



Fire Engineering Assessment (FEA)

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1 EXECUTIVE SUMMARY

NJM Design has been engaged by Akaysha Energy to undertake a fire hazard and risk assessment for the Wurdong Battery Energy Storage System (BESS) located at Wurdong Heights (89 Butcher Rd, Wurdong Heights QLD 4680) which will comprise Powin Battery systems. The proposed BESS has been designed to be 254MW/1,016MWh and has been assessed in this document, however it is expected to be up to 400MW/1,600MWh at a later stage.

The proposed BESS site is close the existing Wurdong Substation and a future 275KV HV substation.

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 units, and the community in which these units are situated. The fire hazards from/to the battery segment units have been indicatively modelled using Powin Battery systems but is subject to change once the equipment manufacturer is selected. It is out of the scope of this report to include consequences related to financial impact, environment, legal and regulatory, community and property protection.

In particular the scope of work is to:

- (a) Provide a risk review consistent with fire risk assessment techniques for Hazardous industry planning.
- (b) Quantify severity of fires including heat radiation level at various distances from BESS and transformer fires and durations of the fire.
- (c) Put the risks into context via comparison with other accepted risks such as those from existing power infrastructure and surrounding buildings in the community.
- (d) Recommend mitigation measures if required considering the above.
- (e) Risks to equipment such physical damage, dust-build up and faults to monitoring systems are not included in this report and should be managed by the project separately.

A review of the below standards and reports as they relate to fire safety has also been undertaken.

- (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) FM Global Data Sheet 5-33 Factory Mutual Insurance Company. (2017). FM Global Property Loss Prevention Data Sheets 5-33. Factory Mutual Insurance Company.
- (f) AS3000.
- (g) Building Code of Australia (BCA) 2019 Amendment 1.
- (h) Energy Safe Victoria (ESV) “Statement of Technical Findings - Fire at the Victorian Big Battery.
- (i) Superseded Planning Scheme Version 1, Chapter 8.2.3 Biodiversity. Gladstone Regional Council.

2 CONCLUSIONS

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

1. The design of the Powin 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 Very Low, given that the consequence is Minor and the likelihood is very low.
3. The proposed installation procedures and Units have design and requirements that address the issues raised by the Victorian Big Battery (VBB) fire (refer to Appendix B).
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 or vegetation would not be predicted to occur, given that the distances from the subject site (i.e., 30m) surpass the clearances specified by the NCC, the Australian standards and the Planning Scheme of Gladstone Regional Council. This is confirmed by the fire spread analysis performed in Sections 8.2, 8.2.3, 8.2.4, 8.2.5 and 8.2.6.
6. Fire spread between Battery Storage Units is not expected if a Battery Storage Unit reaches flashover, however flashover is not expected to happen due to the fire safety measures and E-Stops (i.e., safety sensors), which will shut down the Battery Storage Unit to delay a possible battery-runaway failure and warn staff to perform the required maintenance before a battery catches on fire.

The fire safety measures available by the providers usually are the following:

- Heat detection.
- Gas detection.

If any of the above is triggered, the Stack 750E Battery Segment is designed to safely shutdown the stack in a fire event. Addressable fire safety equipment is employed in the design of FSS (Fire Safety System) to be able to easily locate and isolate stacks.

- Smoke detection.
- And the E-Stops (i.e., safety sensors) will include:
 - Hydrogen sensor (signals H₂ concentration reached set point).
 - Trouble (loss of AC power or low battery voltage).
 - Fire alarm (signals smoke and/or heat).
 - Fire supervisory (signals tampering, low air, and high air).
 - Door alarm (signals door is open).

E-Stops will shut down the Battery Storage Unit to delay a possible battery-runaway failure and warn staff to perform the required maintenance in accordance with the provider specifications and the emergency management plan before a battery catches fire.

“E-stops reset automatically when conditions return to operating range. Most PCSs also have an E-stop button on them. If an E-stop button is pushed, resetting often requires manually disengaging the E-stop button and remotely clearing the fault (ROC can support this)” [Stack750E Centipede – A modular battery energy storage platform product manual, November 2021, Revision 03].

If a Battery Storage Unit reaches flashover, the equipment is allowed to burn out and adjacent infrastructure is protected in accordance with the equipment supplier’s recommendations. Hence, fire brigade operations will be directed at providing protection to adjoining equipment.

Further to the safety measures above, Powin Battery units are also provided with a climate control and an Environment controller. *“This last is essentially a PLC (Programmable Logic Controller). The PLC orchestrates the HVAC system, the Fire Suppression System (FSS), the Off-Gas Alarm System and any door/intrusion alarms. The controller monitors the system and reports all conditions upstream to the environmental controller in the Collection Segment” [Stack750E Centipede – A modular battery energy storage platform product manual, November 2021, Revision 03].*

A. Active ventilation – should gases be detected in a Stack750E Battery Segment, the HVAC ceases to operate and eight (8) booster fans are activated to vent out the gases and keep it within the safety limits within the battery compartment. These booster fans are backed by UPS for redundancy if auxiliary power to the fans fail.

b. Passive ventilation – if auxiliary power and UPS fails during an active gassing event, the vents are shut open by means of a fail-open actuator. These gasses can still be vented out through natural buoyancy.

7. Given the subject site layout, fire spread from a Battery Storage Unit row is not expected to adjoining transformers or adjacent Battery Storage Unit rows.
8. Given a catastrophic failure of any of the assessed equipment (i.e., Step-up transformers (SUT) and Battery storage unit), only the equipment of fire is expected to be lost and all surrounding equipment/buildings are expected to remain working, and fire spread to adjoining equipment/buildings/allotments is not expected. The BESS will continue working with alternate equipment.
9. Fire brigade intervention is considered not to be affected by a fire based on the preliminary fire modelling results presented within this report.
10. If one of the site entrances were to be obstructed by a fire, it is expected the fire brigade will be able to access through the any alternative entrance on the west or east side of the development.
11. Any other potential building such as a control room is not expected to present a significant fire risk or higher hazard than other small buildings in the community that do not require particular fire safety provisions. However further assessment might be required.
12. The adjoining allotments are “Base parcels” with vegetation (i.e., forest) and therefore the risk of fire spread due to a bushfire is increased, however, given that the closest adjoining lot is 30m away, the analysis demonstrated that that the fire spread to the site is not likely to occur. Nonetheless, non-combustible materials and toughened glazing are proposed to be installed on buildings within the subject site.
13. If the equipment were 2m to 10m closer to the vegetation areas (i.e., located to 20m to 28m from the vegetation areas), the Bushfire Attack Level would increase to of BAL-19, where equipment would be exposed to a radiant heat flux of 19kW/m², which is lower than the critical heat flux to damage process equipment that is considered to be 37.5kW/m².

14. The Powin Energy segments are not expected to be affected by flying embers given the provision of ingress protection IP56/NEMA 4, which means a complete protection from dust and protection from low pressure jets of water from all directions.
15. The BESS layout, streams location, clearances and equipment location of the proposed BESS comply with the Performance Outcomes of the Planning Scheme of Gladstone Regional Council. Fire spread is not expected to occur to streams orders 1, 2 with a clearance of 10m, and to stream orders 3 with a clearance of 25m (refer to section 8.2.6). In accordance with the assessments performed in Section 8.2, SUT transformers and battery storage units might cause fire spread to vegetation within 5m from themselves.
16. It is considered that the design and layout of the BESS will provide an acceptable level of fire safety to personnel, fire brigade and adjacent properties.

3 PROPOSED FIRE ENGINEERING REQUIREMENTS

As part of the risk assessment, the following recommendations are to be implemented to satisfy the objectives of the relevant authorities and the client.

Refer to Appendix A for overall floor plans indicating the main Fire Engineering Requirements.

1. A road not less 4m wide able to support at least 15 tonnes must be designed around and between all the battery arrays, buildings and equipment blocks to facilitate fire brigade intervention procedures. The 9.6m wide road around all the BESS units is considered compliant (Refer to Appendix A and Figure 1 below).

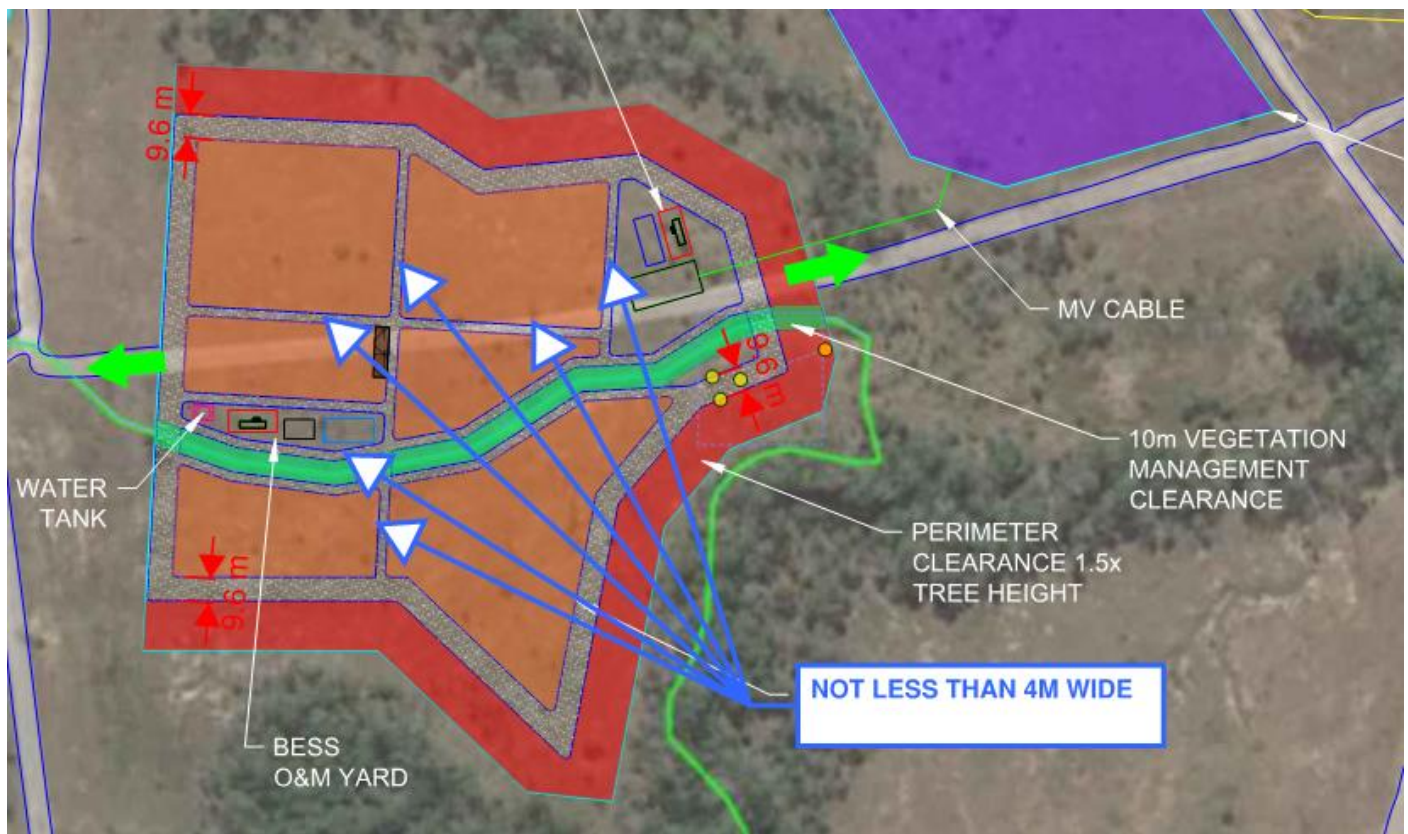


Figure 1: Roads within the allotment.

2. A not less than 28m perimeter clearance must be provided between the arrays of battery segments and the adjoining boundary to the north, south and east sides (this is compliant with the current design shown in Appendix A that shows a 30m clearance from the vegetation).
3. In compliance with the Performance Outcomes (PO18) of the Planning Scheme of Gladstone Regional Council:
 - (a) Stream Order 1 is permitted to have a setback not less than 10m to both sides of the stream.
 - (b) Stream Orders 2 & 3 are permitted to have a setback of not less than 25m.
4. Develop a Fire Management Plan (the CFA Guidelines for renewable Energy Facilities may be used as a guideline to develop the plan).

5. An additional 20m long bay (and 6m wide) within the site must be provided to facilitate the fire intervention procedures within the allotment at the battery array. Refer to Appendix A and Figure 2 below.

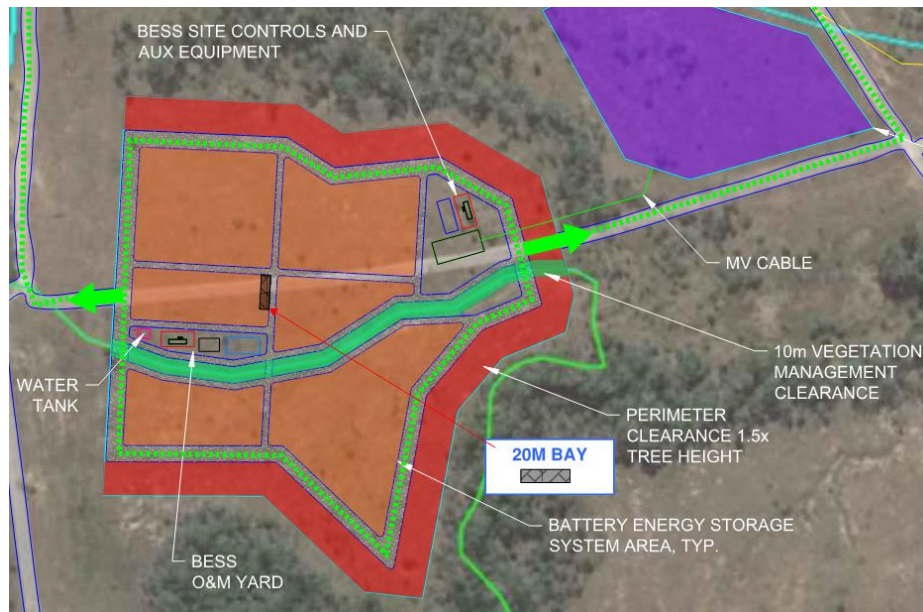


Figure 2: Additional bays within the allotment.

6. The buildings BESS Site controls, Auxiliary equipment, operation and maintenance are permitted to be located to not less than 28m from the boundary and comply with the NCC construction requirements for Type C construction, except that:
 - (c) All wall cladding and external materials must be of non-combustible products.
 - (d) External windows must be provided with 4mm Grade A safety glass in accordance with the requirements of AS3959-2018.
7. Step-up transformers (SUT) located in accordance with the proposed layout in Appendix A, must comply with the following:
 - (a) Have an oil capacity of not more than 3,800 litres (3.8 m³).
 - (b) Be provided with enhanced protection in accordance with AS2067.
 - (c) Where transformers are oil-insulated, transformers must use an FR3 (or similar) Ester oil in lieu of the normal mineral oil.
8. Energy segments units must be provided with at least a smoke detection system.
9. All buildings within the facility must comply with the performance requirements of the NCC where the DtS provisions are not satisfied.
10. Each vehicle and heavy equipment must carry at least a nine (9)-litre water stored-pressure fire extinguisher with a minimum rating of 3A, or other firefighting equipment as a minimum when on-site during the Fire Danger Period.

4 SCOPE

4.1 GENERAL

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

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 and equipment 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.

4.2 SOURCES OF INFORMATION

The development of the study was based on the following information:

- Akaysha Wurdong BESS 254MW/1,016 MWh, version 3, dated 10/08/2023, Sheet “Site plan” (refer to Appendix A).
- Review of other BESS fires and installations in particular the Victorian Big Battery fire and the ESV findings (refer to Appendix B).
- AS 3959-2009 Construction of buildings in bushfire-prone areas.
- Stack750E Centipede – A modular battery energy storage platform product manual, November 2021, Revision 03.
- Powin Large Scale Fire Test, Powin Energy, Rev. 0, 11/29/2021.
- Stack750 Installation Procedure, September 2022.
- ANSI/CAN/UL9540A Test method for evaluating thermal runaway fire propagation in Battery Energy storage Systems – Test Report Number SZE220100019801, dated 2022-02-23.

- Cell Test Report UL9540A – Test method for evaluating thermal runaway fire propagation in Battery Energy storage Systems (AACD)– dated 2021-04-30.

- A new methodology for State-wide mapping of bushfire prone areas in Queensland. CSIRO, 2014 [1].

No Queensland Fire Brigade Guidelines have been identified relating to Battery Energy storage systems (BESS). However, Queensland Government suggests considering the following guidelines:

- Best Practice Guide: Battery Storage Equipment – Electrical Safety Requirements (refer to Section 9.2).
- National Electrical and Communications Association (NECA).
- Master Electricians Australia.

4.3 PROJECT STAKEHOLDERS

The relevant stakeholders in accordance with NCC A2.2(4)I for the Wurdong BESS project are detailed in Table 1:

Table 1 – Design and Regulatory Stakeholders.

Role	Organisation
Client	Akaysha Energy
Architect	Power Switch LLC
Fire Safety Engineer	NJM Design (Vic) Pty Ltd.
Fire Brigade	Queensland Fire and Emergency Services (QFES)

4.4 OBJECTIVES

4.4.1 General

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 units, and the community in which these units are situated.

4.4.2 Legislative requirements

The primary objectives of the NCC, as summarised in the first edition of the International Fire Engineering Guidelines (IFEG) [2], are to protect:

- Life safety of occupants – the occupants must be able to leave the building (or remain in a safe refuge) without being subjected to hazardous or untenable conditions.
- Adjacent buildings – structures must not collapse onto adjacent property, and fire spread by radiation should not occur.

- Life safety of fire fighters – fire fighters must be given a reasonable time to rescue any remaining occupants before hazardous conditions or building collapse occurs.

4.4.3 Client objectives

It is understood that the client's objectives are to comply with the requirements of the NCC.

The fire safety objectives are met if the relevant legislation and regulations are complied with as stated in Clause A2.0 of the NCC, 'Compliance with the NCC is achieved by satisfying the Performance Requirements.'

The NCC Performance Requirements are intended to meet the objectives and functional statements of the NCC, being:

- Life safety of occupants – the occupants must be able to egress the building, or remain in a safe location, without being exposed to untenable conditions.
- Allow for Fire Brigade Intervention – provisions should be made to allow the Fire Brigade to undertake firefighting operations before the onset of untenable and hazardous conditions, as defined in the Fire Brigade Intervention Model (FBIM) [3].
- Protection of neighbouring buildings – structures should not collapse onto adjacent property or spread fire due to flame extensions or radiation.

5 RISK ASSESSMENT METHODOLOGY

5.1 INTRODUCTION

This Fire Hazard and Risk 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 3.

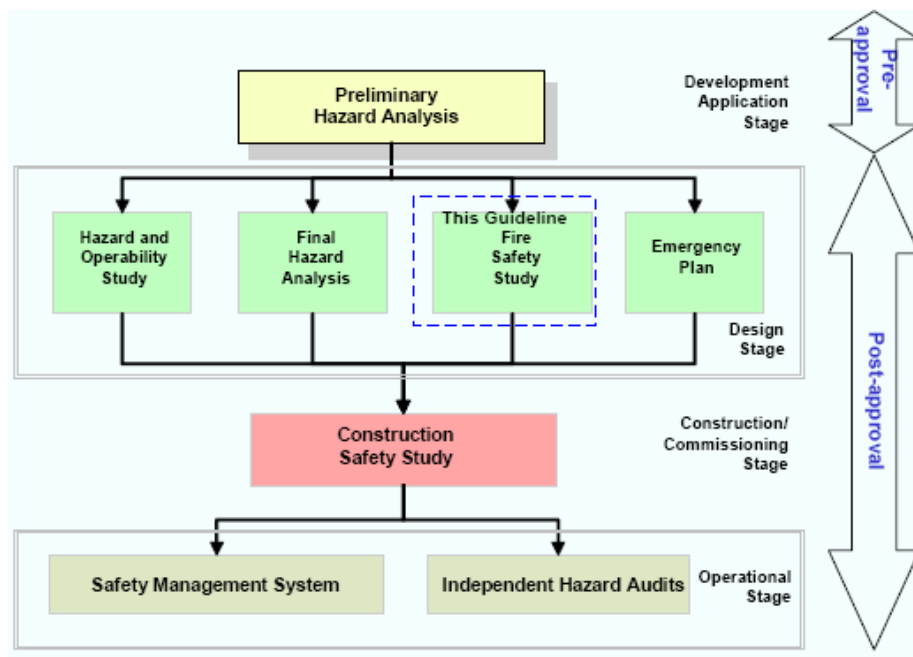


Figure 3: The Hazards-Related Assessment Process

Several 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. –0 – 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 involved.

