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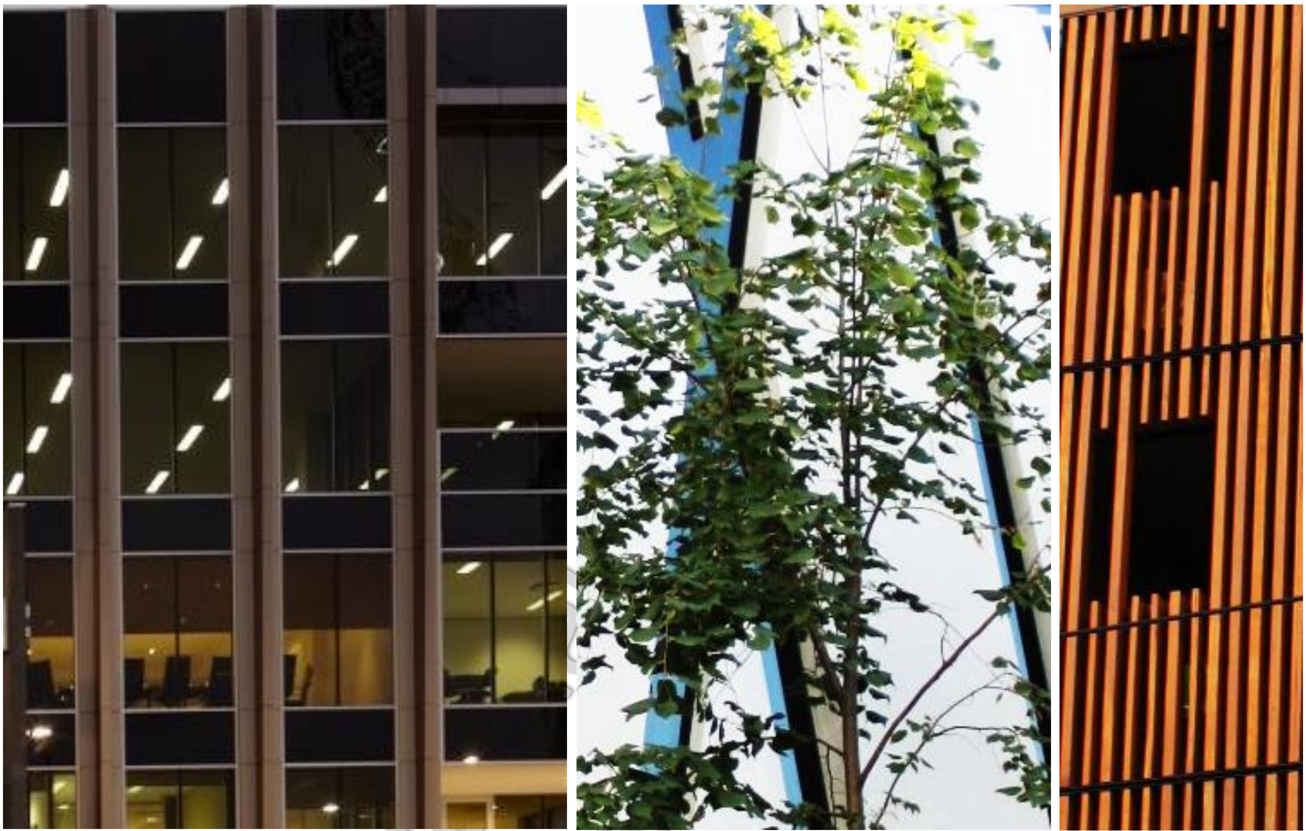
Fire Hazard and Risk Assessment

Elaine Battery Energy Storage System (BESS)



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1 Executive Summary

1.1 General

NJM Design has been engaged by Akaysha Energy to undertake a fire hazard and risk assessment for the Battery Energy Storage System (BESS) located at Elaine Victoria (225 Elaine-Blue Bridge Road). The site is adjacent to the existing Elaine Terminal Station. The new BESS will comprise Tesla Megapacks.

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.

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.

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. Design Guidelines and Model Requirements: Renewable Energy Facilities, Country Fire Authority, August 2023.

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

g. AS3000.

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

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

1.2 Conclusions

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

1. The design of the BESS units is acceptable and covers all fire initiation and fire spread risks to an acceptable level.

2. Based on the AS5139 Risk Methodology the risk of a fire would be considered 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 would not be predicted to occur, based on that the distances from the subject site surpass the clearances specified by the NCC and the Australian standards. This is confirmed by the fire spread analysis performed in Sections 6.2, 6.3 and 6.4.

6. Fire spread between Tesla Megapacks is not expected if any of them reaches flashover, Elaine BESS design proposes an approximate separation of 8.7ft (2.6m), which exceeds the distances proposed by the provider. Also, flashover is not expected to happen due to the fire safety measures, which will shut down the BESS or activate safety procedures to delay a possible battery-runaway failure and warn staff to perform the required maintenance before a battery catches fire.

   The fire safety measures provided will be the following:

   - Overpressure vents.
   - An internal safety circuit called an enable circuit (also known as HVIL - high-voltage interlock loop) that shuts down all major power components when other faults are detected.
   - Remote shutdown provisions.
   - Electrical protection such as overcurrent protection, inverter protection, ground fault protection and lighting strike protection.
   - Over temperature.
   - Loss of communication.
   - Over voltage.
   - Isolation.

7. Given the subject site layout, fire spread from a Megapack row is not expected to adjoining transformers or adjacent Megapack rows.

8. Fire brigade intervention is considered not to be affected by a fire based on the preliminary fire modelling results presented within this report. Access roads will be provided around the site with strategically located hydrants to cover either a transformer or a battery fire. Hence the fire brigade personnel will be able to fight the fire from outside the critical area and will not be exposed to hazardous conditions.

   It is noted that if the fire happens to a BESS, the provider indicates not to use water and to allow the Megapack to burn completely, and only to apply water to adjacent equipment as required.

9. In order for the site entrance to be affected by a fire there would need to be a fire within the adjacent units as well as a wind towards the south. The boosters and brigade access are separated from the battery units and transformers and hence the predicted fire size is not large enough to block the entrance to the site even with the wind in the correct direction.

10. The firefighting water will be sufficient for 4 hours supply based on at least 1 hydrant. The hydrants will be located such that all areas can be covered by at least 2 hydrants. The water storage tank is therefore required to have at least 144kL.

11. The other parts of the infrastructure such as the transformers and control room do not present a significant fire risk or higher hazard than other kiosk type transformers and small buildings in the community that do not require particular fire safety provisions.

12. The adjoining allotments have managed grassland. AS3959-2018 considers this grassland as a low threat and hence the development does not require specific construction specifications.

13. Based on the analysis performed in Section 7.5, it is considered that the design and layout of the BESS complies with the CFA guidelines, hence providing an acceptable level of fire safety to personnel, fire brigade and adjacent properties.

1.3 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 main Fire Engineering Requirements.

1. A firebreak of at least 10m wide must be designed and maintained as shown in Appendix A (this is compliant in the proposed layout in Appendix A).
2. The five (5) metre perimeter road within the perimeter fire break (as shown in Appendix A) must be maintained and designed to comply with the requirements of the CFA Guidelines for renewable Energy Facilities [1] (also refer to Section 7.5) (this is compliant in the proposed layout in Appendix A).
3. A Fire hydrant system must be provided in accordance with AS 2419.1-2005: Fire hydrant installations, Section 3.3: Open Yard Protection and any additional requirements of the Fire Brigade (also refer to Section 7.5). Furthermore, location of hydrants must be located as follows (refer to section 6.2):
    a. Be located not less than 12.0m from the transformers of the Substation 220KV HV.
    b. Be located not less than 10.0m from the BESS transformers and switch gears (refer to section 6.2).
    c. The hydrants will be located such that all areas can be covered by at least 2 hydrants.
4. Develop a Fire Management Plan as required by the CFA Guidelines for renewable Energy Facilities [1] (refer to Section 7.5), which must contain the following content (figure below).

Fire Management Plan Structure and Content	
A summary of fire hazards and risks to and from the site, specific to its location, infrastructure, activities and occupancy.	Based on sound hazard identification and risk management processes. This must include risks to firefighter safety during emergencies.
Description of control measures to prevent fire occurring and limit the consequences of fire at the facility.	Fire permits, ignition source controls, hot work permits, job hazard analyses, infrastructure/vehicle/equipment/road/fence/access maintenance, waste management, compliant dangerous goods storage and handling, vegetation/fuel reduction and management, peat management, Emergency Plan.
Description of control measures to prevent and reduce the consequences of external fire impacting the facility.	Bushfire monitoring, bushfire preparedness, reduced personnel presence/ activities/travel on days of Severe and above Fire Danger Rating, creation and management of fire breaks at the site perimeter and around infrastructure, vegetation/fuel reduction and management, Emergency Plan.
Details of equipment and resources to manage fire at the facility.	Fire detection and suppression systems, fire water supplies, automatic shut-down and isolation systems, monitored alarms, communications equipment, occupant warning systems, designated evacuation assembly areas, Emergency Information Container(s), Emergency Plan.
Policies and procedures that ensure all control measures are appropriate and effective, and remain so.	Performance standards for risk controls, specific activities to verify controls (servicing/maintenance, housekeeping inspections, external audits), review processes for risk control effectiveness.
Procedures for review of the Fire Management Plan.	Review triggers and schedule, organisational accountability for the Plan, allocated responsibilities (to persons or roles) for the ongoing review and development of the Plan.

Figure 1: Fire Management Plan Requirements as per CFA guidelines

5. A containment and management plan of contaminated fire water runoff from the BESS is to be developed by the facility.
6. Where transformers are oil-insulated, transformers shall use an FR3 (or similar) Ester oil where practical in lieu of the normal mineral oil.

7. The transformer at the 220KV HV Substation must be located at more than 15m from any of the adjoining buildings which have combustible façade or be surrounded by firewalls as defined by AS2067 where these clearances can't be achieved.
8. Smaller transformers (i.e., switch gear and BESS transformers) located in accordance with the proposed layout in Appendix A, must not have an oil capacity of more than 3,800 litres (3.8 m^3).
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.

2 SCOPE

2.1 GENERAL

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

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

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

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

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

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

2.2 BASIS OF THE STUDY

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

- General Layout, Sheet GA2, received via email on 03/11/2023.
- Red Flag Assessment dated October 2022.
- Review of other BESS fires and installations in particular the Victorian Big Battery fire and the ESV findings.
- CFA Design Guidelines and Model Requirements: Renewable Energy Facilities (Version 4, August 2023).
- Megapack 2XL Deflagration Analysis. Fire & Risk Alliance, LLC. Report, Revision 0, dated 15/06/2023 [2].
- Fire Protection Engineering Analysis. Fisher Engineering. Project reference 22035, dated 23/01/2023 [3].
- Industrial Lithium-Ion Battery Emergency Response Guide. Tesla INC. revision 2.6, 2022 [4].
- Megapack 2 XL Design and Installation Manual. Tesla INC. Revision 2.0, 2023 [5].
- Megapack 2 XL Operation and Maintenance Manual. Revision 1.0, 2023 [6].
- Planning permit number PA2302247, dated 17 November 2023.

3 Risk Assessment Methodology

3.1 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 2.

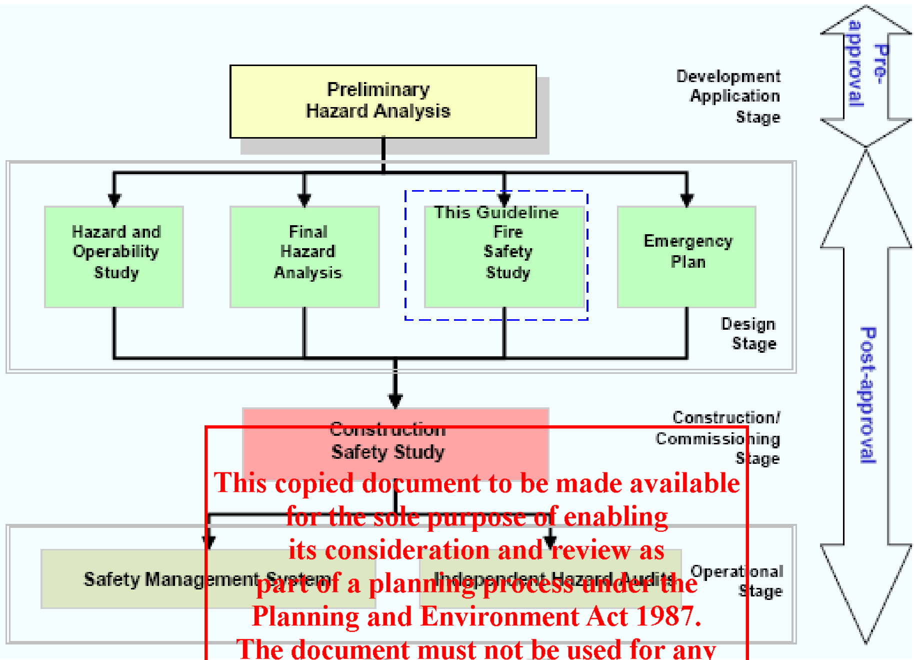


Figure 2: The Hazards-Related Assessment Process

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. 10 – Land Use Safety Planning (Consultation Draft).

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

3.2 Risk Management

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

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

Table 1: Risk Control Effectiveness

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

The following table was used to rate the likelihood of different risks occurring (Table 2) that has been extracted from Appendix G of AS5139:

Table 2: Example likelihood of occurrence rating

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

3.3 Consequence Rating

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

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

Table 3: Consequence rating Appendix G AS5139

Table G.1 — Typical risk consequence table

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

3.4 Risk Criteria

The likelihood and consequences of a risk occurring were used to determine the risk rating of either catastrophic, major, moderate, minor or insignificant. The matrix below was used to provide a visual method of categorising risks based on their risk rating.

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

Table 4: Risk 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

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

Table 5: Risk Treatments

Avoid:	Do not proceed with the activities that create the risk.	
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:	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	

3.5 Fire Spread Acceptance Criteria

- IEEE Std 979-2012:

Table B.3 of IEEE Std 979-2012 [7] gives some typical examples of the amount of radiant heat necessary to ignite common materials used in substations.

IEEE Std 979-2012
IEEE Guide for Substation Fire Protection

Table B.3—Radiant heat flux level and damage

Impact of radiant heat flux	Heat flux (kW/m²)
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
Plastic melts	12.5
Pain threshold reached after 8 s Second-degree burns after 20 s	9.5
Possible failure of ceramic bushings	5
Skin burns	5

Figure 3: Typical radiant heat flux intensities-based IEEE Std 979-2012 [7]

Ausgrid Network Standard NS187 [8] parameters will be considered to assess the porcelain supports of ROI OHL Steelworks.

Item	Maximum allowable radiant heat flux (kW/m^2)	Comment
Porcelain bushing/Insulators	12.5	Damage may occur requiring replacement or in extreme case resulting in catastrophic failure.

- AS 1530.4-2014:

Where other façade/lining materials are present in adjoining building or equipment, Table A3 of AS 1530.4-2014 [9] contains a listing of heat flux required for radiant ignition for piloted and unpiloted ignition. The heat flux (q_{cr}) level for piloted ignition is taken as 13 kW/m^2, and for non-piloted ignition is taken as 25 kW/m^2. Refer to Figure 4.

Typical radiant heat flux intensities to cause various phenomena are tabulated in Table A3.

TABLE A3

TYPICAL RADIANT HEAT INTENSITIES FOR VARIOUS PHENOMENA

Phenomena	kW/m^2
Maximum for indefinite exposure for humans	
Pain after 10 s to 20 s	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 black drill fabric after a long time	38
Non-piloted ignition of cotton fabric after 5 s	42
Non-piloted ignition of timber in 20 s	45
Non-piloted ignition of timber in 10 s	55

Figure 4: Typical radiant heat flux intensities based on AS 1530.4-2014

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/m^2 at 2.0 m AFFL.

4 BESS Facility Description

4.1 Location

The Elaine BESS is located at Elaine Victoria (225 Elaine-Blue Bridge Road), towards the west of Melbourne as shown below (Figure 5), next to the existing Elaine Terminal Station.

Figure 5: Site Location

The subject Elaine BESS is bounded by the existing Elaine Terminal Station to the east, and by agricultural land to the north, west and south sides.

As described in the Red Flag Assessment, *"the north is agricultural land extending to the Mt Doran State Forest, to the east is the Ballarat – Geelong Railway Line with several dwellings on the eastern side of the tracks, to the south is the Lal Lal Wind Farm which is the most visually dominant aspect of the surrounding area, and to the west is the Midland Highway"*. Elaine BESS can be accessed through Midland Highway and Murphys Road on the south-west of Elaine BESS.

