Revision Date: September 2024

Almonte BESS Site I and II

Fire Risk Assessment

&

Community Risk Analysis

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1 Battery Energy Storage System – Tesla Megapack 2XL

1.1 Almonte Battery Energy Storage System

The Almonte Battery Energy Storage System (BESS Site I and II) are made up of eighteen (18) Tesla constructed Megapack 2XL Units.

The Tesla Megapack 2 XL is a modular, fully integrated, AC-coupled battery energy storage system and utilizes a deflagration control system in the form of pressure-sensitive vents and sparker systems to manage explosion risk. The Megapack 2 XL with a core technology platform (cells, vents, sparker system, etc.) utilizes lithium iron phosphate battery cells provided by Contemporary Amperex Technology Co.

Figure 1-1 Typical Tesla Megapack Unit

Figure 1-2 Typical Tesla Megapack Site Arrangement

2 Fire Hazards

2.1 BESS Failure Modes

In accordance with NFPA 855 Standard for the Installation of Energy Storage Systems the following failure modes require evaluation for consequences.

1. Thermal runaway condition in a single cell, module or unit.
2. Failure of an energy storage management system.
3. Failure of a required ventilation or exhaust system.
4. Failure of a required smoke detection, fire detection, fire suppression, or gas detection system

In the case of the Tesla Megapack 2Xl two additional failure modes required per 2021 International Fire Code (IFC) §1207.1.4.1 have been considered.

5. Voltage surges on the primary electric supply.
6. Short circuits on the load side of the energy storage system.

The Tesla Hazard Mitigation Analysis for the Tesla Megapack 2Xl describes these the failure modes and the anticipated overall effectiveness of protective barriers in place to mitigate the consequences of a battery-related failure.

The ***TESLA Megapack 2/XL Hazard Mitigation Analysis, February 22nd, 2023 | Rev. 4*** may be referred to in **Appendix A**.

2.2 Failure Mode Consequences

During base operations the BESS Lithium-ion batteries do not release flammable gasses during charging, discharging, or normal operations. However, in the event a failure mode occurs and continues unmitigated the following may result:

- Cell / Module fire leading to fire spread beyond containment
- Cell / Module off-gassing leading to explosion.
- Cell failure leading to balance of system fire.
- Environmental hazards

Given the threat of thermal runaway resulting in a fire of a cell, module or unit or the generation of flammable gases resulting in a fire the batteries have been subjected to destructive testing conducted by Tesla on a representative and fully populated Megapack 2 XL. This destructive fire testing utilized a more aggressive approach than what is required by the UL 9540A test method in order to force the system into a more severe cascading thermal runaway event. This destructive test was conducted to demonstrate the Megapack 2/XL's ability to fail in a safe manner, even in the extreme event of a catastrophic failure within an entire battery module.

Figure 2.1 is a Threat / Consequence Matrix. It summarizes the barriers in place to prevent a threat (failure mode) from triggering a hazard event and further summarizes the barriers in place to prevent to the hazard event from continuing to occur or mitigating the consequence it will have.

Figure 2-1 Threat / Consequence Matrices

Threat (Failure Mode)	Hazard Event - Thermal Runaway or Battery Failure	Threat Barrier												
		Battery Management System	*Megapack Management System*	*Module Management System*	*Active Cell Protections*	*Cell Thermal Abuse Tolerance*	*Module Thermal Abuse Tolerance*	*System Shutdown Disconnect*	*Passive Circuit Protection & Design*	*Cell Electrical Abuse Tolerance*	*System Electrical Abuse Tolerance*	*Voltage Monitoring*	*Inverter / Power Control Systems*	**Total Barriers**
	Single Cell Thermal Runaway Condition	X			X	X	X							4
	Multi-Cell Therma Runaway Condition	X			X	X	X							4
	Internal Defect or Failure	X			X	X	X							4
	Module Battery Management System Failure		X					X	X	X				4
	Megapack Battery Management System Failure			X				X	X	X				4
	Site Control (Balance of Plant / System) Control System / Programmable Logic Control (PLC)		X	X				X	X	X				5
	Voltage Surge On Primary Electrical Supply	X						X	X		X	X	X	6
	Ground Fault Short	X							X		X			3
	Hazardous Voltage Condition	X						X	X		X	X	X	6

A Ground Fault Short has the fewest barriers to prevent the failure mode resulting in a hazard event (thermal runaway or battery/cell failure).

Consequences	Hazard Event - Thermal Runaway or Battery Failure	Consequence Barriers							
		Battery Management System	*Deflagration Protection*	*Thermal Isolation Cascading Protection*	*Facility Design & Siting*	*Emergency Response Plan*	*Network Operations Centre*	*Fire Service Response*	**Total Barriers**
	Cell / Module Fire Leading to Fire Spread Beyond Containment	X	X	X	X	X	X	X	7
	Cell / Module Off-gassing Leading to Explosion	X	X		X	X	X	X	6
	Cell Failure Leading to Balance of System Fire	X	X	X		X	X	X	6
	Environmental Hazards	X	X		X	X	X	X	6

Should the hazard (thermal runaway or battery/cell failure) not be prevented a minimum of six (6) barriers are in place to prevent the identified consequences from occurring. In most cases three-four (3-4) barriers are inherent to the design of the Tesla Megapack 2 XL. Facility Siting & design, the development of a Site-Specific Emergency Response Plan and liaison with Municipal Fire Services further establishes barriers to prevent or mitigate identified consequences from progressing.

2.3 UL 9540A Testing

The UL 9540A test method provides a method to evaluate thermal runaway and fire propagation of a lithium-ion BESS at the cell level, module level, unit level, and installation level. The results of the test method can be used to determine the fire and explosion protection systems/features required for a BESS installation. The results of the test may also include thermal runaway characteristics of the cell; cell thermal runaway gas composition; products of combustion; heat release rate; and smoke release rate.

The results of the cell, module, and unit-level test results for the MP2XL are contained in the ***TESLA Megapack 2/XL Hazard Mitigation Analysis, February 22nd, 2023 | Rev. 4*** referred to earlier and contained in **Appendix A**.

An interpretation of the of the testing and summary of the results are retained in the ***Tesla Megapack 2XL - Fire Protection Engineering and UL 9540A Interpretation Report*** which is contained in ***Appendix B.***

However, the following are key findings from the UL 9540A testing.

1. UL 9540A cell and module level testing demonstrated that flammable gases vent from the Megapack 2XL cells during thermal runaway; however, the cells do not release toxic gases sometimes associated with the failure of lithium-ion batteries, such as Hydrogen Cyanide, Hydrogen Chloride or Hydrogen Fluoride.
2. UL 9540A unit level testing forced six cells into thermal runaway, which resulted in propagation to a seventh cell; however, thermal runaway did not propagate beyond the seventh cell.
3. 2. The MP2XL can meet or exceed all the installation level codes and standards, such as the IFC and NFPA 855, required for outdoor, ground mounted BESS installations when it is installed in accordance with the MP2XL Design and Installation Manual.

3 Consequence and Community Risk Analysis

Should an unmitigated failure mode occur, and a BESS unit degrade into a fire the resulting release to the atmosphere may have an impact on the community. To understand these risks Compass has evaluated the surrounding community land use, identified community resources and undertaken consequence modeling to better understand the potential threat to the community should a failure scenario occur.

3.1 Almonte BESS I & II Surrounding Community Land Use

South - Adjacent land use South of the BESS site consists of fallow and active farm lands. Beyond 500 m a grouping of low-density single-family dwellings exist with multiple routes of egress.

West - Adjacent land use West of the BESS site consists of a small woodlot and farm lands. Ramsay Concession 8 is located approximately 725 m to the West.

North - Adjacent land use North of the BESS site consists of a small woodlot and farm lands. A small watercourse flows East from the woodlot towards the Mississippi River located East of County Road 29, approximately 900 m to the North.

East -Adjacent land use East of the BESS site consists of farm lands / 2-3 farmsteads with single-family dwellings. County Road 29 is located approximately 750 m to the East.

3.2 Consequence Modeling

While the ***Megapack 2/XL Hazard Mitigation Analysis and Tesla Megapack 2XL - Fire Protection Engineering and UL 9540A Interpretation Report*** indicate that the cells during thermal runaway do not release any significant concentrations of toxic gases such as Hydrogen Cyanide, Hydrogen Chloride or Hydrogen Fluoride, however, for the purpose of the community risk assessment it was deemed a credible scenario. As such, a summer and winter sequence were developed to look at the potential release of the most harmful compound linked to thermal runaway of batteries and fires; ***Hydrogen Fluoride.***

For the purpose of determining potential consequence zones following an emergency incident involving a Tesla Megapack 2XL Unit Compass has used the ALOHA model. Developed by the U.S. Environmental Protection Agency and U.S. National Oceanic & Atmospheric Administration it is a hazard model used to plan for and respond to chemical emergencies. Modeled consequence zones utilize Emergency Response Preparedness Guidelines (ERPGs) to illustrate potential chemical hazard consequences.

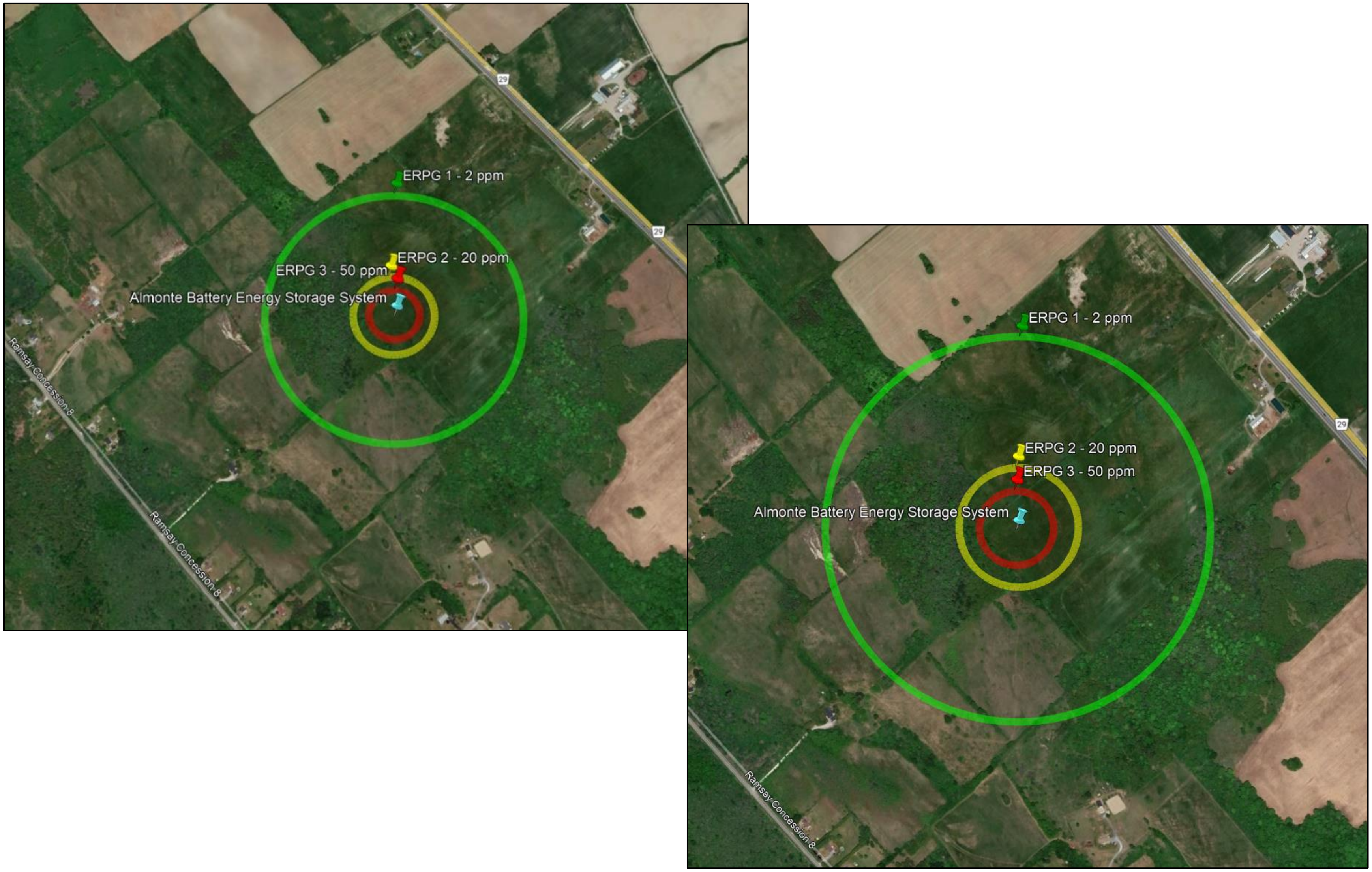
The following table illustrates the Emergency Response Preparedness Guidelines based on the scenario.

Scenario	ERPG 1 (2 ppm)	ERPG 2 (20 ppm)	ERPG 3 (50 ppm)
Summer	307 m	96 m	60 m
Winter	379 m	117 m	73 m

On Page 9 a visualization of the modeled consequences is provided; Summer followed by Winter.

Details of the consequence modeling and associated scenarios can be reviewed in Compass's ***Almonte BESS I & II Emergency Response Plan Appendix E***.

Figure – Summer / Winter Sequence – Hydrogen Fluoride Consequence Zones



Alternatively, based on the Tesla completed UL 9540A testing a mix of decomposition gases will be emitted to the atmosphere. This plume will predominately consist of Carbon Dioxide, Carbon Monoxide, Methane, and Hydrogen. Given this scenario first responders may also refer to the Transport Canada Emergency Response Guidebook – Guide # 147 [Lithium Ion & Lithium-Ion Salt Batteries] which recommends an isolation buffer of 500 m for all public and emergency responders in the event of a fire.

This figure illustrates the location of a 500 m isolation zone in accordance with Guide #147 of the Emergency Response Guidebook.

Figure – Lithium Ion & Lithium-Ion Salt Batteries **Guide #147 of the Emergency Response Guidebook.**

Based on land use and proximity to the Almonte BESS site no significant consequences are anticipated should the site suffer an off-normal event that evolves into a thermal runaway event and/or fire.

4 Design Safety

Compass has selected the Tesla Megapack design for its Battery Energy Storage Systems due to its safety testing results and its safety features.

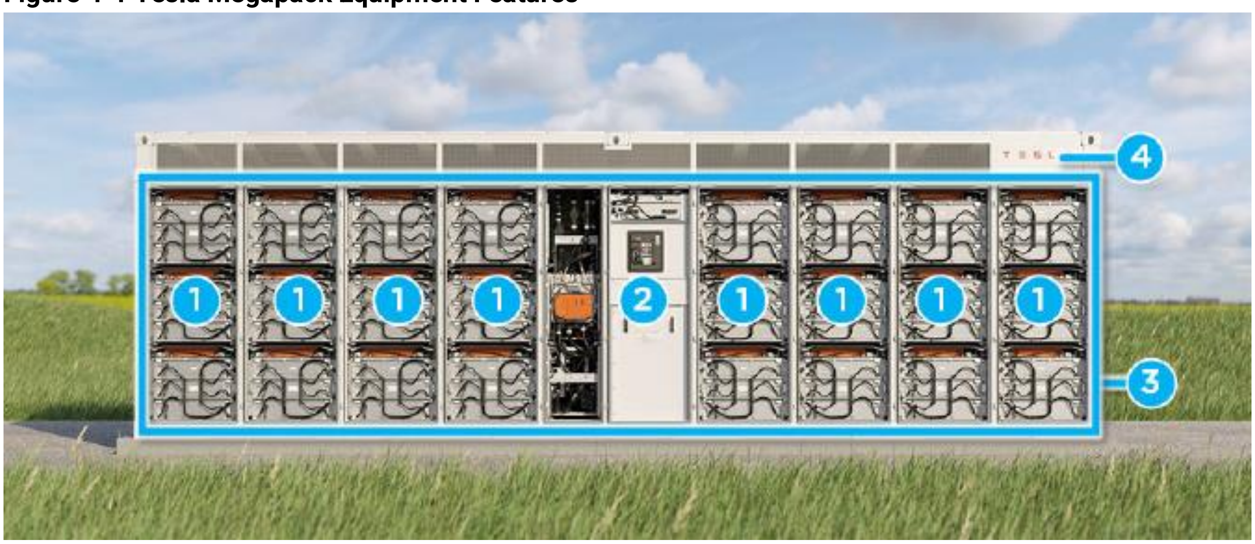
4.1 Tesla Megapack 2 XL Fire Safety Features

The Tesla Megapack 2 XL is equipped with a number of fire safety features designed to mitigate the propagation of a battery failure or prevent the failure from occurring altogether. These protections are aligned with the requirements of the 2020 Edition of NFPA 855, as well as the 2021 International Fire Code §1207 Electrical Energy Storage Systems. The following are the key fire safety features of the Megapack design, details of which can be found in the previously referenced Tesla documents.

- Battery Management System
- Thermal Management System
- Deflagration Control System
- Fire Detection
- Remote Monitoring by Workbench Energy Network Operations Centre
- Remote Monitoring by Tesla's 24/7 Operations Center

Each Tesla Megapack 2XL Unit contains four (4) primary operational and safety elements.

Figure 4-1 Tesla Megapack Equipment Features



1. Battery modules with active and passive fuses – externally serviceable
2. Touch-safe Customer Interface Bay
3. Non-walk-in IP66 enclosure and deflagration mitigation
4. Thermal roof with overpressure vents

4.2 Compass Administrative Safety Features

In addition to design safety Compass has established additional administrative controls to further enhance the safety of its BESS systems. These controls are noted; in cases, in more detail in the ***Compass Greenfield Development Emergency Management Plan.*** The following are the administrative programs that further improve the safety of Almonte BESS I and II system.

- Employee Safety Training
- Contractor and Visitor Safety Management
- Emergency Shutdown Procedures
- Standard Operating Procedures
- Site-Specific Emergency Response Plans
- Security Management

5 Record, Plan, Train

The Almonte BESS I and II site; once commissioned, will be just one of many critical pieces of electrical infrastructure in the Province of Ontario. To ensure the continuity of that service Compass has developed an Emergency Management Plan (EMP). The EMP defines the Compass's efforts in terms evaluating for hazards that have the potential to impact its operations, it defines the prevention and mitigation programs that it has implemented to prevent systems like Almonte from suffering from an emergency.

Should an incident occur the EMP defines Compass's emergency preparedness efforts to ensure that the organization as well as emergency responders and community stake holders are aware of the consequences of such an event and understand how to safety respond and mitigate the consequences.

To mitigate the consequences of an event at the Almonte BESS Site I & II Compass has developed a Site-Specific Emergency Response Plan. This plan will be a living document that will be communicated to local emergency services and revised annually based on internal emergency drills and exercises; and external drills and exercises involving external partners, such as the community.

Additionally, to support communication of these plans Compass will liaise with the Mississippi Mills Fire Department and other municipal services, delivering site awareness training and strengthening response capacity.

Refer to the ***Compass Greenfield Development Emergency Management Plan*** and the ***Almonte BESS Site I and II Emergency Response Plan*** for additional information.

