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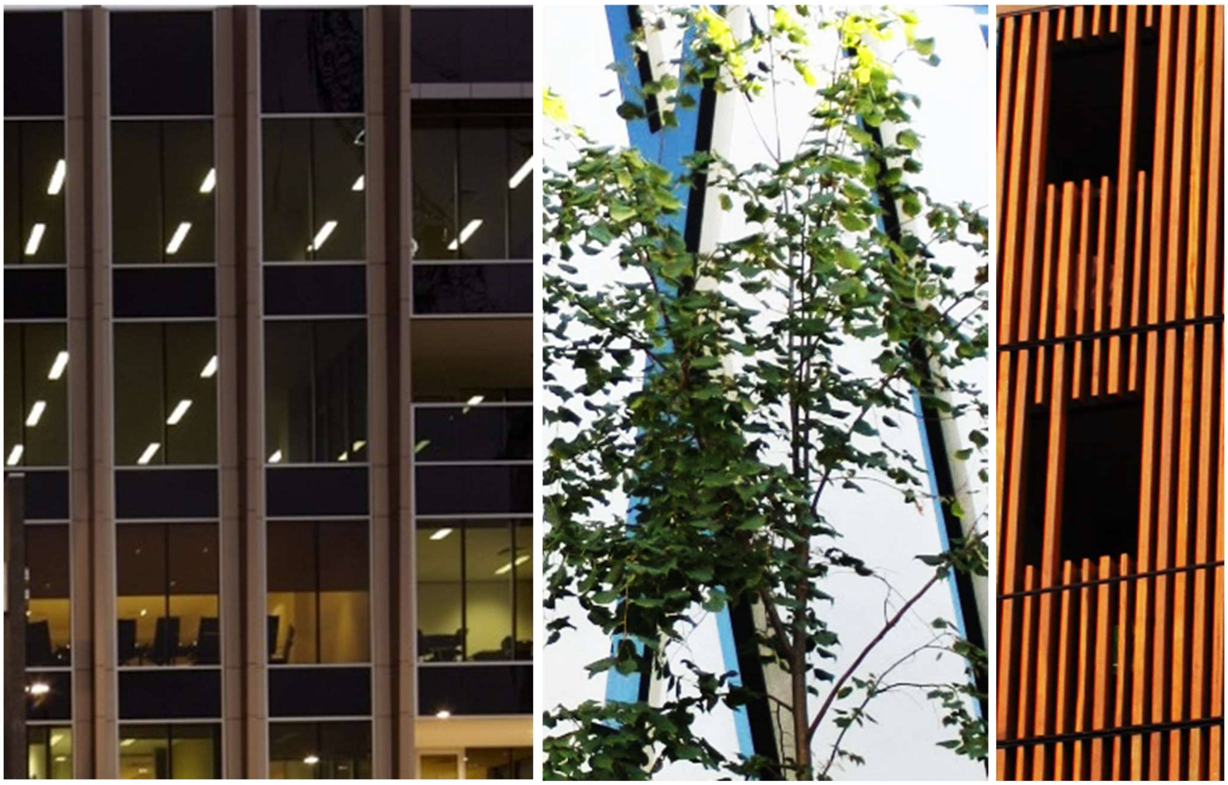
Fire Hazard and Risk Assessment

Thomastown Terminal Station Battery Energy Storage System



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1 EXECUTIVE SUMMARY

NJM Design has been engaged by Jacobs on behalf of AusNet to undertake a fire hazard and risk assessment for the Battery Energy Storage System (BESS) project located at Thomastown Terminal Station (TTS).

The objective of this report is to identify primary fire risks associated with the implementation and function, location, proposed fire systems and fire brigade intervention of the BESS units. This includes the fire risks from the unit itself, those posed to the attending fire brigade, the buildings in close proximity to the unit, and the community in which these units are situated.

In particular the scope of work is to:

- provide a risk review consistent with fire risk assessment techniques for Hazardous industry planning.
- quantify severity of fires including heat radiation level at various distances from BESS and transformer fires and durations of the fire; and
- put the risks into context via comparison with other accepted risks such as those from existing power infrastructure and surrounding buildings in the community
- recommend mitigation measures if required.

A review of relevant fire, electrical and building standards was conducted as part of the study (refer Section 2.1). Notably, findings of *Energy Safe Victoria's (ESV) Statement of Technical Findings – Fire at the Victorian Big Battery* have been considered.

Based on the results of the assessment it is concluded that:

1. The design of the BESS units is acceptable and covers all fire initiation and fire spread risks to an acceptable level
2. Based on the AS5139 Risk Methodology the risk of a fire would be considered rare and the risk level Very Low
3. The proposed installation procedures and units have design requirements that address the issues raised by the Victorian Big Battery (VBB) fire
4. The risk of fire development and spread is no worse than that posed by existing utility infrastructure in the community or the adjacent buildings in the community
5. Fire spread to adjacent allotments would not be predicted to occur.
6. Fire brigade intervention is considered not to be affected by a fire based on the preliminary fire modelling results presented within this report.
7. In order for the site entrance to be affected by a fire there would need to be a fire within the adjacent units as well as a wind from south or southwest which is not the predominant direction. The boosters and brigade access are separated from the battery units and transformers and hence the predicted fire size is not large enough to block the entrance to the site even with the wind in the correct direction.
8. The firefighting water will be sufficient for 4 hours supply based on at least 2 hydrants. The hydrants will be located such that all areas can be covered by at least 2 hydrants.
9. The other parts of the infrastructure such as the transformers and control room do not present a significant fire risk or higher hazard than other kiosk type transformers and small buildings in the community that do not require particular fire safety provisions.

It is considered that the design and layout of the BESS provides an acceptable level of fire safety to personnel, fire brigade and adjacent properties.

2 SCOPE

2.1 GENERAL

NJMDesign has been engaged by Jacobs on behalf of AusNet to undertake a fire hazard and risk assessment for the Battery Energy Storage System (BESS) project located at Thomastown Terminal Station (TTS).

The objective of this report is to identify primary fire risks associated with the implementation and function, location, proposed fire systems and fire brigade intervention of the BESS units. This includes the fire risks from the unit itself, those posed to the attending fire brigade, the buildings in close proximity to the unit, and the community in which these units are situated.

A review of the design to applicable standards has been undertaken as well as a comparative risk assessment to existing power utility infrastructure and industrial facilities in the same setting. This included:

a. AS 5139 Electrical Installations – Safety of battery systems for use with power conversion equipment

b. Best Practice Guide for Battery Storage Equipment - Electrical Safety Requirements, Version 1.0 – Published 06 July 2018

c. NFPA 855, Standard for Stationary Energy Storage Systems (in development),

d. AS2067 has also been reviewed to place the risk of the BESS units in context with existing power utility infrastructure in the community.

e. Design Guidelines and Model Requirements: Renewable Energy Facilities, Country Fire Authority, March 2022.

f. FM Global Data Sheet 5-33 Factory Mutual Insurance Company. (2017). FM Global Property Loss Prevention Data Sheets 5-33. Factory Mutual Insurance Company.

g. AS3000

h. Building Code of Australia (BCA) 2019 Amendment 1

i. Energy Safe Victoria (ESV) “Statement of Technical Findings - Fire at the Victorian Big Battery

An assessment of the likelihood of ignition and fire spread from a battery unit was undertaken. This assessment included the investigation of the likely heat release rate (HRR) of a fire and its impact on an adjacent building as a result of radiant heat transfer.

It is beyond the scope of this fire risk assessment to assess the likely spread at ground level of firefighting water run-off.

NJM Design makes all reasonable efforts to incorporate practical and advanced fire protection concepts into its advice. The extent to which this advice is carried out affects the probability of fire safety. It should be recognised, however, that fire protection is not an exact science. No amount of advice can, therefore, guarantee freedom from either ignition or fire damage.

The implementation of the findings of this report is the responsibility of others, including but not limited to:

- Development of drawings and specifications.
- The installation of hardware and construction system.
- The operation and maintenance of those systems.

2.2 Basis of the Study

The development of the study was based on the following:

- Visual site inspections carried out by NJM Design representatives accompanied by representatives of Jacobs and AusNet Services.
- Visual inspection of the proposed location of the facility.
- Review of documentation provided by AusNet Services representatives including fire services design documentation.
- Review of other BESS fires and installations in particular the Victorian Big Battery fire and the ESV findings

2.3 Qualifications

The assumptions and qualifications on which this Study is based include but are not limited to the following:

- Site inspections were limited to the general visual inspection of the green field site.
- The work did include the inspection within existing adjacent buildings for compliance with current or previous design, installation or construction Standards, Codes or regulations applicable at the time of construction or installation.

3 Risk Assessment Methodology

3.1 Introduction

This Fire Safety Assessment formulates part of an integrated assessment process for safety assurance of development proposals, which are potentially hazardous. The assessment is based on the methodology outlined in the Hazardous Industry Advisory Papers (HIPAPS).The process is shown diagrammatically in Figure 1.

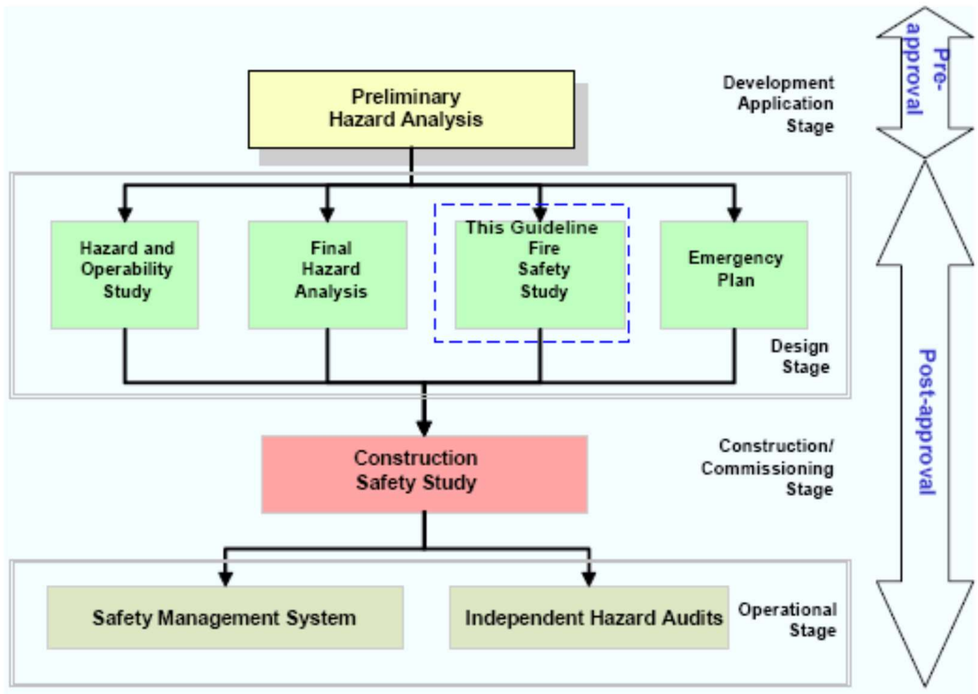

Figure 1: The Hazards-Related Assessment Process

A number of Hazardous Industry Advisory Papers (HIPAPS) have been published to assist stakeholders in implementing the process, i.e.:

- No. 1 - Industry Emergency Planning Guidelines
- No. 2 - Fire Safety Study Guidelines
- No. 3 - Environmental Risk Impact Assessment Guidelines
- No. 4 - Risk Criteria for Land Use Planning
- No. 5 - Hazard Audit Guidelines
- No. 6 - Guidelines for Hazard Analysis
- No. 7 - Construction Safety Studies
- No. 8 - HAZOP Guidelines
- No. 9 - Safety Management System Guidelines
- No. 10 - Land Use Safety Planning (Consultation Draft)

The studies detailed in the HIPAP papers involve case-specific hazard analyses and design of fire safety arrangements to meet those hazards. The approach is particularly important where significant quantities of hazardous materials as is the case with BESS units are involved.

3.2 Risk Management

The hazards identified as part of this assessment have been assessed using the below risk criteria and ranking based on past HIPAP studies and industry practices undertaken by the author.

The effectiveness of the existing controls was rated using the following criteria (Table 1).

Table 1 Risk Control Effectiveness

Level	Descriptor	Control Rating Guidance Description
1	Excellent	The system is effective in mitigating the risk. Systems and processes exist to manage the risk and management accountability is assigned. The systems and processes are well documented and understood by staff. Regular monitoring and review indicate high compliance with the process.
2	Good	Systems and processes exist which manage the risk. Some improvement opportunities have been identified but not yet actioned. Formal documentation exists for key systems and processes in place to manage the risk that is reasonably understood by staff.
3	Fair	Systems and processes exist which partially mitigates the risk. Some formal documentation exists, and staff have a basic understanding of systems and processes in place to manage the risk.
4	Poor	The system and process for managing the risk has been subject to major change or is in the process of being implemented and its effectiveness cannot be confirmed. Some informal documentation exists; however, staff are not aware or do not understand systems or processes to manage the risk.
5	Unsatisfactory	No system or process exists to manage the risk.

The following table was used to rate the likelihood of different risks occurring (Table 3) that has been extracted from Appendix G of AS5139:

Table 2 Likelihood Rating Criteria

Table G.2 — Example likelihood of occurrence rating

Likelihood rating	Definition of likelihood of occurrence rating
Almost certain	Probability of occurrence: greater than 90 %
	Expected to occur whenever system is accessed or operated
	The event is expected to occur in most circumstances
Likely	Probability of occurrence: 60 % – 89 %
	Expected to occur when system is accessed or operated under typical circumstances
	There is a strong possibility the event may occur
Possible	Probability of occurrence: 40 % – 59 %
	Expected to occur in unusual instances when the system is access or operated
	The event may occur at some time
Unlikely	Probability of occurrence: 20 % – 39 %
	Expected to occur in unusual instanced for non-standard access or non-standard operation
	Not expected to occur, but there is a slight possibility it may occur at some time
Rare	Probability of occurrence: 1 % – 19 %
	Highly unlikely to occur in any instance related to coming in contact with the system or associated systems
	Highly unlikely, but it may occur in exceptional circumstances, but probably never will

3.3 Consequence Rating

The following table was used to rate the consequence of different risks occurring (Table 3)

The consequence for each risk was considered in relation to its cumulative effect in the period under review.

Table 3 Consequence rating Appendix G AS5139

Table G.1 — Typical risk consequence table

Consequence/ impact category	Consequence/impact rating definitions				
	Catastrophic	Major	Moderate	Minor	Insignificant
Health and safety	Any fatality of staff, contractor or public	Non-recoverable occupational illness or permanent injury	Injury or illness requiring medical treatment by a doctor	Injury requiring first aid	No or minor injury
		Injury or illness requiring admission to hospital	Dangerous/reportable electrical incident	Circumstances that lead to a near miss	
Environmental	High, long term or widespread impact (spill, emission, or habitat disturbance) to sensitive environment	Substantial impact — large spill or emission requiring Emergency Services attendance	Moderate impact — Spill or emission not contained on site with clean up needed	Minor cleanup/rectification — spill or emission not contained on site	Small spill or emission that has no impact on site or installation
	Environmental agency response with significant fine	Recovery of environment likely but not necessarily to pre-incident state	Death or destruction of protected flora or fauna	Environment expected to fully recover to pre-incident state	Clean up requires no special equipment and has no potential impact
	Long term recovery of environment to pre-incident state not likely	Any spill into sensitive area (wet tropics, fish habitat, potable water supply)	Environment likely to recover to pre-incident state in short to medium term	Environmental nuisance (short-term impact) caused by noise, dust, odour, fumes, light	
Legal and regulatory	Breach of licences, legislation or regulations leading to prosecution	Breach of legislation or regulations leading to: (a) contravention notice from authorities; or (b) court order; or (c) fine over $1000	Breach of legislation, regulations leading to: (a) warning notice; or (b) fine of up to $1000; or (c) enforceable undertakings	Breach of legislation regulations, policies or guidelines leading to an administrative resolution	No issues
Asset impact	Equipment destruction, repair not possible, asset repair greater than original cost of works	Equipment damage repaired at a cost of between 50 % and 100 % of original cost of works	Equipment damage repaired at a cost of between 15 % and 50 % of original cost of works	Equipment damage repaired at a cost of between 2 % and 15 % of original cost of works	Simple equipment damage with no or same day repair at a cost of less than 2 % of original cost of works

3.4 Risk Criteria

The likelihood and consequences of a risk occurring were used to determine the risk rating of either low, medium, high or extreme. The matrix below was used to provide a visual method of categorising risks based on their risk rating.

To determine the risk rating, the Likelihood rating is added (+) to the Consequence rating. The addition of the two numbers produces a continuum number that is a number from 2 through to 10. (Table 4)

Table 4 Risk rating

Table G.3 — Risk matrix table

Consequence (how serious)	Likelihood (how often)				
	Rare	Unlikely	Possible	Likely	Almost certain
Catastrophic	Medium	High	High	Extreme	Extreme
Major	Medium	Medium	High	High	Extreme
Moderate	Low	Medium	Medium	High	High
Minor	Very low	Low	Medium	Medium	Medium
Insignificant	Very low	Very low	Low	Medium	Medium

The risk treatment options, which are available for the treatment of risks, are based on five main concepts:

Table 5 Risk Treatments

Avoid:	Do not proceed with the activities that create the risk.
	Find and implement measures that ensure the risk is monitored and

Treat:	mitigated. Control involves reducing the likelihood and/or consequence.	
	Change the likelihood:	Reduce the likelihood of an adverse event occurring through preventative measures. E.g., Training, Awareness, Procedures, Asset Management.
	Change the Consequences:	Reduce the size of the losses associated with undertaking an activity. E.g., Emergency response, Contingency and Disaster recovery plans.
Share:	Risks are shared with suppliers, business partners or other organisations Not considered applicable for the subject facility.	
Transfer:	Risk or part of a risk is transferred to another party. Even though the risk may have been transferred, it should be noted that it still exists. Not considered applicable for the subject facility.	
Retain:	Retention of a risk, primarily where no other options exist, or it is not commercially feasible to treat it in any other way. Only really acceptable for Low to Medium risks	

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4 BESS Facility Description

4.1 Location

The facility is located in the vacant land, owned by AusNet, to the Northwest of the existing Thomastown Terminal Station.

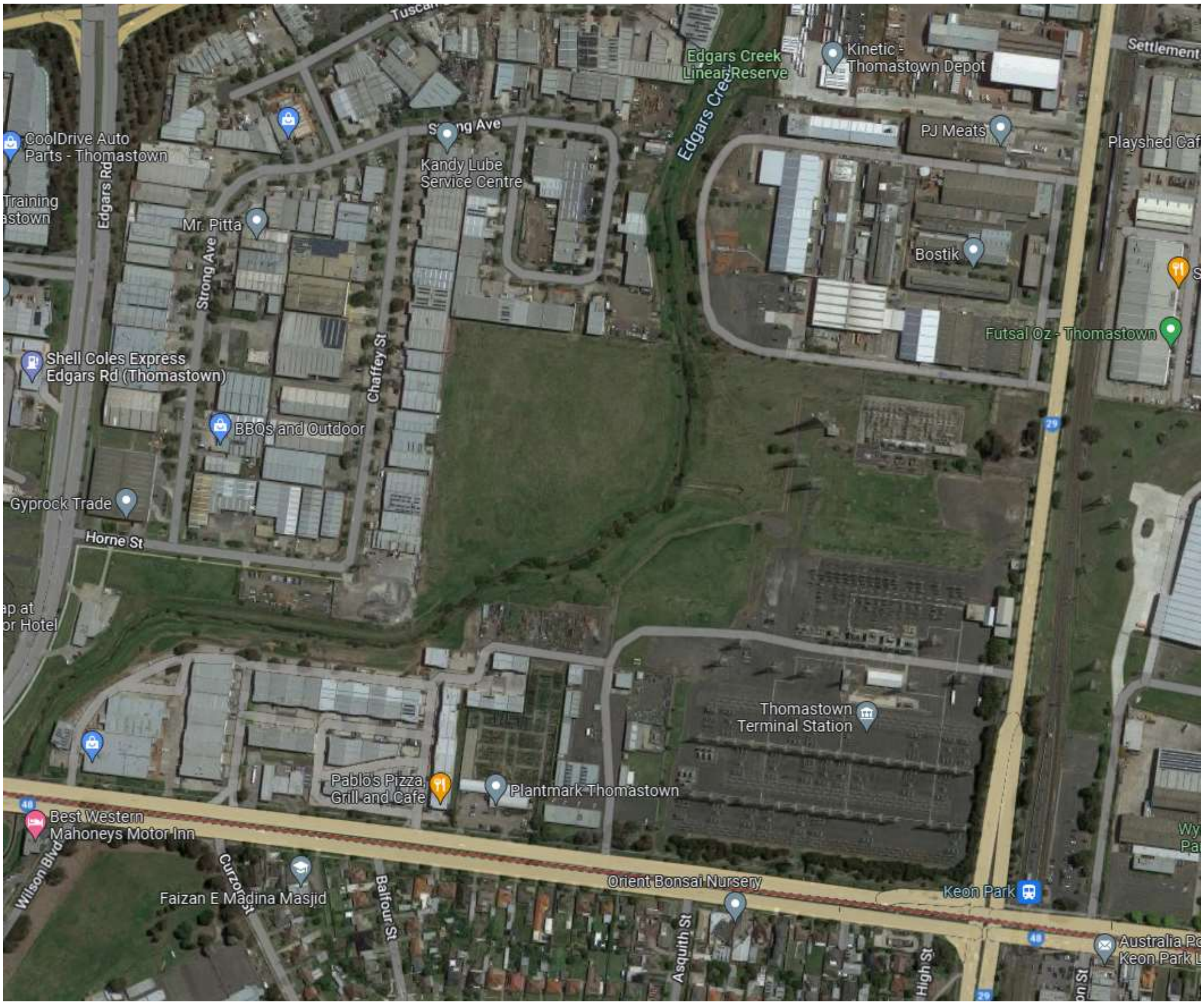

Figure 2 Site Location

4.1.1 Land Zones

The site is zoned as Industrial 1 based on the Vicplan zoning maps.

Figure 3: Site Zoning (UFZ – Urban Floodway Zone, IN1Z – Industrial Zone 1.)

Edgars creek runs to the South and East of the site. An urban floodway is located in the Northeast corner of the site and to the southwest of Edgars Creek.

The creek is bounded by native vegetation zone either side of the creek. The land subject to inundation overlay (LSI) occurs to the east and south of the site and along the creek to Edgars Road (Appendix A).

An area of Aboriginal Cultural Heritage exists along Edgars Creek but no specific areas requiring protection from a fire event are understood to have been identified.