Figure 6: Site geography

4.1.1 Land Zones

The site and its surroundings are classified as farming zones (FZ) and Bushfire prone areas in accordance with the Vicplan zoning maps (Figure 7 and Figure 8). It is noted that the subject site is not BMO (Bushfire management overlay).

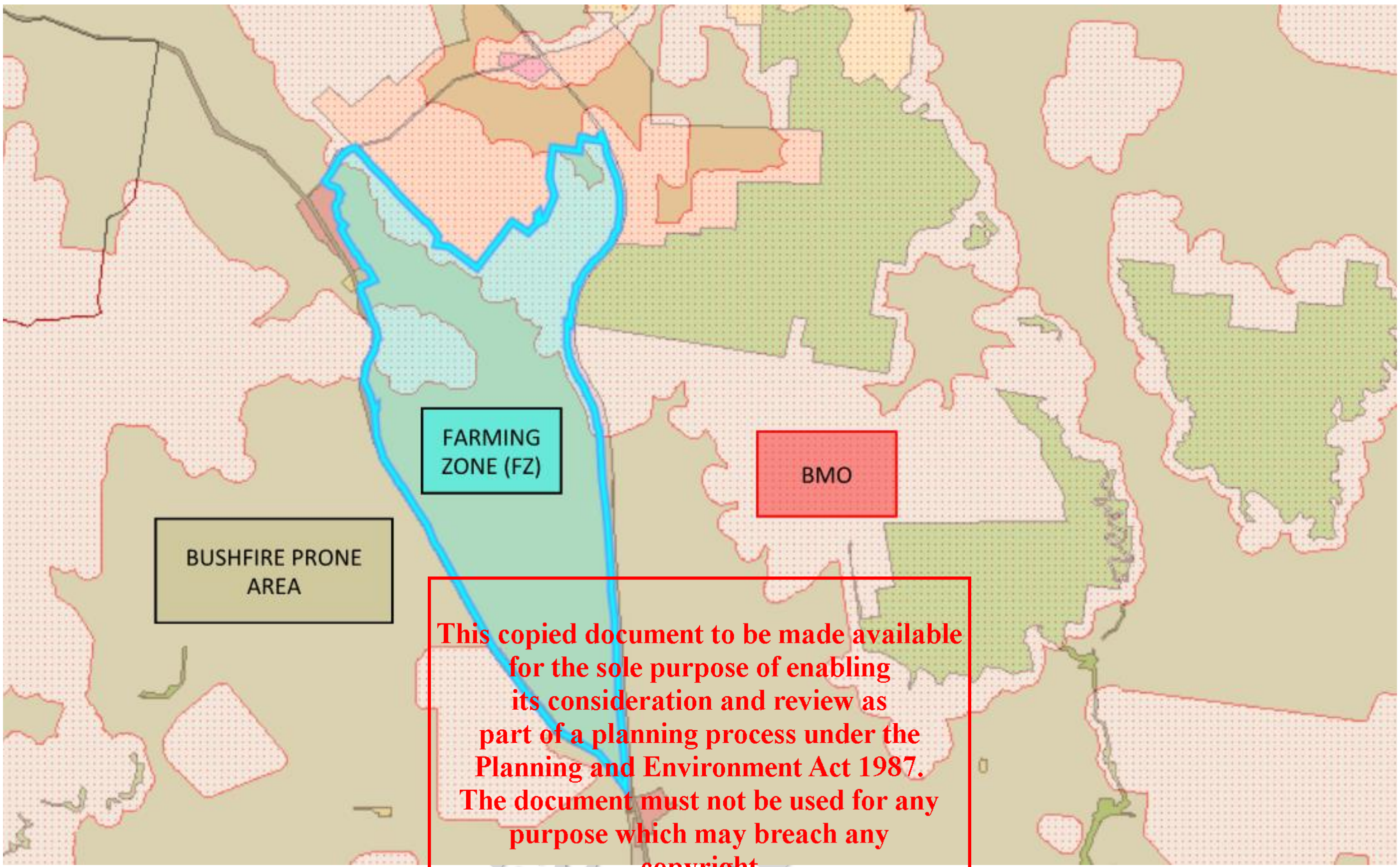


Figure 7: Site and surroundings Zoning (farming)

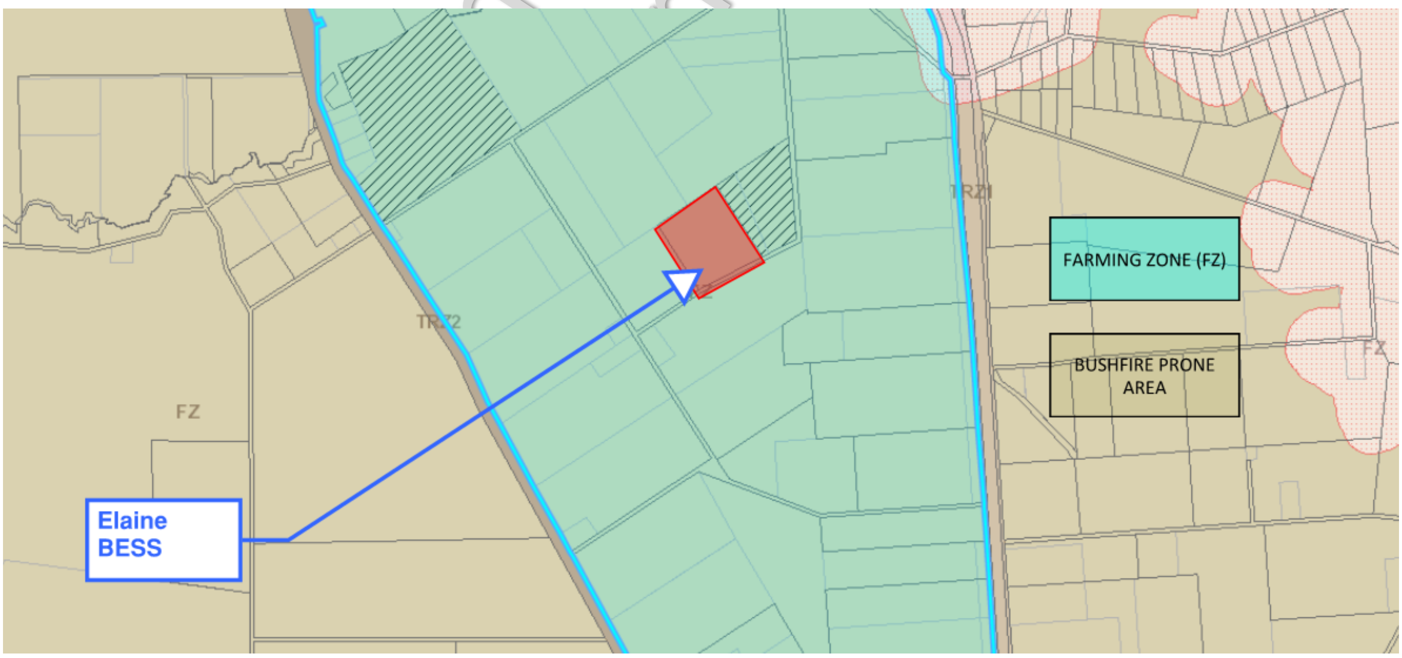


Figure 8: Site Zoning (farming)

4.1.2 Elaine weather conditions

The closest weather station to Elaine Terminal station is Durdidwarrah. In accordance with the available data, the average weather conditions are the following (Figure 9):

- The average temperature is 17°C and the highest mean maximum temperature is 24.1°C for the month of January.
- The mean relative humidity is 74%.
- Wind statistics (Figure 10):
  - Wind is calm 10% of the time.
  - The strongest wind comes from the north with a speed of more than 40 km/hr (11.1m/s), approximately 2% of the time.
  - Wind from the north most of the time (20% of the time), from the west 19% of the time, from the south 9% of the time, and from the east 6% of the time.
  - Average speed of the wind is 3.24 m/s.

Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Years	
Temperature															
Mean maximum temperature (°C)	24.1	24.0	21.4	17.2	13.9	11.1	10.5	11.7	14.0	16.7	19.4	22.2	17.2	77	1903 2000
Mean minimum temperature (°C)	11.3	11.8	10.5	8.5	6.5	4.6	4.0	4.4	5.6	7.0	8.4	10.1	7.7	78	1903 2000
Rainfall															
Mean rainfall (mm)	42.8	47.0	50.3	55.8	57.3	56.6	53.3	60.0	68.0	68.8	63.3	54.8	680.7	140	1874 2022
Decile 5 (median) rainfall (mm)	35.6	30.8	41.1	47.4	53.6	51.5	49.6	57.0	59.9	66.8	51.5	45.9	662.9	129	1874 2022
Mean number of days of rain ≥ 1 mm	5.0	4.8	5.8	7.8	9.4	9.8	10.7	11.4	10.9	10.0	8.0	6.9	100.5	127	1874 2022
Other daily elements															
Mean daily sunshine (hours)															
Mean number of clear days														0	1999 1999
Mean number of cloudy days														0	1999 1999
9 am conditions															
Mean 9am temperature (°C)	17.0	17.0	15.3	12.3	9.5	7.0	6.5	7.5	9.7	12.1	13.7	15.8	12.0	74	1914 2000
Mean 9am relative humidity (%)	66	70	74	80	85	89	88	83	78	73	70	68	77	74	1900 2000
Mean 9am wind speed (km/h)	11.7	9.5	9.9	10.9	9.7	9.9	11.8	13.8	14.3	13.7	12.7	12.3	11.7	30	1965 2000

Figure 9: Durdidwarrah weather statistics.

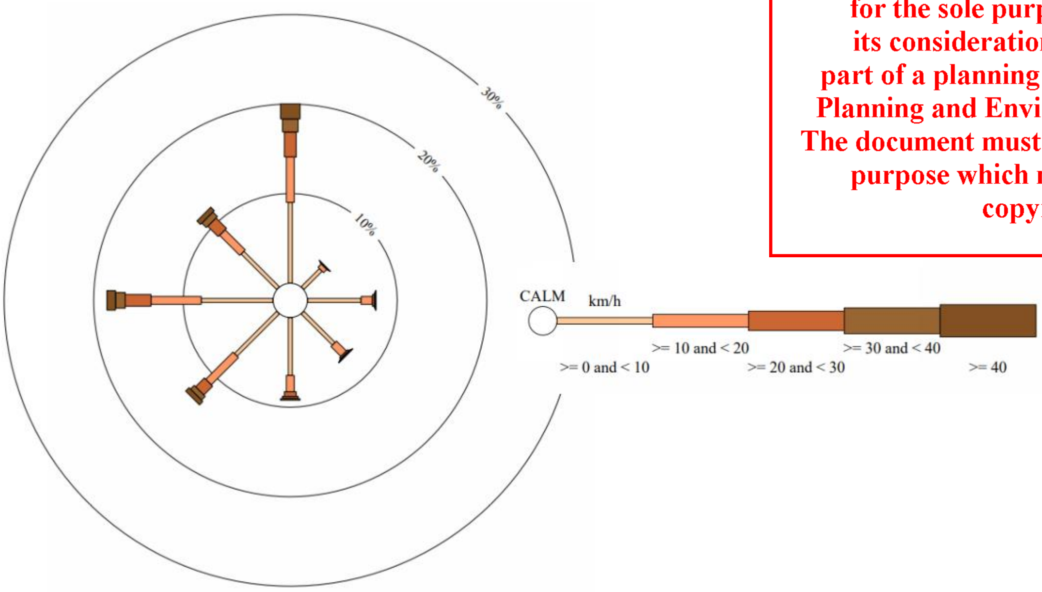


Figure 10: Wind Rose for Durdidwarrah weather station.

4.2 FACILITY LAYOUT

4.2.1 General

Elaine BESS facility is as presented in the plans in Appendix A.

The equipment part of the new facility is the following:

- Battery storage arrays, where each Tesla Megapack is composed by the following:
  - Battery module bays.
  - Thermal cabinets.
  - Customer bay interface.
  - Thermal roof.
  - IP66 enclosure.
- BESS transformers and switch gear. They will use FR3 fluid oil, and their oil capacity is expected to be not more than 3,800 litres (3.8 m^3).
- Rooms for control, operation, and maintenance purposes.
- 220 kV HV Substation. There will be 2 transformers with an approximate capacity of 190MVA. They will use mineral oil and their oil capacity is expected to be not more than 60,000 litres (60.0 m^3). Their bunds' dimensions will be approximately 18m x 10m x 0.35m.
- Water tanks.

As part of the layout and safety measures, there are 10m wide firebreaks and 5.0m wide road access as shown in Appendix A. The battery array has the below layout distribution.

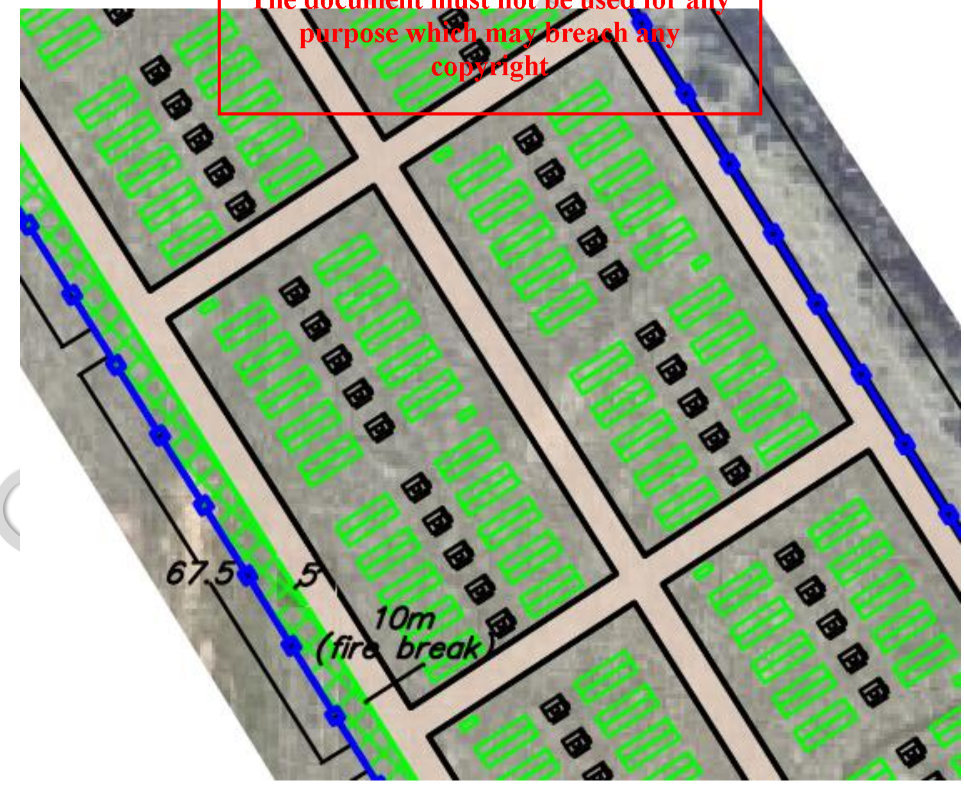


Figure 11 BESS array layout

The facility will be enclosed within a security fence.

4.2.2 Adjacent Properties

The immediate allotments are agricultural land to the north, west and south sides, and the existing Elaine Terminal Station to the east. The existing Elaine Terminal Station is separated from the east boundary of the project site allotment by grassland and mounds.

The main access with be through a road on the south of the allotment by Murphys Road.

All adjoining boundaries are classified as bushfire prone areas where fire spread can occur due to the existing vegetation. A bushfire assessment is addressed in Section 6.4. Figure 12 shows a sample of the adjoining allotments.

Figure 12: Allotments boundaries view.

Given the results of the fire modelling and the UL testing of the Tesla Megapack, fire spread beyond the unit of fire origin or facility is not predicted to occur. The surrounding land use is also not predicted to result in fire spread to the facility (refer to Section 6.5 of this report).

4.3 Fire Brigade

4.3.1 Fire Brigade Stations

The closest fire brigade stations are Elaine Fire Station, located at 6.9km away (Figure 13), and Morrisons Fire Station, located at 13.8 km away (Figure 14). They both access the subject site from the south via Midland Highway and Murphys Road.