6 Review

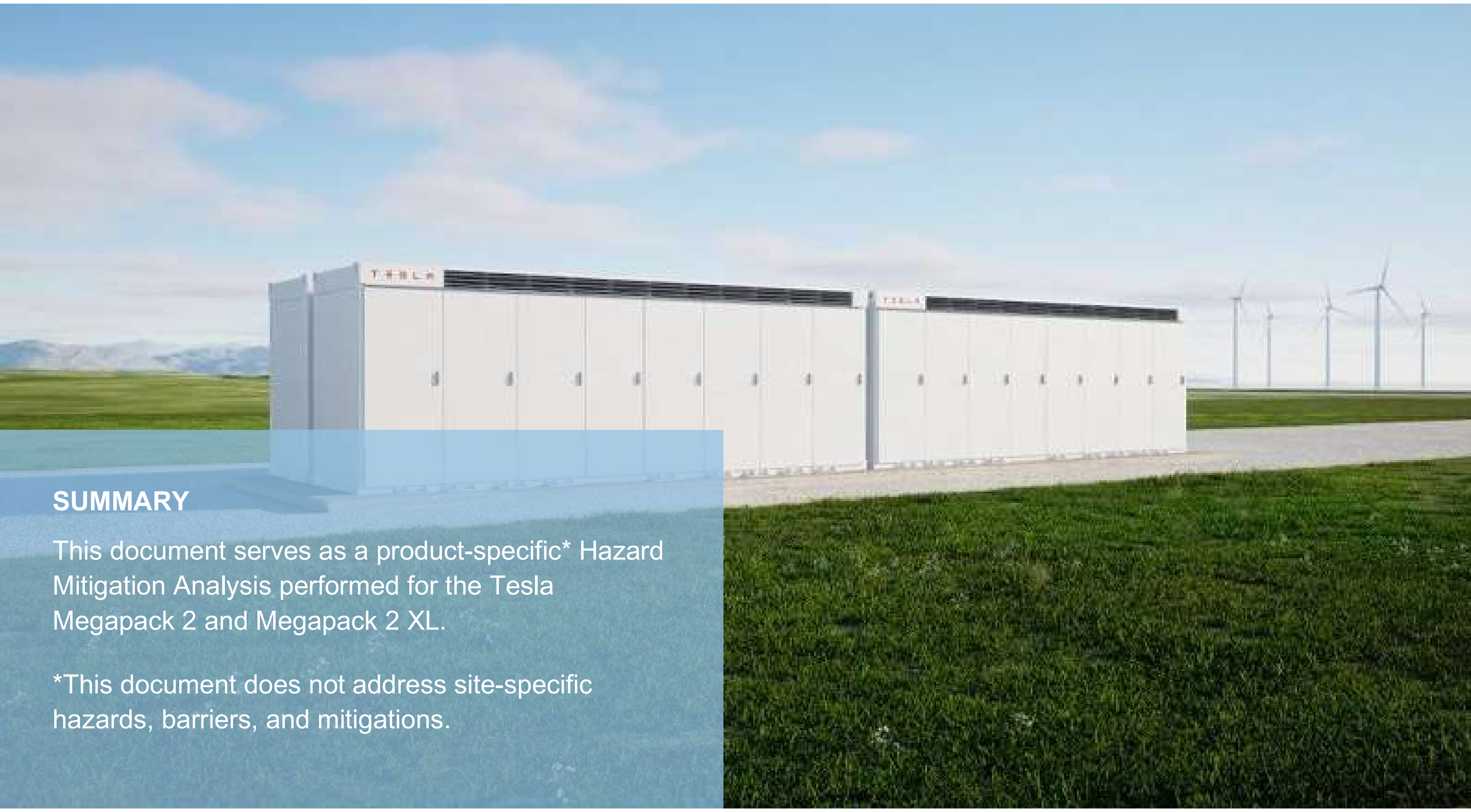
Compass has committed to a process of continual improvement. Emergency preparedness engagement with its community partners will benefit from this process. As Compass evolves and additional projects are brought to market Compass will strengthen its emergency management program through lessons learned and the continued engagement and consultation with its business and community partners.

Appendix A – Tesla Megapack 2/XL Hazard Mitigation Analysis

TESLA MEGAPACK 2/XL

HAZARD MITIGATION ANALYSIS

February 22nd, 2023 | Rev. 4



SUMMARY

This document serves as a product-specific* Hazard Mitigation Analysis performed for the Tesla Megapack 2 and Megapack 2 XL.

*This document does not address site-specific hazards, barriers, and mitigations.

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Rev. 2	11/15/2022	Comments addressed – minor changes	N. Petrakis	
Rev. 3	12/27/2022	Comments addressed – minor changes	N. Petrakis	
Rev. 4	2/22/2022	Comments addressed – minor updates	N. Petrakis	

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1 INTRODUCTION

1.1 Background

Energy Safety Response Group (ESRG) has been retained by Tesla, Inc. to perform a product specific Hazard Mitigation Analysis (HMA) in accordance with *NFPA 855 Standard for the Installation of Stationary Energy Storage Systems §4.1.4 Hazard Mitigation Analysis* and the *2021 International Fire Code (IFC) §1207.1.4.1*. This HMA can be utilized to assess the anticipated overall effectiveness of protective barriers in place to mitigate the consequences of a battery-related failure. The analysis was performed based on the current documentation available at the time of the report.

1.2 Applicable Codes and Standards

The 2020 edition of *NFPA 855 Standard for the Installation of Energy Storage Systems §4.1.4 Hazard Mitigation Analysis* requires an evaluation on the consequences of the following failure modes:

1) *Thermal runaway condition in a single module, array, or unit*
2) *Failure of an energy storage management system*
3) *Failure of a required ventilation or exhaust system*
4) *Failure of a required smoke detection, fire detection, fire suppression, or gas detection system*

Additionally, for the completeness, this report also includes two additional failure modes required per *2021 International Fire Code (IFC) §1207.1.4.1:*

5) *Voltage surges on the primary electric supply*
6) *Short circuits on the load side of the ESS*

For the purposes of this report, only single failures modes shall be considered for each mode given above.

Per *NFPA 855 §4.1.4.2, Analysis Approval,* the AHJ shall be permitted to approve the hazardous mitigation analysis as documentation of the safety of the ESS installation provided the consequences of the analysis demonstrate the following:

1) *Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 §4.3.6.*
2) *Suitable deflagration protection is provided where required.*
3) *ESS cabinets in occupied work centers allow occupants to safely evacuate in fire conditions.*
4) *Toxic and highly toxic gases released during normal charging, discharging, and operation will not exceed the PEL in the area where the ESS is contained.*

5) *Toxic and highly toxic gases released during fires and other fault conditions will not reach concentrations in excess of immediately dangerous to life or health (IDLH) level in the building or adjacent means of egress routes during the time deemed necessary to evacuate from that area.*
6) *Flammable gases released during charging, discharging, and normal operation will not exceed 25 percent of the LFL.*

The following key codes, standards, and local requirements are referenced throughout the report:

- *NFPA 855 Standard for the Installation of Stationary Energy Storage Systems*, 2020 Edition
- *International Fire Code §1207 Electrical Energy Storage Systems*, 2021 Edition
- *UL 9540A Standard for Test Method for Evaluation Thermal Runaway Fire Propagation in Battery Energy Storage Systems,* 4th Edition
- *UL 9540 Standard for Energy Storage Systems and Equipment,* 2nd Edition

1.3 Summary of Findings

Based on review of documentation provided by Tesla, Inc., ESRG finds that adequate protections are provided for the fault conditions listed per *NFPA 855 §4.1.4* and *IFC §1207.1.4.1,* as well as for analysis approval requirements per *NFPA 855 §4.1.4.2*. Key findings include:

- The Tesla Megapack 2/XL is equipped with a number of protection systems (e.g., deflagration control system consisting of overpressure vents and sparker system, BMS control, electrical shutdowns and disconnects, etc.) that are anticipated to effectively manage all applicable fault conditions required per *NFPA 855 §4.1.4* and *IFC §1207.1.4.1.*

NFPA 855 §4.1.4* and *IFC §1207.1.4.1 Hazard Mitigation Analysis Requirements	
Thermal runaway condition in a single module, array, or unit	The system is provided with several passive and active measures to mitigate or contain a propagating thermal runaway condition. UL 9540A testing further shows that the effects of thermal runaway are contained within the module and Unit.
Failure of an Energy Storage Management System	Multiple levels of system monitoring provide redundant protection in the unlikely event of a failure of the energy storage management system.
Failure of a Required Ventilation or Exhaust System	The Megapack 2/XL is not required to have a ventilation or exhaust system. A proprietary explosion protection system is designed to mitigate the effects of flammable gasses generated during an abnormal condition.

Failure of a Required Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System	The Megapack 2/XL does not rely on dedicated smoke detection, fire suppression, or gas detection systems to mitigate the hazards associated with thermal runaway. Along with subsequent safety actions, the BMS fault notifications are transmitted to Tesla's 24/7 Operations Center, alerting key stakeholders of any abnormal conditions.
Voltage Surges on the Primary Electric Supply	Voltage surges on the primary electric supply are mitigated by BMS and inverter controls, voltage monitoring, and automatic disconnects.
Short Circuits on the Load Side of the ESS	Short circuits on the load side are mitigated by BMS controls and automatic safety actions.

- The Tesla Megapack 2/XL is compliant with all applicable Analysis Approval requirements per *NFPA 855 §4.1.4.2.*

***NFPA 855 §4.1.4.3* – Analysis Approval**	
Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 §4.3.6.	N/A – The Megapack 2/XL is intended for outdoor installations.
Suitable deflagration protection is provided where required.	The Megapack 2/XL is provided with a proprietary explosion protection system. The effectiveness of the explosion protection system was validated during internal destructive fire testing.
ESS cabinets in occupied work centers allow occupants to safely evacuate in fire conditions.	N/A – The Megapack 2/XL is not intended for installation within occupied work centers.
Toxic and highly toxic gases released during normal charging, discharging, and operation will not exceed the PEL in the area where the ESS is contained.	N/A – Lithium-ion batteries do not release toxic or highly toxic gases during normal charging or discharging operations.
Toxic and highly toxic gases released during fires and other fault conditions will not reach concentrations in excess of immediately dangerous to life or health (IDLH) level in the building or adjacent means of egress routes	Internal Unit level testing conducted on the products of combustion from the Megapack 2/XL indicated that there was no Mercury (Hg) observed, and trace levels of HF far below NIOSH Immediately Dangerous to Life or Health (IDLH) levels.

during the time deemed necessary to evacuate from that area.	
Flammable gases released during charging, discharging, and normal operation will not exceed 25 percent of the LFL.	N/A – Lithium-ion batteries do not release flammable gasses during charging, discharging, or normal operations.

- The effectiveness of the Megapack 2/XL's proprietary explosion mitigation system has been validated by UL 9540A Unit level and additional large-scale fire and destructive testing and has shown to be effective in preventing the occurrence of any hazardous pressure waves, debris, shrapnel, or ejection of enclosure pieces during a failure event.
- When subjected to a near-simultaneous failure of 6 cells within a module during UL 9540A full-scale fire testing, the Tesla Megapack 2 has proven that the system is provided with robust thermal runaway propagation prevention. As indicated in the UL 9540A Unit Level testing report by TUV, "the testing performed on MP2 is considered harsher with higher gas concentrations, and fundamental engineering analysis for MP2XL shows comparable behavior as worst case" therefore the testing results for the Megapack 2 can be utilized as comparable results for the Megapack 2 XL. The Megapack 2/XL does not rely on any internal or external fire suppression systems to prevent cascading thermal runaway propagation at the module and unit (Megapack-to-Megapack) level.
- Additional voluntary destructive testing was conducted by Tesla on a representative Megapack 2/XL. This testing utilized a more aggressive approach than typical UL 9540A testing by initiating a thermal runaway of all 48 cells within a module simultaneously and forcing a catastrophic failure of a battery module. Results of this testing showed that due to the robustness of the system design the following is noted:
    - It is difficult to initiate and maintain any cascading thermal runaway within the unit.
    - In the unlikely event of a fire, the system will consume itself slowly in a safe and controlled manner, without any explosive bursts, projectiles, or unexpected hazards.
- During the aforementioned testing, third-party analysis on products of combustion collected indicated no Hg and trace levels of HF far below NIOSH Immediately Dangerous to Life or Health (IDLH) levels.
- Voluntary fire propagation modeling was conducted by Tesla to determine the anticipated impacts on representative target Megapack 2 units from an external heat flux generated by a failing unit. Even with worst-case wind scenarios taken into account, in the unlikely event of a Megapack 2/XL fire, the model shows that thermal runaway would not propagate to the adjacent units that are installed as per Tesla's site design requirements.

2 ENERGY STORAGE SYSTEM DESCRIPTION

2.1 Megapack 2/XL Overview

The Tesla Megapack 2 and Megapack 2 XL (which may also be referred to as Megapack 2/XL or MP2/XL throughout this report), is a modular, fully integrated, AC-coupled battery energy storage system (BESS or ESS). The Megapack 2 is an updated version of the original Megapack 1 and utilizes similar deflagration control systems in the form of pressure-sensitive vents and sparker systems to manage explosion risk. The Megapack 2 XL is a design evolution of Megapack 2, which leverages the same core technology platform (cells, vents, sparker system, etc.) The Megapack 2/XL, however, utilizes lithium iron phosphate (LFP) battery cells provided by CATL, as opposed to the nickel manganese cobalt oxide (NMC) and nickel cobalt aluminum oxide (NCA) cells used in the Megapack 1.

Megapack 1	Megapack 2
	
Cells and Battery Modules:	
Cylindrical 2170 NMC	Prismatic LFP
1,000 Cells per Tray, 12 Cell Trays 12,000 Cells per Battery Module	112 Cells per Tray, 3 Cell Trays 336 Cells per Battery Module
Each Module Equipped with an Integrated BMS	
Layout/Construction:	
Modular Cabinet Design, Not Occupiable	
Thermal Bay, Customer Interface Bay, IP66 Battery Module Bay, and Thermal Roof	
23.5 x 5.4 x 8.3 ft	23.75 x 5.4 x 8.2 ft
Up to 17 Battery Modules	Up to 19 Battery Modules
Safety Features:	
Thermal Management System: Closed Loop Liquid Coolant System and R-134A Refrigerant	
Customer Interface Bay: User-accessible Area Designed for Operation and Servicing	
Electrical Fault Protection: Passive and Active Safety Control Mechanisms (Fuses, Circuit Interrupters, Pyrotechnic Fuse) Installed within the Battery Module Circuits and Distribution Circuit	
Autonomous BMS with 24/7 Remote Monitoring by Tesla Operation Facilities	
No Integral Fire Detection or Fire Suppression System	
Thermal Insulation	No Thermal Insulation[1]
Explosion Control System:	
33 Overpressure Vents, 8 Sparkers	22 Overpressure Vents, 12 Sparkers[1]

[1] Modified explosion control system and thermal insulation to account for the different cells (NMC vs. LFP) utilized in the MP2.

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<tr><td colspan="2">No Free-Flowing Liquid Runoff Observed After the Test</td></tr>
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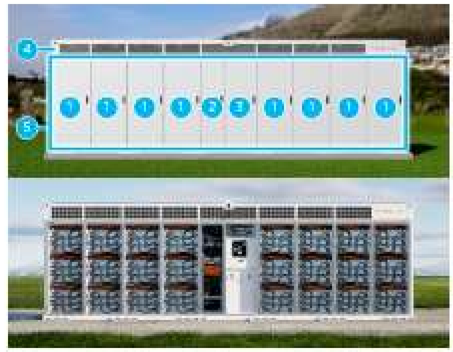
<table>
<tr><th>Megapack 2</th><th>Megapack 2XL</th></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Cells and Battery Modules:</td></tr>
<tr><td colspan="2">Same Cells, Battery Modules and Integrated BMS</td></tr>
<tr><td colspan="2">Layout/Construction:</td></tr>
<tr><td colspan="2">Same Modular Cabinet Design, Not Occupiable with the Same or Substantially Similar Thermal Bay, Customer Interface Bay, IP66 Battery Module Bay, and Thermal Roof</td></tr>
<tr><td>23.75 x 5.40 x 8.20 ft</td><td>28.83 x 5.42 x 9.17 ft</td></tr>
<tr><td>Up to 19 Battery Modules (3,100.8 kWh)</td><td>Up to 24 Battery Modules (3,854.0 kWh)</td></tr>
<tr><td colspan="2">Safety Features:</td></tr>
<tr><td colspan="2">Same or Substantially Similar Thermal Management System, Customer Interface, Electrical Fault Protections and Autonomous BMS with 24/7 Remote Monitoring by Tesla Operation Facilities</td></tr>
<tr><td colspan="2">No Integral Fire Detection or Fire Suppression System</td></tr>
<tr><td colspan="2">Explosion Control System:</td></tr>
<tr><td>22 Overpressure Vents, 12 Sparkers</td><td>26 Overpressure Vents, 12 Sparkers</td></tr>
<tr><td colspan="2">Listings and Certifications</td></tr>
<tr><td colspan="2">Has the Same Component and BESS Design Certifications/Listings (UL 9540 and IEC 62933-5-2)</td></tr>
<tr><td colspan="2">Meets the Same Installation Level Codes and Standards (IFC and NFPA 855)</td></tr>
<tr><td colspan="2">UL 9540A Unit Level Test Results</td></tr>
<tr><td colspan="2">Same UL 9540A Fire Test Results: No Fire Propagation or Evidence of Sustained Flaming, No Flames Observed Outside the Cabinet, No Fire Propagation to Adjacent Cabinets, Integral Fire Suppression or Manual Fire Suppression (Hose Lines) Not Required to Stop Cabinet to Cabinet Fire Spread, No Observations of Explosion Hazards, No Free-Flowing Liquid Runoff Observed After the Test</td></tr>
</table>

Each Megapack 2 unit contains up to 19 modules with inverters, a thermal bay and associated thermal roof components, an AC circuit breaker, and a set of customer interface terminals and internal controls circuit boards. The Megapack 2 XL uses identical components to the Megapack 2, including batteries, converters, and explosion protection systems. The main difference (other than the footprint) to the Megapack 2 is that that the Megapack 2 XL contains 24 AC battery modules rather than 19. Depending on the system configuration (2-hour or 4-hour), each Megapack can be configured with different quantities of battery modules which, together with the site's grid voltage, determine Megapack's nominal power rating. All components are housed in a cabinet-style enclosure, with access for maintenance provided via enclosure doors. The Megapack 2/XL, therefore, cannot be physically entered by any person and is thus not considered a walk-in container, occupied building, or structure as defined by *NFPA 855* and *IFC*. Thermal management is provided to the internal Megapack 2/XL components via active liquid cooling and heating system utilizing 50/50 ethylene glycol and water and R-134a refrigerant.

The Megapack 2/XL and constituent components are tested and certified to UL 9540, UL 1642, UL 1973, IEC 62619, and IEC 62933-5-2. UL 9540A (4^{th} Edition) large-scale fire testing was performed at the Cell, Module, and Unit level (Installation level testing was not required, as all Unit level performance criteria were met). From the UL 9540A Unit level report by TUV, "Based on the limited module propagation observed during MP2 testing (7 cells in runaway) the behavior would be the same with MP2XL. With the increase in volume and sparker count, the deflagration risk is minimized. The testing performed on MP2 is considered harsher with higher gas concentrations, and fundamental engineering analysis for MP2XL shows comparable behavior as worst case".

