheds

Like any electrical system, PV systems are subject to electrical faults such as arc faults, short circuits etc. Should these occur, hot spots can ignite flammable material nearby.

The subject panels have been subject to the UL 790 test and achieve a pass, meaning, the panels provide a "*light degree of fire protection to the roof deck".* Note that this does not indicate that a PV array fire does not contribute to the fuel load of a building. Fire classifications (A, B or C under UL 790) indicate the panels behavior to external fire sources outside the building to meet building construction requirements for fire rating. Class C is noted to be on the lower scale for fire protection.

In the event of a fire originating from the solar panels, it is expected for a number of panels to be involved, despite the Class C rating achieved under UL 790. This is because Class C roof covering rating does not equate to being fire rated or non-combustible. In fact, the typical construction of crystalline silicon type photovoltaic modules consists of several layers as shown in Figure 19.

Of the various layers, the following are noted as being combustible (Hong-Yun Yang et al, 2015):

- EVA film - used to encapsulate the PV module, and
- EVA Backsheet – used to protect the PV module from UV and moisture.

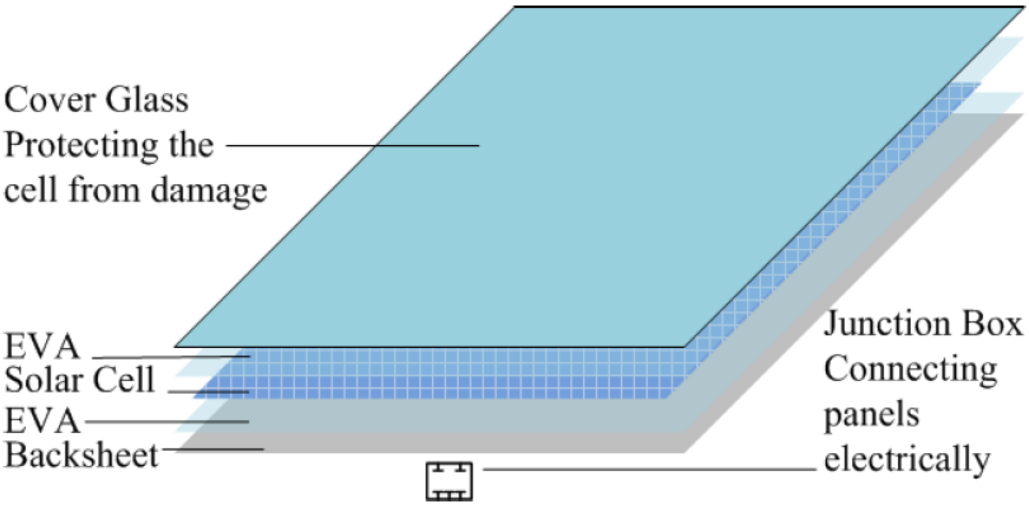

Figure 19: Typical construction of Solar Panels (Hong-Yun Yang et al, 2015)

Research undertaken by (Xiaoyu Ju et al, 2017) on polycrystalline silicon PV panels indicate that PV panels are highly sensitive to the change of external heat flux. The study found that the flashover propensity of crystalline silicon PV panels are low risk when heat flux is less than or equal to 30 kW/m^2, but intermediate risk at 40 kW/m^2 or more.

Other studies undertaken by (Hong-Yun Yang et al, 2015) report that similar crystalline silicon PV modules can resist ignition fora critical heat flux up 26 kW/m^2. And both studies report that an increase in heat flux induces a rapid decrease in ignition time of PV Panels.

The study also provides an indication of Heat Release Rate (HRR) of PV modules as a function of time with varying degrees of incident heat flux. The HRR was noted to vary greatly as irradiance level was increased from 28 kW/m^2 to 45 kW/m^2. Experimental results are replicated in Figure 20 and are used to define the solar array fire scenario of this report.

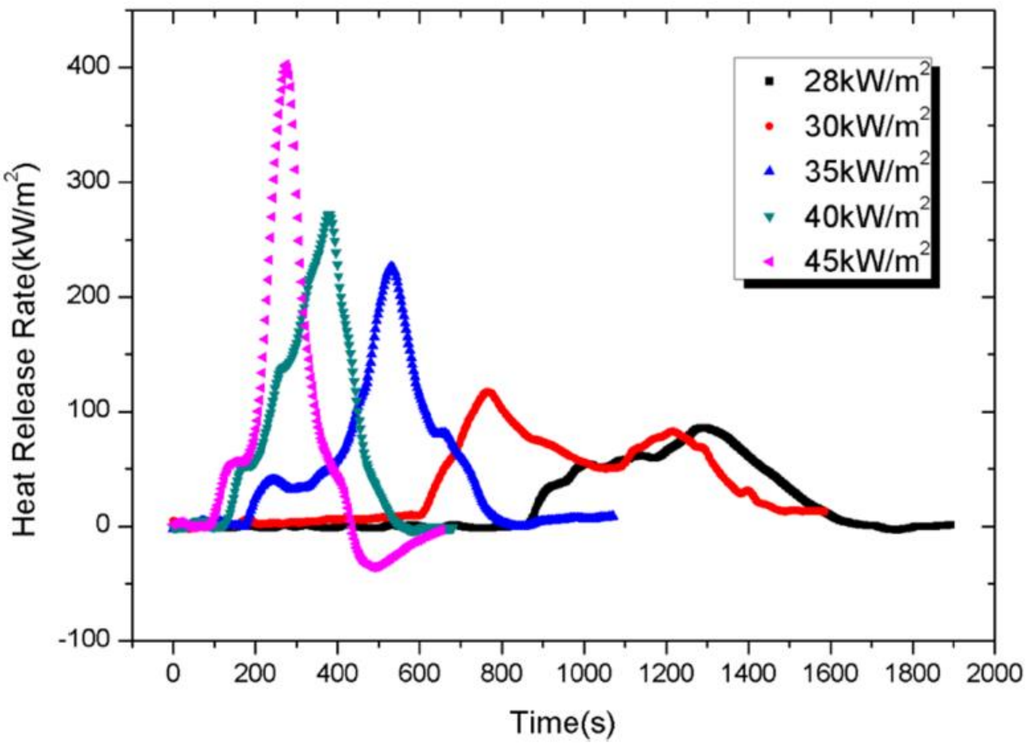

Figure 20: HRR vs Time at various irradiance levels for crystalline silicon PV modules (Hong-Yun Yang et al, 2015)

Based on the experimental results, when the incident heat flux was increased from 28 kW/m^2 to 45 kW/m^2, it was observed that the peak HRR increased from 85 kW/m^2 to 402 kW/m^2. The rapid spike in HRR for higher irradiance levels also resulted in a rapid drop shortly afterwards. Consequently, they also exhibited shorter burnout times as evident in the graph.

At lower irradiance levels of 28 kW/m^2 and 30 kW/m^2, the heat release rates over time were more consistent, hovering in the range of 50-80 kW/m^2 on average.

These findings are utilised to develop a likely fire scenario for the proposed solar array installation.

The fire scenario assessed for the purposes of this report is a fire occurring due to electrical arcing at the panel, and any combustible parts supporting the solar module is ignited. The following sequence of events are anticipated based on the research findings and are applied accordingly:

- Ignition of combustible elements on the roof (expected and recommended to be limited) emits a radiant heat flux of 30 kW/m^2, sufficient to cause the solar panels to ignite.
- While the peak HRR for the PV cell, exposed to a radiant heat flux of 30 kW/m^2 reaches approximately 100 kW/m^2, this is only for a short period of time before decaying back to the range of 50 - 80 kW/m^2. Assuming even a best case scenario where 50 kW/m^2 is consistently radiated from the flaming panel, following it reaching the peak of 100 kW/m^2, this is sufficient to ignite adjacent panels given the minimal separation distances.
- Each adjacent panel down the array involved in the fire will theoretically be exposed to a higher degree of incident radiant heat flux (from the previous panel), increasing as the fire travels down the array. Due to this, it is assumed in a worst-case scenario that all 72 m of solar panels of a single roof can be involved in a single fire event.

However, it is reasonable to assume that not all 72 m of panels will be burning simultaneously, given on the burnout times recorded in the study being around 400 s, and takes approximately 100 s to ignite when exposed to the higher incident heat flux of 45 kW/m². Therefore, it is more reasonable to assume that approximately 18 m of panels (1/4 of the total length of panels installed) may be subject to flaming at the same time. The fire scenario is illustrated in Figure 21.

- There are limited studies documenting flame heights of a solar panel fire, and therefore, a best estimate is used when electing a flame height for the radiation assessment. Based on reviewing of photographs of past fire events, it is estimated that a 1 m flame height would be sufficient to capture a plausible fire scenario. It is assumed that the 18 m of panels involved in the fire will all be producing flames to a height of 1 m.

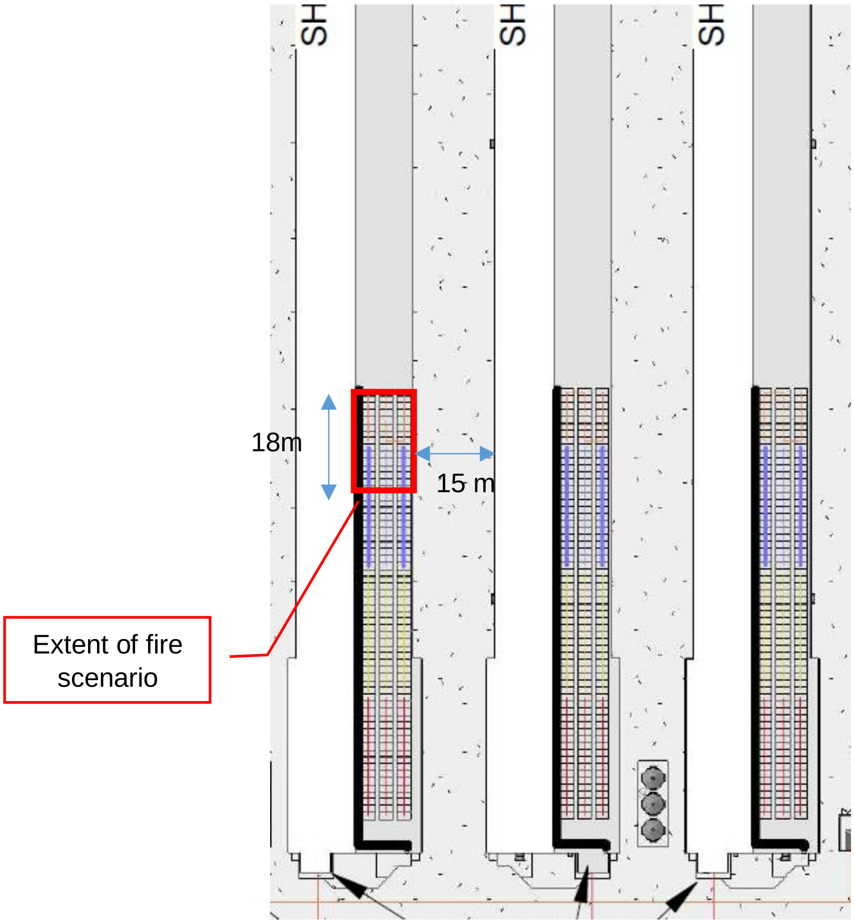

Figure 21: Solar arrays burning in fire scenario at any given time

The study by (Hong-Yun Yang et al, 2015) reported peak heat release rate of involved solar panels up to incident heat fluxes up to 45 kW/m², the corresponding peak HRR at 45 kW/m² is approximately 400 kW/m². While it is expected for the peak HRR to increase as incident heat flux increases, it is noted that the burnout time is at the same time reduced, limiting the exposure time at the elevated heat flux.

As there is insufficient information to deduce a theoretical peak HRR for heat flux beyond 45 kW/m², it is assumed that a radiant heat flux of 400 kW/m² is maintained continuously during the burning process across the full 18 m length of panels involved.

This is considered conservative, as although some panels may exhibit a peak heat flux exceeding 400 kW/m² it is expected to be for shorter durations. Therefore, it is unlikely that all panels radiate at such high intensity for an extended period of time.

Detailed calculations for radiant heat flux emitted to an adjacent poultry shed is detailed in Appendix D.

Table 10: Radiant heat flux received from solar fire

Surrounding Infrastructure	Heat radiating surface dimensions	Radiant Heat Flux Received
Poultry shed located 15 m away	18 m of solar panels at any given time, with a flame height of 1 m 18 m x 1 m (Parallel to adjacent shed)	8.2 kW/m^2

Table A3 of AS 1530.4-2014 provides typical radiant heat intensities for various phenomena and suggests that piloted ignition occurs at approximately 13 kW/m^2.

As well, the solar panels on the next shed do not face one another – they are on consistent roof sides of the PPUs, minimising exposure from one shed to the next. The calculated radiant heat flux of 8.2 kW/m^2 is also well below the ignition point of the solar panels on the next PPU.

As the poultry shed located 15 m away received a radiant heat flux below this threshold, fire spread between the PPU's are not expected.

5.5 BESS Fire (If Installed)

The BESS fire identified in Table 6Table 6 is assessed in detail in this section.

The most prevalent risk with the operation of BESS utilising lithium-ion batteries is an event referred to as thermal runaway. Thermal runaway is described by (National Fire Protection Association (NFPA), 2020) as:

"The condition when an electro-chemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing, fire, or explosion"

As noted in studies by (DNV GL, 2017), events which can lead to thermal runaway include:

1. *Low ambient pressure*
2. *Overheating*
3. *Vibration*
4. *Shock*
5. *External short circuit*
6. *Impact*
7. *Overcharge*
8. *Forced discharge*

The study further notes that,

'in some cases contaminants in the battery (as a result of manufacturing defects) weaken the ability of the battery to withstand instances of these eight abuse factors"

While there are several means that cause cells to undergo thermal runaway, the assessment does not focus on the root cause of such event as they are primarily either inherent risks (defects) or are typically managed by compliant electrical installations and a Battery

Management System (BMS) included in the proposed design (AlphaESS Australia Pty Ltd, 2022).

Instead, the study assumes that a thermal event has occurred and assesses the potential risk and impacts from this point, taking into consideration the fire safety features provided as per the technical requirements for the fire extinguishing system from the supplier, refer Appendix C.

Note that while the study does not dwell on the root cause of thermal runaway, one controllable measure recommended is to enhance the protection of batteries against impact. To this degree, ***it is recommended that bollards be provided around the BESS for impact protection.***

5.5.1 Sequence of events leading to fire scenario

During a thermal runaway event, off-gas is vented from battery cells as temperature and pressure increases. The composition of off-gas released can vary depending on the battery chemistry but comprise primarily of flammable gas. Studies by (Cai et al, 2020) suggest that in most battery abuse experiments, off gas produced by lithium-ion batteries include CO_2, CO, H_2 and volatile organic components (VOCs).

Gas compositions can be evaluated through the UL 9540A testing, however at the time of this assessment, this level of information was not made available.

In the absence of this information, it is assumed that the off-gas produced is comprised of predominantly flammable gas and contain a moderate to high degree of toxic gas. **A UL 9540A test must be provided to confirm the off-gas composition as this will be required to determine relevant protection measures against explosion or deflagration.**

5.5.1.1 Build-up of flammable gas

As off-gas is produced, the concentration of flammable gas within the BESS is expected to increase. In cases where this is unmanaged and left to accumulate, a deflagration or explosion event can occur. To mitigate this risk, measures should be undertaken in accordance with NFPA 855.

While the technical specifications for the BESS state that:

"The design, construction and installation of the energy storage system and related equipment shall comply with the requirements of NFPA 855 General Requirements, Chapter 4 and, where applicable, the specific technical provisions of Chapter 9 through 13",

there do not appear to be a means which specifically protect against explosion or deflagration for the subject system.

In accordance with NFPA 855, Section 4.12.1, it is recommended that the BESS system to be provided with one of the following;

(1) Explosion prevention systems designed, installed, operated, maintained and tested in accordance with NFPA69; or

(2) Deflagration venting installed and maintained in accordance with NFPA68

Code councils (International Code Council, 2021) and researchers (DNV GL, 2017) recommend providing mechanical ventilation to remove flammable and toxic gases during a failure event to potentially mitigate explosion hazards. Research and testing undertaken by (DNV GL, 2017) suggests a ventilation rate of 0.32 cfm/kWh may be suitable for safe operation of a BESS.

In the absence of data from supplier and manufacturer, this relationship is applied to estimate a ventilation rate for the system, yielding a flow rate of 410 cfm (0.32 x 1.28 MWh).

This rate is assumed to satisfy the *Deflagration Prevention by Combustible Concentration Reduction* method detailed in Chapter 8 of NFPA 69 for deflagration prevention, **but is required to be validated by the manufacturer/supplier.**

As described in NFPA 69,

"This technique for combustible concentration reduction shall be permitted to be considered where a mixture of a combustible material and an oxidant is confined to an enclosure and where the concentration of the combustible can be maintained below the lower flammable limit (LFL)"

Section 8.3.1 of the standard further details the permissible *Combustible Concentration Limits* under this method.

*"**The combustible concentration shall be maintained at or below 25 percent of the LFL for all foreseeable variations in operating conditions and material loadings, unless the following conditions apply:***

1) ***Where continuously monitored and controlled with safety interlocks, the combustible concentration shall be permitted to be maintained at or below 60% of the LFL.***
2) *Aluminum powder production systems designed and operated in accordance with NFPA 484 shall be permitted to be maintained at or below 50% of the LFL"*

As the off-gas composition is unknown at the time of this assessment, it is conservatively assumed that the LFL during thermal runaway of cells will exceed the 25%, and therefore, will require adoption of continuous monitors and controls with safety interlocks.

The continuous monitoring of flammable gas levels shall be undertaken by suitably installed gas detectors that are interlocked to the emergency exhaust system upon a predetermined % of LFL being detected in the container. Gas detectors (H_2, CO and VOC combustible gas) are detailed as a requirement in the technical specifications in Appendix C.

Where the *Deflagration Prevention by Combustible Concentration Reduction of NFPA 69 is appropriate,* it is recommended that upon detection of 10% LFL within the container that the gas detectors activate and automatically trigger the interlocked emergency ventilation system to ventilate the container"

The relevant mitigation system, either to NFPA 68 or NFPA 69, and relevant parameters should be confirmed with the manufacturer/supplier as the design develops to ensure appropriate protection measures are provided for the M48112-S battery modules and final design.

5.5.1.2 Fire event and radiant heat flux emitted

As thermal runaway continues and off-gas is vented, there is the potential for conditions in the container to initiate a fire event as battery temperatures increase.

While it is noted that the BESS container is to be provided with an automatic gaseous suppression system, the assessment assumes that the system is unsuccessful in extinguishing the fire, or that, although the fire may be extinguished, the build-up of flammable gas requires the emergency ventilation system to be reinstated, also reinitiating the fire. **It is recommended that the BESS container is provided with a form of automatic suppression system.**

The assessment considers a fully developed BESS fire based on the information provided to date and where applicable, reasonable assumptions based on literature and studies. In estimating the parameters of such fire, radiation heat flux to the surroundings can be approximated.

Specific details regarding the approach and calculations are provided in Appendix D.

Based on the calculations, the radiant heat flux received at various distances is summarised in Table 11 and Table 12, showcasing exposure to infrastructure located at various orientations and distances to the BESS. Infrastructure in proximity to the BESS and the received radiant heat flux is visually presented in Figure 22 and Figure 23.

It is noted that radiation is emitted radially from a source, however for the assessment, the heat flux received at a given distance, irrespective of the y-axis (on the page) is assumed to be the same for a high level estimation of heat flux.

Where the incident radiant heat flux is excessive when assessed against the critical criteria for the various types of infrastructure, recommendations are provided and a more detailed heat flux calculation is undertaken. These recommendations are detailed in Section 6.2.

Table 11: Radiant heat flux received at elements located east and west of the BESS

Parameter	Radiant Heat Flux received at various distances to the BESS (located to the east and west of the BESS container)					
	1 m from BESS	2 m from BESS	3 m from BESS	4 m from BESS	5 m from BESS	6 m from BESS
Received from BESS container (kW/m^2)	11.0	7.4	5.2	3.9	3.0	2.4
Received from Flame (kW/m^2)	7.4	4.1	2.5	1.7	1.2	0.4
Total Heat Flux (kW/m^2)	**18.4**	**11.5**	**7.7**	**5.6**	**4.2**	**2.8**

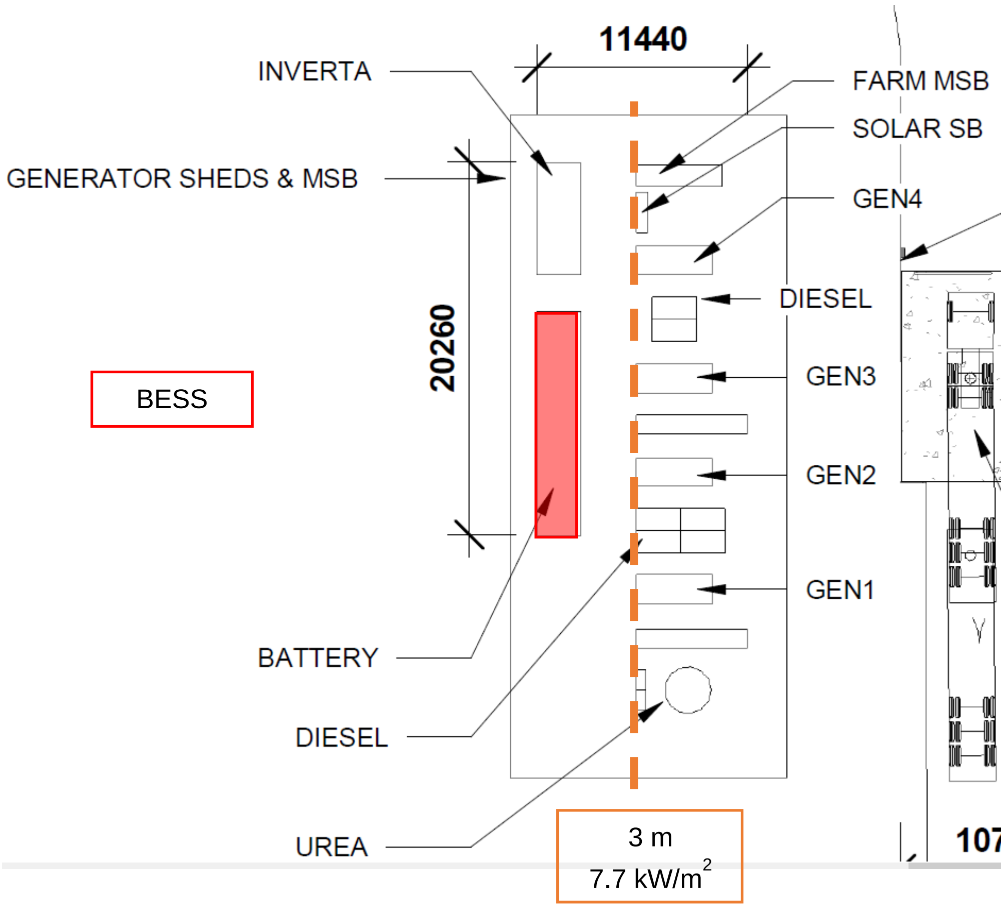

Figure 22: Radiant Heat Flux Received to infrastructure to the east of BESS

Table 12: Radiant heat flux received at elements located north and south of the BESS

Parameter	Radiant Heat Flux received at various distances to the BESS (located to the north and south of the BESS container)					
	1 m from BESS	2 m from BESS	3 m from BESS	4 m from BESS	5 m from BESS	6 m from BESS
Received from BESS container (kW/m^2)	9.3	4.8	2.5	1.5	1	0.7
Received from Flame (kW/m^2)	5.5	2.7	1.5	1.0	0.7	0.4
Total Heat Flux (kW/m^2)	**14.8**	**7.5**	**4.0**	**2.5**	**1.7**	**1.1**

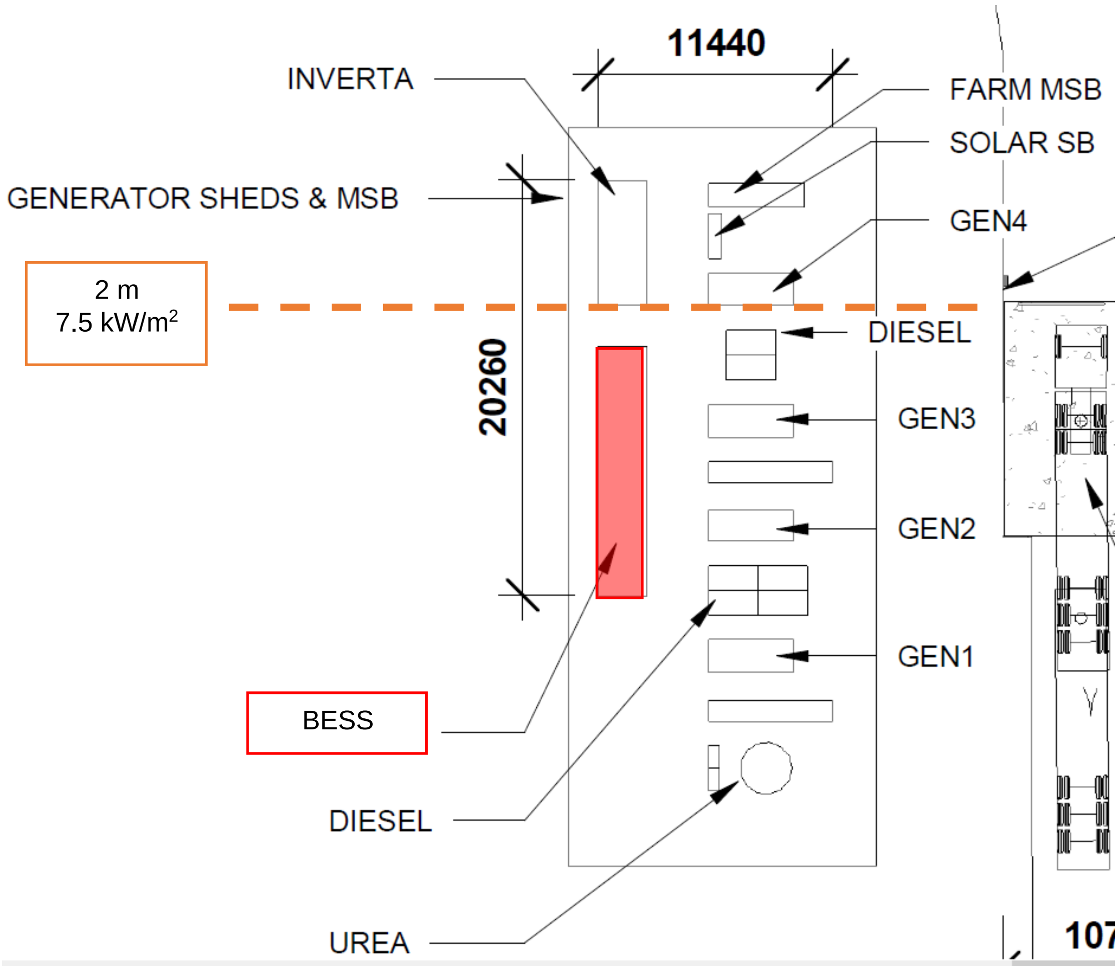

Figure 23: Radiant Heat Flux Received to infrastructure to the east of BESS

5.5.2 Assessment of radiant heat flux

Based on the proposed layout of the site, infrastructure located to the east of the BESS includes;

- Diesel storage
- Generators
- Switch boards
- Urea storage tank

Infrastructure located directly north of the BESS is limited to the 20 ft container comprising of:

- Power Conversion System (PCS)
- Transformer
- Static Transfer System (STS)

Critical parameters in relation to the assessment of these elements are detailed in Table 13.

Table 13: Assessment of Incident Radiant Heat Flux and Recommendations

Infrastructure / Material	Critical parameter for ignition	Consequence based on proposed location of Infrastructure / Material
Diesel storage tank	Auto-ignition temperature of diesel (without flame or spark) is 210°C (Engineering Toolbox, 2003)	Radiant heat flux received at diesel tanks is approximately 7.7 kW/m^2. This can potentially result in auto ignition of diesel fuel.
Generators	Generators are assumed to be of generally non-combustible construction and assumed to be fed directly from the diesel storage tanks	In accordance with Table A3 of AS 1530.4 the radiant heat flux for non-piloted ignition of timber after a long time is 25 kW/m^2 Incident heat flux is not expected to ignite generators.
Switchboard	Switchboard enclosures are assumed to be of generally non-combustible construction	In accordance with Table A3 of AS 1530.4 the radiant heat flux for non-piloted ignition of timber after a long time is 25 kW/m^2 Incident heat flux is not expected to ignite switchboards.

Infrastructure / Material	Critical parameter for ignition	Consequence based on proposed location of Infrastructure / Material
Urea storage tank	Urea is classified a non-flammable chemical. (CAMEO Chemicals, n.d.)	Nil
20 ft container	The container is assumed to be of steel, therefore of non-combustible construction	In accordance with Table A3 of AS 1530.4 the radiant heat flux for non-piloted ignition of timber after a long time is 25 kW/m^2 Incident heat flux is not expected to cause ignition of the steel container. However, the heat transferred to within the container may result in high operating temperatures, potentially exposing equipment within.
Vegetation	Depending on vegetation state and type, ignition due to radiant heat flux can vary. Noting that embers are also a source of ignition for flammable sources such as vegetation.	Vegetation in proximity to BESS may be exposed to levels of radiant heat and/or embers and ignite.

Note that the consequences derived for the proposed BESS system has assumed the following parameters:

- *Deflagration Prevention by Combustible Concentration Reduction* method of NFPA 69 is appropriate for the proposed battery system design.
- Emergency ventilation rate of 410 cfm is provided to the battery stacks and is sufficient to satisfy exhaust rates required under NFPA 69 *Deflagration Prevention by Combustible Concentration Reduction* method to achieve required LFL concentrations.
- The emergency ventilation system is given priority over the gaseous suppression system to re-initiate upon detection of a predefined % of LFL, even following activation of the said suppression system.

It is recommended that the above parameters are verified by the supplier or manufacturer to ensure the findings remain valid.

5.6 Other potential site fires

Whilst an LPG fire is the considered a high risk, lower fire risk hazards that may be present on site. These are summarised in Table 14.

Table 14: Lower risk Fire Hazard Assessment

Event	Cause	Potential Consequences	Prevention/Protection Requirements to Reduce Risks to Acceptable Level
Arcing/ Sparks/ Explosion of High voltage transformers (including power poles)	High voltage transformer breakdown Adverse weather conditions	Arcing/Sparks/Explosion causing fire Network power grid offline Localised fires (could spread to become lager fires) Disruptions to site operations	Annual inspections (and maintenance where required) of transformers Maintenance of ground coverage, trees, shrubs, grass from power sources
Gas heater fire	Gas heater mounted on the walls of the shed malfunctions and initiates a fire	Localised fire involving PIR panels Localised fire could spread to outside area as it develops Loss of production/operation Damage to plant, equipment, buildings etc	Heaters are mounted away from the PIR wall by heater mounts, providing an air gap between the body of the heater and the wall. Penetrations of the PIR panel for the insulated air duct into the sheds are to be capped and protected accordingly.
Failure of High voltage electrical lines	High winds and external debris causing electrical supply lines to break	Electrical supply lines contact with ground (earthing) causing sparks and localised fires Network power grid offline Disruption of operations	Maintenance of ground coverage, trees, shrubs, grass from areas surrounding incoming power lines
Fires in chemical store	Mixing of incompatible materials Electrical ignition sources causing fire	Localised fires inside workshop Localised fires could spread to outside areas Damage to plant, equipment, buildings etc. Loss of production/ operation	Incompatible materials kept separate from each other. No decanting or mixing of chemicals inside the store No ignition sources in store with the exception of lighting. Provision of firefighting equipment and appropriate training for staff.

Event	Cause	Potential Consequences	Prevention/Protection Requirements to Reduce Risks to Acceptable Level
Small fires in workshop	Ignition of combustible/ flammable material arising from hot works (welding, grinding etc.) being undertaken	Localised fires inside workshop Localised fires could spread to outside areas Damage to plant, equipment, buildings etc. Loss of production/operation	Hot works to be undertaken under a permit to work system and properly risk assessed. Good housekeeping removing refuse and/or other combustible material for working areas. Provision of firefighting equipment and appropriate training for staff.
Bushfires/grass fires	Arson Lightning strike/adverse weather conditions Human error	Introduction of ignition sources within the hazard zones. Ignition of flammable and combustible material. Loss of infrastructure and livestock.	Maintain vegetation to a minimum on site. It is noted that tree/shrub plantings are around the perimeter of each PPU, however grass will be maintained and mowed. No combustible material within 3m of the diesel tanks (Section 2.2.5(d) AS1940) No Combustible materials within 6m of the LPG facility (Section 6.2.5(e) AS 1596) Appropriate firefighting equipment is available, operational and staff are trained to use it
Electrical Fire in BESS container (non-battery related) – (if installed)	Short circuit of electrical cabling within BESS container	Resulting in thermal runaway of batteries, leading to potential fire and explosion.	Gaseous suppression system to automatically activate in the event of fire being detected

6. Fire Prevention Strategies / Measures

Prevention of incidents is the primary key in achieving fire safety adequacy. Through appropriate design and layout of the facility, operating procedure and arrangements, fire incidents can be prevented.

This section of the report shall delve into identifying measures which may potentially minimise the likelihood of fires and/or reduce their severity or extent.

6.1 Management of LPG

The following requirements are expected to mitigate the risk of fire and fire spread to LPG storage tanks.

- LPG storage will be separated into four areas, one at each of the PPUs and these areas are a minimum of approximately 870 m apart.
- The location of the above-ground LPG storage tanks will comply with the following requirements for ventilation, access and set up:
  - Above-ground storage tanks will be in the open air, outside buildings;
  - Nearby buildings, fences and the like will be distanced from the tanks so as to permit free access around the tanks and cross-ventilation for the tanks;
  - The minimum distance to an adjacent LPG tank is equal to the diameter of the largest tank;
  - Groups of LPG tanks at one PPU will be separated by a minimum of 15 m, unless no tanks in either group exceeds 2m diameter, in which case the distance may be reduced to 10 m.
- LPG storage at each PPU will be within the storage and handling requirements of A*S 1596:2014 The Storage and Handling of LPG* for both public places and private places. The location of storage tanks will readily exceed the 10.15 m minimum distance to a public place and 17.45 m to a protected place (poultry shed in this case).
- LPG storage facilities will be designed by Elgas, a long-standing and reputable LPG supplier, and will confirm with AS 1596:2014.
- LPG will be delivered to the development site in specific purpose rigid tankers (ranging in size between 4 tonnes and 12 tonnes) at a frequency of just over 1 delivery each week on average.
- At least one hose reel complying with AS/NZS 1221 and installed in accordance with AS 2441 shall be provided.
- The water supply to the hose reel may be provided by any available on-site reticulated water supply system or from any form of storage system provided that the hose reel is able to deliver at least 0.33 L/s. Where the supply is from a storage system, the duration shall be at least 15 minutes.
- The number and location of hose reels shall be such as to ensure that a hose nozzle will reach every point in an area bounded by a line around and 5 m distance from any tank and tanker standing area.
- Maintenance shall be in accordance with AS 1851:2012.

The design controls to be implemented in accordance with AS.NZS 1596:2014 in conjunction with significant separation distances as determined from the fire scenario assessment (26.5 m between LPG tank and poultry sheds) and is not expected to result in a hazardous development on site and does not pose a significant off site risk.

6.2 Management of Solar Panels

Drawing from recent events in Australia, it has been reported that the primary cause of PV related fires can be due to the following:

- Defective parts leading to arc faults i.e. DC isolators, sensors, junction boxes
- Poor installation leading to arc faults i.e. loose joints,

It is noted that events such as lightning strike may also cause a fire, however this is considered unlikely and is not detailed further.