4.1.2 Adjacent Infrastructure and Transport

The site is separated to the adjacent non-industrial areas and transport infrastructure by the following distances:

- Metropolitan Ring Road – North – 455m
- Edgards Road – West – 318m
- Mernda Train Line – East – 361m
- Mahoneys Road – South 239m
- Residential houses – South – 283m

Figure 4 Separation Distances to other land uses

4.1.3 Fire Brigade Stations

The closest fire brigade stations are:

- Thomastown Fire Station – Station 7 – 1.3km
- Epping Fire Station – Station 11 – 6.5km

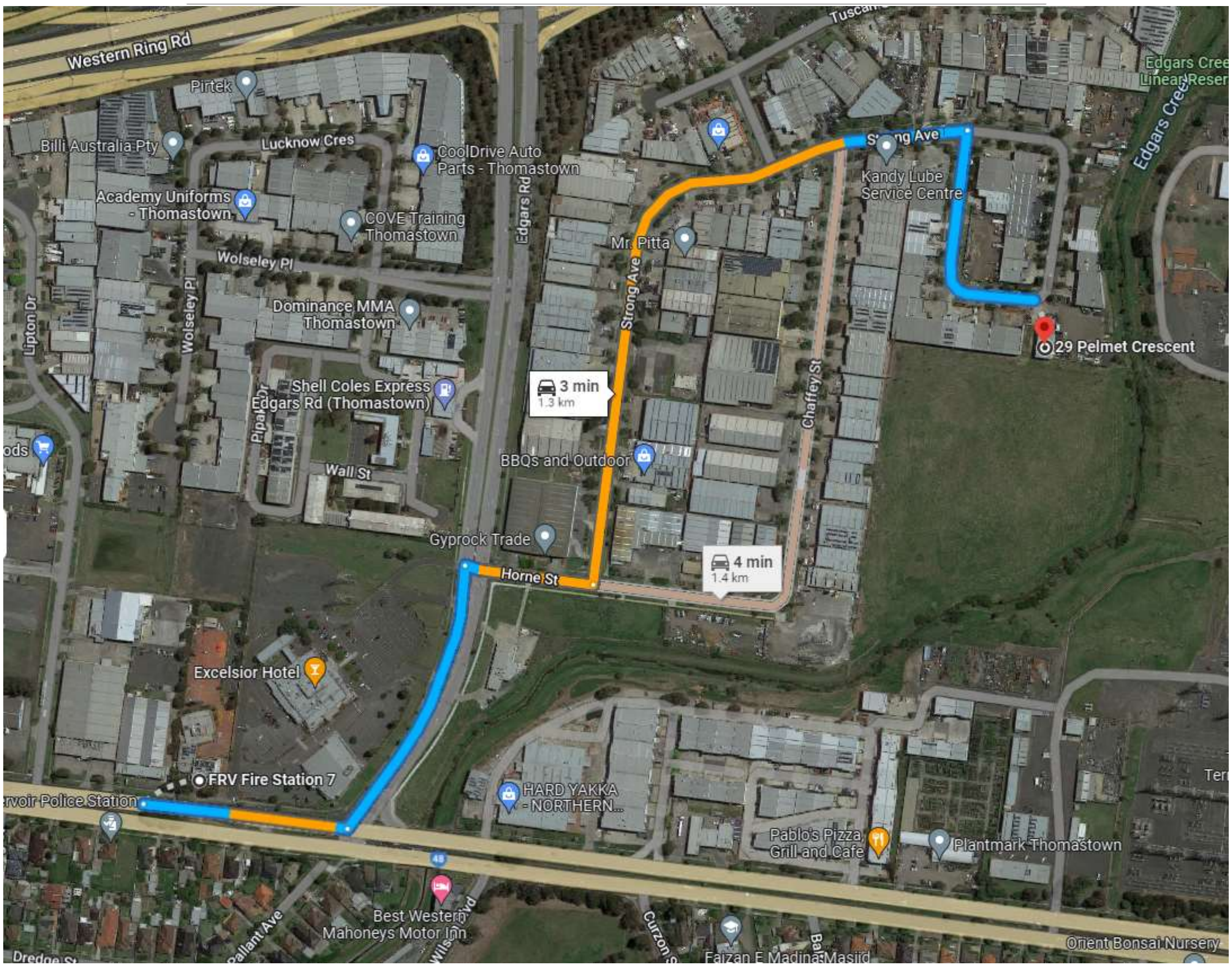

Figure 5 Thomastown Fire Station

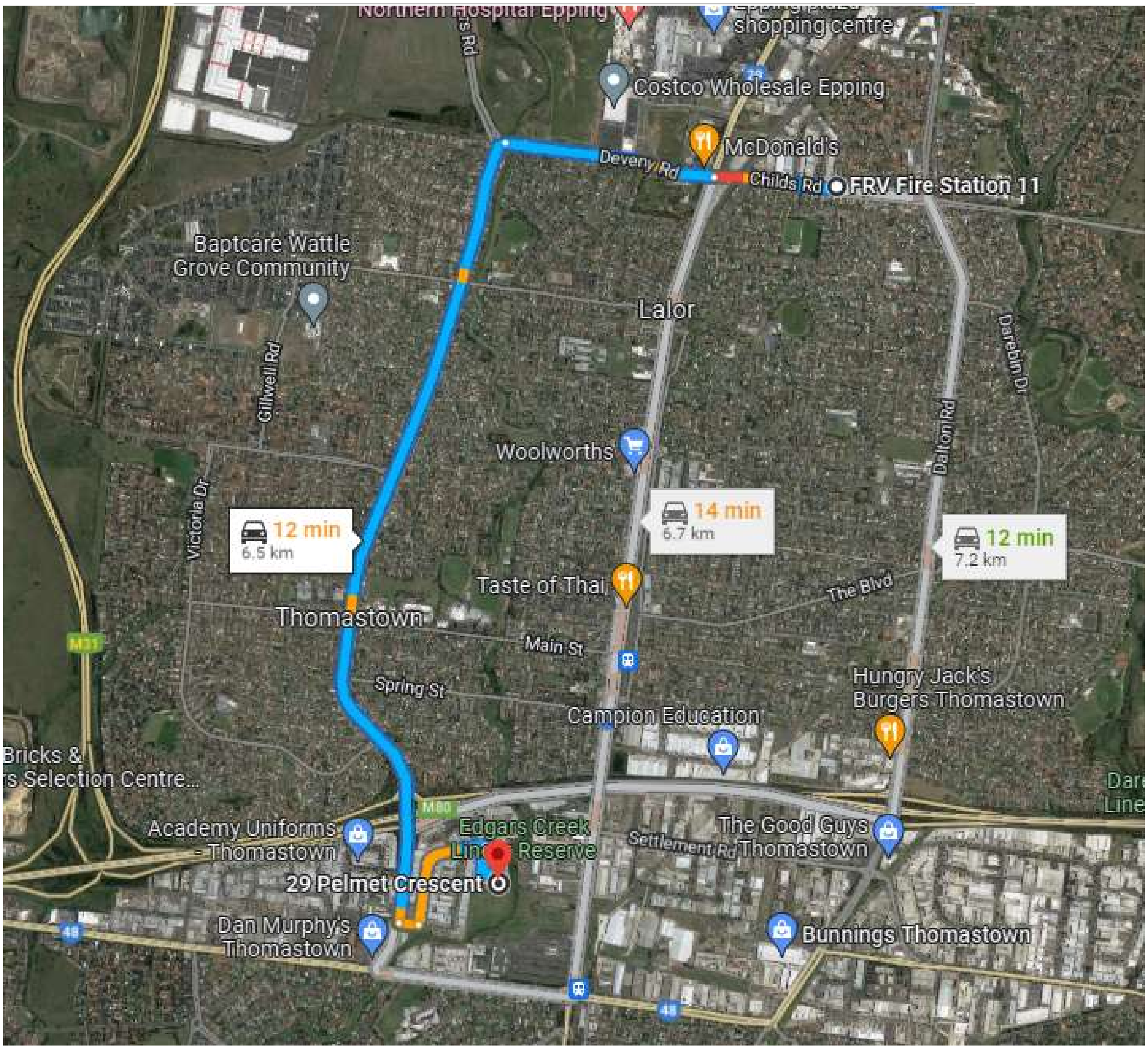

Figure 6 Epping Fire Station

4.2 Facility Layout

4.2.1 General

The facility is as presented in the plans in Appendix A.

The battery units are separated into "islands" by the 6m fire brigade track and maintenance road. The units are further split into a north and south side by a 10m high noise wall.

Each battery unit is approximately 8.8m x 1.66m and located back-to-back. The set of two units are then separated from the adjacent set of two units by 2.54m and from the transformer by 1.7m. Each transformer is separated from the adjacent transformer by 2.11m.

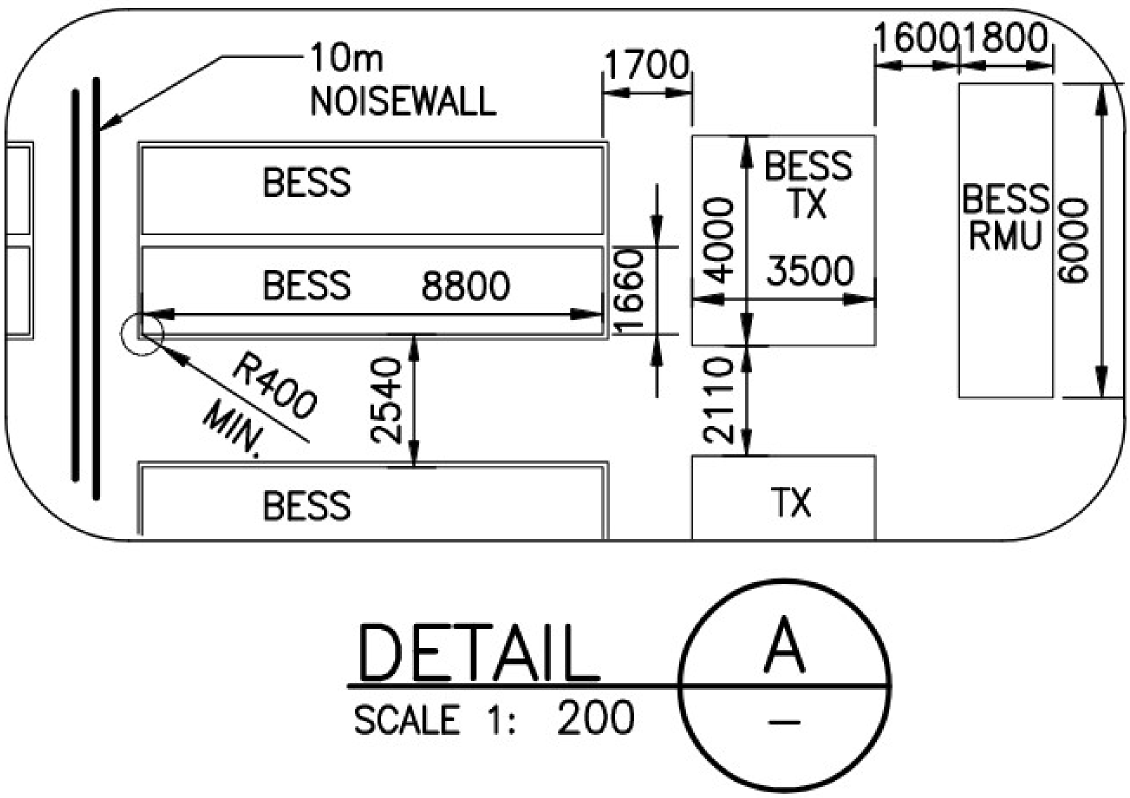

Figure 7 BESS unit layout

The noise wall is proposed to be constructed from an acoustic panel material consisting of steel sheets and a mineral wool interlayer similar to Flex shield Sonic system modular panel (Appendix C). The wall system has been tested to AS1530.4 and has achieved a fire rating of -/120/-. Accordingly, when supported by steel posts each side the sound walls would serve as a fire rated separation between the main rows of battery units in each island.

The risk of fire spread, and exposure of the booster location is significantly reduced.

4.2.2 Brigade Access

Access to the site is off Pelmet Crescent via a 6m wide driveway between two adjacent facilities. The walls of the buildings bounding the driveway are concrete panel walls with no openings.

Figure 8 Site access

The fire tanks and booster are to be located adjacent to the access driveway that serves as the start of the fire brigade access track that is continuous around the entire facility as a 6m wide road. The 6m wide fire brigade track extends around and within the facility and separates the battery units into smaller areas. Attack fire hydrants are to be located around the fire track such that all areas can be covered by at least two hydrants.

The hardstand surface that is required by AS 2419.1–2005 to be provided to serve feed and attack fire hydrants as well as fire brigade booster connections will be designed in accordance with FRV Guideline 13, Version7, August 2017, i.e.:

- to withstand a uniformly distributed load over the entire area of 7 kPa or 0.7 tonnes/m^2 and a continuous water discharge from a fire brigade appliance. (This is to prevent the pumper from being undermined by water issuing from the appliance over an extended period.)
- shall be designed to withstand a point load of 15 tonnes (or 150kN) so that it can withstand an aerial appliance at any location within the boundaries of the hardstand.

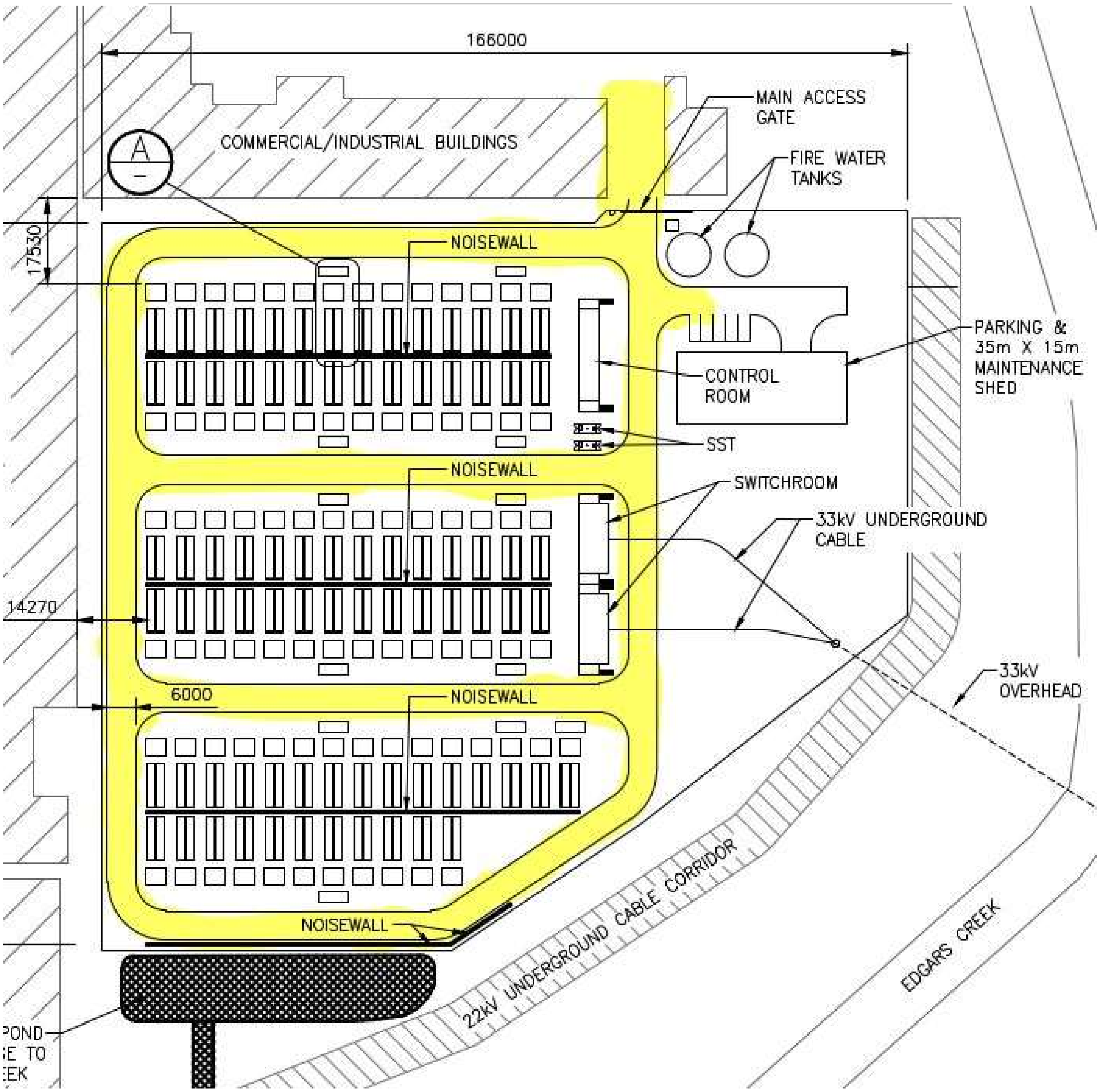

Figure 9 Ste plan showing the fire track around and through the site

A control room (<500m^2) and switch rooms are located to the East of the batteries. A laydown parking and future expansion area is to be located to the East of the site.

The facility will be enclosed within a security fence and the fire track will run within the fence.

A drainage system will run between and around the battery units that drains into a water treatment / detention pond.

4.3 Adjacent Properties and Site Access

4.3.1 Adjacent Properties

The adjacent properties consist of small industrial buildings, i.e., no large isolated buildings or registered hazardous areas. The land is zoned Industrial 1 Zone which means the area is "intended to provide a wide range of general industrial and warehouse land uses. To prevent competition for industrial land, business and retail uses are not permitted in this zone. This includes bulky goods premises."

The buildings to the North are constructed to the boundary line and have a concrete panel wall on the boundary.

Figure 10 Building to the north of the property boundary. Note access driveway located between the buildings.

The buildings to the west are constructed from masonry and are generally located 3m off the property boundary although some veranda and the like have been constructed up to the boundary. The buildings contain window openings to the East elevations i.e., facing the subject property.

Figure 11 Properties to the West

4.3.2 Prevailing Weather

The wind rose data from the Viewbank weather station, approximately 10km from the site indicates that following wind speeds and directions for the period 1999 to 2021:

- Calm 6% of the time
- The wind was in the North, Northeast or East 49% of the time
- The wind was from West, Southwest or South 35% of the time
- The predominate wind is from the Northeast at 21% of the time
- Wind from the southwest has:
    - a maximum range of 20 to 30 km/hr that occurs 0.9% of the time
    - a range of 10 – 20 km/hr that occurs 4.3% of the time and
    - a range of 0 to 10km/hr that occurs 5% of the time
- Wind from the West has:
    - A maximum range of 30 – 40km/hr that occurs 0.2% of the time
    - A range f 20-30 km/hr that occurs 2% of the time
    - A range of 10 – 20km/hr that occurs 6.3% of the time
    - A range of 0 – 10km/hr that occurs 5% of the time

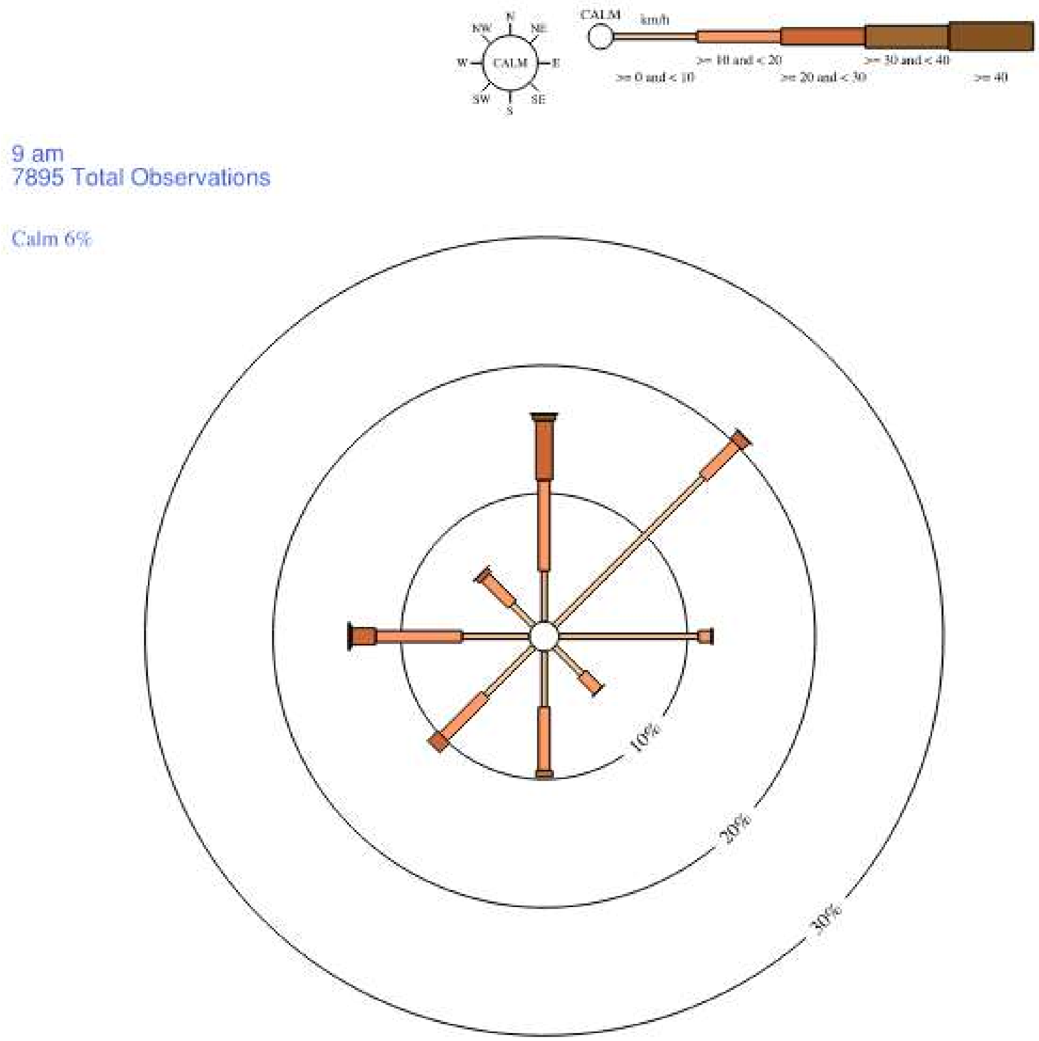

Figure 12 Wind Rose for Viewbank

The fire brigade facilities are located Northeast/ East of the battery units and hence would only be affected by winds from the West and Southwest.

The presence of the 10m high acoustic sound walls, neighbouring buildings and the gap between two buildings at the entrance would mean that the battery units are in a semi-protected location especially from those battery units to the south and west of the site when the wind is in the south or southwest.

The main vehicle entrance, fire tanks and booster are located approximately 25m to the East of the nearest battery unit.