Figure 2-1 - Tesla Megapack 2

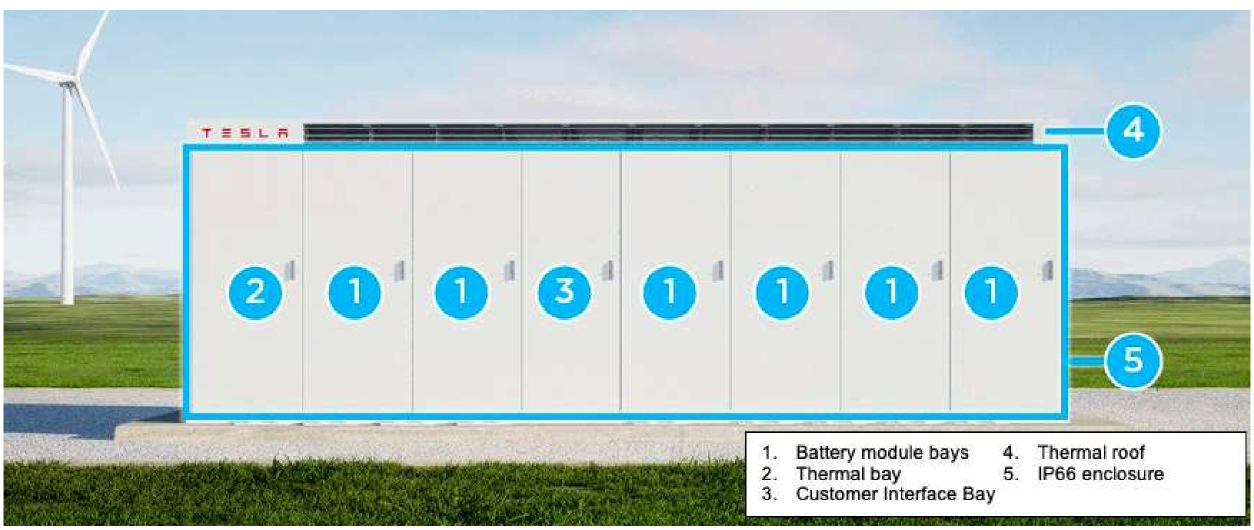


Figure 2-2 - Megapack Internal Architecture

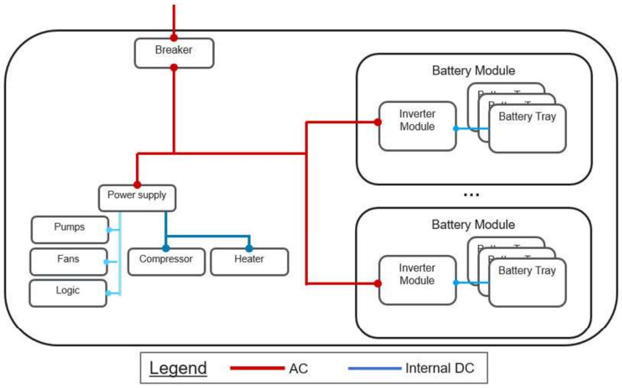


Figure 2-3 - Battery Module

Figure 2-4 - Tesla Megapack 2 Thermal Management System

Figure 2-5 - Tesla Megapack 2 XL

1. Battery modules with active and passive fuses – externally serviceable
2. Touch-safe Customer Interface Bay
3. Non-walk-in IP66 enclosure and deflagration mitigation
4. Thermal roof with overpressure vents

For more information on the Tesla Megapack 2 and Megapack 2 XL, please refer to official product documentation provided by Tesla.

2.2 Fire Safety Features

The Tesla Megapack 2/XL is equipped with a number of fire safety features designed to mitigate the propagation of a battery failure or prevent the failure from occurring altogether. These protections are aligned with the requirements of the 2020 Edition of NFPA 855, as well as the 2021 International Fire Code §1207 Electrical Energy Storage Systems.

2.2.1 Deflagration Control System

Each Megapack 2/XL is provided with an integral and proprietary explosion mitigation system (deflagration control). This explosion mitigation system is comprised of numerous pressure-sensitive (overpressure) vents located at the top of the Megapack and a sparker system; working in conjunction to ignite any flammable gasses that could be generated within the unit during a failure event. The Megapack 2 is provided with twenty-two (22) overpressure vents and 12 sparkers, while the Megapack 2 XL is provided with twenty-six (26) overpressure vents and 12 sparkers. Any overpressures generated from the ignition of flammable gasses within the unit will be relieved via the nearest pressure-sensitive vents and routed upwards, protecting the Megapack's structural integrity and preventing any hazardous pressure build-up within. The sparkers are located throughout the Megapack at various heights and continuously operate to ensure that any flammable gas build-up is ignited early – limiting the concentration of flammable gas within the unit and activating the pressure-sensitive vents to create a natural ventilation pathway to the exterior.

2.2.2 Battery Management System (BMS)

An integrated Battery Management System (BMS) monitors key datapoints such as voltage, current, and state of charge (SOC) of battery cells, in addition to providing control of corrective and protective actions in response to any abnormal conditions. Each battery module is equipped with a dedicated BMS, with a Megapack-level bus controller supervising output of all modules at the AC bus level. Critical BMS sensing parameters include battery module over / under voltage, cell string over / under voltage, battery module over temperature, temperature signal loss, and battery module over current. In the event of any abnormal conditions, the BMS will generally first raise an information warning, and then trigger a corresponding corrective action should certain levels be reached.

2.2.3 Fire Detection

In addition to monitoring of thermal sensors within the Megapack by the BMS – which may be transmitted to Tesla's 24/7 Operations Center, described below, and made available to a Subject Matter Expert (SME) if abnormal conditions are detected –External multi-spectrum infrared (IR) flame detectors can be provided to meet compliance with prescriptive requirements for automatic fire detection systems if they are mandated by the site-specific installation codes and standards.

While the IR detectors were not activated during UL 9540A unit level testing for the Megapack 2/XL (as no fire occurred), full-scale testing of previous Megapack systems showed that the external third-party multi-spectrum IR detectors effectively detected failure conditions that initiated within the unit.

2.2.4 Site Controller and Monitoring

The Tesla Site Controller provides a single point of interface for the utility, network operator, or customer SCADA systems to control and monitor the entire energy storage site. It hosts the control algorithm that dictates the charge and discharge functions of the battery system units, aggregating real-time information and using the information to optimize the commands sent to each individual Megapack unit.

The Megapack 2/XL is supported by Tesla's 24/7 Operations Center , which is designed to support the global fleet of energy storage products. In conjunction with local operation centers, the Megapack 2/XL has 24/7 remote monitoring, diagnostics, and troubleshooting capabilities. In the event of an emergency, this information may be made available to a Subject Matter Expert (SME) responsible for the system to inform emergency response personnel.

2.2.5 Fire Suppression Systems

NFPA 855 and the *2021 IFC Chapter 12* both require fire control and suppression systems to be provided in certain installation conditions for battery ESS. These fire suppression systems, however, are typically required for rooms, areas within buildings, and "walk-in" units when installed outdoors.

All components of the Tesla Megapack 2/XL are housed in a cabinet-style enclosure, with access for maintenance provided via enclosure doors that cannot be physically entered by any person. The installation codes and standards, thus, would not consider the Tesla Megapack 2/XL walk-in container, occupied building, or structure as defined by *NFPA 855* and *IFC*.

The Tesla Megapack 2/XL does not rely on any external or internal fire suppression systems to limit cascading thermal runaway. Additional bespoke testing and subsequent fire modeling has indicated that the Megapack's passive construction provides a robust thermal resistance from the impacts of an adjacent Megapack during a large-scale failure.

2.2.6 Electrical Fault Protection Devices

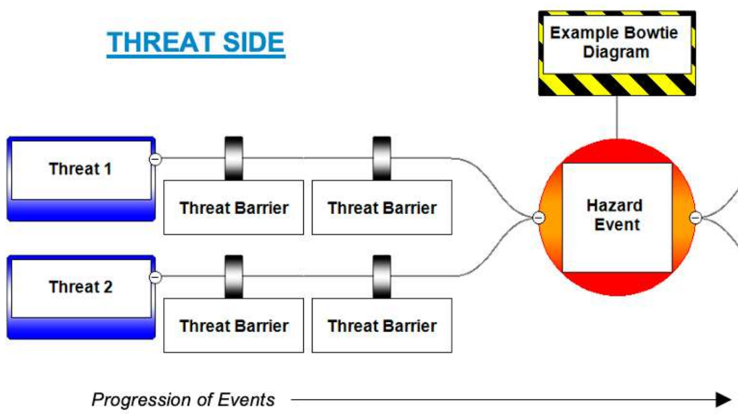
Multiple levels of passive and active electrical protections are provided for the Megapack 2/XL. At the battery module level, overcurrent protection is provided for each module in the form of single-use fusible links, providing interruption of overcurrent in the battery module in the case of an abnormal electrical event. Inverter modules, which are installed at each of the battery modules, are equipped with both DC protection via high-speed pyrotechnic fuse for passive or active isolation of battery module, as well as dedicated AC contactor and AC fuses should an abnormal electrical event occur at the inverter module on the AC side of the circuit. Additionally, the Megapack 2/XL is equipped with DC ground fault detection system and AC circuit breaker with ground fault trip settings for distribution system protection.

3 HAZARD MITIGATION ANALYSIS

3.1 HMA Methodology

ESRG utilizes the bowtie methodology for hazard and risk assessments, as is described in *ISO.IEC IEC 31010 §B.21*, as it allows for in-depth analysis on individual mitigative **barriers** and serves as a strong tool for visualizing the chronological pathway of **threats** leading to critical hazard events, and ultimately to greater potential **consequences**, as depicted in the figure below. This simple diagrammatic way of describing and analyzing the pathways of a risk from hazards to outcomes can be considered to be a combination of the logic of a fault tree analyzing the cause of an event and an event tree analyzing the consequences.

Figure 3-1 - Example Bowtie Diagram



Each fault condition per *NFPA 855* and *IFC* assessed in Sections 3.4.1 – 3.4.6 below is accompanied by a corresponding bowtie diagram indicating critical *threat* and *consequence* pathways and the mitigative barriers between them. As the most critical risk posed by lithium-ion battery cells comes from the propagation of thermal runaway from a failing cell (or multiple cells) to surrounding cells, this serves as the primary critical hazard for the subsequent failure scenarios.

In addition to main barriers for fault conditions on the *threat* side of the diagram, the *consequence* barriers on the right side of the diagram (e.g., explosion protection and emergency response plan) **also** contribute added layers of safety on top of the main threat barriers shown. It is important to note that the barriers on the left side, along a threat path, are intended to keep the threat from becoming a thermal runaway, while the barriers on the right side, along the consequence pathway, are intended to keep that single thermal runaway from evolving into one of the more severe consequences such as fire spread beyond containment, off-gassing leading to explosion, or fire spread beyond containment. For more on the methodology and relevant terminology, see Appendix B of this report.

3.2 Relevant Supporting Information

3.2.1 UL 9540A Large-Scale Fire Testing

UL 9540A (4th Edition) testing was performed for the constituent Cell, Module, and Unit levels of the Tesla Megapack 2/XL.

Cell Level Test Report [1]

UL 9540A (4th Edition) Cell level testing was performed on the Contemporary Amperex Technology Co., Ltd. (CATL) 3.22V, 157.2Ah lithium iron phosphate (LFP) battery cell at UL LLC (Changzhou) Quality Technical Service Co., LTD. in July 2021. The test was re-run on February 25th, 2022.

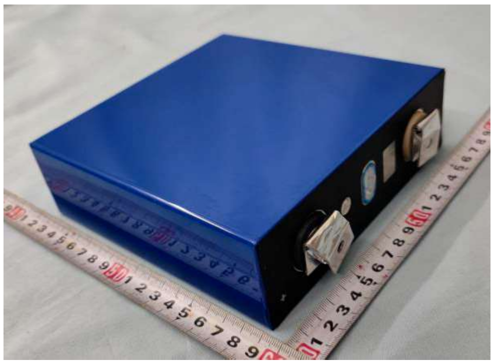
Thermal runaway was initiated via film strip heater, resulting in average cell surface temperature of 174°C and average cell surface temperature at thermal runaway of 239°C. Gas analysis of the gas generated from the well were identified as flammable. As these performance criteria per *UL 9540A Clause 7.7* and *Figure 1.1* were not met, Module level testing was required.

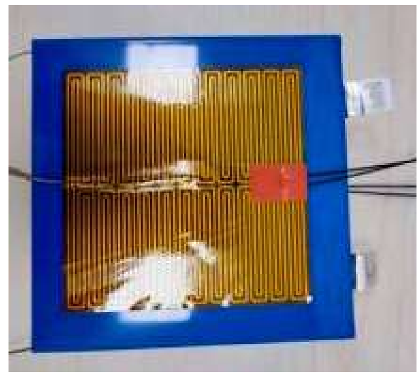
Table 3-1 – Results of Gas Analysis (Excluding O_2 and N_2)

Gas Component	Measured %	Component LFL
Carbon Monoxide (CO)	10.881	10.9
Carbon Dioxide (CO_2)	27.107	N/A
Hydrogen (H_2)	50.148	4.0
Methane (CH_4)	6.428	4.4
Acetylene (C_2H_2)	0.264	2.3
Ethylene (C_2H_4)	3.283	2.4
Ethane (C_2H_6)	1.100	2.4
Propane (C_3H_8)	0.125	1.7
C4 (Total)	0.190	N/A
C5 (Total)	0.027	N/A
C6 (Total)	0.005	N/A
Benzene (C_6H_6)	0.004	1.2
Toluene (C_7H_8)	0.002	1.0

Dimethyl Carbonate ($C_3H_6O_3$)	0.055	N/A
Ethyl Methyl Carbonate ($C_4H_8O_3$)	0.004	N/A
Total	100	-

Figure 3-2 – Cell Level Testing – Flexible Film Heater Installation





Module Level Test Report [2]

UL 9540A (4th Edition) Module level testing was performed on the Contemporary Amperex Technology Co., Ltd. (CATL) MP2 360.64Vdc, 156Ah battery module at TÜV SÜD SW Rail Transportation Technology (Jiangsu) Co., Ltd. in December of 2021 and repeated in May of 2022.

Thermal runaway was initiated via film strip heaters installed on both of the wide side surfaces of each cell, similar to the cell level test. In the module level test, however, two cells were heated simultaneously to force multiple cells into thermal runaway at the same time.

Thermal runaway propagated from the initiating cells to all cells within the MP2 tray (module). Sparks and flying debris were observed, however, there were no explosive discharges of gases. Gases generated from the cell were identified as flammable, but there was no detection of toxic gases that are sometimes associated with lithium-ion battery failure such as HF, HCL, and HCN. Unit level testing to the UL 9540A test method is required due to the fact that the gases generated are flammable.

Table 3-2 - Module Level Test Gas Analysis

Gas Name	Chemical Structure	Measurement Peak (ppm)	Detection Method
Carbon Monoxide	CO	204.84	FTIR
Carbon Dioxide	CO_2	6720.62	FTIR
Methane	CH_4	67.83	FTIR
Acetylene	C_2H_2	17.11	FTIR
Ethene	C_2H_4	Not Detected	FTIR
Ethane	C_2H_6	Not Detected	FTIR
Propane	C_3H_8	Not Detected	FTIR
Butane	C_3H_4	Not Detected	FTIR
Pentane	C_3H_6	Not Detected	FTIR
Benzene	C_6H_6	9.01	FTIR
Hexane	C_7H_{14}	Not Detected	FTIR
Hydrofluoric Acid	HF	Not Detected	FTIR
Hydrogen Chloride	HCL	Not Detected	FTIR
Hydrogen Cyanide	HCN	Not Detected	FTIR
Hydrogen	H_2	446	Hydrogen Sensor
Total Hydrocarbons	(Propane Equivalent)	246.53	FID

Figure 3-3 - Highlights of Module Testing

Unit Level Test Report [3]

UL 9540A (4th Edition) Unit level testing was performed for the Tesla Megapack 2/XL model 1748844-XX-Y at TUV Rheinland of North America, Inc. May 9, 2022.

Burn marks were observed on initiating AC battery module, though no external damage was observed. No damage to target units or adjacent walls were observed. All performance criteria for outdoor ground mounted non-residential use ESS were met, therefore Installation level testing was not required.

A full review of Unit level testing was provided by Fisher Engineering, Inc., as is briefly summarized below.

3.2.2 Tesla Megapack 2/XL: Fire Protection Engineering Analysis

A fire protection engineering analysis and UL 9540A Unit level fire test analysis report was provided by Fisher Engineering, Inc. (FEI) which includes review of the Megapack 2 construction, design, fire safety features, and large-scale fire test data [4]. A brief summary of key takeaways is provided below. For more information, please refer to **Tesla_Megapack_2_and_XL_-_FPE Report_Final.pdf**.

Key takeaways from the report include:

1. The MP2 XL design is almost identical to the MP2 other than being greater in length to accommodate the additional battery modules. Given the limited module propagation observed during UL 9540A unit level testing of the MP2 (seven cells went into runaway) the behavior is expected to be no different with the MP2 XL. As such, a stand-alone UL9540A unit level fire test for the MP2XL was not performed. The UL 9540A unit level fire test results, described above for the MP2, can be applied to the MP2XL.
    a. Similarly, after reviewing the MP2 unit level fire test results and comparing the MP2 and MP2 XL to one another, TÜV determined the MP2 UL 9540A unit level fire test results can be applied to the MP2XL and an additional UL 9540A unit level fire test for the MP2XL was not required for its listing.

2. The largest variant of the Megapack 2 was tested at a worst-case scenario (i.e., 100% SOC with BMS and TMS disabled) to the UL 9540A Unit level fire test method in which six cells within a battery module of the initiating Megapack 2 unit were forced into thermal runaway. Thermal runaway propagated to a seventh cell but did not propagate any further. No propagation to adjacent battery modules or target Megapack units occurred.
3. All Unit level performance criteria outlined in 9540A, Table 9.1 for outdoor, ground-mounted ESS were met, therefore Installation level testing was not required. Specifically, these results included:
    a. No flaming was observed outside of the unit.

b. Surface temperatures of battery modules within the target units did not exceed the temperature at which thermally initiated cell venting occurs. The maximum temperatures recorded at the battery modules of the adjacent cabinets were 13.8°C and 13.2°C, which are significantly below the temperature at which cell venting occurs (174°C).

c. Surface temperatures of exposures 5 ft (1.52 m) to the side and 8 ft (2.44 m) in front of the initiating unit did not exceed 97°C (175°F) above ambient. The maximum external surface temperatures recorded at the instrumented wall 5 ft to the side was 25.9°C (78.6°F) with a temperature rise above ambient of 5.5°C (9.9°F). The maximum external surface temperatures recorded at the front target 8 ft directly in front of the initiating unit was 16.8°C with a temperature rise above ambient of 5.5°C. These temperatures are significantly below the maximum permitted temperature rise above ambient of 97°C (175°F).

d. Explosion hazards, including, but not limited to, observations of a deflagration, projectiles, flying debris, detonation, or other explosive discharge of gases were not observed.

e. Heat flux did not exceed 1.3 kW/m2. The maximum heat flux recorded was 0.0000016 W/m2, which was the sensor installed on the front target cabinet and was the ambient heat flux the sensor was exposed to throughout the test.

4. A maximum surface temperature of 16.8°C was measured on the front target Megapack 2 unit installed 8 ft in front of the initiating Megapack 2 unit, and 13.8°C and 13.2°C at the battery modules of the adjacent unit. Based on cell venting and thermal runaway temperatures from 9540A Cell level test report (174°C and 239°C, respectively), propagation to the battery modules within a unit at clearances of 8 ft is not possible.

5. Smaller capacity MP2 cabinets, populated with less than nineteen battery modules, would be expected to perform similarly given they are designed and constructed substantially similar (with the same cells, battery modules, fire safety features, etc.) than the larger capacity 3,100 kWh MP2 cabinet tested and described in the Fisher report.

6. None of the fire detectors activated during the fire test (two multi-spectrum IR flame detectors and two thermal imagers), which is expected, as no flaming was observed outside of the cabinet during the test; however, previous testing on the Tesla Megapack 1 units demonstrated that multi-spectrum IR flame detectors can detect a fire should flames exit the cabinet through the roof.