Aside from utilising quality products and reliable installers for the proposed PV panels, **it is recommended to minimise any use of combustible materials on the roof where the panels are installed to mitigate a large fire risk should a fire event occur.**

6.3 Management of BESS Container (If Installed)

Section 5.5 detailed the consequence of incidents pertaining to the BESS and surrounding infrastructure. Several recommendations were discussed in this section to minimise the likelihood of a thermal runaway and potentially reduce the resultant severity following such case.

These recommendations are summarised as follows:

- Provision of bollards around the perimeter of the BESS for impact protection,
- In accordance with NFPA 855, Section 4.12.1, it is recommended that the BESS system to be provided with one of the following;
  (1) Explosion prevention systems designed, installed, operated, maintained and tested in accordance with NFPA 69; or
  (2) Deflagration venting installed and maintained in accordance with NFPA 68
- Where the *Deflagration Prevention by Combustible Concentration Reduction of NFPA 69 is appropriate,* it recommended that upon detection of 10% LFL within the container that the gas detectors activate and automatically trigger the interlocked emergency ventilation system to ventilate the container.

Further to the above, the consequence assessment identified potential fire spread scenarios based on the proposed infrastructure layout around the BESS. These scenarios are replicated in Table 13 below and include appropriate recommendations to mitigate against these risks.

Table 15: Assessment of Incident Radiant Heat Flux and Recommendations

Infrastructure / Material	Critical parameter for ignition	Consequence based on proposed location of Infrastructure / Material	Recommendation
Diesel storage tank	Auto-ignition temperature of diesel	Radiant heat flux received at diesel tanks is	Diesel tanks, if located directly to the east of the BESS shall be separated at least 6 m away

Infrastructure / Material	Critical parameter for ignition	Consequence based on proposed location of Infrastructure / Material	Recommendation
	(without flame or spark) is 210°C (Engineering Toolbox, 2003)	approximately 7.7 kW/m^2. This can potentially result in auto ignition of diesel fuel.	Alternatively, Diesel storage tanks may be located at the distance of 3 m away from the BESS to the east or west, providing it is located further northwards or southwards and maintain a clear distance of at minimum 3 m measured vertically from the from the north or southern face of the BESS. Refer Figure 24 for illustration. Incident heat flux in this zone is approximately 2.5 kW/m^2 and is not expected to reach diesel auto ignition temperatures.
Generators	Generators are assumed to be of non-combustible construction and assumed to be fed directly from the diesel storage tanks	In accordance with Table A3 of AS 1530.4 the radiant heat flux for non-piloted ignition of timber after a long time is 25 kW/m^2 Incident heat flux is not expected to ignite generators.	Nil, proposed location is not expected to increase risk of fire spread. Generators located 3 m from BESS container are not expected to ignite from radiant heat
Switchboard	Switchboards are assumed to be of non-combustible construction	In accordance with Table A3 of AS 1530.4 the radiant heat flux for non-piloted ignition of timber after a long time is 25 kW/m^2 Incident heat flux is not expected to ignite switchboards.	Nil, proposed location is not expected to increase risk of fire spread. Switchboards located 3 m from BESS container are not expected to ignite from radiant heat
Urea storage tank	Urea is classified a non-flammable chemical. (CAMEO Chemicals, n.d.)	Nil	Nil, proposed location is not expected to increase risk of fire spread. Urea tanks located 3 m from BESS container are not expected to ignite from radiant heat

Infrastructure / Material	Critical parameter for ignition	Consequence based on proposed location of Infrastructure / Material	Recommendation
20 ft container	The container are assumed to be of steel, therefore of non-combustible construction	In accordance with Table A3 of AS 1530.4 the radiant heat flux for non-piloted ignition of timber after a long time is 25 kW/m^2 Incident heat flux is not expected to cause ignition of the steel container. However, the heat transferred to within the container may result in high operating temperatures, potentially exposing equipment within.	While ignition of the 20 ft container is unlikely, the heat transferred to within the container may cause an increase in operating temperature. It is recommended that the container be at least 5 m away from BESS. Refer Figure 24 for illustration.
Vegetation	Depending on vegetation state and type, ignition due to radiant heat flux can vary. Noting that embers are also a source of ignition for flammable sources such as vegetation.	Vegetation in proximity to BESS may be exposed to levels of radiant heat and/or embers and ignite.	It is recommended that vegetation is cleared within 10 m of the BESS, serving as fire break. Refer Figure 25.

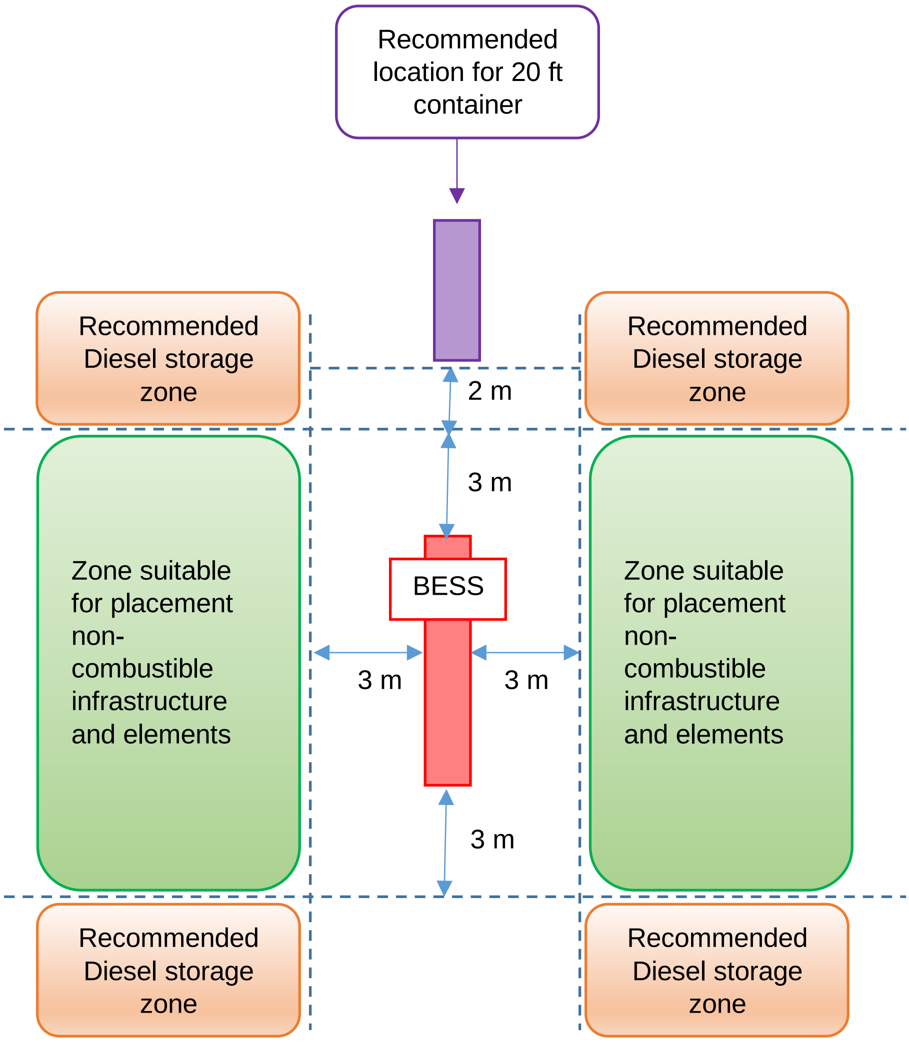

Figure 24: Recommended Zones for Infrastructure

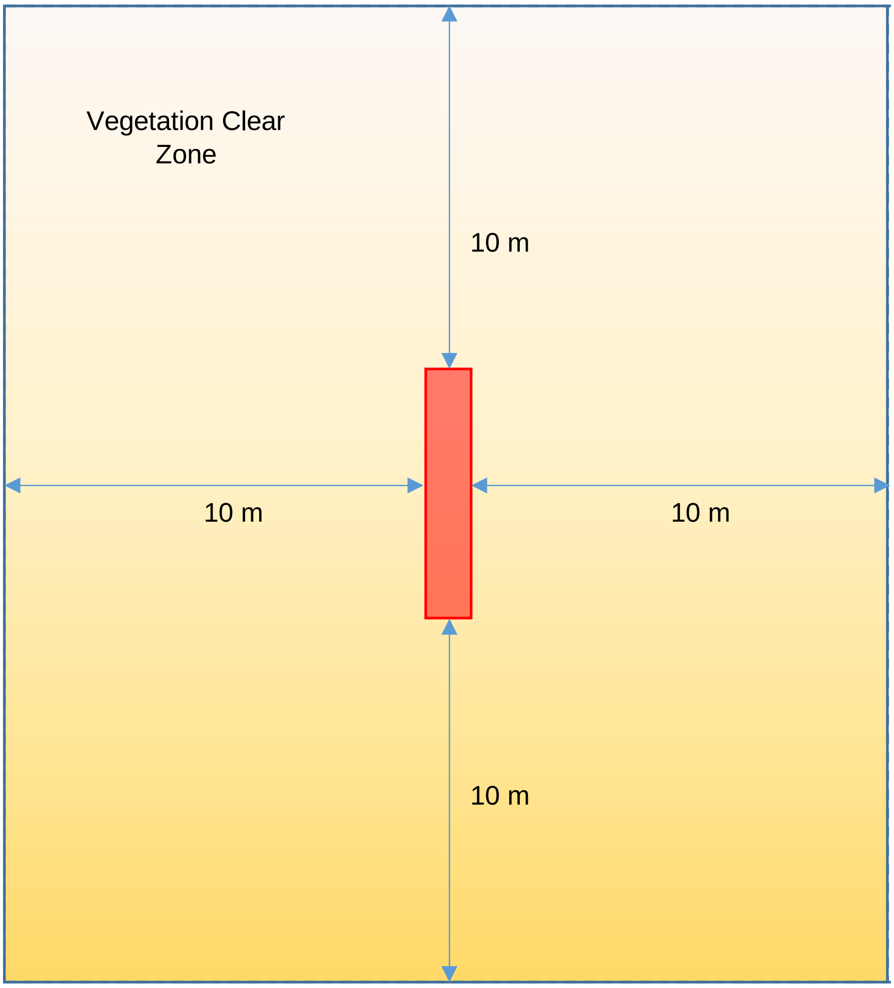

Figure 25: Vegetation clear zone

Other preventative measures for the operation of the BESS include:

- Provision of a non-permeable bund to the BESS for the purpose of contaminated water containment. Design parameters are detailed in Section 9.

6.4 Fire Management

In addition to the LPG management requirements detailed above, the following fire prevention strategies will be implemented as to further minimise the likelihood of a fire event and/or reduce a fires severity:

- The buildings will be designed in accordance with the requirements of the Building Code of Australia.
- Electrical installations will be installed and maintained compliant with relevant Australian Standards, including AS 3000:2007 - Electrical Wiring Rules.
- Fire extinguishers will be installed at designated locations compliant with relevant Australian Standards (refer Section 8).
- Fire hydrants will be provided to the poultry sheds in accordance with AS 2419.1, modified where acceptable under the Building Code of Australia for Farm Building Use/Performance Solution.

- Appropriate warning/identification signs will be installed for fuels and fire protection equipment.
- Certified diesel and LPG tanks will be installed.
- Diesel fuel tank bund design will include minimum capacities for the applicable storage size of the fuel tank(s).
- Dissimilar fuels shall be separated in accordance with AS 1940:2017
- Annual maintenance and testing will be undertaken.
- General housekeeping procedures will be regularly undertaken to ensure any trees/shrubs in the vicinity of electrical installations are adequately pruned or removed to maintained clearance and the areas around electrical installations are kept clear of any combustible materials.
- Site-specific training for employees and contractors in the use of fire extinguishing/protection equipment.

6.4.1 Emergency Plan

An Emergency Plan shall be prepared for the development in accordance with the requirements of the Hazardous Industry Planning Advisory Paper No. 1 – Emergency Planning Guideline (NSW, 2011) to a level of detail commensurate with the nature of the development, prior to occupation of the building.

7. Requirements for Detection and Protection

This section of the study shall consider the requirement for fire detection and protection at the proposed development, taking into consideration the identified risks detailed in Section 4, Consequences in Section 5, the fire prevention strategies/measures in Section 6 and BCA Requirements.

7.1 Background and BCA Requirements (Poultry Sheds)

The poultry sheds are considered as “farm buildings” under the BCA. The building is subject to a performance solution permitting the building to be a standard Class 8 farm building in lieu of a large isolated building. In relation to the provision of fire fighting equipment, BCA Clause E1.0 stipulates that;

(a) Where a Deemed to Satisfy Solution is proposed, Performance Requirements EP1.1 to EP 1.6 are satisfied by complying with –

(i) E1.1 to E1.10; and

(ii) …

(iii) …

(iv) …

(v) …

(vi) For farm buildings and farm sheds, Part H3.

As the subject buildings are considered as farm buildings, Part H3 supersede the requirements of E1.0 (Refer BCA Clause H3.8).

Under Part H3, the following clauses are required to achieved in relation to fire fighting equipment on farm buildings.

7.1.1 BCA Clause H3.9 – Fire hydrants and water supplies

In relation to fire hydrants and water supplies, BCA Clause H3.9 states the following;

Note: The bold text is understood to be relevant to the subject design;

(a) A farm building –

(i) with a total floor area greater than 500 m^2; and

(ii) located where a fire brigade station is –

(A) no more than 50 km from the building as measured along roads; and

(B) equipped with equipment capable of utilising a fire hydrant.

must be –

(iii) provided with a fire hydrant system installed in accordance with AS 2419.1, except reference to ‘4 hours’ water supply in clause 4.2 is replaced with ‘2 hours’, or

(iv) located on the same allotment as an access point to a water supply which –

(A) has a minimum total capacity of 144,000 litres; and

(B) is situated so as to enable emergency services vehicles access to within 4 m; and

(C) is located within 60 m of the building and not more than 90 m from any part of the building.

(b) For the purpose of (a)(iv), water supply for a farm building must consist of one or any number of the following;

(i) A water storage tank

(ii) A dam

(iii) A reservoir

(iv) A river

(v) A lake

(vi) A bore

(vii) A sea

(c) If the whole or part of the water supply referred to in (a)(iv) is contained in a water storage tank, it must be –

(i) Located no less than 10 m from the building; and

(ii) Fitted with at least one small bore suction connection and one large bore suction connection where-

(A) Each suction connection is located in a position so as to enable emergency service vehicles access to within 4 m; and

(B) The suction connections are located not less than 10 m from the building and

(C) 'small bore suction connection' and ' large core suction connection' have the meanings contained in AS 2419.1

As each poultry shed occupies a total floor area of approximately 2,880 m^2, and is located less than 50 km from the nearest manned fire station (Manilla Fire Station), the requirements of H3.9 are to apply at the development.

It is understood that the building is subject to a performance solution to treat the poultry sheds as a BCA Class 8 farm buildings in lieu of a large-isolated building. As a result, it has been advised that the facilities will be provided with a hydrant system to H3.9 or AS 2419.1.

If a H3.9 compliant system is deemed not appropriate to the sites, it is understood that approval will be sought for an AS 2419.1 performance solution. The AS 2419.1 performance solution would address a modified ring main hydrant system providing 90 m hose coverage (in lieu of 60m), two hours of stored water (in lieu of 4 hours) and utilise the farms water distribution pump pack to charge the ring main (replacing the requirement for two stand by pumps).

7.1.2 BCA Clause H3.10 – Fire hose reels

BCA Clause H3.10 states that;

A fire hose reel system need not be provided to serve a farm building where portable fire extinguishers are installed in accordance with H3.11.

The development will not be provided with fire hose reels.

7.1.3 BCA Clause H3.11 – Portable fire extinguishers

The requirement for portable fire extinguishers are stipulated in BCA Clause H3.11 as follows:

- *A farm building not provided with a fire hose reel system in accordance with E1.4 must be provided with –*
  - *(i) One portable fire extinguisher rated at not less than 5 ABE in each room containing flammable materials or electrical equipment: and*
  - *(ii) One portable fire extinguisher rated not less than 4A60BE adjacent to every required exit door; and*
  - *(iii) Location signs complying with clause 3.3 to 3.9 of AS 2444 above each required portable fire extinguisher.*
- *A farm shed must be provided with not less than one portable fire extinguisher for ever 500 m^2 of floor area or part thereof, distributed as evenly as practicable throughout the building.*
- *A portable fire extinguisher required by (b) must be –*
  - *(i) Of ABE type; and*
  - *(ii) Not less than 4.5 kg in size; and*
  - *(iii) Installed in accordance with Section 3 of AS 2444.*

The poultry sheds will be provided with fire extinguishers in accordance with BCA Clause H3.11.

7.2 Protection and firefighting at poultry sheds

As noted above, the poultry sheds shall be protected in accordance with BCA DtS Provisions, namely;

- Provided fire fighters with a fire hydrant system in accordance with H3.9 or AS 2419.1, modified where acceptable under the Building Code of Australia for Farm Building Use/Performance Solution;
- Provided with fire extinguishers throughout the development in accordance with BCA Clause H3.11.

Note that provision of the above fire safety systems to the poultry shed inherently protects the neighbouring LPG Tanks as further discussed in Section 7.4.

7.3 Fire Detection Systems

Due to the nature of the developments operation, there is minimal staff located on site and therefore no formalised alarm system has been adopted. Should a fire be detected, other staff members are notified via a round robin phone call system and fire brigade is understood to be engaged by dialling 000.

There are no fire detection and/or alarm systems installed throughout the development, barring the BESS containers as detailed in the section to follow.

As indicated in the SLR PHA study (SLR, 2018), the development is expected to meet all the requirements stipulated by the DPIE and hence would not be considered, with suitable engineering and design controls in place, to be an offensive or hazardous development on site or would not be impacted by any hazardous incidents from adjoining facilities on site.

7.4 Protection and firefighting LPG

7.4.1 Section 13 AS/NZS 1596:2014

Section 13 of AS/NZS 1596:2014 explains that the fighting of fire associated with LPG installations depend upon the nature of the surroundings and any associated structures, hazards and activities that may threaten the LPG facility, rather than solely on the quantity of LPG being stored.

The standard further notes that the requirements of firefighting is based on surroundings and less on the need of the LPG installation as a gas fire is most often terminated by stopping the gas flow, and almost never by extinguishing a fire. The actual LPG installation may not require a great deal of firefighting equipment if the engineering fire safety requirements of AS/NZS 1596:2014 are in place.

Where an above ground storage tank is located in a Class B site (as in the subject case) in relation to a protected place or public place (refer Section 13.5.1 of AS/NZS 2596-2014), the firefighting requirements for the whole of the site shall be determined from an evaluation of the needs and the available facilities of the particular site.

The following are principles detailed in Clause 13.5 of AS/NZS 1596:2014 which are relevant to the LPG tanks;

- *When an on-site hydrant system is specified, hydrants shall be provided in accordance with Clause 13.7.1 for the tank.*
- *For all other tank installations, at least a hose reel installation in accordance with Clause 13.7.2 shall be available for the tank.*
- *Where the capacity of an individual tank or group of tanks exceeds 50 kL, the installation shall be assessed for heat protection in accordance with Appendix M and treated in accordance with Clause 13.5.2*

The total capacity of LPG storage at Farms 2 and 4 exceeds the 50,000 L limit (57,375 L and 51,000 L respectively). A heat protection assessment has been carried out in accordance with Appendix M of AS/NZS 1596:2014 as well as calculations for a fire event at the nearby poultry shed as detailed is in Section 5.3.

According to the assessment in accordance with Appendix M, 20.24 m is required between the tanks and a protected place (poultry shed). The proposed distance between the LPG tanks and poultry shed is a minimum of 26.5 m, therefore no additional heat protection is required to the LPG. This separation distance is further supported through the assessment of extreme fire conditions in Section 5.3.1. The incident radiant heat flux calculated in the scenario was less than the 10 kW/m^2 stipulated in AS/NZS 1596:2014.

Any associated buildings and the like will need to have fire fighting equipment to comply with building regulations and should be counted as an important part of the overall protection of the site, including the LPG installation.

Therefore the firefighting requirements for the whole site shall be determined from an evaluation of the needs and the available facilities of the particular site, conducted on the basis of the following principles:

- Fire hydrant system provided is commensurate with BCA Clause H 3.9 and relevant Australian Standards, modified where acceptable under the Building Code of Australia for Farm Building Use/Performance Solution.
- Hose reels shall comply with AS 1221 and installed in accordance with AS 2441.

- Fire extinguishers provided in accordance with BCA Clause H3.10 and relevant Australian Standards.

7.4.2 Fire Extinguishers

In accordance with AS/NZS 1596:2014, Section 13.7.5, where fire extinguishers used around LPG, it shall have a minimum rating of 2A 60B(E) and comply with AS/NZS 1841.1, 1841.5 and 1850.

7.5 Detection, Protection and firefighting for BESS (If Installed)

7.5.1 Detection

As detailed in Section 2.1 of the technical specifications in Appendix C, **the BESS container is to be provided with heat, smoke, H_2, CO and VOC combustible gas detectors**. **Signals from each of the detectors are noted to be linked to the Emergency Management System (EMS) and notify the nearby fire station.**

However, due to the site being in a rural area, signals from the EMS is instead reported back to the office/alarm system onsite, in which Proten is to develop procedures for response to a detection scenario in the BESS, including call out to the fire brigade.

The specifications indicate the following sequence for operation of fire extinguishing agent (HFM-227EA gas, also known as FM-200 clean agent):

- For single detector activation, sound and light alarm signal is issued without fire extinguishing instruction.
- With multiple detectors activated, sound and light alarm signal is issued, and fire extinguishing instructions issued after a delay of 30 seconds. The solenoid valve will initiate the suppression system.

7.5.2 Protection

7.5.2.1 Automatic suppression and emergency ventilation

Studies undertaken by (DNV GL, 2017) acknowledge that fixed suppression gas agents may be deployed as a first line of defence to reduce or mitigate flammability in a BESS environment until ventilation and/or cooling is implemented. While gas suppression may extinguish a fire, it is unable to stop cell exothermic reactions, therefore, off-gas may still build up following extinguishment of a fire.

The research by (DNV GL, 2017) recommend that if temperatures continue to rise or an in increasing level of smoke and gas is detected following deployment of gaseous suppression, that forced ventilation and water extinguishing be considered.

Where the *Deflagration Prevention by Combustible Concentration Reduction of NFPA 69 is appropriate,* it recommended that upon detection of 10% LFL within the container, that the gas detectors activate and automatically trigger the interlocked emergency ventilation system to ventilate the container.

It is recommended that following deployment of an extinguishing agent, should gas build-up still occur and a 10% LFL is reached, then the emergency ventilation system to be reinstated. Details and recommendations for the LFL threshold for initial activation of the emergency ventilation system is discussed in Section 5.5.1.1.

7.5.2.2 Firefighting

The poultry farms are provided with a pseudo-ring main which utilises the water distribution pump back to charge the pipes with water supplied water storage tanks. Storage tank capacities for each farm is 1,500 kL. Specific details on water storage tanks are provided in Section 9.2.

In the absence of guidance around renewable energy facilities in NSW around firefighting requirements, design guidance is sought from the *Renewable Energy Facilities* guideline published by the (Country Fire Authority, 2022) of Victoria.

The following recommendations are presented:

- Fire hydrants shall be installed in accordance with AS 2419.1-2005, Section 3.3 Open Yard Protection, and Table 3.3: Number of Fire Hydrants Required to Flow Simultaneously for Protected Open Yards. Except, that fire hydrants must be provided and located so that every part of the BESS is within reach of a 10 m hose stream issuing from a nozzle at the end of a 60 length of hose connected to a fire hydrant outlet.

7.6 Detection, Protection and firefighting for Solar Panels

Being installed on the roof of poultry sheds, detection is not afforded for the PV panels. For similar reasons, no means of automatic protection is provided nor expected based on (Country Fire Authority, 2022) renewable energy facility guidelines.

The only means of water application to the panels is through fire brigade intervention, utilising the available water on site to extinguish a solar array fire. The guidelines require at least one (1) x 45,000 L static water tank for every 100 ha occupied by solar arrays.

8. Detailed Drawings of Fire Services Layout

The fire services layout is presented in Figure 26 through to Figure 29. The figures illustrate the location of fire hydrants and fire extinguishers at each farm.

While the fire hydrant layout has not yet been provided for the BESS (If Installed), potential locations are indicated in Figure 30.