5.2 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 2).

Table 2: 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 [4]:

Table 3: Example likelihood of occurrence rating

Likelihood rating	Definition of likelihood of occurrence rating
Almost certain	Probably of occurrence: greater than 90%.
	Expected to occur whenever system is accessed or operated.
	The event is expected to occur in most circumstances.
Likely	Probably of occurrence: 60% - 89%.
	Expected to occur when system is accessed or operated under typical circumstances.
	There is a strong possibility the event occurs.
Possible	Probably of occurrence: 40% - 59%.
	Expected to occur in unusual instances when the system is accessed or operated.
	The event may occur at some time.
Unlikely	Probably of occurrence: 20% - 39%.
	Expected to occur in unusual instances 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	Probably 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,

5.3 CONSEQUENCE RATING

The following table was used to rate the consequence of different risks occurring (Table 4). The consequence for each risk was considered in relation to its cumulative effect in the period under review.

Table 4: Typical risk consequence rating table (Table G–1 – Appendix G AS5139) [4]

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.	

Consequence/Impact category	Consequence / impact rating definitions				
	Catastrophic	Major	Moderate	Minor	Insignificant
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: <ul style="list-style-type: none"> - Contravention notices from authorities, or - Court order, or - Fine over \$1,000. 	Breach of legislation or regulations leading to: <ul style="list-style-type: none"> - Warning notice, or - Fine of up to \$1,000, or - Enforceable undertakings. 	Breach of legislation or 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 of repair at a cost of less than 2% of original cost of works.

5.4 RISK RATING AND TREATMENT

The likelihood and consequences of a risk occurring were used to determine the risk rating of either Extreme, High, Medium, Low and Very Low. The matrix below was used to provide a visual method of categorising risks based on their risk rating (Table 5).

Table 5: Risk matrix rating

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

Consequence (how serious)	Likelihood (how often)				
	Rare	Unlikely	Possible	Likely	Almost certain
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 6: Risk Treatments

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

5.5 FIRE SPREAD ACCEPTANCE CRITERIA

■ IEEE Std 979-2012:

Table B.3 of IEEE Std 979-2012 [5] gives some typical examples of the amount of radiant heat necessary to ignite common materials used in substations.

Table 7: TableB.3-Typical radiant heat flux intensities-based IEEE Std 979-2012 [5]

Impact of radiant heat flux	Heat flux (kW/m ²)
Sufficient to cause damage to process equipment	37.5
Equipment failure	35
Damage to unprotected metal	30
Spontaneous ignition of wood	25
Cable insulation degrades	20
Pilot ignition of wood	12.5

Impact of radiant heat flux	Heat flux (kW/m ²)
Plastic melts	12.5
Pain threshold reached after 8s. Second degree burns after 20s.	9.5
Possible failure of ceramic bushings	5
Skin burns	5

■ AS 1530.4-2014:

Where other façade/lining materials are present in adjoining building or equipment, Table A3 of AS 1530.4-2014 [6] contains a listing of heat flux required for radiant ignition for piloted and unpiloted ignition. The heat flux (q_{cr}) level for non-piloted ignition is taken as 25 kW/m². Refer to Table 8.

Table 8: Typical radiant heat flux intensities based on AS 1530.4-2014

Phenomena (Maximum for indefinite exposure for humans)	kW/m ²
Pain after 10s to 20s	4
Pain after 3 s	10
Piloted ignition of cotton fabric after a long time	13
Piloted ignition of timber after a long time	13
Non-piloted ignition of cotton fabric after a long time	25
Non-piloted ignition of timber after a long time	25
Non-piloted ignition of gaberdine fabric after a long time	27
Non-piloted ignition of back drill fabric after a long time	38
Non-piloted ignition of cotton fabric after 5s	42
Non-piloted ignition of timber in 20s	45
Non-piloted ignition of timber in 10s	55

The assessment methodology requires that a fire will not cause a received heat flux (q_r) in excess of the critical heat flux (q_{cr}) on the allotment boundary or equipment.

Acceptance will be demonstrated if $q_r < q_{cr}$.

■ Fire Brigade:

Acceptable levels of radiation for Firefighter operations shall be a maximum of 3.0 kW/m² at 2.0 m AFFL.

6 FACILITY AND OCCUPANT CHARACTERISTICS

6.1 FACILITY LAYOUT

6.1.1 General

Wurdong BESS facility is as presented in the plans in Appendix A. The power storage equipment of the facility is the following:

- Battery storage segments arrays.
- Collection segments.
- Inverters.
- Transformers.
- BESS Operation & Maintenance (O&M) yard.
- BESS Site controls and Auxiliar equipment.

There will be a 10m wide swale through the centre of the site to allow for stormwater management.

6.1.2 Dominant Occupant Characteristics

Based on the use of the subject site, the occupant characteristics and attributes have been identified as part of the performance process and are summarised in Table 9 below.

Table 9 – Dominant Occupant Attributes.

Attributes	Description
Staff	
State of awareness	Generally alert, awake and aware of their surroundings. It is considered that being a place of work the staff members will not be under the influence of drugs or alcohol.
Familiarity with the building	Due to being members of staff it is expected that they will generally be aware of the building configuration and exit routes.
Mental and physical aspects	Staff are generally not expected to have a mental or physical impairment.
Emergency training	It is not expected that the members of staff are trained in the operations of the firefighting systems. However, it is expected that the staff members will be aware of the actions required during an event requiring an evacuation.

6.1.3 Location and adjacent allotments

The Wurdong BESS is located at 89 Butcher Rd, Wurdong Heights QLD 4680, to the southwest of the existing Wurdong Substation, as shown below (Figure 4).

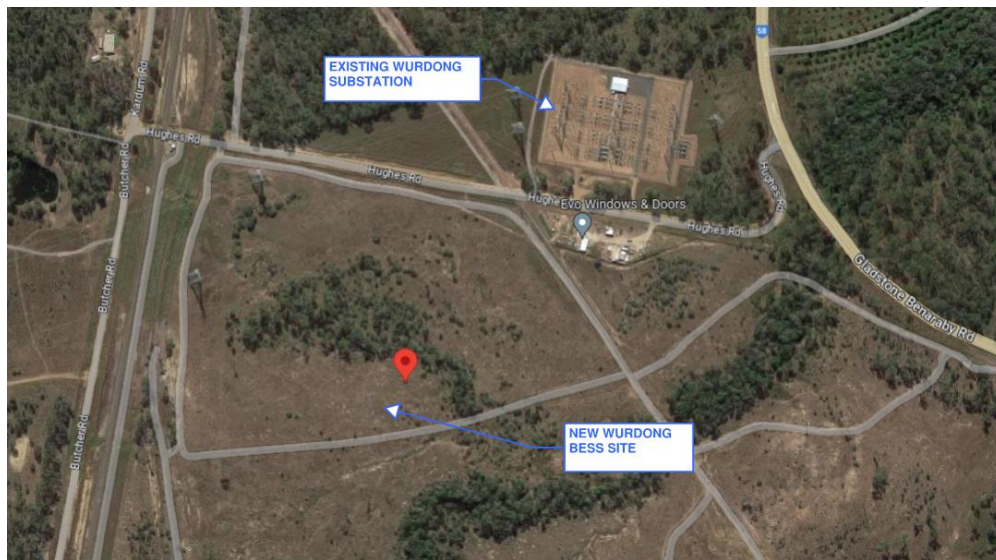


Figure 4: Site Location

The subject Wurdong BESS site is bounded to the north by Hughes Road, to the west by Butcher Road, to the east by another road and by vegetation on the south.

The new BESS will be located through an existing road so it will have access from the east and the west, and to facilitate the movement around the site bifurcation will be constructed to the north (Figure 5).

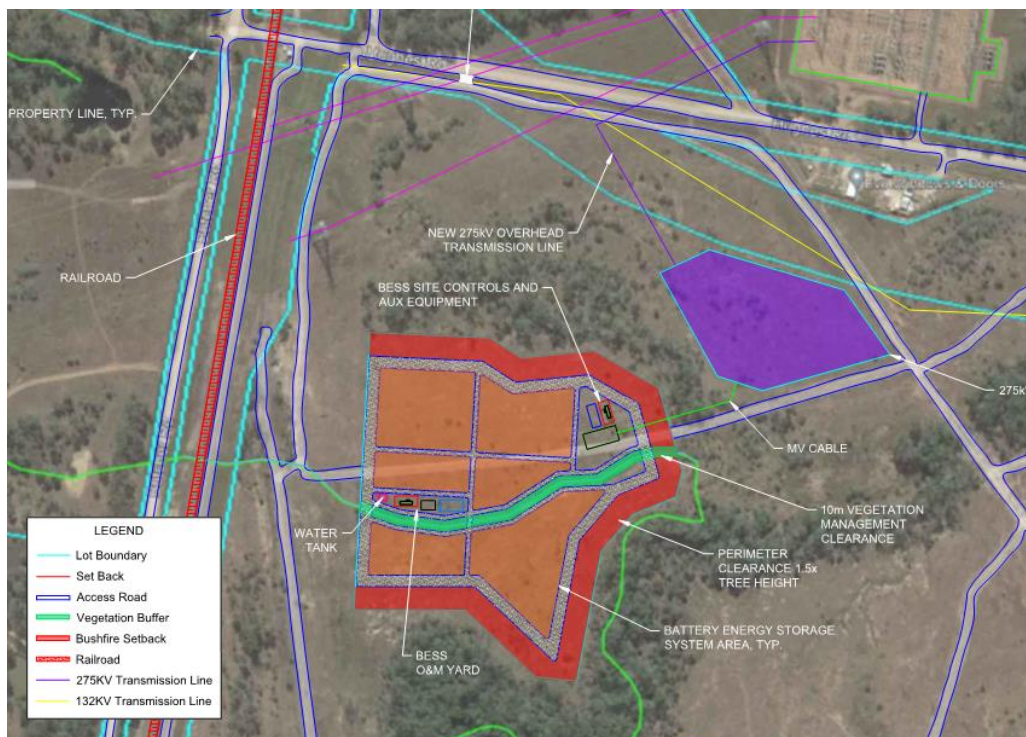


Figure 5: Access roads to the subject site.

The proposed site for the BESS also has varied streams. Streams are watercourses and drainage features shown on a vegetation management watercourse and drainage feature map.

The subject BESS has streams orders 1, 2 & 3. The meaning of each numerical ordering classification of each stream segment goes according to its position within a catchment. The existing streams and their numbers are shown in the figure below.

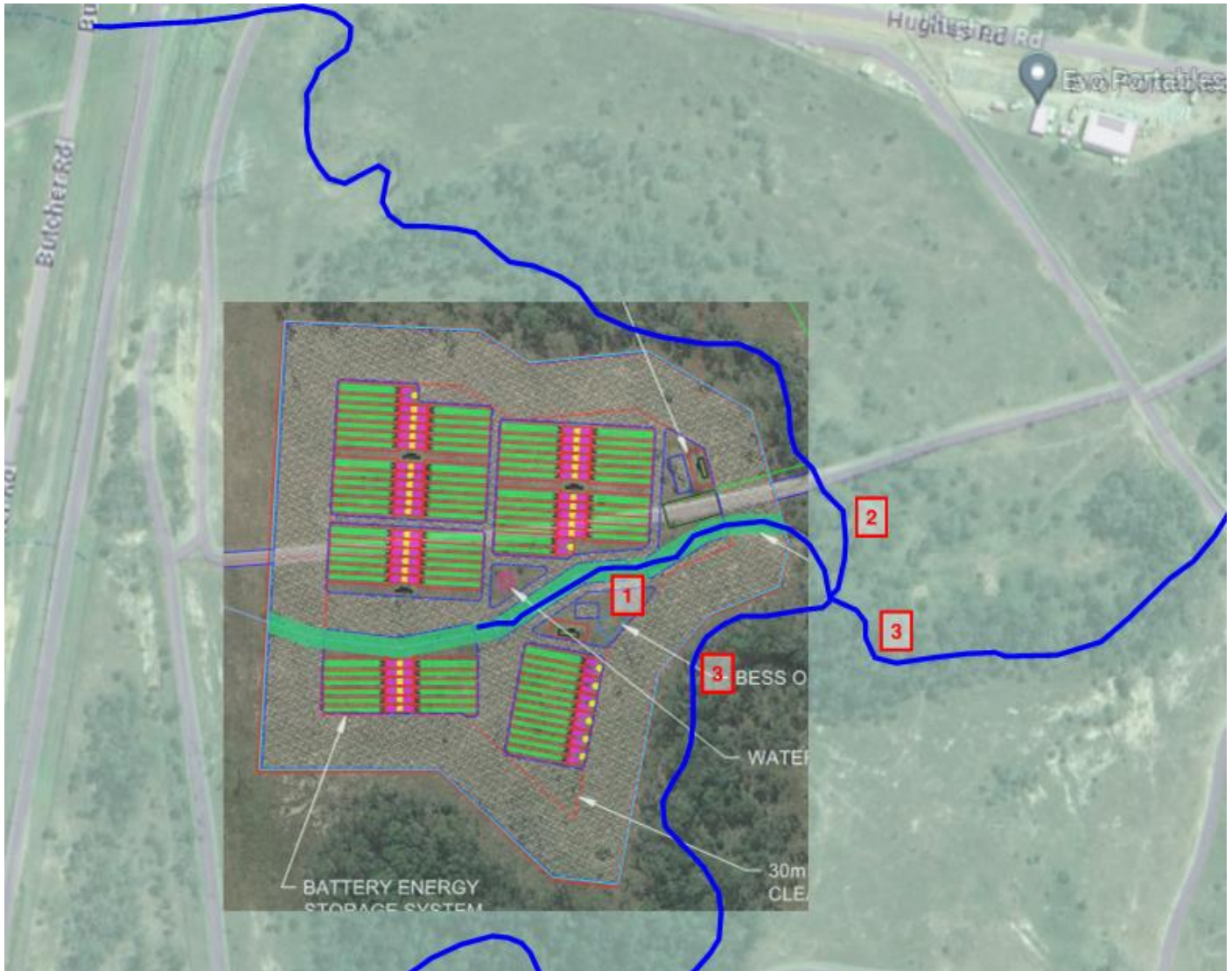


Figure 6: Water streams to subject site.

In accordance with the Gladstone Regional Council [7], the subject Wurdong BESS is “Base parcel” (i.e., land which will be used for a project that is not a roadway project, single-family residential project, sidewalk project, or trail project) and is surrounded by multiple “Base Parcels” (Figure 7 and Figure 8).

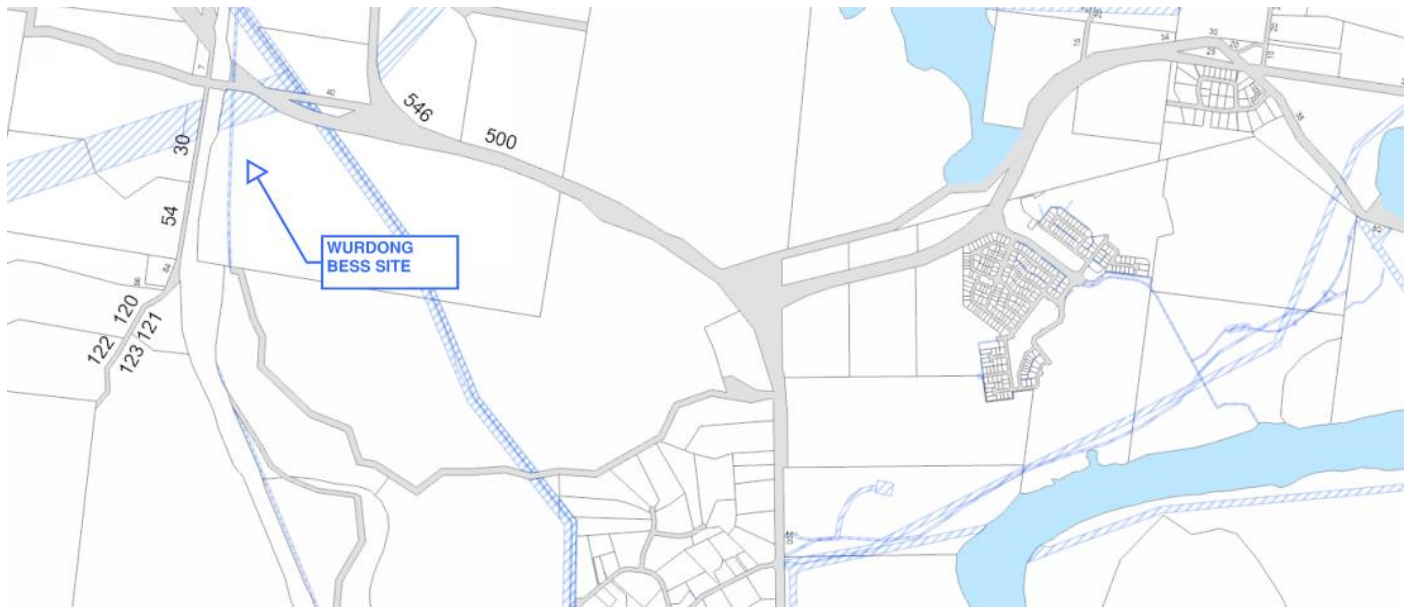


Figure 7: Land use map.



Figure 8: Specific subject site location.

Furthermore, the subject site is located in a “Potential Impact buffer” (Figure 9).

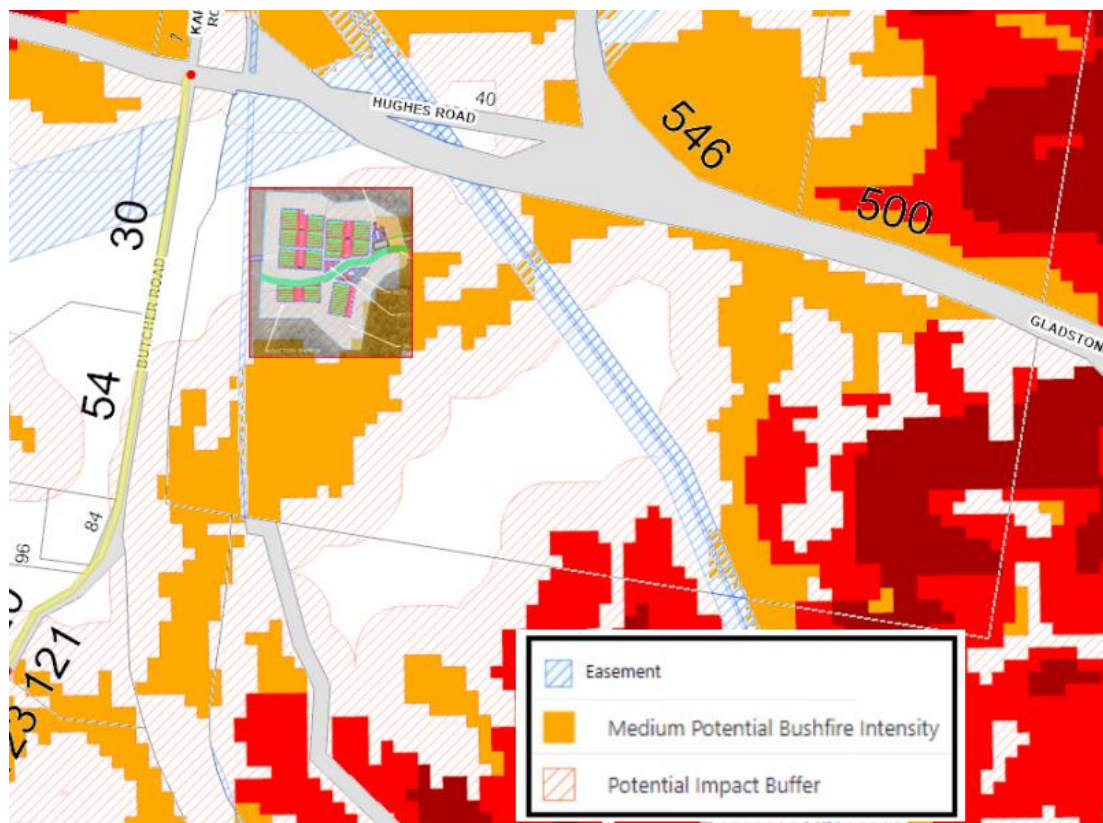


Figure 9: Bush fire hazard areas [7]

A “Potential Impact buffer” area is located to an area of Very high, High or Medium Potential Bushfire Intensity and hence may be subject to significant flame attack, radiant heat or ember attack (Figure 10) [1].