7. An internal fire suppression system or an external fire suppression system is not required to stop propagating thermal runaway from cell to cell, module to module, or MP2 cabinet to cabinet when near simultaneous failure of up to six cells occurs within the same battery module.

8. Manual fire suppression (hose lines) is not required to stop propagating thermal runaway and the spread of fire from a MP2 cabinet to adjacent MP2 cabinets installed

6 in (150 mm) behind and to the sides when a near simultaneous failure of up to six cells occurs within the same battery module.

3.2.3 Tesla Megapack 2/XL: Internal Fire Testing

3.2.3.1 Destructive Unit Level Testing

Voluntary destructive testing was conducted by Tesla on a representative and fully populated Megapack 2 XL. This destructive fire testing utilized a more aggressive approach than what is required by the UL 9540A test method in order to force the system into a more severe cascading thermal runaway event. This destructive test was conducted to demonstrate the Megapack 2/XL's ability to fail in a safe manner, even in the extreme event of a catastrophic failure within an entire battery module. Additionally, the destructive testing further validated the design of the Megapack 2/XL proprietary explosion mitigation system.

This testing was conducted at the Northern Nevada Research Center on May 19th, 2022. The test utilized film heaters to simultaneously heat forty-eight (48) cells within a module, creating a severe failure scenario that is well beyond what is contemplated by the UL 9540A test method. The goal of this testing was to assess the risk of a large-scale fire resulting from an initiating Megapack 2/XL during a thermal runaway event propagating to an adjacent Megapack 2/XL. The results of this testing show some key takeaways, as detailed in the Fisher Engineering FPE report:

- Thermal runaway propagated from the initiating cells to all the cells in the initiating tray.
- A thermal event occurred, likely initiated by the ignition of flammable gases by the sparker system. An overpressure vent installed above the initiating battery module opened and was visually confirmed through video. The cabinet doors immediately adjacent to the initiating battery module remained closed. No hazardous pressure waves, debris, shrapnel, or pieces of the cabinet were ejected.
- After approximately 10 minutes of smoking, a sustained fire began within the initiating battery module. The fire spread to the adjacent battery bays until reaching the CIB and stopped. The fire only burned half of the cabinet.
- Fire spread from battery bay to battery bay was a slow progressing event. In total, visible flames were observed for 6 hours and 40 minutes while the four battery bays (bays 7-10) burned, as shown in Figure 18 of the Fisher report.
- Maximum flame heights were observed to be 11.5 ft (3.5 m) from ground to the top of the flame, 2.5 ft (0.75 m) above the top of the cabinet and had a base (a width) of 3.3 ft (1 m) during peak flame intensity. This peak flame intensity occurred approximately 60-90 minutes after initial flaming was observed.
- An analysis of the pressure profile inside the cabinet during the test demonstrated the operation of the explosion control system, as shown in Figure 19 of the Fisher report. Pressure inside the cabinet increased to nearly 11 kPa (1.60 psi) until the deflagration vent opened and the pressure diminished. The overpressure vents

are designed to operate at approximately 12 kPa (1.74 psi), or 2.5 times below the cabinet's strength of 30 kPa (4.35 psi).

3.2.3.2 Fire Modeling – Propagation Model

Subsequent fire propagation modeling was conducted to assess the fire propagation risk to adjacent Megapack 2/XL units during a more severe event such as what was observed during the internal destructive testing referenced in Section 3.2.3.1. This fire propagation model showed that due to the robustness of the system design, it is unlikely that a fire from an initiating Megapack 2/XL would propagate to the adjacent Megapack 2/XL, even during worst-case scenario wind conditions. The modeling assessed two scenarios – a non-flaming event and the impact of heat transfer on a target Megapack 2/XL as well as a flaming event and the impact of radiative heat transfer on a target Megapack 2/XL installed per Tesla's recommendations.

3.2.3.3 Product of Combustion - Unit Level Testing

Tesla conducted additional internal Unit Level testing to obtain and analyze the products of combustion from a failing Megapack Unit. The products of combustion were collected at locations 20 ft upwind and 5 ft downwind from the initiating unit to assess airborne contaminants which may be present during an incident. Subsequent third-party analysis concluded that no traces of Mercury was present over the entire 2.5-hour test duration. Hydrogen Fluoride (HF) was detected at values of 0.10 and 0.12 parts per million (ppm) in the two sampling locations over the course of the test – far below accepted NIOSH Immediately Dangerous to Life or Health (IDLH) value of 30 ppm for HF.

3.2.4 Emergency Response Guide

A product-level Emergency Response Guide (ERG) was provided by Tesla and provides an overview of the product materials, handling and use precautions, hazards, emergency response procedures, and storage and transportation instructions. Tesla's Emergency Response Guide is publicly available to all First Responders and can be found at: https://www.tesla.com/firstresponders

In addition to this product-level guide, a site-specific Emergency Response Plan (ERP) will provide an additional level of safety and familiarization for first responders who may be arriving on-scene to an incident at an installation utilizing the Megapack 2/XL system.

3.3 Primary Consequences of ESS Failure and Mitigative Barriers

The dynamics of lithium-ion ESS failures are extremely complex, and the pathway of failure events may vary widely based on system design, mitigative approaches utilized, and even small changes in environmental or situational conditions. However, the primary consequences stemming from a propagating lithium-ion battery failure largely fall into a number of specific hazard scenarios, as depicted in the diagram and associated table below (though other scenarios not listed may certainly also occur). These primary consequences serve as the basis for the consequence side of the majority of the fault condition diagrams in the following sections of this report.

While not explicitly detailed in the simplified diagram below, the criticality and effectiveness of the barriers may vary based on associated threat or consequence pathway. For example, a water-based suppression system may be more critical for mitigation of cell or module combustion from spreading, ultimately leading to fire spread beyond containment, than it is for preventing off-gassing within the enclosure, potentially leading to explosion. Similarly, the same water-based suppression system may be more effective for mitigating spread of fire throughout the system than it is for reducing risk of explosion).

Figure 3-4 - Primary Consequence Diagram

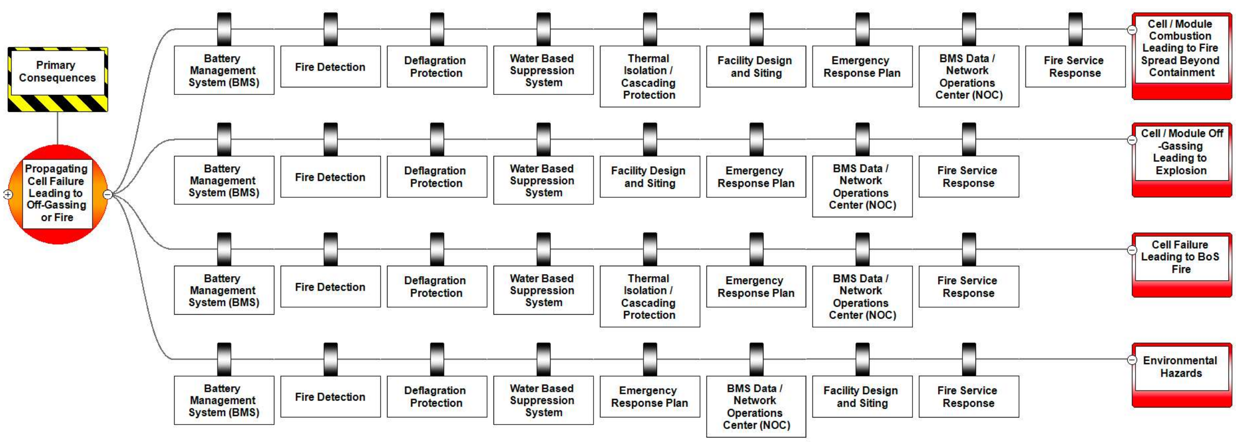


Table 3-3 - Primary Consequence Barriers

PRIMARY CONSEQUENCE BARRIERS	
Battery Management System (BMS)	Critical BMS sensing parameters for the Megapack 2/XL include battery module over / under voltage, cell string over / under voltage, battery module over temperature, temperature signal loss, and battery module over current. In the event of any abnormal conditions, the BMS will generally first raise an information warning, and then trigger a corresponding corrective action should certain levels be reached.

Fire Detection	Multi-spectrum infrared detectors can be provided to satisfy automatic fire detection requirements of the regulations adopted for that installation.
Water-Based Suppression System*	The Megapack 2/XL does not rely on any external or internal water-based suppression system to prevent or mitigate hazards resulting from large-scale failure.
Deflagration Protection	The Megapack 2/XL is equipped with deflagration protection in the form of pressure-sensitive vents and sparker system designed to ignite any flammable gases and release in a controlled manner before they are allowed to accumulate and create an explosive atmosphere within the enclosure.
Electrical Fault Protection Devices	The Megapack 2/XL is equipped with a number of electrical fault protection in the form of battery module overcurrent protection, inverter DC and AC protection, and ground fault protection.
Facility Design and Siting*	Proper siting based on appropriate separation distances from nearby exposures, land area and use, facility type, and other design factors may increase strength of this barrier. Project developers using the Megapack 2/XL should follow Tesla recommended installation guidelines.
Emergency Response Plan / First Responders*	A product-level Emergency Response Guide (ERG) is provided for the Tesla Megapack 2/XL, outlining key product information, safety hazards, and general emergency response procedures. A site-specific Emergency Response Plan (ERP) in accordance with the requirements of the locally adopted codes/standards will provide an additional level of safety for individual installations utilizing the Megapack 2/XL. Additionally, adequate familiarization designated subject matter experts (SMEs) and corporate first responders can greatly improve the strength of this barrier.
BMS Data Availability / Operations Center	Tesla Site Controller provides point of interface for the utility, network operator or customer SCADA systems to control and monitor the energy storage site. 24/7 remote monitoring by Tesla’s Operations Center can be provided if requested.
Fire Service Response*	It is unknown if an adequate water supply or source will be available at most sites for firefighting purposes. As recommended in Tesla’s Emergency Response Guide (ERG); a defensive firefighting approach shall be utilized, with water sprayed on neighboring exposures and neighboring enclosures if advised by Tesla or at the discretion of the first responders. Site-specific training and installation familiarization for local responding stations may further increase the strength of this barrier, and that fire department equipment and capabilities will be strong with this familiarization.
** Barrier may vary on site-by-site basis and are therefore not fully assessed within the scope of this report.*	

3.4 Fault Condition Analysis

Per *NFPA 855 §4.1.4.2*, the analysis shall evaluate the consequences of the following failure modes and others deemed necessary by the AHJ:

1) *Thermal runaway condition in a single module, array, or unit*
2) *Failure of an energy storage management system*
3) *Failure of a required ventilation or exhaust system*
4) *Failure of a required smoke detection, fire detection, fire suppression, or gas detection system*

For completeness, additional failure modes required per *2021 IFC §1207.1.4.1* are also considered in the analysis.

5) *Voltage surges on the primary electric supply*
6) *Short circuits on the load side of the ESS*

For the purposes of this report, it shall be assumed that all construction, equipment, and systems that are required for the ESS shall be installed, tested, and maintained in accordance with local codes and the manufacturer's instructions. The assessment is based on the most recent information provided by the Tesla, Inc. at the time of this writing.

The following table provides a summary of findings from the hazard mitigation analysis performed in fulfillment of *NFPA 855 §4.1.4.2,* with each fault condition described in greater detail, accompanied by simplified bowtie diagrams for visualization of mitigative barriers. Additionally, full bowtie diagrams with barrier descriptions are provided in Appendix A.

Table 3-4 - Summary of Fault Condition Analysis

Compliance Requirement	Comments
1. Thermal runaway condition in a single module, array, or unit	A number of passive and active measures are implemented to reduce the potential of a thermal runaway event from occurring including BMS control and active cooling to internal components. Battery modules and cells have been listed to UL 1973 and UL 1642. Should a thermal runaway event occur, additional mitigative measures are provided to prevent further propagation of failure throughout the system (see Section 3.3 above for list of all consequence barriers).
2. Failure of an energy storage management system	In the event of a failure of module-level BMS, the Megapack-level BMS (which may be considered "ESMS")

	shall isolate effected modules, mitigating against further propagation of failure across the system. Should a failure of the Megapack-level BMS occur, each module is equipped with a dedicated BMS to provide corrective actions in case of detection of abnormal operation outside of set parameters. To further isolate any failure stemming from a failure of the energy storage management system, passive and active electrical fault protections are provided at multiple levels, as described in Section 2.2.6 above.
3. Failure of a required ventilation or exhaust system	The Megapack 2/XL does not utilize a system to exhaust flammable gasses, as lithium-ion batteries do not release flammable gas during normal operations. Flammable gasses generated during abnormal operations are mitigated by the Megapack 2/XL's proprietary explosion mitigation system.
4. Failure of a required smoke detection, fire detection, fire suppression, or gas detection system	The Tesla Megapack 2/XL does not rely on a dedicated smoke detection, fire detection, or gas detection system. Multi-spectrum infrared (IR) detection can be provided to satisfy the automatic fire detection requirements of the locally adopted codes/standards. Should IR detection systems fail, it is anticipated that BMS fault notifications shall be transmitted to Tesla's 24/7 Operations Center, alerting system owner to abnormal conditions. Data from the BMS may be communicated to Certificate of Fitness holder to provide guidance to the fire department in case of emergency. The Megapack 2/XL does not rely on an integrated fire suppression system (such as internal water-based or gas-phase suppression system) to mitigate the hazards associated with propagating thermal runaway. Bespoke fire testing and subsequent fire modeling has shown that the robust passive thermal protection of the Megapack 2/XL design will prevent an unlikely fire from cascading to an adjacent Megapack from the initiating system. Furthermore, UL 9540A Unit level testing indicates that no flaming occurred and that no propagation of heat from the initiating unit to adjacent units / modules reached levels capable of initiating cell venting or thermal runaway.

5. **Voltage surges on the primary electric supply** *(IFC §1207.1.4.1(4))*	Voltage surges on the primary electric side are anticipated to be mitigated by the provided BMS and inverter controls, voltage monitoring and automatic disconnect provided by the BMS, in addition to a number of passive circuit protections briefly noted in Section 2.2.6 of this report.
6. **Short circuits on the load side of the ESS** *(IFC §1207.1.4.1(5))*	Short circuits on the load side of the ESS are anticipated to be mitigated by BMS control and subsequent safety actions, in addition to a number of passive circuit protections briefly noted in Section 2.2.6 of this report.

3.4.1 Thermal Runaway Condition

Thermal runaway, as defined per *NFPA 855 §3.3.20*, is defined as the condition when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing, fire, or explosion. The cause of a thermal runaway event can range from a manufacturer defect in the cell, external impact, exposure to dangerously high temperatures, or a multitude of controls and electrical failures. Furthermore, a thermal runaway event in a single cell can propagate to nearby cells, thus creating a cascading runaway event across battery modules and racks, leading to more heat generation, fire, off-gassing, and increased potential for a deflagration event.

The Tesla Megapack 2/XL is equipped with a number of passive and active mitigations such as BMS Control and active thermal management system for cooling of internal components to reduce the potential of a thermal runaway event from occurring, as is depicted on the *threat* side of the diagram below. Threat scenarios accounted for include single-cell thermal runaway, multi-cell thermal runaway, and internal defect or failure not resulting in thermal runaway, leading to the primary hazard event (propagating cell failure leading to off-gassing or fire).

Should thermal runaway occur within a battery module, a number of key barriers are provided to mitigate against propagation of failure throughout the system leading to more severe consequences, which are described in detail in Section 3.3 of this report above.

Figure 3-5 - Thermal Runaway Condition Diagram

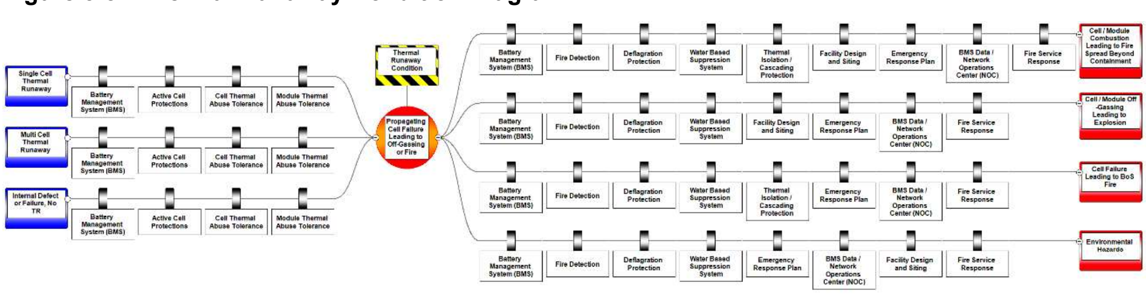


Table 3-5 - Thermal Runaway Condition Barriers

Barrier	Barrier Description
THREAT BARRIERS	
Battery Management System (BMS)	BMS provides sensing and control of critical parameters and triggers protective or corrective actions if system is operating out of normal parameters. Parameters include battery module over / under voltage, cell string over / under voltage, battery module over temperature, temperature signal loss, and battery module over current. In the event of any abnormal conditions, the BMS will first raise an information warning and then trigger a corresponding corrective action should certain levels be reached.
Thermal Management System	Active thermal management system provides liquid cooling to internal components within the Megapack 2/XL to limit heat diffusion.
Cell Thermal Abuse Tolerance	Cell has been tested and listed to UL 1973 in which thermal abuse tolerance was tested.
Module Thermal Abuse Tolerance	Module has been tested and listed to UL 1973 in which thermal abuse tolerance was tested.
CONSEQUENCE BARRIERS	
See Section 3.3 above for list of primary consequence barriers.	

3.4.2 Failure of an Energy Storage Management System

The loss, failure, or abnormal operation of an energy storage control system (controllers, sensors, logic / software, actuators, and communications networks) may directly impact the proper function of the system. The Tesla Megapack 2/XL utilizes a tiered hierarchy of controls starting at the module level up to the site level.

In the event of a failure of module-level BMS, the Megapack-level BMS (which may be considered "ESMS") shall isolate effected modules, mitigating against further propagation of failure across the system. Should a failure of the Megapack-level BMS occur, each module is equipped with a dedicated BMS to provide corrective actions in case of detection of abnormal operation outside of set parameters. To further isolate any failure stemming from a failure of the energy storage management system, passive and active electrical fault protections are provided at multiple levels, as described in Section 2.2.6 above.

Finally, should a propagating thermal runaway occur, a number of key barriers are provided to mitigate against propagation of failure throughout the system leading to more severe consequences, which are described in detail in Section 3.3 of this report above.