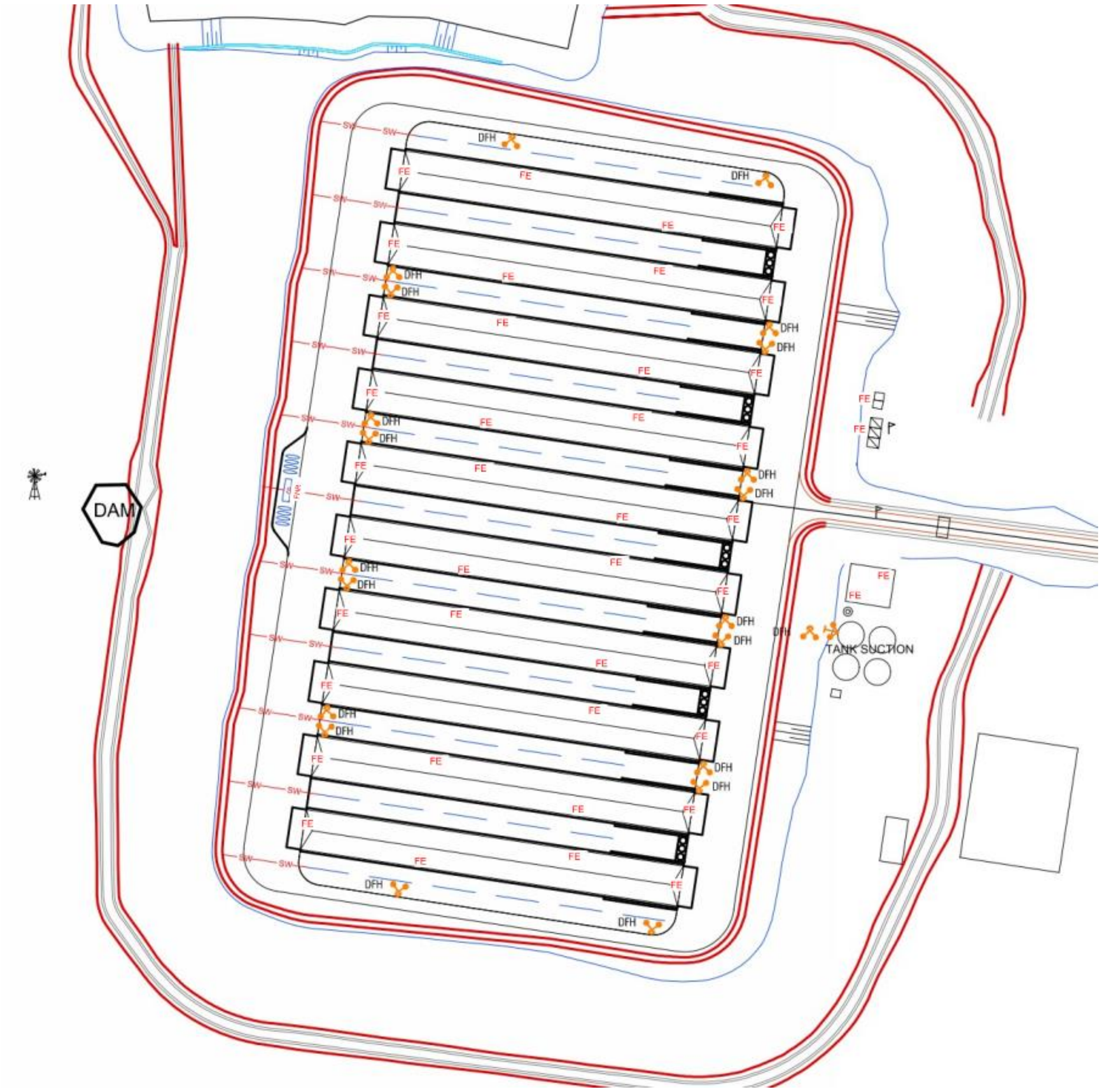

Figure 26: Farm 1 – Fire hydrant and fire extinguisher layout

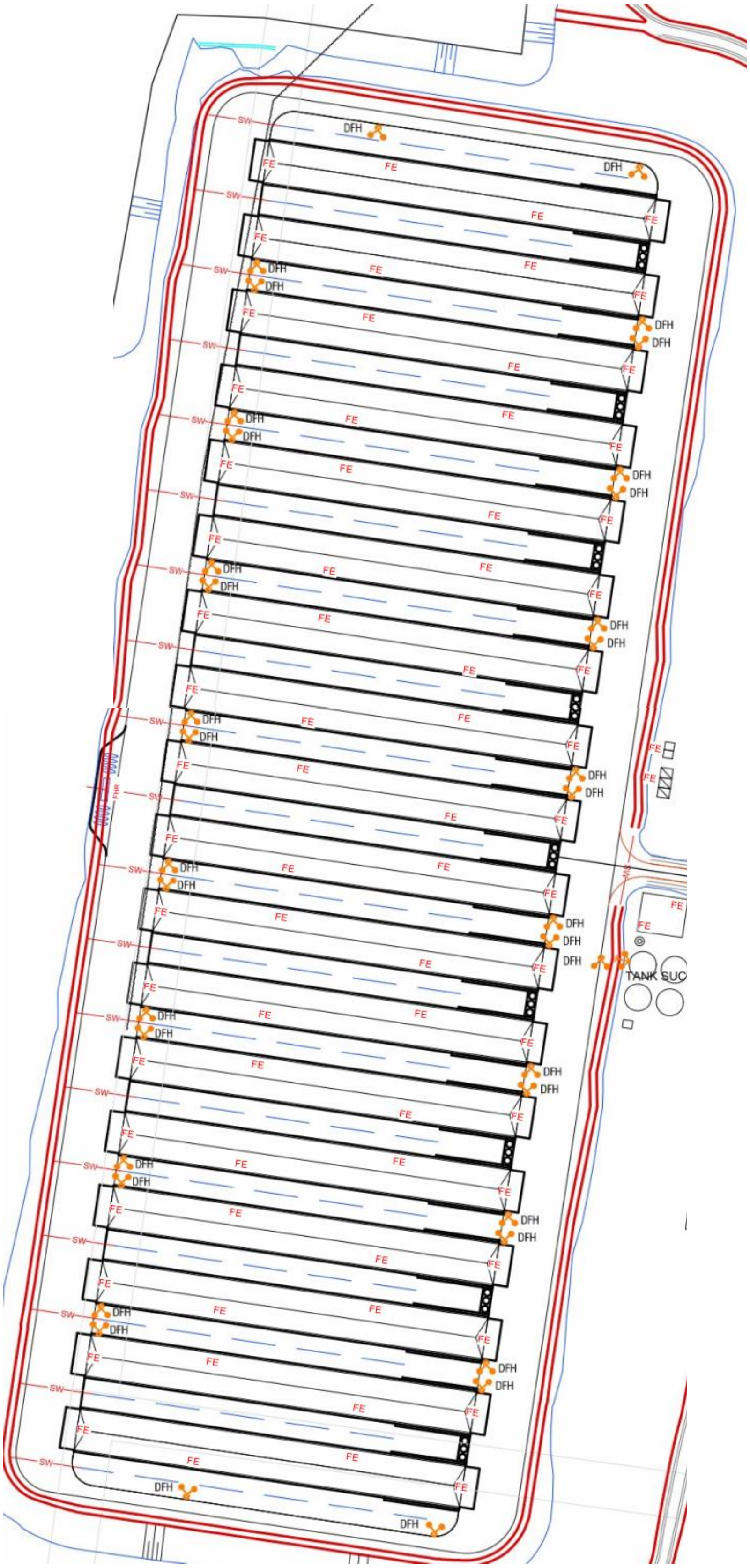

Figure 27: Farm 2 - Fire hydrant and fire extinguisher layout

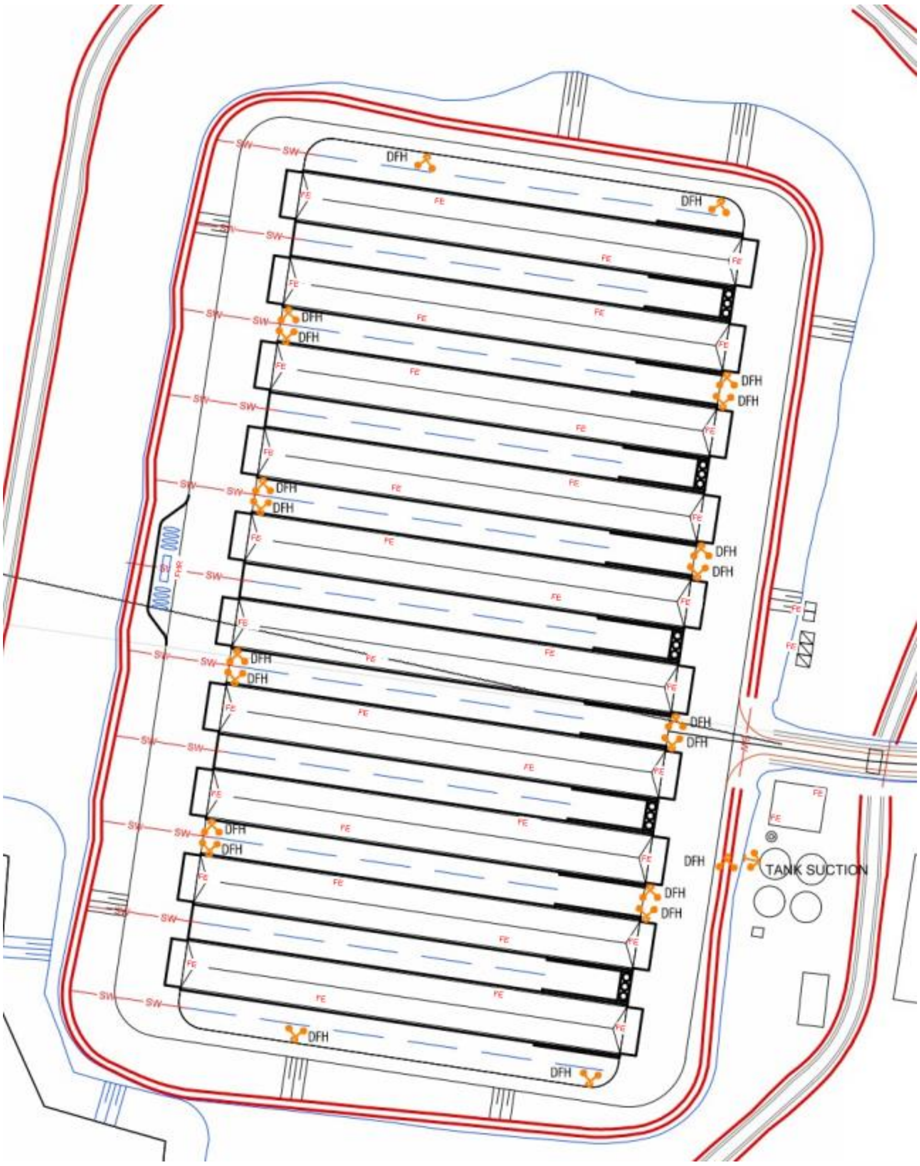

Figure 28: Farm 3 - Fire hydrant and fire extinguisher layout

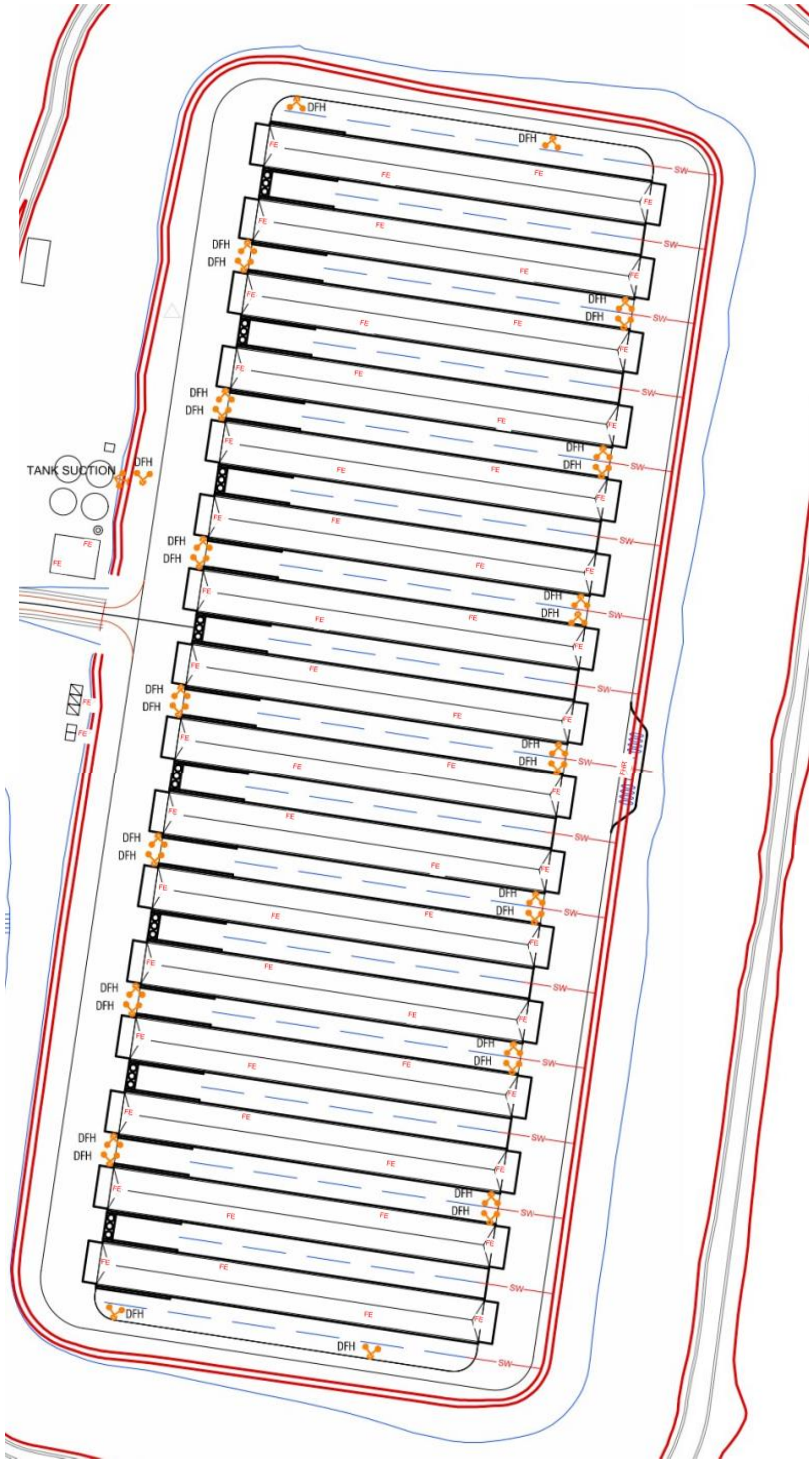

Figure 29: Farm 4 - Fire hydrant and fire extinguisher layout

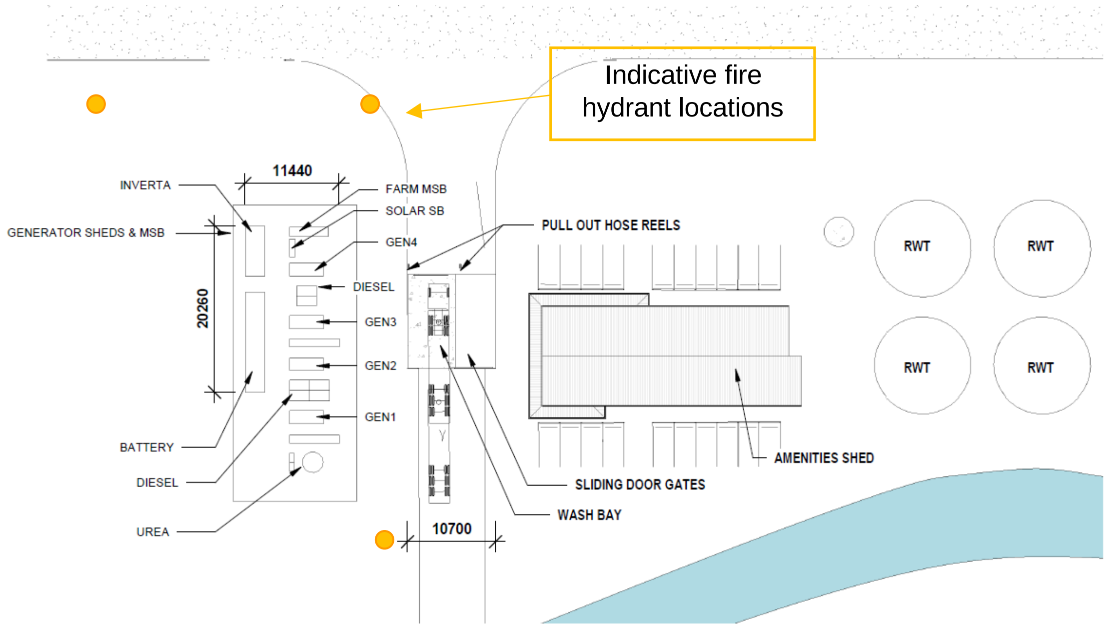

Figure 30: Indicative location for fire hydrants serving the BESS (If Installed)

9. Fire Fighting Water Demand and Supply

As detailed in Section 7, firefighting at the development will be through a H3.9 or AS 2419.1 system, modified where acceptable under the Building Code of Australia for Farm Building Use/Performance Solution. It is noted that the fire hydrants are served by a pseudo-ring main which utilises the farms water distribution pump pack to charge the pipes, replacing the requirement for two stand-by pumps.

With the exception of fire extinguishers, there are no use of form or other chemical suppressants for fighting.

9.1 Location and Coverage

The system provides 90 m hose coverage from each hydrant (in lieu of 60 m, subject to a separate performance solution). Refer to Figure 31 through to Figure 34 for hydrant locations throughout the four PPUs.

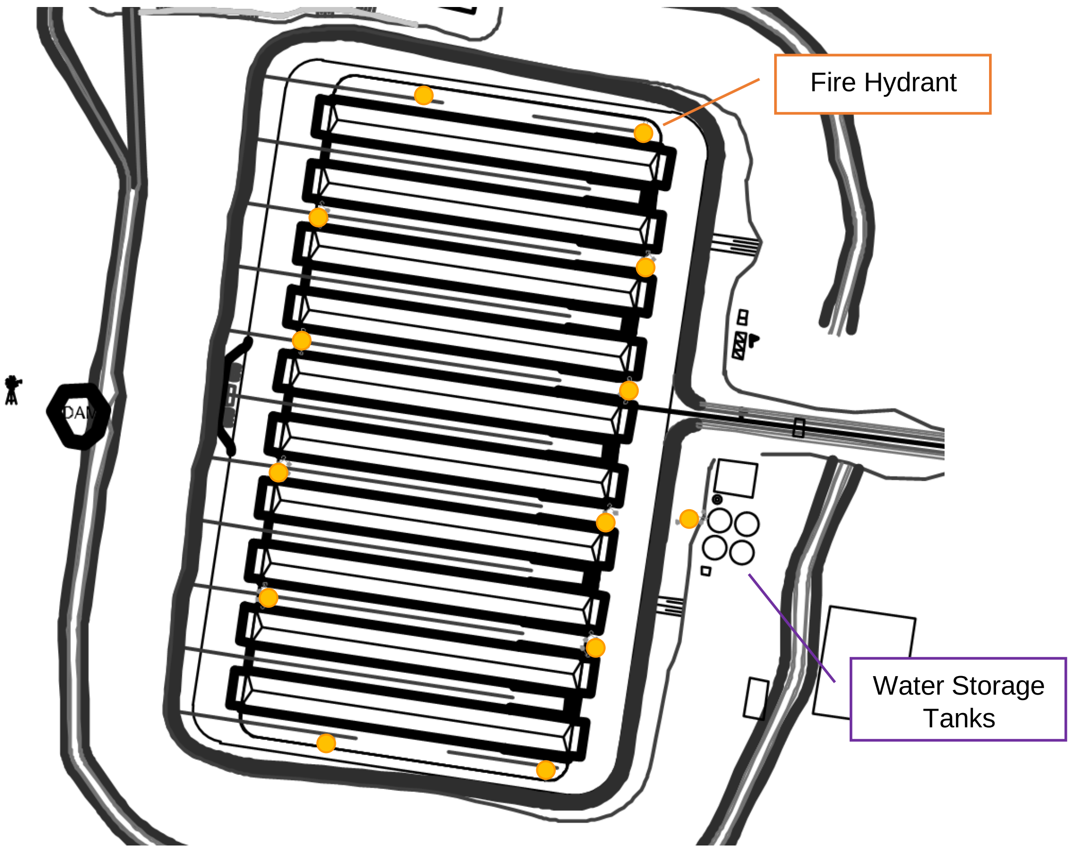

Figure 31: Hydrant Locations - Farm 1

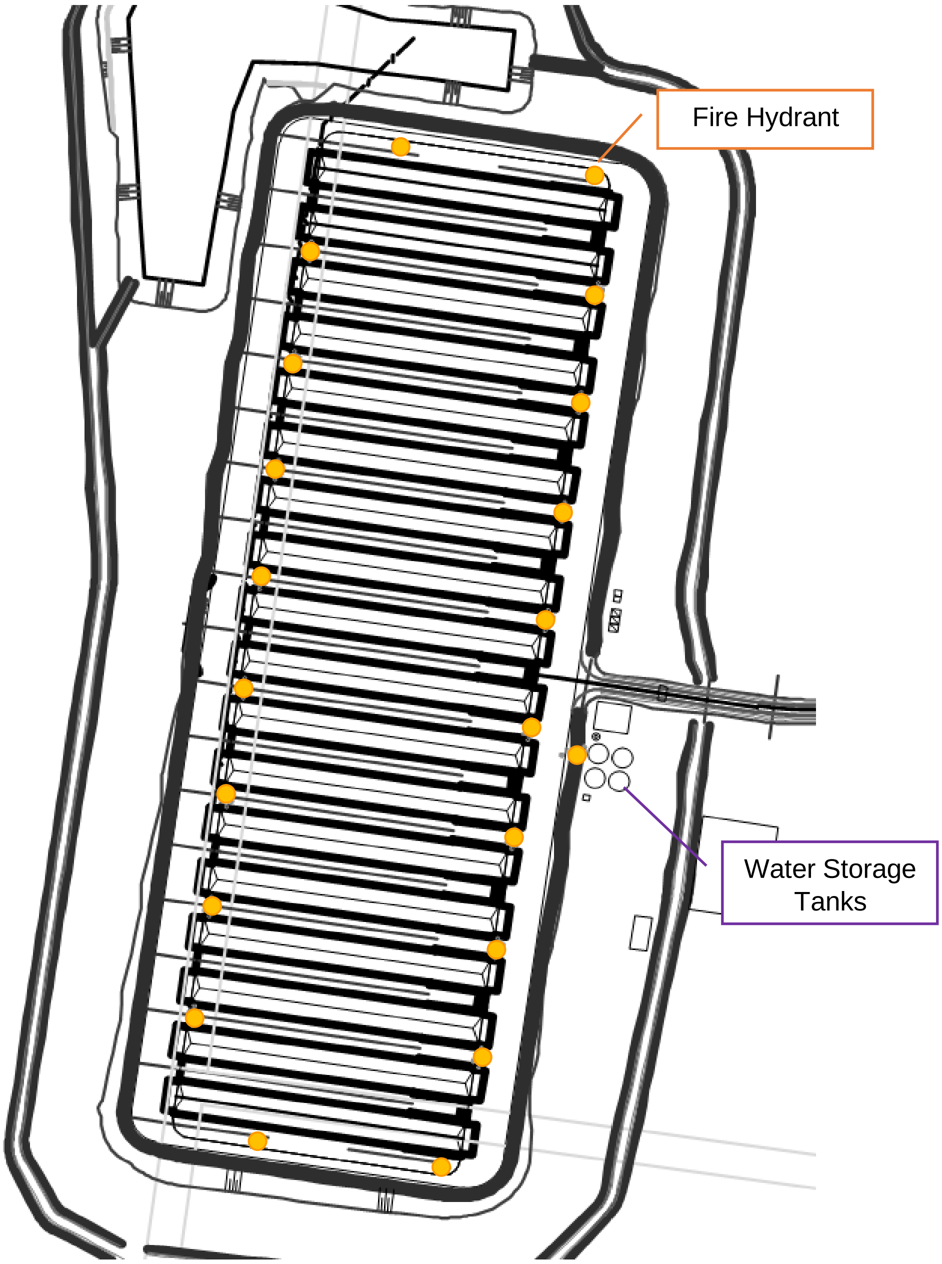

Figure 32: Hydrant Locations - Farm 2

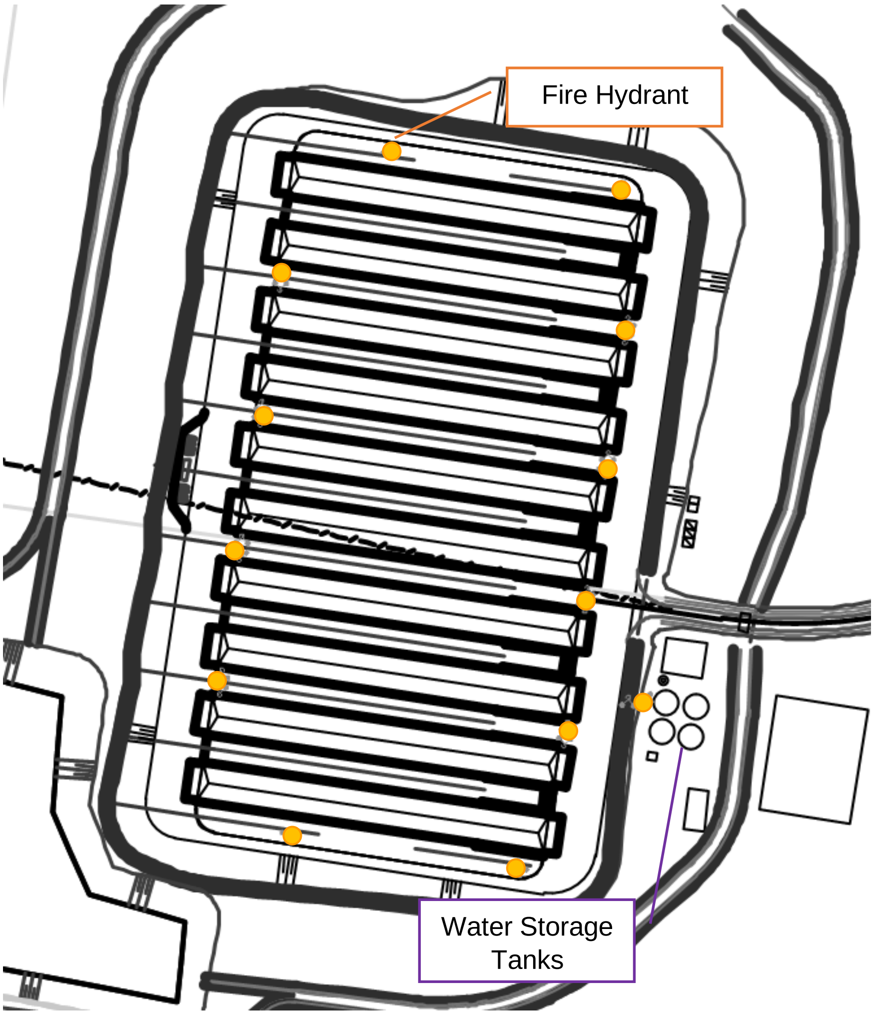

Figure 33: Hydrant Locations - Farm 3

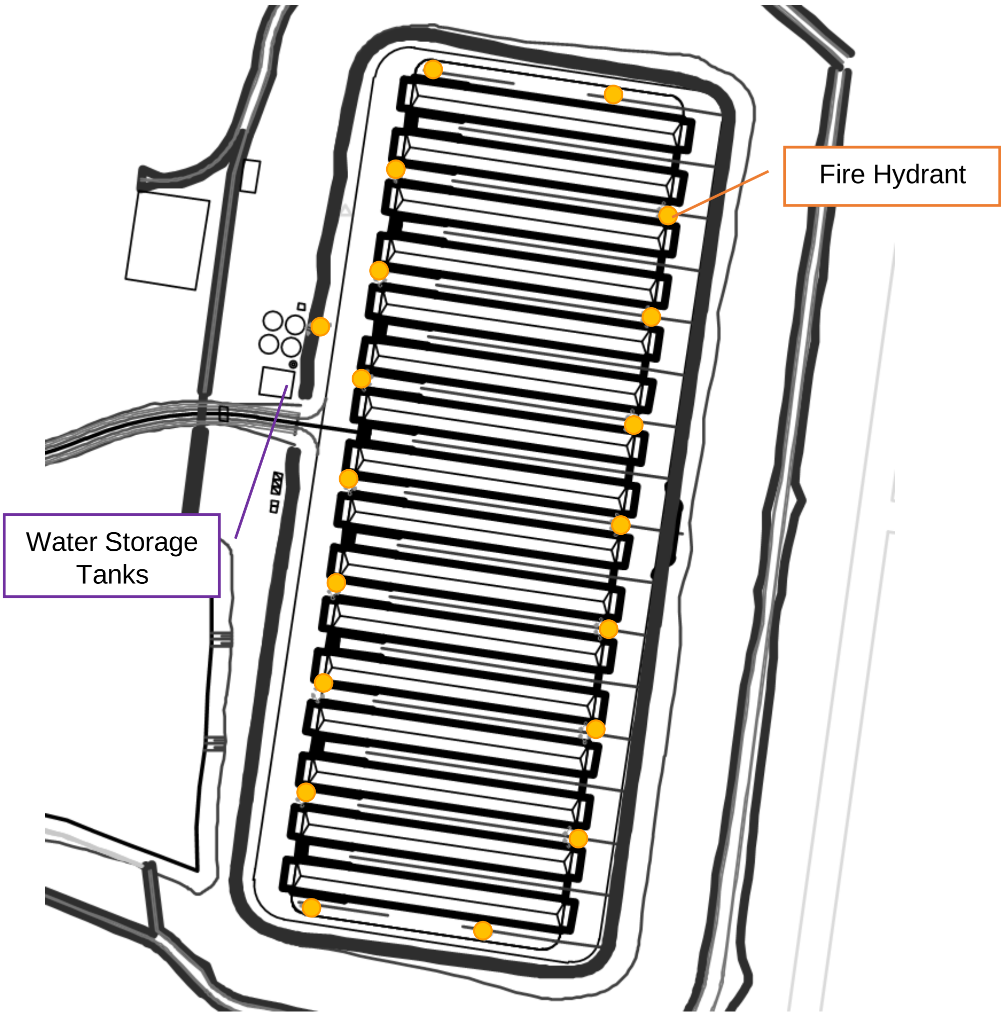

Figure 34: Hydrant Locations - Farm 4

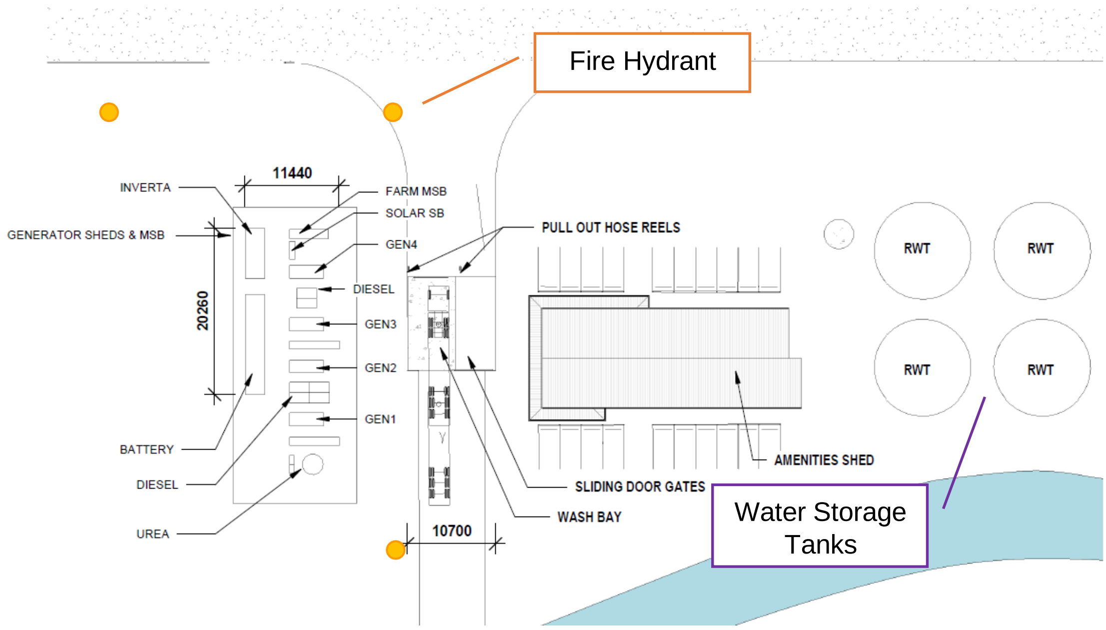

Figure 35: Indicative location for fire hydrants serving the BESS (If Installed)

9.2 Firefighting water supply

Each PPU will be provided with four zincalume water storage tanks, each tank with a storage capacity of 375 kL. The combined storage capacity at each PPU of 1,500 kL is noted to be sufficient to service the PPU shed ventilation systems and bird consumption for two days.

The tanks are automatically filled from pressurised lines to remain near capacity at all times and low level alarms will be fitted to tanks at approximately two thirds full capacity to alarm should water levels drop below this point.

The amount of water stored at each farm is therefore above the demand requirements of the hydrant system required to serve the poultry shed (and associated solar panels) as well as the BESS (If Installed), and being automatically filled ensures that they are suitably available for fire brigade use in the event of a fire. It is unlikely that a BESS and poultry farm fire and/or solar panel fire to occur simultaneously, however in the unlikely event that this does occur, there is still sufficient water supply provided.

As each farm is provided with its own water tanks, the water supply at farm for the purpose of fire hydrant operation is independent of each other and therefore in the highly unlikely event of two fires occurring on separate farms, the demand for water at each farm is not impacted.

The location of the water tanks are approximately 200 m from the LPG Tanks and 75 m from the BESS (If Installed) such that a fire event occurring at either location is not expected to compromise the water supply.

9.3 Water demand calculations

9.3.1 Poultry shed

In accordance with AS 2419.1-2005 Table 2.1, the number of hydrants required to flow simultaneously for a BCA Class 8 building that has a floor area between 500 m^2 and 5000 m^2 is two (2). The minimum flow rate for each hydrant is 10 L/s, therefore a demand for 20 L/s over two (2) hours, results in a requirement of 144,000 L of water to be stored.

The available water supply of 1,500 kL satisfies the demand for the poultry sheds, and is capable of providing extended water supply should it be required.

The pressure provided to the hydrants shall be in accordance with the requirements of AS 2419.1.

9.3.2 Solar Panels

In the absence of local guidelines around renewable energy installations, recommendations from the Victorian Country Fire Authority (CFA) Renewable Energy Facility Guidelines (Country Fire Authority, 2022) are considered for the solar installation

The guidelines require solar energy facilities to:

"incorporate at least one (1) x 45,000 L static water tank for every 100 ha"

As the solar arrays occupy an area less than 100 ha, at least 45,000 L of static water is required.

The available water supply of 1,500 kL satisfies the demand for the solar panels, and is capable of providing extended water supply should it be required.

9.3.3 BESS (If Installed)

Similar to that of solar installations, the BESS installation draw recommendations from the Victorian Country Fire Authority (CFA) Renewable Energy Facility Guidelines (Country Fire Authority, 2022).

The guidelines recommend that a hydrant system is to be provided in accordance with AS 2419.1-2005 Section 3.3 Open Yard Protection, and Table 3.3: Number of Fire Hydrants Required to Flow Simultaneously for Protected Open Yards. The number of simultaneous hydrants required to operate for the BESS yard is based on the floor area of the BESS area.

The BESS yard at the development occupies a floor area < 3000 m^2 and therefore requires a single hydrant to flow.

The minimum flow rate for the hydrant is 10 L/s, therefore the demand required for a duration of four (4) hours is 144,000 L.

The available water supply of 1,500 kL satisfies the demand for the poultry sheds, and is capable of providing extended water supply should it be required.

9.3.3.1 BESS fire burnout times (If installed)

While the duration of a battery fire is difficult to quantify given the number of variables involved, including, battery chemistry, casing construction and size of the system, configuration of the batteries within the rack and container etc. It is estimated that a water supply of four (4) hours is a reasonable duration for preventing fire spread from a BESS fire when drawing on past events and large-scale testing to date.

In July 2021, a single Megapack (Tesla BESS) at the Victoria Big Battery site in Geelong, Australia was involved a fire. The site provides 450 MWh of energy storage across 212 Tesla Megapacks, equating to a per container battery capacity of approximately 2.12 MWh. The fire origin Megapack resulted in fire spread to an adjacent megapack but was reported to burn out (without the provision of water onto the fire itself) after six (6) hours (Fisher Engineering, Inc., 2021).

The proposed BESS container has a battery capacity of 1280 kWh, approximately half that of a single Tesla Megapacks. In the event that the BESS container is involved in a fire, this would place it in a more positive position in terms of duration compared to the two Megapacks involved at VBB. Acknowledging that the development of the fire may vary given the number of variables involved (i.e. chemistry, container construction, etc).

While the burnout duration for the proposed BESS container is still expected to be shorter, due to the smaller capacity, it is prudent to also consider the expected amount of water required to prevent fire spreading beyond the BESS yard for the proposed site. In the case of the VBB, hundreds of BESS units were closely packed, and located in proximity to supporting infrastructure such as transformers, potentially increasing the risk of fire spread. Compared to the subject site, only a single BESS container is installed and radiative heat calculations being undertaken in this report, which provides the indicative layouts in Figure 24 and Figure 25 to set adequate separation distances to infrastructure in order to mitigate the risk of fire spread.

To introduce an additional datapoint for fire durations, attention is drawn to the large-scale free burn tests undertaken by NFPA and FM Global (National Fire Protection Association (NFPA), 2020). The free burn tests were undertaken on a single rack of LFP batteries with a capacity of 100 kWh and similarly on a rack of LNO/LMO batteries. The recorded burnout times were recorded to be 7100 s and 7270 s respectively (approximately 2 hours).

With the proposed battery being 1.28 MWh, it is expected to burn out after 2 hours, but prior to 6 hours, making 4 hours a reasonable estimate.

As a redundancy, the site is provided with a total water capacity of 1,500 kL, permitting extended water supply should it be required.

10. Containment of Firefighting Water

As detailed in Section 9, the primary source of firefighting water is provided through the means of a fire hydrant system.

It is noted that an engineered surface water management system will be installed at each of the farms to mitigate the impact of surface water runoff from the development. The systems will be designed to capture the runoff from 200 mm of rainfall (SLR, 2018).

10.1 Poultry shed

Each poultry shed will be surrounded by a 0.4 m, high dwarf concrete nib wall with strategically located seepage holes to convey excess water from the sheds into grassed swales located between each of the sheds.

Excess water is then able to be conveyed via underground pipes into a table drain located around the perimeter of the farm. Perimeter drains will then convey the water to a detention dam.

The detention dam provided at each PPU is designed to capture all runoff generated from within the farm site from approximately 200 mm of rainfall, which is equivalent to the depth of rainfall for a 1% annual exceedance probability, 72 hour event.

The detention dams at each farm are understood to have the storage capacities as summarised in Table 16 (EME Advisory, 2019).

Table 16: Design capacity of surface water management system

Farm	Approximate storage capacity in volume (m^3)	Approximate storage capacity in Litres (L)
1	33,600	33,600,000
2	50,875	50,875,000
3	36,168	36,168,000
4	50,255	50,255,000

Based on the design capacity of the engineered surface water management system, any firefighting water runoff (144,000 L based on hydrant operation for 2 hours) is expected to enter the controlled surface water management system and captured in the detention dam. The design capacity at each farm far exceeds the potential output from the hydrant system, indicating the system is capable of containing firefighting water, including during rain events. Treatment of water within detention dam is possible if required.

10.2 Solar Panels

A degree of fire-fighting water applied on solar panels will likely fall within the bunding applied to the poultry sheds for containment, however (Country Fire Authority, 2022) guidelines recognise that water run off from solar panels are not anticipated to contaminate water supplies and therefore are not required. The detention dams provided at each PPU are therefore sufficient for the solar panels.

10.3 BESS (If Installed)

Current plans do not indicate bunding to the proposed BESS. However, **it is recommended that a suitably designed bunding system to be designed and incorporated for the purpose of capturing potential contaminated water run off during fire fighting.**

The system design should incorporate methods of draining excess water to underground pipes similar to that deployed for the poultry sheds to ensure sufficient catchment of water.

11. First Aid Fire Protection Arrangements and Equipment

11.1 Notification of Emergencies

In the event of a fire emergency, fire services shall be notified immediately via 000. Fire Rescue NSW, NSW Police and NSW Ambulance being the first responders are responsible for managing the emergency upon arriving on site.

11.2 Site Evacuation Procedure

The site evacuation procedure shall be developed for the site and shall be applied if a fire event requires the evacuation of the site.

An Emergency Plan shall be prepared for the development in accordance with the requirements of the Hazardous Industry Planning Advisory Paper No. 1 – Emergency Planning Guideline (NSW, 2011) to a level of detail commensurate with the nature of the development

11.3 Emergency Equipment

In addition to the fire protection system detailed throughout the study, the provision of fire aid fire protection equipment is considered. The development shall be provided with equipment summarised in Table 17.

Table 17: Safety Equipment

Item	Location(s)	Maintenance Requirements
Fire extinguishers	As locations as stipulated in AS 2444:2001	As stipulated in AS 1851.1-1995
SDSs	PPU site office and at chemical storage locations	Checked for currency every 12 months
First Aid Kits	PPU site office and as necessary	Checked for currency every 12 months
Spill Kits	Chemical storage facility	Checked for currency and compatibility every 2 years
Personal Protective Equipment	PPU Site Office	As required

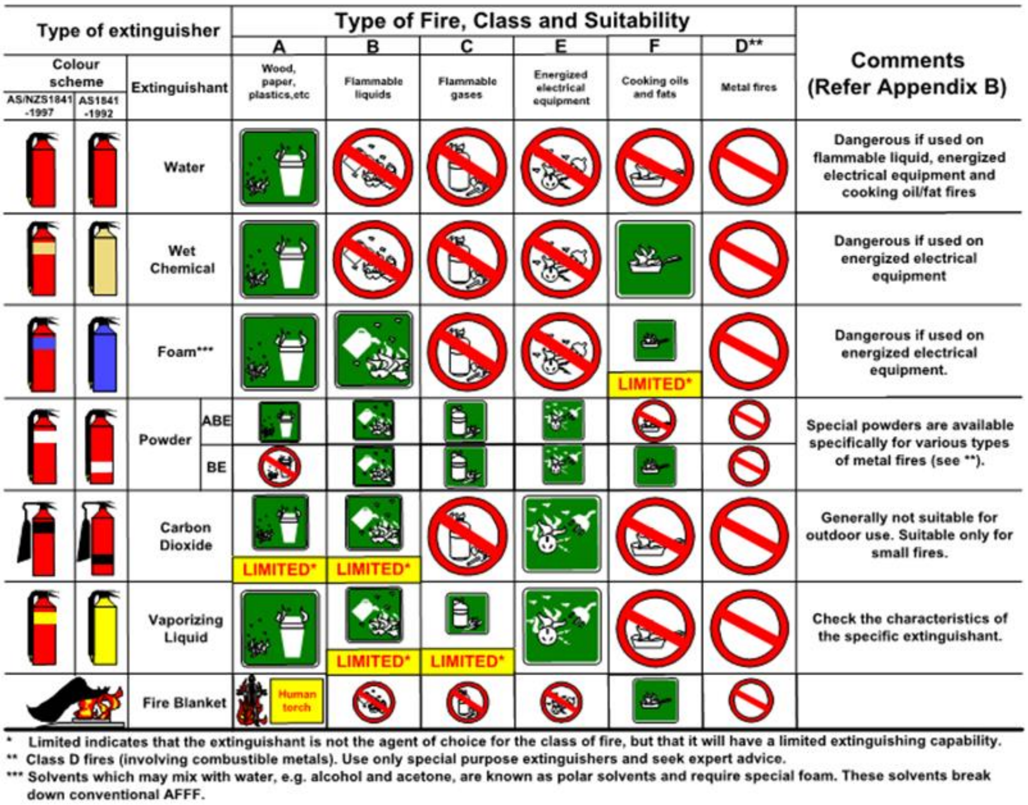

Figure 36: Figure A1 of AS 2444

The location fire extinguishers are shown in Section 8.

11.4 Emergency Control Centre

The site office at each PPU shall function as an Emergency Control Centre (ECC) in the event of an emergency. To assist site managers, site wardens and emergency responders, an Emergency Resource Pack containing relevant documentation including but not limited to the following is required to be provided at the ECC:

- The quantity and location of LPG being stored (including details of emergency shutoff)
- Emergency plan,
- Contact details of ProTen and regulatory authority contact details; and
- A manifest of chemicals and quantities stored and their respective safety data sheets (including a plan marking their locations)

11.5 Training and Testing

Site managers shall ensure that all employees and contractors are inducted and trained prior to works being commenced on site.

Emergency training requirements shall be documented in the Emergency Plan.

The Emergency Plan shall be reviewed and tested every 12 months as per the requirements of the POEO(G) Regulation.

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13. Key Assumptions and Limitations

- This report: has been prepared by GHD for ProTen Tamworth Pty Ltd and may only be used and relied on by ProTen Tamworth Pty Ltd for the purpose agreed between GHD and ProTen Tamworth Pty Ltd, as set out in section 1.1 of this report.
- This report and design only covers the "Departures from the DtS" which are addressed by fire engineering Performance Solutions. These have been identified to us by the Regulatory Reviewer. We are not required nor have we undertaken our own Regulatory Review.
- "Departures from the DtS" which are not addressed by fire engineering Performance Solutions are required to meet the Deemed To Satisfy provisions and therefore not covered in this report or design.
- GHD otherwise disclaims responsibility to any person other than ProTen Tamworth Pty Ltd arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.
- The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.
- The documentation relied upon has been reviewed only to the degree reasonable as pertaining to GHD's scope, as defined through contract and design intent. It is expressly not GHD's responsibility to,
  - Familiarise ourselves with all information or documentation relating to the project, or the potential fire safety aspect derivatives thereof,
  - Conduct a 'full fire engineering assessment' in any way defined, implied or assumed, for matters outside of GHD's scope,
  - Prepare a holistic fire safety strategy for the building or carry out a full fire engineering assessment of all information and documentation relating to the project, or the potential fire safety aspect derivatives thereof.
- The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.
- The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.
- This report is consistent with the fire safety provisions, objectives and limitations of the Building Code of Australia (BCA):
  - We have been informed that building features not part of a Performance Solution will comply with the Deemed to Satisfy provisions of the BCA.
  - This report excludes the analysis and design of fires including incendiary ones involving accelerants, explosives and/or multiple ignition sources, or acts of terrorism.
  - The concepts outlined in this report assume a complete and operational building, and do not address protection of the building during construction, renovation or demolition.