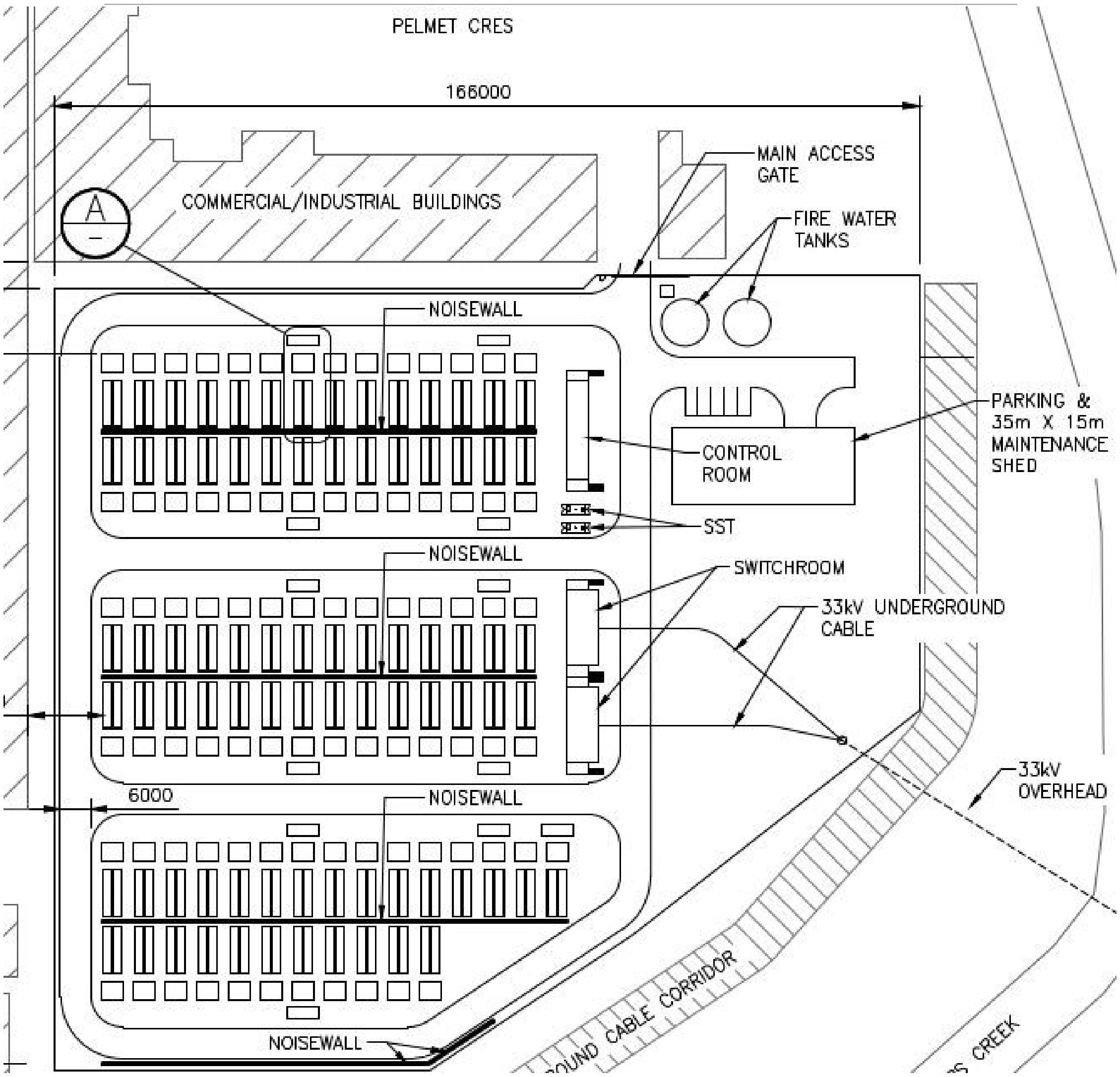

Figure 13 Location of the battery Units to the fire booster and tanks

The presence of the fire rated noise wall means the fire tanks and hardstand means they are protected from the main area of the facility and the level of exposure is significantly reduced.

4.3.3 Edgards Creek Maintenance track

The local council and Melbourne water have a maintenance track to the Southwest of the site.

The track has a surface of natural ground, grass and dirt and is not paved. The track also has no street lighting such that use of the track at night or in wet weather would be hazardous. The land is not part of the project land title.

Figure 14 Southwest end of Edgars creek

This track is between an earth berm that is approximately 1.5m high to the north along the adjacent property boundary and a 2m drop to the creek to the south. The track is within the inundation overlay of the creek. The entrance from Edgars Road and the rear of the Wattyl Paint Centre carpark is approximately 350m from the southwest corner of the site.

Given the difficulty in making the maintenance track suitable for emergency use, the fact it is not part of the property boundary, and possible inundation of the track due to heavy rain it is considered that it is not a reliable secondary access.

4.3.4 FRV Guideline 13 Hardstand and Emergency Vehicular Access for Firefighting Appliances

The scope of Guideline 13 is:

“This guideline applies to the design and construction of emergency vehicle access roads and hardstand surfaces within the FRV district.”

The guideline references BCA clause C2.3 and C2.4 that requires the fire brigade road to be 6m wide and capable of providing emergency vehicle access from a public road. This is satisfied with access from Pelmet Crescent.

It is noted that the Guideline does not state that two independent access points are required into a site only the road provides access around an entire site for large, isolated buildings.

The Guideline also provides the following issues for consideration:

- the provision of external fire hydrants usually determines the requirements for hardstand and emergency vehicle access. All buildings and protected areas, irrespective of type, size or classification, require emergency vehicle access and hardstand for external fire hydrants and fire brigade booster connections (This will be provided in the proposed layout)
- in the case of low-rise buildings with large floor areas, e.g., a large shopping complex or warehouse, hardstand is required to be provided adjacent to specific firefighting equipment and emergency vehicle access is also required to be provided around the building (This will be provided in the proposed layout)
- in the case of a fire in a non-sprinkler protected building (but not limited to a very large floor area) every

type of firefighting appliance may be required to attend a fire incident. This includes specialist firefighting aerial appliances, which are the heaviest appliances operated by FRV (This will be provided in the proposed layout as the road will be designed for aerial appliances as well as pumper appliance)

- greater point loads are generated from those specialist firefighting (aerial) appliances that utilise small area stabiliser pads (jacking points) (The access roads and roads between the units will be designed to accommodate the required point loads)
- as emergency vehicle access roads may also be used for general traffic routine inspections need to be undertaken to ensure that these areas remain clear and functional at all times. Potential traffic management issues should be considered in the design of roadways, for example, roll-over kerbing and passing areas (This will be accommodated in the design)
- location of emergency vehicle access and hardstand at premises containing dangerous goods should take into consideration prevailing wind directions, and the knock-on effect of fire on other dangerous goods storage areas located at the site (The battery units and transformers are not considered to contain dangerous goods. However, the assessment of the effects of wind has been performed and demonstrated not to affect the proposed site access)

The proposed single entrance from Pelmet Crescent to the north is not likely to be affected by the predominant winds and is no worse than access to industrial sites that can also have a single 6m wide access.

5 Fire Hazards

5.1 Hazards

One of the main hazards associated with the use of lithium batteries for energy storage is overheating and thermal run away resulting in a fire. Cell thermal runaway refers to rapid self-heating of a cell derived from the exothermic chemical reaction of the highly oxidizing positive electrode and the highly reducing negative electrode; it can occur with batteries of almost any chemistry.

Lithium-ion batteries contain highly energetic materials and combustible materials (i.e., electrode, separator, electrolyte and organic solvents). If it is subject to overcharging, short circuit, extrusion, collision, exposed in fire, etc., it can trigger thermal run-away and lead to a fire and explosion.

The combustion process of batteries could be summarized into the following stages: heating to ignition, violent ejecting or explosion, stable burning and weakening and extinguishment. Both the state of charge and incident heat flux have significant impact on the combustion behaviour of the battery. The battery with high charge presents a fierce combustion process and higher surface temperature than the others, especially when imposed with a high external heat flux.

5.2 Past BESS Fires

In order to obtain an understanding of the hazards associated with BESS facilities a summary of past fires is presented below including the Moorabool Fire

5.2.1 Victorian Big Battery fire

The Energy Safe Victoria (ESV) "Statement of Technical Findings - Fire at the Victorian Big Battery" provides a summary of the key findings into the fire.

On 30 July 2021, the Victorian Big Battery (VBB) experienced a fire that involved two Battery units during commissioning.

The root cause of the fire was found to be a leak within the cooling system that caused a short circuit that led to a fire in an electronic component. This resulted in heating that led to a thermal runaway and fire in an adjacent battery compartment within one unit, which spread to an adjacent second unit.

The contributing factors into the fire were reported to be:

- The supervisory control and data acquisition (SCADA) system took 24 hours to 'map' to the control system and provide full data functionality and oversight to operators. The unit that caught fire had been in service for 13 hours before being switched into an off-line mode when it was no longer required as part of the commissioning process. This prevented the receipt of alarms at the control facility.
- A key lock was operated correctly to switch the unit to off-line service mode (which was no longer required for ongoing commissioning), but this caused:
    - telemetry systems for monitoring the condition of the (now out of service) unit to shut down and so remove visibility of the developing event
    - the battery cooling system to shut down
    - the battery protection system to shut down, including the high voltage controller (HVC) that could have operated a pyrotechnic fuse to disconnect the faulty battery unit.

The lesson learnt from the fire were reported to be:

- Each cooling system is to be fully functionally, and pressure tested when installed on site and before it is put into service
- Each cooling system in its entirety is to be physically inspected for leaks after it has been functionally, and pressure tested on site

- The SCADA system has been modified such that it now 'maps' in one hour and this is to be verified before power flow is enabled to ensure real-time data is available to operators
- A new 'battery module isolation loss' alarm has been added to the firmware; this modification also automatically removes the battery module from service until the alarm is investigated
- Changes have been made to the procedure for the usage of the key lock during commissioning and operation to ensure the telemetry system is operational
- The high voltage controller (HVC) that operates the pyrotechnic fuse remains in service when the key lock is isolated.

The over pressure vents in the roof of the units involved in the VBB fire were seen as the main fire propagation method and a weakness in the fire spread prevention. (The effect of vents on possible fire spread scenarios versus the consequence of an overpressure event if they were not installed will be assessed as part of the detailed assessment of the final unit design)

The wind conditions at the time of the VBB fire were 37 – 56km/hr which based on the wind data for the Thomastown location would only occur less than 0.2% of the time, i.e., a probability of 0.002.

It was recommended in the report that one of the hardware mitigation measures is the installation of newly designed, thermally insulated steel vent shields within the thermal roof of all units.

The fire did not spread beyond the two units and no members of the public or emergency services were indicated to have suffered significant injuries.

5.2.2 S&C Electric Lithium-Ion ESS fire in Wisconsin

The fire occurred in the S&C Electric facility in 2016. Within this facility, energy storage systems are designed, assembled, and operated before being deployed. The fire was initially assumed to have initiated with the lithium-ion batteries, however, the investigation later determined that the fire started in the battery manufacturer's DC power and control compartment – not the batteries themselves. The DC power and control unit that started the fire was part of a larger system that was being assembled – therefore the safety features normally integrated into an ESS were not yet installed in this particular fire event.

The units at the proposed site will be fully functional at the time of delivery and installed and commissioned at the time of installation including safety systems.

5.3 Thermal Runaway / Fire within a battery

One of the reasons lithium-ion cell thermal runaway reactions can be very energetic is these cells have very high-energy densities compared to other cell chemistries. The other reason that lithium-ion cell thermal runaway reactions can be very energetic is because these cells contain flammable electrolyte, and thus, not only do they store electrical energy in the form of chemical potential energy, but they also store appreciable chemical energy (especially compared to cells with water-based electrolytes) in the form of combustible materials.

Self-heating of lithium-ion graphitic anodes in the presence of electrolyte initiates at temperatures in the 70 to 90°C. Thus, if a cell is brought to this initiating temperature in an adiabatic environment, it will eventually self-heat to the point thermal runaway initiates. For a typical 100% charged cell brought to its self-heating temperature, thermal runaway will occur after approximately two days if the cell is well-insulated. Should initial temperature be higher, time to thermal runaway will be shorter. For example, if a typical lithium-ion cell is placed into an oven at more than 150°C (300°F), such that separator melting occurs, additional heating due to shorting between electrodes will occur and cell thermal runaway will initiate within minutes. However, if heat is allowed to escape, time to thermal runaway may be longer, or the cell may never achieve thermal runaway.

Measurement of cell case temperatures during thermal runaway experiments have been performed by laboratories such as UL. For fully charged cells, these temperatures can reach in excess of 600°C case temperatures. The temperature rise is driven by reactions of the electrodes with electrolyte and release of stored energy. Some cathode materials will decompose and may change their crystalline structure which may result in the release of small quantities of oxygen that can participate in reactions internal to the cell (e.g., oxidation of the aluminium current collector).

This fact has led to a misconception that lithium-ion cells burn vigorously because they "produce their own oxygen." This idea is incorrect. No significant amount of oxygen is found in cell vent gases.[1] Any internal production of oxygen will affect cell internal reactivity, cell internal temperature, and cell case temperature, but plays no measurable role in the flammability of vent gases.

5.3.1 Research and Testing of Lithium-Ion Batteries and BESS

Full-scale testing of a large, containerised lithium-ion battery energy storage system has yet to be conducted. However, other testing has been conducted to provide insight into the fire hazards associated with lithium-ion battery energy storage systems. A few of the larger-scale testing and research reports will be summarized below:

1. FPRF/Exponent Hazard Assessment of Lithium-Ion Battery Energy Storage Systems
2. FAA Fire Hazards of Lithium-Ion Batteries – testing of pallet load of lithium-ion batteries in an aircraft cargo hold
3. DNV GL/Con-Edison Considerations for ESS Fire Safety

5.3.1.1 FPRF/Exponent Hazard Assessment of Lithium-Ion Battery ESS

Exponent Inc. and the NFPA's Fire Protection Research Foundation conducted a full-scale fire test of a Tesla Powerpack – 100kWh lithium-ion BESS at 100% SOC[2]. Two tests were conducted, one with an external ignition source of 400 kW and another with an internal ignition by heater cartridges. The internal test set individual cells into thermal runaway to simulate an internal failure, and the external test led the internal cells into failure through heat exposure.

The results of the external ignition test determined the following:

1. A fire in the Powerpack resulted in internal temperatures exceeding 1093 °C.
2. External temperatures reached 232 °C.
3. Flames were observed coming out of the exhaust vent and out of the BESS front door.
4. Flames several feet high was observed from the exhaust vent of the Powerpack.
5. Heat flux of approximately 25kW/m^2 measured 1.8m from front of BESS.
6. All batteries and electronics of the BESS were damaged.

The internal ignition test gave the following results:

1. A fire in the Powerpack resulted in internal temperatures exceeding 1093 °C.
2. Temperatures at pods below the initiator pod showed temperature ranges between 26 and 82°C.
3. External temperatures reached 21 °C.
4. Initiator pod was damaged, but other cells were not damaged.

5.3.1.2 US FAA-Style Flammability Assessment of Lithium-Ion Cells and Battery Packs in Aircraft Cargo Holds

Exponent conducted flame attack tests on single prismatic batteries and prismatic battery packs inside a cargo hold [3]. The result of this testing provides insight into battery behaviour under fire conditions as well as temperature

[1] Lithium-Ion Batteries Hazard and Use Assessment, Final Report, Celina Mikolajczak, PE, Michael Kahn, PhD, Kevin White, PhD ,Richard Thomas Long, PE, Exponent Failure Analysis Associates, Inc., July 2011 National Fire Protection Association, Fire Protection Research Foundation.

[2] Blum, A. F., & Long, Jr., R. T. (2016). Hazard Assessment of Lithium-Ion Battery Energy Storage Systems. Quincy: National Fire Protection Association

[3] Mikolajczak, C. (2005). US FAA-Style Flammability Assessment of Lithium-Ion Cells and Battery Packs in Aircraft

profiles of the fire events.

Key findings from these small-scale tests include the following:

1. Frequent battery case rupture events were observed in the prismatic battery back testing.
2. Direct flame impingement on small, unpackaged quantities of prismatic battery packs can lead to thermal runaway of individual cells and venting of gases. The vent gases are generally ignited by the pre-existing flame, increasing the total heat flux produced by the fire.
3. Testing of 4 cell li-ion battery packs produced ceiling temperatures between 400°C and 600°C.

5.3.1.3 FAA Energetics of Lithium-Ion Battery Failure

The Federal Aviation Administration (FAA) has worked to quantify the hazard of lithium-ion batteries under a fire event since a fleet of the Boeing 787 Dreamliner were grounded as a result of hazards associated with LIB fires. In addition to the fire events, large numbers of lithium-ion batteries are being shipped as cargo on aircraft. Although the failure of a single cell is a low probability event (1/1,000,000), the large quantity of batteries on aircraft and the severe impact of an event on the survivability of the aircraft make the risk a safety concern to the passengers.[4]

To analyse the hazard of lithium-ion batteries undergoing a thermal runaway event in an aircraft, a pallet load of 18650 cylindrical batteries were forced into thermal runaway within a cargo hold of an aircraft. This test showed that all of the batteries became involved in the fire. This testing provided data regarding lithium-ion battery fires and heat release rate curves providing insight into the growth function of a fire involving multiple packs of lithium-ion batteries. This study is applicable to quantifying a fire event in a ESS due to the number of batteries in a confined compartment.

The results indicated the heat release rate per battery cell was approximately 5kW.

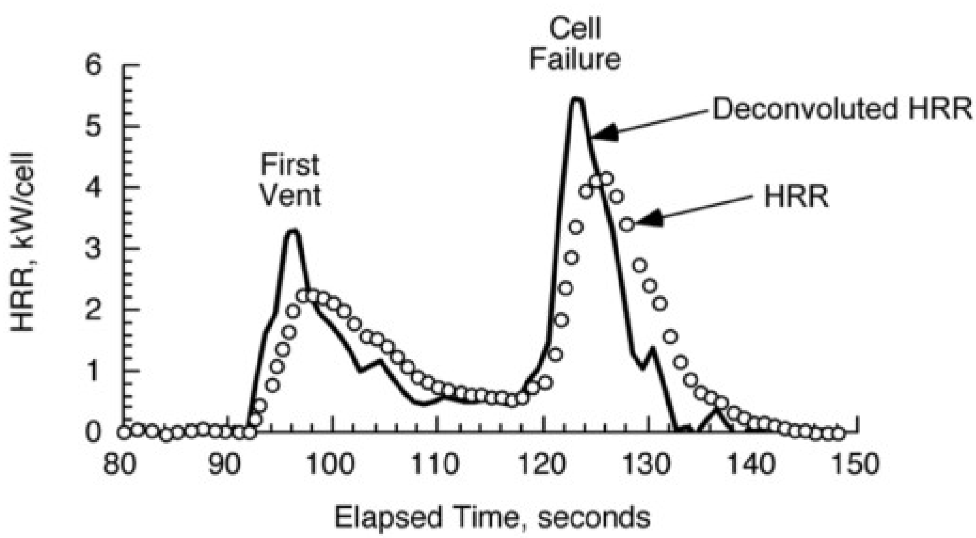

Figure 2. Lithium-ion cell failure at 70% SOC exposed to 50 kW/m^2 irradiance in fire calorimeter; points are data from standard method; solid line is data corrected for instrument response

Figure 15 Results of a single group of batteries

Cargo Holds. Exponent. Menlo Park: Exponent.

[4] Lyon, R. E., Walters, R. N., Crowley, S., & Quintiere, J. G. (2015). Fire Hazards of Lithium-Ion Batteries. Federal Aviation Administration. Atlantic City: Federal Aviation Administration.

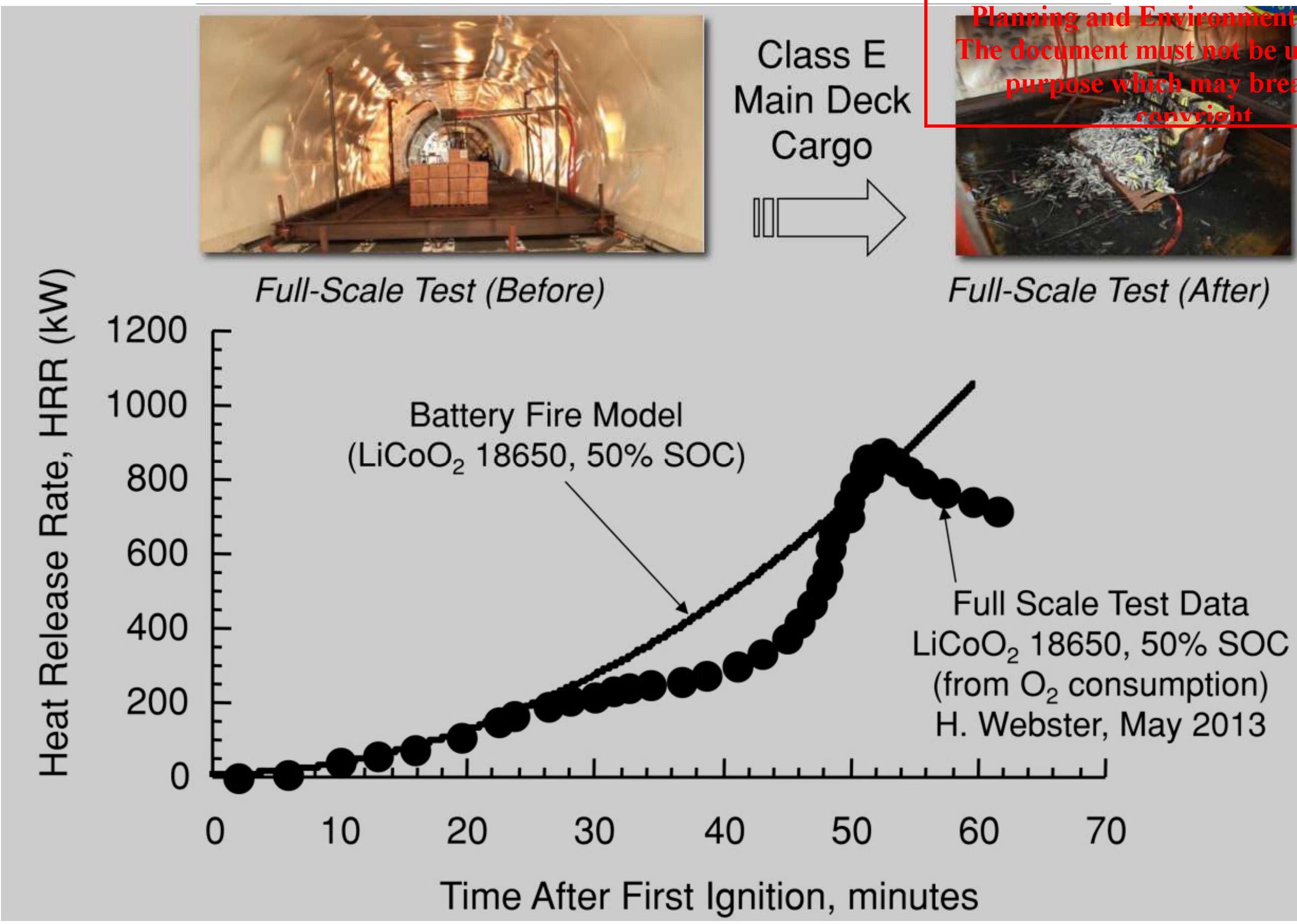

Figure 16Results of full-scale tests on 18650 batteries

The peak heat release rate is approximately 1MW.

5.3.1.4 DNV GL Considerations for ESS Fire Safety

DNV GL and Rescue Methods were contracted by Con-Edison Power and the New York State Energy Research and Development Authority (NYSERDA) to address a series of frequently asked questions regarding BESS Fire Safety[5]. This work included testing of lithium-ion batteries of various chemistries as individual cells and battery modules. The individual cells were exposed to a 4-kW radiant heat source until they vented inside DNV GL's Large Battery Destructive Testing Chamber. For the module testing, modules between 7.5 and 55 kWh were ignited inside a partially closed metal container by direct flame impingement from a propane torch. The module testing provided data concerning the effect of oxygen, toxicity, and heat release rate of the fire.

A few key findings from this testing are discussed below:

1. Batteries are more volatile at higher states of charge (SOC).
   a) Mass loss rate is proportional to SOC. Average mass loss rate: 18% mass loss over 41.7 min.
2. If flames are visible and temperature is rising, the ESS is likely to have multiple batteries and/or modules involved in the fire. Rising temperatures within the ESS is an indication of increasing risk.
3. The batteries themselves emit flammable gases

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[5] DNV GL. (2017). Considerations for ESS Fire Safety. Dublin: DNV GL

4. Recommended Ventilation Rate Correlation of 0.095 - 0.15 l/s/Wh.
5. HRR produced variable results; Range was between 2.5 – 80 kW/kg, dependent on volume of gases, duration of release, rate of ignition, and gaseous mixture.
6. Partially burned systems can continuously emit flammable gases as long as the cells retain their heat – even if the fire has been extinguished.