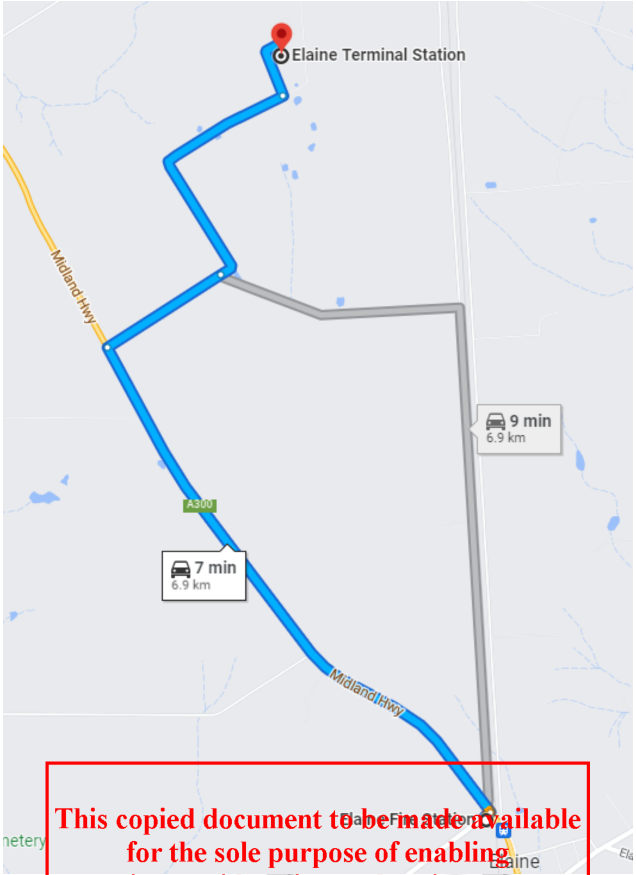


Figure 13: Elaine Fire Station

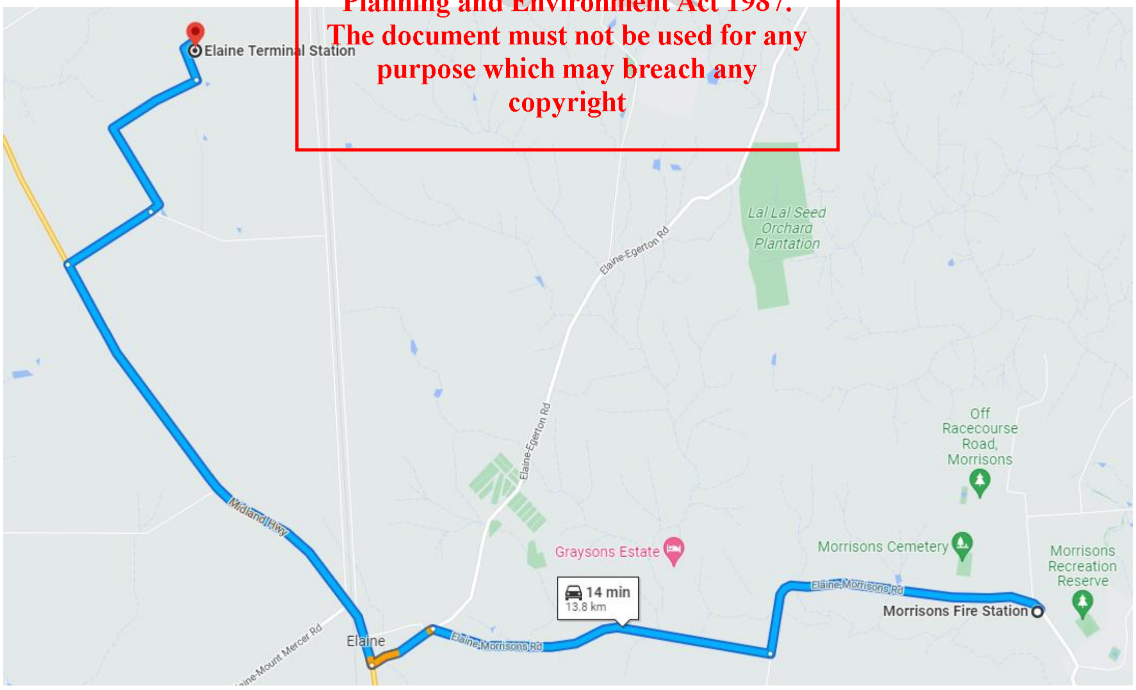


Figure 14: Morrisons Fire Station

4.3.2 Fire Brigade Access

The site has a safe access point direct from Murphys Road on the south-east side of the allotment and a secondary emergency access on the south-west side of the allotment, furthermore, there will be an alternative entrance to be used for emergencies located on the north-west side of the allotment (Figure 15).

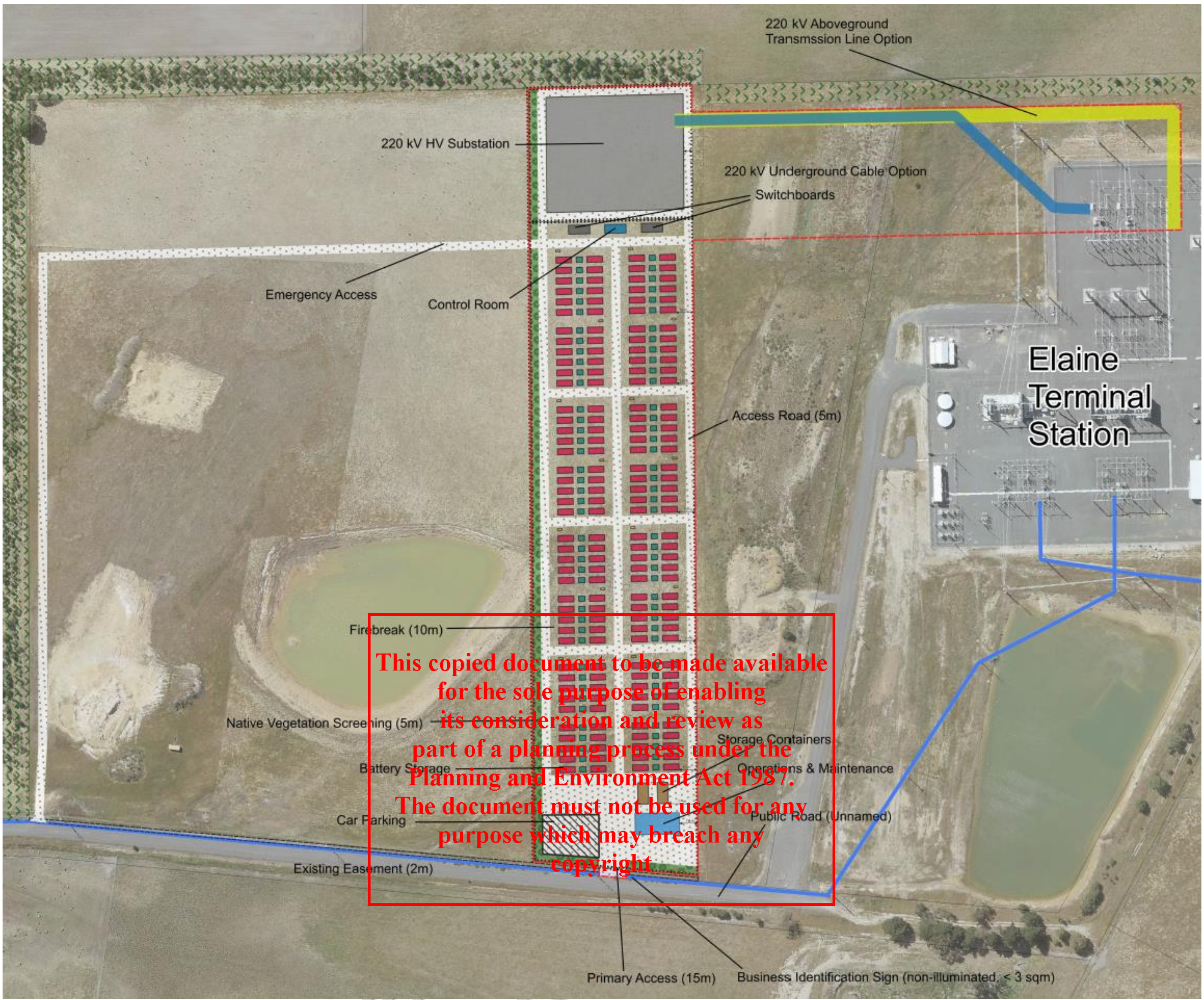


Figure 15: Access roads

The access roads are not less than 5.0m wide, surpassing the requirements of the CFA guidelines. The water tank and main facilities for fire brigade intervention purposes are located at the main entrance so the fire brigade intervention is facilitated, then the road diverges into 2 roads to access either side of the battery arrays (Figure 16) (also see Appendix A).

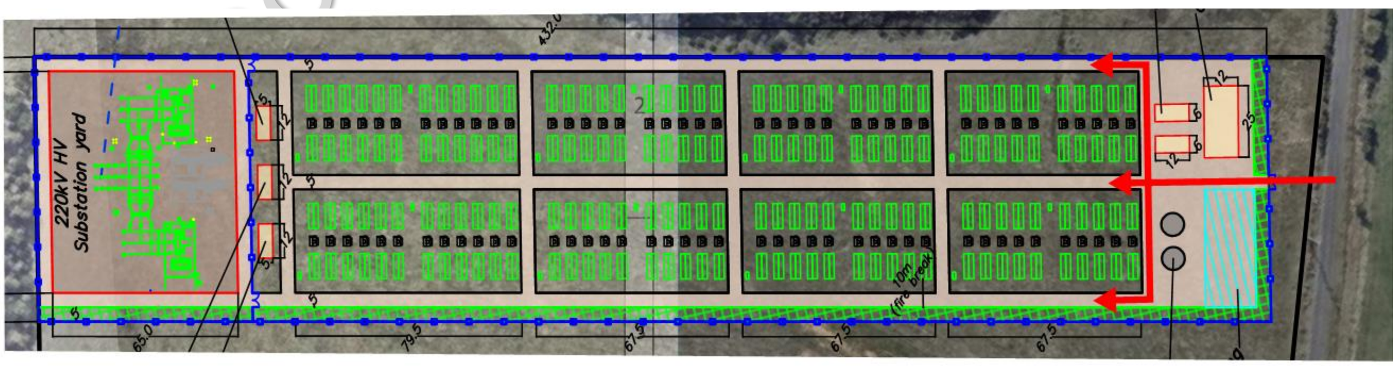


Figure 16: Main site access

The battery arrays (see Appendix A) are separated by no less than 5.0m wide roads for fire brigade track and maintenance purposes, and the roads extend around and within the facility. The fire track will run within the fence that encloses the facility.

Attack fire hydrants are to be located around the fire track such that all areas can be fully covered in accordance with AS 2419.1-2005.

The hardstand surface that is required by AS 2419.1–2005 to be provided to serve feed and attack fire hydrants as well as fire brigade booster connections will be designed in accordance with CFA Guideline (section 7.5) and FRV Guideline 13, Version7, August 2017, i.e.:

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

Further provisions for the fire brigade intervention procedures in accordance with the CFA Guideline are addressed in Section 7.5.

5 Fire Hazards

The subject Elaine 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 adjoining equipment.

The main fire hazards are given by the following equipment:

- Tesla Megapack 2 XL energy storage units.
- BESS transformers and switch gear.
- 220 kV HV Substation.

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.

5.1 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 or exposed to fire, this can trigger thermal runaway and lead to fire and explosion.

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

5.1.1 Past BESS Fires

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

5.1.1.1 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 Elaine BESSS location would only occur approximately 7% of the time, i.e., a probability of 0.07.

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

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

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

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

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

5.1.2 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.

5.1.2.1 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.

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

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

The results of the external ignition test determined the following:

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

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

- A fire in the Powerpack resulted in internal temperatures exceeding 1,093°C.
- 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/m^2 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.

5.1.2.1.2 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 hold [3]. 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.

5.1.2.1.3 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.

[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.

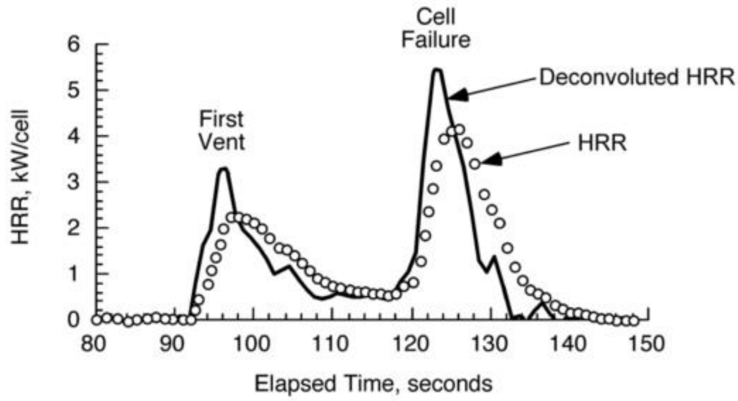


Figure 2. Lithium-ion cell failure at 70% SOC exposed to 50 kW/m^2 irradiance in fire calorimeter; points are data from standard method; solid line is data corrected for instrument response

Figure 17: Results of a single group of batteries

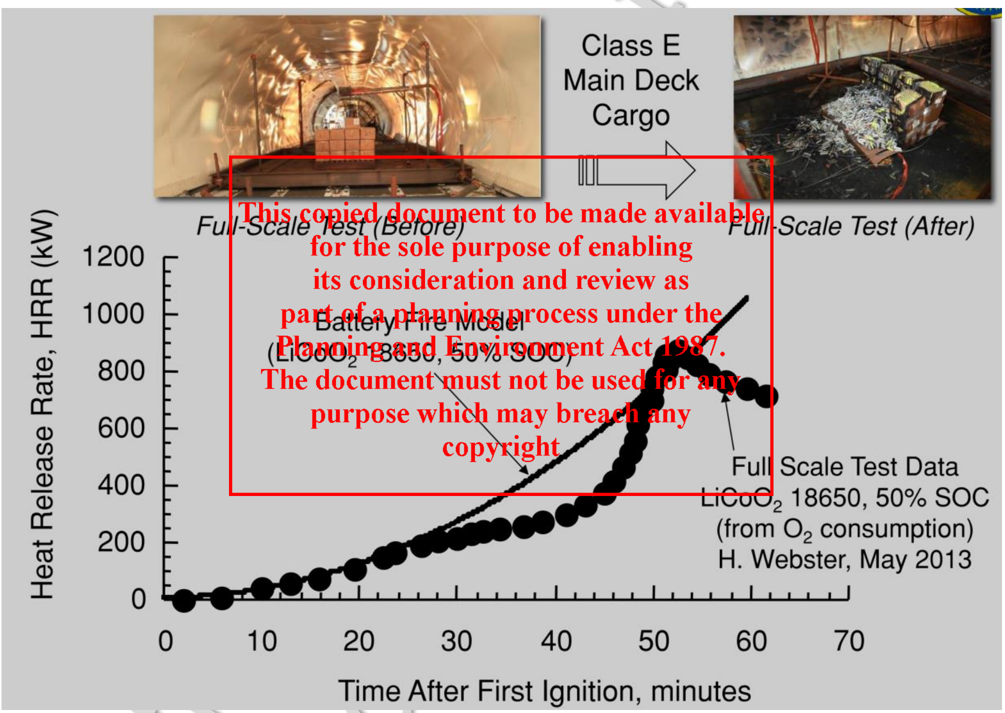


Figure 18: Results of full-scale tests on 18650 batteries

The peak heat release rate is approximately 1MW.

5.1.2.1.4 DNV GL Considerations for ESS Fire Safety

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

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

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

5.1.2.2 Rate of Heat Release

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

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

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

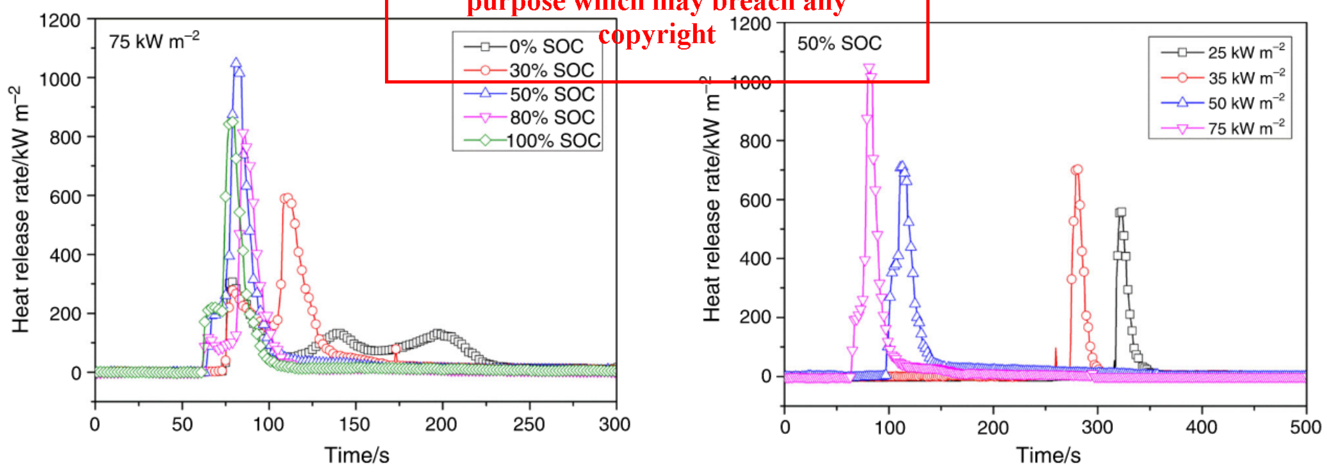


Fig. 7 Heat release rate of batteries at different SOCs under an incident heat flux of 75 kW m^{-2}

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

Figure 19: Tested heat release rates for Lithium-ion batteries

Based on the above review and an average of 200kW/m^2, it is considered that each Battery module bay of the Megapack will have an average heat release rate of approximately 6.0MW, considering that a fire in a Battery module bays’ dimensions are approximately 3.0m x 1.6m x 2.7m (i.e., superficial area of 30m^2) [3].