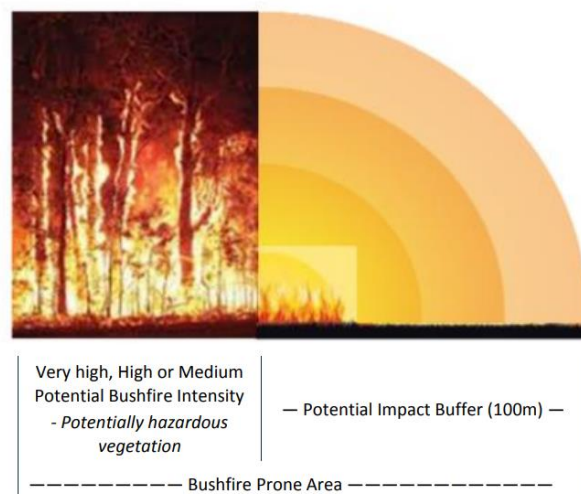


Figure 10: Potential impact buffer.

6.1.4 Wurdong weather conditions

In accordance with the available data, the average weather conditions on site are the following, based on the summary statistics from the Gladstone Airport Office Station:

- The maximum average temperature is 27.5°C and the highest temperature can reach up to 30.8°C.
- The mean relative humidity is 64%.
- The highest average speed of the wind is 21.1 km/h (5.9 m/s) towards east and northeast, and it remains calm less than 0.5% of the time (Figure 11).

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.

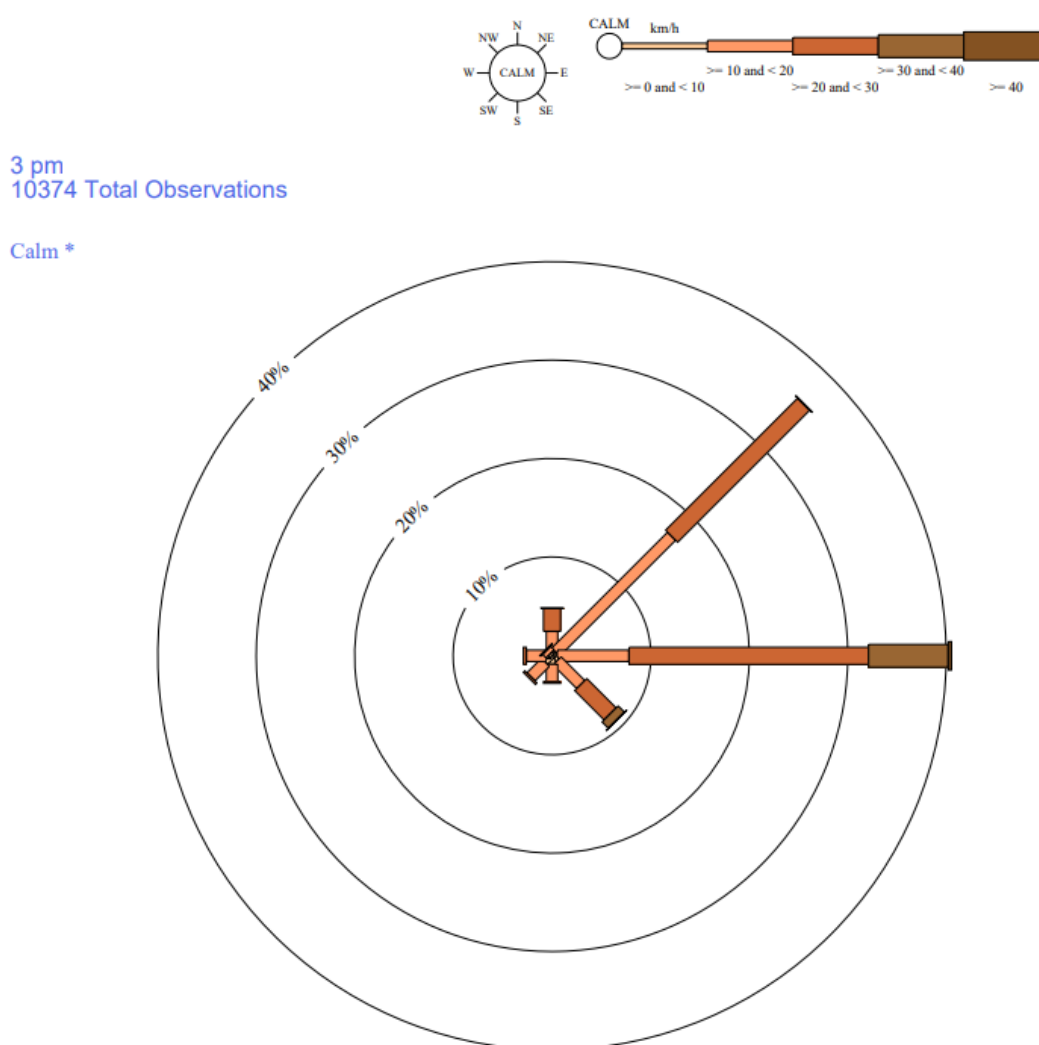


Figure 11 – Wurdong Heights wind statistics.

6.2 FIRE BRIGADE

6.2.1 Fire Brigade Objectives

The overall philosophy of the Fire Brigade objectives throughout Australia is to protect life, property and the environment from fire as noted in the FBIM [3] and Guideline 33 [8].

Firefighters must be given reasonable time to enter buildings to conduct occupant search and rescue activities and to carry out internal firefighting before exceeding conditions that are likely to threaten fire fighter safety and prior to building collapse.

Under reasonable circumstances, structures must not collapse onto adjoining property, and fire spread must be prevented. Also, fire spread within a building must be limited.

The Fire Brigade also has functions with regard to property protection and considerations regarding occupational health and safety for its employees. These issues are outside the building regulatory framework and NCC.

6.2.2 Fire Brigade Stations

The closest fire brigade station is the Boyne Island Fire Station located to 10.4km away (Figure 12) at 2 Gilbert Ct, Boyne Island QLD 4680.

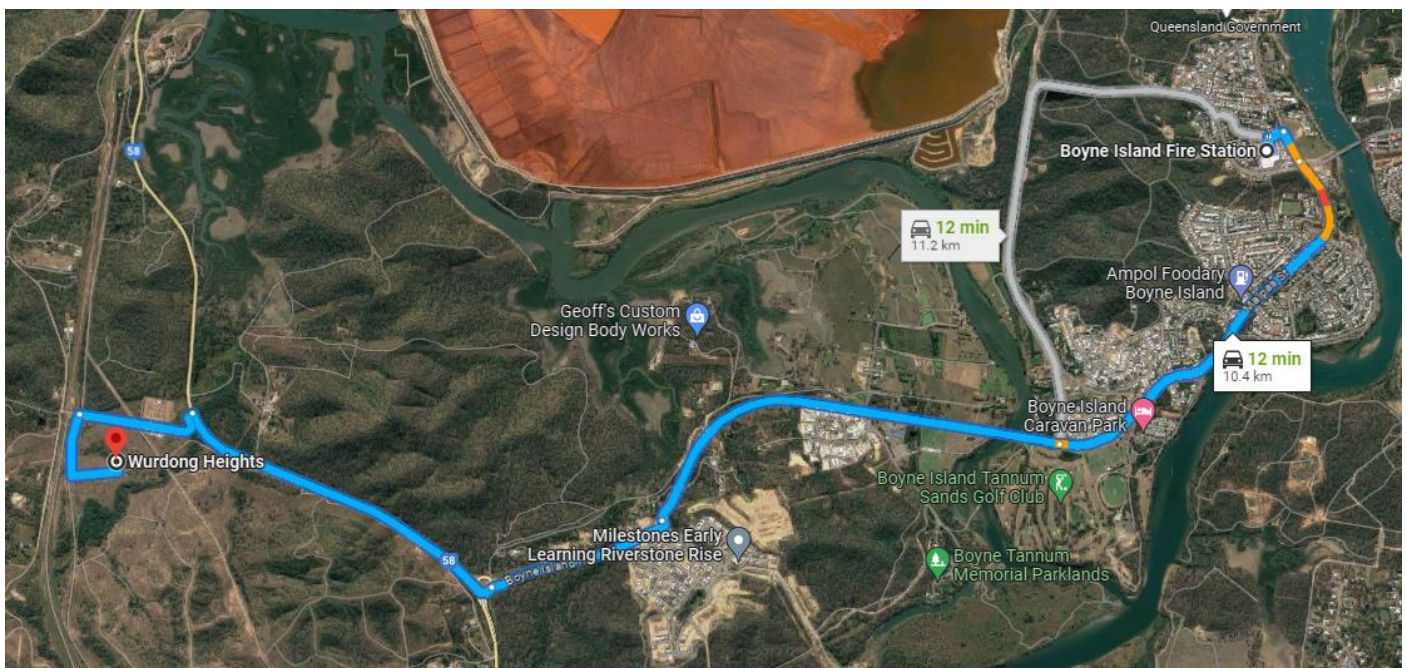


Figure 12: Boyne Island Fire Station to site.

6.2.3 Fire Brigade Access

The fire brigade will access the subject site from the north via Hughes Road, and then a bifurcation in the road will allow the fire brigade to reach the site either from the east or the west, as shown in Figure 13 below (also refer to Appendix A).

Two alternative access roads and bays are provided to facilitate the fire brigade intervention procedures, and the roads travel around and within the subject site to assure access to all site parts in case one of the access roads is obstructed.

The access roads are not less than 4m wide, which is adequate for access of the fire brigade.



Figure 13: Main site access.

7 FIRE HAZARDS

The subject Wurdong BESS will comprise a number of equipment components that have a risk of fire ignition, and hence a risk of fire and spread to the boundary or within the allotment equipment/buildings.

The main fire hazards are given by the following equipment:

- Battery storage segments arrays.
- Collection segments.
- Inverters.
- Transformers.
- BESS Operation & Maintenance (O&M) yard.
- BESS Site controls and Auxiliary equipment.

Furthermore, given the location of the development, the risk of a bushfire will also be addressed.

The following section will explain past events and findings regarding the above fire risks.

7.1 BATTERY HAZARDS

One of the main hazards associated with the use of lithium batteries for energy storage is overheating and thermal runaway 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 they are subject to overcharging, short circuit, extrusion, collision and exposed in fire, this can trigger thermal runaway 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.

7.2 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.

7.2.1 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 (refer to Appendix B).

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 lessons learnt from the fire were reported to be:

- Each cooling system is to be fully functional, 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 Wurdong BESS location would only occur approximately 36% of the time, i.e., a probability of 0.36.

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.

7.2.2 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.

7.2.3 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 range. 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.

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.

7.2.3.1 Research and Testing of Lithium-Ion Batteries and BESS

Full-scale testing of a large, containerized 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:

- FPRF/Exponent Hazard Assessment of Lithium-Ion Battery Energy Storage Systems.
- FAA Fire Hazards of Lithium-Ion Batteries – testing of pallet load of lithium-ion batteries in an aircraft cargo hold.
- DNV GL/Con-Edison Considerations for ESS Fire Safety.
- Powin Large Scale Fire Test, Powin Energy, Rev. 0, 11/29/2021.
- Fire Protection Engineering Analysis to Tesla BESS units. Fisher Engineering. Project reference 22035, dated 23/01/2023 [9].

7.2.3.1.1 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% SOC². 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:

- A fire in the Powerpack resulted in internal temperatures exceeding 1,093°C, and external temperatures reached 232°C.
- Flames were observed coming out of the exhaust vent and out of the BESS front door.
- Flames several feet high were observed from the exhaust vent of the Powerpack.
- Heat flux of approximately 25kW/m² measured 1.8m from front of BESS.
- All batteries and electronics of the BESS were damaged.

The internal ignition test gave the following results:

- A fire in the Powerpack resulted in internal temperatures exceeding 1,093°C.
- Temperatures at pods below the initiator pod showed temperature ranges between 26 and 82°C.
- External temperatures reached 21°C.
- Initiator pod was damaged, but other cells were not damaged.

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

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

The exponent conducted flame attack tests on single prismatic batteries and prismatic battery packs inside a cargo hold³. The result of this testing provides insight into battery behaviour under fire conditions as well as temperature profiles of the fire events.

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

- Frequent battery case rupture events were observed in the prismatic battery pack testing.
- 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.
- Testing of 4 cell li-ion battery packs produced ceiling temperatures between 400°C and 600°C.

7.2.3.1.3 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 18,650 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 BESS due to the number of batteries in a confined compartment.

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

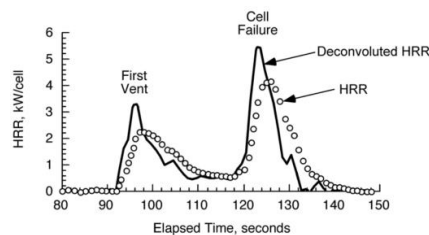


Figure 2. Lithium-ion cell failure at 70% SOC exposed to 50 kW/m² irradiance in fire calorimeter; points are data from standard method; solid line is data corrected for instrument response

Figure 14: Results of a single group of batteries.

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

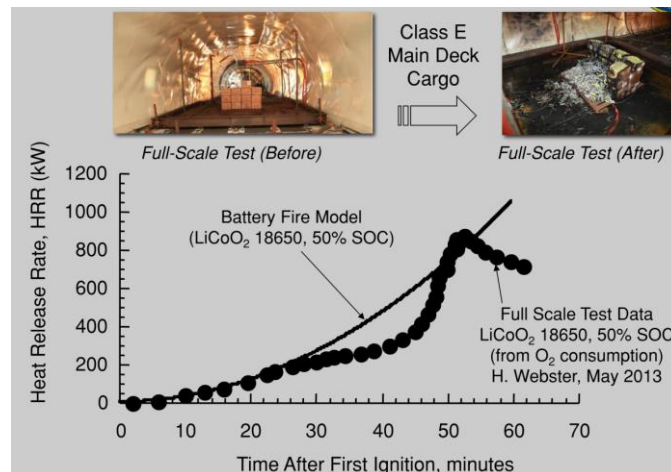


Figure 15: Results of full-scale tests on 18650 batteries.

The peak heat release rate is approximately 1MW.

7.2.3.2 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 Safety⁵. 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:

- Batteries are more volatile at higher states of charge (SOC).
- Mass loss rate is proportional to SOC. Average mass loss rate: 18% mass loss over 41.7 min.
- 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.
- The batteries themselves emit flammable gases.
- Recommended Ventilation Rate Correlation of 0.095 – 0.15 l/s/Wh.
- HRR produced variable results. The range was between 2.5 – 80 kW/kg, depending on volume of gases, duration of release, rate of ignition, and gaseous mixture.

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

- Partially burned systems can continuously emit flammable gases as long as the cells retain their heat – even if the fire has been extinguished.

7.2.3.3 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 700 kW/m^2 to 1050 kW/m^2 and an average of approximately $150 - 200\text{ kW/m}^2$.

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 ($7.5\text{ m} \times 1.6\text{ m} \times 2.5\text{ m}$) 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 4.5 MW to 6 MW .

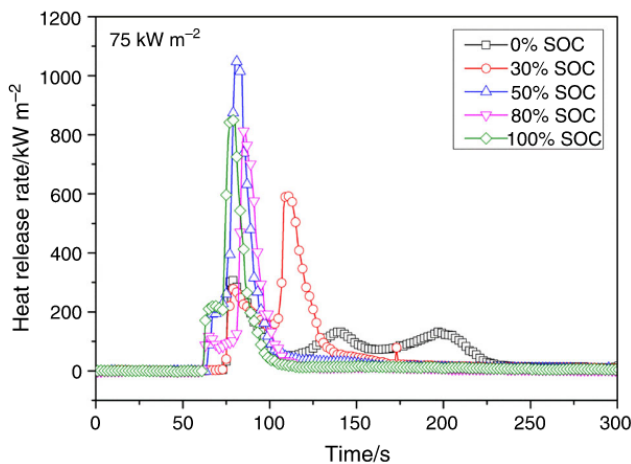


Fig. 7 Heat release rate of batteries at different SOC levels under an incident heat flux of 75 kW m^{-2}

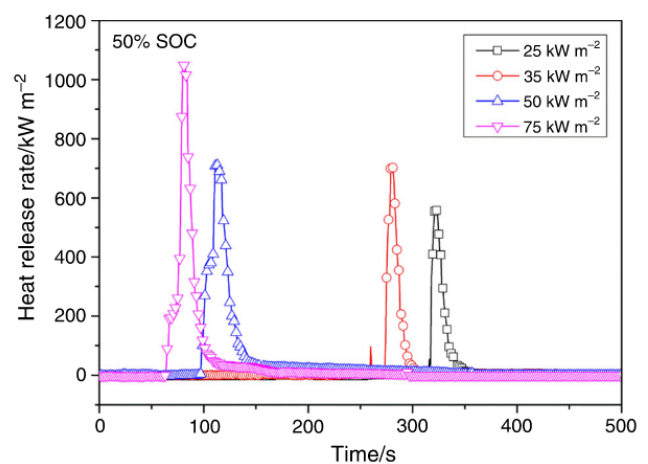


Fig. 8 Heat release rate of batteries with 50% SOC under different incident heat fluxes

Figure 16: Tested heat release rates for Lithium-ion batteries.

Based on the above review it is considered that each unit of the subject site will have an average heat release rate of approximately 6.2 MW , considering that each units' dimensions are $2.44\text{ m} \times 1.72\text{ m} \times 3.23\text{ m}$ (i.e., superficial area of 31 m^2) (see Appendix A) and an average of 200 kW/m^2 .

7.3 TRANSFORMERS

The following section details the likelihood of transformer fires from various sources:

- The last Australian CIGRE reliability report in 1995 came up with a failure rate for a failure causing a fire as 0.01% , i.e., $1 \times 10^{-4}/\text{yr}$. This was for transformers above 60 kV .

- A more recent survey (not a formal survey) covering 1800 transformer tanks from 6 utilities over 7 years calculated a risk of causing a fire as 0.09%, i.e., 9×10^{-4} /year (re CIGRE transformer Technology Conference 2008, presentation on Risk of Transformer fires by Arne Petersen).
- With regard to the Victorian transmission system for transformers 220 kV and above, there has only been one fire in 32 years giving a rate of 0.021%, 2.1×10^{-4} /yr.
- The New Zealand Ministry of Commerce, now known as the Ministry of Economic Development (MED), is a government department responsible for the government ownership of public properties. The number of distribution substations and the population in New Zealand are provided in their annual statistics reports. The statistical data on the number of distribution substations in New Zealand was obtained from the MED between 1946 and 1995. Since the statistical data after 1995 was not available, the number of distribution substations between 1995 and 2006 is estimated based on the growth rate measured in the previous 50 years. The NZFS FIRS database during the 6 years period from January 2000 to January 2006 indicated 24 fire incidents, 20 fire incidents were related to distribution substations and 4 fire incidents are related to power or terminal substation. The 4 fires related to power or terminal substations were indicated to originate in switchgear areas or transformer vaults as shown in Figure 17.

Therefore, the average rate of fire starts in a transformer is – 4×10^{-4} /year.

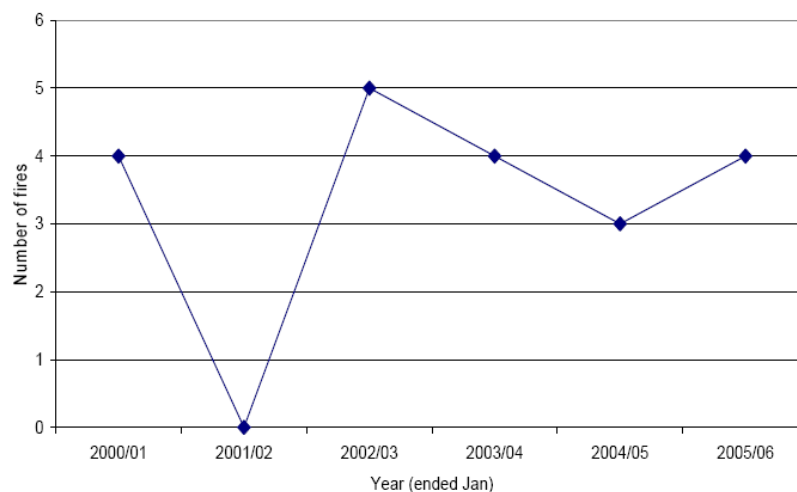


Figure 17: Number of distribution substation fires in 2000/06 (Source NZFS FIRS)

8 RISK ASSESSMENT

8.1 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 8×10^{-8} per year.