5.3.2 Rate of Heat Release

The Rate of Heat Release for the battery units is dependent on the state of charge as well as the size of the batteries and the incident heat flux.

It was reported in “Fire behaviour of lithium-ion battery with different states of charge induced by high incident heat fluxes”, by Zhi Wang that the peak heat release rate of a battery unit is approximately 700kW/m^2 to 1050kW/m^2 and an average of approximately 150 – 200kW/m^2.

Note these are individual small batteries and not part of a BESS unit and the area is the surface area of the batteries. Based on the size of the units in the VBB fire as reported by the ESV investigation 7.5m x 1.6m x 2.5m) and assuming the front and the top of the unit (are burning based on the location of the ventilation the heat release rate is predicted to be 4.5MW to 6MW.

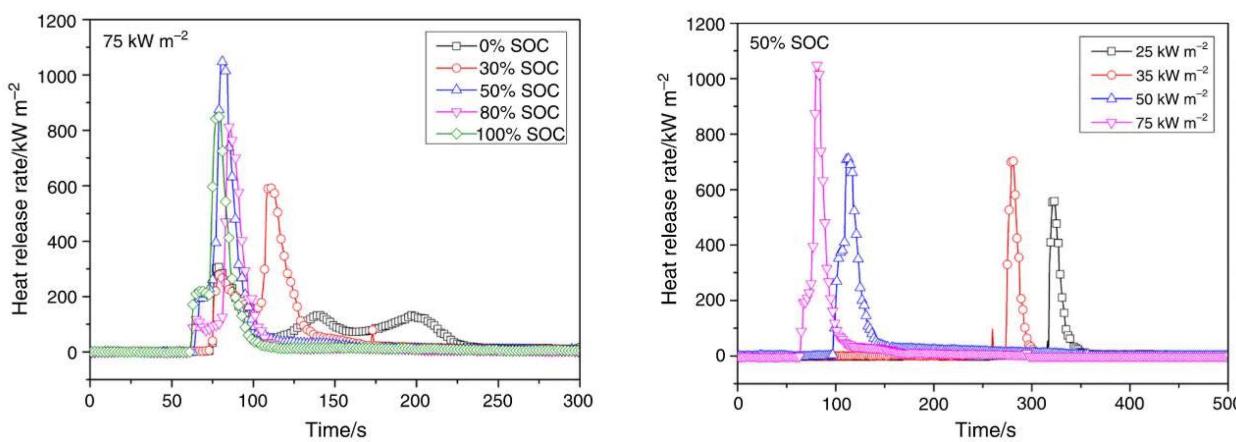


Fig. 7 Heat release rate of batteries at different SOCs under an incident heat flux of 75 kW m^{-2}

Fig. 8 Heat release rate of batteries with 50% SOC under different incident heat fluxes

Figure 17 Tested heat release rates for Lithium-ion batteries

Based on the above review it is considered that each unit will have an average heat release rate of approximately 5MW.

6 RISK ASSESSMENT

6.1 LIKELIHOOD

In the Article "Burning concern: Energy storage industry battles battery fires", in the S&P Global market Intelligence website, 24 May 2019 it was reported by Ken Boyce, a principal engineer at product safety certification, testing and advisory firm UL LLC that: "In general, it's a very safe technology. Lithium-ion battery cells fail at a rate of only around one in every 12 million". This is the rate of 8x 10^{-8} per year.

From May 2, 2020, to Jan. 22, 2021, 21 ESS many fires were reported across Korea from 1490 systems installed. This is a rate of 1.4%, i.e., Rare based on table 2 from Appendix G of AS5139 above.

The likelihood of a fire is therefore considered to be Rare

Accordingly, the risk of a fire would be rated as Very Low.

6.2 CONSEQUENCE

The consequence of a fire in a battery will be modelled and assessed as part of the fire engineering report.

However, it is considered that based on a heat release rate of 5MW for one unit or 10MW for two adjacent units assuming they both burn at their peak, the total heat release rate would be significantly less than that associated with the adjacent industrial and warehousing land uses.

Given the industrial zoning of the area and the presence of the Terminal Station with large transformers that could produce fire of 100MW it is considered that the presence of the BESS unit will not present a more significant fire to the community than already exists.

The fire brigade will have a 6m wide access road around and through the facility with multiple hydrant points. The hydrants are located such that all areas can be reached by at least two hydrants. Accordingly, it is considered that the risk to the fire brigade and ability to control the fire is no worse than for any other industrial facility within the area.

Given the fire separation to the adjacent buildings fire spread is not predicted to occur at a greater level than for BCA compliant buildings within the community.

6.2.1 Preliminary Fire modelling

Preliminary fire and smoke modelling of a 5MW fire enclosed within a steel structure with venting from the roof and openings at the sides assuming doors are open provided the following results. (Note this is based on units similar to those in the VBB fire and more detailed modelling will be performed once the final unit design is known.) This is considered to be a worst-case design as the fire is allowed to be fully ventilated. In reality the fire may be less ventilated as indicated in the pictures of the VBB fire where flames were only seen at the top of the unit.

The modelling has been based on a battery unit in the open and fully exposed t the wind. The closest units to the brigade hardstand would be protected by the 10m high noise wall for a wind from the south or southwest which is required for smoke to be directed to the hard stand. It is therefore considered that exposure of the hardstand from a battery unit is significantly reduced.

Thermocouples were located at various heights and distances from the unit.

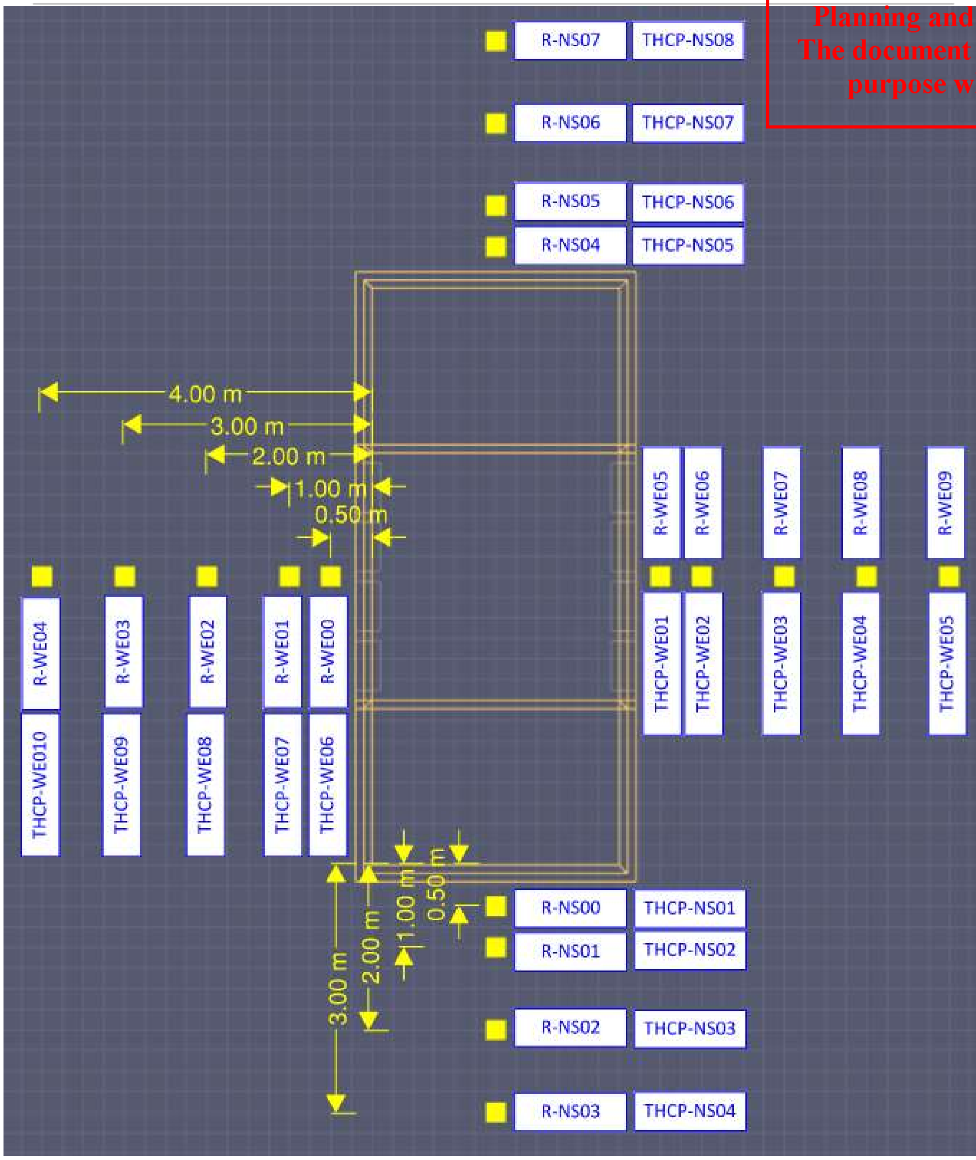


Figure 18: Model set up

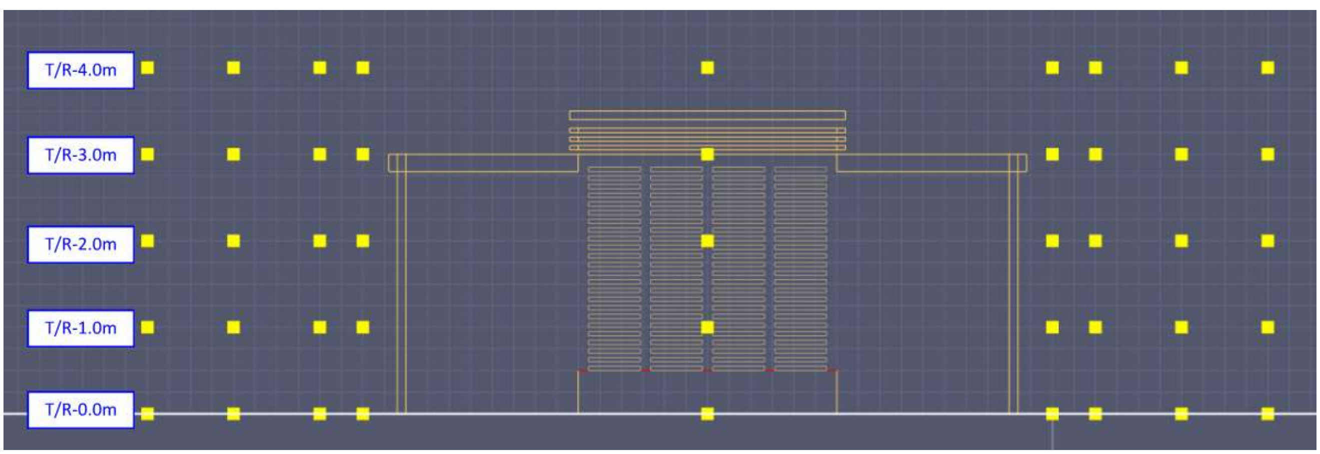
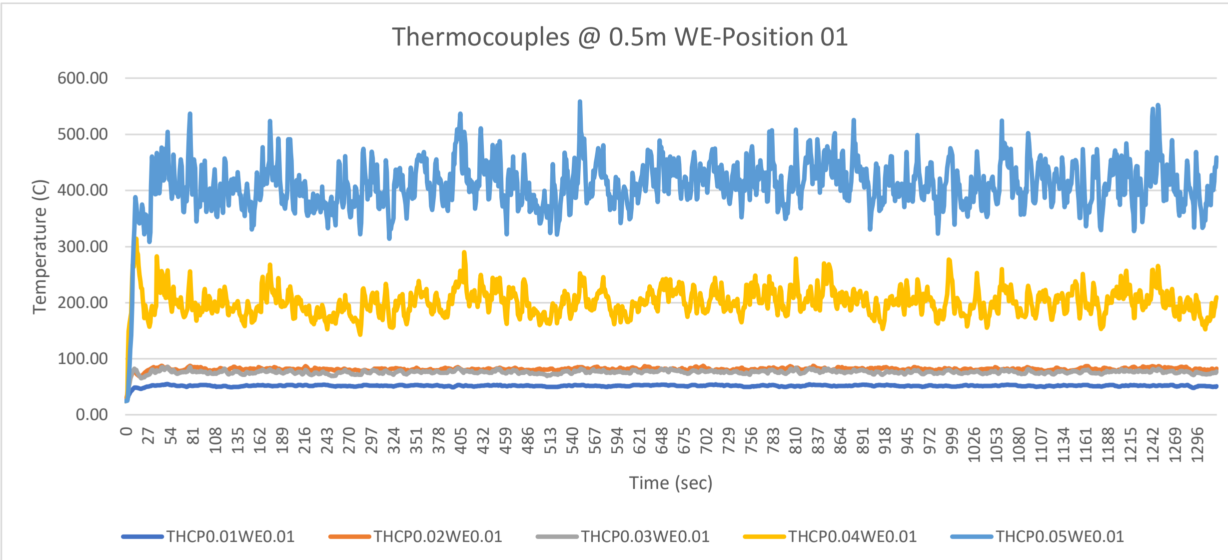


Figure 19 Model set up. Elevation View

6.2.1.1 No Wind

For the no wind case temperature peaks above 550°C are reached above 4m high only to the West and East sides of the model within 0.5m from the unit. This corresponds to the area immediately opposite and above the assumed roof level vents such that the thermocouples were in the vented plume.



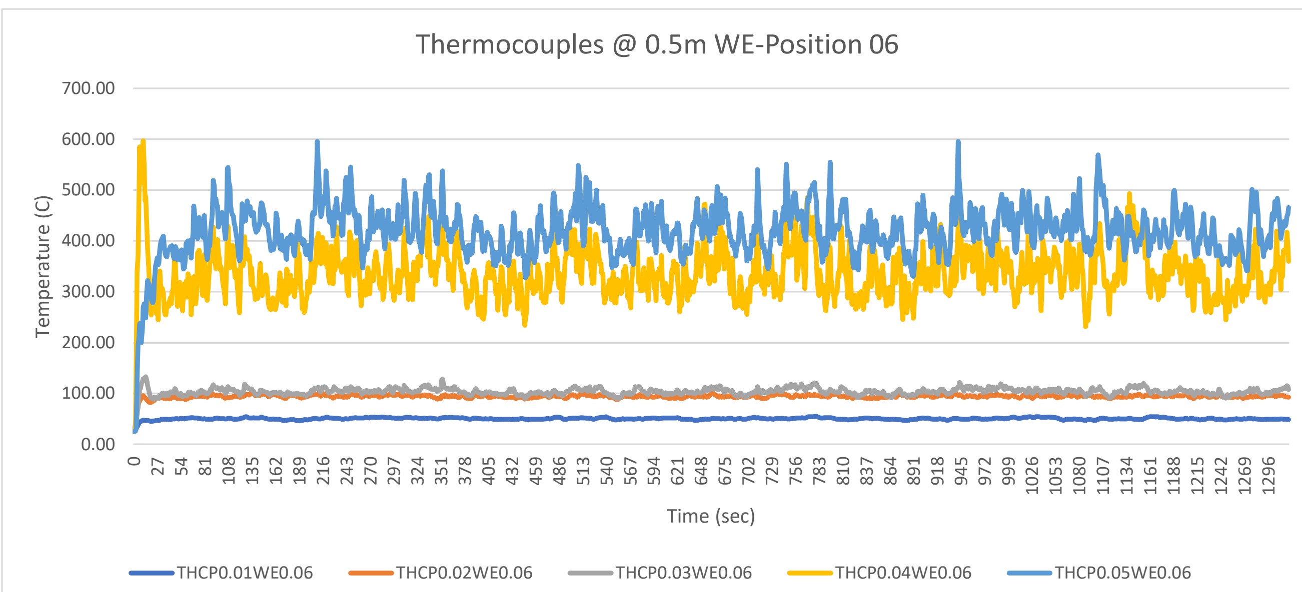


Figure 20 maximum temperatures for no wind case

Heat flux of approximately 10 kW/m^2 are reached within 2m opposite the vents.

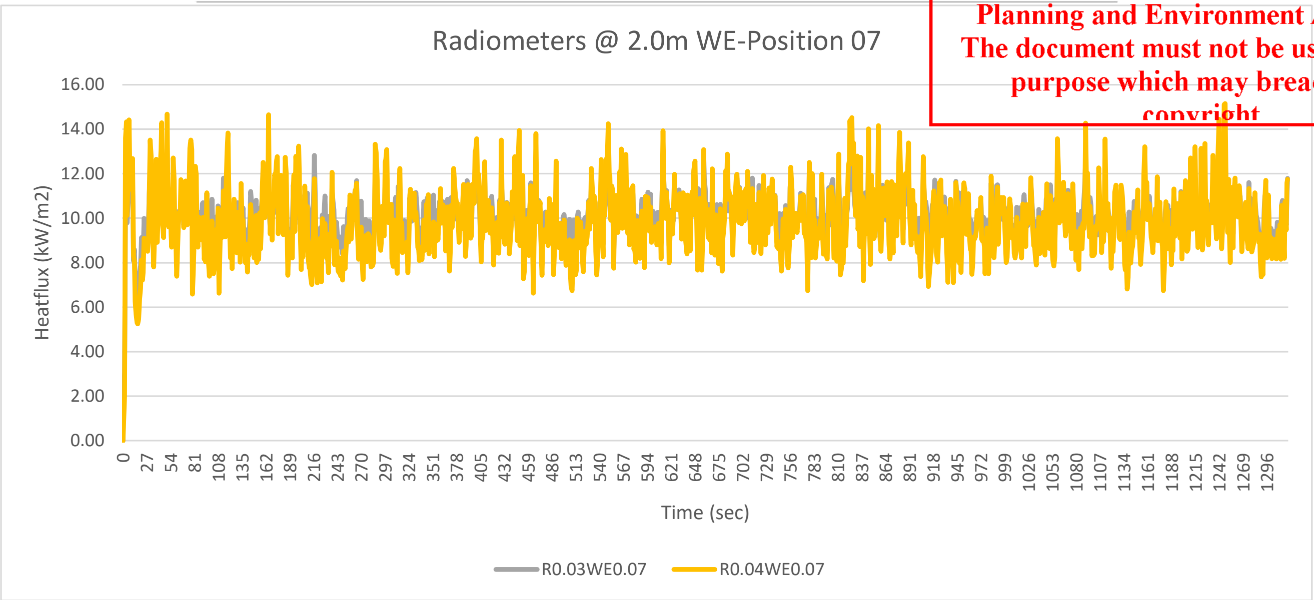


Figure 21 maximum radiation levels

Note the thermocouple at position 7 is at the height of the vents and 2m from the subject unit. The units are in groups of 2 and located 2.54m apart. Therefore, fire spread between groups of two units is not predicted to occur in still conditions. (Note the 10m high sound walls are expected to create barriers to the wind across the site)

Assuming the chosen BESS units have vents on the top but located to the outer edge the vents may be 2.7m apart. Accordingly, fire spread from one vent to another would also be reduced. The risk of fire spread between adjacent units will be confirmed in the next stage as details of the units are developed.

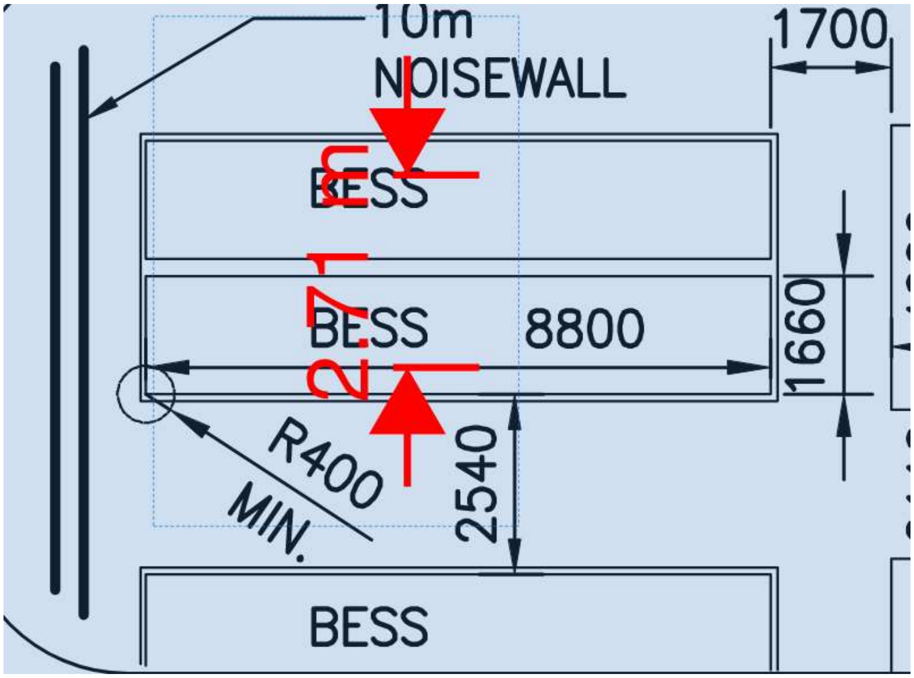


Figure 22 Assumed location of vents that would minimise risk of fire spread

6.2.1.2 South Wind

The same fire was modelled with an assumed wind of 23m/hr from the south. This wind speed is predicted to only occur 2.3% of h time for the proposed facility.

Temperature peaks above 550°C are reached between 1.0m and 4.0m high to the west side of the model within 1.0m from the unit.

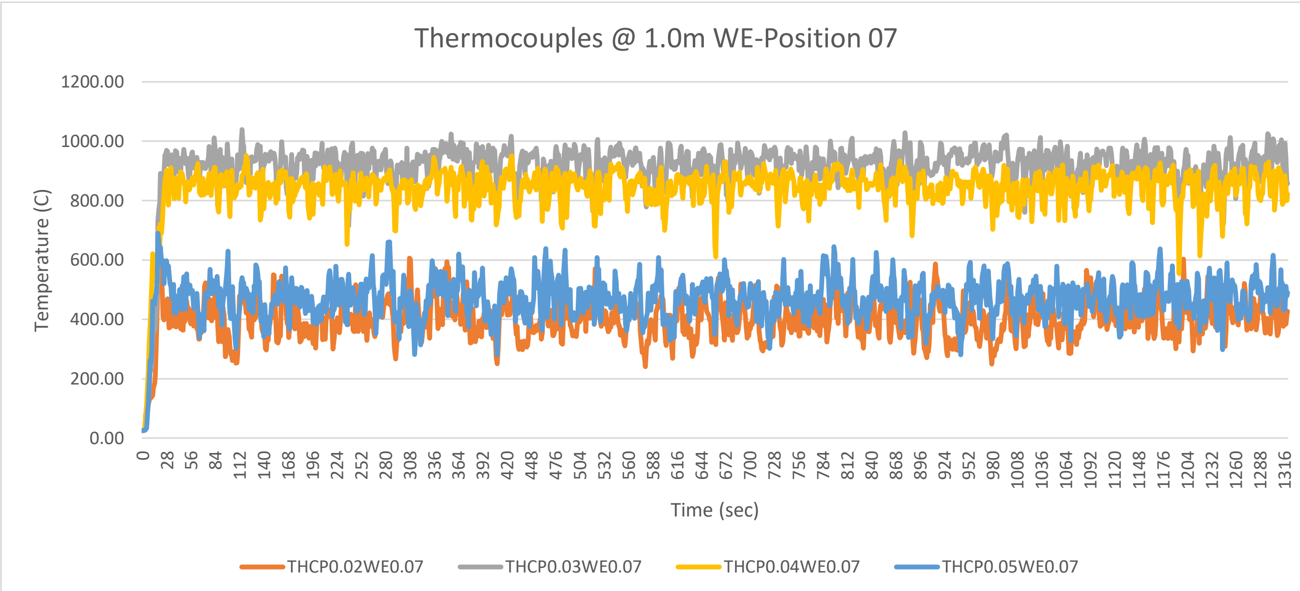


Figure 23 Temperatures with south wind, i.e., along the unit

Heat flux above 12.5 kW/m² are reached within 4m from the unit, between 0m and 4m high to the west side. After 3m high or at greater distances the heat flux decreases significantly.