5.2 Substations

The combustible materials in distribution substations and equipment involved in substation fires may include the electrical wire or cable insulation, transformers (e.g., transformer fluids, especially oil), valves, outdoor or indoor oil-insulated equipment, oil-insulated cable, hydrogen-cooled synchronous condensers, PCB-insulated equipment and other items.

The Ministry of Economic Development (MED) provides annual statistics reports in New Zealand. In accordance with MED, from the substation's fires in New Zealand between 1946 and 1995, 65% of these fires had the electrical wire or cable insulation as the object first ignited (Figure 20). Compared to the cable insulation, the probability of having transformer or transformer fluid as the object first ignited is much lower (20%).

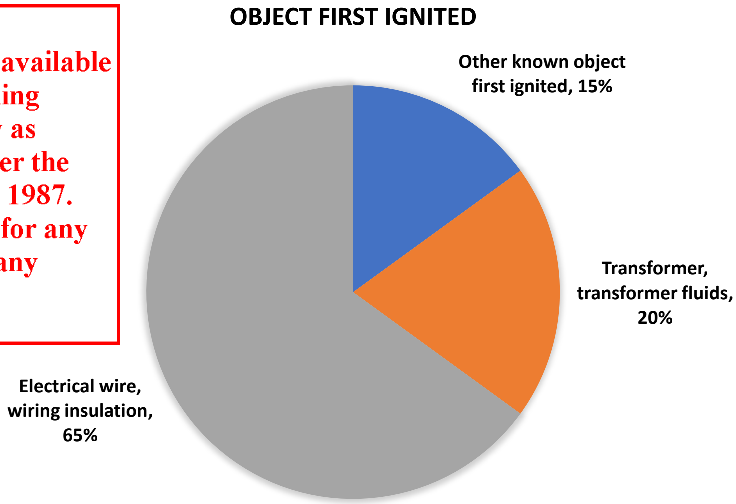


Figure 20: Substation fires distribution.

The EEP (Electrical Engineering Portal) [10] indicates that fires in substation are not common, however consequences are catastrophic for the company and consumers. The EEP lists the types and origins of fires in substations between 1971 and 1994 in Figure 21.

Types and Origins of Fires	Percentages
Oil-insulated circuit breakers	14.0
Current transformers	14.0
Power transformers	9.3
Hot work procedures (welding, cutting, and grinding)	9.3
Potential transformers	7.8
Engine-driven generators	7.0
Arson	6.3
Smoking	6.0
Lightning	4.7
Flammable liquid storage or handling	3.1
Terrorism	1.6
Miscellaneous fires	15.8

Figure 21 – Types and origins of Substations fires. [10]

Also, CIGRE [11] has completed a survey of reliability and failures of in-service high voltage equipment, such as SF_6 circuit breakers, disconnectors, earthing switches, instrument transformers and GIS. The survey gathered data from 90 utilities from 30 countries. The main findings were the following:

- The overall failure frequency for circuit breakers is 0.30 major failures per 100 circuit breaker years of service.

- For disconnectors and earthing switches the overall major failure frequency is determined to be 0.21 major failures per 100 circuit breaker years of service.
- Instrument transformers have an overall failure frequency of 0.053 major failures per 100 single phase instruments transformers years of service.
- In general, individual equipment installed in GIS appears to have lower failure frequencies than equipment in air insulated substations. The overall major failure frequency for GIS bays is about 0.37 major failures per 100 GIS circuit breaker bay years of service (a GIS circuit breaker bay includes one circuit breaker and all associated disconnectors, instrument transformers, interconnecting busducts and/or parts of busbars and associated terminals).

5.3 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., $1x10^{-4}$/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%, $2.1x10^{-4}$/yr.

- The New Zealand Ministry of Commerce, now known as the Ministry of Economic Development (MED), is a government department responsible for the government and 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 22.

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

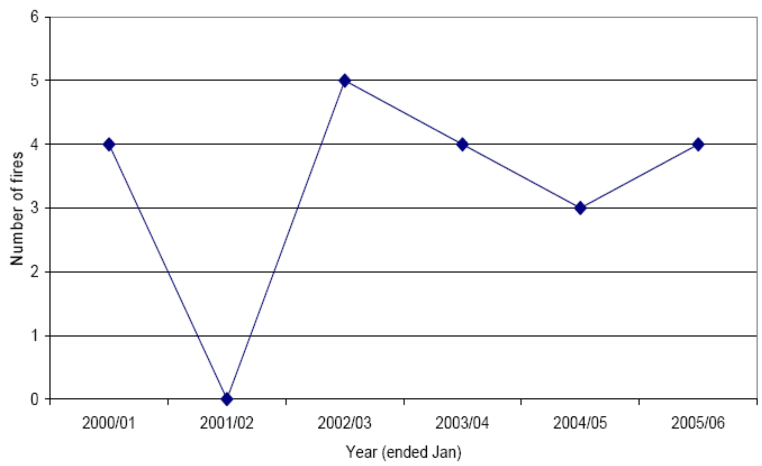


Figure 22: Number of distribution substation fires in 2000/06 (Source NZFS FIRS)

6 Risk Assessment

6.1 Likelihood

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

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

The likelihood of a fire is therefore considered to be Rare.

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

6.2 Consequence

The consequence of a fire in a battery 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, 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 in the Terminal Station, largest transformer could produce a fire of 332MW (Figure 23). 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:

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

Where:

- $\dot{m}_{\infty}$: 0.039 kg/m^{2}s
- $k\beta$: 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.

6.2.1 220KV HV Substation.

In accordance with the methodology described above and considering the characteristics of the transformer of the substation, a bund of approximately 157m^2 with a fire of 197.4 MW (Figure 23) is estimated.

Volume oil	60000.00	L	
	60.00	m^3	
Bund			
Area TK & Radiator	23.00		
Ideal mass loss	0.039	kg/sm^2	
kb	0.70	m^{-1}	
Xx	0.70	Combustion efficiency	
A	157.00	m^2	
V Bund	52.33	m^3	
D	14.14	m	
m"	0.039	kg/m^2.s	$\dot{m}'' = \dot{m}''_{\infty}(1 - e^{-k\beta D})$ (Equation 3.6, *Enclosure Fire Dynamics*)
Hc	4.605E+07	J/kg	
q	1257.10	kW/m^2	
Ballast Factor	1.00	-	Without ballast = 1, with ballast = 0.2.
Q	197.36	MW	$\dot{Q} = A_f \dot{m}'' \chi \Delta h_c$ (Equation 3.5, *Enclosure Fire Dynamics*)

Figure 23: HRR Calculation substation

The FDS model boundary conditions are presented in Figure 24, and the fire scenario characteristics are as follows:

- Fire Origin: Transformer at substation 220KV HV.
- Fire growth: Instant.
- Weather conditions (refer to Section 4.1.2): Wind speed – 3.24m/s; temperature – 17°C; Relative humidity – 74%.
- Heat release rate: 197.4 MW (Figure 23 above).
- Hydrocarbon (transformer fires, properties obtained from Table 3-4.19 of SFPE handbook):
  - REAC ID="REAC"

C=4.00 N=0.00

H=10.00 HEAT_OF_COMBUSTION=4.605 x10^7

O=0.00 SOOT_YIELD=0.0600 gr/gr

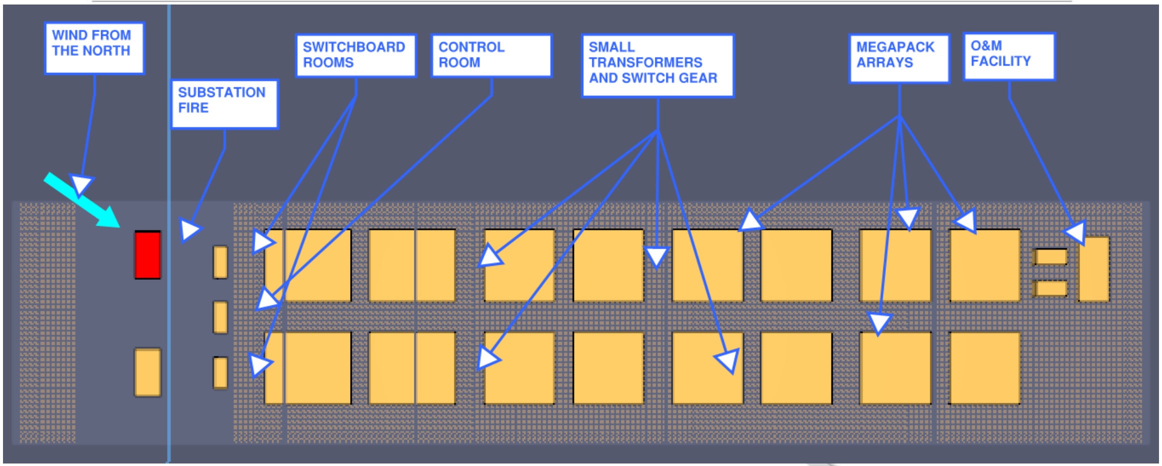


Figure 24 – FDS Model

Given the location of the subject facility equipment, Table 8 below summarizes the heat flux received at the different locations (approximate distances) within Elaine BESS.

Table 6: Heat flux results (Red is not acceptable)

Exposed equipment	Distance (m)	Incident Radiation (kW/m²)	
		No wind (Figure 25)	Wind (Figure 26)
Control room	22.0	< 1.8	< 1.8
Switchboard rooms	22.0	< 1.8	< 7.1
Adjoining transformer within substation	27.0	< 1.8	< 5.4
Megapacks (the closest)	40.0	< 1.7	< 1.7
BESS transformers and switch gear	40.0	< 1.7	< 1.7
O&M Building and water tanks	353.0	< 1.7	< 1.7

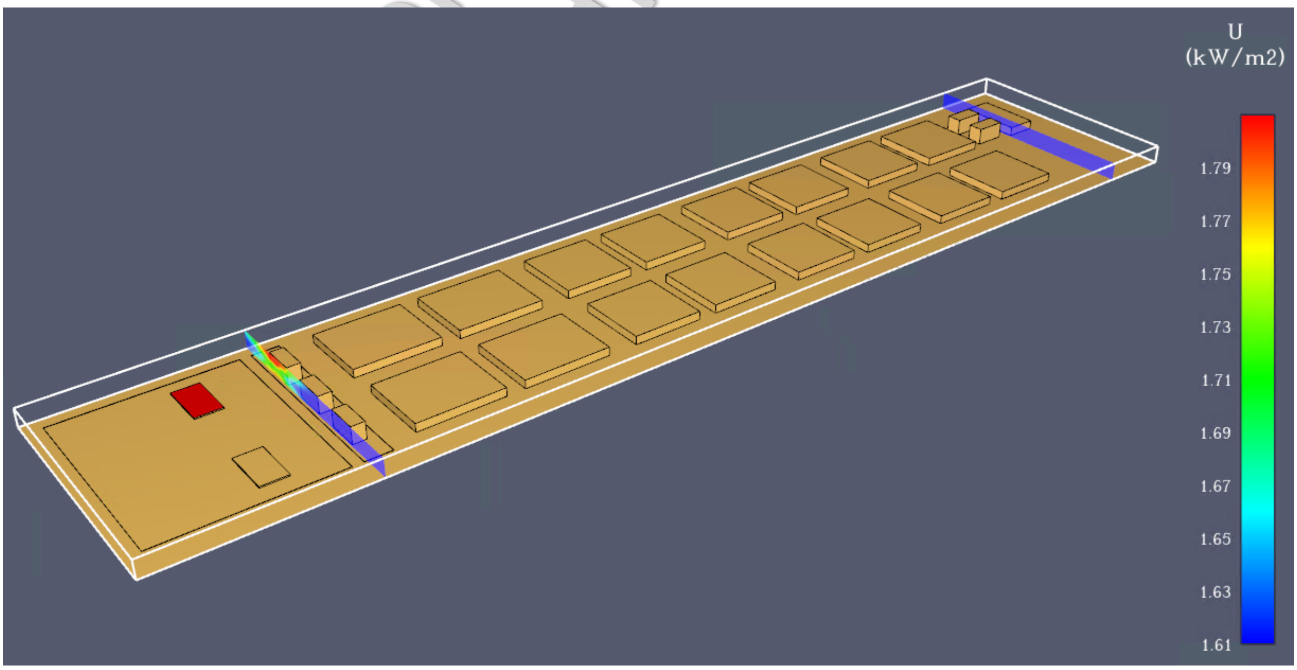


Figure 25: Radiant heat flux intensities without wind

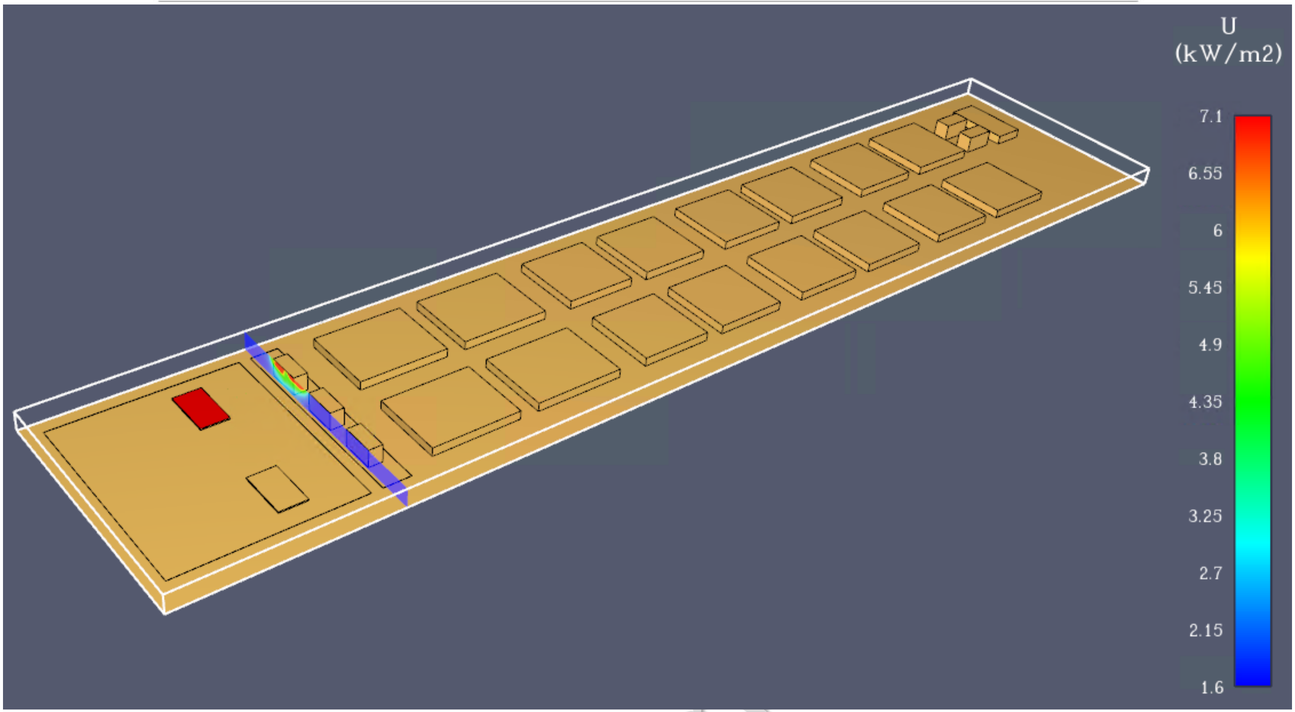


Figure 26: Radiant heat flux intensities with wind

The results indicate that regardless the presence of wind, the maximum heat flux levels received at the different critical locations from a fire in at the substation are well below the critical heat flux for piloted ignition, un-piloted ignition, and for porcelain bushing/Insulators. Hence, fire spread is not expected to occur.