- Egress and fire safety provisions for persons with disabilities including compliance with the Disability Discrimination Act (DDA) were considered to the same degree as the BCA.
- Unless stated otherwise, protection of property (other than adjoining property), business interruption or losses, personal or moral obligations of the owner/occupier, reputation, environmental impacts, broader community issues, amenity or non-fire related matters in the building such as health, security, energy efficiency, and occupational health & safety or the re-installation and costs associated with any damages from fire are specifically excluded from this analysis.
- All essential equipment services and strategies will be maintained, to the operational capacity to which they were designed, installed, commissioned and certified, in accordance with the manufacturer's instructions. Therefore, all essential equipment services and strategies discussed within this report are assumed to function correctly during a fire situation.

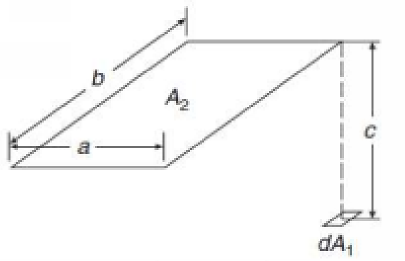
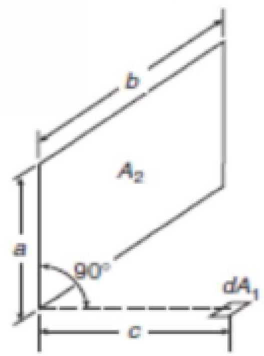
- This report is not a compliance or conformance audit for any fire safety system. For example, operational checks of fire safety equipment, verification of construction techniques, fire resistance levels or the witnessing of fire drills or exercises are specifically excluded from the scope of this report.
- The recommendations, data and methodology apply to the subject building and must not be utilised for any other purpose. Any modifications or changes to the building, fire safety management system, or building usage from that described in this report may invalidate the findings, necessitating a re-assessment.
- GHD has prepared this report on the basis of information provided by ProTen Tamworth Pty Ltd and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.
- There is no such thing as a “zero-risk” or “guaranteed safe” building. Even if all of the above listed measures were to be undertaken, there is still a possibility that a fire event may occur.
- It is GHD’s recommendation that this document and the measures proposed herein be discussed by and with relevant stakeholders with the objective to obtain agreement, and ultimately sign-off by relevant parties. Stakeholders envisaged to form part of the signatory group are listed in Table 3.
- GHD has prepared this document for the sole use of ProTen Tamworth Pty Ltd and for a specific purpose, expressly stated herein. No other party should rely on this document without the prior written consent of GHD.
- GHD undertakes no duty, nor accepts any responsibility, to any third party who may rely upon or use this document.
- This document has been prepared based on ProTen Tamworth Pty Ltd’s description of its requirements and GHD’s experience, having regard to assumptions that GHD can reasonably be expected to make in accordance with sound professional principles.
- GHD accepts no liability for information provided by ProTen Tamworth Pty Ltd or other third parties used to prepare this document or as the basis of the analysis. Subject to the above conditions, this document may be transmitted, reproduced or disseminated only in its entirety.

Appendices

Appendix A- Fire Severity Calculations

A.1. Radiant heat incident on neighbouring poultry sheds

Project: Title:	**ProTen - Rushes Creek** Radiation Heat Flux Calculations	Page: 1

Ref	Calculations	Comments
		Version 1.6 R1
	Emitting Radiation Calculation	
Ref 1	$\dot{q}''_e = \varepsilon \sigma T^4_{emitter}$	
	Input	
	Emissivity, ε 1.00	
	Stefan-Boltzmann constant σ 5.67E-11 $kW/m^2/K^4$	
	Absolute Temperature of emitter, $T_{emitter}$ 1023.087 °C	
	Output	
	Radiant heat flux emitted, $\dot{q}''_e$ 160.0 kW/m^2	
	Distance from boundary 0.00 m	Away from building
	Max radiant heat flux emitted at target plane, 3.4 kW/m^2	
	Configuration Factor Calculation	
Table 1-4.1 in Ref 1	Parallel Configuration  $X = a/c \quad Y = b/c$ $F_{d1-2} = \frac{1}{2\pi}\left[\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left(\frac{Y}{\sqrt{1+X^2}}\right) + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left(\frac{X}{\sqrt{1+Y^2}}\right)\right]$	This configuration factor formula is for 1/4 plane element only.
	Perpendicular Configuration  $X = a/b \quad Y = c/b \quad A = 1/\sqrt{X^2 + Y^2}$ $F_{d1-2} = \frac{1}{2\pi}[\tan^{-1}(1/Y) - AY\tan^{-1}A]$	This configuration factor formula is for 1/2 plane element only.

Ref	Calculations	Comments
		Version 1.6 R1

Input for Parallel Radiation Calculation

Table 1: Emitting Radiation for Various Windows Parallel to Target

Openings	Width	Height	c_1	$x_{l,b}$	$y_{l,b}$	Include in Analysis
	m	m	m	m	m	
PS end wall	18.00	2.20	26.50	0.00	0.00	Yes

c_1 is the distance from an opening to the boundary

Input for Perpendicular Radiation Calculation

Table 2: Emitting Radiation for Various Windows Perpendicular to Target

Openings	Width	Height	c_2	$x_{l,b}$	$y_{l,b}$	Hot Source Direction	Include in Analysis
	m	m	m	m	m		
PS side wall	42.40	2.60	26.50	0.00	0.00	+x	Yes

c_2 is the closest distance from an opening to the boundary

Ref	Calculations	Comments
		Version 1.6 R1

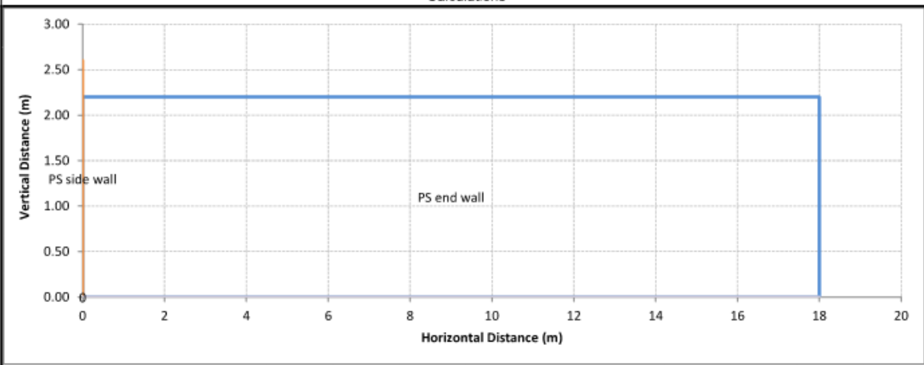


Figure 1: Elevation of Openings

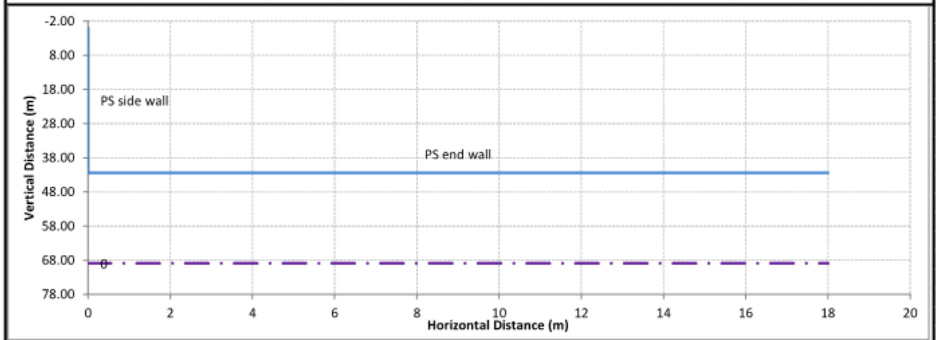


Figure 2: Plan of Openings

A.2. Radiant heat incident on neighbouring poultry sheds

GHD	Project: ProTen - Rushes Creek Title: Radiation Heat Flux Calculations	Page: 1

Ref	Calculations	Comments
Ref 1	***Emitting Radiation Calculation***	Version 1.6 R1

$$\dot{q}_e'' = \varepsilon \sigma T_{emitter}^4$$

Input

Emissivity,	ε	1.00	
Stefan-Boltzmann constant	σ	5.67E-11	$kW/m^2/K^4$
Absolute Temperature of emitter,	$T_{emitter}$	1023.087	°C

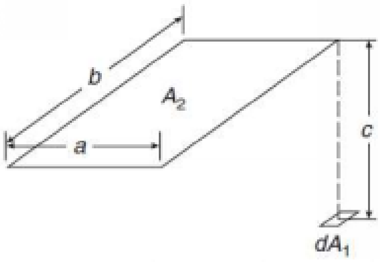
Output

Radiant heat flux emitted,	$\dot{q}_e''$	160.0	kW/m^2	
Distance from boundary		0.00	m	Away from building
Max radiant heat flux emitted at target plane,		10.6	kW/m^2	

Table 1-4.1 in Ref 1

Configuration Factor Calculation

Parallel Configuration

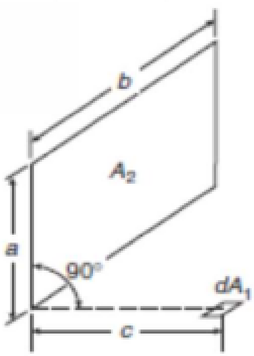


$$X = a/c \qquad Y = b/c$$

$$F_{d1-2} = \frac{1}{2\pi}\left[\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left(\frac{Y}{\sqrt{1+X^2}}\right) + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left(\frac{X}{\sqrt{1+Y^2}}\right)\right]$$

This configuration factor formula is for 1/4 plane element only.

Perpendicular Configuration



$$X = a/b \qquad Y = c/b \qquad A = 1/\sqrt{X^2 + Y^2}$$

$$F_{d1-2} = \frac{1}{2\pi}\left[\tan^{-1}(1/Y) - AY\tan^{-1}A\right]$$

This configuration factor formula is for 1/2 plane element only.

Project:	ProTen - Rushes Creek	
Title:	Radiation Heat Flux Calculations	Page: 2

Ref	Calculations	Comments
	Input for Parallel Radiation Calculation **_Table 1: Emitting Radiation for Various Windows Parallel to Target_**	Version 1.6 R1

Openings	Width	Height	c_1	$x_{l,b}$	$y_{l,b}$	Include in Analysis
	m	m	m	m	m	
PS side wall	42.40	2.20	15.00	0.00	0.00	Yes

c_1 is the distance from an opening to the boundary

Input for Perpendicular Radiation Calculation

Table 2: Emitting Radiation for Various Windows Perpendicular to Target

Openings	Width	Height	c_2	$x_{l,b}$	$y_{l,b}$	Hot Source Direction	Include in Analysis
	m	m	m	m	m		

c_2 is the closest distance from an opening to the boundary

Ref	Calculations	Comments
		Version 1.6 R1

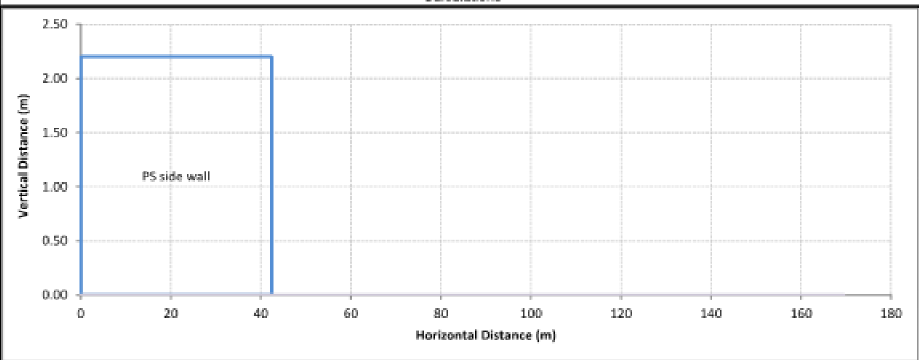


Figure 1: Elevation of Openings

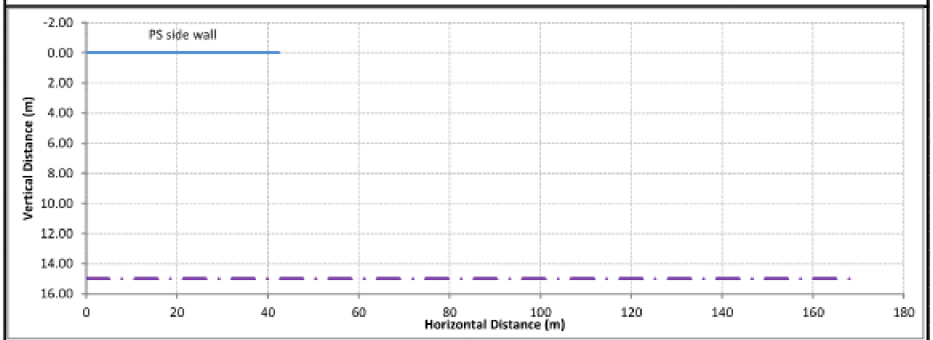


Figure 2: Plan of Openings

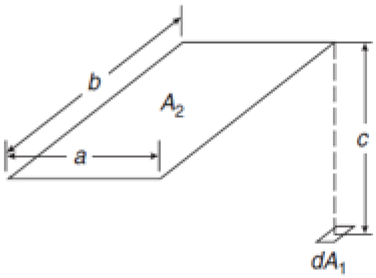
Radiant heat incident on neighbouring poultry sheds (Solar fire)

GHD

Project: **Proten - Rushes Creek**
Title: Radiation Heat Flux Calculations

Ref	Calculations	Comments
		Version 1.6 R1
	Emitting Radiation Calculation	
Ref 1	$\dot{q}''_e = \varepsilon \sigma T^4_{emitter}$	
	Input	
	Emissivity, ε: 1.00	
	Stefan-Boltzmann constant σ: 5.67E-11 $kW/m^2/K^4$	
	Absolute Temperature of emitter, $T_{emitter}$: 1357 °C	
	Output	
	Radiant heat flux emitted, $\dot{q}''_e$: 400.3 kW/m^2	
	Distance from boundary: 0.00 m	Away from building
	Max radiant heat flux emitted at target plane, 8.2 kW/m^2	

Ref	Calculations	Comments
Table 1-4.1 in Ref 1	***Configuration Factor Calculation***	
	Parallel Configuration	This configuration factor formula is for 1/4 plane element only.



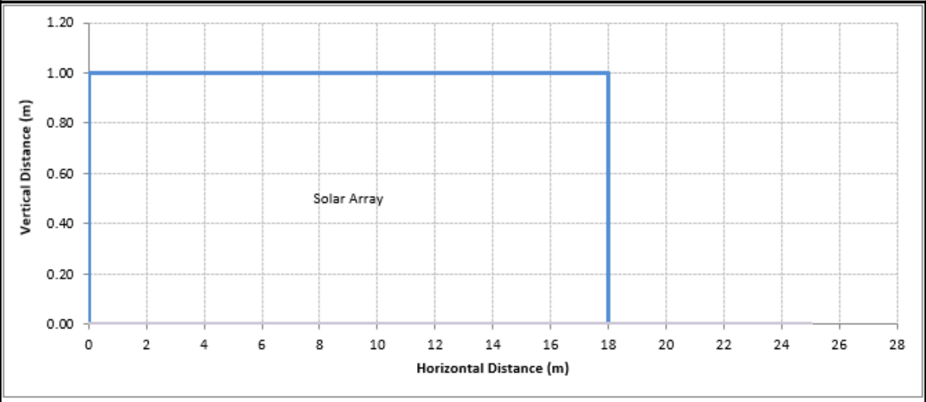
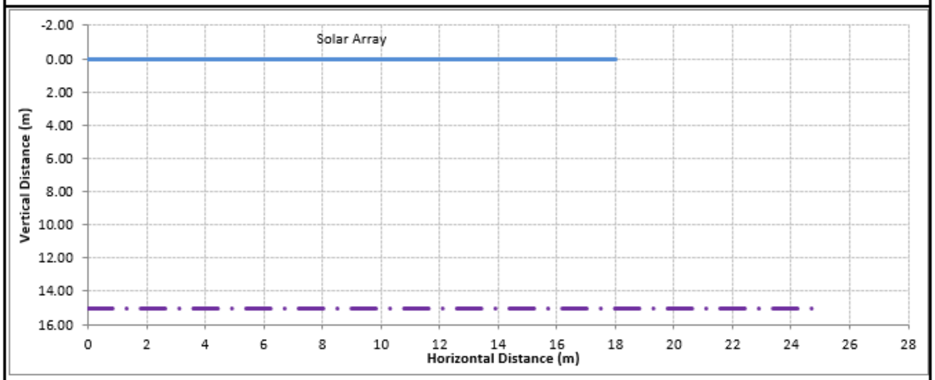
$X = a/c \qquad Y = b/c$

$$F_{d1-2} = \frac{1}{2\pi}\left[\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left(\frac{Y}{\sqrt{1+X^2}}\right) + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left(\frac{X}{\sqrt{1+Y^2}}\right)\right]$$

Project: Title:	Proten - Rushes Creek Radiation Heat Flux Calculations	
Ref	Calculations	Comments
	Input for Parallel Radiation Calculation ***Table 1: Emitting Radiation for Various Windows Parallel to Target***	Version 1.6 R1

Openings	Width	Height	c_1	$x_{i,b}$	$y_{i,b}$	Include in Analysis
	m	m	m	m	m	
Solar Array	18.00	1.00	15.00	0.00	0.00	Yes

c_1 is the distance from an opening to the boundary

Project: Title:	**Proten - Rushes Creek** Radiation Heat Flux Calculations	
Ref	Calculations	Comments
	 **Figure 1: Elevation of Openings**  **Figure 2: Plan of Openings**	Version 1.6 R1

Appendix B– PIR Fire Performance Study of Rigid PIR Boards (Non-sandwhiched, with and without protetive layer)

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RESEARCH ARTICLE

WILEY

Fire performance of charring closed-cell polymeric insulation materials: Polyisocyanurate and phenolic foam

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Summary

Results are presented from 2 series of ad hoc experimental programmes using the cone calorimeter to investigate the burning behaviour of charring closed-cell polymeric insulation materials, specifically polyisocyanurate (PIR) and phenolic (PF) foams. These insulation materials are widely used in the construction industry due to their relatively low thermal conductivity. However, they are combustible in nature; therefore, their fire performance needs to be carefully studied, and characterisation of their thermal degradation and burning behaviour is required in support of performance-based approaches for fire safety design. The first series of experiments was used to examine the flaming and smouldering of the char from PIR and PF. The peak heat release rate per unit area was within the range of 120 to 170 kW/m^2 for PIR and 80 to 140 kW/m^2 for PF. The effective heat of combustion during flaming was within the range of 13 to 16 kJ/g for PIR and around 16 kJ/g for PF, while the CO/CO_2 ratio was within 0.05 to 0.10 for PIR and 0.025 to 0.05 for PF. The second experimental programme served to map the thermal degradation processes of pyrolysis and oxidation in relation to temperature measurements within the solid phase under constant levels of nominal irradiation. Both programmes showed that surface regression due to smouldering was more significant for PF than PIR under the same heat exposure conditions, essentially because of the different degree of overlap in pyrolysis and oxidation reactions. The smouldering of the char was found to self-extinguish after removal of the external heat source.

KEYWORDS

charring foams, combustion, insulation materials, performance-based design, pyrolysis, smouldering

1 | INTRODUCTION

Stringent requirements for energy efficiency are driving a trend towards the more widespread use of insulation materials in the built environment. Several types of insulation materials, which are able to meet the multiple design criteria often required for buildings, can be found in the market. A typical classification for insulation materials in the European market, proposed by Papadopoulos et al,[1] distinguishes 4 main groups: (1) inorganic materials such as foams or fibrous materials, (2) organic materials such as expanded foams or fibrous materials, (3) combined materials, and (4) new technology materials. Expanded organic foams such as closed-cell rigid polyisocyanurate (PIR) and phenolic (PF) foams are common combustible insulation materials that are increasingly being used for the design of energy-efficient buildings due to their relatively low thermal conductivity, low density, good durability, and ease of installation.[2] These factors, in conjunction with the

Nomenclature: $E_{CO \rightarrow CO_2}$, heat release per mass unit of oxygen consumed for the combustion of carbon monoxide (J/g); E_{O_2}, heat release per mass unit of oxygen consumed (J/g); ΔH_c, heat of combustion (J/g); m, mass (g/s); $\overline{m}$, normalised mass (−); $\dot{m}$, mass flow rate (g/s); $\dot{Q}$, heat release rate (W); t, time (s); T, temperature (K or °C); X, volume fraction (mol/mol); $\dot{V}$, volumetric flow (m^3/s)
Greek letters: γ, volumetric expansion factor (−); ϕ, oxygen depletion factor (−)
Subscripts: 0, initial; *air*, of air; *eff*, effective; *end*, of the end duration of the test; *e*, of the exhaust or extraction; *i*, of the species i; *loss*, of total loss from the sample; *s*, loss from the sample
Acronyms: DTG, differential thermogravimetric analysis; HRR, heat release rate; HRRPUA, heat release rate per unit area; OC, oxygen consumption calorimetry; PIR, closed-cell rigid polyisocyanurate foam; PF, closed-cell rigid phenolic foam

requirement for lower thermal transmittances in building assemblies,[3] lead to these materials increasingly being a preferred option for design.

1.1 | Fire hazards from combustible insulation

The increase in production and extended usage of combustible materials in buildings such as closed-cell cellular polymers has recently given rise to several concerns in the fire safety community.[4,5] This is however not a new problem, and many aspects have already been addressed by several authors and institutions in the past.[6] Indeed, to identify the potential fire hazards to life safety from insulation materials in buildings, numerous authors have extensively studied the fire performance of different types of insulation under different approaches.[6-23] The biggest concern, represented as the flammability and energy release, has classically been addressed using bench-scale experimentation,[13-21] eg, determining the limiting oxygen index according[24] to ASTM D2863 and assessing ignition properties, heat release, and flame spread by using the cone calorimeter[25] or the LIFT apparatus.[26] During recent decades, the fire performance of these materials has been improved by applying flame retardancy techniques, ie, promoting charring behaviour and endothermic reactions in the solid phase, which is typically researched at material scale using thermogravimetry.[7-9] The generation of toxic species due to the combustion and pyrolysis of these plastics has also been raised as a potentially significant concern, and several authors have studied the toxicity of emissions from insulation materials commonly used in buildings.[10-12]

While most of this work has clearly served to rate the hazard from insulation products under specific testing scenarios, several authors highlight that the extrapolation of the performance observed from small-scale testing is hardly applicable to larger scale due to the combination of complex phenomena.[22,23,27,28] Although significant efforts are constantly made to reduce the flammability/combustibility of these materials, there is potential for confusion from the belief that the risk associated with these hazards can be effectively mitigated by obtaining better ratings from standard testing. Harmonisation of standardised testing is intended to offer a plausible representation of the fire hazards from construction products. Yet quantification of the risks associated with the use of combustible insulation in buildings remains as a significant challenge for practitioners.

1.2 | Design tools to quantify the risk from combustible insulation

Recently, new methodologies for the fire safe design of insulation systems have been proposed on the basis of their material behaviour under severe conditions of heat exposure.[29] The methodology proposed by Hidalgo et al considers the mitigation of the fire hazard from combustible insulation materials by designing suitable thermal barriers that control the onset of pyrolysis,[29,30] ie, delaying the onset of hazard generation. Previous work demonstrated that the onset of hazard could be conservatively defined as a "critical temperature."[31] For charring foams, the critical temperature was defined as the temperature at which the peak of the main pyrolysis reaction is obtained by differential thermogravimetric analyses (DTGs) at sufficiently low heating rates and under nonoxidative atmospheres.

The proposed methodology represents a conservative approach for the quantitative fire safe design of construction systems including insulation materials, ie, a framework by which the risk can be quantified. Nevertheless, additional models are required by practitioners and regulatory bodies if quantification of the evolution of hazard after the onset of pyrolysis is to be understood,[32] ie, potential heat release contribution and generation of toxic species from the insulation. The quantification of these hazards is determined by the terms (1) production rate of pyrolysis gases, (2) heat of combustion from pyrolysis gases, and (3) gas species generated by the pyrolysis and combustion. To be able to quantify these parameters and propose a model for performance-based design, a thorough understanding of the material behaviour under conditions of heat exposure is required. This study aims at achieving a thorough understanding of the material behaviour beyond standard testing and parameters, thus identifying the underlying processes that govern those issues, ie, the thermal degradation and thermal evolution of the condensed phase at a relevant scale.

1.3 | Research significance and objectives

In previous work, we presented studies on flammability properties from PIR and PF, as well as their thermal decomposition processes at a material scale by thermogravimetry.[31] The purpose of that work was to determine parameters for the proposed performance-based design methodology.[29] Values of critical temperature established previously, which represent the onset of hazard (pyrolysis), correspond to 300°C to 370°C for rigid PIR insulation and 425°C for the specific PF studied.[31] The present work explores the fire performance of these materials on the basis of their burning behaviour. Variables such as the heat of combustion, emissions of carbon monoxide (CO) and carbon dioxide (CO_2), and consumption of oxygen (O_2) from the combustion are assessed. Thus, the information presented here aims to provide relevant data for the development and application of models capable of predicting the production rate of energy, pyrolysis, and combustion products under different scenarios.

Then the scope of the work presented herein is to present an original methodology to assess the fire performance of representative samples of 2 common commercial rigid closed-cell plastic insulation materials (PIR and PF). This work explores which phenomena should be considered for the development and application of models that can quantify their burning hazard. To achieve this, the following goals are pursued:

1. Macroscopic analysis of the fire performance of these foams by studying heat release rate (HRR), mass loss, and gas emissions from cone calorimeter ad hoc experiments.
2. Mapping of the thermal degradation processes in relation to temperature measurements within the solid phase and correlating the evolution of the thermal profile experienced by the material to results obtained by thermogravimetric analyses presented elsewhere.[31]

The present work is vital for the further development of engineering tools that could assist performance-based designs of building assemblies including combustible insulation. As noted by Hidalgo et al,[29] although the current regulatory fire safety frameworks in the EU[33,34] do not provide a suitable approach for insulation materials, further instrumentation and inclusion of quantitative approaches could complement current standardised testing practices. This approach would help to provide a better understanding and quantification of the fire hazards from insulation materials.

It should be noted that the final fire performance of plastic foams such as PIR and PF strongly depend on the chemical composition and manufacturing process,[35] eg, content of isocyanurate linkages and type of isocyanate-reactive component for PIR, or degree of reticulation for PFs. This information is however largely inaccessible to the public. Since the purpose of this work is to establish a methodology that allows for a comprehensive analysis of phenomena relevant to the eventual fire performance characterisation, 3 current commercially available types of PIR from different manufacturers were selected. These products are certified by their manufacturers to correspond to isocyanurate-based foams (PIR) rather than urethane-based foams (PUR). Only one PF product was selected aiming at a performance comparison with respect to PIR foams; previous thermogravimetric studies have shown essential differences between these products.[31]

2 | EXPERIMENTAL PROGRAMME DESCRIPTION

The experimental programme designed to achieve the objectives noted above was based on the use of the cone calorimeter apparatus,[25] as 2 different series of ad hoc experiments:

1. Piloted experiments and transferring the heat to the sample by radiation from the cone, as presented for the flammability experiments on insulation materials presented elsewhere.[31] The main measurements consisted of mass loss and gas species such as oxygen, carbon dioxide, and carbon monoxide, supported by visual observations.
2. Nonpiloted experiments and transferring the heat to the sample by radiation from the cone. The main measurements consisted of gas species and temperature measurements within the samples, supported by visual observations.

2.1 | Materials

The studied insulation materials comprised 3 types of rigid polyiscocyanurate foam (hereby referred as PIRa, PIRb, and PIRc) and one type of PF. These thermoset plastics are manufactured as rigid closed-cell polymers by blowing a gas through the entire structure of the foam. At present, the blowing agents mainly used are n-pentane, iso-pentane, cyclo-pentane, and various hydrofluorocarbons that have zero ozone depleting potential.[36]

Three different PIR foams from various suppliers were selected to assess the difference in their performance. Polyisocyanurate, which is manufactured based on the mix of an organic isocyanate component and an isocyanate-reactive component, is known to present different possible formulations depending on the isocyanate-reactive component used, which determines its thermal stability.[8] Results in further sections show that the characteristic fire performance from the 3 foams was similar. Therefore, for studying PF, only one product was selected with the intention to assess its characteristic performance with respect to PIR foam.

These materials are often supplied as rigid boards with a protective layer on the surface, which is expected to have some impact on the observed performance during the tests. For the products studied herein, the protective layer corresponds to a low emissivity composite aluminium foil/paper facing. To examine this, samples with and without protective layer were tested. Nevertheless, it should be noted that since this work mainly pursued the characterisation of the material, rather than the product to specific testing methods, the effect of the protective layer must be addressed carefully. Samples with a surface area of 90 mm by 90 mm and 100 mm thick were tested in the 2 series of experiments. Samples with the protective layer removed are shown in Figure 1.

2.2 | Set-up #1: piloted experiments with the heat transferred by radiation

The set-up of these experiments is detailed elsewhere,[31] the results of which are complementary to those presented here. In the previous publication, the measurements were used to assess the critical temperature and thermal inertia of several insulation materials for a performance-based methodology. Temperature measurements were not taken for this experimental programme. The results presented in following sections will rather focus on HRR, mass loss, heat of combustion, and gas emissions. These provide an assessment of the burning behaviour of these foams with no protective layer, thus a characterisation of the material rather than the product.

2.3 | Set-up #2: non-piloted experiments with the heat transferred by radiation

For these experiments, samples were wrapped with aluminium foil at the bottom and lateral sides, with a 6-mm Nickel 200 block at the bottom and altogether wrapped in two 3-mm-thick layers of ceramic insulation paper. The aluminium foil was mainly used to prevent air penetration in the sample from the sides and only allows it from the top. From a heat transfer perspective, the foil is transparent for the conducted heat due to its low thickness and high thermal diffusivity, thus acting as a thermally thin material. The 2 layers of ceramic paper were used to reduce the thermal gradients on the surface of the sample sides. It should be noted that an adiabatic boundary condition at the sides will always be unattainable with this set-up since the conductivity of the ceramic paper is higher than the materials tested.* A schematic drawing of the conceptual set-up and the real set-up is shown in Figures 2 and 3, respectively.

It should be noted that this set-up was used to provide relevant and reliable results that could facilitate future modelling tasks. Thus, the characterisation of the boundary condition at the back face of the material is achieved by using the 6-mm Nickel 200 plate at

*Thermal conductivity of ceramic paper: 0.08 and 0.11 $W\cdot m^{-1}\cdot K^{-1}$ at 600°C and 800°C, respectively.

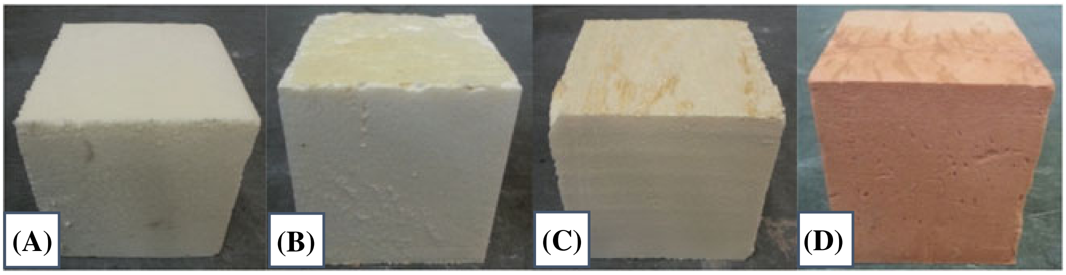

FIGURE 1 Samples of insulation materials before testing. A, PIRa; B, PIRb; C, PIRc; and D, PF. PIR, polyisocyanurate; PF, phenolic foam [Colour figure can be viewed at wileyonlinelibrary.com]

the bottom of the samples. This approach was described by Carvel et al,[37] who recommended the use of a heat sink for material characterisation purposes.

As for the boundary condition at the exposed surface, several values of irradiation from the radiant heater were used. The heat fluxes were selected in such a way that mapping of the different thermal degradation processes was highlighted. The minimum heat flux for each material was defined as a thermal exposure that did not trigger the onset of pyrolysis after reaching thermal equilibrium. Specific values of external heat flux for each material are noted in Table 1.

Experiments were performed at least twice to verify the repeatability of the results and for 2 different configurations, ie, with no protective layer and with a noncoloured protective layer attached to the exposed surface to explore different phenomena and thermal behaviour experienced by the foams.

Measurements of temperature were taken within the sample by using 1.5-mm bead K-type thermocouples. The temperature of the metallic plate at the back was also measured. Thermocouples were installed at the centre of the section and every 2 mm in-depth and in parallel to the exposed surface with the intention of reducing the error in the thermocouple measurement, which is a recommended procedure for materials of particularly low conductivity.[38,39] The first thermocouple was placed within a range of 2 to 3 mm from the surface. No temperature correction was considered by the heat losses introduced by the thermocouple. Additionally, 2 thermocouples were inserted 30 mm horizontally off the second in-depth thermocouple for some experiments. This procedure aimed to clarify whether the heat transfer through the sample was behaving either one-dimensionally or two-dimensionally. The positioning of the thermocouples is shown in Figure 2. A summary of the conditions for all the performed experiments is presented in Table 1.

Gas species such as carbon dioxide, carbon monoxide, and oxygen were measured at the apparatus exhaust duct, which nominal volumetric flow corresponded to 24 L/s. Mass loss was not measured for this experimental programme, as the thermocouples would interfere with the measurements.