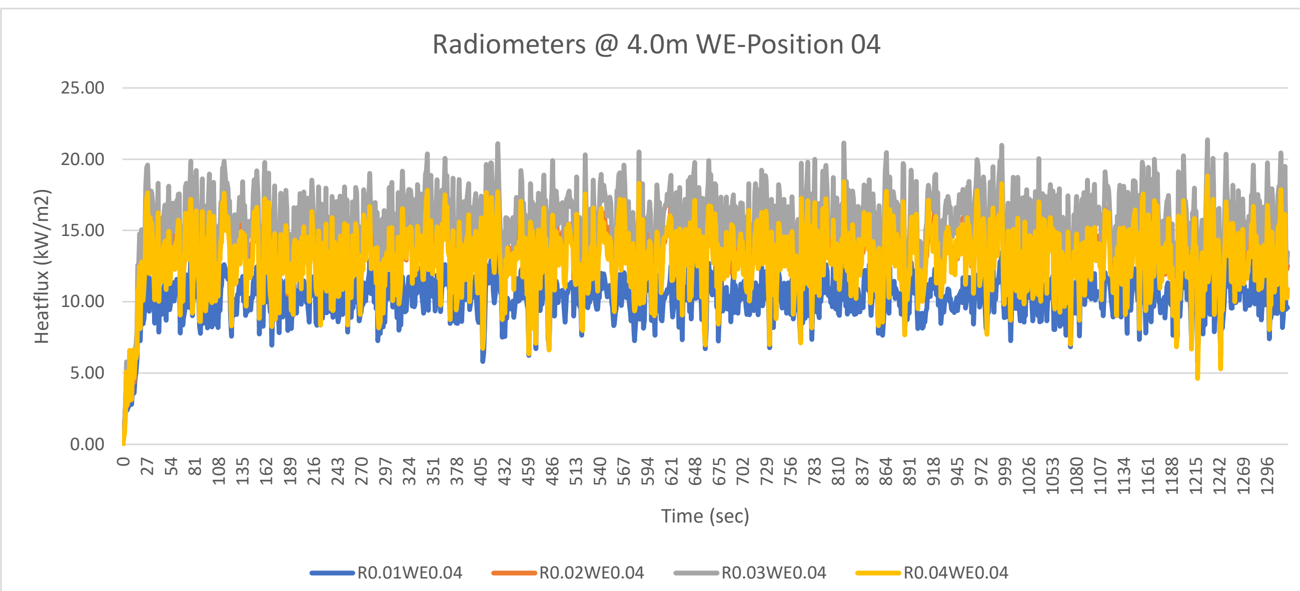


Figure 24 Radiation with south wind, i.e., along the unit

6.2.1.3 Wind from the east across the unit

Temperature peaks above 550°C are reached at 1m high only to the west side of the model within 1.0m from the unit.

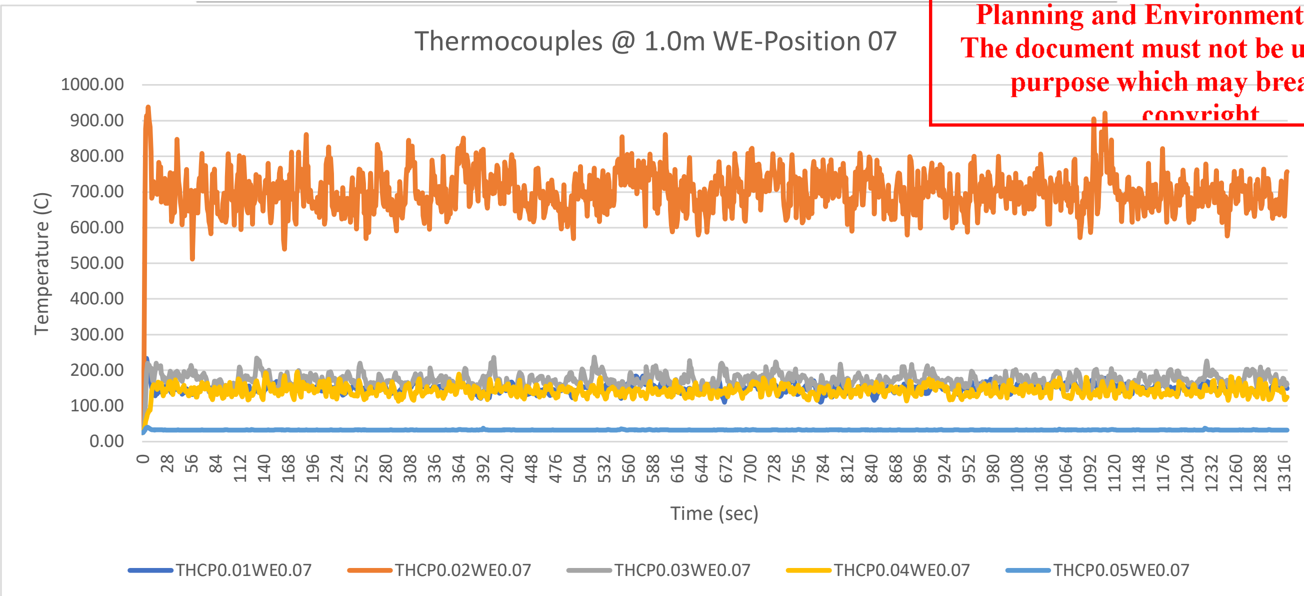


Figure 25 Temperatures within 1m of the side of the unit

Heat flux above 12.5 kW/m^2 are reached within 3m from the unit, between 0m and 2m high to the west side. After 2m high the heat flux decreases.

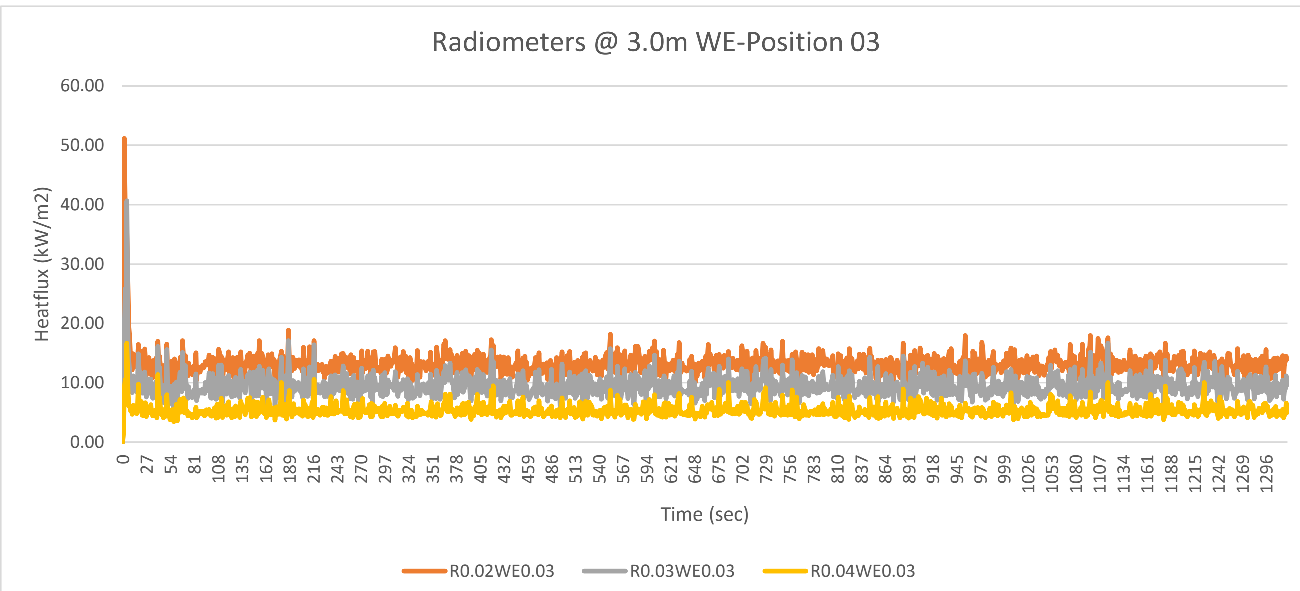


Figure 26 Heat flux

It is expected the same result on the opposite side if the wind flows in the opposite direction.

The results indicate that in a wort case scenario with maximum ventilation that the conditions immediately adjacent to the fire plume can result in fire spread as seen in the VBB fire. However away from the unit on fire the conditions ae not considered to present a risk of further fire spread or to emergency services or occupants.

The conditions at the site entrance over 20m away from the nearest battery unit are not considered to be affected by a battery fire even if the wind blows in the direction of the entrance based on the predicted temperatures an incident radiation levels.

Furthermore, detailed modelling of the effects of the noise walls and other fires will be undertaken as part of the final fire engineering assessment.

6.3 Fire in other Area of the facility

The facility contains a control room and switch rooms. The fire associated with these buildings are considered to be no greater than a small office type building. The control room is approximately 20m from the hardstand.

Based on the International Fire Engineering Guidelines the likelihood of an office fire is 6.2×10^{-3} per year and a fire size of approximately 250kW/m^2. Accordingly, the peak fire size is predicted to be 23MW assuming adequate ventilation.

Given the separation distances to the battery units and other areas of over 20m it is considered that the risk of fire spread is extremely low and significantly less than that for a building with BCA compliant separation distances (3m to the boundary) that are considered to represent the community acceptance level for fire spread.

6.4 Bushfire / Grass Fire

The facility is not within a designated bushfire zone.

The facility is surround by other buildings and the Thomastown Terminal station and hence there is limited bush or grassland. The Edgars creek has some minor trees and bushes as well as grassed areas.

Figure 27 Minor vegetation along the creek

These areas are separated by the access road and security fence such that if a fire did occur it is unlikely to actually reach the battery units.

AS3959 indicates the following vegetation is excluded from assessment as classified vegetation

2.2.3.2 *Exclusions—Low threat vegetation and non-vegetated areas*

The following vegetation shall be excluded from a BAL assessment:

(a) Vegetation of any type that is more than 100 m from the site.

(b) Single areas of vegetation less than 1 ha in area and not within 100 m of other areas of vegetation being classified vegetation.

(c) Multiple areas of vegetation less than 0.25 ha in area and not within 20 m of the site, or each other or of other areas of vegetation being classified vegetation.

(d) Strips of vegetation less than 20 m in width (measured perpendicular to the elevation exposed to the strip of vegetation) regardless of length and not within 20 m of the site or each other, or other areas of vegetation being classified vegetation.

(e) Non-vegetated areas, that is, areas permanently cleared of vegetation, including waterways, exposed beaches, roads, footpaths, buildings and rocky outcrops.

(f) Vegetation regarded as low threat due to factors such as flammability, moisture content or fuel load. This includes grassland managed in a minimal fuel condition, mangroves and other saline wetlands, maintained lawns, golf courses (such as playing areas and fairways), maintained public reserves and parklands, sporting fields, vineyards, orchards, banana plantations, market gardens (and other non-curing crops), cultivated gardens, commercial nurseries, nature strips and windbreaks.

NOTES:

1 Minimal fuel condition means there is insufficient fuel available to significantly increase the severity of the bushfire attack (recognizable as short-cropped grass for example, to a nominal height of 100 mm).

2 A windbreak is considered a single row of trees used as a screen or to reduce the effect of wind on the leeward side of the trees.

It is considered that the minor trees along the creek at the east and southeast side of the facility would fall under the above exclusions.

The batteries are located at over 40m from the vegetation along the side of the creek and hence are not considered to be affected by any fire that may develop within the creek area.

6.5 Adjacent Building

The adjacent buildings are small industrial facilities that have either a compliant fire rated wall to the boundary or are set back 3m from the boundary. The batteries are set back a further 10m from the boundary fence.

The BCA allows non-load bearing openings within buildings to be 3m from the boundary or 6m from another building on the same allotment. Given the separation distances of the battery units from the boundary it is considered that the likelihood of a fire and the consequence are no worse than in the general community.

6.6 Transformers

A transformer is located at the end of each set of batteries. The transformers have a galvanised steel bund at the base of the skid. The bunds have a capacity of 392L

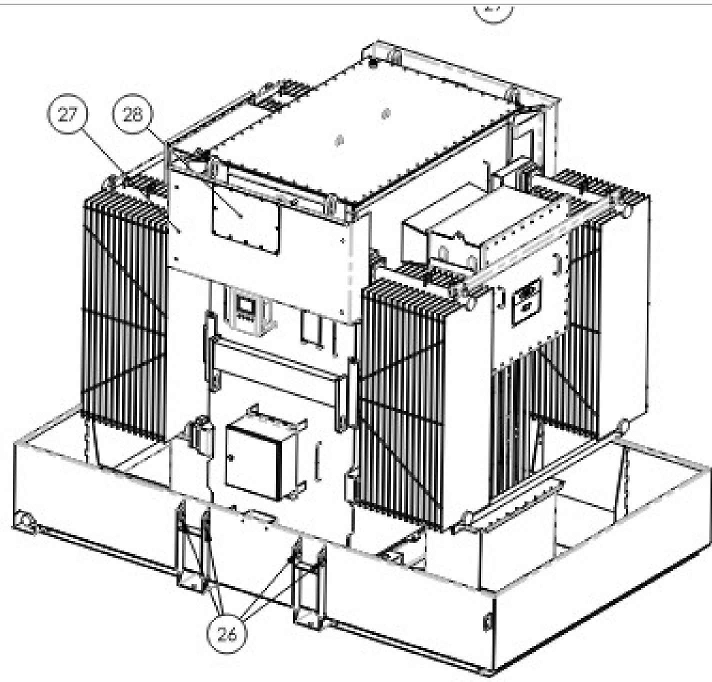


Figure 28 Transformer showing bund at the base

The bunds are approximately 3.7m long and 2.8m wide, i.e., $10.4m^2$.

In order to assess the impact of a transformer fire on other objects, the transformer fire was treated as a pool fire as it is based on liquid hydrocarbon fire. The method used to calculate the heat flux received at a target was one that is generally accepted in the risk engineering discipline detailed in the Yellow Book (Committee for the Prevention of Disasters).

Enclosure Fire Dynamics gives a correlation equation (Equation 3.6) to estimate the free burn mass loss rate as below:

$\dot{m}'' = \dot{m}''_{\infty}(1 - e^{-k\beta D})$ (Equation 3.6, *Enclosure Fire Dynamics)*

where

- $\dot{m}''_{\infty}$: 0.039 kg/m^2s
- Δh_c : 46.4 MJ/kg
- $k\beta$: 0.7 (m^{-1})
- D: diameter of the pool fire as a circle i.e., $3.6m^2$

As can be seen from the above equation the fire size in terms of mass loss rate and hence heat release rate is independent of the transformer size and volume of oil.

The predicted fire size is 13.8MW. Note this is approximately the same as kiosk transformers in the generally community and is based on all oil being involved in the fire.

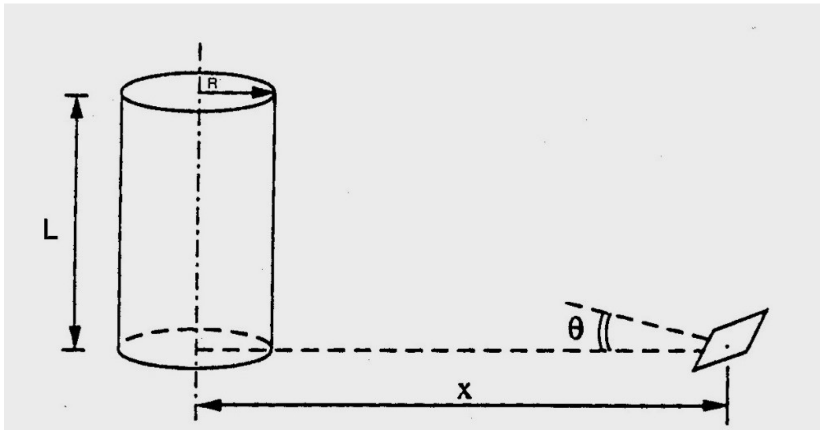
6.6.1 Flame Dimensions of Pool Fire

The pool fire was approximated as a cylindrical flame. Two conditions of the pool fire were investigated:

a) No wind / still conditions
b) Wind speed at 5.5 m/s (20 km/h)

For the former conditions, the geometry of the pool fire is best approximated as an upright cylinder while for the latter conditions, a tilted cylinder geometry is best (Figure 29).

(a)



(b)

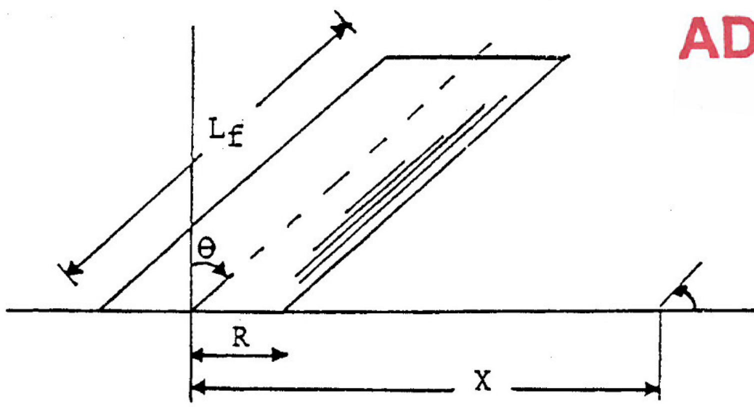


Figure 29: (a) Target and flame geometry of vertical cylindrical radiator. (b) Target and flame geometry of tilted cylindrical radiator

Thus, two flame height correlations were used in order to calculate the flame height at still conditions and at windy conditions.

6.6.1.1 No Wind Condition

The following flame height correlation was used to estimate flame height at **still** conditions:

$$L = 0.23\dot{Q}_c^{2/5} - 1.02D \quad (2)$$

where

- $\dot{Q}_c$ = Rate of heat release (W)

6.6.1.2 Wind Condition

For a confined pool fire wind influences the flame dimensions, such as the length of the tilted cylinder, the tilt angle of the cylinder and the change of flame base. The correlation used to calculate tilted flame length is given below:

$$\frac{L}{D} = 55 \times \left(\frac{m''}{\rho_{\text{air}} \times \sqrt{g \times D}} \right)^{0.67} \times (u^*)^{0.21} \quad (3)$$

where

- ρ_{air} = density of air (kg/m^3).
- g = gravitational acceleration (9.81 m/s^2); and
- $u^* = \frac{u_w}{u_c}$ is the scaled wind velocity

u_w is the wind velocity at a height of 10 m which in the case of the current analysis is at 3 m/s, while u_c is the characteristic wind velocity (m/s) and is defined below:

$$u_c = \left(\frac{g \times m'' \times D}{\rho_{\text{air}}} \right)^{1/3} \quad (4)$$

In order to calculate the tilt angle (θ) the Froude (Fr_{10}) and Reynolds (Re) numbers are required:

$$\text{Fr}_{10} = \frac{{u_w}^2}{gD} \quad (5)$$

$$\text{Re} = \frac{u_w D}{\upsilon} \quad (6)$$

where υ = kinematic viscosity of air (m^2/s)

The relationship between the tilt angle and the Froude and Reynolds numbers is as follows:

$$\frac{\tan\theta}{\cos\theta} = 0.666 \times (\text{Fr}_{10})^{0.333} \times (\text{Re})^{0.117} \quad (7)$$

The tilt angle of the flame in degrees was obtained by the following:

$$\theta = \arcsin\left(\frac{\sqrt{4 \times c^2 + 1} - 1}{2c} \right) \quad (8)$$

where c = tanθ/cosθ

The diameter of the tilted flame will become elongated and is given by:

$$\frac{D'}{D} = 1.5 \times (Fr_{10})^{0.069} \quad (9)$$

- D = Pool diameter (m)
- D' = Actual elongated flame base diameter (m)

6.6.2 Surface Emissive Power

The surface emissive power was calculated using:

$$SEP_{act} = SEP_{max} \times (1-\varsigma) + SEP_{soot} \times \varsigma \qquad (10)$$

where

- SEP_{soot} = surface emissive power of soot, which is about 20×10^3 J/(m^2·s)

ς = 80% which has been found to be a representative figure for pool fires of oil products.

$$SEP_{max} = F_s \times m'' x \frac{\Delta H_c}{1 + 4 \times \frac{L}{D}} \qquad (11)$$

where

- F_s = Fraction of the generated heat radiated from the flame surface. Taken to be 0.35.
- m'' = mass burning rate (kg/(m^2·s))
- ΔH_c = Heat of combustion (J/kg)
- L = Average height of flame (m)
- D = Pool diameter (m)

6.6.3 Heat Flux at Certain Distance

The calculation of the heat flux at a certain distance i.e., the target from the fire consists of three steps:

- Atmospheric transmissivity calculation
- View factor calculation
- Heat flux calculation

The atmospheric transmissivity (τ_a) accounts for the fact that the emitted radiation is partly absorbed by the air present between the radiator and the target. It is given by:

$$\tau_a = 1 - \alpha_w - \alpha_c \ (12)$$

where α_w and α_c are the absorption factor for water vapour and carbon dioxide, respectively.

- α_w is obtained from Figure 6.2 of Ref. [2] which graphically shows the relationship between α_w, air temperature, partial pressure of water and distance between radiator and target. A similar relation for α_c is found in Figure 6.3 of Ref. [2].

The heat flux received at the target differs according to the orientation of the flame relative to the target. Two cases were examined:

- The vertical flame (still conditions) modelled by a vertical cylindrical radiator
- The tilted flame (windy conditions) whereby the target is downwind of the flame (worse case) and modelled by tilted cylindrical flame.

The geometrical relations for these two cases are found within Appendix 6.1 of Ref. [2].

The results of the above assessment for the transformers in relation to the brigade hard stand 23m away are presented below:

Table 6: Predicted radiation received at the hardstand from the closest transformer (24m)

Wind Condition	Radiation received at distance X (kW/m^2)
	24m
Yes	5.6
No	4.5

Given the presence of the sound wall it is more likely that still conditions would be developed adjacent to the battery unit until the plume reaches the height of the sound wall (10m) at which point it will be clear of the hard stand and brigade.

With respect to the distance between the transformer and the closest BESS unit at 1.7m the predicted exposure levels are presented in table 7 below

Table 7: Predicted radiation received at the BESS unit from the closest transformer (1.7m)

Wind Condition	Radiation received at distance X (kW/m^2)
	24m
Yes	14.4
No	12.6

7 Comparison with Relevant Standards

7.1 AS 5139 Electrical Installations – Safety of Battery Systems for Use with Power Conversion Equipment

AS NZS 5139 2019 specifies requirements for general installation and safety requirements for battery energy storage systems (BESSs), where the battery system is installed in a location, such as a dedicated enclosure or room, and is connected with power conversion equipment (PCE) to supply electric power to other parts of an electrical installation.