Also, conditions are considered for fire brigade intervention purposes. Based on the results of the model, fire brigade operations may be impacted within a distance of between 12m to 22m from the transformer due to a heat flux higher than 3.0 kW/m^2 (Figure 28).

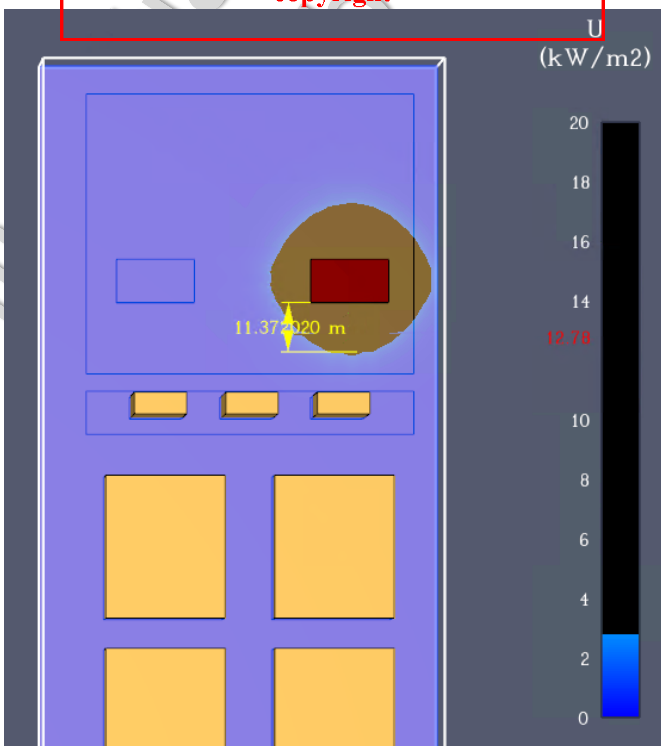


Figure 27: Radiant heat flux higher than 3kW/m^2 without wind

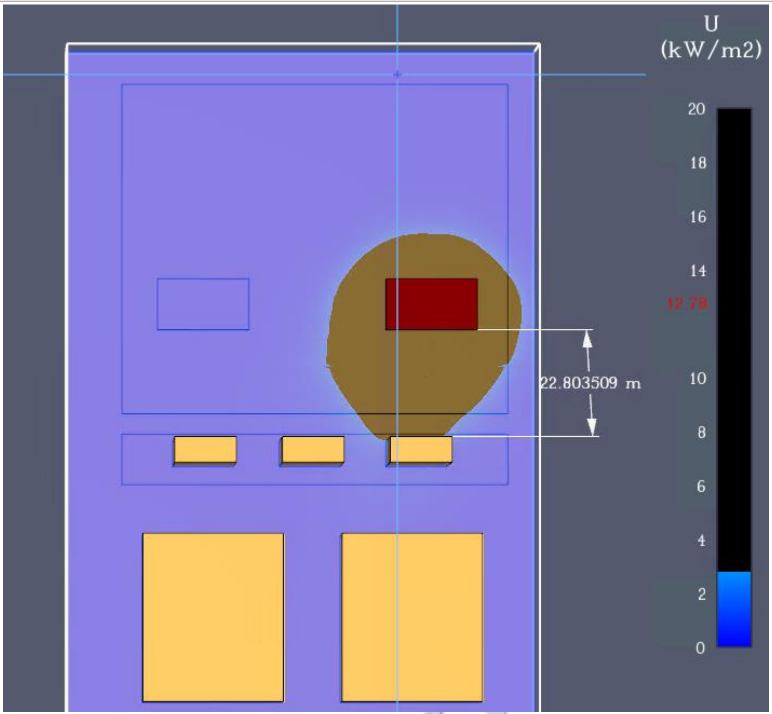


Figure 28: Radiant heat flux higher than 3kW/m² with wind conditions

6.2.2 Smaller transformers (i.e., switch gear and BESS transformer)

BESS transformers and switch gears are located between each array of batteries.

Switch gears and BESS transformers will use FR3 fluid oil, and their oil capacity is expected to be not more than 3,800 litres (3.8 m^3).

Preliminary 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 18m^2 have shown a heat release rate of 15.23MW (Figure 29 and Figure 30).

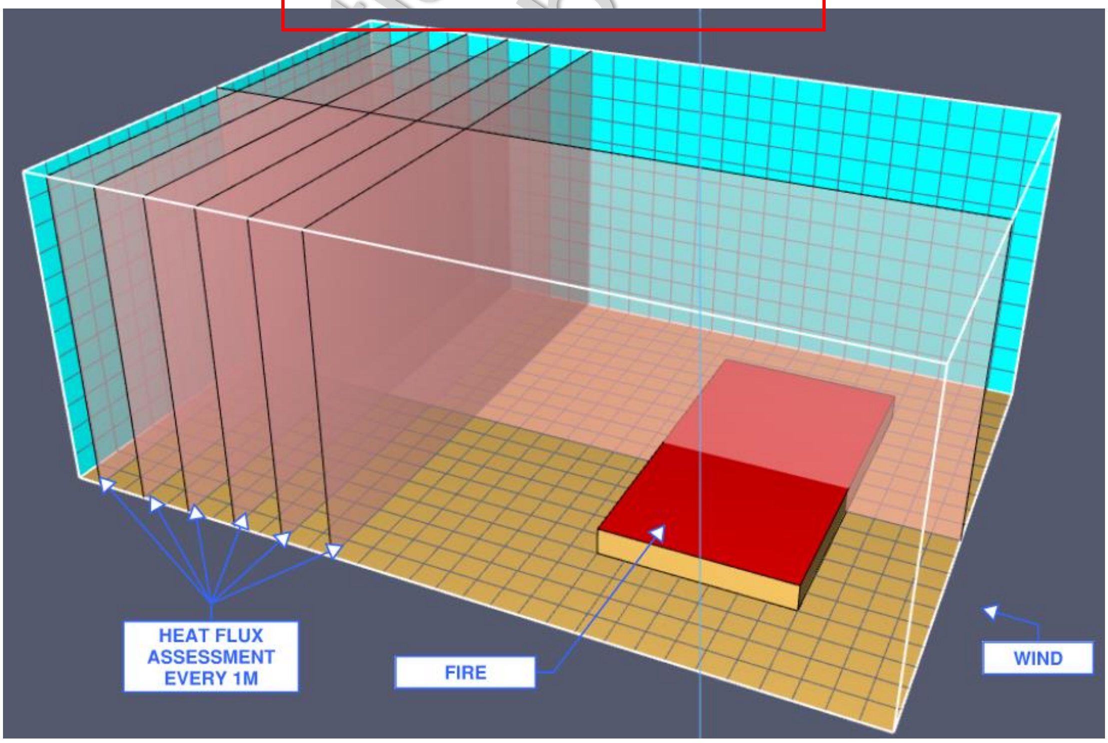


Figure 29: Preliminary fire and smoke modelling

Volume oil	4000.00	L	
	4.00	m^3	
Bund			
Ideal mass loss	0.039	kg/sm^2	
kb	0.70	m^{-1}	
Xx	0.70	Combustion efficiency	
A	18.28	m^2	
V Bund	4.00	m^3	
D	4.82	m	
m"	0.038	$kg/m^2.s$	$\dot{m}'' = \dot{m}''_{\infty}(1 - e^{-k\beta D})$ (Equation 3.6, *Enclosure Fire Dynamics*)
Hc	3.160E+07	J/kg	
q	833.21	kW/m^2	
Q	15.23	MW	$\dot{Q} = A_f \dot{m}'' \chi \Delta h_c$ (Equation 3.5, *Enclosure Fire Dynamics*)
Qc	10659.4	kW	
Density Oil	890.00	kg/m^3	

Figure 30: HRR Calculation BESS transformers

Table 7 below lists the distance between equipment.

Table 7: Distance between equipment

Equipment to assess	Adjoining equipment	Distance (m)
BESS transformers and switch gear	BESS transformer and switch gear	2.9
	220KV HV Substation transformers	40.0
	Megapacks	2.6
	Water tanks	~10.0
	Rooms	≥ 13.0

Table 8 below summarizes the average heat flux received at different distances from a fire in the BESS transformers and the switch gears.

Table 8: Heat flux results (Red is not acceptable)

Distance (m)	Incident Radiation (kW/m^2)	
	No wind (Figure 31)	Wind 3.47m/s (Figure 32)
3.5	7.67	25.18
4.0	6.12	14.39
5.0	3.93	6.21
6.0	2.53	4.03
7.0	1.63	3.02
8.0	1.01	1.90
9.0	0.59	1.08
10.0	0.34	0.68

The results indicate that when wind is not present, the maximum heat flux levels received at 3.5m are well below the critical heat flux for the piloted and un-piloted ignition.

However, when the wind is present, there is a risk of fire spread within 4.0m, heat flux levels are above the critical heat flux for the piloted and un-piloted ignition, and also above the critical value for porcelain bushing/Insulators.

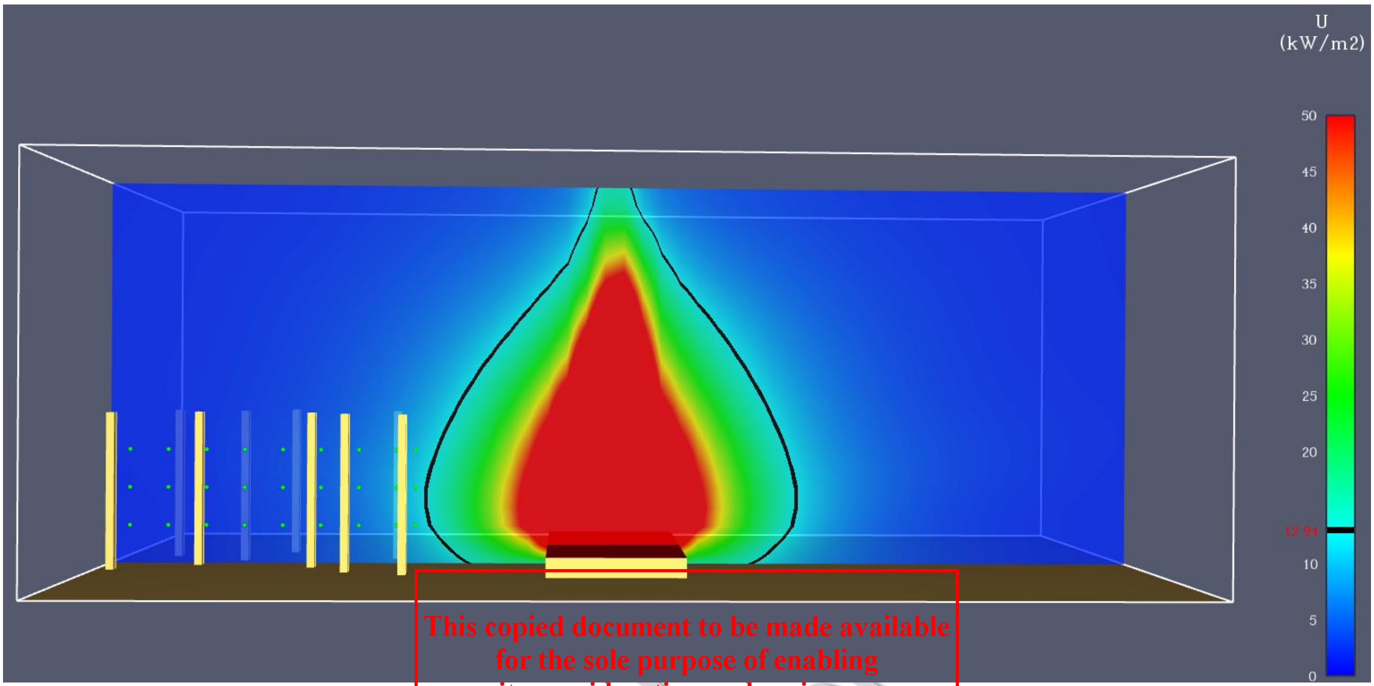


Figure 31: Radiant heat flux intensities without wind

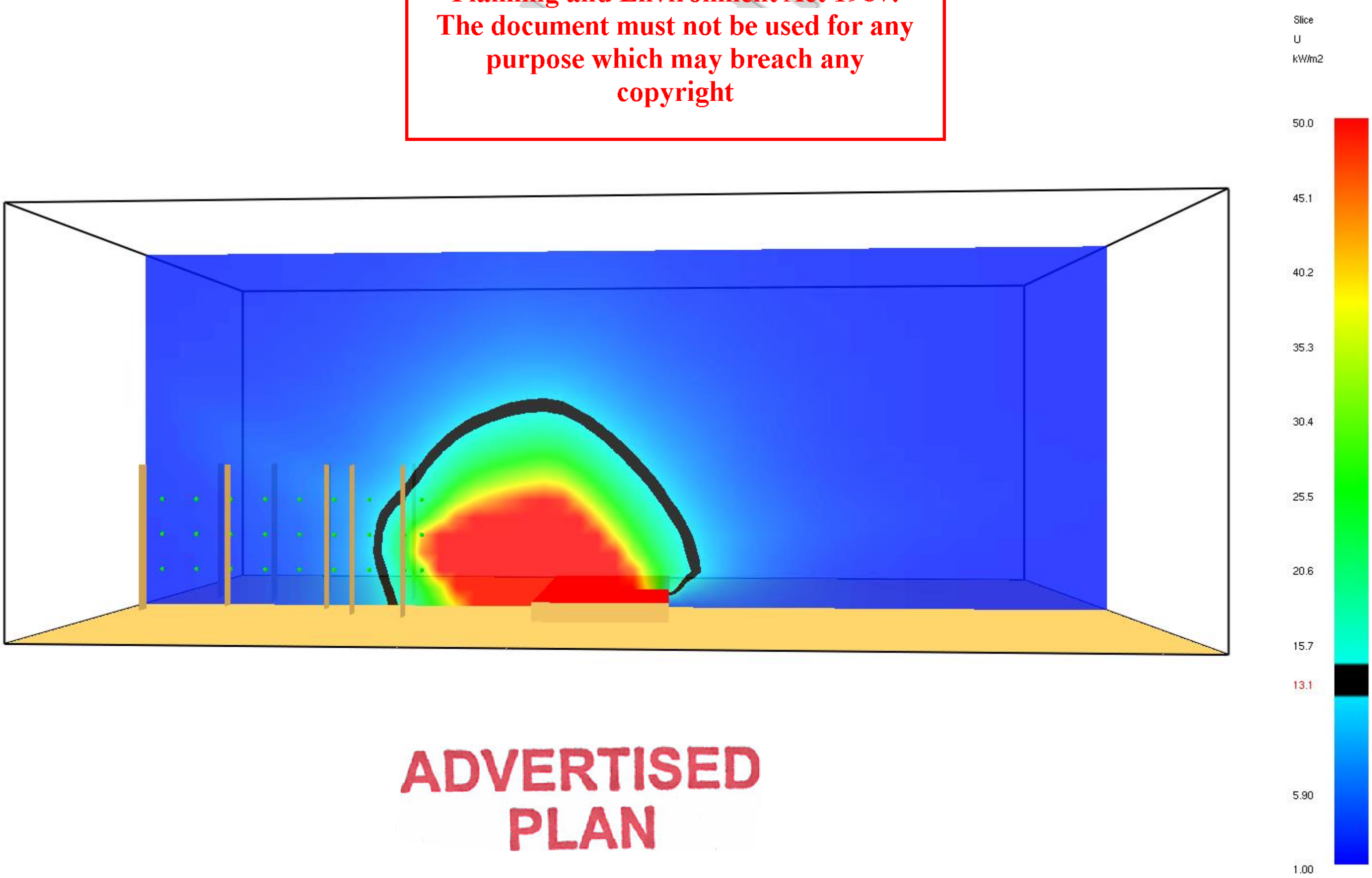


Figure 32: Radiant heat flux intensities with wind

Given the above results, there is only a risk of fire spread from the BESS transformer and switch gear to the adjoining BESS transformer and Megapacks which are separated approximately 2.6m from each other, however the Megapacks and transformers are fully enclosed and require a higher radiant heat flux to be affected. Water tanks and rooms do not have a risk of fire spread in this scenario.

Based on the results of the model, fire brigade operations may be impacted within a distance of 10m from the transformer due to a heat flux higher than 3.0 kW/m^2 (Figure 33) with wind conditions.