Figure 3-6 - Failure of an Energy Storage Management System Diagram

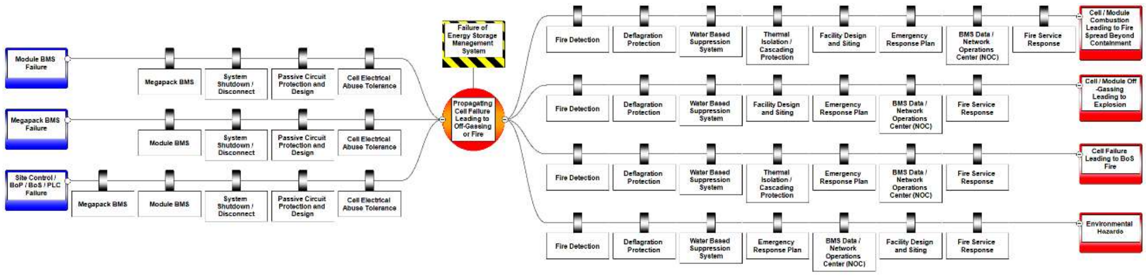


Table 3-6 - Failure of an Energy Storage Management System Barriers

Barrier	Barrier Description
THREAT BARRIERS	
Energy Storage Management System (ESMS)	Megapack-level Energy Storage Management System (ESMS) supervising output of all modules at AC bus level to provide isolation / protective actions in case of module BMS failure.
Module BMS	Module-level BMS to provide isolation / protective actions in case of ESMS failure.
System Shutdown / Disconnect	Multiple levels of passive and active electrical protections are provided for the Megapack 2/XL including module overcurrent protection via fusible links on the DC side of the modules, inverter DC and AC protections, and ground fault detection.
Passive Circuit Protection and Design	Fused disconnects and DC disconnect switches, in addition to ground fault detection / interruption and over voltage protection provided.
Cell Electrical Abuse Tolerance	Cell tested and certified to UL 1642 Standard for Lithium Batteries.
CONSEQUENCE BARRIERS	
See Section 3.3 above for list of primary consequence barriers.	

3.4.3 Failure of a Required Ventilation or Exhaust System

The Megapack 2/XL does not utilize a system to exhaust flammable gasses, as lithium-ion batteries do not release flammable gas during normal operations. Flammable gasses generated during abnormal operations are mitigated by the Megapack 2/XL's proprietary explosion mitigation system.

3.4.4 Failure of a Required Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System

The Tesla Megapack 2/XL does not rely on a dedicated smoke detection, fire detection, or gas detection system. Multi-spectrum infrared (IR) detection can be provided to satisfy the automatic fire detection requirements of the locally adopted codes/standards. Should IR detection systems fail, it is anticipated that BMS fault notifications shall be transmitted to Tesla's 24/7 Operations Center, alerting system owner to abnormal conditions. Data from the BMS may be communicated to a Subject Matter Expert to provide guidance to the fire department in case of emergency.

The Megapack 2/XL does not inherently rely on an integrated or external fire suppression system. A fire is not expected to propagate through the system or to nearby exposures based on UL 9540A Unit level testing, indicating that no flaming occurred and that no propagation of heat from the initiating unit to adjacent units / modules reached levels capable of initiating cell venting or thermal runaway. Bespoke fire testing and subsequent fire modeling has further assessed the robustness of the Megapack 2/XL system design and resistance to propagating failures. Furthermore, fire department response is expected to be strong based on training, robust firefighting capabilities and timely response.

Figure 3-7 - Failure of Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System Diagrams

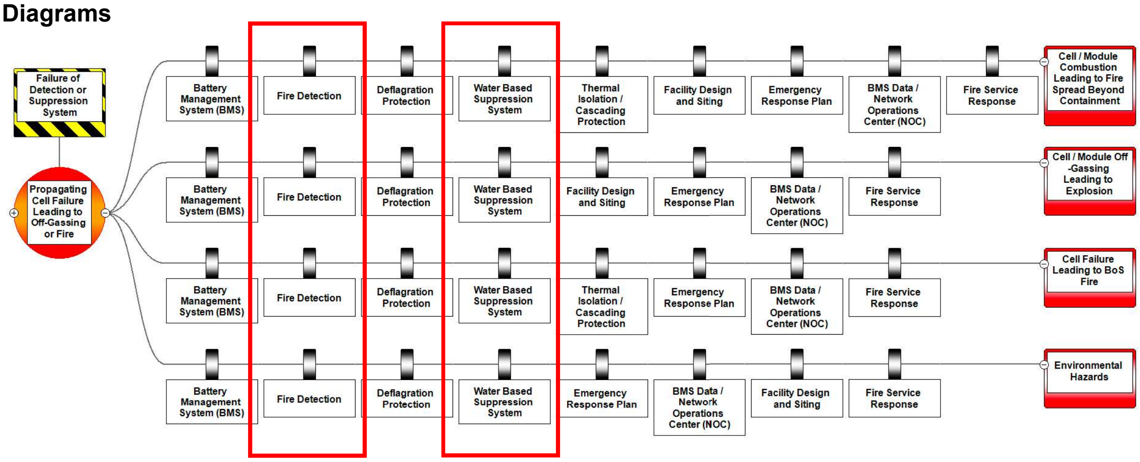


Table 3-7 - Failure of Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System Barriers

Barrier	Barrier Description
CONSEQUENCE BARRIERS	
Battery Management System (BMS)	BMS provides sensing and control of critical parameters and triggers protective or corrective actions if system is operating out of normal parameters. Parameters include battery module over / under voltage, cell string over / under voltage, battery module over temperature, temperature signal loss, and battery module over current. In the event of any abnormal conditions, the BMS will first

	raise an information warning and then trigger a corresponding corrective action should certain levels be reached.
Deflagration Protection	The Megapack 2/XL is equipped with deflagration protection in the form of pressure-sensitive vents and sparker system designed to ignite any flammable gases and release in a controlled manner before they are allowed to accumulate and create an explosive atmosphere within the enclosure.
Thermal Isolation / Cascading Protection	Thermal isolation shown to be effective in limiting heat transfer between Megapacks in UL 9540A Unit level testing.
Facility Design and Siting*	Facility design and siting may vary based on site-by-site basis. It should be ensured that sites follow Tesla recommended guidance for siting and other installation specifications be followed.
Emergency Response Plan / First Responders*	Product-level Emergency Response Guide (ERG) provided by Tesla. Additional level of safety may be provided via site-specific Emergency Response Plans (ERP) in accordance with the locally adopted codes/standards.
BMS Data / Operations Center	Megapack data accessible remotely via Tesla's 24/7 Operations Center.
Fire Service Response	Site-specific training and installation familiarization for local responding stations will increase the strength of this barrier, and fire department equipment and capabilities will be strong with this familiarization.
** Barrier may vary on site-by-site basis and are therefore not fully assessed within the scope of this report.*	

3.4.5 Voltage Surges on the Primary Electric Supply

Voltage surges on the primary electric supply are expected to be largely mitigated by voltage monitoring and corrective actions taken by the BMS. Should corrective actions triggered by the BMS fail to prevent further propagation of failure, a number of electrical fault protections are provided for the Megapack 2/XL, as are briefly described in Section 2.2.6 of this report.

Figure 3-8 - Voltage Surges on the Primary Electric Supply Diagram

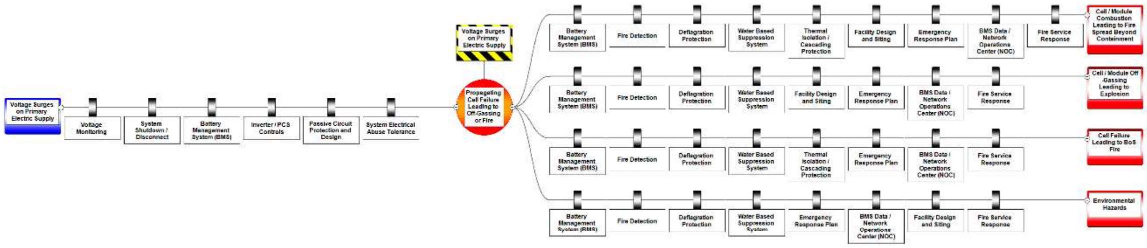


Table 3-8 - Voltage Surges on the Primary Electric Supply Barriers

Barrier	Barrier Description
THREAT BARRIERS	
Voltage Monitoring	Voltage is measured by BMS, triggering fault and alarm monitor indicators, and potential system disconnect or other corrective actions if operating out of normal parameters.
System Shutdown / Disconnect	Multiple levels of passive and active electrical protections are provided for the Megapack 2/XL including module overcurrent protection via fusible links on the DC side of the modules, inverter DC and AC protections, and ground fault detection.
Battery Management System (BMS)	BMS provides sensing and control of critical parameters and triggers protective or corrective actions if system is operating out of normal parameters. Parameters include battery module over / under voltage, cell string over / under voltage, battery module over temperature, temperature signal loss, and battery module over current. In the event of any abnormal conditions, the BMS will first raise an information warning and then trigger a corresponding corrective action should certain levels be reached.
Inverter / PCS Controls	Inverter modules equipped with both DC protection via high-speed pyrotechnic fuse for passive or active isolation of battery module, as well as dedicated AC contactor and AC fuses should an abnormal electrical event occur at the inverter module on the AC side of the circuit.
Passive Circuit Protection / Design	Fused disconnects and DC disconnect switches, in addition to ground fault detection / interruption and over voltage protection provided.
System Electrical Abuse Tolerance	System tested and listed to UL 9540.
CONSEQUENCE BARRIERS	

See Section 3.3 above for list of primary consequence barriers.

3.4.6 Short Circuits on the Load Side of the ESS

Short circuits on the load side of the ESS are anticipated to be largely mitigated by BMS control and passive circuit protection and design (e.g., fused disconnects, ground fault detection / interruption, and overvoltage protection), as described in previous sections of this report. The Megapack 2/XL has been tested and listed to UL 9540A, demonstrating adequate system electrical abuse tolerance and compatibility of constituent components.

Finally, as is consistent across all previous fault conditions covered above, should propagating thermal runaway occur, a number of key barriers are provided to mitigate against propagation of failure throughout the system leading to more severe consequences, which are described in detail in Section 3.3 of this report above.

Figure 3-9 - Short Circuits on the Load Side of the ESS Diagram

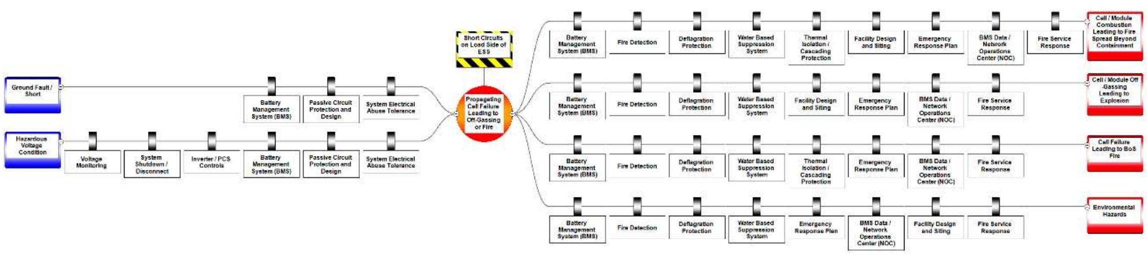


Table 3-9 - Short Circuits on the Load Side of the ESS Barriers

Barrier	Barrier Description
THREAT BARRIERS	
Battery Management System (BMS)	BMS provides sensing and control of critical parameters and triggers protective or corrective actions if system is operating out of normal parameters. Parameters include battery module over / under voltage, cell string over / under voltage, battery module over temperature, temperature signal loss, and battery module over current. In the event of any abnormal conditions, the BMS will first raise an information warning and then trigger a corresponding corrective action should certain levels be reached.
Voltage Monitoring	Voltage is measured by BMS, triggering fault and alarm monitor indicators, and potential system disconnect or other corrective actions if operating out of normal parameters.

System Shutdown / Disconnect	Multiple levels of passive and active electrical protections are provided for the Megapack 2/XL including module overcurrent protection via fusible links on the DC side of the modules, inverter DC and AC protections, and ground fault detection.
Passive Circuit Protection / Design	Fused disconnects and DC disconnect switches, in addition to ground fault detection / interruption and over voltage protection provided.
System Electrical Abuse Tolerance	System tested and listed to UL 9540.
CONSEQUENCE BARRIERS	
See Section 3.3 above for list of primary consequence barriers.	

3.5 Analysis Approval

Per *NFPA 855 §4.1.4.3*, the AHJ shall be permitted to approve the hazardous mitigation analysis as documentation of the safety of the ESS installation provided the consequences of the analysis demonstrate the following:

1) *Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 4.3.6.*
2) *Suitable deflagration protection is provided where required.*
3) *ESS cabinets in occupied work centers allow occupants to safely evacuate in fire conditions.*
4) *Toxic and highly toxic gases released during normal charging, discharging, and operation will not exceed the PEL in the area where the ESS is contained.*
5) *Toxic and highly toxic gases released during fires and other fault conditions will not reach concentrations in excess of immediately dangerous to life or health (IDLH) level in the building or adjacent means of egress routes during the time deemed necessary to evacuate from that area.*
6) *Flammable gases released during charging, discharging, and normal operation will not exceed 25 percent of the LFL.*

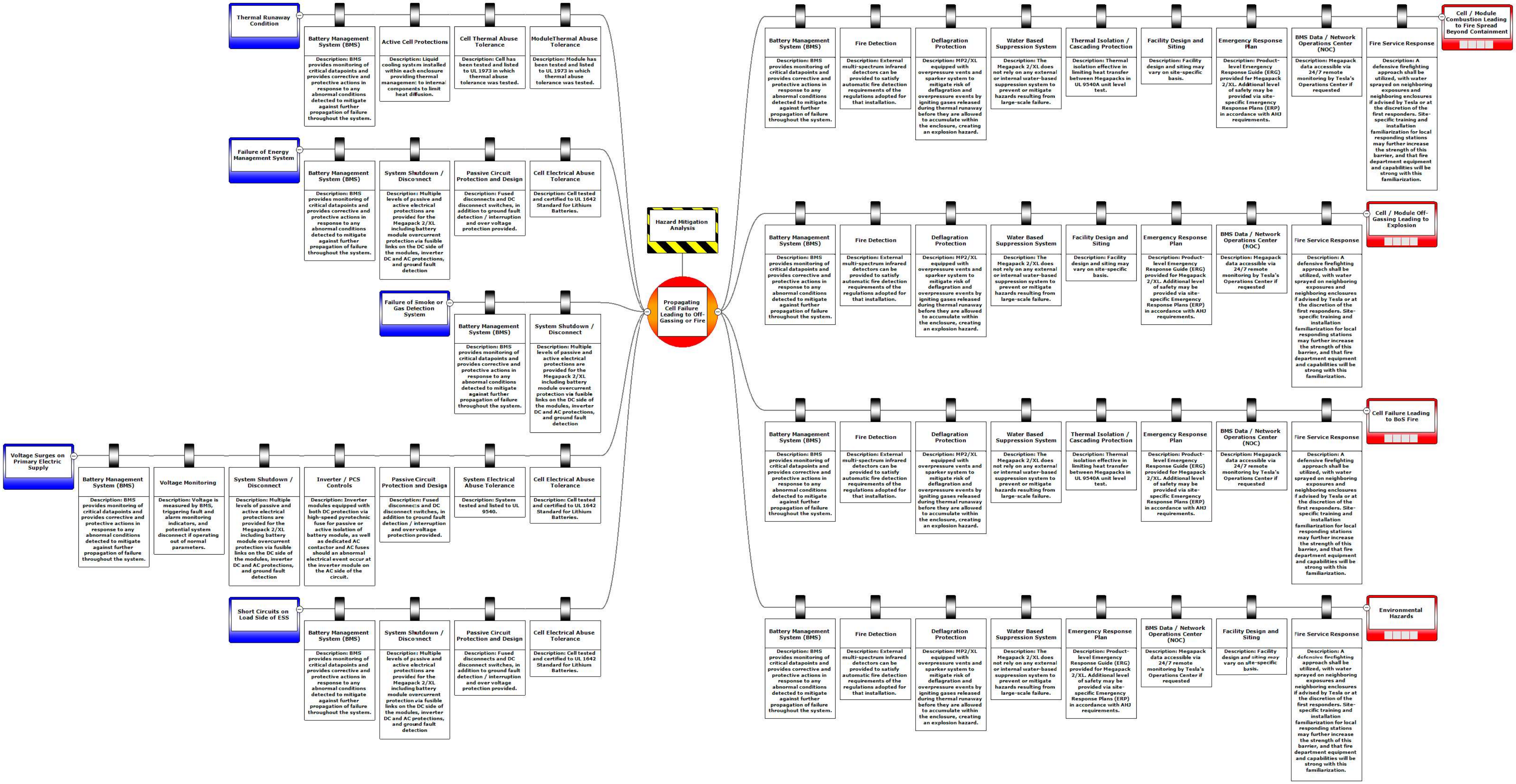
Table 3-10 - Summary of Analysis Approval

Compliance Requirement	Comments
1. Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 4.3.6.	**Not applicable.** The Megapack 2/XL is intended for outdoor ground-mounted installations only and shall not be installed within any ESS rooms or structures.
2. Suitable deflagration protection is provided where required.	**Compliant.** The Megapack 2/XL is equipped with deflagration protection in the form of pressure-sensitive vents and sparker system designed to ignite any flammable gases and release in a controlled manner before they are allowed to accumulate and create an explosive atmosphere within the enclosure.
3. ESS cabinets in occupied work centers allow occupants to safely evacuate in fire conditions.	**Not applicable.** The Megapack 2/XL is not intended to be installed in any occupied work centers.
4. Toxic and highly toxic gases released during normal charging, discharging,	**Not applicable.** Lithium-ion batteries do not release toxic gases during normal operation.

and operation will not exceed the PEL in the area where the ESS is contained.	
5. Toxic and highly toxic gases released during fires and other fault conditions will not reach concentrations in excess of immediately dangerous to life or health (IDLH) level in the building or adjacent means of egress routes during the time deemed necessary to evacuate from that area.	**Compliant.** Additional testing and third-party analysis performed on products of combustion from the Megapack 2/XL at locations 20 ft and 5 ft conclude no traces of Mercury or 27 different metals tested for. HF was detected at values of 0.10 and 0.12 ppm over the course of the test – far below accepted NIOSH Immediately Dangerous to Life or Health (IDLH) value of 30 ppm for HF. Environmental considerations (e.g., facility siting, nearby buildings, exposures, or public ways) should be taken into account on a site-by-site basis.
6. Flammable gases released during charging, discharging, and normal operation will not exceed 25 percent of the LFL.	**Not applicable.** Lithium-ion batteries do not release flammable gases during charging, discharging, or normal operation. In the case of flammable off-gases being released due to a thermal runaway event, the Megapack 2/XL is equipped with pressure-sensitive vents and sparker system designed to ignite any flammable gases and release in a controlled manner before they are allowed to accumulate and create an explosive atmosphere within the enclosure.