Clause 2.2.3 indicates a BESS as having the following components.

a) Power Conversion Equipment (PCE)

b) Battery Interface and Connection

c) Battery System

Table 3.1 classifies various batteries by the hazard type as reproduced below.

Table 3.1 — Hazard classifications by battery type

Battery chemistry	Electrical hazard	Energy hazard	Mechanical hazard	Fire hazard: level 1 or 2	Explosive gas hazard	Chemical hazard	Toxic fume hazard
Lead acid	✓	✓	✓	Level 2 (Note 2)	✓	✓	✓
Nickel alkaline	✓	✓	✓	Level 2 (Note 2)	✓	✓	✓
Lithium ion	✓	✓	✓	Level 1 (Note 1)	✓ (Note 3)	N/A	✓
Flow	✓	✓	✓	N/A	✓ (Note 4)	✓	✓ (Note 4)
Hybrid ion	✓	✓	✓	N/A	N/A	N/A	✓

Key

N/A = not applicable

NOTE 1 Lithium ion pre-assembled battery system equipment or pre-assembled integrated BESS equipment conforming to the *Best Practice Guide: battery storage equipment — Electrical Safety Requirements* are N/A for this hazard classification.

NOTE 2 Lead acid and nickel alkaline based batteries with cases that conform to V0 specification in accordance with relevant product standards are N/A for this hazard classification. Refer to Clause 3.2.6.2.

NOTE 3 Lithium chemistries that release hydrogen under fault conditions should be considered an explosive gas hazard, e.g. lithium manganese.

NOTE 4 Flow batteries having an acidic water-based solution have a significant risk of producing explosive gases and toxic fumes.

NOTE 5 Where the table or the notes state N/A that is only related to the classification level for Table 3.1, so as to assist in clarifying action required to be taken as outlined in Sections 4, 5 and 6. This is based on accepted knowledge, additional actions or other measures in place to minimize the risks so far as is reasonably practicable for the identified hazard, and it is not intended to necessarily indicate any particular hazard does not exist for the particular battery type.

Lithium-Ion batteries would have a fire hazard level of 1. It is also noted that a BESS unit that complies with the Best Practice Guide is not covered by the standard.

Clause 3.2.6.1 states that "battery systems and BESS's shall be installed in such a manner that, **in the event of a fire originating within the battery system or battery energy storage system, the spread of fire will be kept to a**

minimum."

The likely risk of fire spread will be modelled as part of the fire engineering report. However, given the separation between groups of 4 units it is considered that the proposed facility complies.

Note 5 to clause 3.2.6.3 Lithium-Ion Batteries states:

> NOTE 5 Lithium ion pre-assembled battery system equipment or pre-assembled integrated BESS equipment conforming to the Best Practice Guide: battery storage equipment — Electrical Safety Requirements are considered to minimize the risks so far as is reasonably practicable for the identified hazard and are not applicable for this fire hazard classification (see Table 3.1).

Clause 4.2.1 requires that a risk assessment be performed.

Section 4.2.4 relates to a BESS in a room and is not applicable to the facility. However, the clause refers to the need for separation from combustible materials and refers to the need for separation of 300mm from the wall. Given the separation distances to other buildings, adjacent allotments etc it is considered that the facility complies.

Clause 4.3.4 requires that where the BESS is installed within a building with a fire indicator panel that a detector be placed in the room with the BESS. It is considered that the monitoring of the devices linked to the operator who can call the brigade etc is an acceptable detection system.

Clause 4.3.8 states that where an alarm system is installed within a BESS it shall be installed so that on an alarm it causes an action to be initiated to correct the fault.

The alarms within the BESS are monitored by the Battery Management System (BMS) that monitors current, voltage, resistance and temperature as well as a Local Control System (LCS). The LCS receives information from the BMS and relays it to United Energy instantaneously. The design is therefore considered to comply with clause 4.3.8.

Clause 5.2.4 Protection against the spread of fire requires that the equipment shall not contribute to the spread of fire in accordance with AS3000 Clause 1.5.12 which states:

> **1.5.12 Protection against the spread of fire**
>
> **Protection shall be provided against fire initiated or propagated by components of the electrical installation.**
>
> Electrical equipment shall be selected, installed and protected such that the equipment will not—
>
> (a) obstruct escape routes, either directly or by the products of combustion; or
>
> (b) contribute to, or propagate a fire; or
>
> (c) attain a temperature high enough to ignite adjacent material; or
>
> (d) adversely affect means of egress from a structure.
>
> NOTES:
>
> 1 Clause 2.9.2.5 (h) contains requirements for the placement of switchboards in or near fire exits and egress paths.
>
> 2 Clauses 2.9.7, 3.9.9 and Appendix E contain requirements dealing with the prevention of the spread of fire.

Clause 6.3.4.4 requires that the BESS have a BMS that monitors all potential and controllable fault conditions that could result in fire. It is considered that the subject units have a BMS and various alarm monitoring devices that comply with the clause. Where the BMS monitors excessive temperatures or minimum temperatures or overcurrent the system is shut down and charging of the batteries disconnected as required by Clause 6.3.4.5 to 6.3.4.8.

The BESS is required by the standard to be ventilated to avoid the building up of flammable and explosive gases which the subject unit is.

7.1.1 AS5139 Appendix G Risk Assessment

Appendix G of the standard provides information on conducting a risk assessment with respect to BESS units.

The likelihood table is provided in Table G.2

Table G.2 — Example likelihood of occurrence rating

Likelihood rating	Definition of likelihood of occurrence rating
Almost certain	Probability of occurrence: greater than 90 %
	Expected to occur whenever system is accessed or operated
	The event is expected to occur in most circumstances
Likely	Probability of occurrence: 60 % – 89 %
	Expected to occur when system is accessed or operated under typical circumstances
	There is a strong possibility the event may occur
Possible	Probability of occurrence: 40 % – 59 %
	Expected to occur in unusual instances when the system is access or operated
	The event may occur at some time
Unlikely	Probability of occurrence: 20 % – 39 %
	Expected to occur in unusual instanced for non-standard access or non-standard operation
	Not expected to occur, but there is a slight possibility it may occur at some time
Rare	Probability of occurrence: 1 % – 19 %
	Highly unlikely to occur in any instance related to coming in contact with the system or associated systems
	Highly unlikely, but it may occur in exceptional circumstances, but probably never will

Based on a review of the hazards as identified in Section 5 of this report all the hazards are considered to be Rare, i.e., probability of occurrence less than 1% or $1x10^{-2}$ per year.

The level of consequence is given in Table G.1

Table G.1 — Typical risk consequence table

Consequence/ impact category	Consequence/impact rating definitions				
	Catastrophic	Major	Moderate	Minor	Insignificant
Health and safety	Any fatality of staff, contractor or public	Non-recoverable occupational illness or permanent injury	Injury or illness requiring medical treatment by a doctor	Injury requiring first aid	No or minor injury
		Injury or illness requiring admission to hospital	Dangerous/reportable electrical incident	Circumstances that lead to a near miss	
Environmental	High, long term or widespread impact (spill, emission, or habitat disturbance) to sensitive environment	Substantial impact — large spill or emission requiring Emergency Services attendance	Moderate impact — Spill or emission not contained on site with clean up needed	Minor cleanup/rectification — spill or emission not contained on site	Small spill or emission that has no impact on site or installation
	Environmental agency response with significant fine	Recovery of environment likely but not necessarily to pre-incident state	Death or destruction of protected flora or fauna	Environment expected to fully recover to pre-incident state	Clean up requires no special equipment and has no potential impact
	Long term recovery of environment to pre-incident state not likely	Any spill into sensitive area (wet tropics, fish habitat, potable water supply)	Environment likely to recover to pre-incident state in short to medium term	Environmental nuisance (short-term impact) caused by noise, dust, odour, fumes, light	
Legal and regulatory	Breach of licences, legislation or regulations leading to prosecution	Breach of legislation or regulations leading to: (a) contravention notice from authorities; or (b) court order; or (c) fine over $1000	Breach of legislation, regulations leading to: (a) warning notice; or (b) fine of up to $1000; or (c) enforceable undertakings	Breach of legislation regulations, policies or guidelines leading to an administrative resolution	No issues
Asset impact	Equipment destruction, repair not possible, asset repair greater than original cost of works	Equipment damage repaired at a cost of between 50 % and 100 % of original cost of works	Equipment damage repaired at a cost of between 15 % and 50 % of original cost of works	Equipment damage repaired at a cost of between 2 % and 15 % of original cost of works	Simple equipment damage with no or same day repair at a cost of less than 2 % of original cost of works

The battery area is not continuously occupied and the risk of a fire and occupants being present is low. The batteries are spaced well apart such that a person could turn and walk away from a fire. Accordingly, it is considered that a moderate health and safety consequence could occur in the event of a fire.

The batteries are separated from each other and the adjacent allotments such that fire spread is not predicted to occur to involve adjacent occupancies.

The site will have drainage and retention such that any impact is retained on site.

The overall consequence ranking is considered to be minor to moderate.

The resultant risk matrix is provided in table G.3

Table G.3 — Risk matrix table

Consequence (how serious)	Likelihood (how often)				
	Rare	Unlikely	Possible	Likely	Almost certain
Catastrophic	Medium	High	High	Extreme	Extreme
Major	Medium	Medium	High	High	Extreme
Moderate	Low	Medium	Medium	High	High
Minor	Very low	Low	Medium	Medium	Medium
Insignificant	Very low	Very low	Low	Medium	Medium

Based on the results of the quantitative assessment contained in this report a fire within the BESS is unlikely to result in further fire spread. Accordingly, the consequence is considered to be minor.

Based on a review of the above standard it is considered that the BESS unit would essentially comply with the standard and present a Low to Very Low risk.

7.2 Best Practice Guide For Battery Storage Equipment - Electrical Safety Requirements, Version 1.0 – Published 06 July 2018

The guide provides safety criteria for battery storage equipment that contains lithium as part of the energy storage medium. Battery storage equipment is generally complete, pre-packaged, pre-assembled, or factory-built equipment within the one enclosure (except for master/slave configurations where there is a main unit and additional battery module units that can be connected together). This includes types that are:

- Battery module
- Pre-assembled battery system (BS) equipment
- Pre-assembled integrated battery energy storage system (BESS) equipment

The introduction to the guide states “While this guide doesn’t specifically cover equipment being used in commercial, industrial or other non-domestic/residential settings, or for systems with an energy storage capacity of over 200kWh, the general requirements and principles of this guide and risk matrix may be applied to offer some guidance in those situations, though there may be additional hazards in those circumstances that have not been identified in this guide.”

It is therefore considered the guide is not fully relevant to the current study but is used for Guidance.

The Guide provides a number of methods to show full or partial compliance to the guide based on a series of tests. Many of the tests relate to non-fire risks and hence are not relevant to this assessment.

The main fire spread recommendations within the guide are the need for battery storage equipment to be housed in metal enclosures with a minimum thickness of 0.2mm. The subject design complies with this requirement. There is also the requirement for isolation devices and installation distances to be supplied with the equipment but not distances are specified.

In order to state compliance with the guide testing to various standards such as AS IEC 62619:2017 Secondary cells and batteries containing alkaline or other non-acid and electrolytes (or IEC 62619 Ed 1 2017), AS/NZS 4777.2:2015 Grid connection of energy systems via inverter requirements for inverter in equipment for connection to grid installations (applicable to pre-assembled integrated battery energy storage system equipment), etc. Given the information supplied it cannot be stated that the present design complies full of the Guide, but it is considered that there is no reason the believe that if the testing were conducted that it wouldn't comply.

7.3 NFPA 855, Standard for Stationary Energy Storage Systems (in development),

NFPA 855 is under development but details with battery systems within containerized systems.

The standard follows the US Building Code NFPA 1 – Life Safety Code and The International Fire Code in recommending the siting and location of outdoor containerized BESS as shown below.

"**Separation: Stationary storage battery systems located outdoors shall be separated by a minimum 5 feet (1.5m)** from the following:

- Allotment boundaries
- public ways
- buildings
- stored combustible materials
- Hazardous materials
- High-piled stock
- Other exposure hazards"

It is considered that the subject facility complies with the above requirement.

7.4 AS2067

Australian Standard AS2067 is the most relevant standard with respect to the location of existing power utility infrastructure. The standard is based on oil transformer equipment and not batteries. However, the fire risk from a transformer is considered to be similar to that of a BESS.

The minimum separation distances are specified in AS2067 Table 6.1 unless a fire rated wall is used to provide protection.

Table 8: AS 2067 Table 6.1

MINIMUM VALUES FOR SEPARATING OUTDOOR TRANSFORMERS

A1

Transformer type	Liquid volume (L)	Clearance G_1 to other transformers or fire resistant surfaces (m)	Clearance G_2 to combustible building surface (m)
Oil-insulated transformers (O)	100 ≤1000	1	6
	>1000 ≤2000	3	7.5
	>2000 ≤20 000	5	10
	>20 000 ≤45 000	10	20
	>45 000 ≤60 000	15	30
	>60 000	23	30
Less combustible liquid-insulated transformers (K) without enhanced protection	100 ≤1000	1	6
	>1000 ≤3800	1.5	7.5
	>3800	4.5	15
Less combustible liquid-insulated transformers (K) with enhanced protection	Clearances G_1 and G_2 to building surface or adjacent transformers		
	Horizontal (m)	Vertical (m)	
	0.9	1.5	
Dry-type transformers (A)	Fire behaviour class	Clearances G_1 and G_2 to building surface or adjacent transformers	
		Horizontal (m)	Vertical (m)
	F0	1.5	3.0
	F1/F2	None	None

Existing kiosk sized transformers would be required to be separated by 6m from a combustible or non-fire rated surface and 1m to a fire rated surface. This is equivalent to FM GLOBAL Data Sheet 5-33 requirement of 20 feet and more than NFPA 855 requirement of 5 feet. It is considered that the separation distances to the control room and swithroom comply with the above requirements

7.5 Design Guidelines and Model Requirements: Renewable Energy Facilities, Country Fire Authority, March 2022

Section 4.2 of the Guide states that the bushfire risk is required to be addressed according to the Victorian Planning Provisions. Given the location of the site is not within a bushfire management zone or have a bushfire overlay attached to it is considered that it complies with the requirements.

Section 4.2 also recommends a fire study to Hazardous Industry Planning Advisory Paper 2: Fire Safety Study Guidelines (2011) be undertaken. This report is considered to satisfy this recommendation.

Section 5.3 states that for BESS facilities the following hazards be addressed:

- Electrical hazards, such as battery faults; overcharging; rapid discharge; loss of remote monitoring systems; internal short circuits; overheating; water ingress; lightning strike (leading to thermal events/runaway).

  Response - The batteries will be monitored such that is there is a faut or electrical runaway the system will be shut down.

- Chemical hazards, such as the inherent hazards of the stored dangerous goods; spills and leaks of transformer oil/diesel spills/leaks, refrigerant gas/coolant; chemical reactions from ignition.

Response - No dangerous goods are indicated to be stored on the site. The small transformers are considered to be adequately separated. The main transformers are located across the creek within the terminal site.

- Potential fire spread due to proximity of batteries (and containers/enclosures) to each other, on-site infrastructure and vegetation (including screening vegetation).

  Response - The battery units are separated from adjacent properties by over 10m. The batteries are arranged such that two units are adjacent to each other and the group of two units of batteries are separated by 2.5m. This distance will be assessed as part of the fire engineering report but is considered to be acceptable based on the preliminary assessment within this report. The main rows of units will be separated by a noise wall with an inherent fire resistance.

- Mechanical damage to battery containers/enclosures due to vehicular impact.

  Response - The facility has a security fence such that only maintenance vehicles can access the site. There is a 6m wide road around and within the facility and the batteries.

- Landscape hazards, such as bushfire/grassfire ignition from fire within the facility, or external ignition of site infrastructure from embers, radiant heat and flame contact.

  Response - The facility s in a relatively flat area free of vegetation. The closest vegetation is over 40m away and is not classified vegetation based on AS3595.

Section 6.1 indicates the following are low risk location attributes:

  - Grassland.
  - No continuous other vegetation types within 1-20km of the project site.
  - Generally flat topography, some undulation may be present.
  - Slopes are less than 5 degrees.
  - Good road access with multiple routes available to and from the project site.
  - No BMO applies.

It is considered that the subject facility complies with the above requirements and can be considered as a low-risk site.

Section 6.2 requires the following with respect to fire brigade vehicle access:

- Construction of a four (4) metre perimeter road within the perimeter fire break.

  Response - A 6 m wide road is provided around and within the site

- Roads must be of all-weather construction and capable of accommodating a vehicle of fifteen (15) tonnes.

  Response - Roads will eb constructed to satisfy FRV Guidelines, i.e., the emergency vehicle access road around the facility is considered as being a hardstand and therefore shall also be designed to withstand a point load of 15 tonnes (or 150kN) so that it can withstand an aerial appliance at any location within the boundaries of the hardstand

- Constructed roads should be a minimum of four (4) metres in trafficable width with a four (4) metre vertical clearance for the width of the formed road surface.

  Response - Roads are 6m wide with greater than 4m vertical clearance

- The average grade should be no more than 1 in 7 (14.4% or 8.1°) with a maximum of no more than 1 in 5 (20% or 11.3°) for no more than fifty (50) metres.

  Response - The site is relatively flat and complies with the above.

- Dips in the road should have no more than a 1 in (12.5% or 7.1°) entry and exit angle.
- Roads must incorporate passing bays at least every 600 metres, which must be at least twenty (20) metres long and have a minimum trafficable width of six (6) metres. Where roads are less than 600 metres long, at least one passing bay must be incorporated.
- Response – All the roads are 6m wide and hence allow passing
- Road networks must enable responding emergency services to access all areas of the facility, including fire service infrastructure, buildings, and battery energy storage systems and related infrastructure.

  Response – Access roads are present around and within the facility such that all areas can be accessed

- The provision of at least two (2) but preferably more access points to the facility, to ensure safe and efficient access to and egress from areas that may be impacted or involved in fire. The number of access points must be informed through a risk management process.

  Response – The site has a safe access road direct from Pelmet Crescent from which the access road then goes around and within the facility. The access point is remote from the battery units such that a fire in the batteries will not cause the access point to be compromised.

- Water access points must be clearly identifiable and unobstructed to ensure efficient access.

  Response – Hydrants will be clearly marked, and a block plan provided at the booster point

- Static water storage tank installations must comply with AS 2419.1-2005: Fire hydrant installations – System design, installation and commissioning.

  Response – water tanks with agreed supply (4 hours based on at least two hydrants operational) will be provided at the entrance to the facility with a compliant hard stand and booster assembly.

- The static water storage tank(s) must be an above-ground water tank constructed of concrete or steel.

  Response – Complies

- The static water storage tank(s) must be capable of being completely refilled automatically or manually within 24 hours.

  Response – Design to be confirmed

- The static water storage tanks must be located at vehicle access points to the facility and must be positioned at least ten (10) metres from any infrastructure (solar panels, wind turbines, battery energy storage systems, etc.).

  Response - Complies

- The hard-suction point must be provided, with a 150mm full bore isolation valve equipped with a Storz connection, sized to comply with the required suction hydraulic performance.

  Response – Will comply

- Adapters that may be required to match the connection are: 125mm, 100mm, 90mm, 75mm, 65mm Storz tree adapters with a matching blank end cap to be provided.

  Response – Will comply

- The hard-suction point must be positioned within four (4) metres to a hardstand area and provide a clear access for emergency services personnel.
- Response - Complies
- An all-weather road access and hardstand must be provided to the hard-suction point. The hardstand must be maintained to a minimum of 15 tonne GVM, eight (8) metres long and six (6) metres wide or to the satisfaction of the CFA.

Response - Complies

- The road access and hardstand must be kept clear at all times.
- The hard-suction point must be protected from mechanical damage (e.g., bollards) where necessary.

  Response – Will comply

- Where the access road has one entrance, a ten (10) metre radius turning circle must be provided at the tank.

  Response – The access road is continuous around the site from the tank location such that turning is not required and vehicles can drive in an out of the site

- An external water level indicator must be provided to the tank and be visible from the hardstand area.

  Response – Will comply

- Signage indicating 'FIRE WATER' and the tank capacity must be fixed to each tank.

  Response – Will comply

- Signage must be provided at the front entrance to the facility, indicating the direction to the static water tank.

  Response – Will comply

- For facilities with battery energy storage systems, the fire protection system must include at a minimum: a) A fire hydrant system that meets the requirements of AS 2419.1-2005: Fire hydrant installations, 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 battery energy storage system is within reach of a 10m hose stream issuing from a nozzle at the end of a 60m length of hose connected to a fire hydrant outlet.

  Response – Table 3.3 of AS2419 is reproduced below

TABLE 3.3

NUMBER OF FIRE HYDRANT OUTLETS REQUIRED TO DISCHARGE SIMULTANEOUSLY FOR PROTECTED OPEN YARDS

Area of yard m^2	Number of fire hydrant outlets required to flow simultaneously (see Note)
≤3 000	1
>3 000 to ≤9 000	2
>9 000 to ≤27 000	3
>27 000	4

NOTE: Where more than one external fire hydrant, each with two valve-controlled outlets is installed and more than one outlet is required to flow, then one outlet on each of the most hydraulically disadvantaged fire hydrants has to achieve the required flow and pressure.

If the number of outlets required to flow exceed the number of fire hydrants installed, then simultaneous flow from each of the two outlets on the most hydraulically disadvantaged fire hydrant will be necessary.

Where only one external fire hydrant with two valve controlled outlets is installed and 2 outlets are required to flow, then simultaneous flow from each of the two outlets will be necessary.

The facility is approximately 21,000m^2 within the security fence but the batteries are separated by the noise walls that have an inherent fire rating of -/120/- and hence the maximum area of batteries is approximately 1,385m^2. Accordingly, 3 hydrant running is required by the standard but at least two will be supplied such that attack can occur on either side.

The water storage tank is therefore required to allow for 2 hydrants at 10L/s each for four hours, i.e., 288kL.

All batteries are able to be reached by at least two hydrants.

- CFA recommends that infrastructure is provided for the containment and management of contaminated fire water runoff from battery energy storage systems. Infrastructure may include bunding, sumps and/or purpose-built, impervious retention facilities. A fire water management plan may include the containment and disposal of contaminated fire water.

  Response – A water drainage and treatment system has been allowed for.

- CFA recommends that battery energy storage systems are equipped with the following elements:
  - Battery management/monitoring systems for monitoring the state of battery systems to ensure safe operation.
  - Detection systems for smoke, heat (thermal), fire and toxic gas (off-gassing) within battery containers.
  - Suppression systems for fire within battery containers.
  - Systems to prevent heat/fire spread within battery containers (such as thermal barriers, shut-down separators, isolation systems, cooling systems).

- Systems to prevent explosion within battery containers (such as ventilation, pressure relief and exhaust systems).
- Warning and alarm systems within the battery containers, and/or the facility, to enable early warning for faults, operation of the battery energy storage system above 'normal'/safe parameters, smoke, off-gassing, and fire.

Response – The battery units will incorporate a battery management system as well as an alarm system within the facility to enable early warning of faults. The battery containers will contain venting or pressure relief to prevent explosions.