3 | ANALYSIS METHODOLOGY

The calorimetry approach considered to evaluate the HRR from the burning of the insulation materials is the species evolution approach based on oxygen consumption (OC).[40] Oxygen consumption rather than carbon dioxide generation calorimetry[41] is used to correlate the HRR due to 2 main reasons: (1) the desiccation system based on calcium sulphate (*drierite*®) tends to absorb carbon dioxide when anhydrous, thus affecting the shape of the measured curve of carbon dioxide, and (2) the variability of energy coefficients for carbon

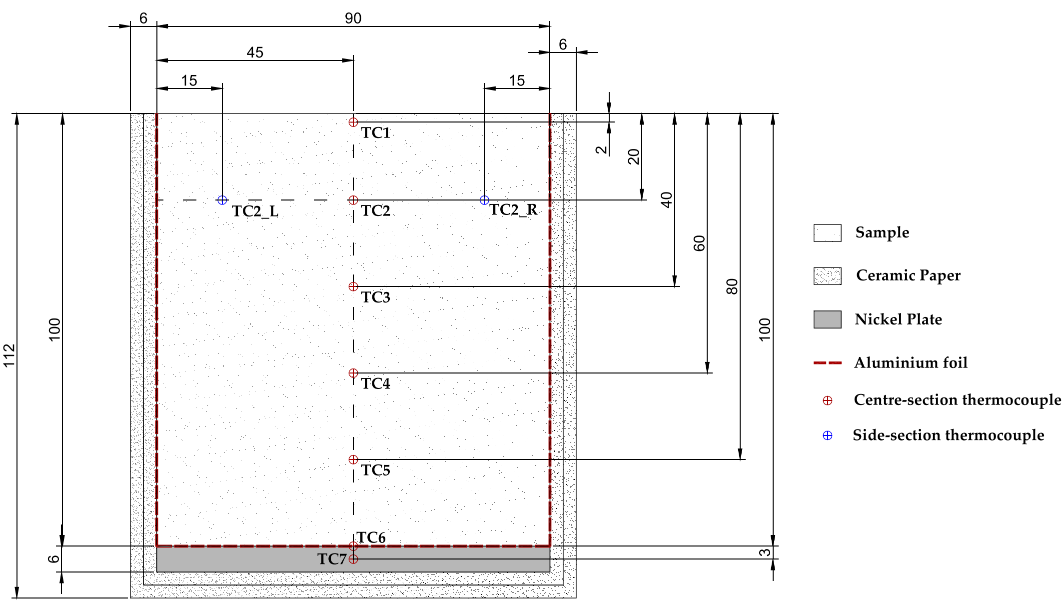

FIGURE 2 Schematics of sample preparation for the set-up #2 [Colour figure can be viewed at wileyonlinelibrary.com]

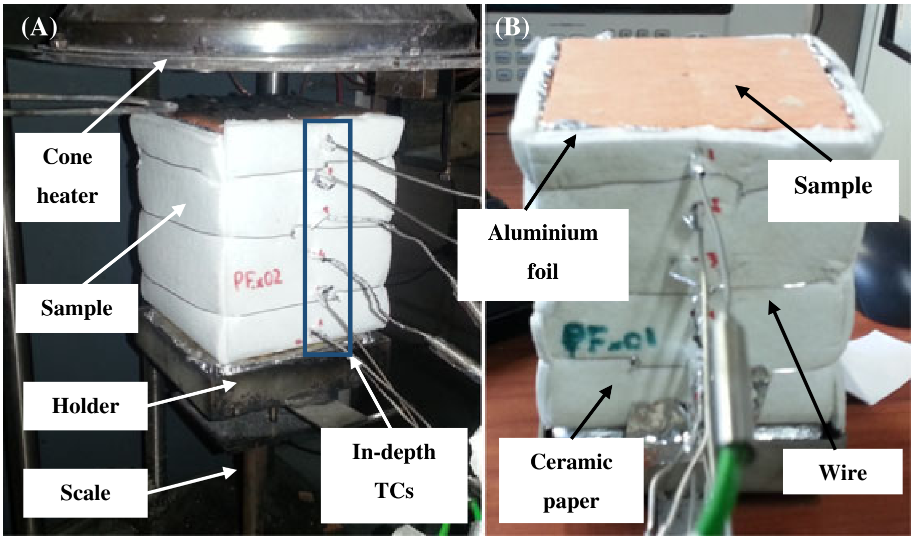

FIGURE 3 A, Sample during testing and B, sample prepared before testing [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Summary of performed experiments (set-up #2)

Material	Configuration	Incident Radiant Heat Flux Range, kW/m^2	Measured Parameters
PIRa Manufacturer-claimed density: 31–34 kg/m^3 Average measured density: 31.2 ± 0.61 kg/m^3	Nominal sample size: 90 mm × 90 mm × 100 mm Exposed surface: (a) With protective layer (b) Without protective layer	10, 25, 35 (2 repetitions)	(1) In-depth temperature (2) O_2, CO_2, and CO gas species
PIRb Manufacturer-claimed density: 32 kg/m^3 Average measured density: 33.0 ± 0.71 kg/m^3	Wrapping: 2 layers of ceramic paper +1 layer of aluminium foil Back boundary condition: Nickel 200 plate (6 mm) +	5, 10, 25, 35 (2 repetitions)	
PIRc Manufacturer-claimed density: 30-32 kg/m^3 Average measured density: 33.5 ± 0.65 kg/m^3	ceramic board (25 mm) Orientation: Horizontal Pilot: No pilot igniter	5, 10, 25, 35 (2 repetitions)	
PF Manufacturer-claimed density: 35 kg/m^3 Average measured density: 38.1 ± 1.05 kg/m^3		5, 10, 15, 25 (2 repetitions)	

dioxide generation calorimetry tends to be larger than OC.[42] Then the formulation considered for the experiments corresponds to OC calorimetry, noted in Equation 1, which was originally proposed by Janssens[43] and has been revisited by Biteau[42]:

$$\dot{Q}_{OC} = \left(E_{O_2}\cdot\phi - (E_{CO\rightarrow CO_2} - E_{O_2})\cdot\frac{1-\phi}{2}\cdot\frac{X_{CO}}{X_{O2}}\right)\cdot\frac{\dot{m}_{ex}}{1+\phi\cdot(\gamma-1)}\cdot\frac{M_{O_2}}{M_{air}}\cdot X^0_{O_2}, \tag{1}$$

where E_{O_2} and $E_{CO\rightarrow CO_2}$ are the energy released per mass unit of oxygen consumed (W/g) and per mass unit of oxygen consumed for the combustion of carbon monoxide respectively (W/g), $\dot{m}_e$ is the mass flow in the exhaust (g/s), γ is the volumetric expansion factor (−), M_{O_2} and M_{air} are the molecular weight of oxygen and air, respectively, (g/mol), and ϕ is the oxygen depletion factor (−).

The effective heat of combustion $H_{c,\,eff}$ (J/g) is quantified based on calculations of HRR and experimental mass loss, given by the following:

$$\Delta H_{c,eff} = \frac{\int_0^{t_{end}}\dot{Q}_{OC}(t)\cdot dt}{m_{loss}}, \tag{2}$$

where $\dot{Q}_{OC}(t)$ is the HRR (W), t_{end} is the end time of the test (s), and m_{loss} is the total mass loss during the test (g). The notation 'effective' relates to an average value obtained by the combustion of the material. However, the combustion process for most of these foams is nonuniform, with transition from flaming to smouldering, as will be shown in further sections. Then, if Equation 2 is applied for the total test time, the obtained values of heat of combustion will represent a lumped value that considers both flaming and smouldering as a single process. The effective heat of combustion from pyrolysis gases for materials that char and experience smouldering is attempted for an arbitrary period up to 200 seconds during the initial flaming combustion. This period is chosen considering the samples exposed to heat fluxes larger than 35 kW/m^2 (refer to Figure 5). Even though a shorter integration time would be more adequate for 25 kW/m^2, this would lead to large errors due to the short transient behaviour of the flaming combustion. It should be noted that, whereas this is an arbitrary criterion, the objective is to compare this value to the effective value considering the total time of the test.

Mass measurements from the samples are normalised with respect to the initial mass of the sample, m_0 (g), as shown in Equation 3 below:

$$\overline{m}(t) = \frac{m(t)}{m_0}, \tag{3}$$

where $\overline{m}(t)$ and $m(t)$ are the normalised mass (−) and measured mass (g), respectively, at any time. As discussed in further sections, the ceramic paper used to prepare the samples is expected to lose mass during the test, thus including an overestimation of the mass loss. This error is estimated as a maximum of 5% of the initial sample mass, which is assessed by running tests at high heat fluxes until almost all the sample is consumed.

To assess the different thermal degradation processes with respect to temperature measurements, the duration of the tests from experimental set-up #2 was selected in a way such that the maximum thermal gradient could be compared to the residue of the sample. Therefore, samples were cut through their centre section after the end of the test, and the level of thermal degradation achieved at different depths assessed by visual colourimetry. Additionally, the consistency of these results is correlated with thermogravimetric experiments presented elsewhere.[31,35]

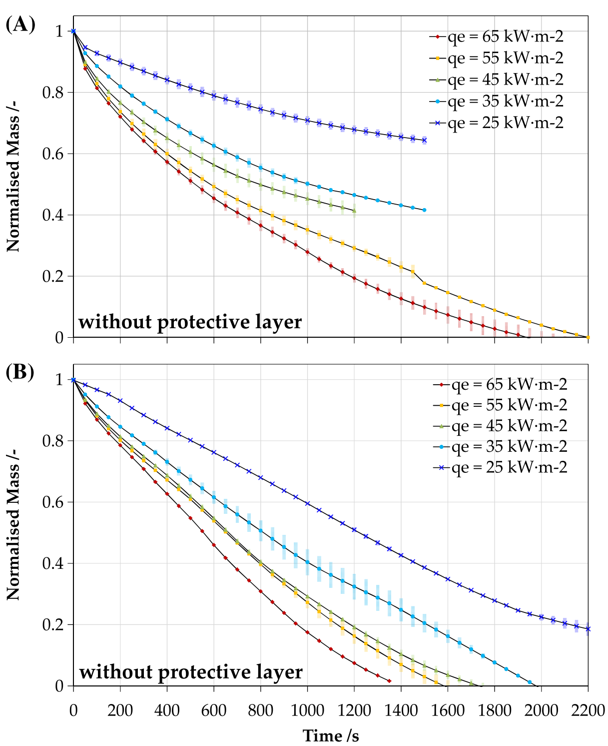

FIGURE 4 Normalised mass ($m(t)/m_0$) of A, PIRa and B, PF samples without protective layer at different heat fluxes. Shading indicates std. dev. from 2 repetitions. PIR, polyisocyanurate; PF, phenolic foam [Colour figure can be viewed at wileyonlinelibrary.com]

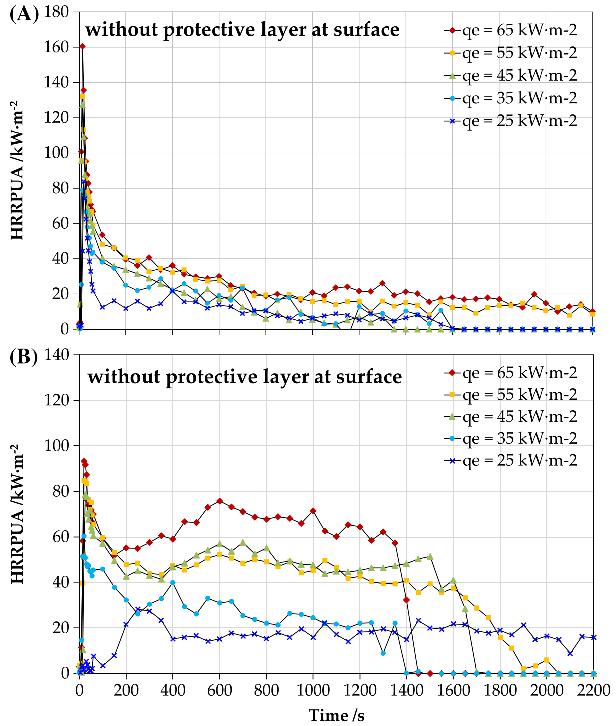

FIGURE 5 Heat release rate per unit area of 100-mm-thick A, PIRa and B, PF samples without protective layer at different external heat fluxes. Average from 2 repetitions. PIR, polyisocyanurate; PF, phenolic foam [Colour figure can be viewed at wileyonlinelibrary.com]

4 | RESULTS AND DISCUSSION

4.1 | Burning behaviour

A summary of the experimental results consisting of mass loss of the samples, HRR per unit area (HRRPUA), and gas species correlations for PIRa and PF is presented below. For simplicity, and since the results from the rest of PIR materials are very similar in performance, only results from PIRa are discussed in this section.

4.1.1 | General observations

The 3 types of PIR were found to behave similarly, with a very fast ignition for every external heat flux larger than the critical. This was followed by a small flame that continued to be reduced until intermittent flaming was only observed by the edges of the sample. Polyisocyanurate foam tended to expand slightly at early stages of the heat exposure. After flaming, a black char layer remained, which tended to glow if the external heat flux was high. The char at the surface continued to get consumed by oxidation, and its thickness started to reduce at different rates depending on the incident radiant heat flux. Flaming at the edges was sporadically observed. The remaining char from PIR was very soft and light. Discolouration of the PIR samples was observed, changing from yellow to orange-brown and finally black colour during the process of thermal degradation. This discolouration is discussed in further sections. It should be noted that the similarity between results from the 3 types of PIR foams is extensively discussed in Hidalgo.[35] Therefore, herein, only main comparative results are presented, and a greater focus is put on PIRa. The reader is

TABLE 2 Calculated effective heat of combustion for plastic foams with no protective layer

Effective Heat of Combustion, kJ/g				
Integration Time	PIRa	PIRb	PIRc	PF
Total test time (t_{end})	19.09 ± 1.99	18.05 ± 2.48	20.52 ± 3.45	20.98 ± 6.01
Up to 200 s (initial flaming)	14.38 ± 0.68	13.22 ± 1.30	16.26 ± 0.84	15.35 ± 0.80

Abbreviations: PIR, polyisocyanurate; PF, phenolic foam.

referred to Hidalgo[35] for assessing the differences in behaviour for 3 different PIR foams.

Phenolic foam was found to have a similar behaviour to PIR, proceeding to char formation after flaming and to smoulder after flame out at the surface. As shown in previous studies,[31] the critical heat flux for ignition is larger than PIR (10-15 kW/m^2 for PIR and 22 kW/m^2 for PF); however, its surface regression by smouldering after ignition was shown here to be much faster. Phenolic foam tended to spall and crack very easily during heat exposure and presented a more brittle behaviour. Popping and snapping sounds could be heard during testing. Discolouration was observed, changing from pink-brown to yellow and finally black colour during the process of thermal degradation. This discolouration is discussed in further sections.

4.1.2 | Normalised mass

Figure 4 shows the average curves of normalised mass from 2 repetitions for PIRa and PF without protective layer at the surface of the samples. For simplicity in the visual assessment of the different evolution of the tests, the mass data are presented as a normalised mass. The normalised mass here refers to the ratio between the mass at any time and the initial mass of the sample before the start of test ($m(t)/m_0$). Therefore, a normalised value of 1 indicates the initial state where the mass of the sample is equal to the initial mass of the sample; a value of 0 indicates that the whole sample has been consumed. For high heat fluxes, samples were tested until near complete consumption of the sample (5% of the mass). Tests at lower heat fluxes (25-45 kW/m^2 for PIR and 25 kW/m^2 for PF) were interrupted earlier, and the sample was removed as no significant flaming was visible anymore. It should be noted that the sample holder materials also experienced loss of mass; therefore, the normalised measurement includes a maximum error or overestimation of up to 5%. This explains why the curves presented in Figure 4 reach an absolute normalised mass of 0 in some instances. Due to the unknown mass loss evolution of the sample holder, a correction has not been applied as this would include further uncertainty in the data outputs.

The mass loss curves of PIR present a reducing slope throughout the tests, indicating that the pyrolysis front was moving through thickness leaving a protective char, thus decreasing the rate of pyrolysis. However, since smouldering was also experienced at the surface of the sample after charring, the change of slope also includes this phenomenon. Phenolic foam mass loss curves are more linear than the ones observed for PIR, while PF mass loss is also observed to be larger than PIR for the same heating conditions. This behaviour is indicative of a more severe consumption of the char at the surface by oxidation (smouldering) for PF. This is consistent with thermogravi-

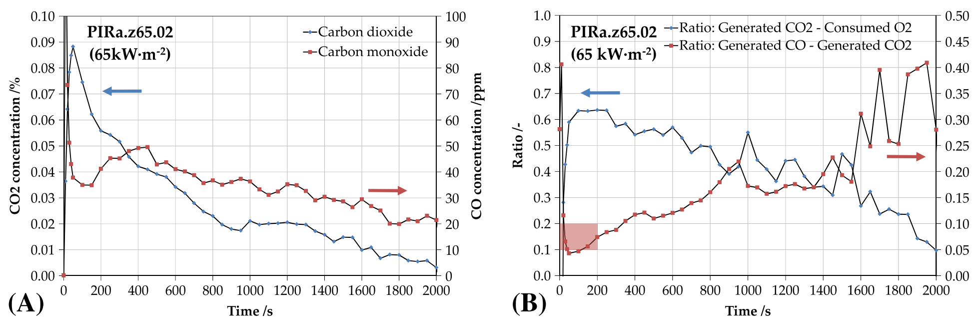

FIGURE 6 A, CO_2 and CO concentrations and B, ratios of generated CO_2 vs consumed O_2 and generated O_2 vs generated CO for PIRa at 65 kW/m^2. The shading denotes the ratio of CO/CO_2 during flaming. PIR, polyisocyanurate; PF, phenolic foam [Colour figure can be viewed at wileyonlinelibrary.com]

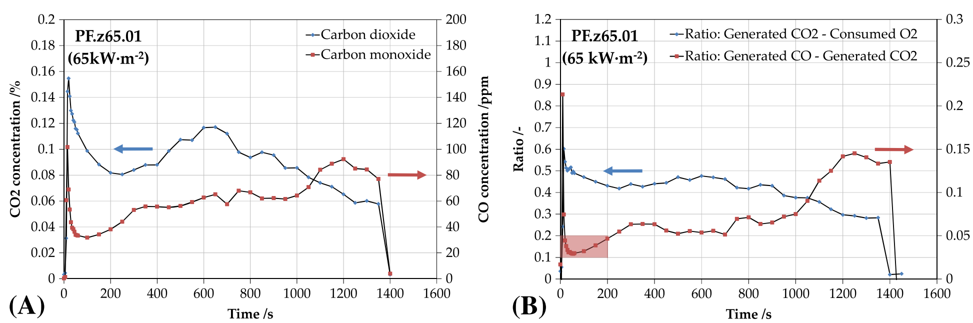

FIGURE 7 A, CO_2 and CO concentrations and B, ratios of generated CO_2 vs consumed O_2 and generated O_2 vs generated CO for PF at 65 kW/m^2. The shading denotes the ratio of CO/CO_2 during flaming. PIR, polyisocyanurate; PF, phenolic foam [Colour figure can be viewed at wileyonlinelibrary.com]

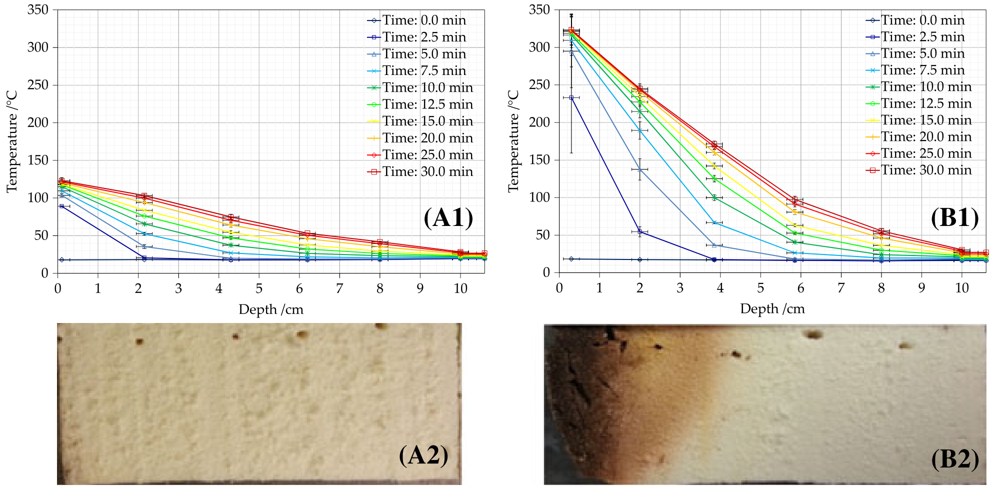

FIGURE 8 In-depth thermal profiles of PIRa at 10 kW/m^2 A1, with and B1, without protective layer. Centre section for the end of the tests A2 and B2. Horizontal error bars: estimated error of ±2 mm in thermocouple positioning. Vertical error bars: standard deviation between 2 repeated tests. PIR, polyisocyanurate [Colour figure can be viewed at wileyonlinelibrary.com]

metric experiments presented elsewhere,[31] which indicated that while PIR presents its main pyrolysis (250°C-350°C) and oxidation (500°C-650°C) domains in 2 different temperature regions, the PF main pyrolysis (400°C-500°C) and oxidation (480°C-550°C) slightly overlap in the same temperature region.

4.1.3 | HRRPUA and effective heat of combustion

Figure 5 shows the average HRRPUA from 2 repetitions for PIRa and PF. In general, PIR samples showed lower HRRPUA than PF throughout the test, except for the peak of HRRPUA. The burning behaviour of PIR and PF showed similar trends, with a large peak of HRRPUA right after ignition, followed by a progressive decay, which is characteristic of charring materials. This is generally expected for any PIR. Nevertheless, PF showed a decay of HRRPUA after the first peak, but an increase for high heat fluxes, which reflects a faster consumption of the char layer.

Table 2 shows the calculated values for the effective heat of combustion for plastic foams PIRa, PIRb, PIRc, and PF. In general, it is observed that the heat of combustion obtained for the pyrolysis gases (flaming) is lower than the effective value obtained considering the total test time.

4.1.4 | Gas species correlations and yields

Figure 6 shows a selection of gas species correlations of specific tests from PIRa and PF, where high heat fluxes are selected to represent clearly the different phenomena taking place. The charts on the left indicate the CO_2 and CO concentrations, while those on the right indicate the ratio of generated CO_2 versus consumed O_2, and the ratio of generated CO versus CO_2.

For PIR and PF, the CO/CO_2 ratio tended to increase greatly during the progress of the test, suggesting a transition from flaming to smouldering combustion, with both phenomena occurring simultaneously during some periods of the test. A ratio between 0.05 and 0.10 is observed during flaming combustion (time before 200 s) for PIR, and between 0.025 and 0.05 for PF; these values are highlighted in Figures 6 and 7, respectively, with a shading. It is difficult to

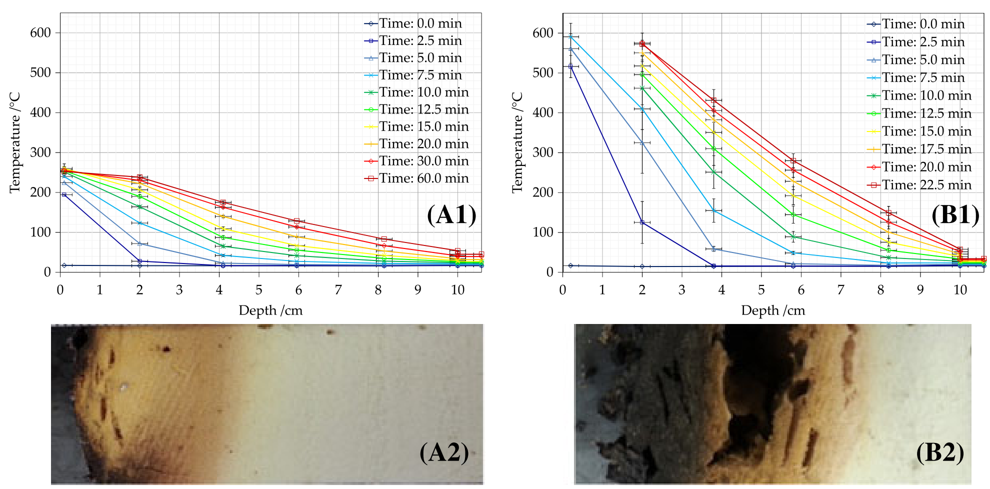

FIGURE 9 In-depth thermal profiles of PIRa at 25 kW/m^2 A1, with and B1, without protective layer. Centre section for the end of the tests A2 and B2. Horizontal error bars: estimated error of ±2 mm in thermocouple positioning. Vertical error bars: standard deviation between 2 repeated tests. PIR, polyisocyanurate [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 10 PIRa sample residue at 25 kW/m^2 without protective layer up to 22.5 minutes A, top view, B, lateral view, and C, lateral view from section. PIR, polyisocyanurate [Colour figure can be viewed at wileyonlinelibrary.com]

establish a constant value since a steady state is not clearly observed. A clear transition from flaming to smouldering combustion cannot be identified as local edge effects are present, thus allowing for flaming at the edges while smouldering occurs at the top surface. The ratio CO/CO_2 continues to increase as the pyrolysis rate and flaming combustion decrease.

Regarding the CO_2/O_2 ratio, a short steady state was initially obtained for PIR, suggesting only flaming combustion from PIR pyrolysates. This continued to decrease during the period of the test indicating the transition to a different burning regime, probably with char being consumed by oxidation and fewer pyrolysis gases being produced due to the spread of the pyrolysis front through thickness. Similar results were obtained for PF, despite the decrease occurring much earlier, followed by a transition to a quasi–steady state. This might be indicative of oxidation of char and flaming of pyrolysis gases occurring simultaneously. At the final stage of the test, this was reduced again, probably mainly due to the oxidation of char.

4.2 | Thermal degradation mapping

4.2.1 | Isocyanurate-based polyurethane foam (PIR)

Figure 8 shows the time history of the in-depth temperature profile for PIRa experiments tested at 10 kW/m^2 with (Figure 8A) and without (Figure 8B) the protective layer at the surface. The in-depth temperature profile is presented for a series of time steps during the test (ie, from 0 to 10 min using a time step of 2.5 min, and from 10 to 30 min using a time step of 5 min). Vertical error bars show the standard deviation from 2 repetitions for each thermocouple position. Horizontal error bars indicate the estimated error in the thermocouple positioning. The results from experiments shown in Figure 8A show good repeatability, while those presented in Figure 8B show worse repeatability, especially for temperature measurements near the surface. This is attributed to the nonuniform thermocouple positioning for repeated experiments, which has a larger impact for measurements near the surface potentially due to the swelling of the material during the thermal decomposition process.

Figure 8A shows a case study where no thermal degradation was observed. Positions close to the surface achieved a quasi-steady temperature in early stages (from 2.5 min), with a maximum value of 123°C ± 4°C. The temperature profile achieved a quasi–steady state after 20 to 25 minutes, with a minimal rate of temperature increase (<1°C/min) for inner positions. The displacement of the thermal gradient towards higher temperatures for inner positions and with steady temperature at the surface is due to the back-boundary layer. The metallic plate, which acts as a heat sink, was slowly increasing in temperature because the thermal wave had reached the sample back face and, consequently, heat was transferred to the plate. The sample section in Figure 8A2 shows that no discolouration was produced in the foam and, consistently, no release of volatiles was observed during the tests.

Figure 8B presents a case study where thermal degradation was observed at the surface of the sample. Thermal gradients were significantly larger than those shown in Figure 8A1, indicating the clear effect of the protective layer on the thermal performance. Positions close to the surface achieved a quasi-steady temperature after 5 minutes, with a maximum value of 323°C ± 20°C, while the temperature profile again achieved a quasi–steady state after 20 minutes, with a minimal rate of temperature increase (<1°C/min) for inner

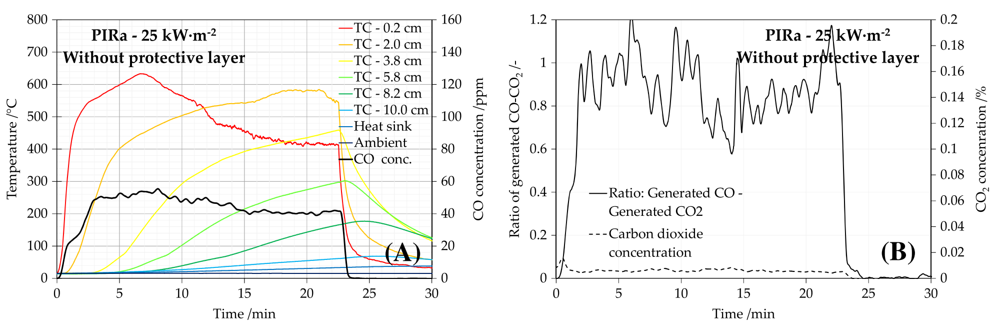

FIGURE 11 Time history of temperatures A, within the solid phase and CO concentration and B, generated CO vs generated CO_2 for PIRa with no protective layer at 25 kW/m^2. PIR, polyisocyanurate [Colour figure can be viewed at wileyonlinelibrary.com]

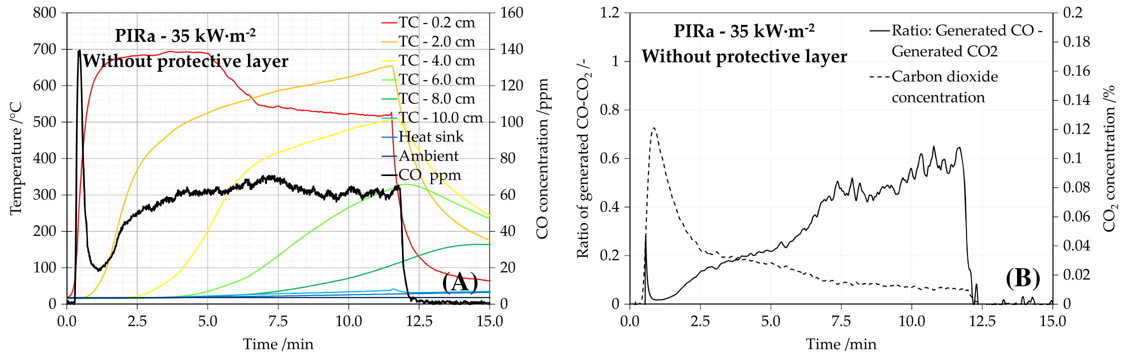

FIGURE 12 Time history of temperatures A, within the solid phase and CO concentration and B, generated CO vs generated CO_2 for PIRa with no protective layer at 35 kW/m^2. PIR, polyisocyanurate [Colour figure can be viewed at wileyonlinelibrary.com]

positions. Three clear tonalities in the discolouration experienced by the sample can be observed in the sample section in Figure 8B2. The discolouration is nonuniform, with higher degradation for regions near the centre line than near the edge. This indicates that the heat transfer was not behaving perfectly in a one-dimensional regime. Some cracking can be observed near the surface, where the discolouration is darker. Additionally, the sample thickness increased by up to 10 mm. A significant release of volatiles was observed after 3 to 4 minutes, but with no ignition during the experiment. Measurements of CO_2 and CO did not present noticeable concentrations compared to the initial baseline; therefore, these are not presented, which confirms that no significant oxidation was produced.

Figure 9 shows the in-depth temperature profiles for PIRa experiments tested at 25 kW/m^2 with (Figure 9A) and without (Figure 9B) the protective layer at the surface. The results from experiments shown in Figure 9A show good repeatability, with vertical error bars being noticeable only for the surface thermocouple. The results from experiments shown in Figure 9B, however, present worse repeatability with the error bars being significantly larger for the 3 first thermocouples. This nonuniformity is attributed to the positioning and, more importantly, to the degradation processes forming cracks within the sample and likely different rate of surface oxidation. Significant differences were observed between the performance of the samples with and without the protective layer, which are attributed to the effect that the protective layer has on the radiation absorption due to its low emissivity, and the blocking of air from contact with the surface, thus reducing or cancelling the surface oxidation for those conditions of heating exposure.

Figure 9A presents a case study where small thermal degradation was observed. Positions close to the surface achieved a quasi-steady

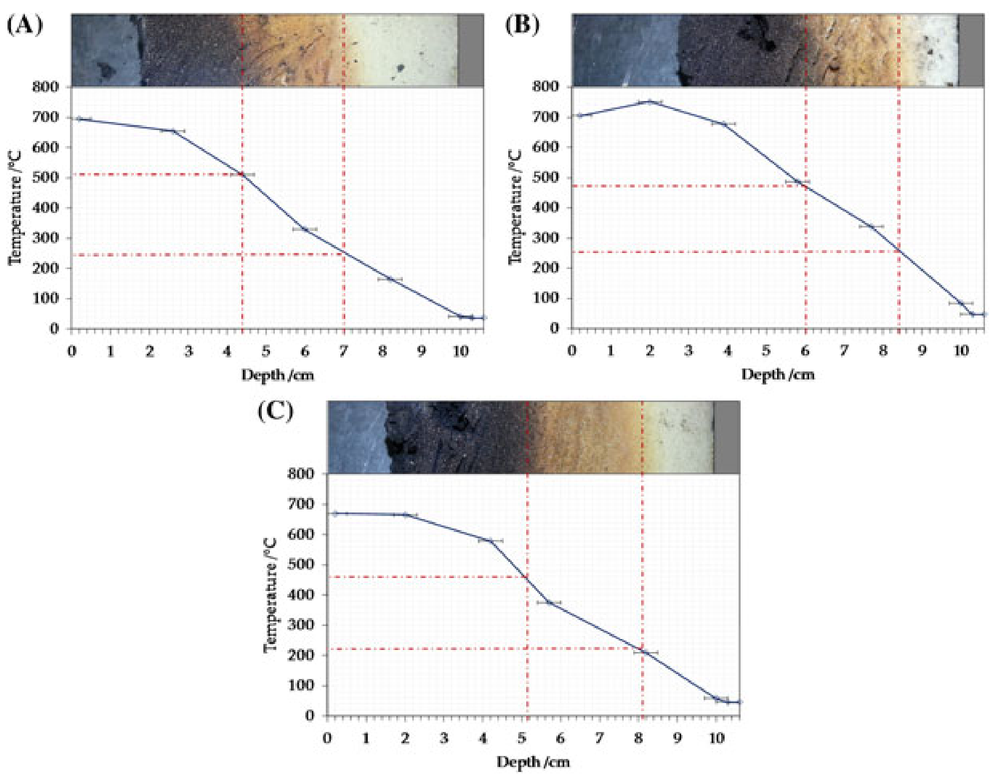

FIGURE 13 Maximum in-depth temperature profile of A, PIRa; B, PIRb; and C, PIRc at 35 kW/m^2 (no protective layer). Horizontal error bars: estimated error of ±2 mm in thermocouple positioning. PIR, polyisocyanurate [Colour figure can be viewed at wileyonlinelibrary.com]

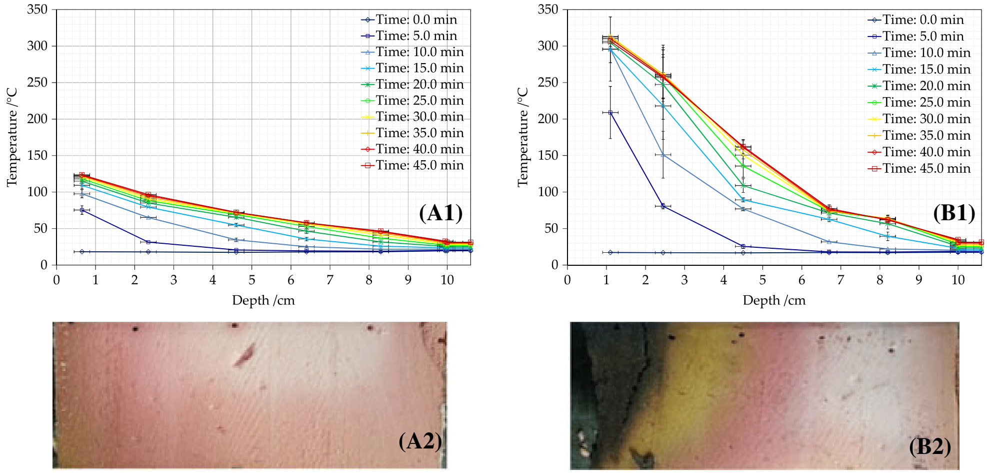

FIGURE 14 In-depth thermal profiles of PF at 10 kW/m^2 with A1, and without protective layer B1. Centre section for the end of the tests A2 and B2. Horizontal error bars: estimated error of ±2 mm in thermocouple positioning. Vertical error bars: standard deviation between 2 repeated tests. PF, phenolic foam [Colour figure can be viewed at wileyonlinelibrary.com]

temperature after 2.5 to 5 minutes, with a maximum value of 252°C ± 5°C, while the temperature gradient achieved a quasi–steady state after 30 minutes, with a minimal rate of temperature increase (<0.5°C/min) for inner positions. Two different tonalities can be observed in the sample section shown in Figure 9A2. This indicates that the heat transfer could be considered as a one-dimensional regime. Small cracks can be observed near the surface. Darker tonalities near the edge of the surface, where the foil ends, might be indicative of an edge effect with lower cooling, therefore presenting higher temperatures. Measurements of carbon dioxide and carbon monoxide did not show concentrations displaced from the baseline, confirming that no oxidation occurred. The sample appeared to have slightly expanded by up to 3 mm.

Figure 9B shows a case study where severe thermal degradation was observed. Positions close to the surface achieved a maximum temperature of 591°C ± 34°C at 7.5 minutes. The lack of measurements from the first thermocouple for the subsequent time steps indicates its detachment from the solid due to consumption of the surrounding material. No steady state was observed for the thermal gradient during the final time steps, with the temperature increasing at a rate of 9°C/min to 10°C/min for inner positions. This rapid rate of temperature change indicates the consumption of material at the surface, thus moving the exposed boundary to lower positions. Three to 4 tonalities can be observed in the sample section shown in Figure 9B2: yellow (virgin material), orange-brown discolouration, and black (char). Small cracks were obtained between the interface of virgin material and orange discolouration, while a series of large cracks can be observed in the brown region, below the char. A thickness regression of approximately 15 mm was obtained, indicating that a significant amount of material was consumed due to surface oxidation.