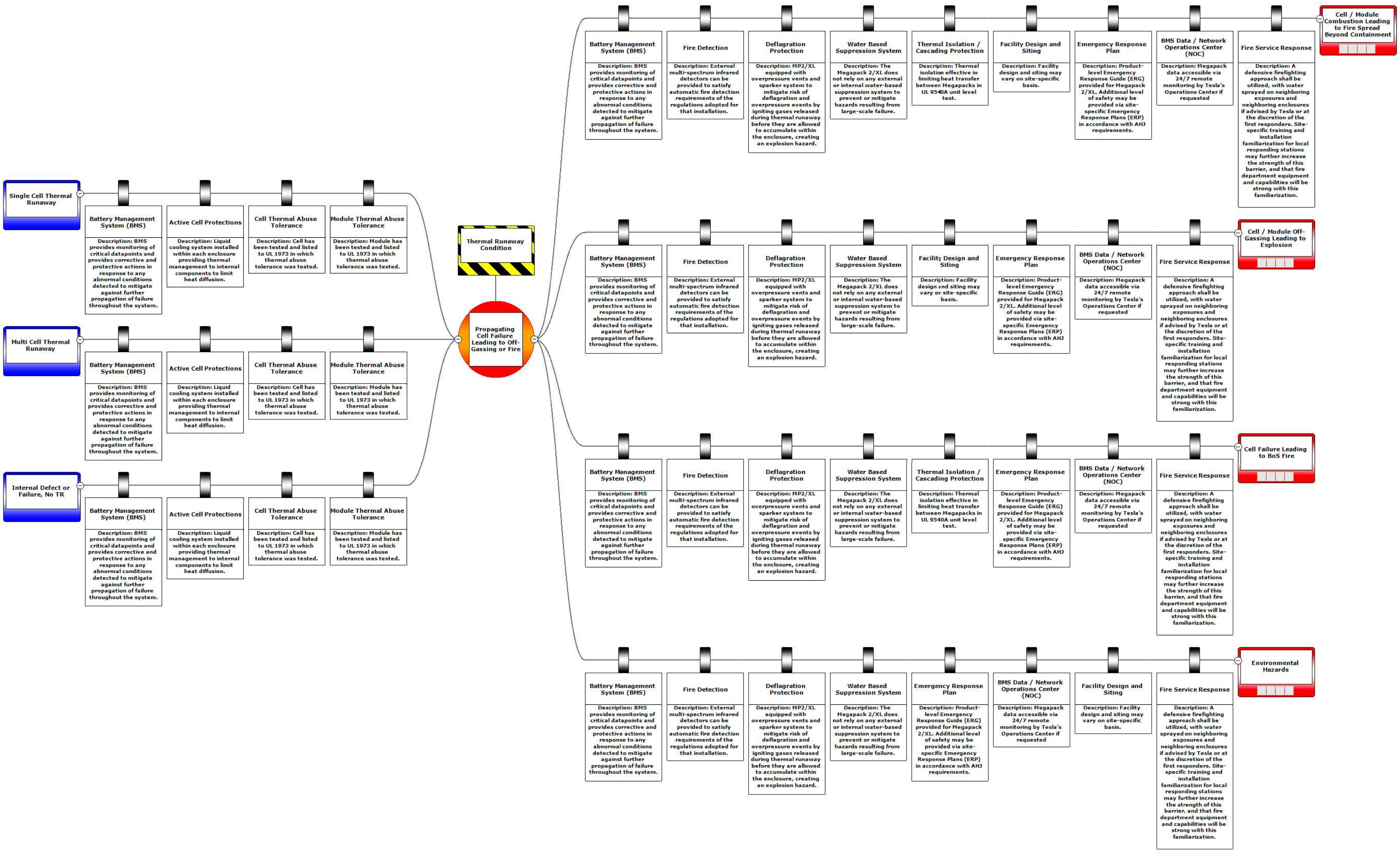
APPENDIX A – DETAILED HMA DIAGRAMS AND BARRIER DESCRIPTIONS

3.6 A.1 All Fault Conditions

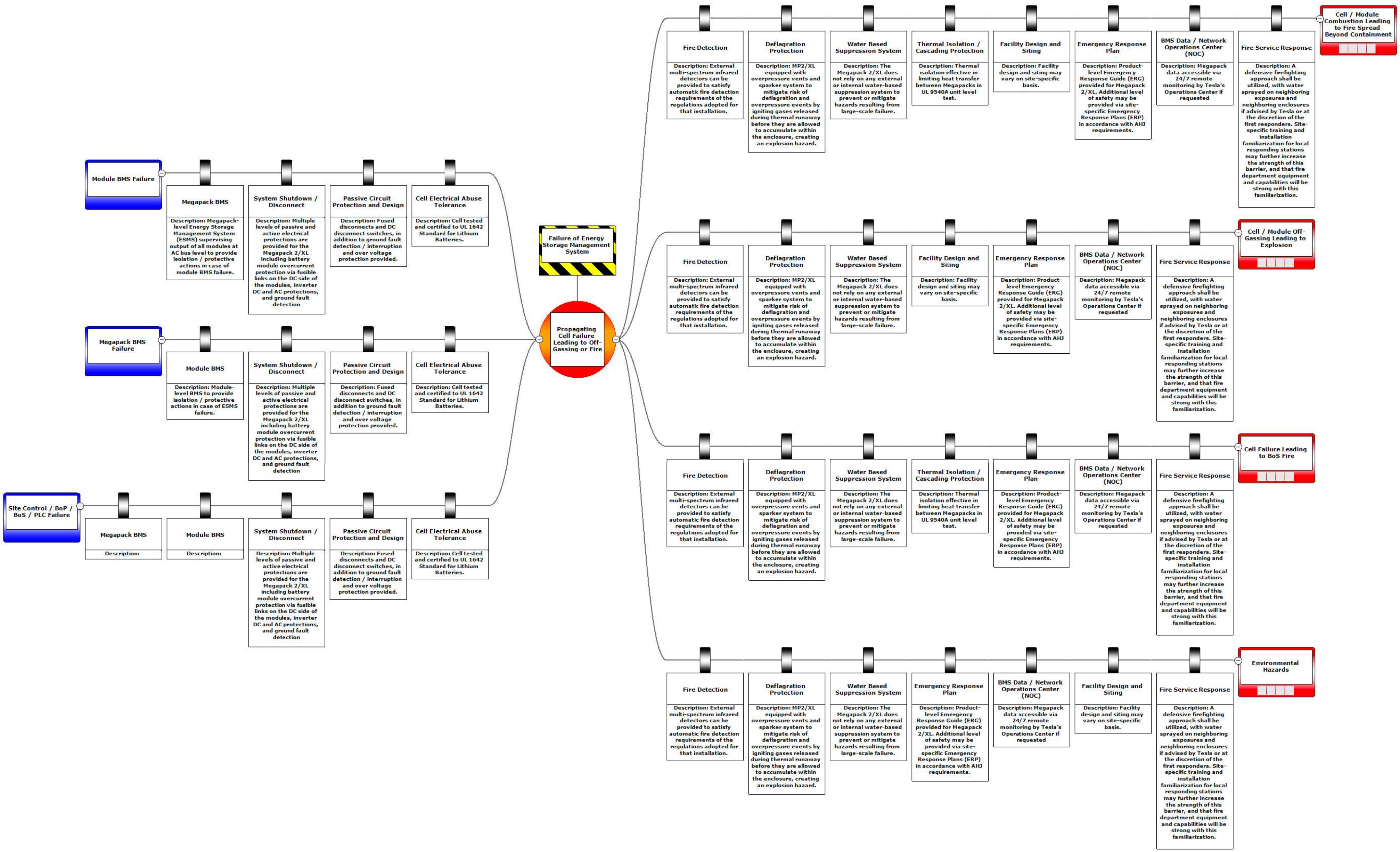


3.6.1

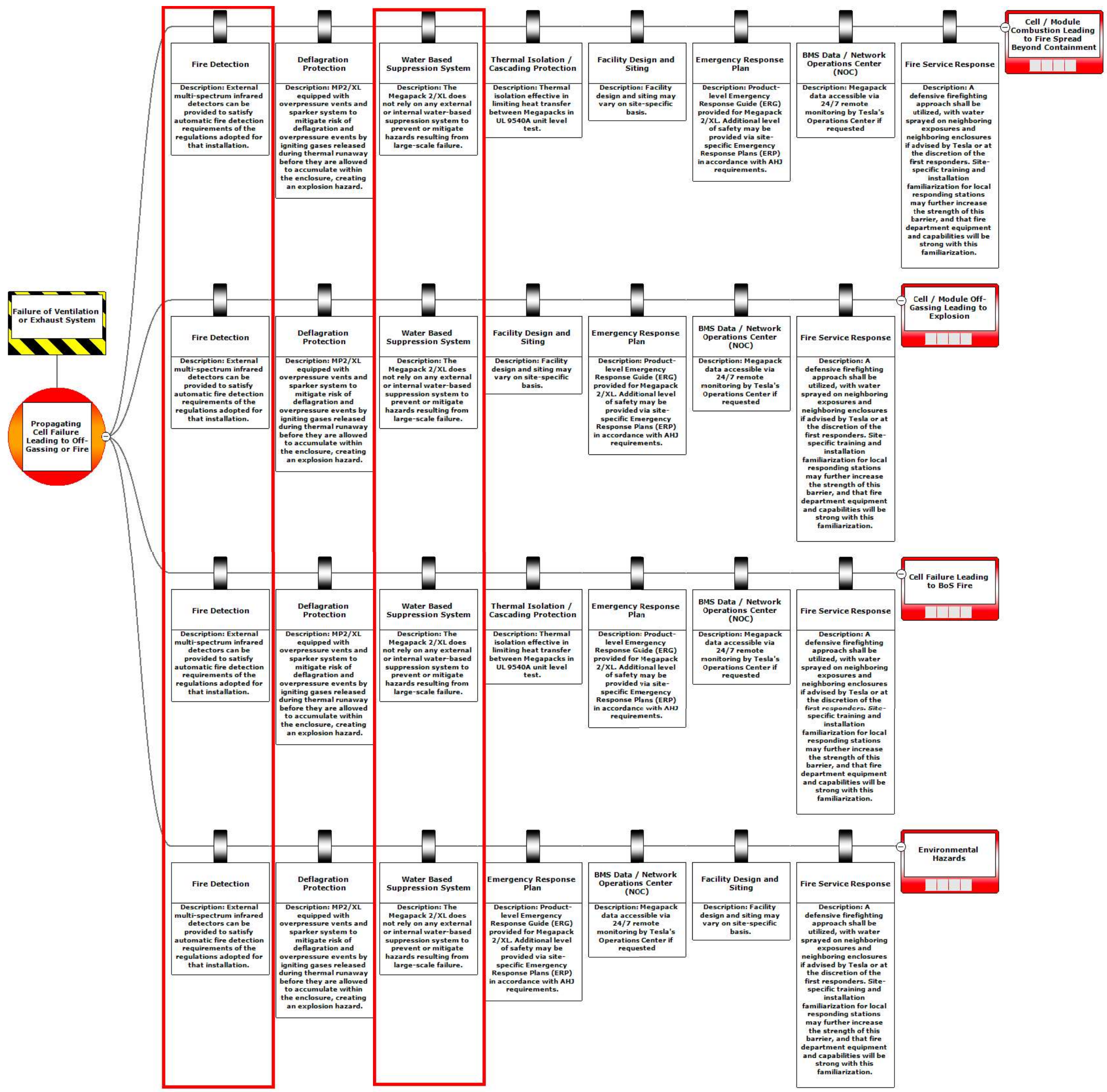
3.7 A.2 Thermal Runaway Condition



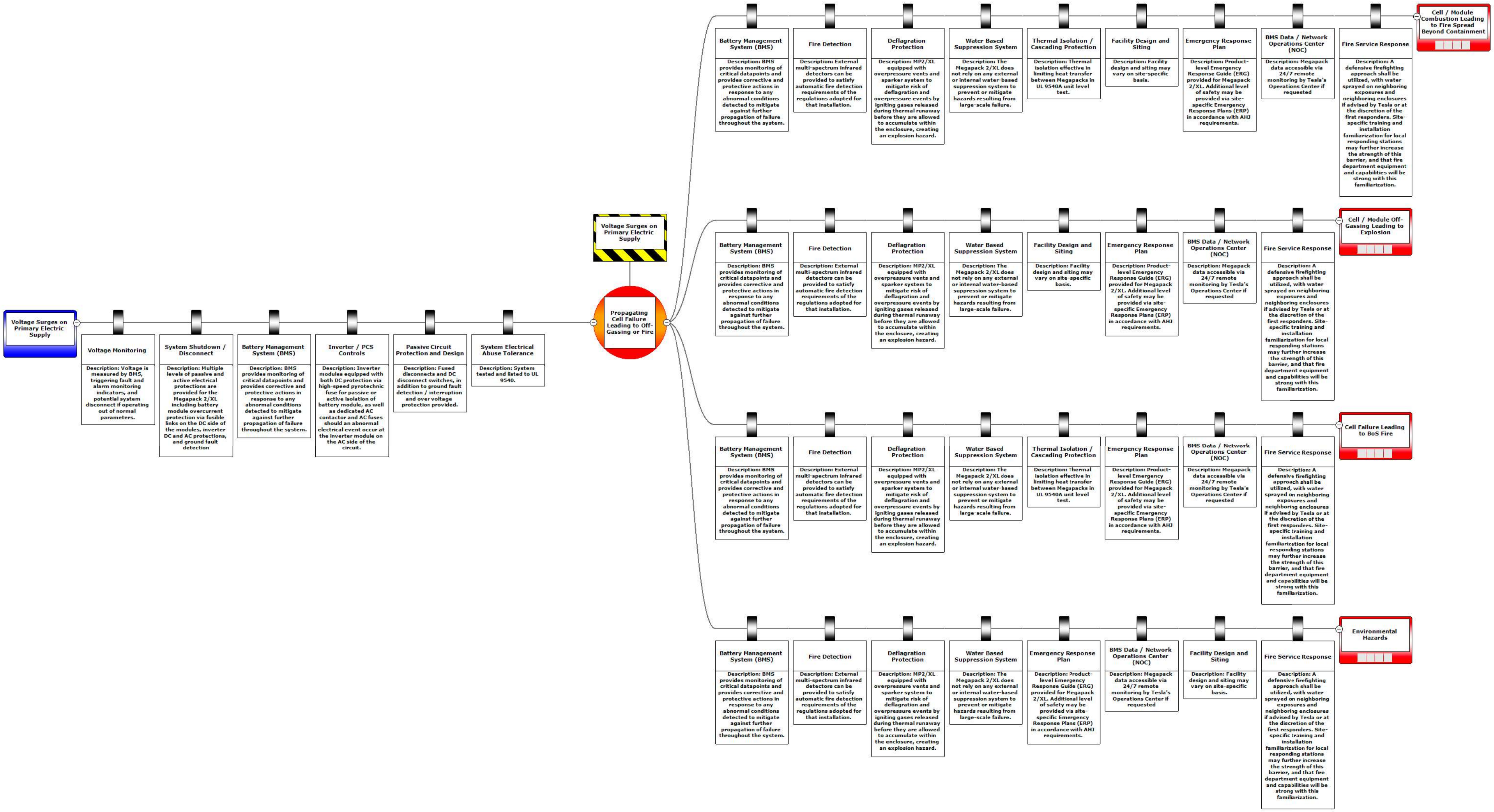
3.8 A.3 Failure of an Energy Storage Management System



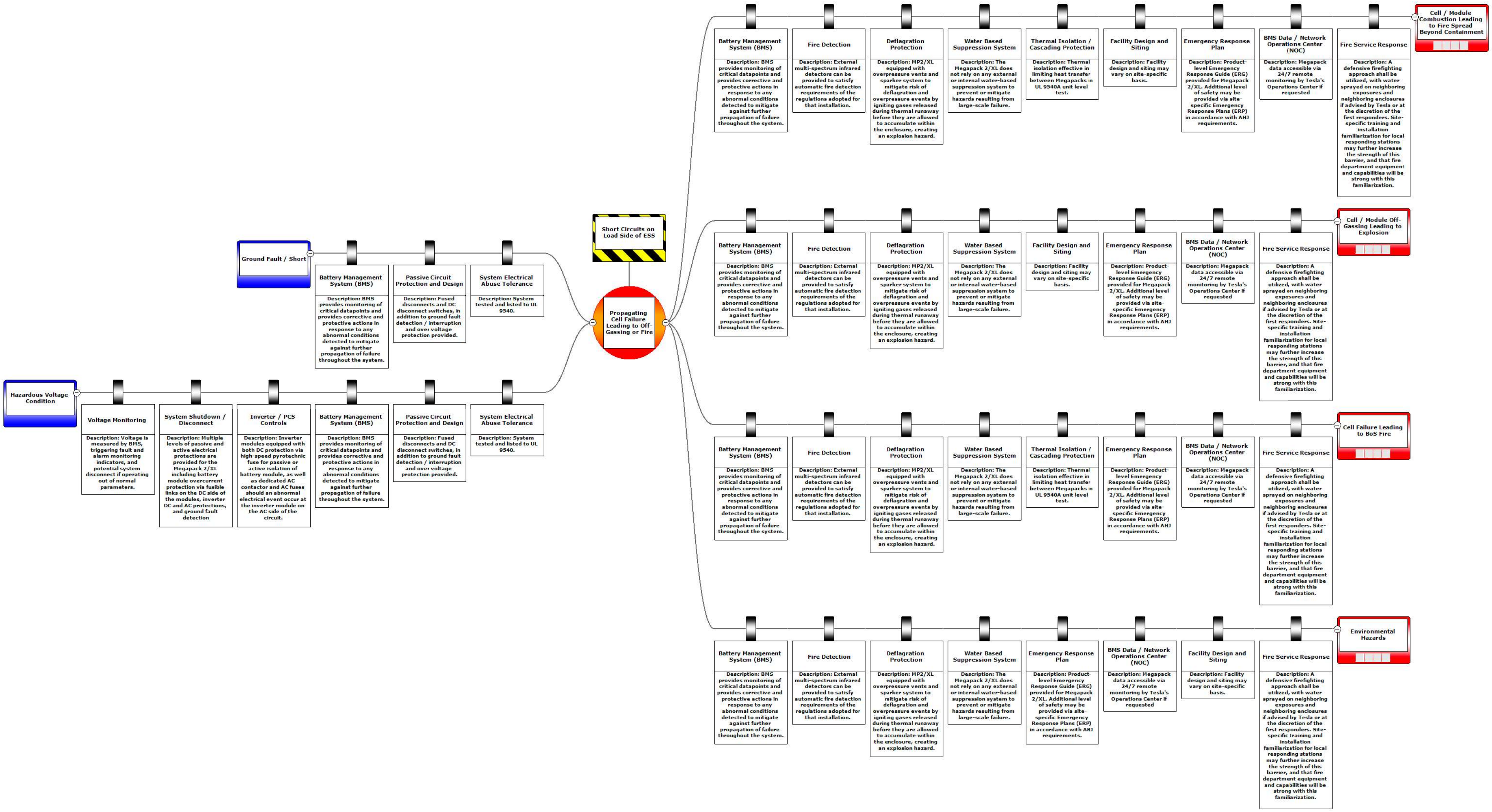
3.9 A.4 Failure of a Required Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System



3.10A.5 Voltage Surges on the Primary Electric Supply



3.11 A.6 Short Circuits on the Load Side of the ESS

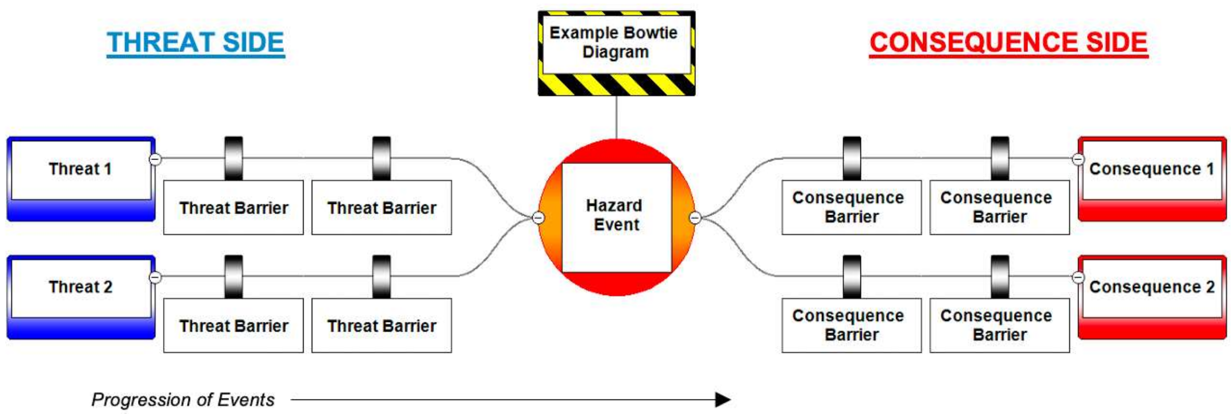


APPENDIX B – HMA METHODOLOGY

This Appendix serves as a supplemental write up for the overall Hazard Mitigation Analysis (HMA) and provides additional context on the Bowtie methodology used, as well as key definitions and concepts.