7.6 Summary

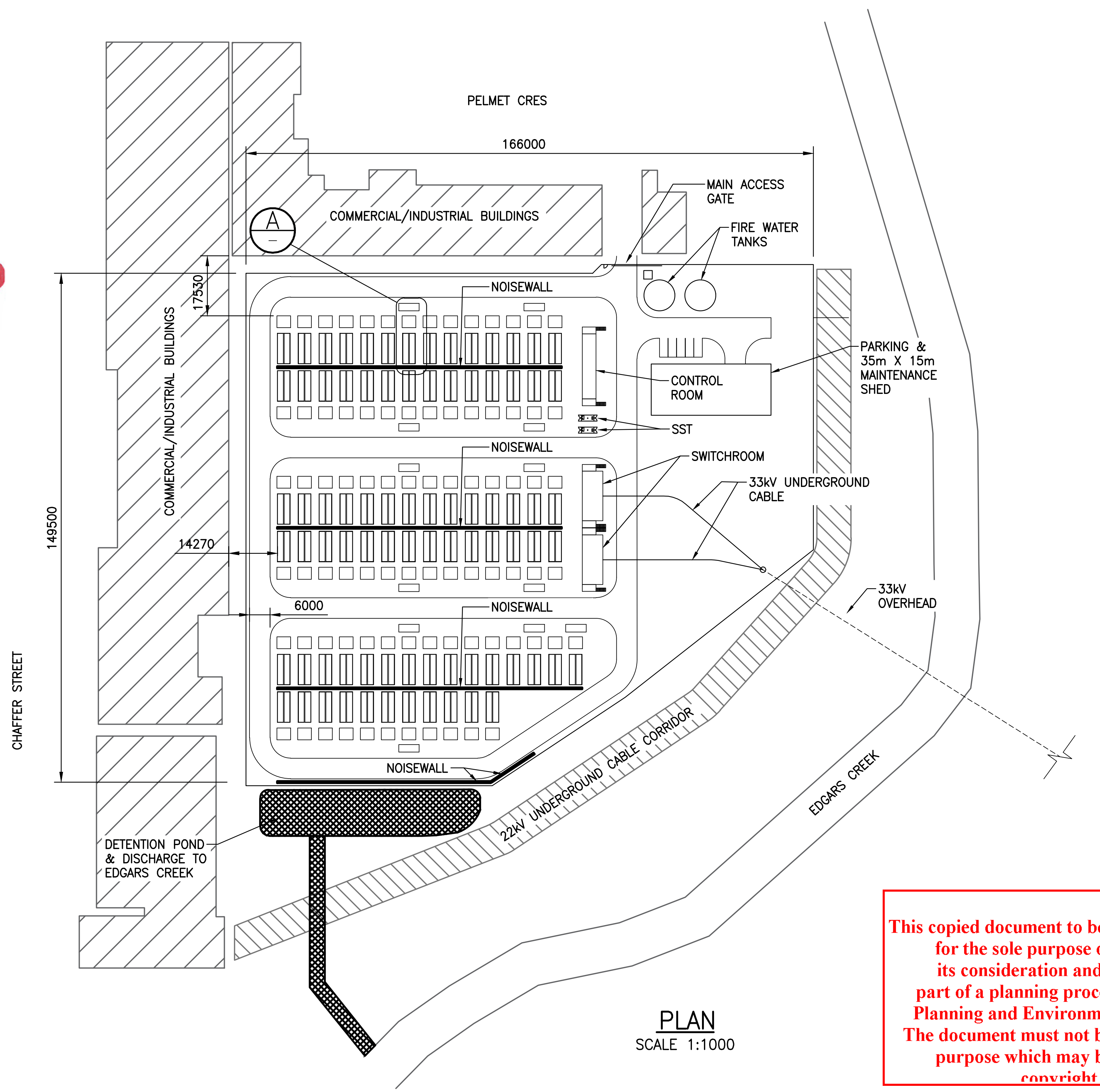
It is considered that the BESS facility complies with the various requirements from the standards and guidelines with respect to location, layout bushfire protection, materials of construction, monitoring systems etc.

8 CONCLUSIONS

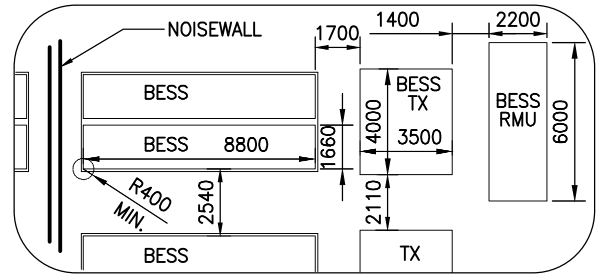
Based on the results of the assessment it is concluded that:

1. The design of the BESS units is acceptable and covers all fire initiation and fire spread risks to an acceptable level
2. Based on the AS5139 Risk Methodology the risk of a fire would be considered rare and the risk level Very Low
3. The proposed installation procedures and units have design requirements that address the issues raised by the Victorian Big Battery (VBB) fire
4. The risk of fire development and spread is no worse than that posed by existing utility infrastructure in the community or the adjacent buildings in the community
5. Fire spread to adjacent allotments would not be predicted to occur.
6. Fire brigade intervention is considered not to be affected by a fire based on the preliminary fire modelling results presented within this report.
7. In order for the site entrance to be affected by a fire there would need to be a fire within the adjacent units as well as a wind from south or southwest which is not the predominant direction. The boosters and brigade access are separated from the battery units and transformers and hence the predicted fire size is not large enough to block the entrance to the site even with the wind in the correct direction.
8. The firefighting water will be sufficient for 4 hours supply based on at least 2 hydrants. The hydrants will be located such that all areas can be covered by at least 2 hydrants.
9. The other parts of the infrastructure such as the transformers and control room do not present a significant fire risk or higher hazard than other kiosk type transformers and small buildings in the community that do not require particular fire safety provisions.
10. It is considered that the design and layout of the BESS provides an acceptable level of fire safety to personnel, fire brigade and adjacent properties.

Appendix A. PROPOSED FACILITY LAYOUT



PLAN
SCALE 1:1000



DETAIL A
SCALE 1: 200

LEGEND

SST	STATION SERVICE TRANSFORMER
TX	TRANSFORMER
RMU	RING MAIN UNIT
— / —	TERMINAL STATION FENCE
----------	33kV OVERHEAD LINE
————	33kV UNDERGROUND HV CABLE
(symbol)	FIRE HYDRANT (TBA)

NOTES:

1. THIS DRAWING IS FOR ESTIMATING PURPOSES ONLY. AND IS NOT FOR CONSTRUCTION. DIMENSIONS AND RATINGS ARE SUBJECT TO DETAILED DESIGN.
2. DESIGN SUBJECT TO EQUIPMENT SELECTION AND ELECTRICAL AND MAGNETIC FIELD STUDY.
3. BESS, TX & RMU ARE INDICATIVE ONLY. ACTUAL SIZE & FOUNDATION MAY BE DIFFERENT AND ARE TO BE CONFIRMED.
4. DIMENSION IS INDICATIVE, ACTUAL POLE LOCATION TO BE DETERMINED BY LINE DESIGNER DURING DETAILED DESIGN.

0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000

SCALE 1:200
DIMENSIONS IN MILLIMETRES

0 10000 20000 30000 40000 50000 60000 70000 80000 90000 100000

SCALE 1:1000
DIMENSIONS IN MILLIMETRES

DATE	REV	DESCRIPTION	BY	CONTRACTOR
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THOMASTOWN BESS
GENERAL ARRANGEMENT
OVERALL

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Legacy No –
Drawing No TTBESS-P01-001
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Appendix B. VBB Fire Investigation

January 25, 2022

Victorian Big Battery Fire: July 30, 2021

REPORT OF TECHNICAL FINDINGS

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Background

The Victorian Big Battery (VBB) is a 300-Megawatt (MW)/450-Megawatt hour (MWh) grid-scale battery storage project in Geelong, Australia. VBB is one of the largest battery installations in the world and can power over one million Victorian homes for 30 minutes during critical peak load situations.[1] It is designed to support the renewable energy industry by charging during times of excess renewable generation. The VBB is fitted with 212 Tesla Megapacks to provide the 300-MW/450-MWh of energy storage. The Megapack is a lithium-ion battery energy storage system (BESS) consisting of battery modules, power electronics, a thermal management system, and control systems all pre-manufactured within a single cabinet that is approximately 7.2 meters (m) in length, 1.6 m deep and 2.5 m in height (23.5 feet [ft] x 5.4 ft x 8.3 ft).

On Friday, July 30th, 2021, a single Megapack at VBB caught fire and spread to a neighboring Megapack during the initial installation and commissioning of the Megapacks. The fire did not spread beyond these two Megapacks and they burned themselves out over the course of approximately six hours. There were no injuries to the general public, to site personnel or to emergency first responders as the Megapacks failed safely (i.e., slowly burned themselves out with no explosions or deflagrations), as they are designed to do in the event of a fire. Per the guidance in Tesla's Lithium-Ion Battery Emergency Response Guide[2] (ERG), emergency responders permitted the Megapack to burn and consume itself while nearby exposures were being monitored at a safe distance. The total impact to the site was two out of the 212 Megapacks were fire damaged, or less than 1% of the BESS.

Following the emergency response, a detailed, multi-entity fire investigation commenced on August 3, 2021. The investigation process included local regulatory entities, Tesla, outside third-party engineers and subject matter experts. The investigation process involved analyzing both the fire origin and cause as well as the root cause of the fire propagation to the neighbor Megapack. In addition, given this is the first fire event in a Megapack installation to date, a review of the emergency response has been performed to identify any lessons learned from this fire event.

This report summarizes those investigations and analyses and has been prepared by Fisher Engineering, Inc. (FEI) and Energy Safety Response Group (ESRG), two independent engineering and energy storage fire safety consulting firms. In addition, this report provides a list of lessons learned from the fire and also highlights the procedural, software and hardware changes that have been implemented based on those lessons learned.

Incident Timeline

At the time of the fire, the VBB was fitted with approximately one-half of the 212 total Megapacks intended for the site. The Megapacks that were installed at VBB were undergoing routine testing and commissioning on the day of the fire. At 7:20 AM Australian Eastern Standard Time (AEST) on the morning of July 30, 2021, commissioning and testing of a number of Megapacks commenced. One such Megapack (denoted herein as MP-1), was not going to be tested that day and was therefore shut off manually by means of the keylock switch.[3] At the time MP-1 was shut down via the keylock switch, the unit displayed no abnormal conditions to site personnel. Around 10:00 AM, smoke was observed emitting from MP-1 by site personnel. Site personnel

1 https://victorianbigbattery.com.au/
2 https://www.tesla.com/sites/default/files/downloads/Lithium-Ion_Battery_Emergency_Response_Guide_en.pdf
3 The keylock switch is a type of "lock out tag out" switch on the front of the Megapack that safely powers down the unit for servicing.

electrically isolated all the Megapacks on-site and called emergency services: Country Fire Authority (CFA). The CFA arrived shortly thereafter and set up a 25 m (82 ft) perimeter around MP-1. They also began applying cooling water to nearby exposures as recommended in Tesla's ERG. The fire eventually spread into a neighbor Megapack (MP-2) installed 15 centimeters (cm), or 6 inches (in), behind MP-1. The CFA permitted MP-1 and MP-2 to burn themselves out and did not directly apply water into or onto either Megapack, as recommended in Tesla's ERG. By 4:00 PM (approximately six hours after the start of the event), visible fire had subdued and a fire watch was instituted. The CFA monitored the site for the next three days before deeming it under control on August 2, 2021, at which time, the CFA handed the site over for the fire investigation to begin.

Note: The time stamp is AEST (UTC+10) which is 19 hours ahead of USA PDT (UTC-7)

Investigation

A multi-entity fire investigation commenced on August 3, 2021. The VBB fire investigation process involved analyzing both the root cause of the initial fire in MP-1 as well as the root cause of the fire propagation into MP-2. The investigations included on-site inspections of MP-1 and MP-2 by the CFA, Energy Safe Victoria[4] (ESV), Work Safety Victoria[5] (WSV), local Tesla engineering/service teams and a local third-party independent engineering firm. In addition to the on-site work immediately after the incident, the root cause investigations also included data analysis, thermal modeling and physical testing (electrical and fire) performed by Tesla at their headquarters in California, USA and their fire test facility in Nevada, USA.

Fire Cause Investigation

On-site inspections commenced on August 3, 2021 and concluded on August 12, 2021. MP-1 and MP-2 were documented, inspected and preserved for future examinations, if necessary. Concurrently, all available telemetry data (such as internal temperatures and fault alarms) from MP-1 and MP-2 were analyzed and a series of electrical fault and fire tests were performed. The on-site investigation findings, the telemetry data analysis, electrical fault tests and fire tests, when combined, identified a very specific series of fault conditions present on July 30, 2021 that could lead to a fire event.

Fire Origin and Cause Determination

The origin of the fire was MP-1 and the most likely root cause of the fire was a leak within the liquid cooling system of MP-1 causing arcing in the power electronics of the Megapack's battery modules. This resulted in heating of the battery module's lithium-ion cells that led to a propagating thermal runaway event and the fire.

Other possible fire causes were considered during the fire cause investigation; however, the above sequence of events was the only fire cause scenario that fits all the evidence collected and analyzed to date.

Contributory Factors

A number of factors contributed to this incident. Had these contributory factors not been present, the initial fault condition would likely have been identified and interrupted (either manually or automatically) before it escalated into a fire event. These contributory factors include:

1. The supervisory control and data acquisition (SCADA) system for a Megapack required 24 hours to setup a connection for new equipment (i.e., a new Megapack) to provide full telemetry data functionality and remote monitoring by Tesla operators. Since VBB was still in the installation and commissioning phase of the project (i.e., not in operation), MP-1 had only been in service for 13 hours prior to being switched off via the keylock switch on the morning of the fire. As such, MP-1 had not been on-line for the required 24 hours, which prevented this unit from transmitting telemetry data (internal temperatures, fault alarms, etc.) to Tesla's off-site control facility on the morning of the fire.
2. The keylock switch for MP-1 was operated correctly on the morning of the fire to turn MP-1 off as the unit was not required for commissioning and testing that morning; however, this action caused telemetry systems, fault monitoring, and electrical fault safety devices[6] to be disabled or operate with

[4] Victoria's energy safety regulator

[5] Victoria's health and safety regulator

[6] These elements include, among other devices, fuses at the cell and module level for localized fault current interruption and a battery module pyro disconnect that severs the electrical connection of the battery module when a fault current is passing through the battery module.

only limited functionality. This prevented some of the safety features of MP-1 from actively monitoring and interrupting the electrical fault conditions before escalating into a fire event.

3. The exposure of liquid coolant onto the battery modules likely disabled the power supply to the circuit that actuates the pyro disconnect.[7] With a power supply failure, the pyro disconnect would not receive a signal to sever and would not be able to interrupt a fault current passing through the battery module prior to it escalating into a fire event.

Fire Propagation Investigation

The VBB fire investigation process involved analyzing not only the root cause of the initial fire in MP-1 but also the root cause of the fire propagation into MP-2. The Megapack has been designed to be installed in close proximity to each other without fire propagating to adjacent units. The design objective of the Megapack in terms of limiting fire propagation was mainly reliant on the thermal insulation of the Megapack's exterior vertical steel panels and the sheer mass of the battery modules acting as a heat sink (i.e., they are difficult to heat up). With this thermal insulation, the Megapack spacing can be as close as 15 cm (6 in) to the sides and back of each unit with 2.4 m (8 ft) aisles in front of each Megapack, as shown in Figure 1. This product spacing has been validated in UL9540A unit level tests.[8] Similar to the fire origin and cause investigation, the on-site inspections were supported simultaneously with an analysis of telemetry data (such as internal temperatures) from MP-2 and fire testing. The on-site investigation findings, the telemetry data analysis and fire tests, when combined, identified a scenario where Megapack to Megapack fire propagation can occur.

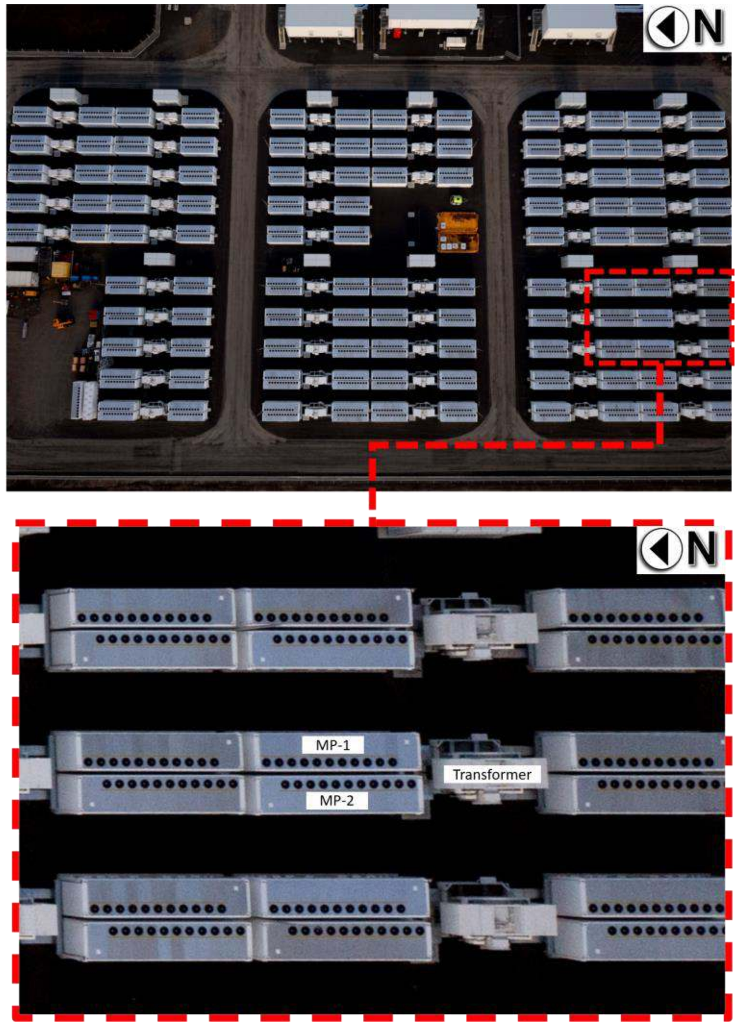

Figure 1 VBB Megapack layout (top) and area of fire origin (bottom)

7 The pyro disconnect is a Tesla proprietary shunt-controlled pyrotechnic fuse that allows for rapid one-time actuation. There is one pyro disconnect per battery module.

8 UL9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*. UL9540A is a test method developed by UL to address fire safety concerns with BESS. The test method provides a method to evaluate thermal runaway and fire propagation at the cell level, module level, and unit level. In addition to cell and module level tests, Tesla performed unit level tests to evaluate, among other fire safety characteristics, the potential for fire propagation from Megapack-to-Megapack. During unit level testing, fire propagation did not occur between Megapacks when they were installed with a spacing of 15 cm (6 in) to the sides and back of each unit.

Fire Propagation Determination

Flames exiting the roof of MP-1 were significantly impacted by the wind conditions at the time of the fire. Wind speeds were recorded between 20-30 knots[9] which pushed the flames exiting the roof of MP-1 towards the roof of MP-2. This direct flame impingement on the top of the thermal roof of MP-2 ignited the internal components of MP-2, most notably, the plastic overpressure vents that seal the battery bay[10] from the thermal roof. Once ignited, the overpressure vents provided a direct path for flames and hot gases to enter into the battery bays, thus exposing the battery modules of MP-2 to fire and/or elevated temperatures. Exposed to temperatures above their thermal runaway threshold of 139°C (282°F), the cells within the battery modules eventually failed and became involved in the fire.

Other possible fire propagation root causes were considered during the investigation; however, the above sequence of events was the only fire propagation scenario that fits all the evidence collected and analyzed to date. Of note, at the time when fire was observed within the thermal roof of MP-2, internal cell temperature readings of MP-2 had only increased by 1°C (1.8°F) from 40°C to 41°C (104°F to 105.8°F)[11] Around the same time that fire was observed within the thermal roof of MP-2, around 11:57 AM (approximately 2 hours into the fire event), communication was lost to the unit and no additional telemetry data was transmitted. However, given the internal cell temperatures of MP-2 had only recorded a 1°C (1.8°F) temperature rise 2 hours into the fire event and while the unit's roof was actively on fire, fire propagation across the 15 cm (6 in) gap via heat transfer is not the root cause of the fire propagation. Furthermore, this telemetry data from MP-2 demonstrates that the Megapack's thermal insulation can provide significant thermal protection in the event of a fire within an adjacent Megapack installed only 15 cm (6 in) away.

Contributory Factors

The wind was the dominant contributory factor in the propagation of fire from MP-1 to MP-2. At the time of the fire, a 20-30 knot (37-56 km/hr, 23-35 mph) wind was recorded out of the north. The wind conditions at the time of the fire pushed the flames exiting out of the top of MP-1 towards the top of MP-2 leading to direct flame impingement on the thermal roof of MP-2. This type of flame behavior was not observed during previous product testing or regulatory testing per UL9540A. In UL9540A unit level testing, the maximum wind speed permitted[12] during the test is 10.4 knots (19.3 km/hr, 12.0 mph); whereas, wind conditions during the VBB fire were two to three times greater in magnitude. As such, the wind conditions during the VBB fire appear to have identified a weakness in the Megapack's thermal roof design (unprotected, plastic overpressure vents in the ceiling of the battery bays) that allows Megapack-to-Megapack fire propagation. This weakness was not identified previously during product or regulatory testing and does not invalidate the Megapack's UL9540A certification, as the cause of fire propagation was primarily due to an environmental condition (wind) that is not captured in the UL9540A test method.

9 This equates to 37-56 kilometers per hour (km/hr) or 23-35 miles per hour (mph).

10 The battery bay is an IP66 enclosure that houses the battery modules. It is distinct from the thermal roof installed above it. Plastic overpressure vents are installed in the ceiling of the battery bay, sealing the two enclosures from one another.

11 As a reference, the Megapack's normal operating cell temperature is between 20-50°C and cell thermal runaway does not occur until 139°C (98°C above cell temperatures of MP-2 before telemetry data was lost).

12 This threshold is necessary for test reliability and reproducibility. If wind conditions are not bounded in some fashion in an outdoor fire test, large variances on product performance could be introduced due to varying wind conditions.

Mitigations

The investigation of the VBB fire identified several gaps in Tesla's commissioning procedures, electrical fault protection devices and thermal roof design. Since the fire, Tesla has implemented a number of procedural, firmware, and hardware mitigations to address these gaps. These mitigations have been applied to all existing and any future Megapack installations and include:

<u>Procedural Mitigations:</u>

- Improved inspection of the coolant system for leaks during Megapack assembly and during end-of-line testing to reduce the likelihood of future coolant leaks.
- Reduce the telemetry setup connection time for new Megapacks from 24 hours to 1 hour to ensure new equipment is transmitting telemetry data (internal temperatures, fault alarms, etc.) to Tesla's off-site control facility for remote monitoring.
- Avoid utilizing the Megapack's keylock switch during commissioning or operation unless the unit is actively being serviced. This procedural mitigation ensures telemetry, fault monitoring, and electrical fault safety devices (such as the pyro disconnect) are active while the Megapack is idle (such as during testing and commissioning).