Figure 10 shows the sample residue from different perspectives for the test presented in Figure 9B (25 kW/m^2 without protective layer for 22.5 min). The surface of the sample presents complex morphology characterised by craters formed by surface oxidation. It can be observed that the char at the edges and lateral sides of the sample presents a smooth morphology, indicating that oxidation did not take place. This is consistent with the set-up that uses aluminium foil to prevent air penetration through the sides, thus limiting oxidation to the top surface.

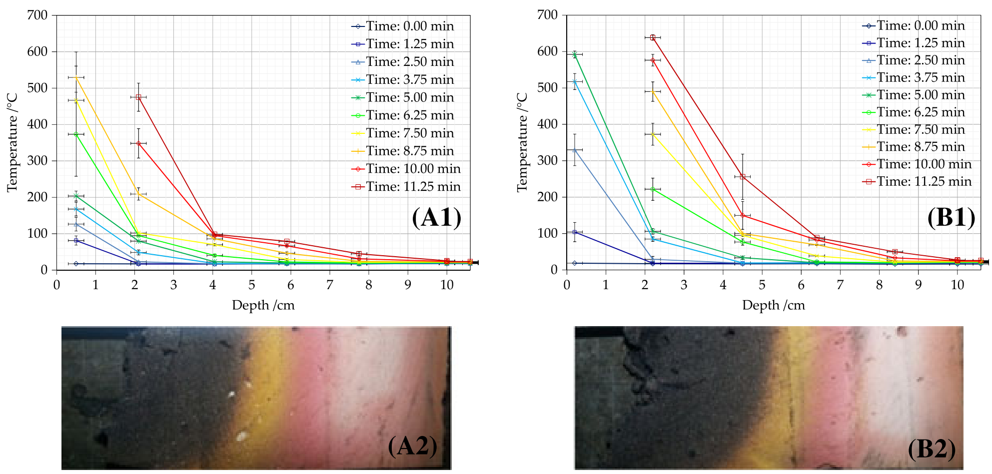

FIGURE 15 In-depth thermal profiles of PF at 25 kW/m^2 with A1, and without B1, protective layer. Centre section for the end of the tests A2 and B2. Horizontal error bars: estimated error of ±2 mm in thermocouple positioning. Vertical error bars: standard deviation between 2 repeated tests. PF, phenolic foam [Colour figure can be viewed at wileyonlinelibrary.com]

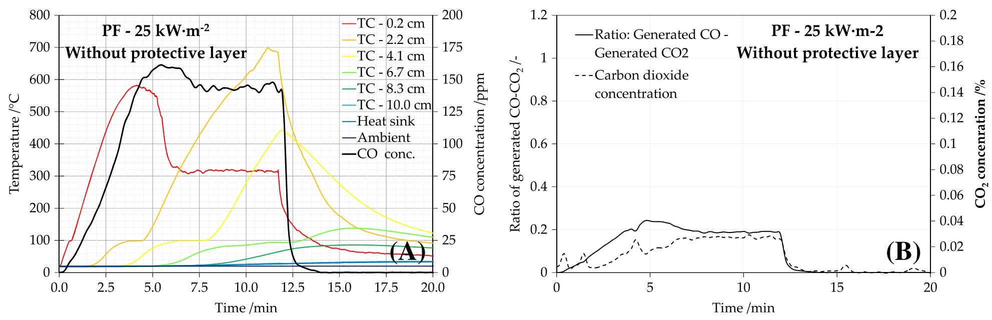

FIGURE 16 Time history of temperatures A, within the solid phase and CO concentration and B, generated CO vs generated CO_2 for PF without protective layer at 25 kW/m^2. PF, phenolic foam [Colour figure can be viewed at wileyonlinelibrary.com]

A large amount of volatiles were released from the start of the test, shown in Figures 9B and 10, but ignition was not achieved. Despite the fact that the heat flux used was above the critical heat flux, a pilot spark was not used. The release of volatiles continued to decrease after 1 minute. Measurements of carbon monoxide are presented in Figure 11A with the time history of temperature measurements. The concentration of CO increased almost from the beginning, probably indicating generation of pyrolysates. The shape of the CO curve changed slope from 2 to 3 minutes, and thereafter the CO generation remained approximately under a steady state during the rest of the test. A slight decrease between 10 and 15 minutes was also observed. These measurements are indicative of smouldering combustion (surface oxidation), with a high CO/CO_2 ratio between 0.8 and 1.2, as shown in Figure 11B. The concentration of CO_2 remained very low in comparison to the generation of CO_2 presented by flaming of PIR pyrolysates in the previous section. Additionally, it is shown that the smouldering was not self-sustained since the thermal gradient and CO generation dropped significantly after the removal of the external heat source. This is due to the closed-cell structure of the foam that does not allow the free circulation of oxygen through the sample, limiting the oxidation to the top surface; therefore, the generation of heat is drastically reduced once the external heat source is removed.

A more severe case study is presented in Figure 12, corresponding to a PIRa sample tested at 35 kW/m^2 without protective layer. The sample auto-ignited after 5 seconds of heat exposure, introducing a different regime that was not observed previously for this experimental series, but for the first series studying heat release. Figure 12A shows the time history of temperatures within the solid phase and the concentration of generated CO. The thermal evolution within the solid was similar to that presented in Figure 11A, but with a faster heating rate. The generation of CO followed a different pattern due to flaming combustion, which was confirmed by the CO_2 concentration presented in Figure 11B. The CO/CO_2 ratio increased over time, indicating simultaneous flaming and smouldering. This is consistent with the behaviour presented in the previous section.

The behaviour from PIRb and PIRc foams was similar to the one presented above. The upper edge of the temperature envelopes for PIRa, PIRb, and PIRc at 35 kW/m^2 is presented in Figure 13, with a section of the sample after the test. The temperature values were interpolated for the interface between the 3 main regions of discolouration (yellow, orange-brown, and black). In general, the first interface was found between 220°C and 260°C, while the second interface was identified between 460°C and 520°C. The first set of temperatures agrees with the value obtained before the onset of the main peak of pyrolysis observed in DTGs under nitrogen atmospheres by Hidalgo et al.[31,35] The second set of temperatures corresponds to the thermal range in which no more significant pyrolysis is obtained under nitrogen atmospheres. Maximum temperatures measured in the solid phase, presented Figure 13, were near 700°C. Thermogravimetric analyses under air atmospheres (50 mL/min flow with 21% of oxygen) showed that the full consumption of mass terminates below 600°C, which indicates that the diffusion of oxygen then dominates the combustion of char at the surface. However, further assessment is required to characterise the mechanisms that govern the combustion of this char.

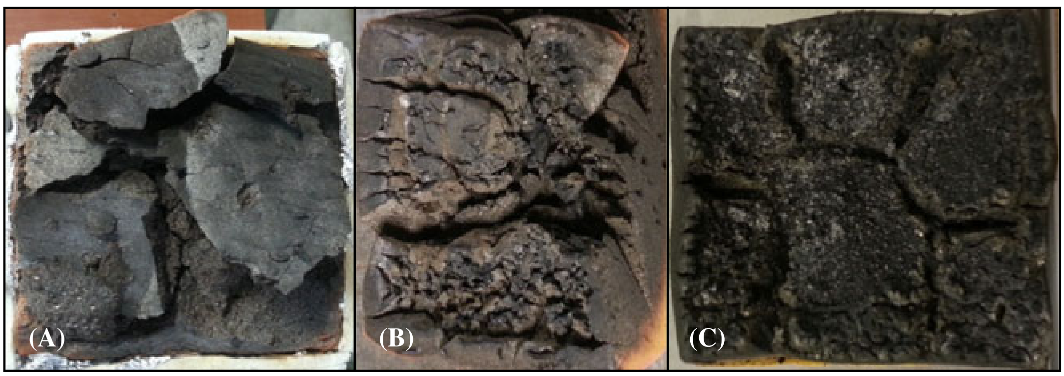

FIGURE 17 PF sample residue at A, 10 kW/m^2; B, 15 kW/m^2; and C, 25 kW/m^2 without protective layer [Colour figure can be viewed at wileyonlinelibrary.com]

4.2.2 | Phenolic foam

Figure 14 shows the time history of the in-depth temperature profile for PF experiments tested at 10 kW/m^2 with (Figure 14A) and without (Figure 14B) protective layer at the surface. The results from experiments shown in Figure 14A present good repeatability in the experiments, while those from experiments shown in Figure 14B present worse repeatability, especially for temperature measurements obtained by the 2 first thermocouples. This is attributed to the nonuniformity of the thermocouple positioning and especially to the thermal degradation observed, with char being detached from the surface.

Figure 14A presents a case study where no clear thermal degradation was observed. Positions close to the surface achieved a quasi–steady state from 10 minutes, with a maximum value of 124°C ± 1°C. The temperature profile achieved a quasi–steady state from 15 to 20 minutes, with a minimal rate of temperature increase (<1°C/min) for inner positions. A change in the slope of the thermal profile was obtained near the second thermocouple once the steady state was achieved. The sample section displayed in Figure 14A2 shows that some discolouration of a darker pink tonality was produced near the surface. Additionally, the sides and bottom of the section have different tonality than the centre, which indicates that material suffers from oxidation at ambient temperatures. No release of volatiles was observed during the tests.

Figure 14B presents a case study where clear thermal degradation was observed at the surface of the sample. Thermal gradients were significantly larger than the ones shown in Figure 14A, indicating the clear effect of the protective layer on the thermal performance again. The temperature close to the surface achieved a quasi–steady state after 10 minutes, with a maximum value of 296°C ± 44°C at this time step. The temperature profile achieved a quasi–steady state from 25 minutes, with a minimal rate of temperature increase (<1°C/min) for inner positions. The in-depth temperature profile during the steady state shows an interesting shape, with 2 different slopes converging at 78°C, indicating temperature dependency of the thermal properties and/or endothermic processes at lower temperatures. This is consistent with the change of slope observed in Figure 14A. Four clear tonalities in the discolouration experienced by the material can be observed in the sample section shown in Figure 14B2. The degradation seems to be nonuniform, with higher degradation for regions near the centre line than near the edge. This indicates that the heat transfer was not behaving perfectly as a one-dimensional regime. Cracks and delamination can be observed within the first 20 mm from the surface, in the char area, as shown in Figure 17A. Delamination is probably due to spalling from the sample; popping and snapping sounds could be heard during the experiment. No significant surface regression or oxidation was observed, but measurements of carbon dioxide and carbon monoxide indicated low concentrations compared to the initial baseline. This is indicative of minor oxidation from the delaminated pieces.

Figure 15 shows the in-depth temperature profiles for PF experiments tested at 25 kW/m^2 with (Figure 15A) and without (Figure 15B) the protective layer at the surface. The results shown in Figure 15A,B present good repeatability except for the first thermocouples. Slightly better performance was observed for the samples with a protective layer (Figure 15A) than those without (Figure 15B), with lower thermal gradients for same times of exposure.

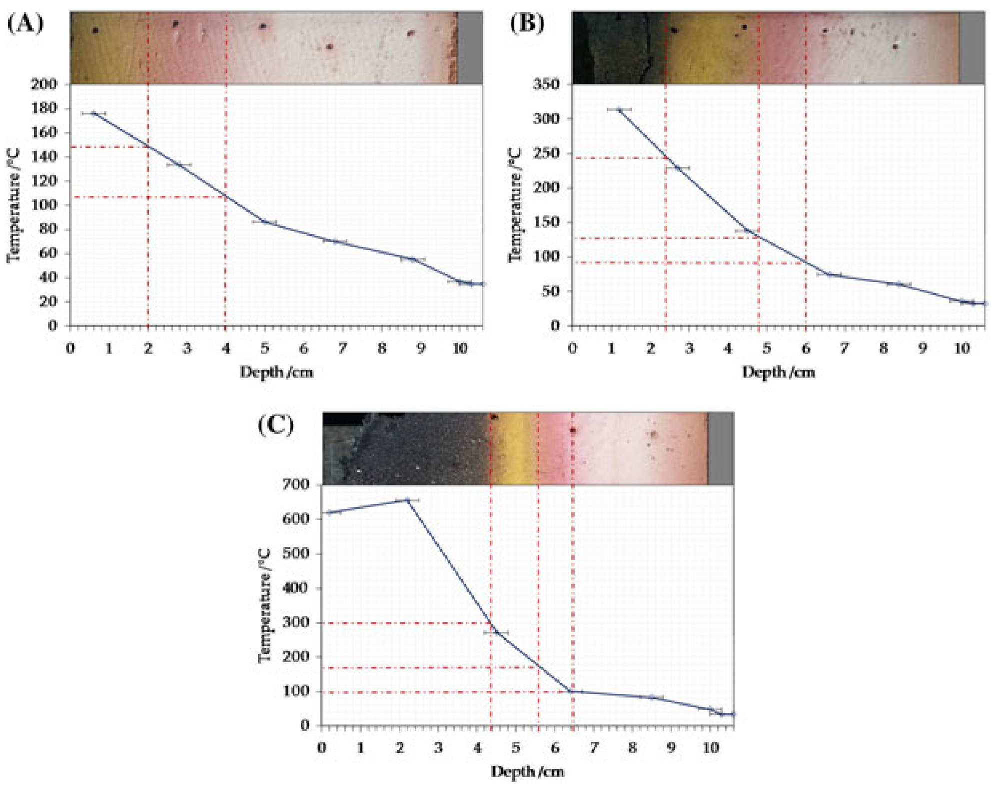

FIGURE 18 Maximum in-depth temperature profile of PF: A, 15 kW/m^2 (foil); B, 10 kW/m^2 (no foil); and C, 25 kW/m^2 (no foil). Horizontal error bars: estimated error of ±2 mm in thermocouple positioning. PF, phenolic foam [Colour figure can be viewed at wileyonlinelibrary.com]

However, the protective layer did not prevent the onset of thermal degradation.

Figure 15A presents a case study where the effectiveness of the protective layer was lost after certain temperature and thermal degradation was eventually achieved. The temperature profile close to the surface showed a moderate rate of temperature increase around 30°C/min to 50°C/min until 5 minutes, achieving a temperature of 204°C ± 14°C, at which point the rate of increase rose significantly since the protective layer started to detach and lift after 4 minutes of heat exposure. As a result, the temperature near the surface achieved a maximum value below 600°C at around 9 minutes, when the thermocouple detached from the initial position due to consumption of the surrounding material. Approximately 20 mm of material was consumed by the end of the tests. Four different uniform tonalities can be observed in the sample section between the edge and the centre line, as shown in Figure 15A2, indicating that the heat transfer could be considered essentially as a one-dimensional regime. No cracks within the core of the sample were obtained, but the top of the sample presented a rough surface with some random cracks. Measurements of carbon dioxide and carbon monoxide showed concentrations displaced from initial baseline, confirming the occurrence of solid-phase oxidation. For simplicity, these results are not presented herein, but for the case shown in Figure 15B, which is equivalent.

Figure 15B shows a case study where severe thermal degradation was observed from early times in the test (2.5 min). The temperature close to the surface achieved a maximum value of 592°C ± 10°C at 5 min. No steady state was observed for the thermal gradient during the final time steps, with the temperature increasing with a rate of 9 to 10°C/min for inner positions. This rate was only observed for positions with a temperature higher than 100°C, indicating a clear endothermic effect at that temperature range. A high rate of temperature increase, without achieving the steady state, indicates the consumption of material at the surface, thus moving the exposed boundary to lower positions. The thermal degradation experienced was similar to that shown in Figure 15A. The surface of the material is presented in Figure 17C, showing crater morphology on the edges and rough surface and random long cracks expanding from the centre to the edges.

Measurements of carbon monoxide are presented in Figure 16A with the time history of temperature measurements. The concentration of CO increased until 5 minutes, when it achieved a steady state at around 150 ppm. These measurements are indicative of smouldering combustion (surface oxidation), suggesting a constant rate of oxidation. Similarly, the CO/CO_2 ratio increased until 5 minutes as shown in Figure 16B, remaining approximately constant at around 0.2. The concentration of CO_2 remained very low in comparison to the generation of CO_2 presented for the flaming of PF in previous sections. Additionally, it is shown that the smouldering was not self-sustained since the thermal gradient and CO generation dropped significantly after removing the external heat source. This is due to the closed-cell structure of the foam that does not allow the free circulation of oxygen through the sample. Additionally, a plateau of temperatures was clearly observed below 100°C in Figure 16A, indicating an endothermic reaction, probably due to water desorption in the polymer.

Images from the surface of the remaining residue for PF experiments without the protective layer at 10, 15, and 25 kW/m^2 are shown in Figure 17. Different patterns indicate the significance of surface oxidation. Figure 17A shows the occurrence of the delamination effect when the achieved temperatures are not high enough to trigger the oxidation of the char created. Figure 17B shows that the oxidation at the surface is not homogenous, indicating the high complexity of the oxidation mechanism, while Figure 17C shows the case of a smouldering process with relatively constant rate of surface regression as shown in Figure 16.

The upper edge of the temperature envelopes for different experiments are presented separately in Figure 18, together with a section of the sample after the test. Temperatures values were interpolated for the interface between the 3 main regions of discolouration (light pink, dark pink, orange-brown, and black). In general, the first interface, which was observed as a plateau of temperature in Figure 18A, was around 100°C, near the change of slope in the thermal gradient. The second interface was identified between 125°C and 160°C, which agrees with the temperature before the first peak of pyrolysis observed in DTGs under nitrogen atmospheres in Hidalgo et al.[32,36] The third interface was identified between 250°C and 300°C, which agrees with the temperature between the first and second peak of pyrolysis observed in DTGs under nitrogen atmospheres. Maximum temperatures measured in the solid phase and shown in Figure 18 were between 600°C and 700°C, while thermogravimetric analyses under air atmospheres showed that all mass consumption ends below 600°C in an air atmosphere. This indicates that the diffusion of oxygen probably dominates the combustion of char at the surface.

5 | SUMMARY

This paper has presented the results from 2 experimental programmes on the basis of ad hoc cone calorimeter tests. This work aimed to investigate the fire performance of charring closed-cell polymeric insulation materials, specifically PIR and PF, so that a comprehensive protocol can be set for assessing the evolution of hazard imposed by the material. The first experimental programme macroscopically analysed the fire performance of these foams by studying HRR, mass loss, and gas species. The second programme mapped the thermal degradation processes in relation to temperature measurements within the solid phase, correlating the evolution of the thermal profile experienced by the material to previous results obtained by thermogravimetry.

The first series of experiments was based on 100-mm-thick samples tested using the cone calorimeter (with spark igniter) and reproducing levels of irradiation from the critical heat flux up to 65 kW/m^2. Calorimetry calculations for PIR and PF samples showed the typical shape obtained from charring materials. A peak of HRRPUA between 120 and 170 kW/m^2 was observed for PIR, with a decay below 60 kW/m^2 represented by the formation of a char layer and the transition of the pyrolysis front towards inner depths. The peak HRRPUA for PF was observed to be in the range 80 to 140 kW/m^2, with a decay and subsequent increase or decrease depending on the external heat flux. Despite its larger critical heat flux for ignition, PF showed larger mass loss and surface regression for the same conditions of heat exposure after a certain time. This is attributed to the overlapping of pyrolysis and char oxidation reactions in a close temperature range for PF, while PIR presents clearly separated temperature ranges for the pyrolysis and char oxidation reactions. The effective heat of combustion for PIR was found to be in the range of 13 to 21 kJ/g, while for PF, the range was 15 to 21 kJ/g. Complimentary gas analyses demonstrated different regimes of combustion for PIR and PF, ie, flaming at the surface with a CO/CO_2 ratio between 0.05 and 0.10 for PIR, and between 0.025 and 0.05 for PF, followed in both cases by smouldering of the char left at the surface, with intermittent flaming at sides and an increasing CO/CO_2 ratio as flaming was reduced. These phenomena may occur simultaneously, depending on the displacement speed of the pyrolysis front and the oxidation rate at the surface.

The second series of experiments was primarily concerned with understanding the thermal evolution and dynamics of the thermal degradation experienced by PIR and PF. This stage was based on 100-mm-thick samples tested with the cone calorimeter (without spark igniter), and reproducing heating scenarios with different severities. Measurements of temperature within the insulation allowed mapping of the different thermal degradation processes, which were previously identified by thermogravimetric techniques. Measurements of gas species (carbon monoxide, carbon dioxide, and oxygen) were also taken to determine whether oxidation processes occurred, ie, flaming from the pyrolysis gases or smouldering from the char generated after pyrolysis.

A technique based on comparing the eventual thermal discolouration through the thickness of a sample was correlated to the upper edge of the temperature envelopes during the test and the thermogravimetric results. Three clear domains were observed in the thermal evolution of PIR and PF, corresponding to the virgin material, pyrolysis region, and char. Polyisocyanurate was found to expand in the regions where it was pyrolysing, creating a series of cracks or gaps within the structure of the foam. Phenolic foam, however, spalled, probably due to the loss of chemically bound water, which was evidenced by plateaus of temperature around 100°C. A clear effect was observed in the thermal performance of the rigid foams such as PIR and PF when samples were tested with the protective layer attached to the exposed surface. This is related to the reduction of the fraction of absorbed heat flux due to the low emissivity of the protective layer, as well as other effects such as the reduction in the rate of oxidation, via avoiding the contact of oxygen with the charred material or the inhibition of a good mixing between air and pyrolysates.

While the pyrolysis was clearly governed by the thermal evolution of the solid phase for these charring materials, the rate of oxidation was identified as a diffusion-controlled mechanism. Indeed, values of temperature higher than those obtained by thermogravimetry under air conditions were observed within the char. The rate of oxidation of the char was also found to be governed by the external heat flux, which also determined the evolution of the pyrolysis front. The smouldering process of the char remaining after pyrolysis from PIR and PF was found to self-extinguish after the external heat source was removed. This indicates that the generated heat from the char oxidation at the surface, with the particular heat losses obtained for the tested conditions, was not sufficient to sustain the process. Additionally, the closed-cell structure does not allow the diffusion of air through the foam, thus limiting the smouldering.

Further work should focus on modelling tasks to characterise the thermal behaviour and pyrolysis of these materials. Additionally, the mechanism of char oxidation should be further investigated.

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Appendix C – BESS and Solar Panel Technical Data

Energy storage system design Proposal - fire extinguishing system

Technical Requirements

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1 Technical conditions and standards

1.1 The equipment is manufactured to meet (but not limited to) the following specifications and standards:

1）T/CEC 373-2020 Technical specification for fire protection of prefabricated lithium iron phosphate battery energy storage power stations

2）GB 50116-2013 Design of automatic fire alarm systems

3）GB 50166-2019 Construction of automatic fire alarm system

4）GB 26851-2011 Fire sound and/or light alarms

5）GB 50370-2005 Design of gas fire extinguishing systems

6）GB 50253-2007 Construction of gas fire extinguishing systems

7）GB 50016-2014（2018） Fire protection design of buildings

8）GB/T 191-2008 pictorial markings for handling of packages

9）GB/T 2408-2008 Plastics - Determination of combustion properties - horizontal and vertical methods

10）GB 16670-2006 Pipe network gas extinguishing device

11）GB 51048-2014 Design of electrochemical storage stations

12）GB 15322-2019 Flammable gas detector

13）GB 50084-2001 Code for design of automatic sprinkler systems

14)GB 50370-2005 Code for design of gas fire extinguishing systems

15）NFPA 855 Specification for installation of stationary energy storage systems

16）NFPA 72 National Code for Fire Alarm and Signal

17）UL9540 Safety standards for storage systems

1.2 General design Principles

This project is considered in accordance with the first-level protection objects specified in GB 50116-2013 automatic fire alarm system. According to the principle of "safety first, prevention first", the automatic fire alarm system should strictly ensure the safety of the equipment and the reliability of the system, to avoid missing and false alarm of the system.

The design, construction and installation of the energy storage system and related equipment shall comply with the requirements of NFPA 855 General Requirements, Chapter 4 and, where applicable, the specific technical provisions of Chapters 9 through 13. The room where the energy storage system is installed should have a fire barrier with a fire rating of at least 2 hours and be separated from the rest of the building;

The NFPA72 National Code for Fire Alarm and Signal shall be in accordance with the code for quantitative constraints on the design, installation and maintenance of fire alarm systems.

The system should be advanced and applicable: the technical performance and quality indicators of the system have reached the international advanced level, and the man-machine interface is friendly, convenient to use, and the system is maintainable in the aspects of installation, debugging, operation and maintenance, and has the characteristics of wide applicability of the project, so as to achieve the best cost performance of the system.

In the system design, the interface and coordination between equipment and equipment and equipment and system should be clear, and it should conform to the corresponding standards and specifications and the general design requirements and concepts of the industry.

The design should fully consider the energy storage system is different from the general building fire demand, to maximize the energy storage system to ensure high safety and high reliability. Such as installation accessories should be matched with universal, standardized and modular high quality industrial products.

During system design, the system configuration should be optimized and the system layout should be coordinated to facilitate equipment maintenance and replacement.

The explosion-proof products used in the system design must provide proof of explosion-proof, and the whole set of fire control system must be sure to pass the relevant on-site fire control acceptance and capital requirements.

2 Main technical parameters

2.1 Fire protection system design requirements

1. The fire fighting system shall meet the design requirements of flammable gas, fire fighting system, water fire fighting (standby) and automatic fire alarm system of the box. It is recommended that the controller and fire extinguishing equipment be installed in a separate compartment or cabinet. The overall scheme is designed according to container-level fire protection.

2. Requirements for fire fighting methods. The battery container is designed according to combustible gas, fire extinguishing system and automatic fire alarm system. The fire extinguishing method adopts the combination of combustible gas, HFC-227 gas fire extinguishing system and standby water fire fighting; The inverter booster container is designed according to the automatic fire alarm system, and the fire extinguishing mode is hand-held dry powder extinguisher.

3. The control of the gas fire extinguishing system is controlled in two ways: automatic and electrical manual. That is, when someone is working or on duty, manual control should be adopted; In the case of no one, the automatic control mode should be adopted. The conversion of automatic/manual control mode can be realized on the fire control

controller (the gas start/stop button is set outside the protection zone, and the emergency stop and emergency start buttons are set inside the gas start/stop button).

4. Detector configuration requirements. According to the causes and characteristics of fire in different protection parts, the combination of heat and smoke fire detectors was used to detect and alarm the protected area. And it meets the requirements of the detection range of various detectors under the condition of the box. H2, CO, VOC combustible gas detectors, smoke detectors and temperature detectors should be installed in battery containers. Install smoke detectors and temperature detectors in the inverter booster container. The fire fighting host receives the signals of each detection controller, and uploads the operating status, working parameters, fault alarm signals and linkage control signals of the fire fighting system to EMS, BMS and the corresponding station fire fighting system.

5, fire alarm requirements: when there is only one kind of detector action in the protection area with detection and alarm system, only sound and light alarm signal is issued without fire instruction. When both detectors are operating, sound and light alarm signals will be issued, and fire extinguishing instructions will be issued after time delay (30 seconds adjustable), and the solenoid valve will be started to extinguish the fire.

6, sound and light alarm should be set in the protection area. Sound and light alarms and release signal signs should be set at the entrance of the protected area.

7. Protection area control mode: Protection area linkage adopts automatic and manual control modes. When someone is on duty near the protected area, manual control should be adopted. When no one is on duty near the protected area, the automatic control mode should be adopted. The conversion of mode is realized on the controller. When the controller sends out the alarm signal, if it is necessary to stop the release of fire

extinguishing agent under abnormal circumstances, the emergency stop button in the gas start stop button can be operated within the delay time to stop the implementation of the fire extinguishing instruction. If it is necessary to extinguish fire, but the alarm system has not enough time to alarm, you can operate the emergency start button to extinguish fire.

8. In order to ensure the reliability of fire fighting, necessary linkage operation should be ensured before or at the same time the fire extinguishing agent is released by the fire extinguishing system. That is, when the fire extinguishing system issues fire extinguishing instructions, the control system will issue linkage instructions to cut off the power supply, shut down or stop all the equipment affecting the fire extinguishing effect.

9. Water fire protection requires the DN65 quick interface reserved outside the container, which can be connected to the emergency rescue water source through the ground fire hydrant or rescue fire truck. In order to cool the container after fire and prevent battery reignition.

10. The communication mode adopts 485 communication or CAN communication. The fire control host receives the detection controller signal, and uploads the system operation status, working parameters, fault alarm signal and linkage control signal to EMS and BMS.

11. The exhaust air volume of the combustible gas alarm system is calculated according to the number of air changes of 60 times per hour, and the specifications, models and quantities of explosion-proof fans of two battery containers are configured (including the electric louves of the exhaust air). And inlet electric louver specifications and models.

12. Combustible gas detector shall have alarm threshold classification function (no less than level 2), and have the function of output node signal independently with different alarm threshold, and provide related linkage and functional process description.

13. The power supply of the fire fighting system must be compatible with the container's overall power distribution system, which can provide

AC220V power supply. In special cases, the power demand list should be provided.

14. In order to ensure the accuracy, safety and consistency of the on-site wiring of the fire fighting system between the compartments of the energy storage unit, it is suggested to add the fire fighting terminal box in each compartment of the energy storage unit as the fire fighting connection interface between the compartments.

2.2 Requirements for automatic fire alarm systems

2.2.1 Fire extinguishing system Requirements

The system carries out intelligent fire detection through compound detectors (H_2, CO, smoke VOC, temperature). A variety of methods such as fixed threshold and sensor trend are used to judge. When the temperature detector detects an anomaly or the smoke detector detects an anomaly in the judgment of "visible smoke", an early warning will be given. On the premise of early warning, if the temperature detector detects an anomaly in the "temperature characteristic value" and has a significant rising trend, a fire early warning should be given.

The detector shall be equipped with a variety of judgment methods: smoke, H_2, co concentration trend judgment, fixed temperature judgment, temperature rise judgment, the fire engine will judge that there is a fire accident in the protection area, enter the fire extinguishing device startup process in the protection area, and perform the start linkage control. When any detector in a protection zone outputs an early warning signal, the fire alarm controller will give a sound and light alarm prompt and perform alarm linkage control.

The detectors were placed within 3 meters of each other.

2.2.2 Fire alarm control unit

The fire alarm controller should be able to realize dynamic data acquisition, centralized processing data storage, system inspection, communication and other functions. It can make compound judgment of different grade signals from detector feedback. The failure of any address point device in the system does not affect the normal operation of other address point devices in the system, and can immediately display the code and address of the fault point.

When the main power supply fails, the control system shall be powered by the DC backup power supply provided by Party B and the backup power supply has the capacity to maintain the system for 3 hours.

The metal shell of the control engine shall be grounded, and its grounding wire shall be connected to the electrical protection grounding main line (PE).

2.2.3 Combined aural and visual alarm

The system has the function of early warning. When the system detects a fire hazard, the indoor and outdoor audible and visual alarms must have distinct sounds.

The audible and visual alarm meets the requirements of GB26851-2011 and GB50116-2013.

The power supply voltage of the audible and visual alarm is 24V DC.

2.2.4 User control switch

The user control switch shall be equipped with emergency start/stop function, and the staff shall be able to operate the fire extinguishing device outdoors after discovering the fire, and execute the system process according to the secondary fire signal of the main engine.

In addition, it is necessary to have manual/automatic switching device. When the personnel enter the energy storage station for maintenance, they can rotate the hand/automatic knob to switch the working state of the system. When the equipment is in manual state, the system will only sound and light alarm and will not start the fire extinguisher, but the forced start signal is still effective for the system; When the equipment is in full automatic state, the system automatically starts the fire extinguisher according to the starting process.

When the system is in the state of fire extinguishing program, the fire extinguishing program can be disconnected through the emergency stop button of the main engine, outdoor emergency stop button, and reset button.

The control switch device shall be equipped with a clear status display label.

2.3 Battery container fire extinguishing system and its accessories performance

2.3.1 Battery compartment pipe network type HFM-227EA gas extinguishing system

1. Protection mode: Adopt full submerged protection mode for containers, and set up a set of pipe network type HFM-227EA fire extinguishing device.

2. Equipment selection: Technical solution adopts HFM-227EA fire extinguishing system.

(1) High fire extinguishing efficiency: the designed fire extinguishing concentration (basically close to the fire extinguishing concentration of Halon 1301 fire extinguishing system (5-8%)) can effectively extinguish class A, B, C fires and electrical fires in the protection zone;

(2) Low toxicity: within the designed fire extinguishing concentration range, humans can stay for a long time without life danger, and it can be widely used in frequently occupied areas or workplaces;

(3) non-conductive: because of its good electrical insulation performance, it can be widely used to extinguish electrical fires;

(4) clean, pollution-free environmental performance: HFC-227ea ozone depletion potential value ODP is zero, no damage to the atmospheric ozone layer, after spraying all gasification, colorless, tasteless, pollution-free, through ventilation can achieve indoor air clean and no residue;

(5) Storage space: HFC-227ea can be stored in liquid state at room temperature, and the designed fire extinguishing concentration is low, saving storage space;

3. System operation and control mode: HFM-227EA fire extinguishing device shall have two starting modes: automatic control and manual control:

Automatic start: When the early warning and firefighting system is in automatic mode, the firefighting host can act by itself to participate in the system firefighting.

In automatic mode, when any of the following items are satisfied:

A) when the combustible gas reaches the first threshold warning;

b) Any action warning of the temperature sensing module or smoke sensing module;

The linkage logic is as follows:

1) The field controller is linked with the in-cabin and out-cabin audible and visual alarms to give early warning, and the in-cabin and out-cabin fire audible and visual alarms are controlled by the fire main engine.

2) a. When the first threshold of the combustible gas detector alarms, the gas fire extinguishing controller will linkage start the ventilation fan, open the shutter, and the BMS will jump open the cabin circuit breaker and cluster relay and cut off the air conditioning power. The flammable gas in the battery box is quickly discharged out of the box.

b. When the combustible gas concentration and battery temperature return to normal, turn off the fan, close the air conditioner, and close the contactor to ensure that the temperature and micro positive pressure system in the box are normal.

3) The fire fighting host in the battery cabin communicates with the fire fighting host in the fire control room to upload the early warning information; The BMS communicates with the EMS system and uploads the warning information to the EMS.

In the automatic control mode, when the following conditions are met:

A) The temperature sensing module and smoke sensing module operate early warning at the same time;

B) early warning of the second threshold of combustible gas;

The linkage logic is as follows:

a) The field controller links the in-cabin and out-cabin audible and visual alarms to send out early warning, and the in-cabin and out-cabin audible and visual alarms are controlled by the fire main engine.

b) Linkage with BMS, jump open the cabin circuit breaker through BMS, and shut down the fan; Remove the AC power supply in the power distribution box cabin by BMS; Activate the gas extinguishing system. If no emergency stop button is pressed outside the battery cabin and no remote stop command is issued in the fire control room within 30 seconds after receiving the start signal for gas firefighting, HFM-227EA will be started for fire extinguishing agent injection and the gas spraying indicator light outside the cabin will be started at the same time.

c) After the release of HFM-227E agent, the staff can judge whether there is reignition according to the on-site situation, and the battery compartment water fire fighting system will be remotely started by the fire main engine in the fire control room to put out the fire.

d) The fire fighting host in the battery compartment communicates with the fire fighting host in the fire control room to upload the early warning information and fire starting information; The field controller communicates with BMS to upload the early warning information and fire starting information. The BMS communicates with the EMS system and uploads the early warning information and fire start information to the EMS.

Manual start: Personnel can start the fire fighting system in the storage container through the emergency start/stop button of the fire controller host or the user control switch, and release the fire extinguishing agent after a certain time delay.

Mechanical start: When both automatic and manual start fail, mechanical emergency operation can be carried out according to the following steps: 1) Manually turn off the linkage equipment and cut off the power supply; 2) Pull out the "mechanical emergency start safety pin" on the electromagnetic drive device of the driving gas cylinder set in the corresponding protection zone, press the mechanical emergency start button, and the electromagnetic drive device will open the container valve of the driving gas cylinder set to release the driving gas and start the fire extinguishing equipment.。

4. System appearance

3 Appearance

1) The dimensions and installation dimensions of the battery compartment container fire extinguishing system meet the design requirements.