From May 2, 2020, to Jan. 22, 2021, 21 ESS 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.

Based on the statistics above and in the previous section, the likelihood of a fire is therefore considered to be *Rare*.

8.2 CONSEQUENCE

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

It will be demonstrated that given the fire separation to the adjacent buildings and equipment, fire spread is not predicted to occur at a greater level than for NCC compliant buildings within the community. (Note this is based on units similar to those in the VBB fire and further assessment will be performed once the final unit design is known).

Given the expected equipment within Wurdong BESS, the Step-up transformers (SUT) transformer could produce a fire of 12.33MW (Figure 20). It is considered that the presence of the BESS unit will not present a more significant fire to the community than already exists.

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:

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

Where:

- $\dot{m}''_{\infty}$: 0.039 kg/m²s
- $k\beta$: 0.7 (m⁻¹)
- D: diameter of the pool fire as a circle.

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.

A liquid fuel pool fire in the transformer will be modelled using the NIST Fire Dynamics Simulator model.

The National Institute of Standards and Technology (NIST) has been developing Fire Dynamics Simulator (FDS), to predict fire spread in a structure. Over the past few years, it has also been used to predict smoke and hot gas plume behaviour produced by outdoor fires. FDS is well documented and is widely used by fire protection engineers around the world. The model is being extended to include fire spread from structure to structure and generalizing FDS to include a means to predict fire spread in both continuous and discrete natural fuels.

The fire growth and spread were modelled using the National Institute of Standards and Technology (NIST) Fire Dynamics Simulator (FDS) software package and Smokeview which is used to view the results.

Fire Dynamics Simulator (FDS) is a computational fluid dynamics (CFD) model of fire-driven fluid flow. The software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires.

8.2.1 Step-up transformers (SUT)

Step-up transformers (SUT) are located between each row of energy segment unit. The transformers have a galvanised steel bund at the base of the skid.

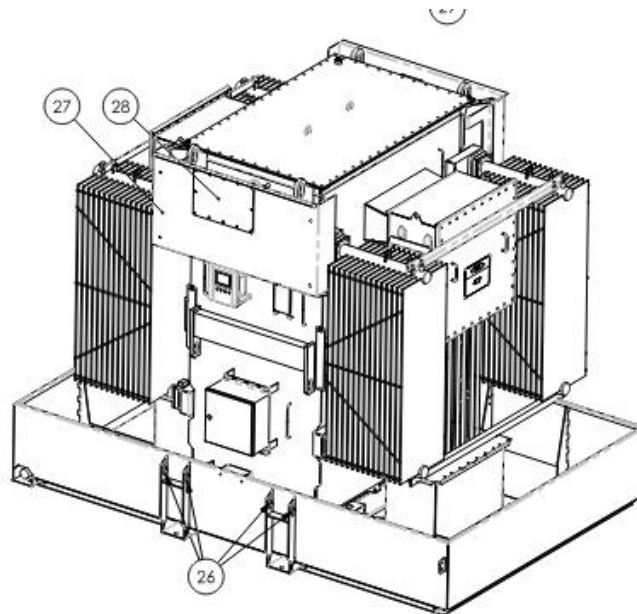


Figure 18: Transformer showing bund at the base.

The Step-up transformers (SUT) will use FR3 fluid oil, and their oil capacity is expected to be not more than 2,000 litres (2.0 m³).

Similar fire and smoke modelling (with and without wind conditions) of similar transformers with an oil volume of 4,000 Litres and a bund area of 12.5m² have shown a heat release rate of 10.12MW (Figure 19 and Figure 20). The model will have the environment conditions from Wurdong listed in section 6.1.4, and heat flux measurements at the distances where equipment/building/vegetation are located.

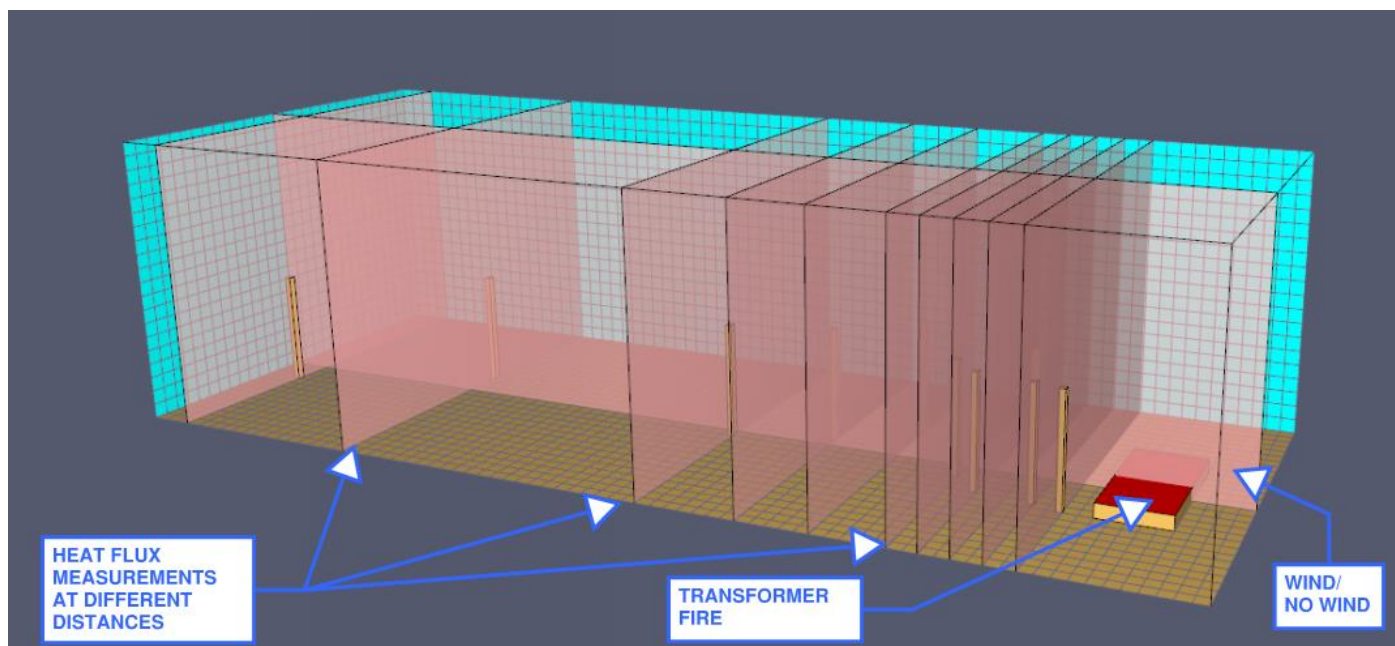


Figure 19: Preliminary fire and smoke modelling.

Volume oil	4000.00	L	
	4.00	m ³	
Bund			
Area TK & Radiator	0.00		
L	5.00	m	
W	2.50	m	
H	0.32	m	
Ideal mass loss	0.039	kg/sm ²	
kb	0.70	m ⁻¹	
X _s	0.70	Combustion efficiency	
X	18.09		Distance between centre of source and target
A	12.50	m ²	
V Bund	4.00	m ³	
D	3.99	m	
m"	0.037	kg/m ² .s	$\dot{m}'' = \dot{m}''_{\infty} (1 - e^{-k_b D})$ (Equation 3.6, Enclosure Fire Dynamics)
Hc	3.160E+07	J/kg	
q	809.83	kW/m ²	
Ballast Factor	1.00	-	Without ballast = 1, with ballast = 0.2.
Q	10.12	MW	$\dot{Q} = A_f \dot{m}'' \chi \Delta h_c$ (Equation 3.5, Enclosure Fire Dynamics)
Qc	7086.0	kW	
Density Oil	890.00	kg/m ³	
Mass Oil Theoretical	3560.00	kg	
Duration Theoretical	129.65	Minutes	
	2.16	hours	
Mass oil Bund	3560.00	kg	
Duration Bund	129.65	Minutes	
	2.16	hours	

Figure 20: HRR Calculation SUT transformers.

Table 10 below lists the distance of the equipment/building/vegetation to the SUT transformers (assuming a fire will occur to any of the transformers shown below):

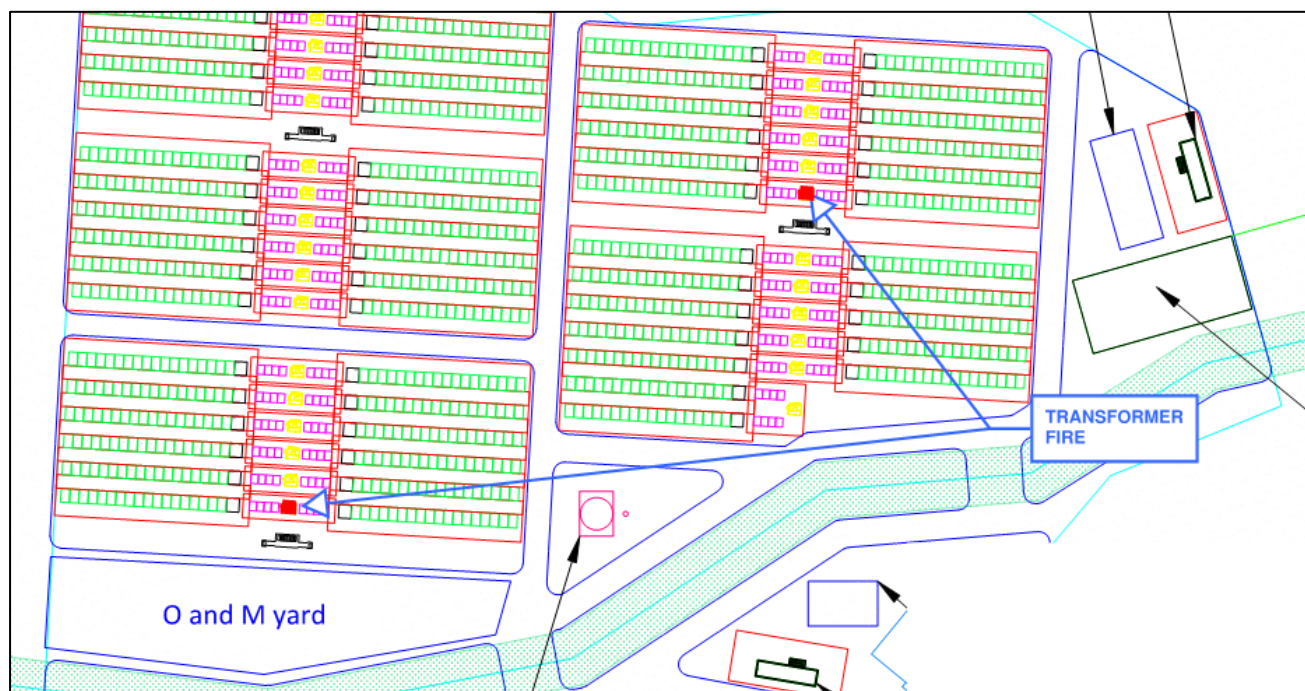


Figure 21: Transformer fire location.

Table 10: Distance between equipment

Equipment to assess	Adjoining equipment	Distance (m)*
Transformer	Transformer	2.8
	Inverter	1.0
	Collection segment	7.7
	Energy Segment Unit	10.0
	BESS Operation & Maintenance (O&M) yard	13.5
	BESS Site controls and Auxiliar equipment	25.0
	Forest vegetation	32.0

*The distances may vary according to the location of the transformer, given the proposed initial layout, the listed distances are considered to be the closest to a given equipment/vegetation/building.

Table 11 below summarizes the average heat flux received at different distances from a fire in the SUT transformers and to the equipment/vegetation/building in the facility.

Table 11: Heat flux results (Red is not acceptable)

Equipment	Distance (m)	Heat flux (kW/m ²)	
		No wind (Figure 22)	Wind 5.9m/s (Figure 23)*
Inverter	1.0	16.0	62.4
Transformer	2.0	14.1	62.4
Transformer	3.0	10.2	56.0
None	4.0	6.0	21.4
None	5.0	0.8	19.3
Collection segment	7.5	0.7	3.2
Energy Segment Unit	10.0	0.5	2.2
BESS Operation & Maintenance (O&M) yard	13.5	0.5	1.5
BESS Site controls and Auxiliar equipment	25.0	0.5	0.8
Forest vegetation	32.0	0.5	0.8

*It is assumed as a conservative measure that the equipment/building/vegetation is located in the direction of the wind, where the maximum heat flux will be received.

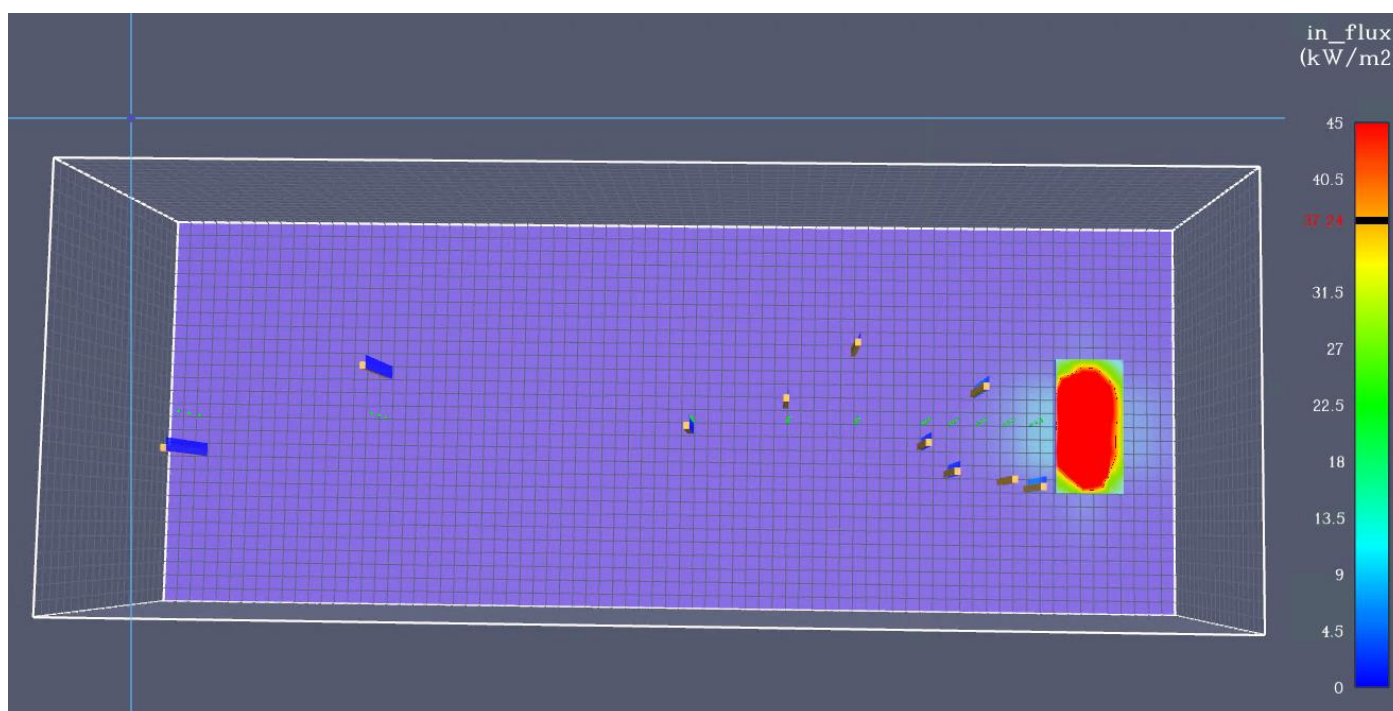


Figure 22: Radiant heat flux intensities without wind.

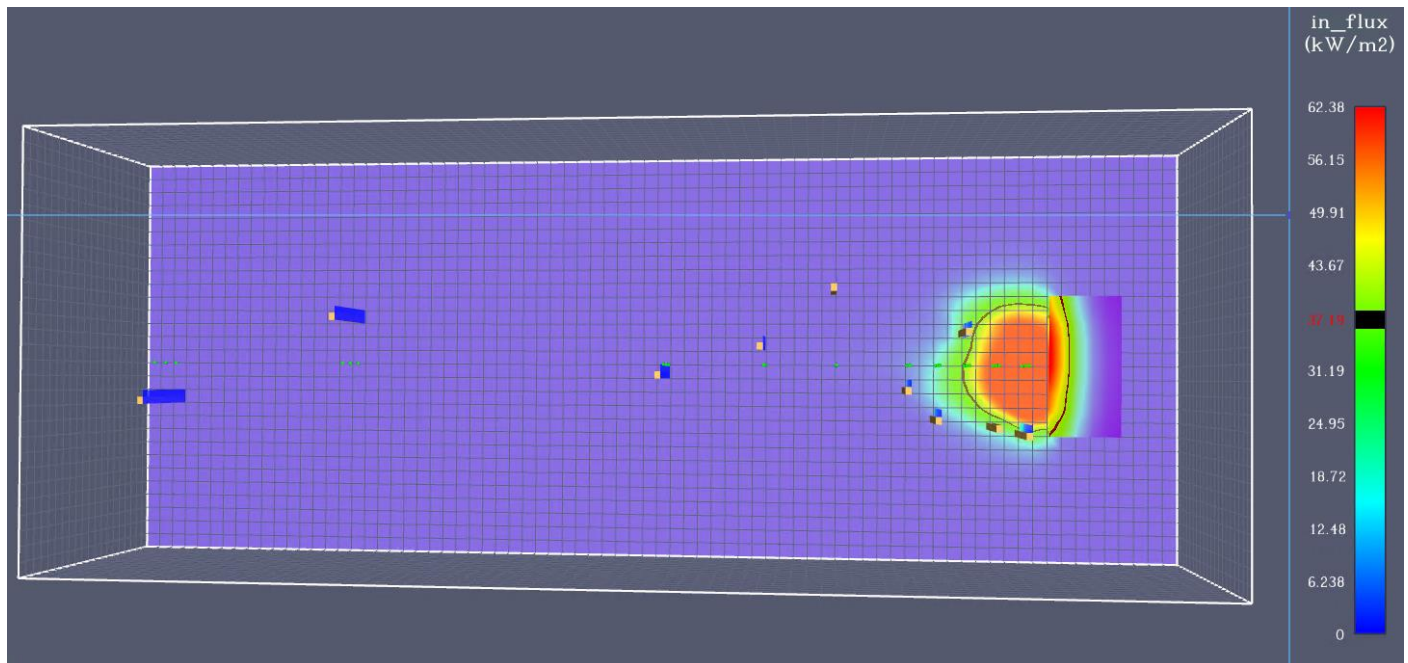


Figure 23: Radiant heat flux intensities with wind.

The results indicate that when wind is not present, the maximum heat flux levels received at further than 1.0m are lower than the critical heat flux to damage process equipment (i.e., 37.5kW/m²) (Figure 22). However, heat flux within 1.0m might damage process equipment.

When the wind is present, there is a risk of damage process equipment within 3.0m, given that heat flux levels are above the critical heat flux (i.e., 37.5kW/m²) to damage process equipment (Figure 23).

The vegetation will be unaffected in both fire scenarios, given that heat flux levels are well below the critical heat flux (i.e., 25.0kW/m²) for non-piloted ignition (Figure 22 and Figure 23). Vegetation would only be affected within a distance of 5m given the measured intensity of the radiant heat flux.

The above results consider the worst-case scenario where the transformer reaches flashover, however the transformer comes with protection that will advise staff about any issues that will mitigate the risk of fire. Furthermore, considering the above results where fire can damage process equipment within 3.0m:

- The buildings will have non-combustible façade materials and windows with bushfire shutter or toughened glazing to prevent fire spread in accordance with the requirements of AS-3959 (see section 8.2.5).

Also, the fire brigade operations may be impacted within a distance of 7.5m in the direction of the wind from the transformer due to a heat flux higher than 3.0 kW/m² (Figure 24) (the black/darker area has a heat flux of 3.0 kW/m² approximately).