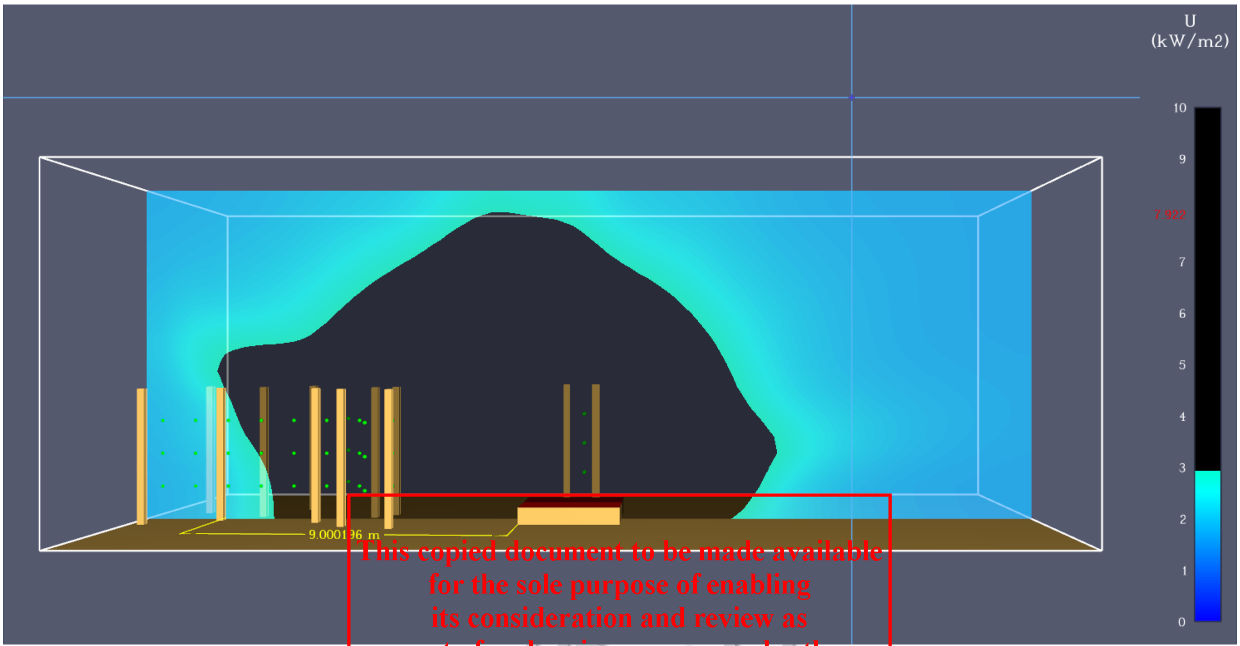
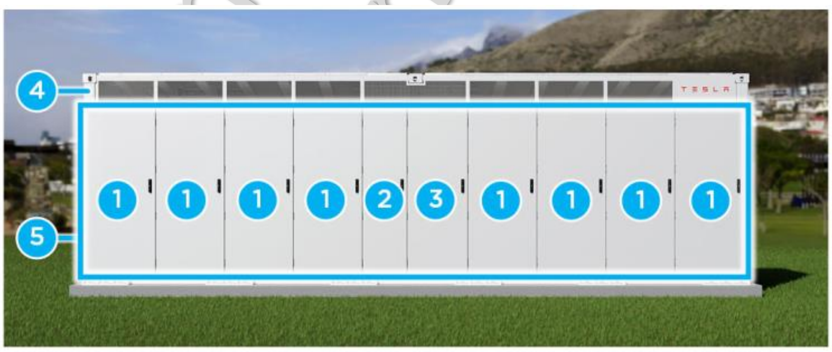


Figure 33: Radiant heat flux higher than 3kW/m^2

6.2.3 Battery Fire - FDS Modelling

The batteries that will be used on site will be based on a Tesla Megapack design. It consists of a modular design with battery module bays, a thermal cabinet, a customer interface bay, a thermal roof and an IP66 enclosure [5].



1. Battery module bays (*Battery Modules on page 11*)
2. Thermal cabinet (*Thermal System on page 12*)
3. Customer Interface Bay (*Customer Interface Bay on page 13*)
4. Thermal roof (*Thermal System on page 12*)
5. IP66 enclosure (*Enclosure on page 13*)

Figure 34: Megapack overview [5].

As described in section 5.1.2.2, in accordance to Zhi Wang's report and the dimensions of the battery storage, if a Tesla battery module bay is on fire, it will achieve an average heat release rate of approximately 6.0MW.

A flashover fire within a battery storage unit has been modelled in accordance with the layout shown in Appendix A, fire tests and installation manuals. This is a conservative model considering that a fire of this scale is not expected to occur.

The model demonstrated the fire spread between Megapacks and fire spread from the Megapack to other rooms or water tanks are not expected if flashover occurs, which is consistent with the Deflagration Analysis and UL9540A test of the Tesla Megapack:

- When flashover occurs, flames and smoke will vent mainly through the top and the upper front top of the energy module. The heat flux level at the adjacent battery units (i.e., 4.0kW/m^2 shown in Figure 35 and Figure 36) is below the threshold for non-piloted ignition (i.e., 25kW/m^2) and damaged to unprotected metal (i.e., 30kW/m^2) as permitted by the of IEEE Std 979-2012 [7] (refer to section 3.5). Similar results occur to Tesla Megapacks, which heat flux models demonstrated heat fluxes of up to 8.5kW/m^2 in adjacent battery packs at 8ft, which are also below aforementioned thresholds (Figure 37) [3].

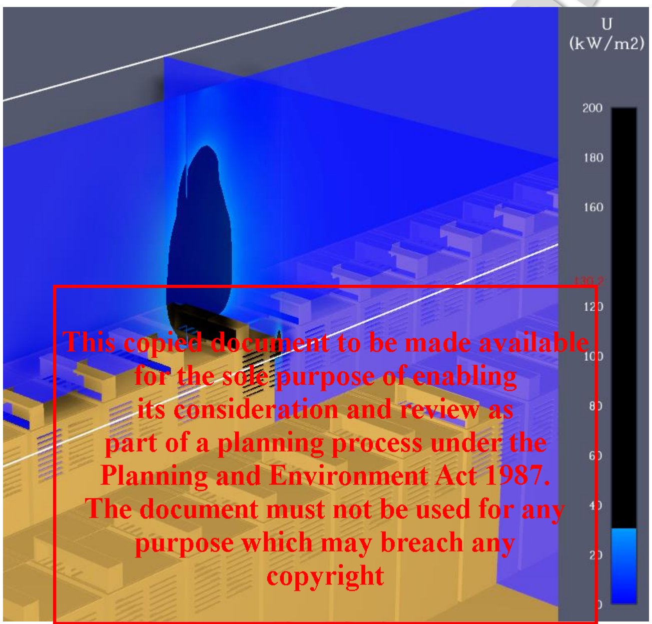


Figure 35: Heat flux at lateral Megapacks.

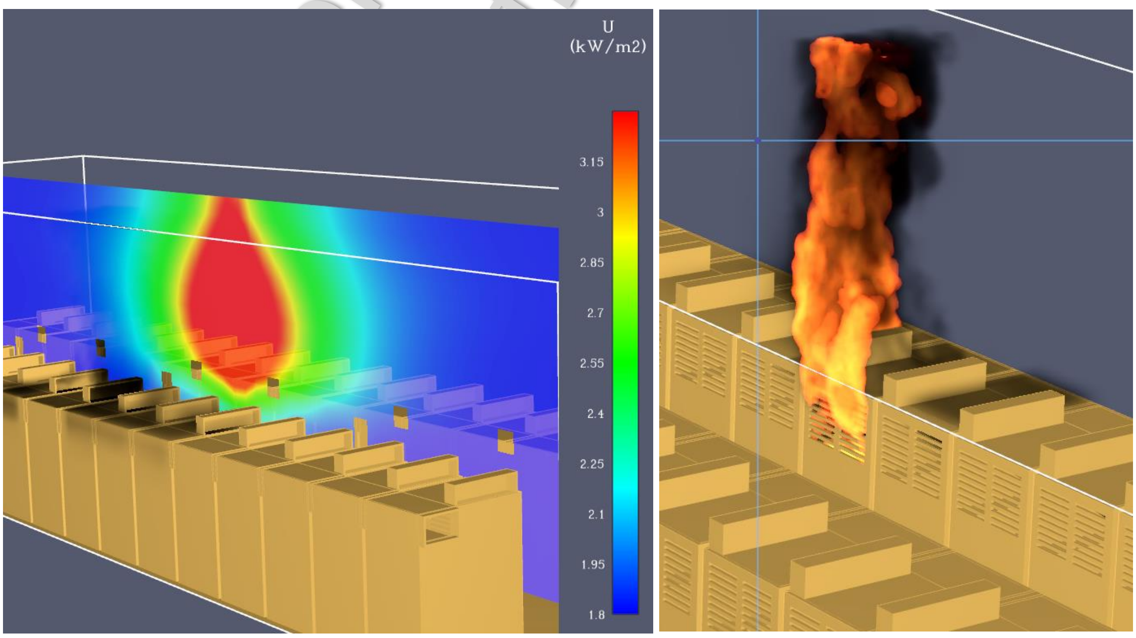


Figure 36: Heat flux at next Megapack row (2.6m apart).

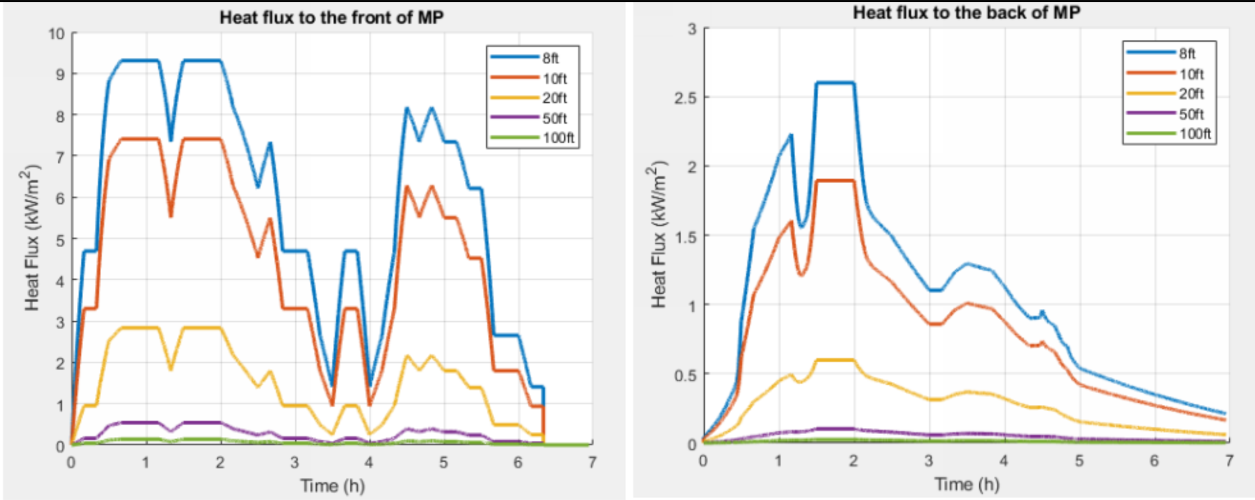


Figure 27 Heat flux versus time as determined by the heat flux model in front of the MP2 cabinet (left) and behind the MP2 cabinet (right).

Figure 37: Heat flux model results at different distances from Tesla Megapack [3].

- Although fire spread is not expected between Megapacks, fire may spread to maximum 1 energy module bay to each side of the fire-origin energy module bay (Figure 38) based on results of the Test as per UP9540A.

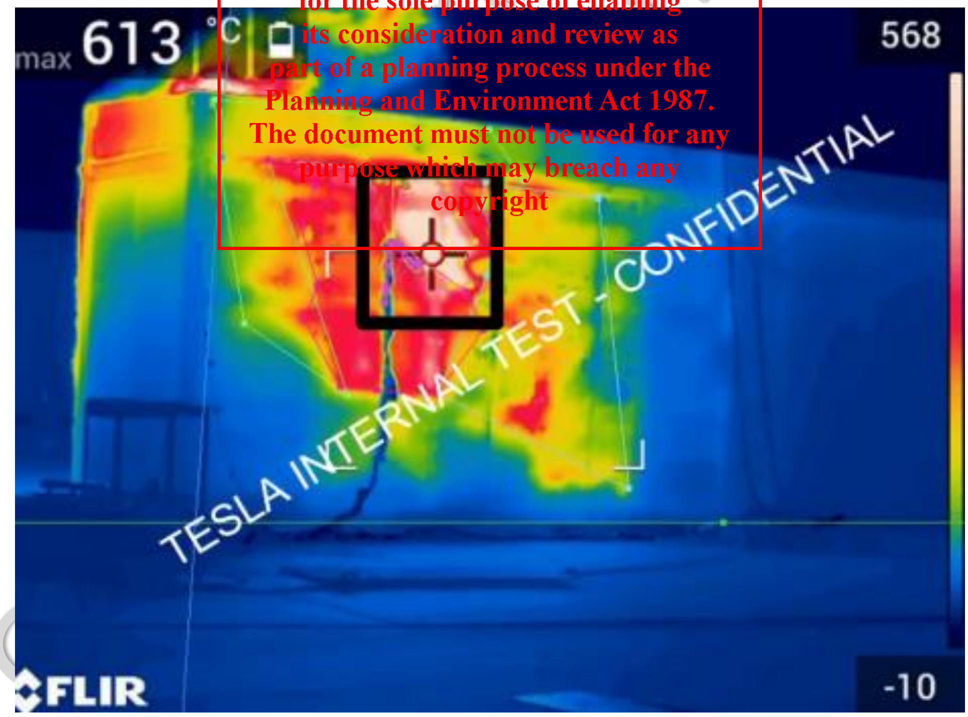


Figure 38: Fire spread between Tesla module bays.

The above results however are subject to a flashover fire. In a real fire scenario, when a battery releases gases, sparkers are installed at the ceiling level of the IP66 battery module bay and towards the bottom of the cabinet to burn those gases safely before they reach dangerous quantity levels. They are designed and programmed to spark regularly to ignite flammable gases that migrate to the top of the cabinet and any flammable gases that accumulate at other elevations within the cabinet, preventing the accumulation of combustible gases to a dangerous level [2].

Further to the sparkers above, Tesla Megapack are provided with the following safety measures to prevent a large fire:

- Overpressure vents.
- An internal safety circuit called an enable circuit (also known as HVIL - high-voltage interlock loop) that shuts down all major power components when other faults are detected.
- Remote shutdown provisions.
- Electrical protection such us overcurrent protection, inverter protection, ground fault protection and lighting strike protection.
- Over temperature.
- Loss of communication.
- Over voltage.
- Isolation, among others.

6.2.4 Battery Fire - CFD Modelling

Fire & Risk Alliance, LLC (FRA) performed a series of CFD models for Tesla to review the explosion control system.

The explosion control system is composed mainly by sparkers and overpressure vents:

- Sparkers are installed at the ceiling level of the IP66 battery module bay and towards the bottom of the cabinet. They are designed and programmed to spark regularly to ignite flammable gases that migrate to the top of the cabinet and any flammable gases that accumulate at other elevations within the cabinet, preventing the accumulation of combustible gases to a dangerous level [2].
- *The overpressure vents are designed to relieve the pressure inside the cabinet before the cabinet fails with a safety factor over 2. This is accomplished through the design of 27 overpressure vents that passively open at an internal cabinet pressure of 12 kPa. The enclosure strength of the MP2XL cabinet exceeds 24 kPa (i.e., 2 times safety factor as required by NFPA 68). Meaning, the overpressure vents open at less than one-half the cabinet strength. Once open, the overpressure vent will continue to ventilate the MP2XL cabinet throughout the duration of a thermal event, reducing the likelihood of additional flammable gas accumulation and deflagrations within the MP2XL during emergency response* [2].

The following is the summary of their findings:

- *The explosion control system design of the MP2XL meets or exceeds the requirements of NFPA 68 and can safely mitigate an internal overpressure during a thermal event via the 27 overpressure vents installed in the ceiling of the battery module bay* [2].
- *Tesla performed a series of CFD models to analyse the dispersion of combustible gases vented during the failure of seven cells within the MP2XL cabinet, as tested during UL9540A unit level testing* [2].
- *CFD modelling demonstrated that the design of the overpressure events of the MP2XL meets the requirements of NFPA 68 in the scenario of seven cells simultaneously going into thermal runaway* [2].
- *CFD modelling further demonstrated that the design of the overpressure events of the MP2XL still meets the requirements of NFPA 68 in the scenario of seven cells simultaneously going into thermal runaway even in the unlikely event of two sparkers failing inside the MP2XL cabinet* [2].
- *An internal gas detection system is not required to mitigate the risk of explosion within a MP2XL cabinet* [2].