ESRG utilizes the bowtie methodology for hazard and risk assessments, as is described in *ISO.IEC IEC 31010 §B.21*, as it allows for in-depth analysis on individual mitigative **barriers** and serves as a strong tool for visualizing the chronological pathway of **threats** leading to critical hazard events, and ultimately to greater potential **consequences**, as depicted in the figure below. This simple diagrammatic way of describing and analyzing the pathways of a risk from hazards to outcomes can be considered to be a combination of the logic of a fault tree analyzing the cause of an event and an event tree analyzing the consequences.

The strength of the bowtie approach comes from its visual nature, which forgoes complex, numerical tables for threat pathways which show a single risk or consequence and all the barriers in place to stop it. On the left side are the threats, which are failures, events, or other actions which all result in a single, common hazard event in the center. For our model, many of these threats are the requirements of the fire code such as an unexpected thermal runaway.



- **Hazard Event / Top Event**

  The hazard (or "top") event – depicted as the center point in the middle of the bowtie diagram – represents a deviation from the desired state during normal operations (in this case, a thermal runaway or cell failure event), at which point control is lost over the hazard and more severe consequences ensue. This event happens before major damage has occurred, and it is still possible to prevent further damage.

- **Threats**

  There often may be several factors that cause a "top event". In bowtie methodology, these are called threats. Each threat itself has the ability to cause the center event. Examples of threats are hazardous temperature conditions, BMS failure, and water damage from condensation, each leading to cell failure (the center event for many of the following bowtie diagrams for lithium-ion ESS failures).

Threats may not necessarily address a fully involved system fire or severe explosion, but rather smaller, precursor events which could lead to these catastrophic consequences. Some threats occur without any intervention, such as defect propagation or weather-related events, while others represent operational errors (either human or system-induced). Often threats may also be consequences of even earlier-stage threats, spawning a new bowtie model that includes the threat at the center point or right side of the new bowtie. The diagrams that follow include careful selection and placement of each of the elements to best capture the perspective of system owners and operators responsible for ensuring safe operation.

- **Consequences**

  Consequences are the results of a threat pathway reaching and exceeding its center event. For the models described here, the center events were selected as the event in which proactive protections give way to reactive measures mostly related to fire protection systems and direct response. As the center event then is defined as either "cell failure" or propagating cell failure, the consequences in the models described assume a condition exists in which flammable gas is being released into the system or a fire is burning within the system.

  Consequence pathways include barriers that may help to manage or prevent the consequence event. Threat pathways are often consequence pathways from a separate hazard assessment, as is the case with thermal runaway. In other words, thermal runaway may result from many different threats at the end of a separate hazard pathway (if not properly mitigated) and may also be the threat that could result in several other consequences. The task force identified a set of common consequences representing areas of key concern to utilities, energy storage system operators, and first responders.

- **Barriers**

  In order to control risks, mitigative "barriers" are placed to prevent propagation of failure events across the system. A barrier can be any measure taken that acts against an undesirable force or intention, in order to maintain a desired state, and can be included as proactive threat barriers or reactive consequence barriers.

  Each barrier in these models is more indicative of a concept that may include a single approach or may consist of a complex series of combined measures. Similarly, the analysis may not include barriers required to prevent the threats at the far left of the diagram (which would be placed even further left) to ensure the models do not extend infinitely, though the incorporation of these variables into site-specific safety evaluations may provide additional benefit. This list does not contain all possible solutions and in some designs, these barriers may not exist at all. Many of the same barriers apply to a number of threats.

Barriers may mitigate hazards or consequences in a variety of ways. For example, common barriers to thermal runaway include active electrical monitoring and controls, redundant failure detection, and even passive electrical safeties (such as over-current protection devices and inherent impedances). Should these systems fail to detect the threat, shutdown the system, or otherwise prevent thermal runaway from occurring, the hazard may persist.

APPENDIX D – REFERENCED DOCUMENTATION

[1] *Tesla_Megapack 2_-_ANSI-UL_9540A_Cell_Level_Report_Redacted.pdf*

[2] *Tesla_Megapack 2_-_ANSI-UL_9540A_Module_Level_Report.pdf*

[3] *Tesla_Megapack 2_Megapack 2XL-_ANSI-UL_9540A_Unit_Level_Report.pdf*

[4] *22035-01R (MP2 UL9540A).pdf*

[5] *Tesla Megapack 2 – FPE Report – Final.pdf*

APPENDIX E – REFERENCED CODES AND STANDARDS

- *NFPA 855 Standard for the Installation of Stationary Energy Storage Systems*, 2020 Edition
- *International Fire Code §1207 Electrical Energy Storage Systems*, 2021 Edition
- *UL 9540A Standard for Test Method for Evaluation Thermal Runaway Fire Propagation in Battery Energy Storage Systems,* 4th Edition
- *UL 9540 Standard for Energy Storage Systems and Equipment,* 2nd Edition

Appendix B - Tesla Megapack 2XL - Fire Protection Engineering & UL 9540A Interpretation Report

Tesla Megapack 2 XL

Fire Protection Engineering and UL 9540A Interpretation Report

FIRE & RISK ALLIANCE

EXECUTIVE SUMMARY

Fire & Risk Alliance (FRA), performed a fire protection engineering (FPE) analysis of Tesla's Megapack 2 XL (MP2XL) battery energy storage system (BESS). The MP2XL (MP2XL) is a lithium-ion BESS with a storage capacity up to four megawatt hours (MWh). The MP2XL is a fully integrated BESS consisting of battery modules, power electronics, control systems, a battery management system, a thermal management system, and an explosion control system all pre-assembled within a single, non-occupiable cabinet. They are meant for outdoor installations, mounted to the ground, for commercial, industrial, and utility applications. This FPE analysis includes a review of the MP2XL, its construction, design, fire safety features, and an analysis of the UL 9540A cell, module, and unit level test data. Based on this review, FRA offers the following summary of our findings:

1. UL 9540A cell and module level testing demonstrated that flammable gases vent from the MP2XL cells during thermal runaway; however, the cells do not release toxic gases sometimes associated with the failure of lithium-ion batteries, such as HCN, HCL and HF.

2. UL 9540A unit level testing forced six cells into thermal runaway, which resulted in propagation to a seventh cell; however, thermal runaway did not propagate beyond the seventh cell.

3. During UL 9540A unit level testing, the MP2XL met all the performance criteria of UL 9540A, Table 9.1. Therefore, UL 9540A installation level testing is not required for a MP2XL installation.

4. The MP2XL can meet or exceed all the installation level codes and standards, such as the IFC and NFPA 855, required for outdoor, ground mounted BESS installations when it is installed in accordance with the MP2XL Design and Installation Manual.

This executive summary is an abbreviated list of findings. Refer to the main report for details of the analysis.

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1. INTRODUCTION

Fire & Risk Alliance (FRA), performed a fire protection engineering (FPE) analysis of Tesla's Megapack 2 XL (MP2XL) battery energy storage system (BESS). The MP2XL is a lithium-ion BESS with a storage capacity of up to four megawatt hours (MWh). The MP2XL is a fully integrated BESS consisting of battery modules, power electronics, control systems, a battery management system, a thermal management system, and an explosion control system all pre-assembled within a single, non-occupiable cabinet. They are meant for outdoor installations, mounted to the ground, for commercial, industrial, and utility applications. This FPE analysis includes a review of the MP2XL, its construction, design, and fire safety features, and an analysis of the UL 9540A cell, module, and unit-level test data. This narrative has been prepared by FRA and summarizes our analysis. It is intended to be used as a tool for a project designer, installer, fire code official (FCO), or an authority having jurisdiction (AHJ) to assist in their design, installation, or review of a MP2XL installation.

1.1 Codes, Standards, and Test Methods

The following codes, standards, and test methods have been applied to this analysis:

- 2024 International Building Code® (IBC).
- 2024 International Fire Code® (IFC).
- 2024 NFPA 1, Fire Code (NFPA 1).
- 2023 NFPA 855, Standard for the Installation of Stationary Energy Storage Systems (NFPA 855).
- 2023 NFPA 68, Standard on Explosion Protection by Deflagration Venting (NFPA 68).
- 2024 NFPA 69, Standard on Explosion Prevention Systems (NFPA 69).
- IEC 60529, Degrees of Protection Provided by Enclosures, 2.2 Edition, January 2019 (IP Code).
- IEC 62619, Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for secondary lithium cells and batteries, for use in industrial applications, Edition 1.0, 2017 (IEC 62619).
- IEC 62933-5-2, Electrical energy storage (EES) systems - Part 5-2: Safety requirements for grid-integrated EES systems - Electrochemical-based systems, April 15, 2020 (IEC 62933-5-2).
- UL 1642, Lithium Batteries, Edition 6, September 29, 2020 (UL 1642).
- UL 1973, Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications, Edition 2, February 7, 2018 (UL 1973).
- UL 9540, Standard for Safety of Energy Storage Systems and Equipment, Edition 2, February 27, 2020 (UL 9540).
- UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, Edition 4, November 12, 2019 (UL 9540A).

1.2 Reference Materials

In addition to the fire codes, standards, and test methods listed above, the following reference materials were reviewed as part of this analysis:

- MP2XL Design and Installation Manual – Rev. 2.2, dated January 30, 2024 (MP2XL DIM).
- MP2XL Operation and Maintenance Manual - Rev. 1.2, dated January 30, 2024 (MP2XL O&MM).
- Industrial Lithium-Ion Battery Emergency Response Guide – Rev. 2.7, dated February 16, 2024 (ERG).
- MP2/2XL UL 9540A Cell Level Fire Test Report, dated February 25, 2022.
- MP2/2XL UL 9540A Module Level Fire Test Report, dated July 15, 2022.
- MP2/2XL UL 9540A Unit Level Fire Test Report, dated August 5, 2022.
- Megapack 2XL Compliance Packet – Rev. 2.8, dated February 14, 2024.

1.3 Acronyms and Abbreviations

Authority Having Jurisdiction	AHJ	Light Electric Rail	LER
Battery Energy Storage System	BESS	Lithium Iron Phosphate	LFP
Battery Management System	BMS	Lower Flammability Limit	LFL
Centimeter	cm	Megapack 2	MP2
Contemporary Amperex Technology Co., LTD	CATL	Megapack 2XL	MP2XL
Controller Area Network	CAN	Megapack 2 & 2 XL	MP2/2XL
Customer Input/Output Terminals	I/O	Megawatt hour	MWh
Customer Interface Bay	CIB	Meter	m
Electrical Energy Storage	EES	Millimeter	mm
Emergency Response Plan	ERP	National Fire Protection Association	NFPA
Energy Storage System	ESS	Nationally Recognized Testing Laboratory	NRTL
Fire Code Official	FCO	Non-walk-in	NWI
Failure Modes and Effects Analysis	FMEA	Parts Per Million	ppm
Feet	ft	Pound Per Square Inch Gauge	psig
Fire Protection Engineering	FPE	Safety Data Sheet	SDS
Fire & Risk Alliance, LLC	FRA	Second	s
Gram	g	State of Charge	SOC
International Electrotechnical Commission	IEC	Supervisory Control and Data Acquisition	SCADA
International Fire Code	IFC	Tesla Site Controller	TSC
Inch	in	Thermal Management System	TMS
Kilogram	kg	TÜV SÜD	TÜV
Kilowatt hour	kWh	UL, LLC	UL

2. MP2XL DESIGN & FIRE SAFETY FEATURES

The MP2XL is a fully integrated BESS consisting of battery modules, power electronics, control systems, a battery management system, a thermal management system, and an explosion control system all pre-assembled within a single, non-occupiable cabinet. The MP2XL has a standardized, modular design that is not customizable or adjustable. MP2XL arrives at the site fully assembled needing just the alternate current (AC) connection and communications cables to be connected on the site. Meaning, every installation has the same MP2XL cabinets that are pre-assembled at the factory. It is approximately 28.9 ft in length, 5.4 ft deep, 9.2 ft in height, and can weigh up to 84,000 pounds (8.800 m by 1.650 m by 2.785 m and 38,100 kg). Below is a brief description of the MP2XL, its components, design listing, and fire safety features. For a more detailed discussion on the MP2XL components, their location, functionality, and purpose, refer to the MP2XL DIM.

2.1 Cabinet Layout

The MP2XL is intended for outdoor installations, ground-mounted to a foundation or base strong enough to support the weight of the equipment and anchor loads (including concrete pads, grade beams, etc.). The thermal roof (part of the thermal management system) is enclosed within an IP20 enclosure that sits above the battery module bays, as shown in Figure 1.

Figure 1 MP2XL internal components: (1) Battery Module Bays, (2) Thermal Cabinet, (3) Customer Interface Bay, (4) IP20 Thermal Roof Enclosure, (5) IP66 Enclosure.

The lithium-ion batteries are housed inside an IP66 steel enclosure (battery module bay) that provides protection against particle and water ingress coming into contact with the battery modules and power electronics. The IP66 enclosure is one continuous unit, meaning each of the ten bays are open to one another. However, when the MP2XL cabinet is populated with battery modules, it cannot be entered. This modular, cabinet style approach allows for the system to be easily maintained and serviced from outside the cabinets (i.e., the battery modules, thermal management system, and power electronics are serviced through doors located on the front of the cabinets or from the top through the thermal roof), thus eliminating the need for personnel to enter an enclosure, structure, building or container to perform those activities. Since the BESS cabinets do not permit walk-in access, it is a non-walk-in style (NWI) BESS, they are not defined as occupied buildings or structures per the IBC, IFC, NFPA 1, or NFPA 855.

2.2 Cells and Battery Modules

The MP2XL can be populated with up to twenty-four battery modules with a maximum storage capacity of 3,854.4 kWh for the 2-hour duration system, 3,847.2 kWh for the 3-hour duration system, and 3,916.8 kWh for the 4-hour duration system. Each battery module contains three battery trays, as shown in Figure 2, which are arrays of prismatic, lithium phosphate (LFP) cells. The LFP cells (the cells) utilized in the MP2XL are 157.2 amp hour (Ah) with a nominal voltage of 3.22 volts (V) and are individually hermetically sealed. They are approximately 50.75 millimeters (mm) by 166.0 mm by 169.3 mm and weigh 2,991 grams (g). Each battery tray contains 112 cells; therefore, each battery module has 336 cells, and a fully populated MP2XL (twenty-four battery modules) has 8,064 cells. Note the MP2XL utilizes the same cells and battery modules found in the Megapack 2 (MP2).

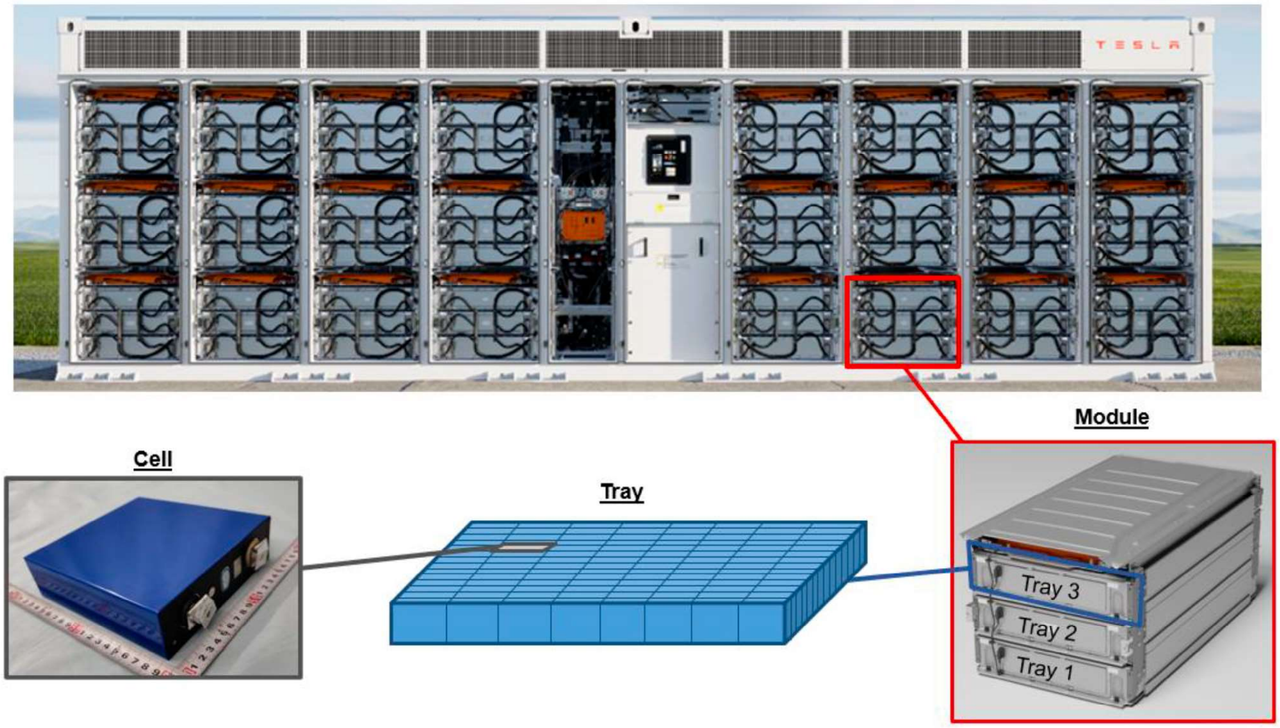

Figure 2 MP2XL, module, generalized tray, and an individual cell layout.

2.3 Customer Interface Bay

The Customer Interface Bay (CIB) is a single bay that includes all the external connections needed for initial MP2XL installation. When the fully assembled MP2XL arrives at the site, the only work necessary inside the cabinet is performed inside the CIB. Once installed, the CIB is a user-accessible area designed for operation and servicing. The CIB includes the main AC breaker, a status panel and controller area network (CAN) interface for service personnel, customer input/output (I/O) terminals, and the keylock switch (a “Lock Out/Tag Out” switch), which shuts down the AC bus to permit MP2XL maintenance by service personnel.

2.4 Thermal Management System

The thermal management system (TMS) provides a suitable operating temperature for MP2XL. The thermal bay and thermal roof house the components of the TMS. The TMS contains a closed-loop liquid cooling system that circulates a 50/50 mixture of ethylene glycol and water throughout the battery modules and power electronics to maintain an optimum battery operating temperature. The TMS works autonomously and does not require user feedback or controls to turn the system on when needed or to adjust temperature settings. The thermal cabinet includes pumps that circulate the liquid coolant through the MP2XL, an in-line heater that can warm the coolant and a compressor that maintains thermal control for the cabinet. The thermal roof, located above the battery bays within its own IP20 enclosure, provides a ventilation airspace for the MP2XL. It contains fans and radiators that cool the ethylene glycol-water solution. Cool air enters the thermal roof through the grates on the front of the MP2XL. The cool air then passes over the radiators, absorbing heat, and then is exhausted out of the top of the thermal roof via fans, as shown in Figure 3. The liquid cooling system utilizes approximately 400 liters (106 gallons) of the ethylene glycol-water solution, and the compressor utilizes 1.5 kilograms (3.3 pounds) of R-134a refrigerant for the 4-hour duration MP2XL and 3.0 kilograms (6.6 pounds) for the 2-hour duration MP2XL.