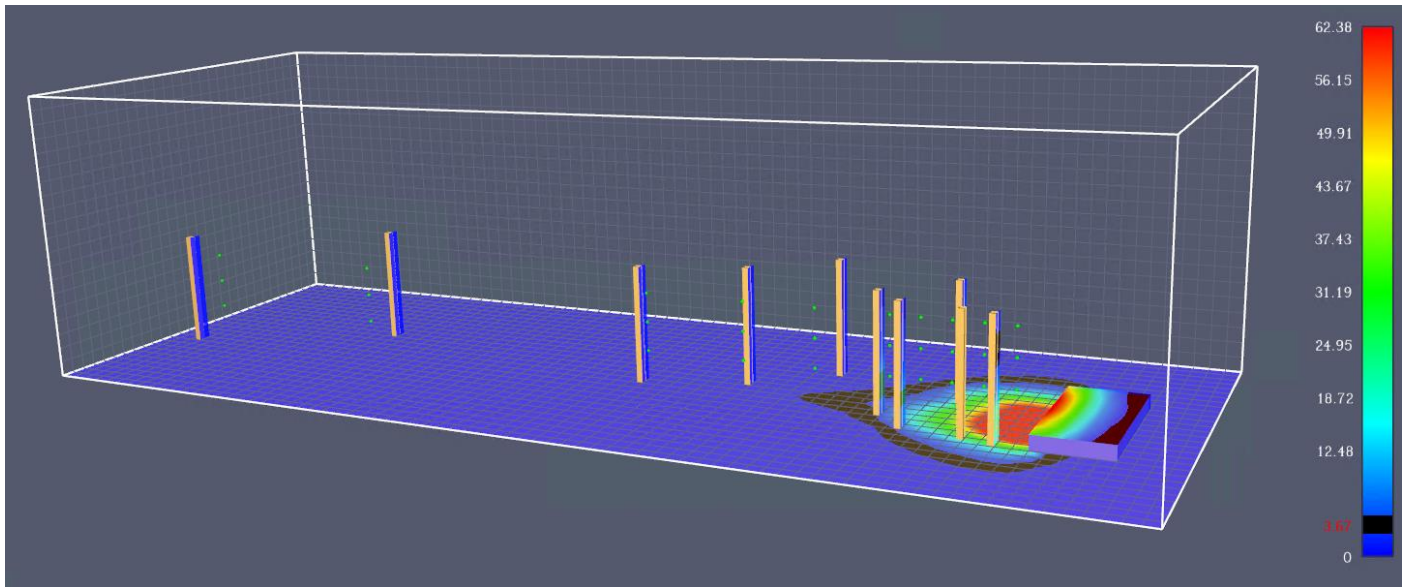


Figure 24: Radiant heat flux higher than 3kW/m^2 .

It is also noted that compared to a real fire scenario in the subject allotment, the presented results are conservative given the size of the fire. The expected heat flux in a real fire scenario will be lower than shown in the preliminary modelling at the different distances from the transformer.

8.2.2 Battery Storage Unit Fire

The proposed batteries to be used on site are a Powin Centipede-type design. The battery storage units consist of a modular design that contains batteries, thermal management equipment, air conditioning and essential safety systems.

As described in section 0, in accordance with Zhi Wang's report and the dimensions of the battery storage, if a storage unit is on fire, it will achieve an average heat release rate of approximately 6.2MW.

A flashover fire within a battery storage unit has been modelled in accordance with layout shown in Appendix A.

Each energy segment has varied compartments. The main 3 compartments for this assessment are the batteries stored within the lower compartment, HVAC (Heating, Ventilation, and Air Conditioning) units on top, and a ladder tray (Figure 25).

The HVAC units have an air intake grid at the top and an exhaust on the roof of the battery storage unit (Figure 25). Given a fire, the air ducts between compartments will allow fire and smoke to spread throughout the battery storage unit without restriction due to their buoyant nature. Other possible holes/connection between inner compartments will be assumed to be part of the air conditioning system for modelling purposes and are not modelled.

The model and the scenario described above, demonstrated the fire spread between battery storage units is not expected if flashover occurs:

- When flashover occurs, flames and smoke will vent mainly through the exhaust on top and the grid at the front top of the battery storage unit (Figure 26).

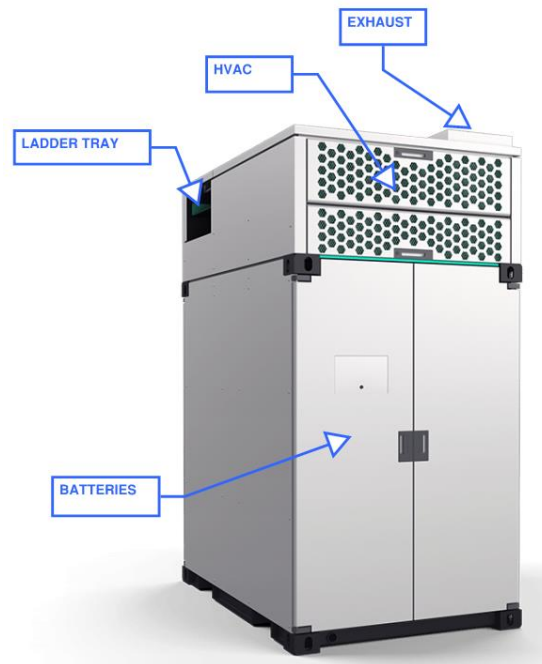


Figure 25: Battery storage unit.

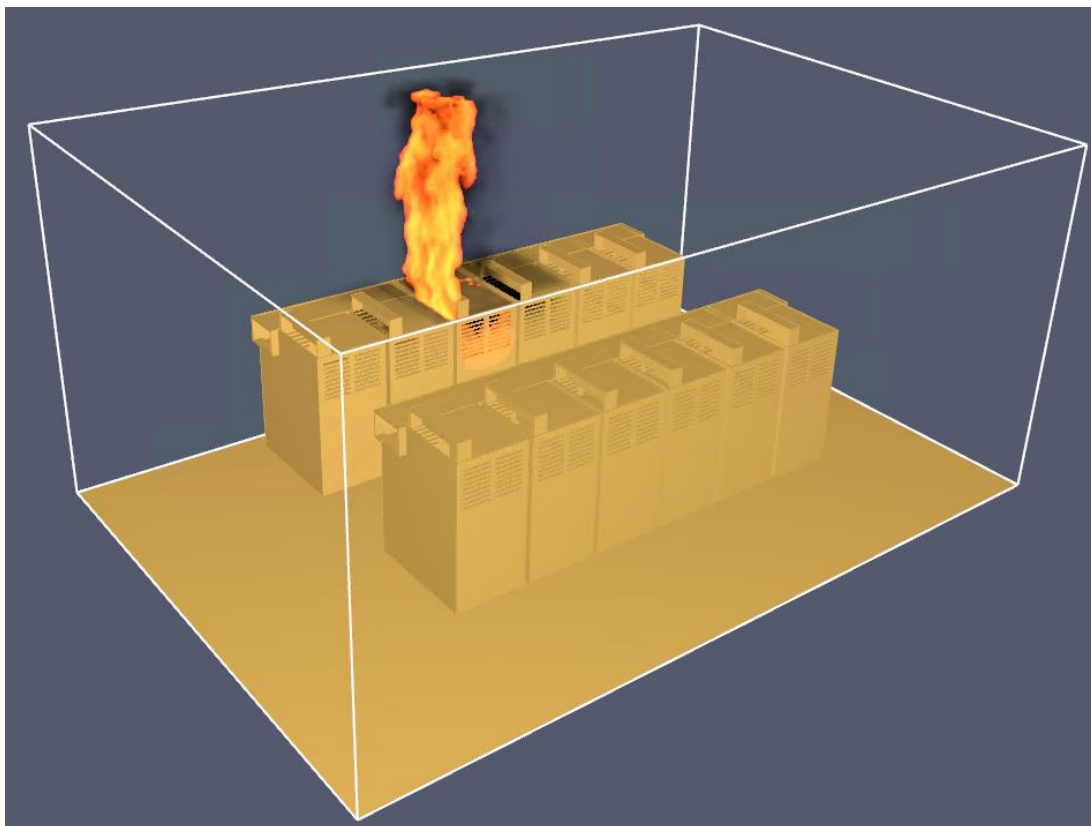


Figure 26: Flash over of Energy Segment Units.

- The heat flux level at the next row of battery storage units at 2.4m is below the threshold for non-piloted ignition (i.e., 25kW/m^2) and damaged to unprotected metal (i.e., 37.5kW/m^2) as permitted by the IEEE Std 979-2012 [5] (refer to section 5.5 and Figure 27). The heat fluxes at the adjoining energy segment units are below 5.5kW/m^2 with no-wind conditions and with wind, hence the wind does not increase the risk of damaging adjoining equipment, buildings or vegetation.

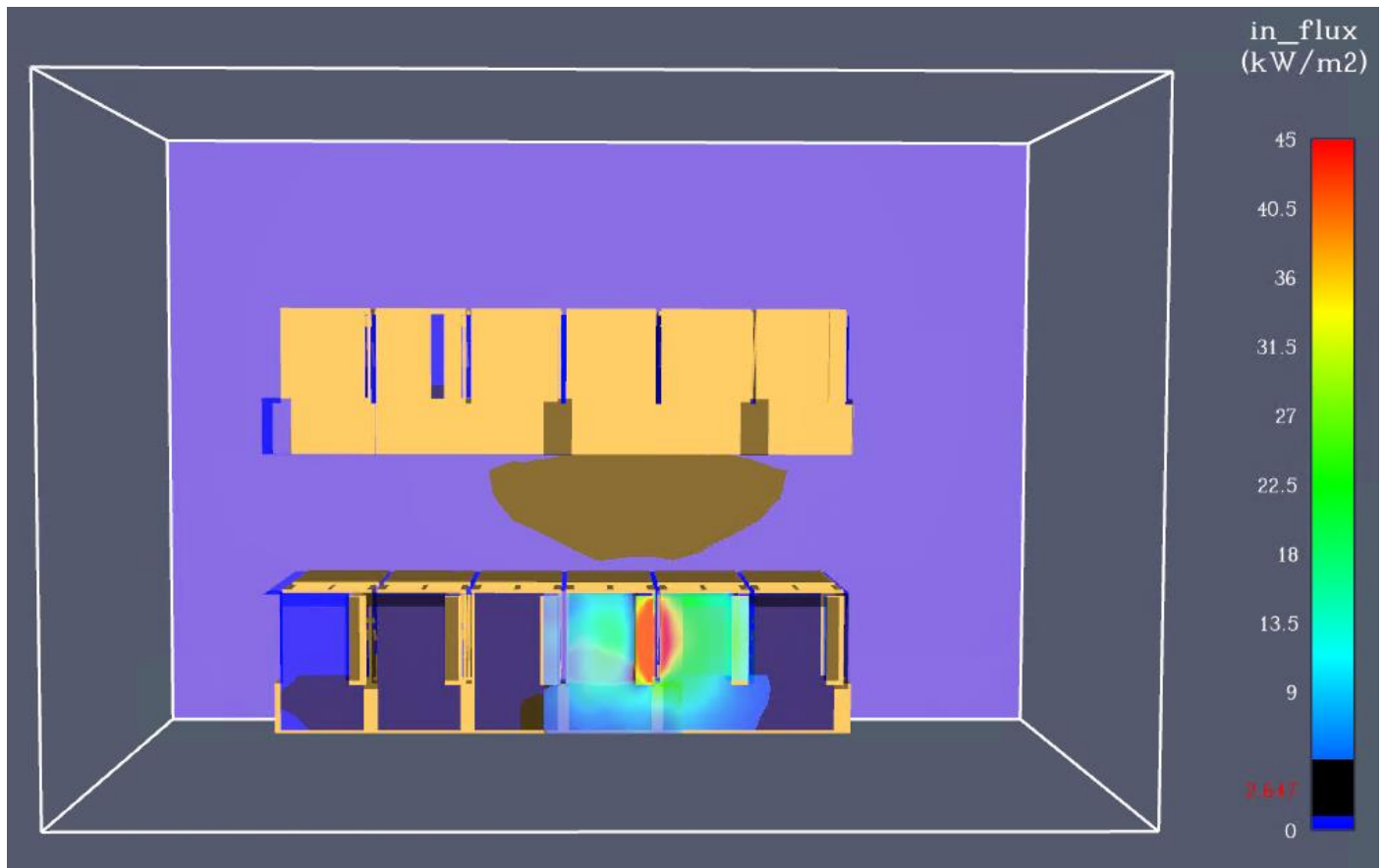


Figure 27: Heat flux to adjacent Energy Segment row without wind (2.4m apart).

- Although fire spread is not expected to adjoining segment units, some smoke spread between battery storage units is expected through the ladder tray area, as it has a ventilation grid connected to the area of the HVACs. The smoke spread is not expected to affect or stop the operation of the adjoining segment units given the buoyant effect of smoke, temperature of smoke, and the location of the smoke detectors, which are located at the lower battery compartment of the energy segment.

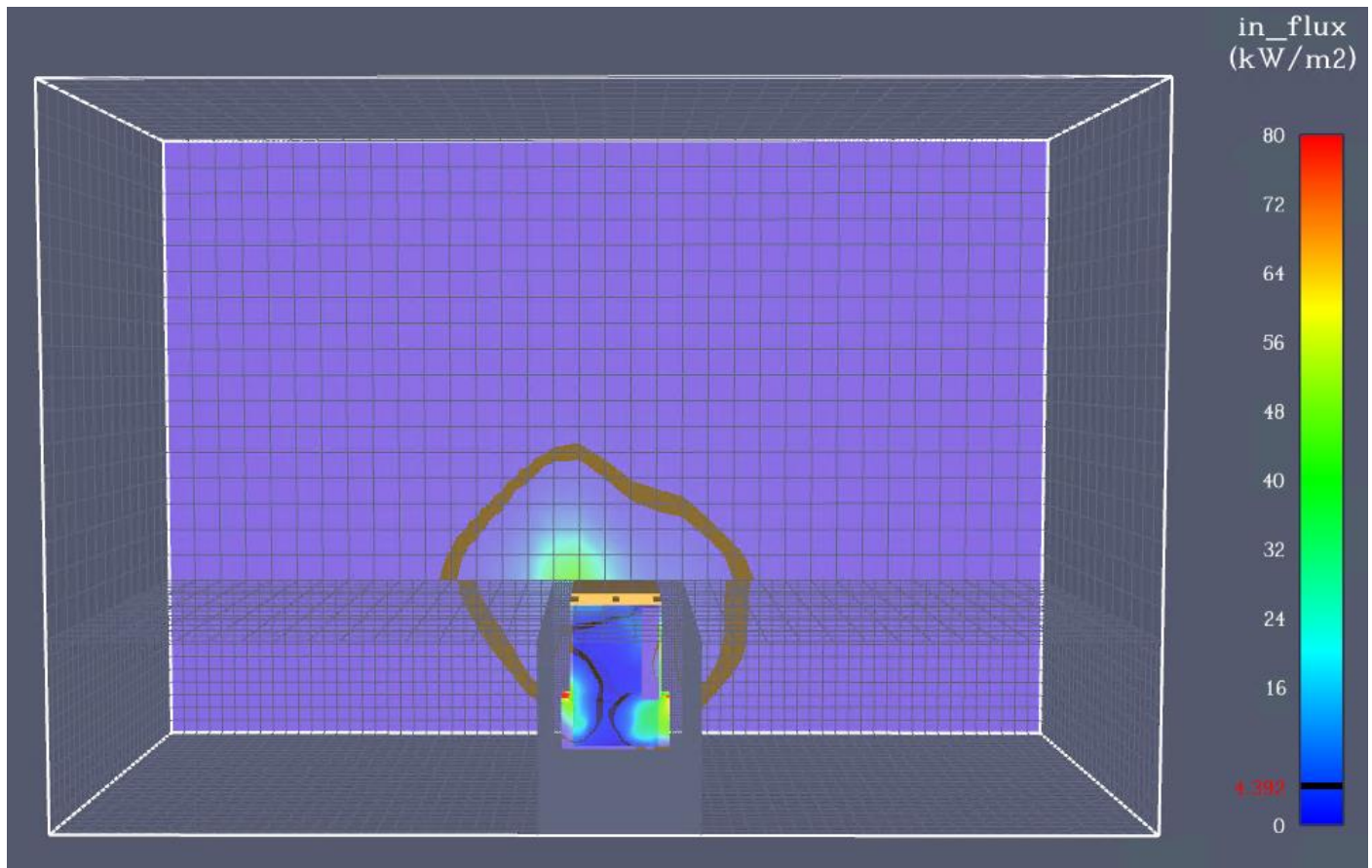


Figure 28: Heat flux to adjacent Energy Segment row with wind (2.4m apart).

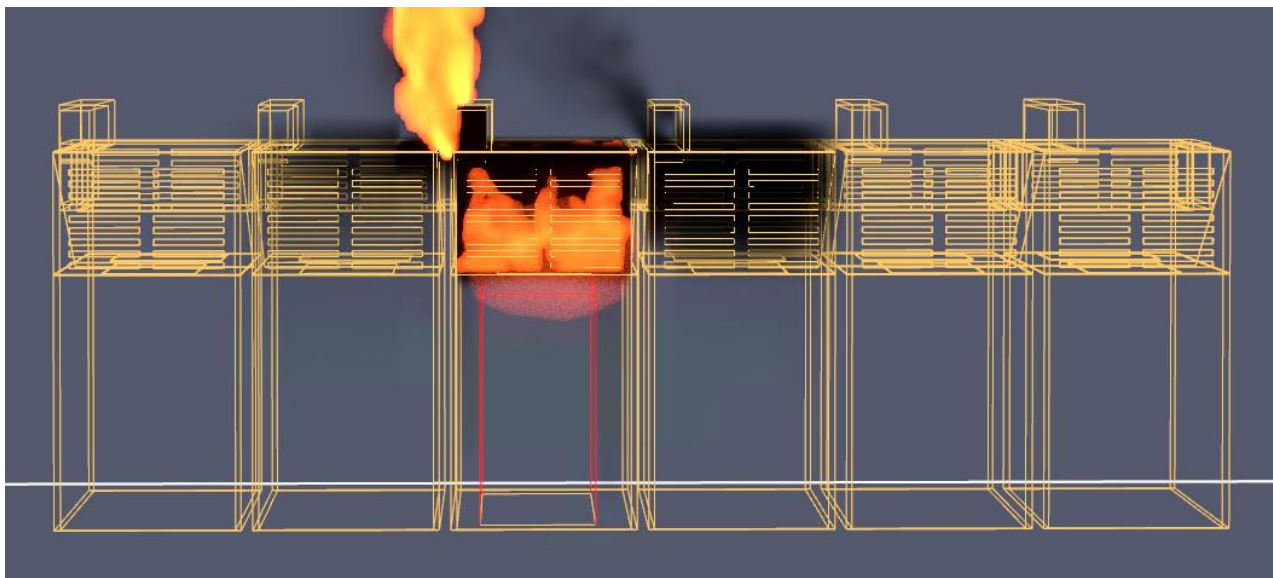


Figure 29: Smoke spread to adjoining Energy Segment units (elevation).

- Considering the smoke spread above, heat flux through the ladder tray area is also assessed with a threshold of 20kW/m^2 in accordance with of IEEE Std 979-2012 [5] (refer to section 5.5) due to the presence of cables. The model suggests that heat flux higher than 20kW/m^2 will happen intermittently in a small section of the adjoining energy segments through the cable tray.

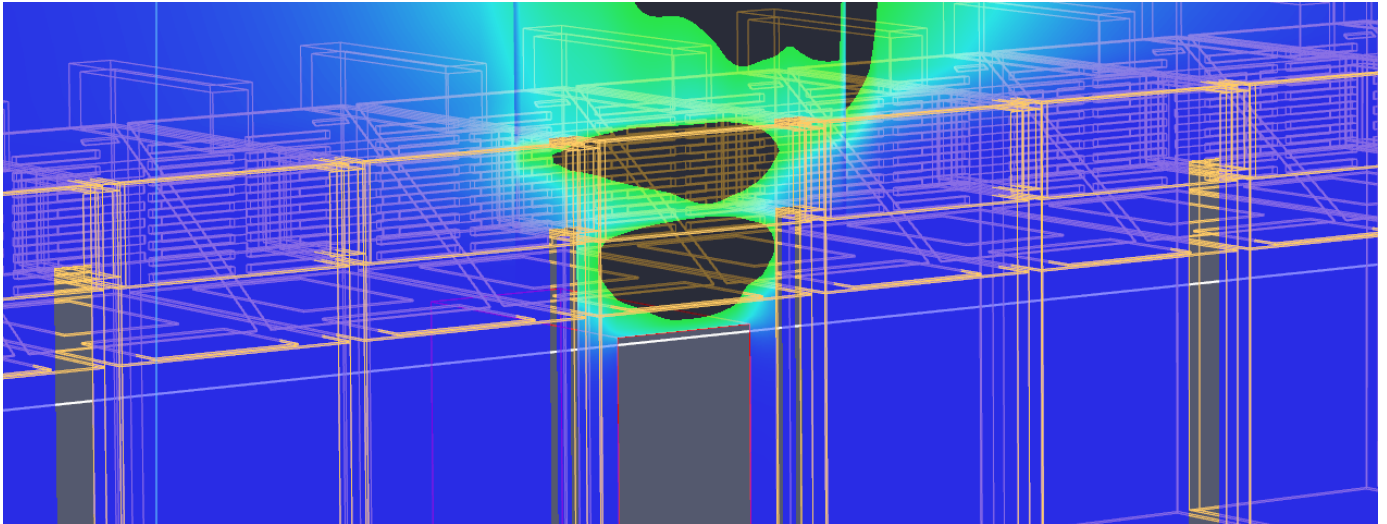


Figure 30: Heat flux through the ladder tray area.