- *Based on the CFD dispersion modelling, the sparker system does not permit the sustained accumulation of flammable gases above their flammable limits, either throughout the entire volume of the cabinet or within smaller partial volumes where a gas detection system would be warranted to detect such a scenario* [2].
- *The operation of the passive overpressure vents does not require a gas detection system to actuate their opening, as demonstrated during large-scale fire testing (see FPE report)* [2].
- *Internal gas/fire detection is not necessary to limit fire propagation from one MP2XL cabinet to adjacent MP2XL cabinets, as demonstrated by large-scale fire testing and fire propagation model (see FPE report)* [2].

6.2.5 Battery Fire - Large scale tests (UL9540A)

Tesla performed a large-scale test in accordance with UL9540A at UL in December 2021, where thermal runaway was initiated via film strip heaters installed on both of the wide side surfaces of each cell. The heaters were programmed to increase the temperature of the cell's surface by approximately 4.5 - 4.8°C per minute until the cell vented and went into thermal runaway [3].

The large description of the test is out of the scope of this documents, however further details can be found in the report provided by Fisher Engineering.

The main results of the test are listed below:

- *Cell and module level UL 9540A testing demonstrated that flammable gases vent from the MP2/2XL cells during thermal runaway; however, they do not release toxic gases sometimes associated with the failure of lithium-ion batteries, such as HCN, HCL and HF* [3].
- *Unit level UL 9540A testing demonstrated that the MP2/2XL meets or exceeds all the performance criteria of UL 9540A, Table 9.1 and UL 9540A installation level testing is not required for a MP2/2XL installation.* Six cells were simultaneous heated, they failed and extended the thermal runaway to a seventh cell only. *The failure did not result in any observations of explosion hazards, including but not limited to, observations of a deflagration, projectiles, flying debris, detonation, or other explosive discharge of gases* [3].

  Fire & Risk Alliance, LLC (FRA) and Tesla indicates *that this seven-cell failure event is beyond what has been identified by Tesla's DFMEA, which is based on extensive field data from all Tesla products (EVs and BESSs) and first-principles assessments as a worst-case scenario* [2].
- *Internal destructive unit level testing demonstrated that the MP2/2XL is capable of safely failing in the extreme case of a catastrophic failure of a battery module (**the forced thermal runaway of 48 cells simultaneously**). This destructive unit level test led to a slow progressing fire that burned for 6 hours and 40 minutes until flaming ceased, only consuming one-half of the battery modules in the cabinet* [3].
- *Fire modelling demonstrated that, in the unlikely event of a fire, it would not propagate from one MP2/2XL cabinet to adjacent cabinets installed 6 inches behind, 6 inches to the side and 8 feet directly in front of the initiating MP2/2XL. This result was analysed for both no wind and worst-case wind conditions where flames could tilt towards the adjacent MP2/2XL cabinets* [3].
- *The MP2/2XL explosion control system can mitigate the deflagration hazard even with an extreme failure scenario of a battery module (the forced thermal runaway of 48 cells simultaneously) resulting in the MP2/2XL safely failing* [3].
- *An integral fire suppression system or an external fire suppression system is not required to stop the spread of fire from a MP2/2XL cabinet to adjacent MP2/2XL cabinets when installed at clearances of 8 feet in front, 6 inches behind and 6 inches to the sides* [3]. Elaine BESS design proposes a separation of 8.7ft (2.6m), which exceeds those distances.

- *Manual fire suppression (hose lines) is not required to stop the spread of fire from a MP2 cabinet to adjacent MP2/2XL cabinets when installed at clearances of 8 feet in front, 6 inches behind and 6 inches to the sides* [3]. Elaine BESS design proposes a separation of 8.7ft (2.6m), which exceeds those distances.
- *Based on a review of the MP2/2XL, its fire safety features, UL 9540A test results, additional internal MP2/2XL unit level fire testing and fire propagation modelling, the MP2/2XL can meet or exceed installation level codes and standards, such as the IFC and NFPA 855, required for outdoor, ground mounted BESS installations when installed in accordance with the MP2 and MP2XL Design and Installation Manual* [3]. Currently the MP2/2XL is listed to all product design standards (such as UL and IEC).

6.3 Adjacent Buildings

The adjacent buildings allotment are grassland areas and are expected to be industrial facilities that have either a compliant fire rated wall or a 3m set back from the boundary.

The batteries are located more than 25.0m from the equipment of the substation and at least 10m from the boundary fence.

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.

6.4 Fire in other Area of the facility

The facility contains a control room, two switch boards, two storage containers and an Operations & Maintenance building. The fire associated with these buildings are considered to be no greater than a small office type building. The largest room is Operations & Maintenance that is located approximately 12m from the hardstand.

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

Given the separation distances to the battery units/Megapacks and other areas of over 10m it is considered that the risk of fire spread is extremely low and significantly less than that for a building with NCC compliant separation distances (3m to the boundary) that are considered to represent the community acceptance level for fire spread.

6.5 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 located approximately 10m from the relevant equipment are agricultural areas that have managed grassland, as shown in Figure 39 taken from the Red Flag Assessment.

The east boundary of the project site allotment belongs to Elaine Terminal station. It also has grassland and mounds, and the mounds comprise strips of vegetation which are less than 20m width located to 20m from the equipment. This site must be permanently cleared due to the use of the land.

Figure 39: Vegetation in the adjoining agricultural allotments.

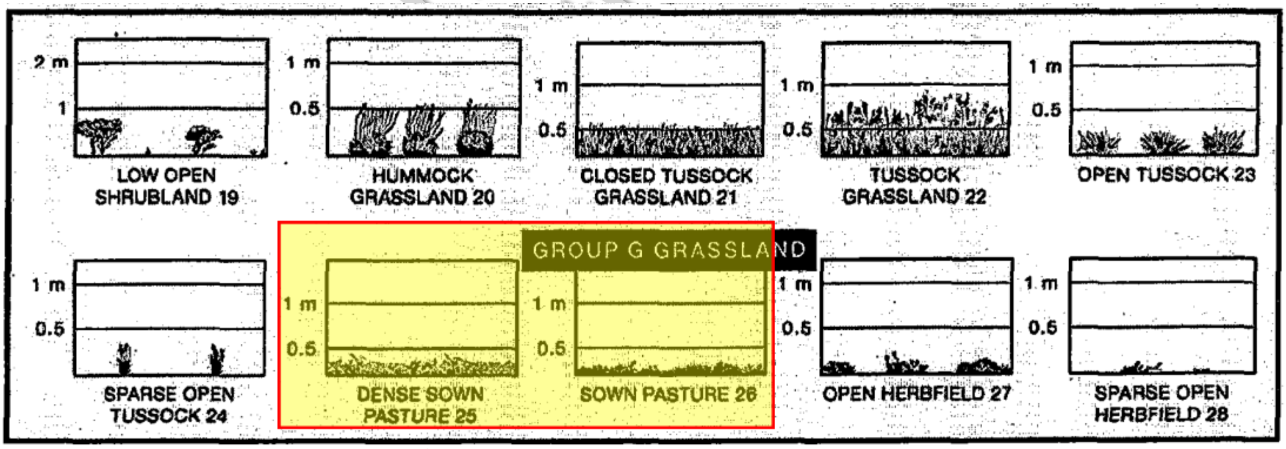
(1) ***FDI Classification:***

In accordance with AS3959-2018 Table 2.1, Victoria has an average FDI of 100.

(2) ***Vegetation classification:***

The vegetation classification has been done based on pictures above.

The adjoining allotments to all sides have managed grassland located at 10m at 0 degrees slope, although the east boundary of the project site allotment also has mounds located at 20m with an approximate up-slope of 5 to 10 degrees. The vegetation is classified as Group G Grassland (figure below).



(3) ***Distance of site from the vegetation:***

The grassland is located at 10m from the equipment.

(4) ***Effective slope:***

The grassland's slope is 0 degrees at 10m to all sides, and an upslope between 5 and 10 degrees to the east side of the project site.

(5) ***BAL Determination:***

In accordance with AS3959-2018, Section 2.2.3.2(f) the grassland and vegetation strips of less than 20m wide with all upslopes are classified and regarded as a low threat (i.e., BAL-LOW), given the flammability, content and low fuel load.

(6) ***Construction provisions:***

Given the above, AS3959-2018 does not suggest or require any construction provisions to be included as part of the design (refer to Appendix C).

7 COMPARISON WITH RELEVANT STANDARDS

7.1 AS 5139 ELECTRICAL INSTALLATIONS – SAFETY OF BATTERY SYSTEMS FOR USE WITH POWER CONVERSION EQUIPMENT

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

Clause 2.2.3 indicates a BESS as having the following components.

a) Power Conversion Equipment (PCE)

b) Battery Interface and Connection

c) Battery System

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

Table 3.1 — Hazard classifications by battery type

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

Key

N/A = not applicable

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

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

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

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

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

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

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 6. However, given the separation between battery arrays/Megapacks is not less 10m, it is considered that the proposed facility complies, and fire spread is not expected.

Large scale tests have also been performed on Tesla Megapacks. The tests demonstrated that fire will not spread to adjoining equipment and will remain within the energy unit. As part of the emergency procedures, the Response Emergency Guide indicates the following: "*Allow the affected unit to consume itself as it is designed to do. Applying water to the burning unit will only slow its eventual combustion*", hence fire spread is also not expected from the equipment providers.

- 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 other buildings and 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. 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 United Energy instantaneously. The design is therefore considered to comply with clause 4.3.8.
- Clause 5.2.4 Protection against the spread of fire requires that the equipment shall not contribute to the spread of fire in accordance with AS3000 Clause 1.5.12 which states:

1.5.12 Protection against the spread of fire

Protection shall be provided against fire initiated or propagated by components of the electrical installation.

Electrical equipment shall be selected, installed and protected such that the equipment will not—

(a) obstruct escape routes, either directly or by the products of combustion; or

(b) contribute to, or propagate a fire; or

(c) attain a temperature high enough to ignite adjacent material; or

(d) adversely affect means of egress from a structure.

NOTES:

1 Clause 2.9.2.5 (h) contains requirements for the placement of switchboards in or near fire exits and egress paths.

2 Clauses 2.9.7, 3.9.9 and Appendix E contain requirements dealing with the prevention of the spread of fire.

The fire spread was assessed in Section 6 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.

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 G.2 — Example likelihood of occurrence rating

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

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

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

Table G.1 — Typical risk consequence table

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

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

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

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

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

The resultant risk matrix is provided in table G.3:

Table G.3 — Risk matrix table

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

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

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

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

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

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

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

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

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

The main fire spread recommendations within the guide are the need for battery storage equipment to be housed in metal enclosures with a minimum thickness of 0.2mm. The subject design complies with this requirement. There is also the requirement for isolation devices and installation distances to be supplied with equipment but no 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.

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

NFPA 855 is under development but deals 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.

7.4 AS2067

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

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

Table 9: AS 2067 Table 6.1

MINIMUM VALUES FOR SEPARATING OUTDOOR TRANSFORMERS

A1

Transformer type	Liquid volume (L)	Clearance G_1 to other transformers or fire resistant surfaces (m)	Clearance G_2 to combustible building surface (m)
Oil-insulated transformers (O)	100 ≤1000	1	6
	>1000 ≤2000	3	7.5
	>2000 ≤20 000	5	10
	>20 000 ≤45 000	10	20
	>45 000 ≤60 000	15	30
	>60 000	25	30
Less combustible liquid-insulated transformers (K) without enhanced protection	100 ≤1000	1	6
	>1000 ≤3800	1.5	7.5
	>3800	4.5	15
Less combustible liquid-insulated transformers (K) with enhanced protection	Clearances G_1 and G_2 to building surface or adjacent transformers		
	Horizontal (m)	Vertical (m)	
	0.9	1.5	
Dry-type transformers (A)	Fire behaviour class	Clearances G_1 and G_2 to building surface or adjacent transformers	
		Horizontal (m)	Vertical (m)
	F0	1.5	3.0
	F1/F2	None	None

The subject facility will have the following transformers:

- BESS transformers and switch gear. They will use FR3 fluid oil, and their oil capacity is expected to be not more than 3,800 litres (3.8 m^3).
- 220 kV HV Substation: There will be 2 transformers that will use mineral oil and their oil capacity is expected to be not more than 60,000 litres (60.0 m^3).

Table 10 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 10: Distance assessment

Equipment to assess	Adjoining equipment	Required Distance (m) as per AS2067	Proposed Distance (m)	Compliant (Yes/No)
220KV HV Substation transformers	All	≥ 15.0	≥ 22.0	Yes
BESS transformers and switch gear	BESS transformer and switch gear	≥ 1.5	2.9	Yes
	220KV HV Substation transformers	≥ 1.5	40.0	Yes
	Megapacks	≥ 1.5	2.6	Yes
	Rooms	≥ 7.5	≥ 13.0	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.

7.5 Design Guidelines and Model Requirements: Renewable Energy Facilities, Country Fire Authority (CFA), August 2023

Section 2.2.2 of the Guide states that the bushfire risk is required to be addressed according to the Victorian Planning Provisions. Given the location of the site is not within a bushfire management zone or a Bushfire Management Overlay (BMO), it is considered that it complies with the requirements. A bushfire assessment has also been performed in Section 6.5 of this document.

Section 3.3.3 states that for BESS facilities the following hazards be addressed:

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

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

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

  Response - No dangerous goods are indicated to be stored on the site. The BESS transformers are considered to be adequately separated. The main transformer of the substation is located at the back of the allotment at a distance of 43m approximately.

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

  Response - The battery units are separated from adjacent properties by over 10m. The batteries are arranged such that each row of the battery array is separated approximately 2.6m from each other. This distance is considered to be acceptable based on the preliminary assessment within this report in section 6.2.

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

  Response - The facility has a security fence such that only maintenance vehicles can access the site. There is a 5.0m wide road around and within the facility and the batteries.

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

  Response - The facility is in a relatively flat area free of vegetation. The closest vegetation is classified as grassland based on AS3595. AS3595 allows grassland to be excluded from the analysis.

Section 3.3.5 also recommends a fire study, Hazardous Industry Planning Advisory Paper 2: Fire Safety Study Guidelines (2011), to be undertaken.

Response – This report is considered to satisfy this recommendation.

Section 4.1 indicates the following are low risk location attributes:

- Grassland.
- No continuous other vegetation types within 1-20km of the project site.
- Generally flat topography, some undulation may be present.
- Slopes are less than 5 degrees.
- Good road access with multiple routes available to and from the project site.
- No BMO applies (also refer to section 6.5).

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

Section 4.2.1 requires the following with respect to fire brigade vehicle access:

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

  Response - A 5.0m wide road is provided around and within the site.

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

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

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

  Response - Roads are not less than 5.0m wide, surpassing the required width.

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

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

- Dips in the road should have no more than a 1 in 8 (12.5% or 7.1°) entry and exit angle.

  Response - The site is relatively flat and complies with the above, however the road design must assure this requirement is achieved.

- Roads must incorporate passing bays at least every 600 metres, which must be at least twenty (20) metres long and have a minimum trafficable width of six (6) metres. Where roads are less than 600 metres long, at least one passing bay must be incorporated.

  Response – All the perimeter roads are not less than 5.0m. The layout will allow alternative egress and access roads.

- Road networks must enable responding emergency services to access all areas of the facility, including fire service infrastructure, buildings, and battery energy storage systems and related infrastructure.

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

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

  Response – The site has a safe access point direct from Murphys Road on the south-east side of the allotment and a secondary emergency access on the south-west side of the allotment. The main access point is remote from the battery units such that a fire in the batteries will not cause the access point to be compromised.

Section 4.2.2 requires the following with respect to firefighting water supply:

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

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

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

Response – Water storage with not less 144kL (based on one hydrant operational for 4 hours as per AS 2419.1-2005) will be provided at the entrance to the facility with a compliant hard stand and booster assembly.

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

  Response – It is considered the design will comply with this requirement.

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

  Response – This matter will be addressed as a condition on the planning permit that requires a Fire Management Plan.

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

  Response – Complies.

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

  Response – It is considered the design will comply with this requirement.

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

  Response – It is considered the design will comply with this requirement.

- The hard-suction point must be positioned within four (4) metres to a hardstand area and provide a clear access for emergency services personnel.

  Response – Complies.

- An all-weather road access and hardstand must be provided to the hard-suction point. The hardstand must be maintained to a minimum of 15 tonne GVM, eight (8) metres long and six (6) metres wide or to the satisfaction of the CFA.