2) The battery compartment container fire extinguishing system shall have a nameplate, and the content marked on the nameplate shall be clear, complete and accurate, and fixed in an obvious visible position.

3) The surface of the silicon steel sheet of the battery compartment container fire extinguishing system is smooth and clean, without oil pollution and air bubbles, without burrs and sharp edges that may damage

the insulation, and the surface is flat, smooth and uniform in color.

BESS AC COUPLE SOLUTIONS

900kWp I 1000kW I 1133.73kWh usable

PREFACE:

This proposal is based on the information and technical inputs provided by Kuga Electrical. Valid for **6 weeks.**

With the provided information by our client correctly we are confident that this proposal would meet all the requirements of this project, any project technical requirements changes would lead to related changes in our proposal. This proposal is indicative non-binding in nature, should we be able to confirm all aspects and assumptions, we will be glad to deliver an offer with same commercial terms.

To proceed the project with this proposal officially, we need the following documents from Kuga Electrical

- ✓ Proposal acceptance letter or email with the requirements confirmed.
- ✓ Purchase Order document with signature.
- ✓ Proforma Invoice countersigned by both parties.
- ✓ Deposit in place if it is applicable in the commercial terms.

DOCUMENT PROPERTIES:

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Prepared by: Alpha ESS Australia PTY. Ltd
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Table of Revisions:

Date	Revisions	Description	Prepared By	Approved By
22/03/2022	V.01	First Version	Ricky Jiang	Ricky Jiang

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1. COMPANY INTRODUCTION:

Established in 2012, **AlphaESS Co., Ltd** was one of the very first ESS pioneers in the entire industry with lithium-ion technology.

AlphaESS specializes in advanced battery storage products and intelligent energy management solutions for both residential and C&I customers. Over the past 8 years more than 40,000 ESS systems and 1GWh of cumulative capacity of ESS products designed and manufactured by AlphaESS have spread to more than 70 countries through our six overseas subsidiaries and business partners around the world, benefitting tens thousands of customers.

AlphaESS is an “ESS-only” focused technology innovative company with over 40% of the employees in R&D department, till now the company has more than 100 patents in energy storage field, keeping the technology and design of its products always leading in the industry. The company and its product solutions also receives numerous of global recognitions such as :

In 16th Jan 2020, AlphaESS was named a 2020 Global Cleantech 100 Company

Global Top-ten Energy Storage System Supplier in 2019 by IHS Markit Report

Top-ten energy storage system suppliers in 2019 (in alphabetical order)

Alpha ESS	Panasonic
BYD	Pylontech
E3DC	Sonnen
LG Chem	Sharp
Nichicon	Tesla

Top ten energy storage brands in the European market in 2018 by EuPD

The Smarter-E Award Finalist 2020,
Outstanding Project-Rural Electrification

IF Design Award 2018, and Reddot
Award Product Design Award 2018

The Government of South Australia
exclusive partner in 2018 in HBS program

The development of the company is also backed up by strong company shareholders like tier-1 lithium cells manufacturer EVE Energy, state-owned gigantic energy group like China General Nuclear Power Corporation(CGN) as well as industry influencers like Dr.Shi (Founder of SUNTECH). The revenue growth of the company was always tripling or even more ever year in the last 5 years.

“Your Smart Energy” is our slogan. AlphaESS is pursuing an ambitious goal of building an “energy internet,” where everyone can produce their own clean energy and lead a sustainable lifestyle.

More information about us can be found on our website www.alpha-ess.com

2. PROJECT BRIEF

This project is developed by Kuga Electrical for the purpose of energy independence

Following are the major technical inputs from Salim as design basis for AlphaESS

Basic Technical Inputs	
Planned Solar PV Size	900kWp
Requested PCS Size	1000KW
Requested Battery Size	>1100kWh
Designed Battery Capacity	1259.7kWh
Usable Battery Capacity	1133.73kWh
Diesel Generator	Yes
Diesel Controller Model	Yes

Other information

3. PROPOSED SOLUTION

3.1 Major items in proposed solution:

Components	Model Name	Descriptions	Qty	Notes
PCS	PWS1-500	Sinexcel 500kW PCS	2	
Transformer	500KVA	Sinexcel 500KVA transformer, 380/400	2	
STS	PWD-STS-2MW		1	
Battery Module	M48112-S	5.7 kWh LFP Battery Storage Module	221	
Battey Rack	1*10	Battery rack suitable for 21 modules M38210-S	27	
PV Inverter	GW80K-MT	Goodwe 80K Inverter	12	
R-BMU	HV900112	High Voltage Control Module/ Cluster BMU	17	
DC Junction Box			2	
Top BMU Box			2	
Equipment Container	20ft	20ft container with FFS/HVAC/Lighting etc	1	
Battery Container	40ft	40ft container with FFS/HVAC/Lighting etc	1	
AC Junction Box	12 in 1		1	
Grid side meter	Meter-CT	Grid side meter with CT2000A	1	
PV side meter	Meter-CT	Grid side meter with CT2000A	1	
Battery cable		Power cables 、 communication cables and so on	23	

3.2 MAJOR COMPONENTS

3.2.1 500Kw PCS

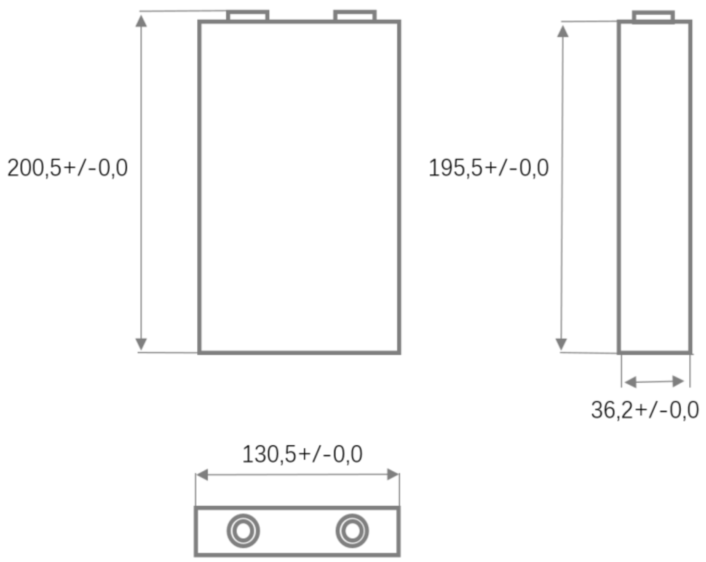
SINEXCEL is a public listed company in China specialized in power quality and power converter products, core technical team is from Emerson and its products has been widely used in projects around the world. More information can be find in www.sinexcel.us

Product Model	PWS1 500KTL
Battery Voltage Range	600-900 V
DC Max. Current	873A
DC Max. Power	550kW
AC. Output Power	500kW
AC. Max. Power	550kVa
Rated Voltage	380V
Rated Frequency	50Hz/60Hz
Peak Efficiency	98.2%
Wiring Mode	3Phase 4 Wire
Working Temp.	-20 oC-50 oC
Size (W*H*D)	1100*2160*800
Weight	600kg

3.2 MAJOR COMPONENTS

3.2.2 M48112-S LFP Battery Cell

EVE Energy is a public listed, top 5 lithium Ion battery manufacturer in China with 9GWh of annual production capacity.
Battery cell LP105 AlphaESS used for this project are EVE premium prismatic aluminium case LFP power cells which are widely used in highest standard Electrical Vehicle



LP105 Cells Structure Drawing

Item	Parameter
Battery Type	lithium iron phosphate
Battery Model	LF105
Single voltage/capacity	3.2V/105Ah
Single voltage range	2.5V～3.65V
Max charge current	1CA
Charge cut-off voltage	3.65V
Max discharge current	3CA
Discharge cut-off voltage	2.5V
Standard charge time	2.5h
Quick charge time	1.0h
Recommended SOC	10%~90%
Charge temp.	0℃~45℃
Discharge temp.	-20℃~55℃
Storage temperature	-20℃~45℃ for 1 month
	0℃~35℃ for 1 year
Storage Humidity	＜70%
Single weight	1915±30g
Internal resistance	≤0.6mΩ
Specific energy	144Wh/kg

3.2 MAJOR COMPONENTS

3.2.3 M48112-S LFP Battery

Item	Parameter
Battery Type	lithium iron phosphate
Battery Model	M48112-S
Energy Capacity	5.7kWh
Usable Capacity	5.13kWh
DoD	90%
Nominal Voltage	51.2V
Internal Resistance	Less than 10m
Nominal Charge Current	112A (1C)
Nominal Discharge Current	112A (1C)
Operation temperature	-10 – 50Celcious
Humidity	15-85%
BMU Power Consumption	Less than 2W
Monitoring Parameters	System Voltage, Current, Cell Voltage, Cell Temperature, PCBA Temperature
Communication	CAN and RS485 Compatible
Weight	65kg
Dimensions	491mm*611mm*160mm

3.2 MAJOR COMPONENTS

3.2.4 M48112-S LFP Battery Rack

Modules are mounted in series to form a rack of battery storage. Each rack also contains an individual rack-level BPU (Battery Protection Unit). The racks are offered in 20 modules each. Please refer to the commercial proposal for the details regarding chosen rack.

Item	Parameter
Rack Type	Rack-10*1
Type of Module	M48112-S
Number of modules per rack	Maximum 10
DC voltage range	250-520V
Size(W*D*H, mm)	743.3*740*2241.5
Weight (kg)	1320
Total rack energy (kWh)	161.2kWh
Rack configuration	240S2P
Cooling	Air cooling

Further, these racks are connected in parallel to form a battery system. Each battery system is paired with a system level R-BMU at the bottom of the rack. The number of racks and connection depends upon power and energy requirements as well as the inverter input range of the complete storage solution. All wire connections are placed on the front side of the rack, with the exception of the power output to the inverter, to allow for easy installation and maintenance.

3.2 MAJOR COMPONENTS

3.2.5 TOP-BMU&EMS

EMS is designed in same module with TOP-BMU. EMS will communicate with PCS, TOP-BMU and AlphaCloud.

TOP-BMU is the master battery management system, required when there are more than one battery cluster.

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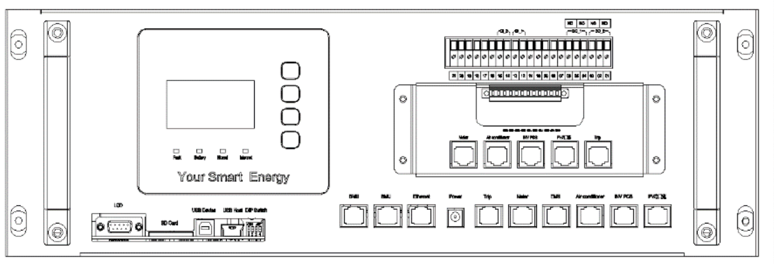
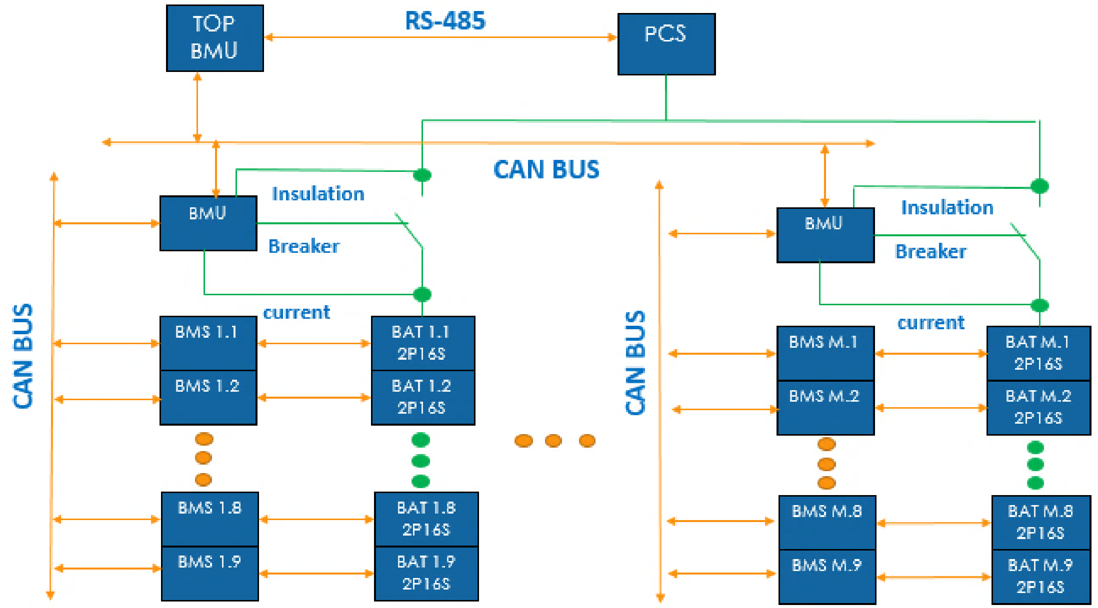


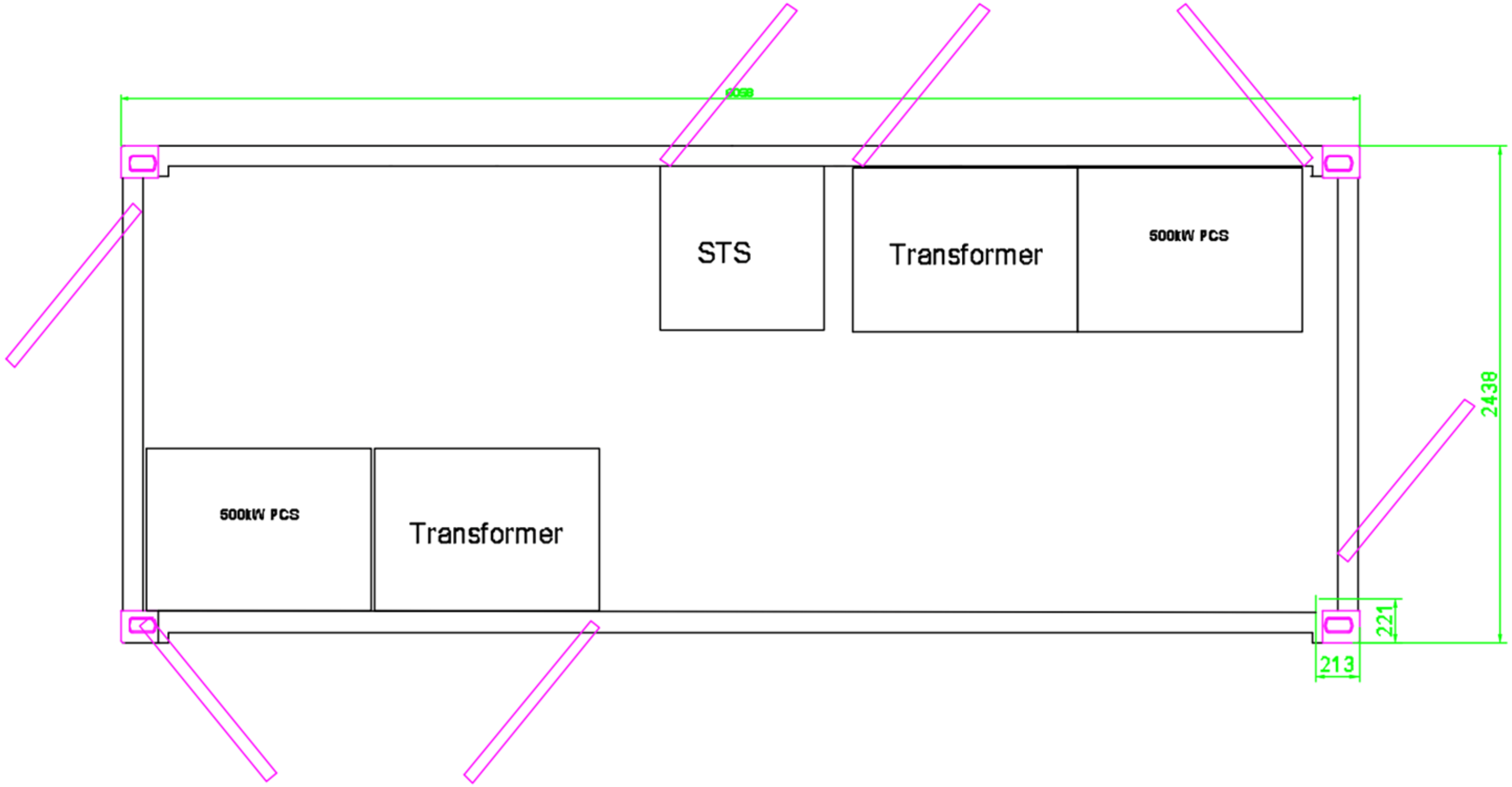


Communication Structure

3.2 MAJOR COMPONENTS

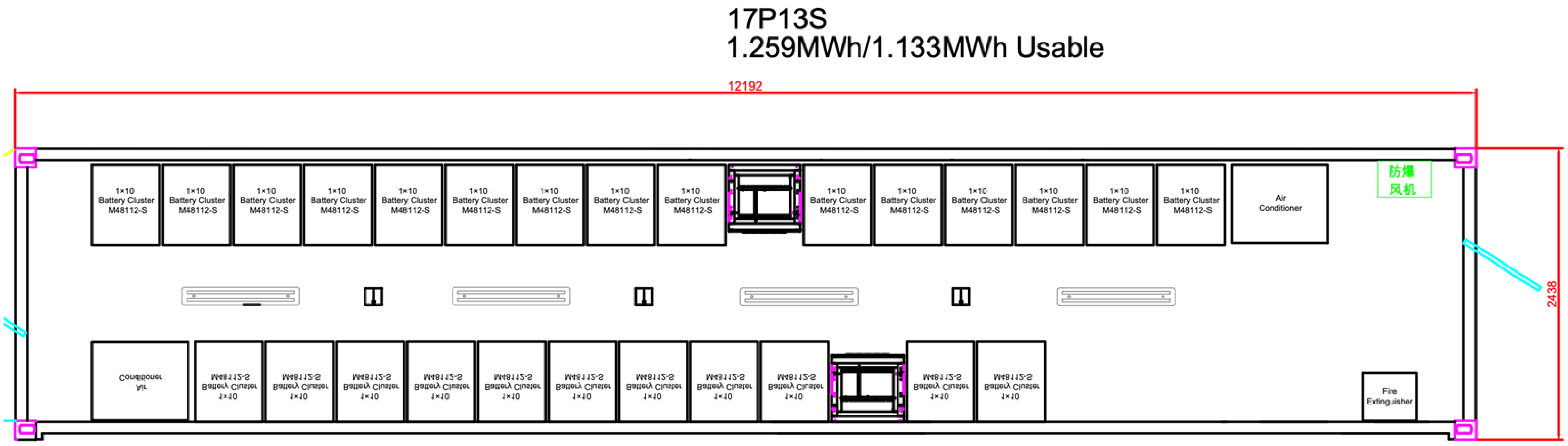
3.2.6 PCS/Battery Container

This project will consist of two containers. All the main PCS, STS and transformers are installed in a 20ft equipment container. There will be an additional 40ft container for all the batteries. For this specific project, 221 x M48112-S batteries will be installed in the 40ft container which will be 1133kWh. Up to 1480MWh batteries can be installed in this container for future battery expansion requirements.



3.2 MAJOR COMPONENTS

3.2.6 PCS/Battery Container - 1133.73kWh design

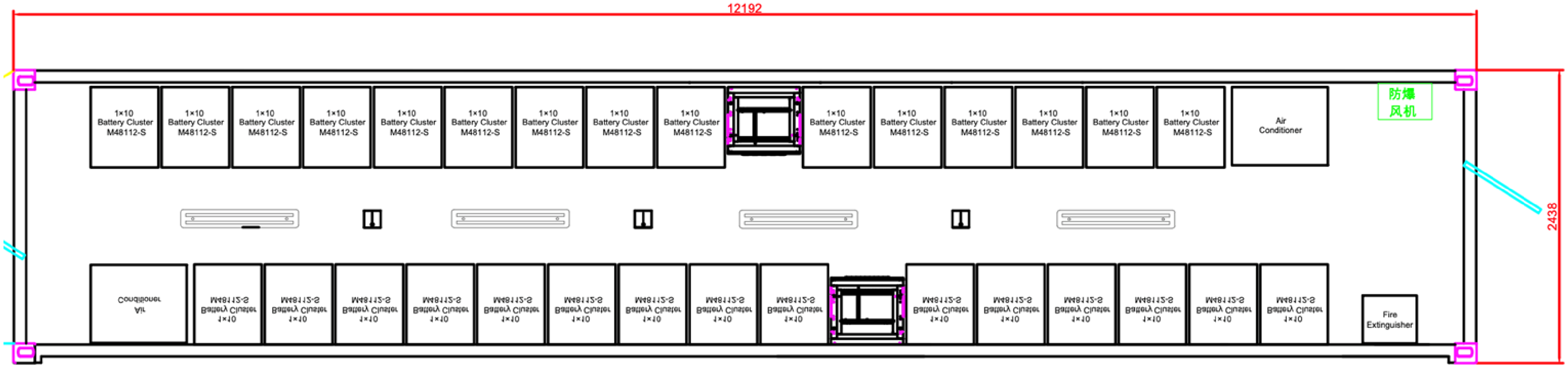


3.2 MAJOR COMPONENTS

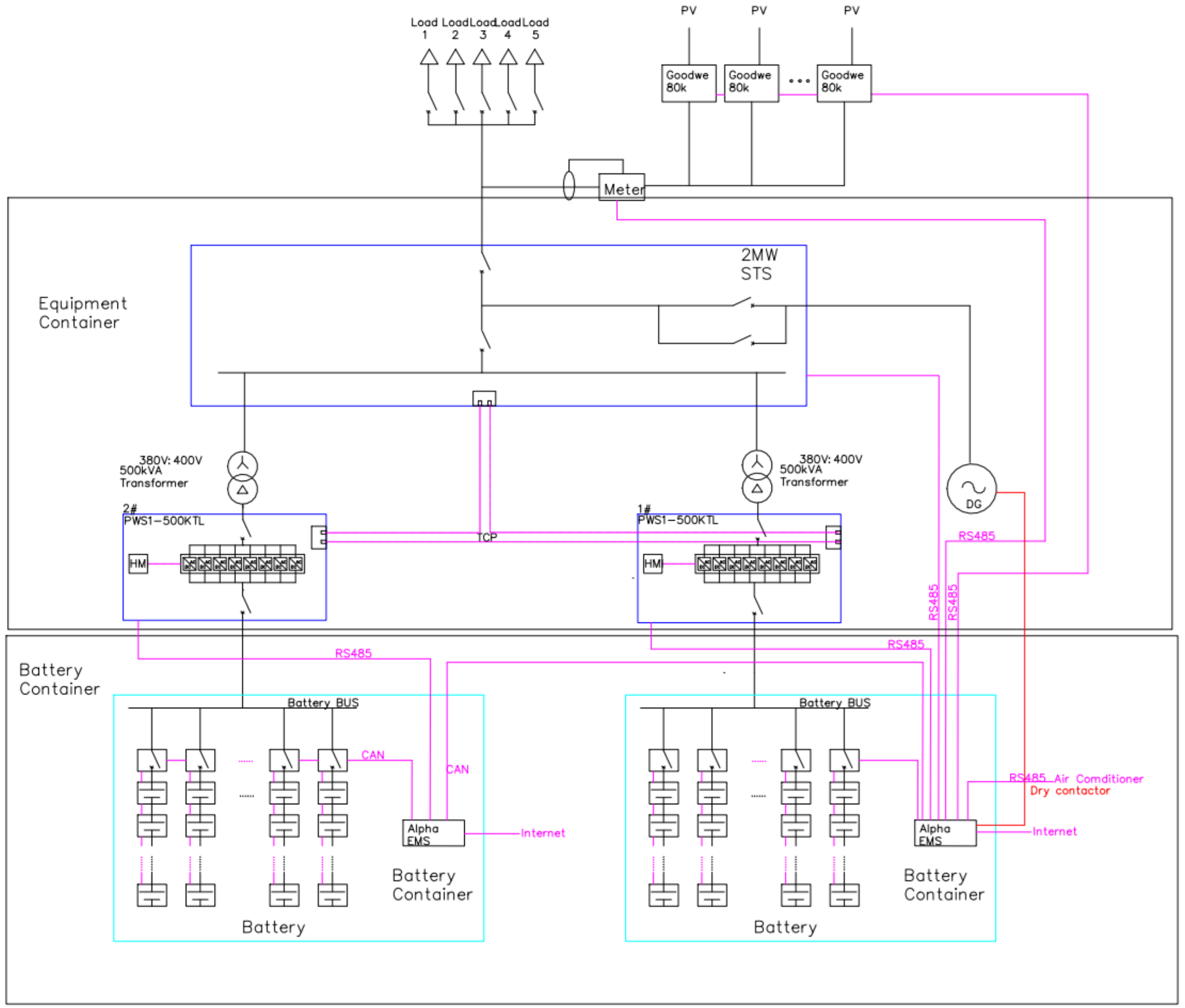
3.2.6 PCS/Battery Container - 1480kWh maximum design

The maximum the container can be expanded to is 1480kWh. Expanding is done by adding a new rack and battery cluster of M48112-S battery cells. The expansion can be done 1 string at a time and will not impact the degradation of existing or new cells due to effective battery management by Alpha.

20P13S
1.48MWh/1.338kWh Usable

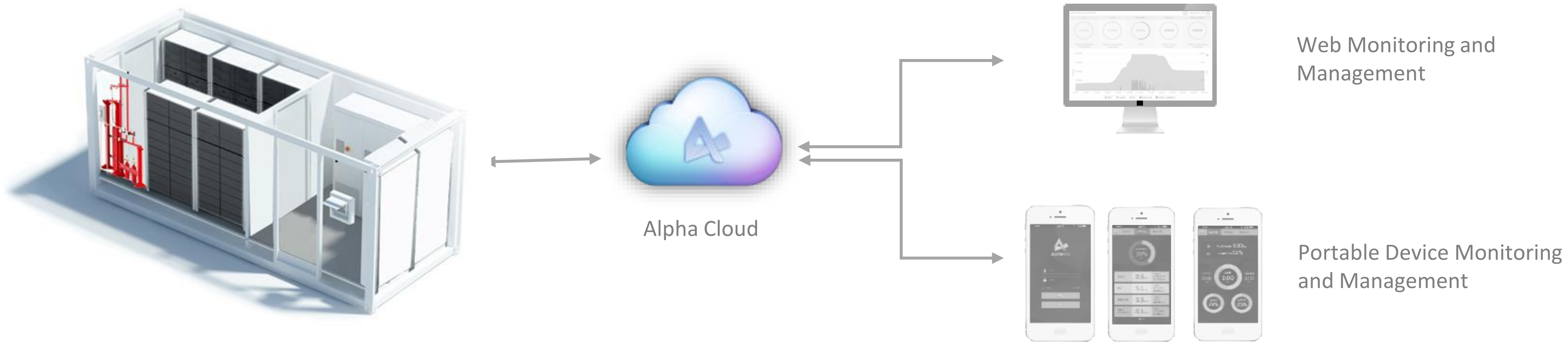


3.3 ELECTRICAL SINGLE LINE DIAGRAM



3.4 ALPHA COULD MONITORING SYSTEM

The AlphaCloud enables the whole system operation to be monitored and managed online remotely, this offers the project owner full transparency on the system performance, also a great continence in doing system maintenance as system operation logics and also all firmware in the BMS or EMS can be updated easily remotely.



- Web and APP monitoring system via Alpha Cloud
- EMS and BMS firmware update by USB driver or remotely online
- Remote setup changes via web monitoring management account

4. SYSTEM COMMISSIONING

Engineer commission support:

- Free remote support.
- Alpha engineer onsite support at no customer cost.
- Commission supporting documents will be provided together with the system delivery.

Supporting documents:

- Installation and operation manual
- Maintenance manual
- Electric diagram
- Parts list
- Checklist
- Acceptance document

“ the warranty terms and conditions subject to the warranty document provided by AlphaESS”

3 Years Product Warranty

10 Battery Performance Warranty

Battery performance warranty:

For systems operate under self-consumption mode, we warrant that the each battery module retains at least eighty percent (80%) of its usable capacity for 120 months from the earlier of (i) the date the battery storage system is installed at the end user's property or (ii) the date two months after the Product being sold to another business or personnel.

For other applications, the warranty can expire earlier if a total energy of 2.92MWh per kWh usable capacity has been dispatched from the battery.

5. SPECIFIC CONDITIONS

Commercial Operation Performance Guarantees – Battery Energy Storage System

- AlphaESS agrees to the 97% availability calculated on quarterly review within the warranty period. AlphaESS would like three months test running period to check all functionality and commissioning before uptime calculation.
- AlphaESS agrees that the maximum charge and discharge rate of the BESS is 1000 kW.
- AlphaESS agrees that the capacity of the BESS system shall be larger than 1100 kWh.
- The round-trip efficiency of the BESS is no lower than 92% (AC) or 95% (DC).
- The control system maximizes the utilisation of solar+battery in preference of diesel.

Damages for under performance

- AlphaESS agrees that damages of $8.33 p/hour over 60 hours of downtime each quarter are paid by Alpha if the -If 97% uptime isn't achieved, AlphaESS can make a warranty claim to have the problem fixed and covered under warranty
- There will be a maintenance fee including regular monitoring checks, site visits, spare part storage and maintain at a rate of $0.01/Wh per annum;
- Attend site within 10 business days and provide rectification plan (repairs/parts/timeframe)
- Written confirmation on commissioning the installation was correctly installed and warranty valid

6. PROJECT REFERENCE

Description

With this East Village project, the centralized battery works as a free market enables residents to trade electricity freely between one to another. The 36 house owners will have their own solar and battery system (Alpha ESS residential energy storage product - SMILE5) to provide their first level of electricity. when their SMILE5 is full, extra electricity will be stored in the centralized battery system. When there is not enough electricity stored in their SMILE5 or excess power is needed, the house owner will be able to pull electricity from the centralized battery as a second level electricity reserve.

Project	20ft container 100 kW / 670 kWh
Application	PV+Storage+ Microgrid
Commission date	Feb, 2019
Address	Fremantle, WA, Australia

6. PROJECT REFERENCE

Description

Oil beam pump operating 24/7 in the middle of dessert. Now it is fully powered by Solar/Battery system. With this off grid application, smart control and monitor system is in placed for security and maintenance purposes. Online monitoring will enable our aftersales engineers to check on the well-being of the system.

Project	20ft container 100 kW / 250 kWh
Application	PV+Storage+ Off Grid
Commission date	Aug, 2019
Address	Moomba, SA, Australia

6. PROJECT REFERENCE

Project	T50 50kW / 103kWh
Application	PV+Storage+ Off Grid
Commission date	Feb, 2020
Address	Gundaroo, NSW, Australia

Description

AlphaESS commissioned an off-grid solar farm project in NSW, Australia. The energy storage system, T50 with 103kWh batteries, was integrated to a 62.5 kW solar system to fulfill the electricity requirement for the entire area, so the whole area can be independent from the grid.
This is a new built area for 16 holiday houses, the solar and battery system will make sure these houses are independent from the grid and stays 100% renewable.

THANK YOU!

CONFIDENTIAL FILE

ATTESTATION OF CONFORMITY

Issued to	:	Alpha ESS Co., Ltd. JiuHua Road 888, Nantong High-Tech Industrial Development Zone, Nantong City
For the product	:	Lithium-ion Battery Module
Trademark	:	Alpha ESS
Type/Model	:	M48112-S
Ratings	:	51.2V,112A
Manufactured by	:	Alpha ESS Co., Ltd. JiuHua Road 888, Nantong High-Tech Industrial Development Zone, Nantong City
Requirements	:	EN 61000-6-4:2007+A1:2011 EN 61000-6-2:2005

This Attestation is granted on account of an examination by DEKRA, the results of which are laid down in test report No. 1882068E-IT-CE-P04V01.

This Attestation implies that the examined types are in accordance with the standards designated under the Electromagnetic compatibility directive 2014/30/EU.

The examination has been carried out on one single specimen of the product, submitted by the manufacturer. The Attestation does not include an assessment of the manufacturer's production. Conformity of his production with the specimen tested by DEKRA is not the responsibility of DEKRA.

Shanghai, 25 September 2018 Number: 3181243.43AOC

DEKRA Testing and Certification (Shanghai) Ltd.

Kate Xu
Certification Manager

The CE marking may be affixed on the product if all relevant and effective EC directives are complied with

DEKRA Testing and Certification (Shanghai) Ltd.
3F 250 Jiangchangsan Road Shibei Hi-Tech Park, 200436 Zhabei District, Shanghai, China
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YOUR
SMART
ENERGY

Alpha·ESS

BATTERY
M48112-S

COMMERCIAL & INDUSTRIAL SERIES

CAPACITY ▶

5.7 kWh modular

+

Modular

Plug & play

Safe

Long lifespan

BATTERY

M48112-S

Alpha·ESS

Model	M48112-S
Physical	
Battery Type	LFP (LiFePO4)
Cell Manufacturer	EVE
System Weight	65 kg
Dimension (W x D x H)	491 x 611 x 160 mm*
IP Protection	IP20
Warranty	3 Year Product Warranty, 10 Year Performance Warranty
Electrical	
Energy Capacity	5.7 kWh
Usable Capacity	5.2 kWh
Depth of Discharge (DoD)	90%
Nominal Voltage	51.2 V
Operating Voltage Range	48 ~ 56.3 V
Internal Resistance	≤ 30 mΩ
Cycle Life	≥ 6000
Operation	
Max. Charging Current	112 A
Max. Discharging Current	112 A
Operating Temperature Range	-10 °C ~ 50 °C**
Relative Humidity	15% ~ 85%
BMS	
Modules Connection	5 ~ 13 in series
Capacity	28.6 / 34.4 / 40.1 / 45.9 / 51.6 / 57.3 / 63.1 / 68.8 / 74.5 kWh
Power Consumption	BMU Unit: ≤ 15 W (Work), ≤ 10 mW (Sleep) Battery: ≤ 0.6 W (Work), ≤ 10 mW (Sleep)
Monitoring Parameters	System voltage, current, cell voltage, cell temperature, PCBA temperature.
Communication	CAN and RS-485 compatible
BMU Model	HV900112 (TOP BMU required with more than one parallel cluster)

* Including hangers and handles
** When the temperature is below 0 °C or above 40 °C, the performance will be limited.

CE IEC

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Appendix D – Heat Transfer Assessment (BESS)

Predicting fire behaviour using analytical models requires the use of first principle equations to help develop the desired bounding parameters, then using these parameters to estimate the expected behaviours. The use of analytical models is considered suitable for assessing of large fires, the category in which a Battery Energy Storage System (BESS) fires would be classified as.

A heat transfer analysis is adopted to assess the behaviour of a fire in a BESS container and the impact it has on adjacent infrastructure. This is achieved by the modelling of a fire at the primary BESS and the estimating the incident radiant heat flux to adjacent infrastructure to determine whether conditions for fire spread are met.

There are three (3) modes of transferring heat that need to be considered in a heat transfer assessment:

- **Conduction** – refers to the direct transfer of heat energy due to contact of two bodies at differing temperatures. Heat flows from the body of higher temperature to lower temperature.
- **Convection –** refers to the transfer of heat energy through a moving fluid such as smoke or gas. Heat is transferred from higher temperature to lower temperature.
- **Radiation –** refers to the transmission of heat energy through electromagnetic waves through space, no matter is required between bodies. Heat is transferred between a body at higher temperature to a body at lower temperature.

All three (3) modes of heat transfer contribute to the development and spread of a fire; however, they play roles in different phases of a BESS fire.