The above results however are given a model of a flashover fire scenario. In a real fire scenario, when a battery releases gases, the smoke detector is expected to detect the smoke and shut down the energy segments as part of the fire safety system. A signal is sent, so staff will proceed with the required maintenance procedures to stop the thermal runaway of the battery and prevent a potential flashover fire and smoke spread.

The results from the models above are consistent with the Powin Large Scale Fire Test UL9540A described in the report issued on 11/29/2021. Three Energy segments with heavily insulated sidewalls were tested to assess the fire spread from the middle unit to the adjacent units on the sides. The test lasted for 86.66 minutes (5,200 seconds) and the fire and heat mainly spread through the trays and vented through the HVAC's vents and doors' gaps (Figure 31 and Figure 32).

The insulated walls also performed well and prevented a significant heat transfer between units and kept the adjacent units well below dangerous temperatures (i.e., 147.7°C); and the flames that came out through the fissures of the doors or the vents showed charring effects of the adjacent units, however the batteries inside remained safe and unaffected (Figure 33).



Figure 31: Fire spread through the ladder tray area.

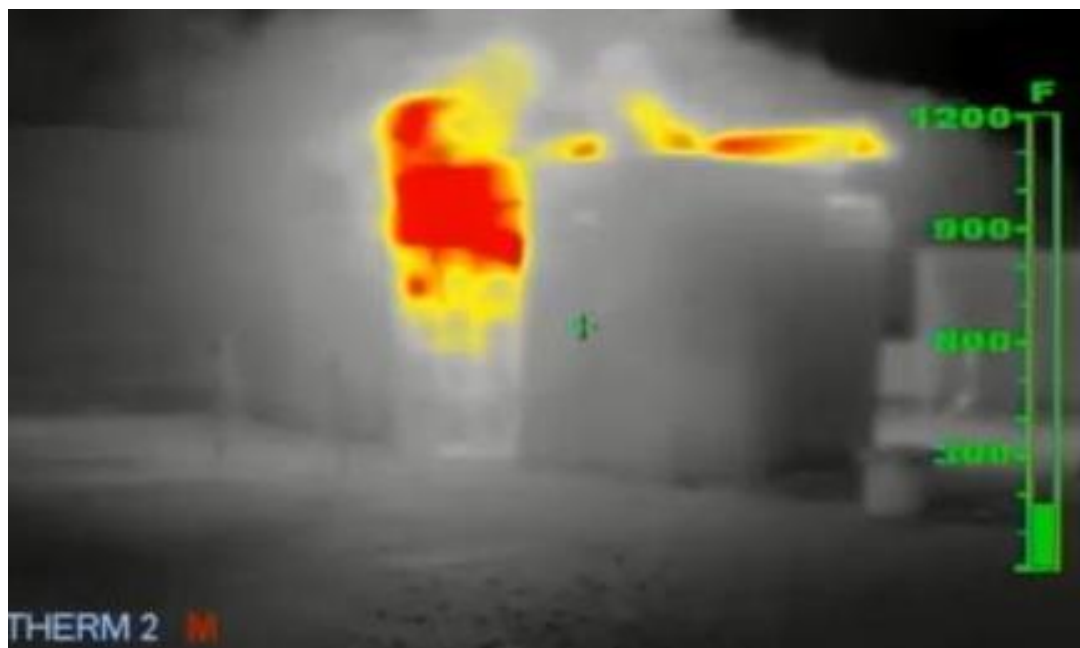


Figure 32: Temperature readings, highest temperatures through the ladder tray area.



Figure 33: Charring to case and safe batteries to battery units adjacent to fire unit.

The above results from the model and the Large-Scale fire tests however are subject to a flashover fire. In accordance with the Thermal runaway tests of the batteries, a battery will release gases between 41 and 49 minutes (i.e., between 2,460 to 2,940 seconds). At this stage the smoke detector is expected to detect the smoke and shut down the energy segments as part of the fire safety system. A signal is sent, so staff will proceed with the required maintenance procedures to stop the thermal runaway of the battery and prevent a potential fire and smoke spread.

8.2.3 Adjacent Allotments

The adjacent buildings allotments are easements and “Base parcels”. Currently the “Base parcels” have vegetation, and the risk of fire spread from those areas to the subject site is addressed in section 8.2.5.

The risk of fire spread from the site to the adjoining sites with vegetation is not expected to occur. As shown in the model above the batteries and transformer are separated from the boundary at least 30m.

The heat flux (q_{cr}) level for non-piloted ignition is taken as 25 kW/m² (refer to section 5.5). Considering a fire either in the Energy segments or in the transformers, the heat flux expected at the boundary are listed in Table 12 below.

Table 12: Heat flux results at the boundary (Red is not acceptable)

Fire location	Incident Radiation (kW/m ²)	
	No wind (Figure 22)	Wind 5.9m/s (Figure 23)
Transformer	1.9	2.3
Energy segment	< 5.5	< 5.5

The results indicate that maximum heat flux levels received at the boundary are well below the critical heat flux for the unpiloted ignition of furnishing materials (25kW/m²), therefore, the fire spread is unlikely to occur.

Furthermore, the NCC 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.

8.2.4 Fire in other Area of the facility

The facility contains Energy segment units, collection segments, inverters, transformers, BESS O&M yard, and BESS site controls & Auxiliary equipment, which have been assessed in the sections above.

There are no other rooms or buildings within the allotment with a risk of fire.

8.2.5 Bushfire Attack Level (BAL) Assessment

The following BAL review has been performed in accordance with AS3959-2018, using the 6 step Simplified Procedure (Method 1) in Section 2.

The adjoining allotments are located to not less than 30m from the transformers and the Energy Segment Units as shown in Appendix A and Figure 34 below:

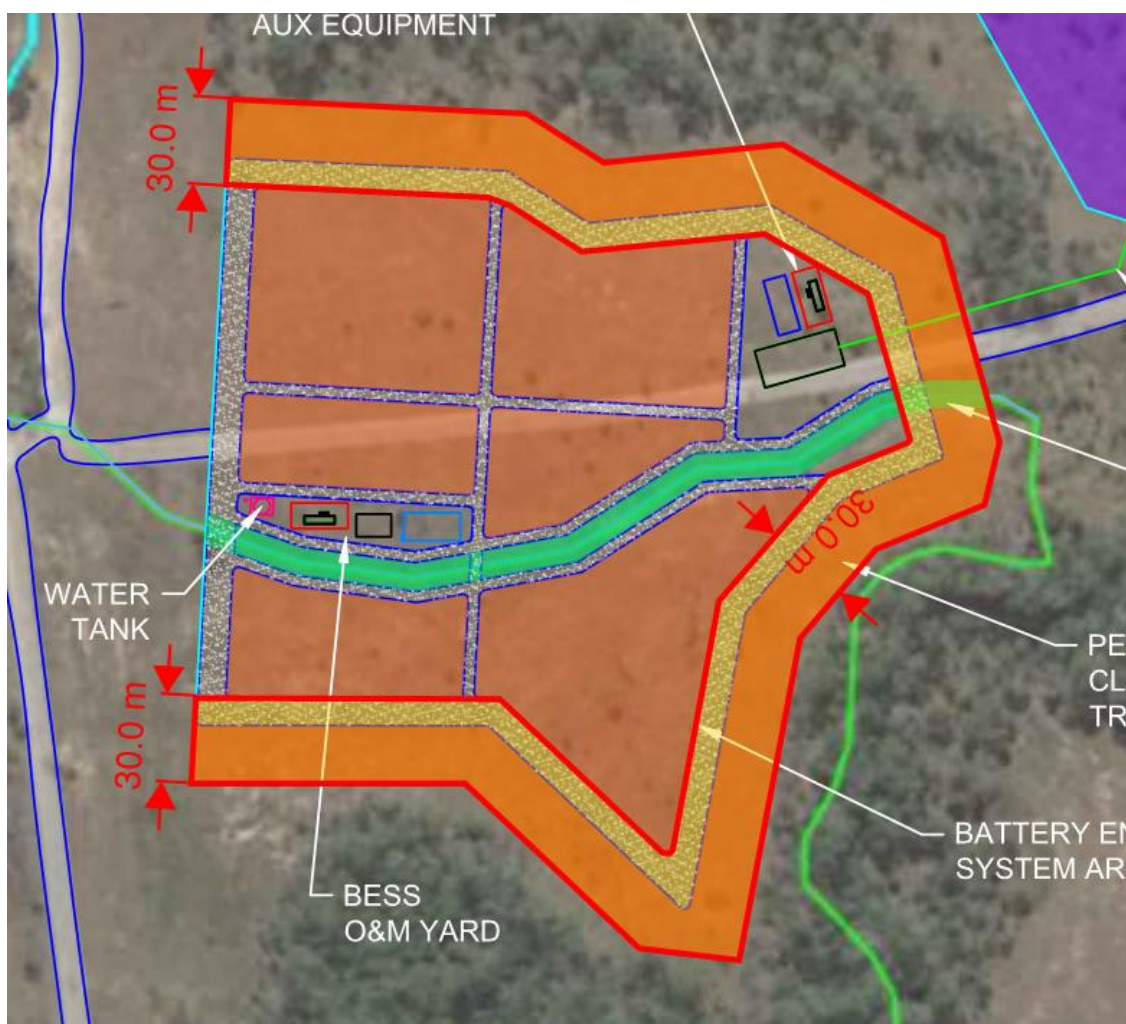


Figure 34: Distance to adjoining allotments from equipment.

The vegetation to consider within 100m from Wurdong BESS allotment is shown in Figure 35 below.

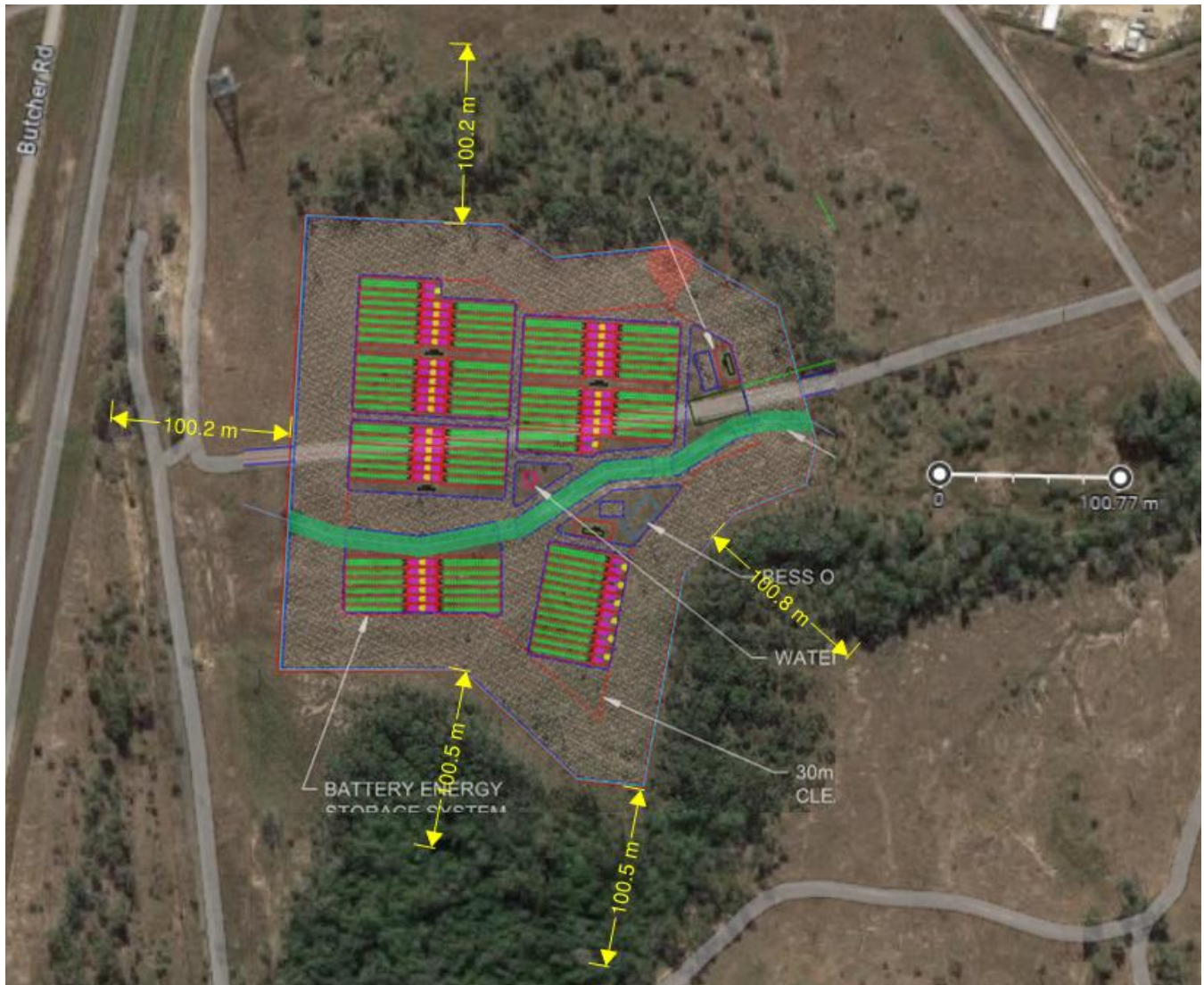


Figure 35: Distance to vegetation from the BESS and its allotment.

(1) FDI Classification:

In accordance with AS3959-2018 Table 2.1, Queensland has an average FDI of 40.

(2) Vegetation classification:

The vegetation classification has been done based on pictures above and Google earth views.

Figure 35 and Figure 36 show that the adjoining allotments and land within 100m from the BESS allotment are open forest with 30m high trees, closed tussock grassland and tussock grassland.



Figure 36: Current vegetation within 100m of the subject site.

Given that the adjoining allotments have grassland and forest, the vegetation is classified as Group A Forest (Figure 37) and Group G Grassland (Figure 38).

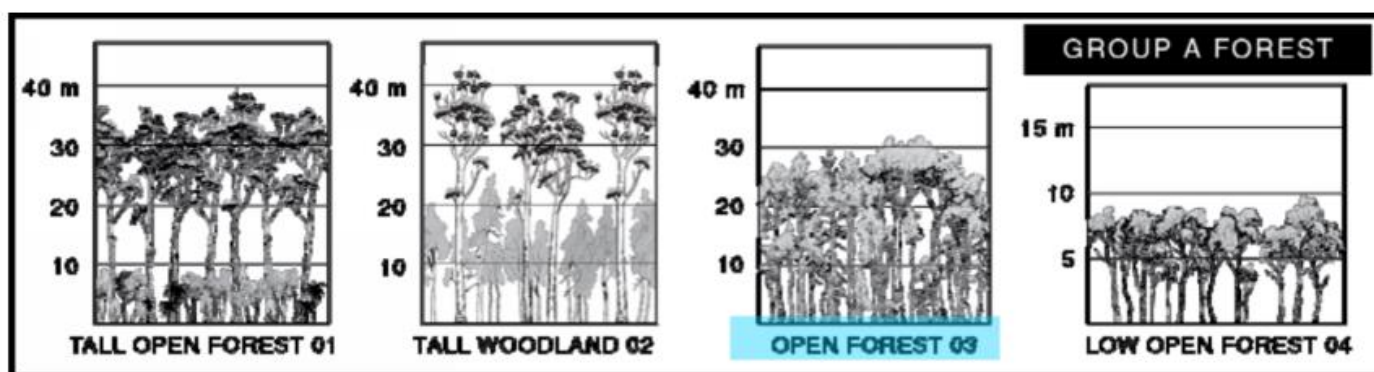


Figure 37: Forest types.

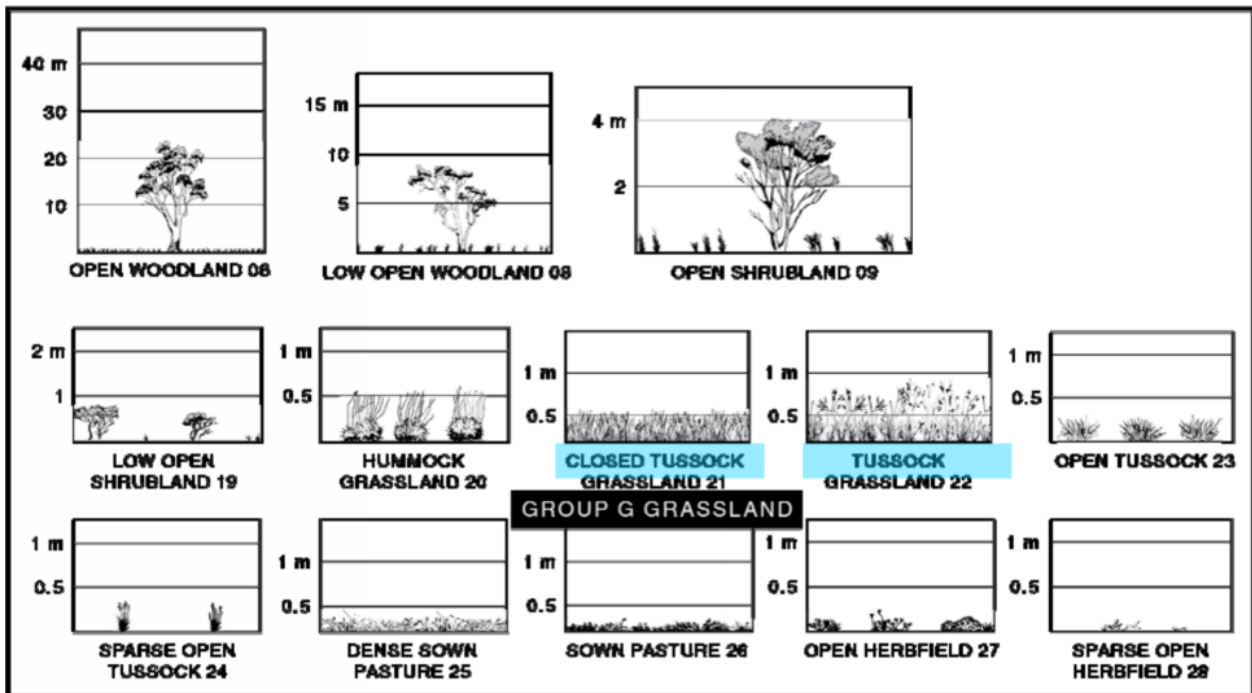


Figure 38: Grassland types.

In accordance with AS3959-2018, Section 2.2.3.2(f) the grassland is classified and regarded as a low threat (i.e., BAL-LOW), given the flammability, content and low fuel load. Therefore, grassland group can be excluded from the BAL assessment.

The most relevant Group A Forest areas to consider are located to the north and around the subject site from the east to the south, where the forest is located and hence classified as a Bushfire prone area with "Medium Potential Bushfire Intensity" (i.e., Potential fire-line intensity of 4,000 – 20,000kW/m) [1].

The hazard due to the Group A forest will be assessed below.

(3) Distance of site from the vegetation:

The grassland generally is located at least 30m from the equipment (excluded), and the forest from the southern to the eastern side of the allotment is located at 30m from the Wurdong BESS.

(4) Effective slope:

The grassland and forest are mostly flat (i.e., 0 degrees).

(5) BAL Determination:

The grassland is classified is excluded from the BAL assessment in accordance with AS3959-2018, Section 2.2.3.2(f).

Given the above characteristics and location of the forest, the forest has a Bushfire Attack Level of BAL-12.5 in accordance with AS3959-2018 Table 2.7.

If the equipment were 2m to 10m closer to the vegetation areas (i.e., located to 20m to 28m from the vegetation areas), the Bushfire Attack Level would increase to of BAL-19, where equipment would be exposed to a radiant heat flux of 19kW/m² (note that the critical heat flux to damage process equipment is considered to be 37.5kW/m²).