<u>Firmware Mitigations:</u>

- Added additional alarms to the coolant system's telemetry data to identify and respond (either manually or automatically) to a possible coolant leak.
- Keep all electrical safety protection devices active, regardless of keylock switch position or system state. This firmware mitigation allows electrical safety protection devices (such as the pyro disconnect) to remain in an active mode, capable of actuating when electrical faults occur at the battery modules, no matter what the system status is.
- Active monitoring and control of the pyro disconnect's power supply circuit. In the event of a power supply failure (either through an external event such as a coolant exposure or some other means), the Megapack will automatically actuate the pyro disconnect prior to the loss of its power supply.

<u>Hardware Mitigations</u>

- Installation of newly designed, thermally insulated steel vent shields within the thermal roof of all Megapacks. These vent shields protect the plastic overpressure vents from direct flame impingement or hot gas intrusion, thus keeping the IP66 battery bay enclosures isolated from a fire above in the thermal roof. Their performance was validated through a series of fire tests, including unit level fire testing of entire Megapack units.[13] The vent shields are placed over the top of the overpressure vents and will come standard on all new Megapack installations. For existing Megapacks, the vent shields can be installed in the field (retrofit) with minimal effort or disruption to the unit. At the time of this report, the vent shields are nearing production stage and will be retrofitted to applicable Megapack sites shortly.

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[13] The tests confirmed that, even with the entire thermal roof fully involved in fire, the overpressure vents will not ignite and the battery modules below remain relatively unaffected by the fire above. For instance, the cells within the battery modules saw a less than 1°C temperature rise while the entire thermal roof was fully involved in fire.

Emergency Response

Beyond the origin and cause and propagation investigations, another key aspect of the VBB fire was the emergency response. The CFA is the responsible fire service organization for VBB, and the facility is in their initial response jurisdiction. The location of the VBB facility is in a semi-rural location. The nearest fire station is the CFA Lovely Banks, approximately 4 km (2.5 miles) distance from VBB and thus relatively close, though other resources had more extended travel distances.

Upon arrival around 10:30 AM, CFA immediately established incident command (IC) in accordance with their protocols, and the IC worked closely with the facility representatives and subject matter experts (SMEs). This close coordination continued throughout the entire event. The facility was evacuated and all-site personnel accounted-for upon notification of the emergency event and the commencement of fire service operations. A 25 m (82 ft) perimeter was established around MP-1 while water application and cooling strategies were discussed with facility representatives and subject matter experts (SMEs). The decision was made to provide exposure protection to Megapacks and transformers adjacent to MP-1 and MP-2 using water hose lines, as recommended in Tesla's ERG. The fire eventually propagated into MP-2; however, flame spread did not advance any further than MP-1 and MP-2. The two Megapacks were permitted to burn themselves out, during which time the CFA did not directly apply water into or onto either Megapack. By 4:00 PM (approximately six hours after the start of the event), visible flames had subdued and a fire watch was instituted. The CFA continued to monitor the site for the next three days before deeming it under control on August 2, 2021, at which time, the fire investigation began.

Key Takeaways

A thorough review of the VBB fire emergency response yielded the following key takeaways:

- Effective Pre-incident Planning: VBB had both an Emergency Action Plan (EAP) and an Emergency Response Plan (ERP). Both plans were available to emergency responders and were effectively used during the VBB fire. For example, all site employees and contractors followed proper evacuation protocols during the fire and as a result, no injuries occurred to those personnel.
- Coordination with SMEs: VBB had thorough pre-incident plans that clearly identified the SMEs, how to contact them, their role and other key tasks. It was reported that the facility SMEs stayed in close contact with the CFA IC throughout the VBB fire, providing valuable information and expertise for the CFA to draw upon. For example, site representatives and SMEs worked closely with the CFA in determining water application and cooling strategies of adjacent exposures.
- Water Application: A key question regarding water application is the necessary amount and duration for effective fire containment. Tesla's design philosophy is based on inherent passive protection (i.e., thermal insulation), with minimal dependence on active firefighting measures like external hose lines. As such, water was not aimed at suppressing the fire but rather protecting the exposures as directed by Tesla's ERG and the SMEs on site. All available data and visual observations of the fire indicates water had limited effectiveness in terms of reducing or stopping fire propagation from Megapack-to-Megapack. The thermal insulation appears to be the dominant factor in reducing heat transfer between adjacent Megapacks. However, water was effectively used on other exposures

(transformers, electrical equipment, etc.) to protect that equipment, which are not designed with the same level of protection as a Megapack is (i.e., thermal insulation).[14]

- The fire protection design approach of the Megapack has inherent advantages over other BESS designs in terms of safety to emergency responders. The Megapack approach minimizes the likelihood of fire spread using passive compartmentation and separation, eliminates the danger to fire fighters of an overpressure event due to design features and a lack of confinement (e.g., outdoor versus indoor), does not rely on active firefighting measures like external hose lines and minimizes the dangers from stranded electrical energy to those involved with overhaul and de-commissioning with a fire response approach permitting the Megapack to burn itself out.

Environmental Concerns

The Environment Protection Authority Victoria (EPA) deployed two mobile air quality monitors within 2 km (1.2 miles) of the VBB site. Locations were chosen where there was potential to impact the local community. The EPA monitors confirmed "good air quality in the local community" after the incident; however, the measurements were not taken during the peak of the fire event. They were sampled around 6:00 PM, or approximately 2 hours after the fire was out. Therefore, the data cannot be used to understand the airborne hazards during the actual fire event. The data does demonstrate that two hours after the fire event, the air quality in the surrounding area was "good" and no long-lasting air quality concerns arose from the fire event.[15]

During the fire event, the CFA coordinated with site personnel to control the water run-off from fire hoses into a catchment. Water samples, collected by Tesla site personnel under the supervision of CFA, were extracted from the catchment. Laboratory results from those samples indicated that the likelihood of the fire having a material impact on the water was minimal. After the incident, as a precaution, the water was removed from the catchment, via suction trucks, and was transported to a licensed waste facility for treatment and disposal. It is estimated that approximately 900,000 liters of water was disposed of from the site after the event.

Community Concerns

Neoen, the project developer and owner, pro-actively engaged with the local community during and following the VBB fire. These engagements included door-to-door visits, phone calls and emails with the residential and agricultural properties within a 2-3 km (1.2-1.9 mile) radius of the VBB site. Neoen found their prior community outreach during the project planning stages to be invaluable as this outreach provided up-to-date contact information for Neoen when reaching out to the local community during and following the fire. In addition, Neoen formed an executive stakeholder steering committee compromising of key organizations within 24 hours of the incident. With multiple parties involved in the emergency response to the fire event

[14] At the time of this report, final fire department reports were not available for review and inclusion. As that information becomes available, additional information regarding water usage and effectiveness may require inclusion in this report. Although the effectiveness of external water in a Megapack fire may be limited, water should still be made available for exposure protection and other unanticipated events in the future, as required by any applicable regulatory requirements.

[15] It should be noted that prior regulatory testing (UL 9540A module level fire testing) has shown that the products of combustion of a Megapack battery module can include flammable and nonflammable gases. Based on those regulatory tests, the flammable gases were found to be below their lower flammable limit (LFL) and would not pose a deflagration or explosion risk to first responders or the general public. The nonflammable gases were found to be comparable to the smoke you would encounter in a typical Class A structure fire and do not contain any unique, or atypical, gases beyond what you would find in the combustion of modern combustible materials.

actively participating in the steering committee, this helped ensure that from the outset communication was timely, efficient, well-coordinated across different organizations and accurate.

In addition to the community outreach, Neoen and Tesla also briefed multiple industry, State and Federal Government Departments and Agencies immediately following the VBB fire and at the conclusion of the investigation process. These briefings helped ensure the wider energy sector with interests in BESS were able to be kept directly informed as information became available.

Overhaul and Remediation

On July 29, 2021 nearly half of the Megapacks had been installed and the site was in the testing and commissioning stage of the project. Following the fire event on July 30, 2021, fire department personnel, regulatory agencies and other emergency responders remained on-site for precautionary purposes until August 2, 2021. At that time the site was turned over for regulatory fire investigations to begin. On-site fire investigations started on August 3, 2021 and continued until August 12, 2021. During this time, starting on August 6, 2021, the site was permitted to continue the installation of Megapacks while the area around MP-1 remained cordoned off for the investigation. On September 23rd, 2021, less than two months after the fire, VBB was re-energized and testing and commissioning restarted. Remediation of the damaged equipment followed shortly after, and lasted a total of three days. All testing and commissioning efforts were completed without any further incidents and on December 8, 2021, VBB officially opened.

Lessons Learned

The VBB fire exposed a number of unlikely factors that, when combined, contributed to the fire initiation as well as its propagation to a neighboring unit. This collection of factors had never before been encountered during previous Megapack installations, operation and/or regulatory product testing. This section summarizes those factors as well as the emergency response to the fire, discusses the lessons learned from this fire event, and highlights the mitigations Tesla has implemented in response.

1. Commissioning Procedures

Lessons learned related to commissioning procedures include: (1) limited supervision/monitoring of telemetry data during the first 24 hours of commissioning and (2) the use of the keylock switch during commissioning and testing. These two factors prevented MP-1 from transmitting telemetry data (internal temperatures, fault alarms, etc.) to Tesla's control facility and placed critical electrical fault safety devices (such as the pyro disconnect) in a state of limited functionality, reducing the Megapack's ability to actively monitor and interrupt electrical fault conditions prior to them escalating into a fire event.

Since the VBB fire, Tesla has modified their commissioning procedures to reduce the telemetry setup connection time for new Megapacks from 24 hours to 1 hour and to avoid utilizing the Megapack's keylock switch unless the unit is actively being serviced.

2. Electrical Fault Protection Devices

Lessons learned related to electrical fault protection devices include: (1) coolant leak alarms; (2) the pyro disconnect being unable to interrupt fault currents when the Megapack is off via the keylock switch and (3) the pyro disconnect likely being disabled due to a power supply loss to the circuit that actuates it. These three factors prevented the pyro disconnect of MP-1 from actively monitoring and interrupting the electrical fault conditions before escalating into a fire event.

Since the VBB fire, Tesla has implemented a number of firmware mitigations that keep all electrical safety protection devices active, regardless of keylock switch position or system state, and to actively monitor and control the pyro disconnect's power supply circuit. Furthermore, Tesla has added additional alarms to better identify and respond (either manually or automatically) to coolant leaks. Additionally, although this fire event was likely initiated by a coolant leak, unexpected failures of other internal components of the Megapack could create similar damage to the battery modules. These new firmware mitigations do not only address damage from a coolant leak. They also permit the Megapack to better identify, respond, contain and isolate issues within the battery modules due to failures of other internal components, should they occur in the future.

3. Fire Propagation

Lessons learned related to fire propagation include: (1) the significant role external, environmental conditions (such as wind) can have on a Megapack fire and (2) the identification of a weakness in the thermal roof design that permits Megapack-to-Megapack fire propagation. These two factors led to direct flame impingement on the plastic overpressure vents that seal the battery bay from the thermal roof. With a direct path for flames and hot gases to enter into the battery bays, the cells within the battery modules of MP-2 failed and became involved in the fire.

Since the VBB fire, Tesla has devised (and validated through extensive testing) a hardware mitigation that protects the overpressure vents from direct flame impingement or hot gas intrusion via the installation of new, thermally insulated, steel vent shields. The vent shields are placed on top of the overpressure vents and will come standard on all new Megapack installations. For existing Megapacks, the vent shields can be easily installed in the field. At the time of this report, the vent shields are nearing production stage and will be retrofitted to applicable Megapack sites shortly.

4. Megapack Spacing

Lessons learned related to Megapack spacing include: no changes are required to the installation practices of the Megapack with the vent shield mitigation (as described above) in place. Based on an analysis of telemetry data within MP-2 during the VBB fire, the Megapack's thermal insulation can provide significant thermal protection in the event of a fire within an adjacent Megapack installed 15 cm (6 in) away. The internal cell temperatures of MP-2 only increased by 1°C (1.8°F), from 40°C to 41°C (104°F to 105.8°F), before communication was lost to the unit, presumably due to fire, around 11:57 AM (approximately 2 hours into the fire event). Fire propagation was triggered by the weakness in the thermal roof, as described above in #3, and not due to heat transfer via the 15 cm (6 in) gap between Megapacks. With the vent shield mitigation in place, the weakness has been addressed and validated through unit level fire testing (i.e., tests involving the ignition of the Megapack's thermal roof). These tests confirmed that, even with the thermal roof fully involved in a fire, the overpressure vents will not ignite and the battery modules remain relatively unaffected with internal cell temperatures rising less than 1°C.

5. Emergency Response

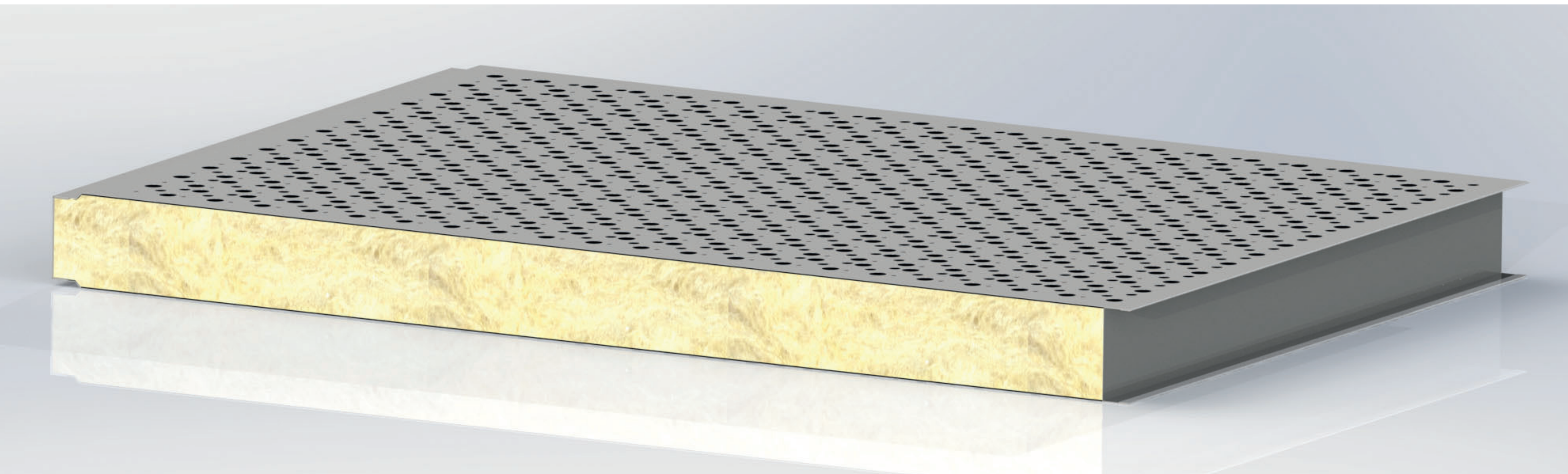
Lessons learned from the emergency response to the VBB fire include: (1) effective pre-incident planning is invaluable and can reduce the likelihood of injuries; (2) coordination with SMEs, either on site or remotely, can provide critical expertise and system information for emergency responders to draw upon; (3) the effectiveness of applying water directly to adjacent Megapacks appears to provide limited benefits; however, water application to other electrical equipment, with inherently less fire protection built into their designs (such as transformers), can be a useful tactic to protect that equipment; (4) the fire protection design approach of the Megapack has inherent advantages over other BESS designs in terms of safety to emergency responders; (5) the EPA indicated that there was "good" air quality 2 hours after the fire demonstrating that no long-lasting air quality concerns arose from the fire event; (6) water samples indicated that the likelihood of the fire having a material impact on firefighting water was minimal; (7) prior community engagement during the project planning stages is invaluable as it enabled Neoen to quickly update the local community and address immediate questions and concerns; (8) early, factual and where possible, face-to-face engagement with the local community is essential when a fire event is unfolding to keep the general public informed; (9) an executive stakeholder steering committee from the key organizations involved in the emergency response can help ensure that any pubic communications are timely, efficient, coordinated and accurate; and (10) effective coordination between stakeholders at the site allowed for rapid and thorough handover process after the incident, the swift and safe decommissioning of the damaged units and the site's quick return to service.

In summary, the VBB fire event proceeded in accordance with its fire protection design and pre-incident planning. It presented no unusual, unexpected, or surprising characteristics (i.e., explosions) or resulted in any injuries to site personnel, the general public or emergency responders. It was isolated to the units directly involved, had minimal environmental impact, did not adversely impact the electrical grid, and had appreciably short mission interruption.

Appendix C. FLEX SHIELD SONIC SYSTEM MODULAR PANEL

flexSHIELD®
Health. Safety. Productivity.

Sonic System
Acoustic Modular Panel
V50, V100



Self-supporting sandwich panel for sound control in industrial environments, with internally perforated steel sheet for sound absorption and solid external steel sheet for noise reduction.
The large perforated surface together with the steel sheet reinforcement ensure high performance.

Certifications

α_s 1.10 — **Sound absorption**
up to NRC of 1.10 in accordance with ASTM C422-90

R_w 37 — **Sound insulation**
up to up to Rw37dB in accordance with AS/NZS ISO717-1-2004

Reaction to fire (materials)
FRL of -/120/- in accordance with AS 1530-4-2014 Sections 1,2 & 3

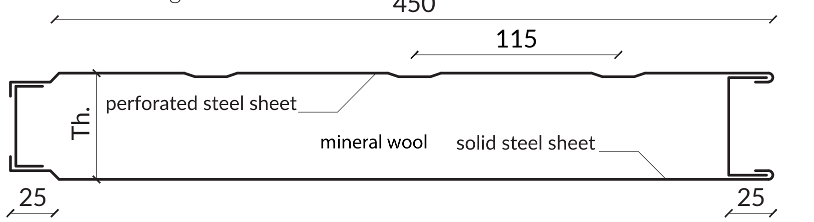
Use and specifications

Acoustic comfort

Fast assembly

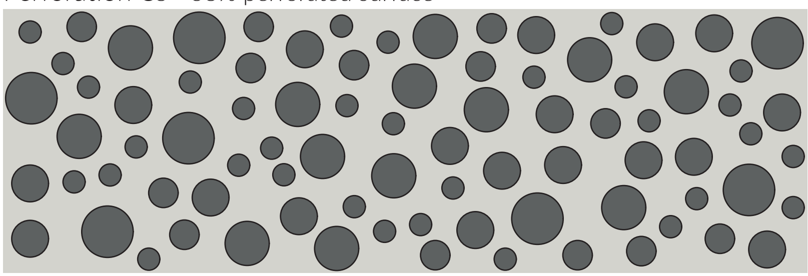
Industrial wall

Technical drawing



Measurements in mm

Perforation CS - 38% perforated surface



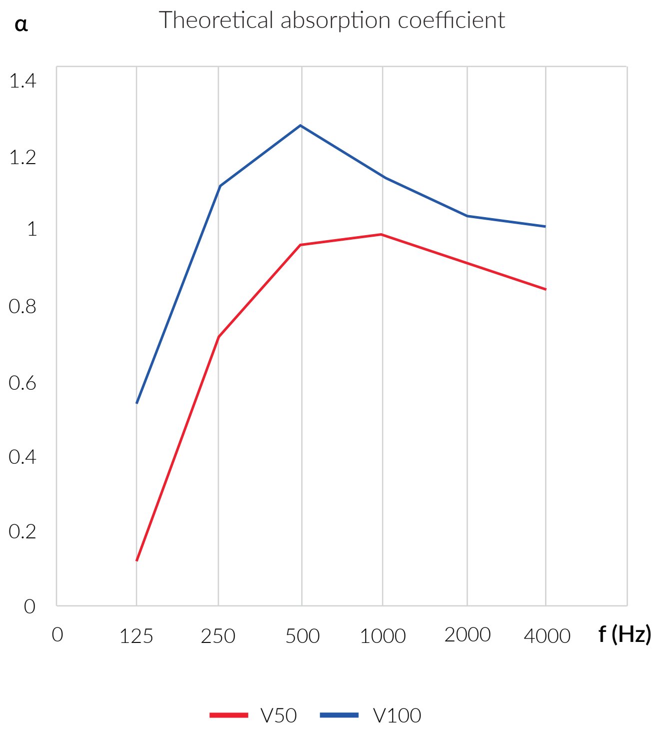
Reference measurements*:

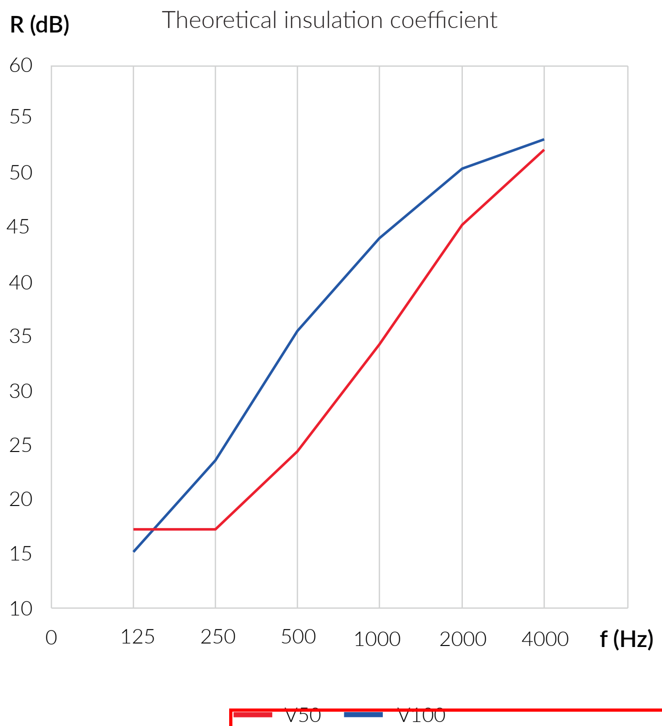
Width.	Length.	Thickness.
450 mm	any length up to 5700 mm	from 50 mm to 100 mm

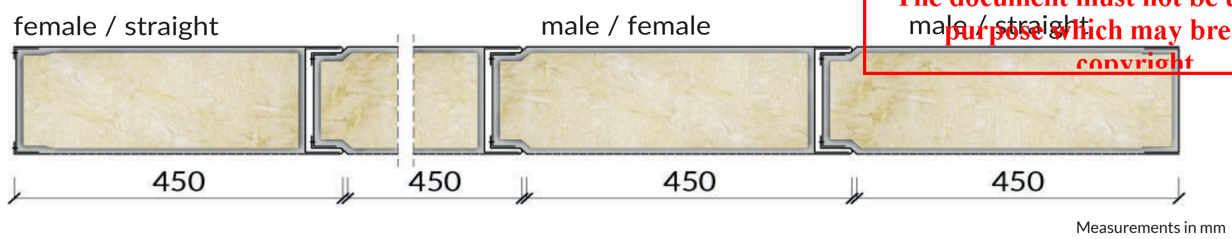
* Size can be customised to prevent cuts and adjustments.

ADVERTISED PLAN

Name	α	R_w (dB)	Internal steel sheet *(mm)*	External steel sheet *(mm)*	Insulated core	Thickness *(mm)*	Weight (kg/m²)	Transmitt. (W/m²K)
V50	1.0	31	0.5	0.7	mineral wool	50	15.6	0.70
V100	1.1	37	0.5	0.7	mineral wool	100	20.9	0.35







The Sonic System Acoustic Modular Panel has different types of joints: the traditional male/female and the two female/straight and male/straight joints. For specific projects, Flexshield can produce panels with customised dimensions to prevent subsequent cuts and adjustments.

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