While both conduction and convection are applicable through the ignition and growth phases of a BESS fire, radiation becomes the dominant mode of heat transfer when the container reaches a temperature above 400 °C (Quintiere, 2016). Both conduction and convection become less applicable.

When considering a plausible BESS fire scenario, being fully developed and long burning in nature, the focus of this assessment ultimately shifts to the radiation component when assessing the potential exposure to adjacent infrastructure. Both conduction and convection are not applicable modes of heat transfer between the container and adjacent infrastructure where they are located a distance apart.

As the fire develops in the fire origin BESS, a temperature difference will be apparent between the fire origin BESS (radiant body) and a nearby structure (target body). This is what determines the rate at which radiant heat exchanges between the two bodies (Janna, 2000).

As the fire origin BESS is assumed to continually burn until all the fuel is consumed, the impact of thermal radiation from the heated surfaces of the fire origin BESS to the target plane need to be considered and assessed through a heat transfer analysis. The incident radiant heat flux can be assessed against critical parameters particular to the make-up of the impacted infrastructure to determine whether fire spread is likely to occur.

D.1. Assumptions

The quantification of radiant heat flux of a BESS is challenging due to the limited proprietary information available in the industry and the large number of variables that can be altered in a given BESS system (chemistry, type of battery cell, size of batteries etc).

Where specific manufacturer lithium-ion battery (LIB) data is supplied, this level of information is used. However, in the absence of project specific data, “best available” information is relied upon and is based on recognised and generally accepted good engineering practice.

In the absence of details from battery vendor at the time of this assessment, the following assumptions are made;

- That an emergency ventilation system is provided to satisfy the *Deflagration Prevention by Combustible Concentration Reduction* method detailed in Chapter 8 of NFPA 69 for deflagration prevention.
- The emergency ventilation rate of the system adopted, 410 cfm, is based on research and testing undertaken by (DNV GL, 2017), which suggests 0.32 cfm/kWh.
- Performance of off-gas ventilation provided to the BESS container assumed to have been designed to prevent the build-up of flammable gas which can result in a deflagration or explosion event. Therefore, hazards associated with deflagration and explosion are not considered in the assessment.
- Ventilation is assumed to be constant throughout the burning process. A constant ventilation rate means the amount of fuel that can be consumed per second is also constant – therefore, a steady state condition can be achieved until all fuel within the containers are consumed. Forced ventilation is assumed to be prioritised over the activation of the gaseous suppression agent.

It is recommended that the above parameters be verified and confirmed with the vendor/supplier/manufacturer to ensure the assessment is reasonably valid.

D.2. Heat Transfer Model

The assessment utilises a solid-flame radiation model, a commonly used method to analyse thermal radiation hazards for large fires, to approximate the radiant heat transferred between a surfaces. This model approximates the fire or radiant heat source as a geometric shape to determine appropriate view factors between the emitter and receiver (what one sees of the other), to calculate the radiant heat transferred between the two bodies.

The two bodies, emitter and receiver, for this assessment, are identified as follows:

- **Emitter** – Two emitter sources are considered for the assessment, those being:
  1) A fully developed fire involving the subject BESS container where the container panels are radiating heat, and,
  2) Flame projections to the topside of the container either through venting of combustible gas or burning away of the container roofing.
- **Receiver** –Infrastructure located within proximity of the BESS as indicated in the layout plan shown in Figure 6.

As discussed in Appendix D, the primary method of heat transfer between the fire origin BESS and a target receiver revolves around radiative heat transfer. Based on Quintiere's Principles of Fire Behaviour Equation 3.5 (Quintiere, 2016), the radiant heat flux incident at a target plane can be expressed through the following governing radiant heat transfer equation;

$$\dot{q}'' = \varepsilon\dot{\sigma}FT^4 \qquad (Equation\ 1)$$

Where;

Table 18: Input Parameters for Radiant Heat Flux Calculation

Parameter	Value or reference to detailing the calculation
$\dot{q}''$ = Radiative Heat Flux [kW/m^2]	Detailed in Appendix D.9
ε, = Emissivity	Emissivity for a rough steel plate is in the range of 0.94-0.97 (Drysdale, 2011). Emissivity of 1 is used for conservatism.
$\dot{\sigma}$ = Stefen-Boltzman Constant [kW/m^{2}K^4]	5.67 x 10^{-11}
F = Geometric View Factor	Detailed in Appendix D.3
T = Temperature of Radiant Body [K]	Detailed in Appendix D.5

To solve for the radiant heat flux emitted and received using the above equation, the geometric view factor, F, and temperature of the radiant body, T need to be derived.

The geometric factor can be determined based on the dimensions, orientation and separation distance of the emitter and receiver. Vendor data on the proposed BESS container and the proposed container arrangement is used to determine the geometric factor. Information regarding the view factor calculation is detailed in Appendix D.3

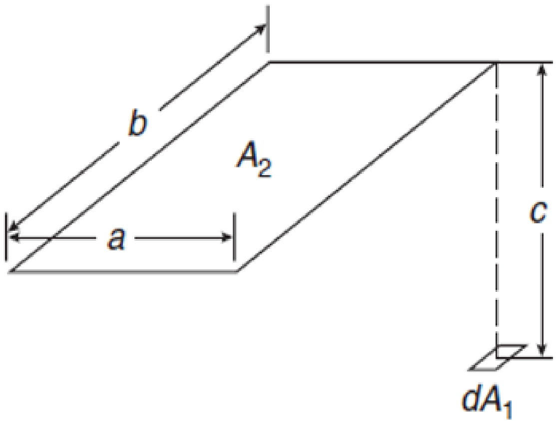
As for the temperature of the radiant body (emitter), this requires the derivation of several other variables. Considering the vendor data provided, research available, and reasonable assumptions - the temperature of the radiant body is assessed in detail under Appendix D.5

D.3. View Factors

View factor for BESS container to target plane

The view factor of an object determines the fraction of radiation received by a target from the emitter. It takes into consideration the shape, orientation, and size of both the emitter and target, as well as the separation distance between them. By determining the view factor of the BESS container to various target planes, the incident radiant heat flux received at the plane can be estimated.

As the container is a geometrically a 3-dimensional rectangle, target planes parallel to the containers emitting surfaces can be modelled as a parallel rectangular plate when determining the view factor. This relationship is documented in (SFPE, 2016) and shown below:



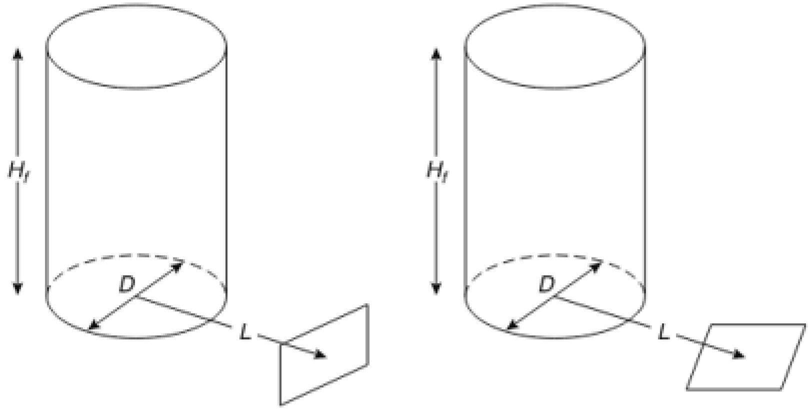
$$X = a/c \qquad Y = b/c$$

$$F_{d1-2} = \frac{1}{2\pi}\left[\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left(\frac{Y}{\sqrt{1+X^2}}\right) + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left(\frac{X}{\sqrt{1+Y^2}}\right)\right]$$

Figure 37: View factor equation for parallel configuration between emitter and receiver – Fig A.6 of (SFPE, 2016)

View Factor for flames to target plane

As discussed in Appendix D.2, the base fire scenario accounts for flame projection above the fire involved BESS container and are treated as emitters of radiant heat. The view factor of the flames to the target BESS containers are derived based on the following:



where

$$A = \frac{h^2 + S^2 + 1}{2S}, \qquad B = \frac{1 + S^2}{2S}$$

$$S = \frac{2L}{D}, \quad h = \frac{2H}{D}$$

$$F_{12,H} = \frac{(B - 1/S)}{\pi\sqrt{B^2 - 1}} \tan^{-1}\sqrt{\frac{(B+1)(S-1)}{(B-1)(S+1)}} - \frac{(A - 1/S)}{\pi\sqrt{A^2 - 1}} \tan^{-1}\sqrt{\frac{(A+1)(S-1)}{(A-1)(S+1)}} \quad (66.17a)$$

$$F_{12,V} = \frac{1}{\pi S}\tan^{-1}\left(\frac{h}{\sqrt{S^2 - 1}}\right) - \frac{h}{\pi S}\tan^{-1}\sqrt{\frac{(S-1)}{(S+1)}} + \frac{Ah}{\pi S\sqrt{A^2 - 1}}\tan^{-1}\sqrt{\frac{(A+1)(S-1)}{(A-1)(S+1)}} \quad (66.17b)$$

Figure 38: View factor equation for cylindrical flame-shape configuration factor for vertical and horizontal targets at ground level - Fig 66.19 of (SFPE, 2016)

D.4. Flame Height

The flame height is estimated using Heskestad's flame height approximation and is a function of the heat release rate and diameter of the flame. For the assessment, it is assumed that the diameter of the flame extends for 6 m (half the BESS containers width), assuming that parts of the containers roofing has been compromised, permitting flames to be ejected.

$$H_f = 0.235\dot{Q}^{\frac{2}{5}} - 1.02D$$

$$H_f = Flame\ Height\ (m)$$
$$D = Diameter\ of\ Flame\ (m)$$
$$\dot{Q} = Heat\ Release\ Rate\ (kW)$$

Figure 39: Heskestad's equation - EN 1991-1-2:2002, Annex C

D.5. Temperature of Radiant Body

As shown in Equation 1, at the heart of radiation heat transfer is the temperature of the radiating body.

Following the initiation of a fire within a BESS, the fire will grow, and a hot gas layer will form within the container. The hot gas layer is a function of the emitted combustion products of the fire plume. The temperature of the hot gas will increase as a function of heat release rate and will heat the container walls through means of convection and radiation. The heat energy transferred to the walls provide the wall panels energy to re-radiate to the ambient side, thus, in the direction of the receiving BESS containers.

The temperature of the radiant body, steel wall panel, is conservatively assumed to be equal to the hot gas temperature of the container at steady state. This is reasonable considering the assumed thickness of the steel container is relatively thin and the high thermal conductivity of steel.

As detailed in assessment in Section 5.4 and assumptions noted in Appendix D.2, it is assumed that an off-gas ventilation system activated by elevated levels of LFL in the container will be provided in accordance with NFPA 69 (to be confirmed with vendor/manufacturer). The purpose of this forced ventilation system serves to extract off-gas produced during thermal runaway.

Forced ventilation is considered a crucial aspect when assessing risks associated with thermal runaway for the following reasons:

- Forced ventilation limits the build-up of flammable vapour clouds within the BESS which may result in a deflagration or explosion event, and
- Limits the peak heat release rate of a BESS fire, maintaining the fire at a constant level until the flammable gases have burnt out (ventilation-controlled fire).

The release of flammable gases during thermal runaway, in an unventilated compartment, introduces the risk of over pressurisation and an explosion hazard due to the amassing of unburnt fuel (Ponchaut, n.d.). Flammable off-gas is unable to be consumed in a sealed compartment due to the limited oxygen available.

The forced ventilation rate for the BESS container is estimated to be 410 cfm based on the relationship of 0.32 cfm/kWh developed by (DNV GL, 2017).

It is further noted in the specifications that the container is to be provided with a gaseous suppression system which activates upon activation of two (2) of any two installed detectors (smoke, thermal, gas). While it is expected for the gaseous agent to trigger in a fire event, it is assumed that the forced ventilation is prioritised over the gaseous system to mitigate against an explosion risk.

Gaseous agents are typically required to be deployed in a sealed environment and held for a period of time to allow the gas to disperse and react with the combustion process. However, in the case of thermal runaway, studies have shown that while gaseous and aerosol agents may be effective in extinguishing a fire, it does not remove heat from a deep-seated battery (DNV GL, 2017), allowing thermal runaway to continue and the potential build-up of combustible gas. Gaseous agents are considered suitable for extinguishing a fire outside the battery racks (non-thermal runaway event) i.e. cable short circuit prior to it developing and impacting the batteries.

Therefore, the gaseous suppression system is disregarded when estimating the heat release rate of the system in a thermal runaway event which results in a fire.

D.6. Peak Heat Release Rate

The heat release rate of a lithium-ion BESS fire is a function of the following parameters:

- Quantity of fuel,
- Ventilation conditions, and
- Phase of the fire

The peak heat release rate quantifies the maximum release rate of heat during the combustion process and typically occurs when the decomposition process is occurring at its fastest rate (Karbhari, 2007). For the case of a forced ventilated BESS fire, the peak heat release rate is limited by the ventilation conditions within the container.

Through determining the peak heat release rate of the BESS fire, the temperature of the hot gas layer can be estimated, and therefore, also the temperature of the radiant body (panels of the BESS container)

The peak heat release rate of a LIB BESS fire can be quantified using the below equations (SFPE, 2016):

$$\dot{Q}_{peak} = \Delta H_{c,eff}\ x\ \dot{m} \qquad (Equation\ 2)$$

and,

$$\dot{m}_{gas} = \dot{m}_{air} + \dot{m}_{fuel} = \rho_{air}\dot{V} + MLR_{fuel} \qquad (Equation\ 3)$$

Where,

Parameter	Value or reference to detailing the calculation
$\dot{Q}_{peak}$ = Peak Heat Release Rate [kW]	$\dot{Q}_{peak} = \Delta H_{c,eff}\ x\ \dot{m} = (28{,}000)(0.1933) = 6{,}495.2$
$\Delta H_{c,eff}$ = Effective Heat of Combustion [kJ/kg]	28,000 (Ponchaut, n.d.)
$\dot{m}_{gas}$ = Mass flow rate (mixed gas layer) [kg/s]	$\dot{m}_{gas} = \rho_{air}\dot{V} + MLR_{fuel} = (1.2)(0.1933) + 0 = 0.23$
ρ_{air} = density of air [kg/m^3]	1.2
$\dot{V}$ = Volumetric flow rate [m^3/s]	0.1933, based on forced ventilation rate of 410 cfm
MLR_{fuel} = Mass loss rate of fuel [kg/s]	Varies based on type of battery but is considered insignificant for calculating mass flow rate of the mixed gas layer when compared to the impact of volumetric flow rate. Assumed to be 0 for assessment.

Equation 3 reasonably assumes that the gas layer within the compartment, consisting of air flow $(\dot{m}_{air})$ and fuel $(\dot{m}_{fuel})$ released from the volatiles of the LIBs are well mixed and are a uniform temperature (Drysdale, 2011). As such, the mass flow rate of the gas within the BESS container is a function of the density of air (temperature dependent) and the volumetric flow rate of the ventilation system; this is in addition to the mass lass rate of fuel.

While the mass loss rate of the battery is an important factor in calculating the heat release rate, it has negligible contribution when compared to the volumetric flow rates within the BESS container when calculating the total heat release rate. Therefore, only the mass flow rate of air (from the mechanical ventilation system) and the heat of combustion for LIBs in air is required to estimate the peak heat release rate.

Based on the input parameters, the peak heat release rate for the given BESS container, $\dot{Q}_{peak}$, is approximately 6,495.2 kW.

D.7. Hot Gas Layer

The provision of forced ventilation to the BESS container largely influences the hot gas temperature within. By maintaining a constant forced mechanical ventilation rate throughout the burning process, the BESS fire becomes ventilation controlled, that is the growth of the fire is governed by the amount of oxygen that is introduced to the system.

The hot gas temperature for a forced ventilation fire can be calculated using the method of Foote, Pagni and Alvares (SFPE, 2016).

$$\frac{\Delta T_g}{T_\infty} = 0.63\left(\frac{\dot{Q}_{peak}}{\dot{m}_g C_p T_\infty}\right)^{0.72}\left(\frac{\mathrm{h}_k A_T}{\dot{m}_g C_p}\right)^{-0.36}$$

Where,

Parameter	Value or reference to detailing the calculation
ΔT_g = Upper gas temperature rise above ambient [K]	707.8 K
T_∞ = Ambient air temperature [K]	300 (27 °C)
$\dot{Q}_{peak}$ = Peak heat release rate of the fire [kW]	Detailed in Appendix D.6
$\dot{m}_g$ = Compartment mass ventilation rate [kg/s]	Detailed in Appendix D.6
C_p= Specific heat of gas [kJ/kgK]	1, Air at ambient temperature of 298 K (Engineering Toolbox, 2003)
A_T = Total area of the compartment enclosing surface [m^2]	34.3
h_k = Effective heat transfer coefficient [kW/m^{2}K]	$\mathrm{h}_k = \frac{k}{\delta} = \frac{0.054}{0.03}$ = 1.8 (SFPE, 2016)
k = Thermal conductivity of compartment surface[kW/mK]	0.054 (Engineering Toolbox, 2003)
δ =Thickness of compartment surface [m]	0.02 (assumed parameter)

As discussed in Appendix D, it is reasonable to assume that the relatively thin steel wall panels of the container will be approximately equal to the temperature of the hot gas layer (reaching equilibrium) as the BESS fire continues to burn at steady state, controlled by the mechanical ventilation system, until all the fuel is consumed (SFPE, 2016).

Therefore, the temperature of the radiant body is treated as 707.8 K

D.8. Flame Characteristics

As a fire continues to burn, flames are anticipated to project from the topside of the container as the roof of the container burns away. This was evident in the case of the Victorian Big Battery Fire (Fisher Engineering, Inc., 2021).

The temperature of the flames is assumed to be at the same temperature as the hot gas and has a diameter of 6 m (half the width of a single BESS container). The emissivity of the flame is conservatively assumed to be 1, representing a black body emitter and is typically seen for high flame emissivity values (Quintiere, 2016).

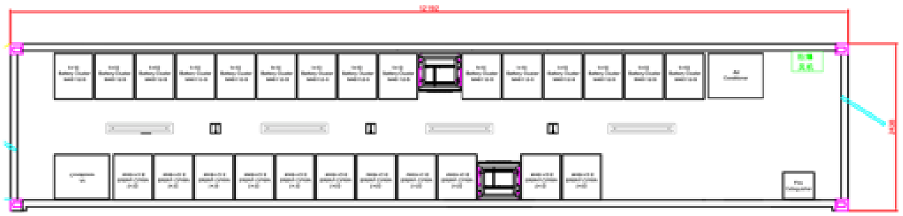
D.9. Radiative Heat Flux

Following the derivation of radiant body temperature in the previous sections, the radiative heat flux received at a target plane can be calculated using Equation 1.

The radiant heat flux received at various distances from the BESS is detailed in Section 5.4 along with the assessment of potential impacts to fire spread.

Detailed sample calculations for the heat transfer assessment for target planes located to the east and west (right and left) of the BESS container are presented below.

BESS Dimensions			This section contains input parameters that describe the BESS, including properties of the BESS wall material. These parameters are used throughout the calculations
Depth	2.438		
Width	12.192		
Height	2.5	assumed	
Properties of steel			
density of steel panel, p(s)	7850	kg/m3	
specific heat of steel, c(s)	0.49	kJ/kgK	
thickness of steel panel, sigma	0.03	m	
Thermal conductivity of steel, k	0.054	kW/mK	



Ventilation Flow Rate conversion			Calculation of the peak heat release under ventillation controlled conditions. Equation Reference: SFPE 5th edition, Drysdale - Thermochemistry
Ventilation rate per recommendation (DNV GL, 201	0.32	cfm/kWh	
Battery Capacity	1280	kWh	
Ventilation rate based on recommendation and battery capacity	409.6	cfm	
Forced Ventillation Air Flow converted to m3/s	0.19	m3/s	

Quantification of Peak Heat Release Rate of ESS Fire Event

Heat release rate for a forced ventilated ESS is dependant on the air flow rate

$$\dot{Q}_c = \dot{m} \cdot \Delta H_c \qquad (5.24)$$

$$\dot{m} = \dot{m}_{air} + \dot{m}_{fuel} = (\rho_{air} * \dot{V}) + MLR_{fuel} \qquad (30)$$

Effective Heat of Combustion, ΔHc	28000	kJ/kg
Mass flow rate (mixed gas layer), m	0.23	kg/s
Mass flow rate of air	-	kg/s
Mass flow rate of fuel	-	kg/s
Density of air	1.2	kg/m3
Volumentric flow rate	0.1933	m3/s
Mass loss rate of fuel (burning rate of fuel)	0	Insignificant in a forced ventillation scenario
Peak HRR, Qpeak	6495.2	**kW**

Once the peak HRR is reached, the ESS compartment will be in fully developed fire phase and will burn at steady state, driven by the ventillation in the compartment until fuel is consumed

Hot Gas Layer Temperature

Ambient Temperatre, Tamb	300	K
Peak HRR	6495.2	kW
specific heat of air	1	kJ/kgK
Effective heat transfer coefficient, h(k), ambient	1.8	kW/m2K
Total surface area of container	132.60	m2
forced ventillation flow rate	0.23	kg/s
Hot Gas Temperature, Tg	**707.8**	**K**
Hot Gas Temperature, Tg	**434.8**	deg C

30 Estimating Temperatures in Compartment Fires 1005

Method of Foote, Pagni, and Alvares

The Foote, Pagni, and Alvares method follows the basic correlations of McCaffrey, Quintiere, and Harkleroad and adds data for forced-ventilation fires. Using Equation 30.10 and not introducing an expression for doorway flow results in the expression [16]

$$\frac{\Delta T_g}{T_\infty} = 0.63\left(\frac{\dot{Q}}{\dot{m}_g c_p T_\infty}\right)^{0.72}\left(\frac{h_k A_T}{\dot{m}_g c_p}\right)^{-0.36} \qquad (30.17)$$

where

ΔT_g = Upper gas temperature rise above ambient (K)
T_∞ = Ambient air temperature (K)
$\dot{Q}$ = Energy (heat) release rate of the fire (kW)
$\dot{m}_g$ = Compartment mass ventilation rate (kg/s)
c_p = Specific heat of gas (kJ/kg·K)
h_k = Effective heat transfer coefficient (kW/m^{2}K)
A_T = Total area of the compartment-enclosing surfaces (m^2)

The heat transfer coefficient can be determined using a steady-state approximation when the time of exposure, t, is greater than the thermal penetration time, t_p, by

$$h_k = k/\delta \quad \text{for} \quad t > t_p \qquad (30.14)$$

The thermal penetration time is defined as

$$t_p = \left(\frac{\rho c}{k}\right)\left(\frac{\delta}{2}\right)^2 \qquad (30.15)$$

Calculates the hot gas temperature within the BESS container based on the Peak HRR calculated above.

Using Method of Foote, Pagni and Alvares

Equation Reference:
SFPE 5th edition, Drysdale – Thermochemistry

Flame Height

Heskestad's flame height approximation

$$H_f = 0.235\dot{Q}^{\frac{2}{5}} - 1.02D$$

H_f = *Flame Height (m)*
D = *Diameter of Flame (m)*
$\dot{Q}$ = *Heat Release Rate (kW)*

Q	6495.2	kW
D	6	m
Hf	1.8	m

Limitations of Heskestad
Diameter less than or equal to 10 m
HRR capped at 50 MW

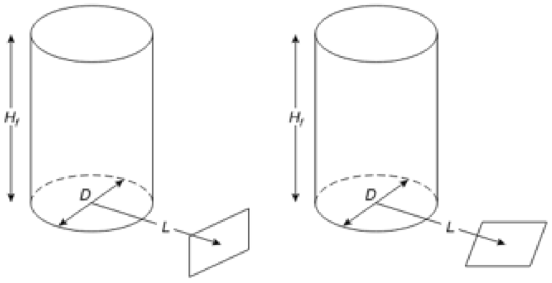
Assumption
Diameter of flame extends for half the width of a single GridSolve Quantum BESS container

Estimation of flame height using Heskestad's equation

Equation Reference:
EN 1991-1-2:2002, Annex C

Shape configuration factor (Between flame and target BESS)

Fig. 66.19 Cylindrical flame-shape configuration factor geometry for vertical and horizontal targets at ground level



$$F_{12,H} = \frac{(B - 1/S)}{\pi\sqrt{B^2 - 1}} \tan^{-1}\sqrt{\frac{(B+1)(S-1)}{(B-1)(S+1)}} - \frac{(A - 1/S)}{\pi\sqrt{A^2 - 1}} \tan^{-1}\sqrt{\frac{(A+1)(S-1)}{(A-1)(S+1)}} \quad (66.17a)$$

$$F_{12,V} = \frac{1}{\pi S}\tan^{-1}\left(\frac{h}{\sqrt{S^2 - 1}}\right) - \frac{h}{\pi S}\tan^{-1}\sqrt{\frac{(S-1)}{(S+1)}} + \frac{Ah}{\pi S\sqrt{A^2 - 1}}\tan^{-1}\sqrt{\frac{(A+1)(S-1)}{(A-1)(S+1)}} \quad (66.17b)$$

where

$$A = \frac{h^2 + S^2 + 1}{2S}, \qquad B = \frac{1 + S^2}{2S}$$

$$S = \frac{2L}{D}, \quad h = \frac{2H}{D}$$

Ref: SFPE handbook, 5th edition

D	6	
Separation Distance	3	m
L	6.00	m
Hf	1.75	m
s	2.00	
h	0.58	
A	1.34	
B	1.25	
F12,H	**0.04**	
F12,V	**0.14**	
F12,Total	**0.18**	

Calculate geometric veiew factor between cylindrical flame and target plane.

Equation Reference:
SFPE 5th edition

Radiant Heat Flux Received Target BESS from flame			Calculate radiant heat flux received at Target from Flame
$\dot{q}'' = \varepsilon\dot{\sigma}FT^4 \quad (Equation\ 1)$			
ε, Emissivity of flame	1		
σ , Stefen-Boltzman Constant	5.67E-11	kW/m2K4	
F12,Total - View Factor of flame and target BESS	0.18		
T, Temperature of flame	707.79	K	
q'",Radiative Heat Flux (flame)	2.53	kW/m2	

Project:	**Proten - Rushes Creek**
Title:	Radiation Heat Flux Calculations

Ref	Calculations	Comments
Ref 1	***Emitting Radiation Calculation*** $\dot{q}''_e = \varepsilon \sigma T^4_{emitter}$	Version 1.6 R1

Input

Emissivity,	ε	1.00	
Stefan-Boltzmann constant	σ	5.67E-11	$kW/m^2/K^4$
Absolute Temperature of emitter,	$T_{emitter}$	434	°C

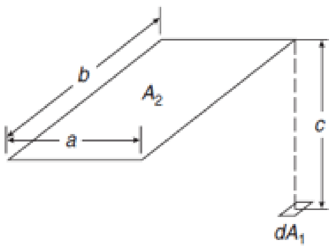
Output

Radiant heat flux emitted,	$\dot{q}''_e$	14.2	kW/m^2	
Distance from boundary		0.00	m	Away from building
Max radiant heat flux emitted at target plane,		5.2	kW/m^2	

Table 1-4.1 in Ref 1

Configuration Factor Calculation

Parallel Configuration



This configuration factor formula is for 1/4 plane element only.

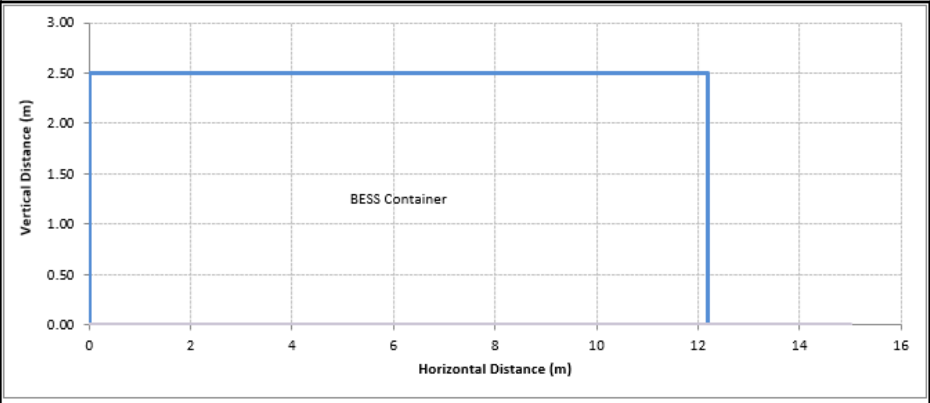
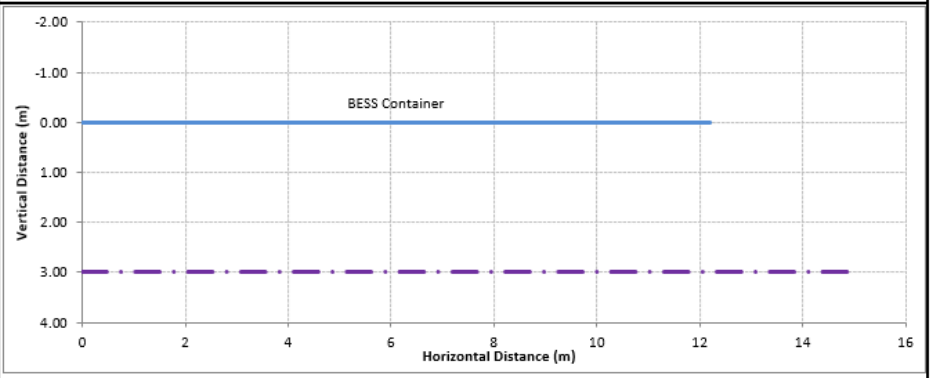
$X = a/c \qquad Y = b/c$

$$F_{d1-2} = \frac{1}{2\pi}\left[\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left(\frac{Y}{\sqrt{1+X^2}}\right) + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left(\frac{X}{\sqrt{1+Y^2}}\right)\right]$$

Project: Title:	Proten - Rushes Creek Radiation Heat Flux Calculations	
Ref	Calculations	Comments
	Input for Parallel Radiation Calculation ***Table 1: Emitting Radiation for Various Windows Parallel to Target***	Version 1.6 R1

Openings	Width	Height	c_1	$x_{i,b}$	$y_{i,b}$	Include in Analysis
	m	m	m	m	m	
BESS Container	12.19	2.50	3.00	0.00	0.00	Yes

c_1 is the distance from an opening to the boundary

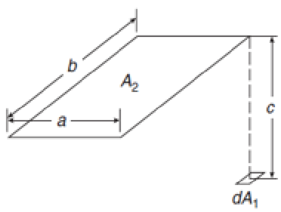
Project: Title:	**Proten - Rushes Creek** Radiation Heat Flux Calculations	
Ref	Calculations	Comments
		Version 1.6 R1
	Figure 1: Elevation of Openings	
		
	Figure 2: Plan of Openings	

Calculation for assessing radiant heat flux received by diesel tanks at recommended location shown in Figure 24.

Radiant heat from BESS container

GHD	Project:	**Proten - Rushes Creek**			
	Title:	Radiation Heat Flux Calculations			
Ref	Calculations				Comments
					Version 1.6 R1
	Emitting Radiation Calculation				
Ref 1	$\dot{q}''_e = \varepsilon \sigma T^4_{emitter}$				
	Input				
	Emissivity,	ε	1.00		
	Stefan-Boltzmann constant	σ	5.67E-11	$kW/m^2/K^4$	
	Absolute Temperature of emitter,	$T_{emitter}$	434	°C	
	Output				
	Radiant heat flux emitted,	$\dot{q}''_e$	14.2	kW/m^2	
	Distance from boundary		0.00	m	Away from building
	Max radiant heat flux emitted at target plane,		1.0	kW/m^2	
Table 1-4.1 in Ref 1	***Configuration Factor Calculation***				
	Parallel Configuration				This configuration factor formula is for 1/4 plane element only.
	Perpendicular Configuration				This configuration factor formula is for 1/2 plane element only.

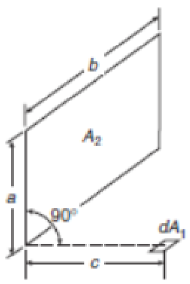
Parallel Configuration



$X = a/c \qquad Y = b/c$

$$F_{d1-2} = \frac{1}{2\pi}\left[\frac{X}{\sqrt{1+X^2}}\tan^{-1}\left(\frac{Y}{\sqrt{1+X^2}}\right) + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\left(\frac{X}{\sqrt{1+Y^2}}\right)\right]$$

Perpendicular Configuration



$X = a/b \qquad Y = c/b \qquad A = 1/\sqrt{X^2 + Y^2}$

$$F_{d1-2} = \frac{1}{2\pi}[\tan^{-1}(1/Y) - AY\tan^{-1}A]$$

Project: **Proten - Rushes Creek**
Title: Radiation Heat Flux Calculations

Ref	Calculations	Comments
		Version 1.6 R1

Input for Parallel Radiation Calculation
Table 1: Emitting Radiation for Various Windows Parallel to Target

Openings	Width	Height	c_1	$x_{i,b}$	$y_{i,b}$	Include in Analysis
	m	m	m	m	m	
BESS width side	12.19	2.50	3.00	0.00	0.00	Yes

c_1 is the distance from an opening to the boundary

Input for Perpendicular Radiation Calculation
Table 2: Emitting Radiation for Various Windows Perpendicular to Target

Openings	Width	Height	c_2	$x_{i,b}$	$y_{i,b}$	Hot Source Direction	Include in Analysis
	m	m	m	m	m		
BESS depth side	2.46	2.50	3.00	12.19	0.00	+x	Yes

c_2 is the closest distance from an opening to the boundary

Project: Title:	**Proten - Rushes Creek** Radiation Heat Flux Calculations	
Ref	Calculations	Comments
		Version 1.6 R1

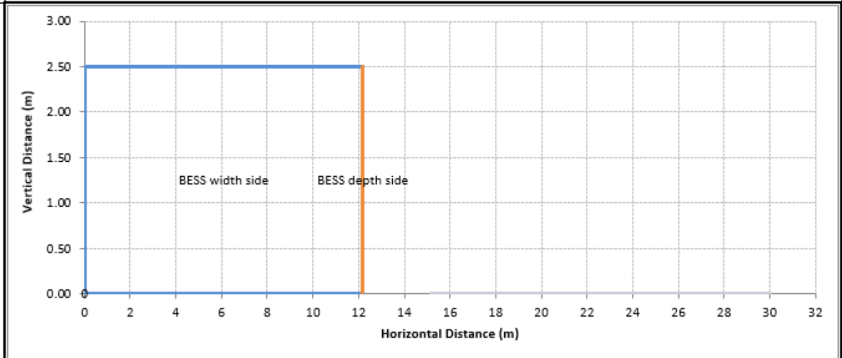


Figure 1: Elevation of Openings

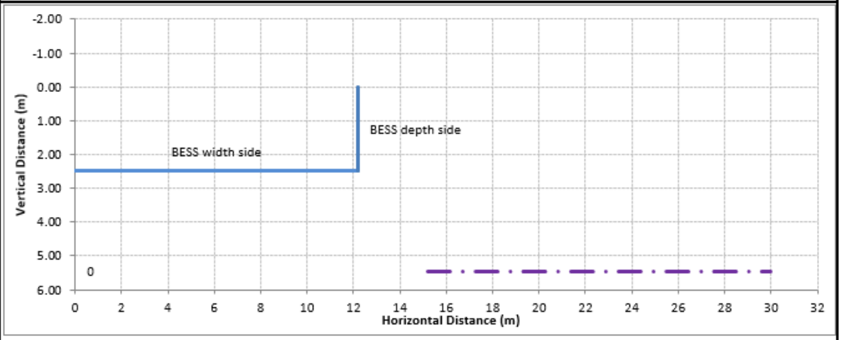


Figure 2: Plan of Openings

Radiant heat flux from the flame is estimated to be similar to the heat flux calculated in Table 12 at a distance of 3 m away for the proposed diesel tank placement zone ie, 1.5 kW/m^2.