(6) **Construction provisions:**

Given the above, AS3959-2018 requires any building parts (i.e., external walls, external windows, external doors, roofs and verandah) to be provided with the construction provisions listed in the standard, which mainly requires:

- Use of non-combustible materials or fire-resistant timber (i.e., high density timber).
- Windows with bushfire shutter or toughened glazing.

Furthermore, in accordance with Leonard et al [1] in the methodology for mapping bushfire prone areas, the heat flux in a range of a 100m of a “Potential Impact buffer” area in accordance with the level of “Potential bushfire intensity” is shown in Figure 39 (i.e., the figure “shows the maximum radiation exposure (kW/m^2) for a range of distances from potentially hazardous vegetation, for different levels of Potential Fire-line Intensity that correspond to the approximate upper and lower levels for Very High, High and Medium Potential Bushfire Intensity” [1]).

Given that the buildings and BESS equipment are located at 30m from the forest, Figure 39 shows they will receive a heat flux from a forest fire of approximately 7kW/m^2 . This heat flux levels are well below the critical heat flux for the piloted ignition of furnishing materials (13kW/m^2) and the critical heat flux for the unplotted ignition of furnishing materials (25kW/m^2). Therefore, the fire spread is unlikely to occur from a forest fire.

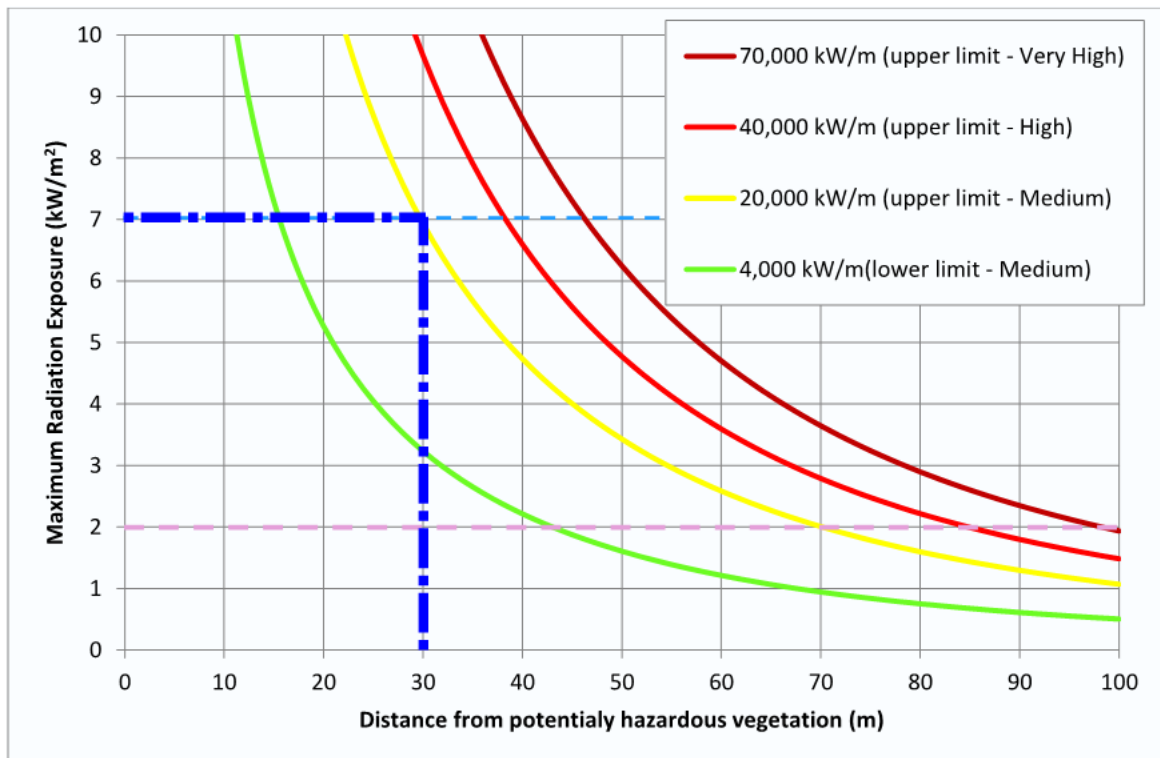


Figure 39: Relationship between maximum radiation exposure (kW/m^2) and distance from hazardous vegetation (m) [1].

The Powin Energy segments are not expected to be affected by flying embers given the provision of ingress protection IP56/NEMA 4, which means a complete protection from dust and protection from low pressure jets of water from all directions.

8.2.6 Hazards to streams as per Gladstone Regional Council Planning Scheme

The proposed site for the BESS has various streams. Streams are watercourses and drainage features shown on a vegetation management watercourse and drainage feature map.

The subject BESS has streams orders 1, 2 & 3. The meaning of each numerical ordering classification of each stream segment goes according to its position within a catchment. The existing streams and their numbers are shown in the figure below.

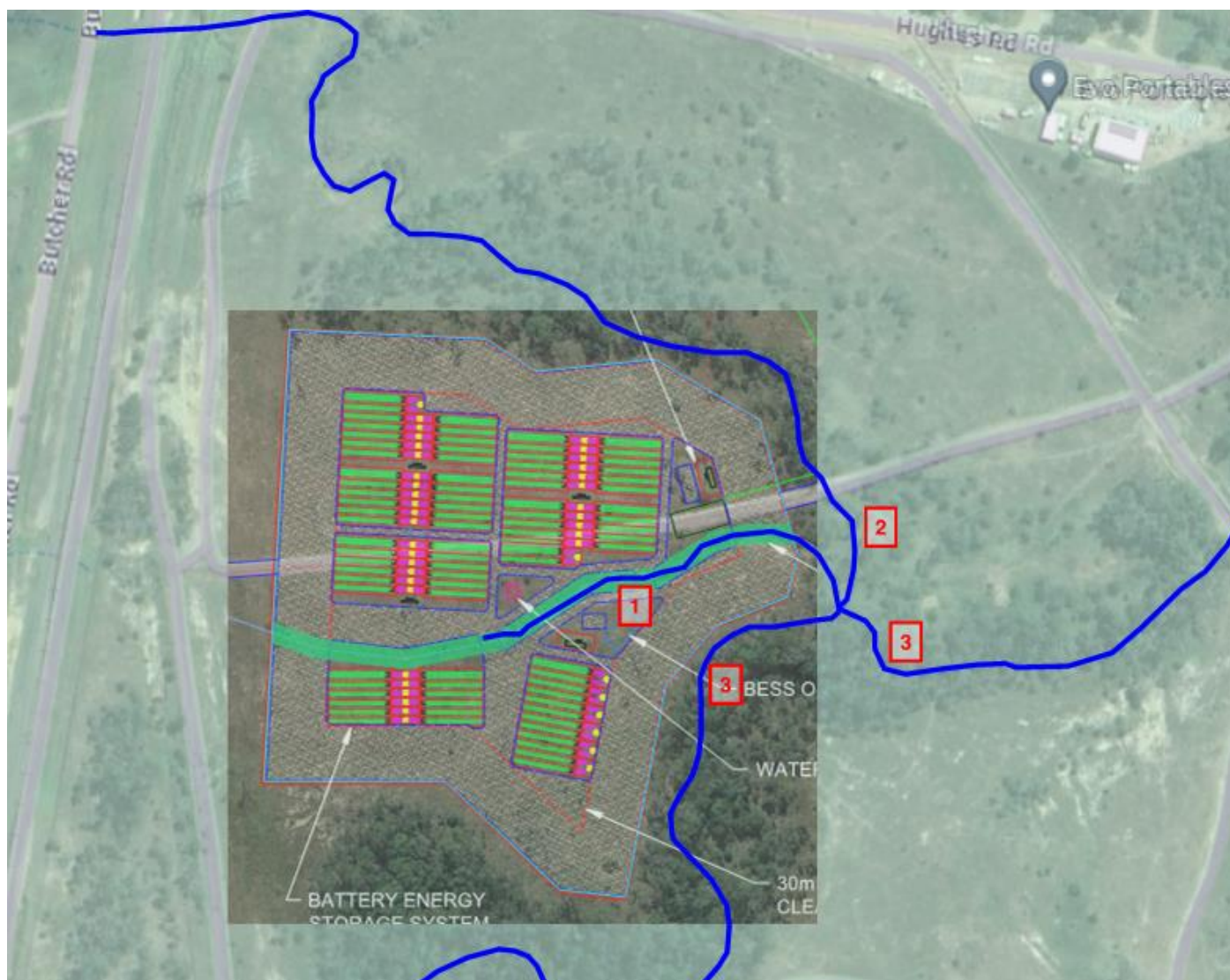


Figure 40: Water streams to subject site.

The Table 13 below describes the Performance Outcomes and the Acceptable Outcomes for Wetland and waterway buffers for the varied stream orders in accordance with the Planning Scheme Biodiversity code of the Gladstone Regional Council.

Table 13 – Wetland and waterway buffers.

PO18	AO18
<p>An adequate buffer to a waterway is provided and maintained to:</p> <ul style="list-style-type: none"> ■ Protect and enhance habitat values, connectivity and other ecological processes and values. ■ Protect water quality and aquatic conditions. ■ Maintain natural micro-climatic conditions. ■ Maintain natural hydrological processes. ■ Prevent mass movement, gully erosion, rill erosion, sheet erosion, tunnel erosion, stream bank erosion, wind erosion or scalding, and ■ Prevent loss or modification of chemical, physical or biological properties or functions of soil. <p>Note—Any setbacks or areas required for bushfire management, safety, recreation, maintenance or any other purpose, are provided in addition to a vegetated buffer provided for ecological purposes.</p>	<p>In all other zones including the Rural Zone, Environmental Management Zone, Conservation Zone, all Industry Zones, Industry Investigation Zone, Emerging Community Zone and Limited Development Zone: Other than where cropping for forestry for wood production, a vegetated and development free buffer is provided and maintained extending from the high bank of the waterway or plan position of a waterway (whichever is the greater) and with a minimum width of:</p> <ul style="list-style-type: none"> ■ Stream order 1 or 2: 25m, or ■ Stream order 3 or 4: 50m, or ■ Stream order 5 and above: 100m. <p>Note—Stream order is mapped on Fish habitat area mapping in OM.</p>

Some of the proposed BESS equipment location does not comply with the clearances proposed by the biodiversity code of the Gladstone Regional Council. See Figure 41 and Table 14 below.

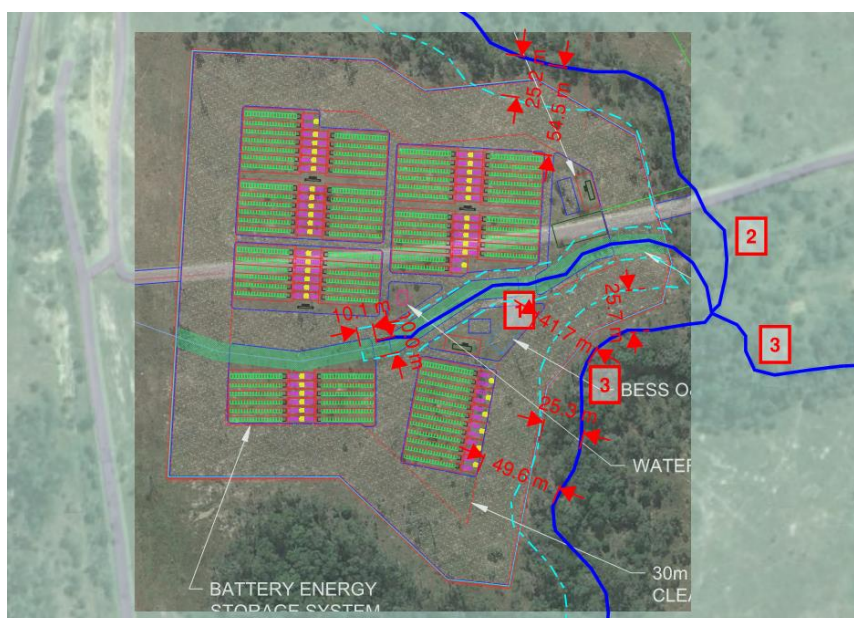
**Figure 41: Water streams distances to BESS equipment.**

Table 14 – Clearances PO18 vs Current BESS layout.

Stream Order	Distance PO18 (m)	Proposed Distance (m)	Compliance (yes/no)
Order 1	25	10	No
Order 2	25	54	Yes
Order 3	50	49 - 55	Yes

■ Stream order 1:

Stream order 1 travels through the BESS site and it is proposed to leave a clearance of 10m to each side of the stream.

Sections 8.2.1 and 8.2.2 demonstrated that a fire to a BESS unit and to a SUT transformer will fire spread to a vegetation in a radius of 5m. Therefore, a clearance of 10m will prevent the fire spread from the BESS equipment.

■ Stream order 2 & 3:

Those streams are located within the vegetation area and the current layout proposes a buffer of 30m to the vegetation area, reaching distances to the BESS equipment of between 49m to 54m.

Sections 8.2.1 and 8.2.2 demonstrated that a fire to a BESS unit and to a SUT transformer will fire spread to a vegetation in a radius of 5m. This is much lower than the distance in the layout, therefore streams 2 & 3 are not expected to be affected by the BESS site.

8.2.7 Consequence summary outcome

Given a catastrophic failure of any of the assessed equipment (i.e., Step-up transformers and Battery storage unit), only the equipment of fire will be lost, and all surrounding equipment/buildings are expected to remain working, and fire spread to adjoining equipment/buildings/allotments is not expected.

If any of that equipment stop working/fails due a catastrophic fire, the BESS will not stop operating and will continue working with alternate equipment.

Based on the fire spread assessments performed in sections 8.2.1 to 8.2.6 above, and the continuous operation of the BESS, the consequence of a fire to the studied equipment can be rated as “Minor”.

8.3 RISK ASSESSMENT OUTCOME

The fire likelihood to the studied equipment has been rated as “Rare” (Section 8.1), and fire spread consequences on adjoining equipment/buildings/allotment have been rated as “Minor” (Section 8.2).

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

Table 15: Risk matrix rating

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

9 COMPARISON WITH RELEVANT STANDARDS

9.1 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 <i>Best Practice Guide: battery storage equipment — Electrical Safety Requirements</i> 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.

Requirements and assessment from AS NZS 5139 2019 are listed below:

- 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 was modelled as part of the fire engineering assessment in Section 8.2. However, given the separation between rows of battery storage units is not less 2.4m, it is considered that the proposed facility complies, and fire spread is not expected.

- 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. This fire risk assessment report complies with this requirement.
- 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 adjacent allotments, 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. This arrangement does not apply to this site, however it is considered that the monitoring of the devices linked to the operator who can call the brigade 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 the electricity distributor instantaneously. The design is therefore considered to comply with clause 4.3.8.

The Battery Management System (BMS) is primarily concerned with battery performance, data acquisition, and safety. The safety measures include fire safety measures and E-Stops (i.e., safety sensors):

The fire safety measures available by the providers usually are the following:

- Heat detection (picture below).
- Gas detection.
- Smoke detection (picture below).

If any of the above is triggered, The Stack 750E Battery Segment is designed to safely shutdown the stack in a fire event. Addressable fire safety equipment is employed in the design of FSS (Fire Safety System) to be able to easily locate and isolate stacks.

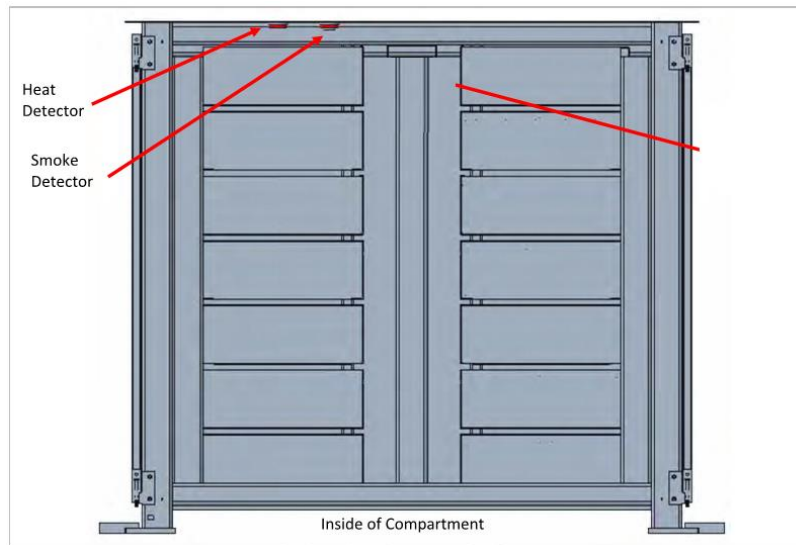


Figure 42: Smoke and heat detectors.

The E-Stops (i.e., safety sensors) will include:

- Hydrogen sensor (signals H_2 concentration reached set point).
- Trouble (loss of AC power or low battery voltage).
- Fire alarm (signals smoke and/or heat).
- Fire supervisory (signals tampering, low air, and high air).
- Door alarm (signals door is open).

E-Stops will shut down the Battery Storage Unit to delay a possible battery-runaway failure and warn staff to perform the required maintenance in accordance with the provider specifications and the emergency management plan before a battery catches fire.

“E-stops reset automatically when conditions return to operating range. Most PCSs also have an E-stop button on them. If an E-stop button is pushed, resetting often requires manually disengaging the E-stop button and remotely clearing the fault (ROC can support this)” [Stack750E Centipede – A modular battery energy storage platform product manual, November 2021, Revision 03].

If a Battery Storage Unit reaches flashover, the equipment is allowed to burn out and adjacent infrastructure is protected in accordance with the equipment supplier’s recommendations. Hence, fire brigade operations will be directed at providing protection to adjoining equipment.

Further to the safety measures above, Powin Battery units are also provided with a climate control and an Environment controller. *“This last is essentially a PLC (Programmable Logic Controller). The PLC orchestrates the HVAC system, the Fire Suppression System (FSS), the Off-Gas Alarm System and any door/intrusion alarms. The controller monitors the system and reports all conditions upstream to the environmental controller in the Collection Segment” [Stack750E Centipede – A modular battery energy storage platform product manual, November 2021, Revision 03].*

a. Active ventilation – should gases be detected in a Stack750E Battery Segment, the HVAC ceases to operate and eight (8) booster fans are activated to vent out the gases and keep it within the safety limits within the battery compartment. These booster fans are backed by UPS for redundancy if auxiliary power to the fans fail.

b. Passive ventilation – if auxiliary power and UPS fails during an active gassing event, the vents are shut open by means of a fail-open actuator. These gasses can still be vented out through natural buoyancy.

- 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 Ergon 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.

The fire spread was assessed in Section 8 in accordance with the current layout. It demonstrated the fire spread will be limited due to the possible sizes of the fires and the distances between equipment. The layout also provides alternatives paths to egress the allotment, hence a fire is not expected to prevent the evacuation from the site.

- 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. Each energy segment unit is provided with a HVAC system on top of the unit.

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 below:

Table 16: Example likelihood of occurrence rating

Likelihood rating	Definition of likelihood of occurrence rating
Almost certain	Probably of occurrence: greater than 90%.
	Expected to occur whenever system is accessed or operated.
	The event is expected to occur in most circumstances.
Likely	Probably of occurrence: 60% - 89%.
	Expected to occur when system is accessed or operated under typical circumstances.
	There is a strong possibility the event occurs.
Possible	Probably of occurrence: 40% - 59%.
	Expected to occur in unusual instances when the system is accessed or operated.
	The event may occur at some time.
Unlikely	Probably of occurrence: 20% - 39%.
	Expected to occur in unusual instances 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	Probably 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 1×10^{-2} per year.

The level of consequence is given in Table G.1.

Table 17: Consequence rating Appendix G AS5139 (Table G1 – 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.	

Consequence/Impact category	Consequence / impact rating definitions				
	Catastrophic	Major	Moderate	Minor	Insignificant
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: <ul style="list-style-type: none"> - Contravention notices from authorities, or - Court order, or - Fine over \$1,000. 	Breach of legislation or regulations leading to: <ul style="list-style-type: none"> - Warning notice, or - Fine of up to \$1,000, or - Enforceable undertakings. 	Breach of legislation or 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 of 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 18: Risk matrix rating

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 Very Low risk.

9.2 BEST PRACTICE GUIDE FOR BATTERY STORAGE EQUIPMENT - ELECTRICAL SAFETY REQUIREMENTS, V1.0 — 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 (i.e., the subject site is 254MW/1,016MWh), 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.”