  Response – It is considered the design will comply with this requirement.

- The road access and hardstand must be kept clear at all times.

  Response – It is an ongoing practice that must be part of the Fire Management Plan.

- The hard-suction point must be protected from mechanical damage (e.g., bollards) where necessary.

  Response – It is considered the design will comply with this requirement.

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

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

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

  Response – It is considered the design will comply with this requirement.

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

  Response – It is considered the design will comply with this requirement.

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

  Response – It is considered the design will comply with this requirement.

- For facilities with battery energy storage systems, the fire protection system must include at a minimum: a) Where reticulated water is available, a fire hydrant system that meets the requirements of AS 2419.1-2005: Fire hydrant installations, Section 3.3: Open Yard Protection, and Table 3.3: Number of Fire Hydrants Required to Flow Simultaneously for Protected Open Yards. Except, that fire hydrants must be provided and located so that every part of the battery energy storage system is within reach of a 10m hose stream issuing from a nozzle at the end of a 60m length of hose connected to a fire hydrant outlet.

Response – Table 3.3 of AS2419 is reproduced below:

TABLE 3.3

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

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

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

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

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

The facility site is approximately 40,000m^2 within the security fence and the distribution of the equipment is as shown in Appendix A.

In accordance with the CFA guidelines, the yard area “may be considered that of the battery installation, including the minimum 10m fire break around the battery infrastructure, rather than the entire area of the yard or site”.

For the purpose of this assessment and given the previous fire spread risk review (see section 6.2, which demonstrates that fire spread is not likely within 10m from the BESS battery), the “yard area” will be defined as one of the battery arrays that are separated approximately 15m from each other and separated by a 5m wide road (see Figure 40).

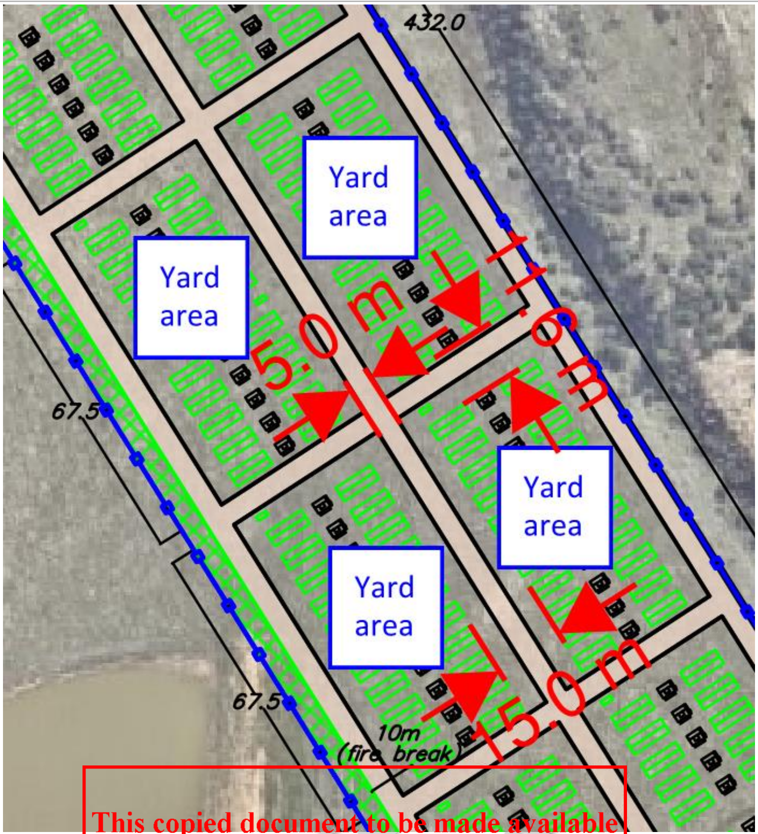


Figure 40: "Yard area" definition.

Each one of these battery arrays has an average are of between 2,400m^2 and 2900 m^2 (i.e., < 3,000m^2), and each 220kV HV transformer yard is approximately 2,500m^2 (i.e., < 3,000m^2). Accordingly, 1 hydrant running for 4 hours is required by the AS 2419.1-2005 for a BESS.

The water storage tank is therefore required to allow for 1 hydrant at 10L/s each for four hours, i.e., 144kL.

When required, a Megapack should be able to be reached by at least two hydrants if one of the hydrants is not accessible due to fire hazard conditions.

- Requirements for Battery Energy Storage Systems (Decentralized) are not included in this document, given that the subject site is not considered a decentralized BESS.

<u>Section 4.2.3 requires the following with respect to fire detection and suppression equipment:</u>

- For on-site buildings and structures, according to the requirements of the National Construction Code.

  Response – Buildings at the facility are considered to comply with the DtS provisions where possible and are considered to achieve the performance requirements of the NCC.

- For storage of dangerous goods, according to the requirements of any Australian Standards for storing and handling of dangerous goods.

  Response – No dangerous goods are indicated to be stored on the site. The BESS transformers are considered to be adequately separated.

- For electrical installations, a minimum of two (2) suitable fire extinguishers must be provided within 3m-20m of each PCU.

  Response – Buildings at the facility are considered to comply with the DtS provisions where possible and are considered to achieve the performance requirements of the NCC. It includes the provisions for the fire protection and extinguish systems (i.e., portable fire extinguishers, fire hose reels and fire hydrants).

- In all vehicles and heavy equipment, each vehicle must carry at least a nine (9)-litre water stored-pressure fire extinguisher with a minimum rating of 3A, or other firefighting equipment as a minimum when on-site during the Fire Danger Period.

  Response – This will be required as part of the fire safety requirements for the subject site; hence it is considered to be compliant.

Section 4.2.4 requires the following with respect to management of Landscape Screening and on-site vegetation:

- Any proposed or existing vegetation must be considered in the Risk Management Plan for its potential to intensify and propagate fire within and away from the site.

  Facilities must be designed so that the radiant heat flux (output) from vegetation does not create the potential for ignition of on-site infrastructure or other vegetation.

  Response – The vegetation around the facility has been assessed in section 6.5 in accordance with AS3959 and risk of fire ignition has been addressed in Sections 6.2.3, 6.2.4 and 6.2.5. It was demonstrated that the risk of fire spread between the vegetation and the facility is not likely to occur. It also considers that there is a 10m perimeter clearance between the facility and the vegetation around it.

Section 4.2.5 requires the following with respect to fire breaks:

- A fire break must be established and maintained around the perimeter of the facility, commencing from the boundary of the facility or from the vegetation screening inside the property boundary, and around the perimeter of control rooms, electricity compounds, substations and all other buildings on-site. The width of fire breaks must be a minimum of 10m, and at least the distance where radiant heat flux (output) from the vegetation does not create the potential for ignition of on-site infrastructure.

  Response – The vegetation around the facility has been assessed in section 6.5 in accordance with AS3959 and risk of fire ignition has been addressed in Sections 6.2.3, 6.2.4 and 6.2.5. It was demonstrated that the risk of fire spread between the vegetation and the facility is not likely to occur. It also considers that there is a 10m perimeter clearance between the facility and the vegetation around it.

Section 4.2.6.4 requires the following with respect to management of Fire Water Runoff:

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

  Response – This matter will be addressed as a condition on the planning permit that requires a Fire Management Plan.

Section 4.3 recommends that battery energy storage systems are equipped with the following elements:

- Battery management/monitoring systems for monitoring the state of battery systems to ensure safe operation.
- Detection systems for smoke, heat (thermal), fire and toxic gas (off-gassing) within battery containers.
- Suppression systems for fire within battery containers.
- Systems to prevent heat/fire spread within battery containers (such as thermal barriers, shut-down separators, isolation systems, cooling systems).
- Systems to prevent explosion within battery containers (such as ventilation, pressure relief and exhaust systems).

- Warning and alarm systems within the battery containers, and/or the facility, to enable early warning for faults, operation of the battery energy storage system above 'normal'/safe parameters, smoke, off-gassing, and fire.

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

7.6 SUMMARY

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

Appendix A. PROPOSED FACILITY LAYOUT

AKAYSHA ENERGY PTY. LTD.
11-13 PEARSON ST
CREMORNE, VIC, AUS

NOTES:
1. 300 MW / 1200 MWh
2. BESS: 336 x TESLA MEGAPACK 2XL
3. PCS:

PROJECT	DRAWN	DESIGNER	DRAWING TITLE	GENERAL LAYOUT	SHEET
***** BATTERY ENERGY STORAGE SYSTEM ADDRESS/COORDS CITY, STATE, COUNTRY, POSTAL	REVIEWED	REVIEWER	PROJECT # AE-XXX	CREATED DD MONTH YYYY	GA2
	APPROVED	APPROVER	REV 1	REV DATE DD MONTH YYYY	

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
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JOHNS CREEK GA 30097

Energy Safety Response Group
8350 US HIGHWAY N 23
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Background

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

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

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

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

Incident Timeline

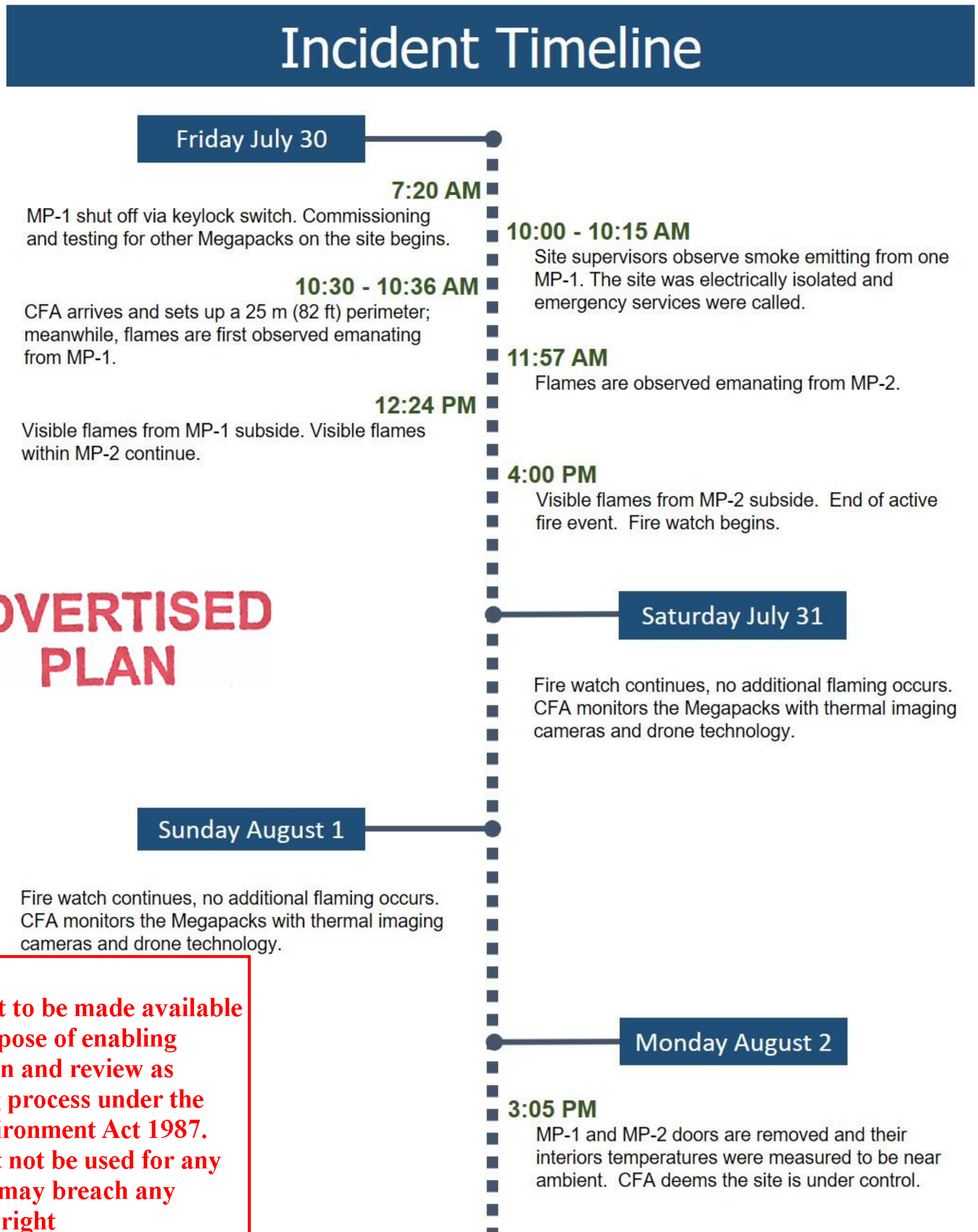
At the time of the fire, the VBB was fitted with approximately one-half of the 212 total Megapacks intended for the site. The Megapacks that were installed at VBB were undergoing routine testing and commissioning on the day of the fire. At 7:20 AM Australian Eastern Standard Time (AEST) on the morning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

1 https://victorianbigbattery.com.au/

2 https://www.tesla.com/sites/default/files/downloads/Lithium-Ion_Battery_Emergency_Response_Guide_en.pdf

3 The keylock switch is a type of "lock out tag out" switch on the front of the Megapack that safely powers down the unit for servicing.

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



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

Investigation

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

Fire Cause Investigation

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

Fire Origin and Cause Determination

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

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

Contributory Factors

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

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

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4 Victoria's energy safety regulator

5 Victoria's health and safety regulator

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

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

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

Fire Propagation Investigation

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

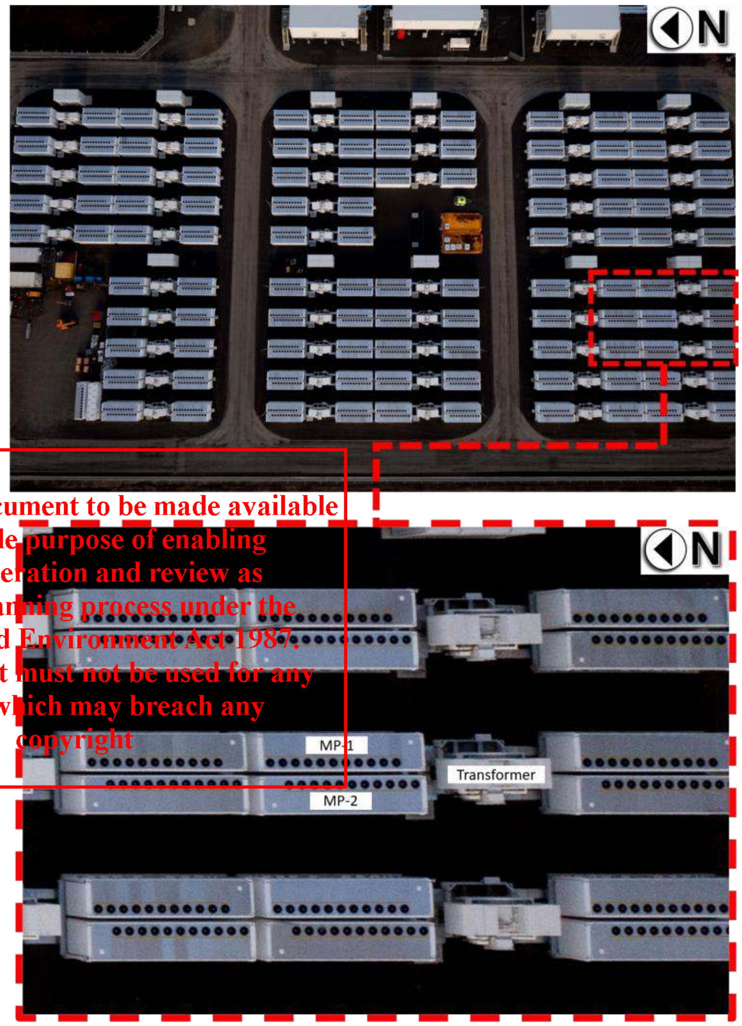

Figure 1 VBB Megapack layout (top) and area of fire origin (bottom)

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

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

Fire Propagation Determination

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

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

Contributory Factors

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

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

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

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

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

Mitigations

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

<u>Procedural Mitigations:</u>

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

<u>Firmware Mitigations:</u>

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

<u>Hardware Mitigations</u>

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

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

Emergency Response

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

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

Key Takeaways

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

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

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

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

Environmental Concerns

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

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

Community Concerns

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

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

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

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

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

Overhaul and Remediation

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

Lessons Learned

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

1. Commissioning Procedures

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

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

2. Electrical Fault Protection Devices

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

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

3. Fire Propagation

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

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

4. Megapack Spacing

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

5. Emergency Response

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

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

Appendix C. AS3959: 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 fitter 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 gound. 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