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 as the energy segments are provided with heavily insulated side walls. There is also the requirement for isolation devices and installation distances to be supplied with the equipment but not distances are specified.

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., are expected to be conducted to the necessary degree in accordance with the manufacturers’ specification when the battery assembly is finished.

9.3 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”.

The subject facility complies with the above requirement as shown in the layout in Appendix A, Energy segments are 2.4m separated.

9.4 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 19: AS 2067 Table 6.1

MINIMUM VALUES FOR SEPARATING OUTDOOR TRANSFORMERS			
Transformer type	Liquid volume	Clearance G_1 to other transformers or fire resistant surfaces	Clearance G_2 to combustible building surface
	(L)	(m)	(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
Less combustible liquid-insulated transformers (K) without enhanced protection	>60 000	23	30
	100 ≤ 1000	1	6
	>1000 ≤ 3800	1.5	7.5
Less combustible liquid-insulated transformers (K) with enhanced protection	>3800	4.5	15
	Clearances G_1 and G_2 to building surface or adjacent transformers		
	Horizontal (m)	Vertical (m)	
Dry-type transformers (A)	0.9	1.5	
	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

The subject facility will have insulated transformers with less combustible liquids and enhanced protection. The subject facility will have transformers that will be located at the end of each row of energy segment units (shown in figure below).

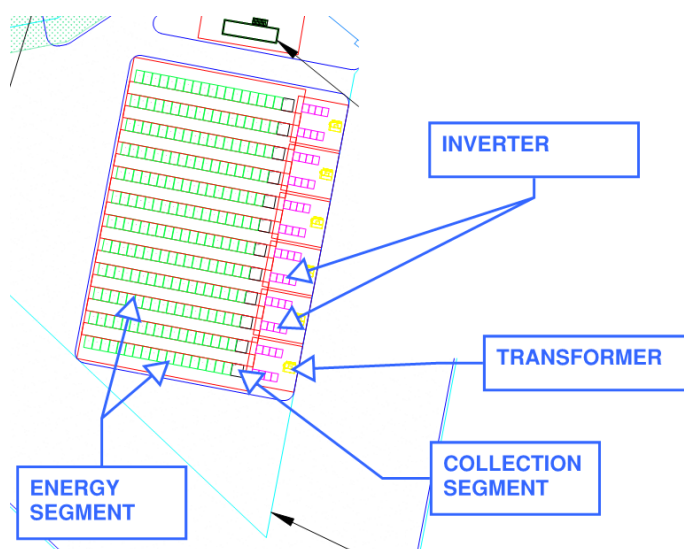


Figure 43: Inverter and transformers

It is understood that the transformers' specification specifies FR3 (or similar) Ester oil in lieu of the normal mineral oil. This oil would have a flash point of approximately 330°C compared to 145°C for standard oil and hence is less likely to result in a fire.

The transformers are not expected to have more than 2,000 litres (2.0 m³).

Table 20 below summarizes the distances of the transformers from the adjoining equipment where there is the main risk of fire spread, compared with the requirements of the Australian Standard AS2067.

Table 20: Distance assessment

Equipment to assess	Adjoining equipment	Required Distance (m)	Proposed Distance (m)	Compliant (Yes/No)
Transformer	Transformer	≥ 0.9	1.0	Yes
	Inverter	≥ 0.9	2.8	Yes
	Collection segment	≥ 0.9	7.7	Yes
	Energy Segment Unit	≥ 0.9	10.0	Yes
	BESS Operation & Maintenance (O&M) yard	≥ 0.9	13.5	Yes
	BESS Site controls and Auxiliar equipment	≥ 0.9	25.0	Yes
	Forest vegetation	≥ 0.9	32.0	Yes

The above demonstrates that all the equipment have compliant distances between them in accordance with the Australian Standard AS2067, in order to mitigate the risk of fire spread.

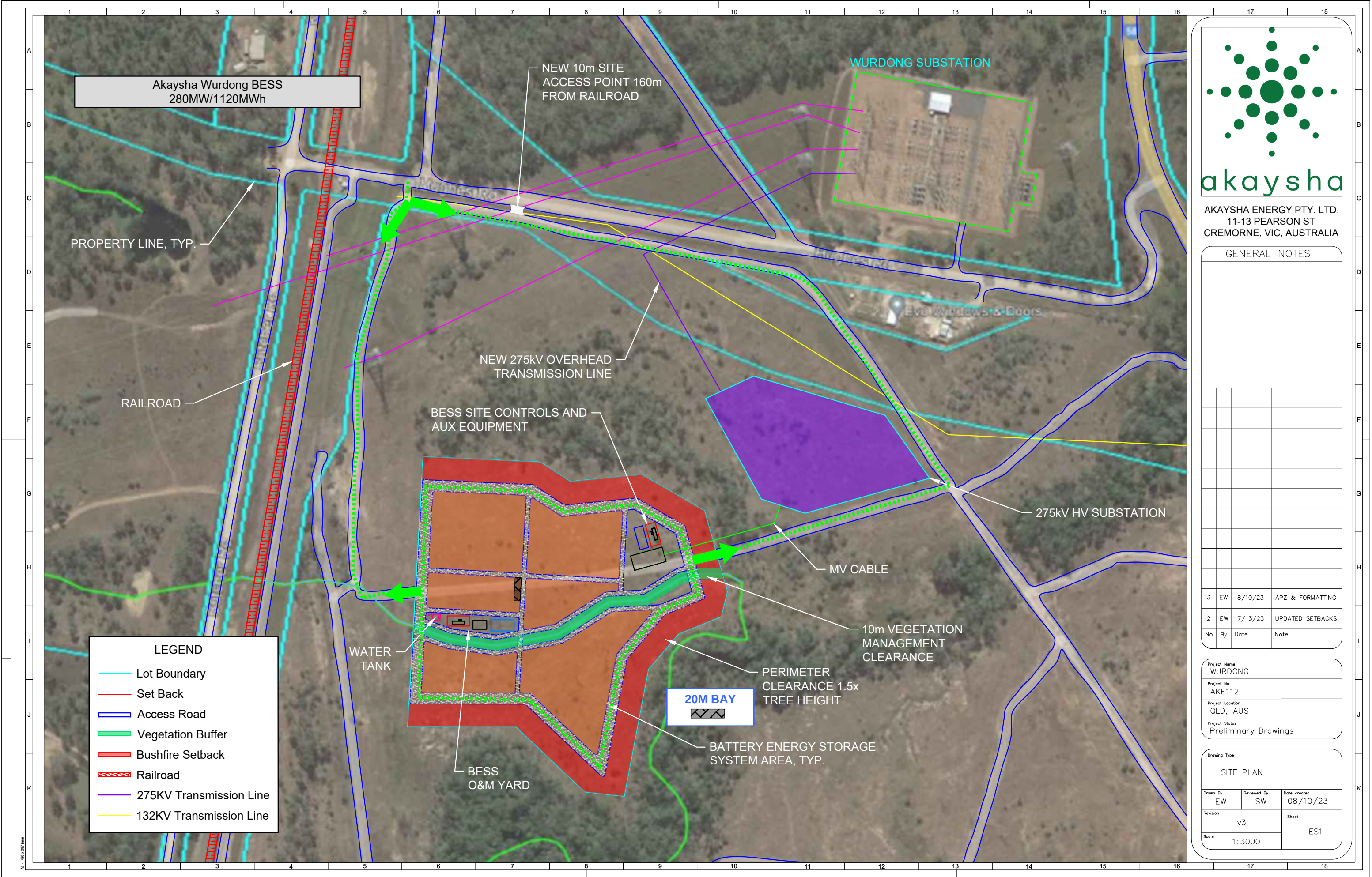
9.5 SUMMARY

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.

10 REFERENCES

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- [9] Fisher Engineering, “Fire Protection Engineering analysis,” 2023.

Appendix A. PROPOSED FACILITY LAYOUT





Appendix B. VBB FIRE INVESTIGATION

January 25, 2022

Victorian Big Battery Fire: July 30, 2021

REPORT OF TECHNICAL FINDINGS

ANDY BLUM, PE, CFEI
SENIOR FIRE PROTECTION ENGINEER

TOM BENSEN, PRINCIPAL FOUNDER
PAUL ROGERS, PRINCIPAL FOUNDER
CASEY GRANT, PE, SENIOR CONSULTANT
GEORGE HOUGH, SENIOR CONSULTANT

Fisher Engineering, Inc.
10475 MEDLOCK BRIDGE ROAD
SUITE 520
JOHNS CREEK GA 30097

Energy Safety Response Group
8350 US HIGHWAY N 23
DELAWARE OHIO 43015

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 Guide² (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

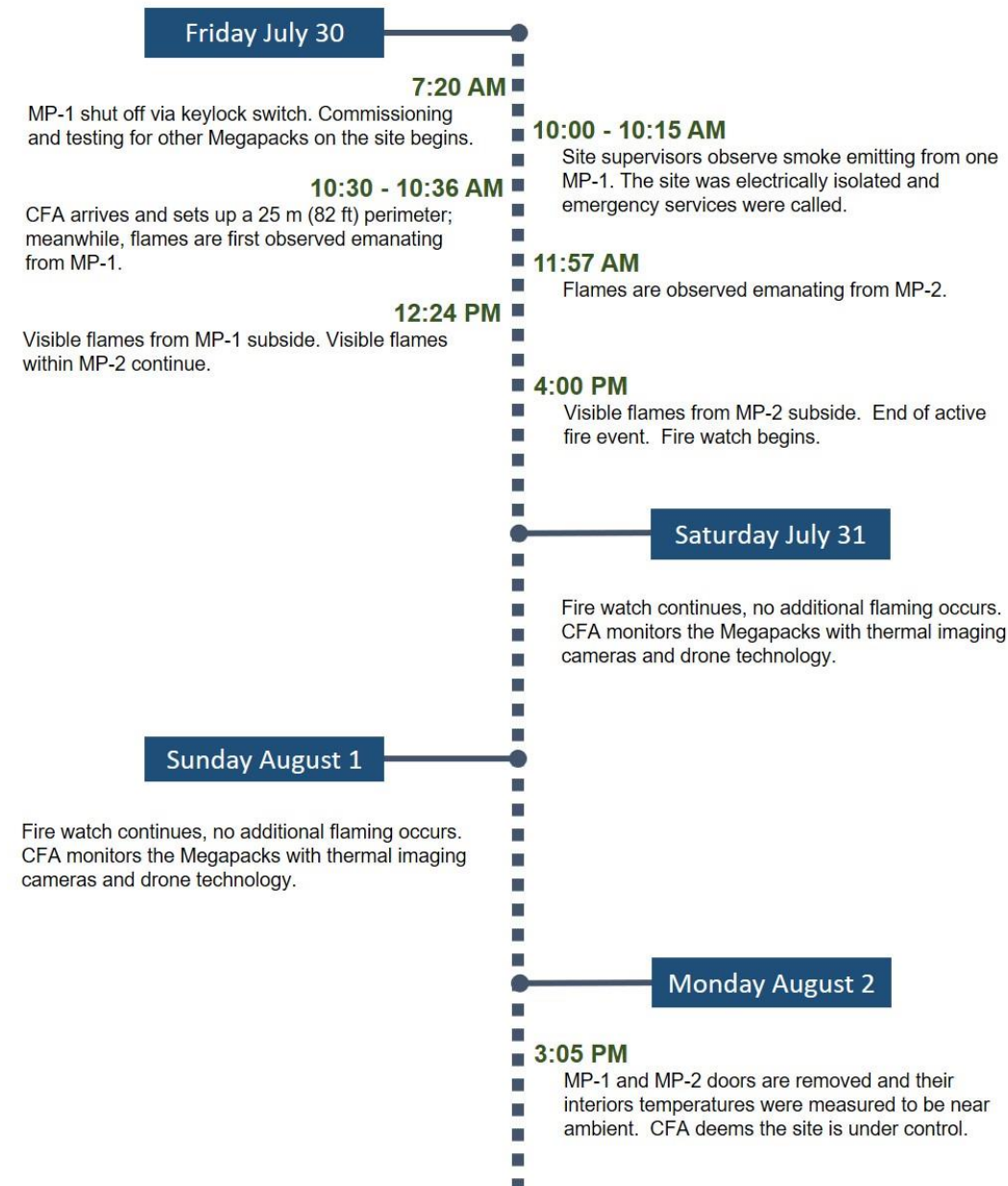
¹ <https://victorianbigbattery.com.au/>

² [https://www.tesla.com/sites/default/files/downloads/Lithium-Ion Battery Emergency Response Guide en.pdf](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.

Incident Timeline



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 Victoria⁴ (ESV), Work Safety Victoria⁵ (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 devices⁶ 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.

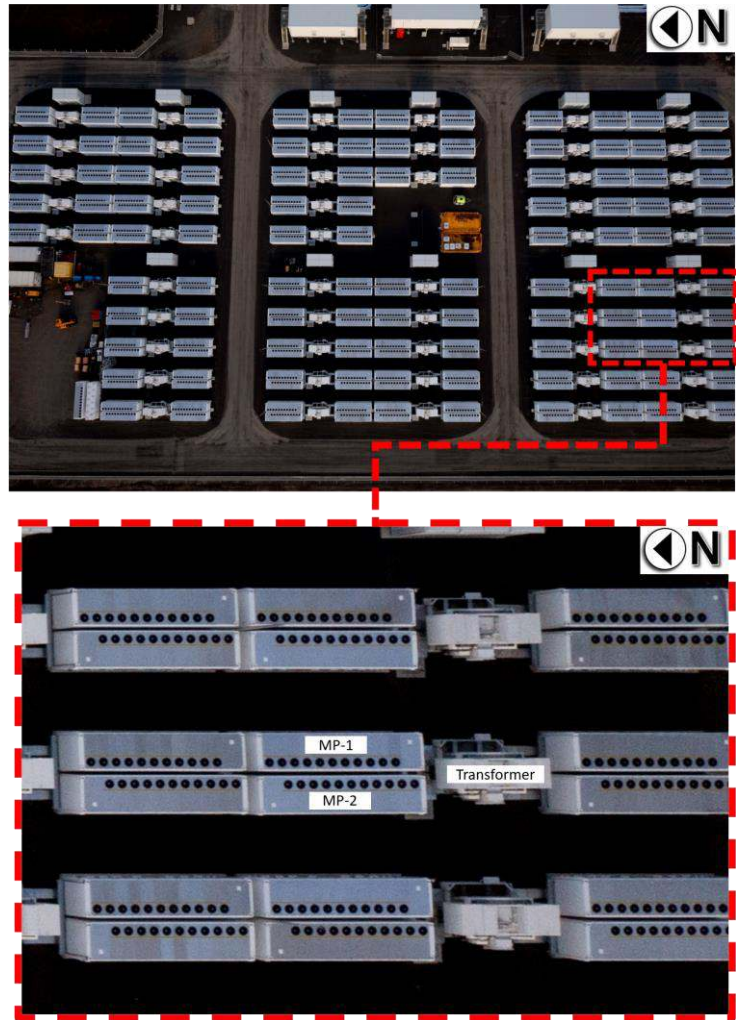


Figure 1 VBB Megapack layout (top) and area of fire origin (bottom)

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 knots⁹ 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 bay¹⁰ 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 permitted¹² 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:

Procedural Mitigations:

- 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).

Firmware Mitigations:

- 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.

Hardware Mitigations

- 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.

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 comprising 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 public 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. AS-3959: CONSTRUCTION REQUIREMENTS

BAL – AS3959 – Construction Requirements

	BAL – LOW	BAL – 12.5	BAL – 19	BAL – 29	BAL – 40	BAL – FZ
SUBFLOOR SUPPORTS	No special construction requirements	No special construction requirements	No special construction requirements	Enclosure by external wall or by steel, bronze or aluminium mesh, non-combustible supports where the subfloor is unenclosed, naturally fire resistant timber stumps or posts on 75mm metal stirrups	If enclosed by external wall refer below 'External Walls' section in table or non-combustible subfloor supports or tested for bushfire resistance to AS1530.8.1	Subfloor supports – enclosure by external wall or non-combustible with an FRL of 30/-/- or be tested for bushfire resistance to AS1530.8.2
FLOORS	No special construction requirements	No special construction requirements	No special construction requirements	Concrete slab on ground, enclosure by external wall, metal mesh as above or flooring less than 400mm above ground level to be non-combustible, naturally fire resistant timber or protected on the underside with sarking or mineral wool insulation	Concrete slab on ground, enclosed by external wall or protection of underside with non-combustible material such as fibre cement sheet or be non-combustible or be tested for bushfire resistance to AS1530.8.1	Concrete slab on ground or enclosure by external wall or an FRL of 30/30/30 or protection of underside with 30 minute incipient spread of fire system or to be tested for bushfire resistance to AS1530.8.2
EXTERNAL WALLS	No special construction requirements	As for BAL-19	External walls – Parts less than 400m above ground or decks etc to be of non-combustible material, 6mm fibre cement clad or bushfire resistant/naturally fire resistant timber	Non-combustible material (masonry, brick veneer, mud brick, aerated concrete, concrete), timber framed, steel framed walls sarked on the outside and clad with 6mm fibre content sheeting or steel sheeting or bushfire resisting timber	Non-combustible material (masonry, brick veneer, mud brick, aerated concrete, concrete), timber framed, steel framed walls sarked on the outside and clad with 9mm fibre content sheeting or steel sheeting or be tested for bushfire resistance to AS1530.8.1	Non-combustible material (masonry, brick veneer, mud brick, aerated concrete, concrete) with minimum thickness of 90mm or an FRL of -/30/30 when tested from outside or be tested for bushfire resistance to AS1530.8.2
EXTERNAL WINDOWS	No special construction requirements	As for BAL-19 except that 4mm Grade A safety glass can be used in place of 5 mm toughened glass	Protected by bushfire shutter, completely screened with steel, bronze or aluminium mesh or 5mm toughened glass or glass blocks within 400mm of ground, deck etc. Openable portion metal screened with frame of metal or metal reinforced PVC-U or bushfire resisting timber	Protected by bushfire shutter, completely screened with steel, bronze or aluminium mesh or 5mm toughened glass or glass with openable portion metal screened and frame of metal or metal reinforced PVC-U or bushfire resisting timber and portion within 400mm of ground level screened.	Protected by bushfire shutter or 5mm toughened glass. Openable portion screened with steel or bronze mesh.	Protected by bushfire shutter or FRL of -/30/- and openable portion screened with steel or bronze mesh or be tested for bushfire resistance to AS1530.8.2

BAL – LOW		BAL – 12.5	BAL – 19	BAL – 29	BAL – 40	BAL – FZ
EXTERNAL DOORS	No special construction requirements	As for BAL-19 except that door framing can be naturally fire resistant (high density) timber	Protected by bushfire shutter, or screened with steel bronze or aluminium mesh or glazed with 5mm toughened glass, non-combustible or 35mm solid timber for 400mm above threshold, metal or bushfire resisting timber framed for 400mm above ground, decking, etc tight fitting with weather strips at base.	Protected by bushfire shutter, or screened with steel bronze or aluminium mesh or non-combustible or 35mm solid timber for 400mm above threshold. Metal or bushfire resisting timber framed tight fitting with weather strips at base.	Protected by bushfire shutter, non-combustible or 35mm solid timber, metal framed tight-fitting with weather strips at base	Protected by bushfire shutter or tight-fitting with weather strips at base and an FRL or -/30/-
ROOFS	No special construction requirements	As for BAL-19	Non-combustible covering. Roof/wall junction sealed. Openings fitted with non-combustible ember guards. Roof to be fully sarked.	Non-combustible covering. Roof/wall junction sealed. Openings fitted with non-combustible ember guards. Roof to be fully sarked.	Non-combustible covering. Roof/wall junction sealed. Openings fitted with non-combustible ember guards. Roof to be fully sarked and no roof mounted evaporative coolers	Roof with FRL of 30/30/30 or tested for bushfire resistance to AS1530.8.2. Roof/wall junction sealed. Openings fitted with non-combustible ember guards. No roof mounted evaporative coolers
VERANDAHS DECKS ETC	No special construction requirements	As for BAL-19	Enclosed sub-floor space – no special required for materials except within 400mm of ground. No special requirements for supports or framing. Decking to be non combustible or bushfire resistant within 300mm horizontally and 400mm vertically from a glazed element.	Enclosed sub –floor space or non-combustible or bushfire resistant timber supports. Decking to be non-combustible	Enclosed sub-floor space or non-combustible supports. Decking to be non-combustible	Enclosed sub-floor space or non-combustible supports. Decking to have no gaps and be non-combustible