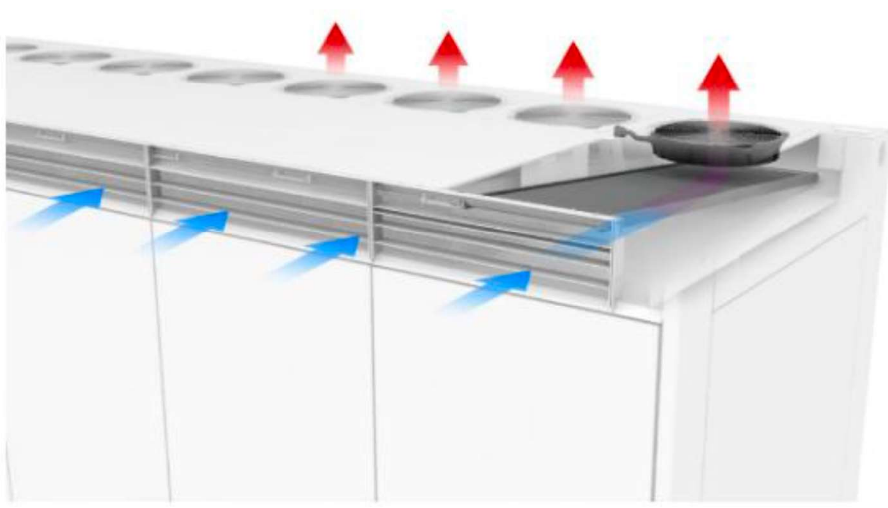

Figure 3 Airflow through the thermal roof.

2.5 Battery Management System

The MP2XL has an integrated battery management system (BMS) that tracks the performance, voltage, current, and state of charge of the cells (among many other datapoints). The BMS is a layered system, where each battery module has its own BMS and the MP2XL itself has a bus controller supervising the output of all the battery modules at the AC bus level. The BMS is engineered to react to fault conditions in an autonomous manner, with safeguards built into the firmware. These fault conditions include, but are not limited to, over-temperature, loss of communication, over-voltage, and isolation. For instance, to prevent a cell over-temperature the TMS is enabled by the BMS to cool the cells/module. This action by the BMS (which is just one example of many ways the BMS can respond to a fault condition) can either prevent thermal runaway from occurring in the cell or prohibit the propagation of thermal runaway to adjacent cells. Depending on the severity of the fault condition, the BMS can automatically isolate the affected battery module temporarily (less severe fault) or it can permanently disconnect the module.

2.6 Site Controller and Monitoring

Beyond the built-in safeguards of the BMS described above, the MP2XL is supported by a Tesla Local Operations Center (LOC), which is designed to support the global fleet of energy storage products. The MP2XL has 24/7 remote monitoring, diagnostics, and troubleshooting capabilities, without needing a Tesla technician on site. Customers and first responders also benefit from immediate hotline support from trained technicians via these LOCs. Additionally, the local energy provider or the facility can monitor the MP2XL through a local Supervisory Control and Data Acquisition (SCADA) system. All faults are transmitted to a Tesla LOC, alerting them to off-normal conditions that may require corrective action, either through remote means or an in-person field service visit. This communication link is accomplished via the Tesla Site Controller (TSC). The TSC provides the single point of interface for the utility, network operator, and/or the customer's SCADA systems to control and monitor the entire energy storage site. It dictates the charge and discharge functions of the MP2XL cabinets, aggregating real-time information and using the information to optimize the commands sent to each individual MP2XL cabinet. As such, every MP2XL has a wired Ethernet connection to the TSC, which communicates with a Tesla LOC via a built-in cellular modem. If the cellular network in the installation area is not sufficient, a hardwired internet connection can be provided. Additionally, if the BESS owner or operator wants a network connection for a control interface, the TSC becomes that point of connection to the MP2XL cabinet at the site

2.7 Electrical Fault Protection Devices

The MP2XL has several passive and active safety control mechanisms installed within the battery module circuit and distribution circuit that would be available to interrupt a fault current. At a high level, these electrical fault protection features include:

- Battery module overcurrent protection: The battery modules contain DC single-use fusible links mounted directly on the battery modules. These fuses are one-time only use safety devices that can interrupt the flow of an overcurrent in the battery module during an off-normal electrical event.

- Inverter DC protection: The inverter modules, which are installed at each of the battery modules, are equipped with a high-speed pyrotechnic fuse that can isolate the battery module passively or actively during an off-normal event.
- Inverter AC protection: In addition, each inverter module is equipped with its own AC contactor and AC fuses should an off-normal electrical event occur at the inverter module on the AC side of the circuit.
- Ground fault protection: Finally, the MP2XL is also provided with a DC ground fault detection system. It measures insulation resistance prior to operation and looks for excessive leakage current during operation. Additionally, the MP2XL also contains an AC circuit breaker, with ground-fault trip settings, which is installed within the CIB to provide distribution system protection.

2.8 Explosion Control System

The MP2XL includes an explosion control system to mitigate the risk of an uncontrolled deflagration. The system includes pressure-sensitive vents (overpressure vents) and sparkers installed throughout the battery module bay. The sparkers are designed to ignite flammable gases very early in a thermal runaway event before they accumulate within the enclosure and become an explosion hazard. They are installed at a variety of locations and heights throughout the battery module bays to ensure the flammable gases released during thermal runaway quickly meet an ignition source. Note, this explosion control system is the same approach that Tesla has utilized in previous versions of the Megapack (Megapack 1 and Megapack 2) and is not a new concept. It has been extensively validated through installation level testing for these previous Megapack versions as well as the MP2XL and its performance has been demonstrated in the field during thermal events involving Megapacks.

The overpressure vents are installed in the roof of the sealed battery bay's IP66 enclosure, as shown in Figure 4. When activated, the overpressure vents open up into the enclosed thermal roof, ensuring that the release of the overpressure vents does not create a projectile hazard. In addition, since they are installed in between the battery module bays and the thermal roof, the overpressure vents are not exposed to the environment, which means they are protected from the elements, such as falling tree limbs or snow, which could impact their functionality.

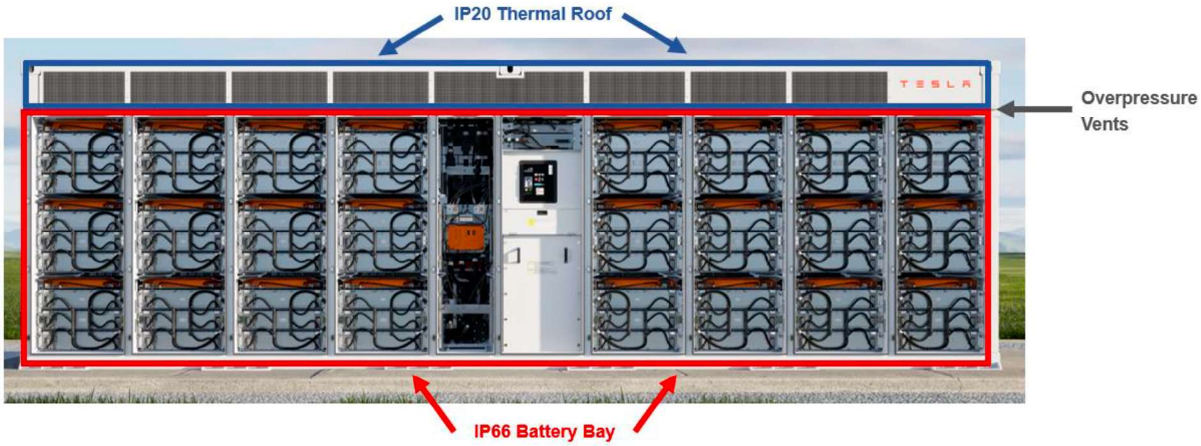

Figure 4 Location of overpressure vents in between the IP66 battery bay and the IP20 thermal roof

Once opened, the overpressure vents permit gases, products of combustion, and flames to safely exhaust through the roof of the MP2XL during a thermal event. By designing this natural ventilation flow path, flammable gases are not permitted to accumulate within the MP2XL cabinet, reducing the risk of a deflagration or explosion that could compromise the cabinet's integrity, push open the front doors, or expel projectiles from the cabinet. In addition, the ventilation path creates a controlled fire condition, should one occur, out the top of the MP2XL cabinet. By maintaining the MP2XL cabinet's integrity, keeping all the doors shut during a fire event, reducing the risk of projectiles, and creating a controlled path for flames to exit the top of the MP2XL cabinet, the likelihood of a thermal event having an impact on life safety, site personnel or first responders, is reduced. In addition, by maintaining these features, the likelihood of a fire propagating to adjacent MP2XL cabinets, electrical equipment, or other exposures is also reduced.

The overpressure vents themselves are passive and are not actuated or controlled by another device. They are designed to release during an overpressure event, such as the rapid ignition of flammable gases by a sparker. The number and total area of overpressure vents were sized following the guidance of NFPA 68 with a safety factor of two times the enclosure's strength, including the front doors. Tesla developed the overpressure vents and sparker system because the direct application of NFPA 68 or NFPA 69 is not suitable for the MP2XL cabinet, which does not have large volumes of open-air space. This engineered approach is permitted by NFPA 855 §9.6.5.6.4 provided it is validated by installation-level fire and explosion testing and an engineering evaluation, which Tesla has performed.

2.9 Fire Detection

The MP2XL does not have an internal fire detection system or one that is integral to its design/construction. If fire detection is required at the BESS site, multi-spectrum IR flame detectors can be installed external to the MP2XL to detect flames exiting the cabinets. Testing performed by Tesla has demonstrated that multi-spectrum IR flame detectors are capable of detecting a fire once flames have exited the cabinet.

2.10 Clearances

The MP2XL can be installed back-to-back and side-to-side with a clearance distance of 6 inches and can be installed 8 feet in front of adjacent MP2XL cabinets. These clearance distances are based on large-scale fire tests and fire modeling results that demonstrate a fire will not propagate from one MP2XL to adjacent MP2XL cabinets.

2.11 Emergency Response

Tesla developed a lithium-ion battery emergency response guide (ERG) to provide guidance to anyone responding to an emergency involving a MP2XL. This guide can be utilized by site owners to develop their own site-specific emergency response plans.

3. MP2XL PRODUCT LISTINGS

The MP2XL and its subcomponents are certified or listed to multiple national and international product design standards. These certifications and listings apply to the cells, battery modules, inverters, power electronics, control systems, integration between the BESS and the grid, as well as the BESS as a whole. The standards highlighted below pertain to the lithium-ion cells, the battery modules, and the MP2XL BESS at the unit level. For a full listing of all certifications and listings for all the MP2XL components, please refer to the MP2XL Compliance Packet.

3.1 Cell and Module Level

The lithium-ion batteries utilized in MP2XL are certified and listed to national and international product safety standards from entities such as UL, LLC (UL) and the International Electrotechnical Commission (IEC). These certifications include, but are not limited to:

UL 1642: This certification standard is applicable to secondary (rechargeable) lithium-ion cells and batteries used as a power source (such as BESS). The standard's requirements are intended to reduce the risk of fire or explosion when the battery is used in a product. For example, the standard subjects lithium-ion batteries to severe abuse conditions and evaluates if they can safely withstand them.

UL 1973: This certification standard is applicable to batteries and battery systems utilized for energy storage. The standard evaluates the battery system's ability to safely withstand simulated abuse conditions. For example, the standard subjects module-level stationary batteries to an internal fire exposure test to force a thermal runaway in one cell to ensure it does not explode, propagate fire to neighboring cells, or propagate to the rest of the modular battery system. UL 1973 applies to stationary BESS applications, such as photovoltaic installations and wind turbine energy storage systems, as well as other specialized energy storage systems, such as light electric rail (LER) operations.

IEC 62619: This safety standard specifies requirements and tests to ensure the safe operation of secondary (rechargeable) lithium-ion cells and batteries used in ESS and in other industrial applications. Electrical safety is covered under Clause 8 of the standard, which requires the completion of a risk analysis to determine specific electrical safety issues associated with the intended use of a given battery system or device.

3.2 Unit Level

The MP2XL, as entire cabinets, are also certified, tested, and listed to national and international product safety standards and test methods, including, but not limited to:

IEC 62933-5-2: This safety standard addresses various aspects of BESS, including the requirements for grid-integrated BESS.

UL 9540: This standard covers energy storage systems (including lithium-ion BESS) for stationary indoor and outdoor installations and establishes the system-level certification for energy storage systems and their associated equipment.

UL 9540A: The test methodology evaluates the fire characteristics and thermal runaway fire propagation of a BESS (including lithium-ion BESS). The test method provides a means to evaluate thermal runaway and fire propagation at the cell level, module level, and unit level. The data generated from the test method can be used to determine the fire and explosion protection required for a BESS installation based on fire test data. This test is specifically referenced by the IFC, NFPA 1, and NFPA 855 to demonstrate the functionality of the BESS fire protection features during large-scale fire testing.

3.3 Installation Level

The MP2XL can meet the installation level requirements in the 2024 Edition of the International Fire Code, the 2023 Edition of NFPA 855, and the 2022 California Fire Code for outdoor, ground-mounted BESS installations when they are installed in accordance with its listing and the MP2XL DIM.

4. UL 9540A TESTING

The UL 9540A test method provides a method to evaluate thermal runaway and fire propagation of a lithium-ion BESS at the cell level, module level, unit level, and installation level. The data generated from the test method can be used to determine the fire and explosion protection systems/features required for a BESS installation. This includes, but is not limited to, thermal runaway characteristics of the cell; cell thermal runaway gas composition; the fire propagation potential from cell to cell, module to module, and unit to unit; products of combustion; heat release rate; smoke release rate; and performance of fire protection systems. A summary of the cell, module, and unit-level test results for the MP2XL is provided below.

4.1 UL 9540A Cell Level Testing

Cell-level testing was conducted at UL in December 2021. UL is an OSHA-approved Nationally Recognized Testing Laboratory (NRTL) and offers the UL mark for products. Testing was performed on five model CB5T0, 3.22 V, 157.2 Ah, LFP cells manufactured by Contemporary Amperex Technology Co., Ltd. (CATL) for use in the Megapack 2 and Megapack 2 XL (MP2/2XL).[1] Each cell was charged to 100% state of charge (SOC) prior to testing. Thermal runaway was initiated via film strip heaters installed on both of the wide side surfaces of each cell, as shown in Figure 5. Meaning two heaters were installed on each cell. The heaters were programmed to increase the temperature of the cell's surface by approximately 4.5°C per minute until the cell vented and went into thermal runaway. The cell was placed within an enclosed enclosure and the products released during testing were collected and analyzed.

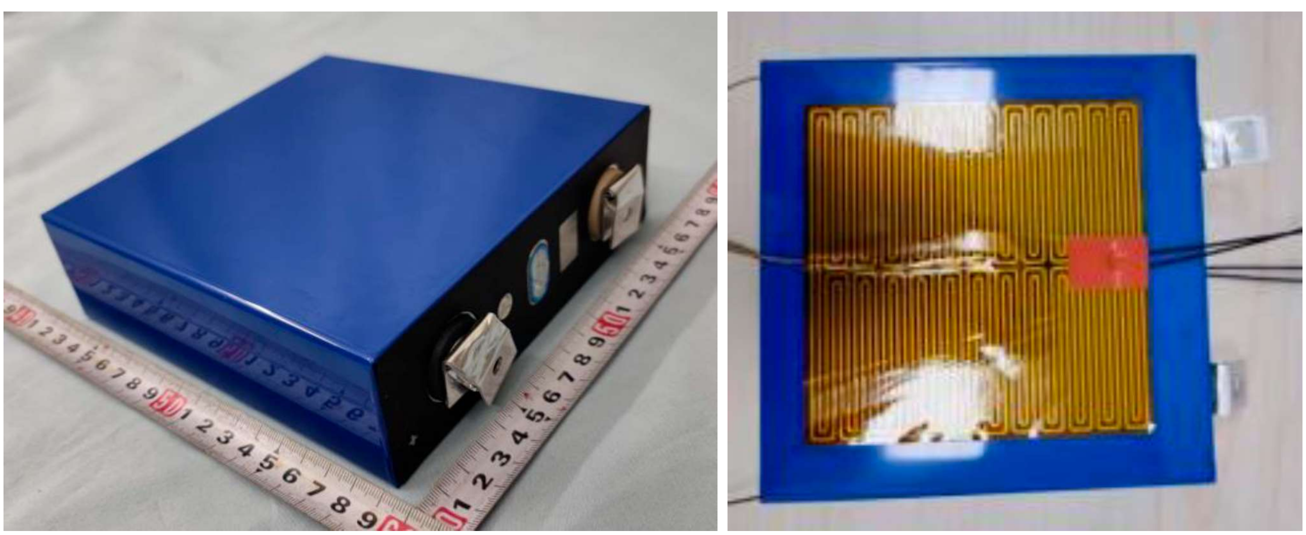

Figure 5 Individual cell tested to UL 9540A (left) and installed film strip heater (right).

[1] Note, as described in Section 2.2, the MP2 and MP2XL utilize the same cells and battery modules.

4.1.1 Test Results

The key flammability and gas composition properties from the UL 9540A cell level tests are summarized below in Table 1 and Table 2.

Table 1 UL 9540A Cell Level Testing: Key Flammability Characteristics

Flammability Property	Value
Average cell surface temperature at gas venting	174°C
Average cell surface temperature at thermal runaway	239°C
Cell vent gas volume released	93.3 L
LFL, % volume in air at the ambient temperature	7.15%
LFL, % volume in air at the venting temperature	6.05%
Burning Velocity (S_u)	90.0 cm/s
Maximum pressure (P_{max})	98.46 psig

Table 2 UL 9540A Cell Level Testing: Cell Vent Gas Composition (Excluding O_2 and N_2)

Gas Name	Chemical Structure	% Measured	Component LFL
Carbon Monoxide	CO	10.881	10.9
Carbon Dioxide	CO2	27.107	N/A
Hydrogen	H2	50.148	4.0
Methane	CH4	6.428	4.4
Acetylene	C2H2	0.264	2.3
Ethylene	C2H4	3.283	2.4
Ethane	C2H6	1.100	2.4
Propene	C3H6	0.379	1.8
Propane	C3H8	0.125	1.7
-	C4 (Total)	0.190	N/A
-	C5 (Total)	0.027	N/A
-	C6 (Total)	0.005	N/A
Benzene	C6H6	0.002	1.2
Toluene	C7H8	0.002	1.0
Dimethyl Carbonate	C3H6O3	0.055	N/A
Ethyl Methyl Carbonate	C4H8O3	0.004	N/A
Total	-	100	-

4.1.2 Key Takeaways

Key takeaways from the tests include:

- The average cell vent and thermal runaway temperature was determined to be 174°C (345°F) and 239°C (462°F), respectively.
- 93.3 liters of cell vent gases were released.
- The cell vent gas mixture is flammable and has an LFL of 7.15% at ambient temperature.
- The cell vent gases were predominantly (approximately 95%) Carbon Monoxide (CO), Carbon Dioxide (CO_2), Hydrogen (H_2), and Methane (CH_4).
- Toxic gases sometimes associated with lithium-ion batteries, such as Hydrogen Fluoride (HF), Hydrogen Chloride (HCL), and Hydrogen Cyanide (HCN) were not vented from the cell.

4.1.3 Performance Criteria

UL 9540A, Section 7.7 outlines the performance criteria for the cell level test. If all these conditions are met, further testing (such as module, unit, or installation level tests) are not required. The acceptable performance criteria during the UL 9540A cell level test are as follows:

1. Thermal runaway cannot be induced in the cell.
2. The cell vent gas does not present a flammability hazard when mixed with any volume of air, at both ambient and vent temperatures.

Given the cell went into thermal runaway and vented flammable gases, UL 9540A module level testing was required.

4.2 UL 9540A Module Level Testing

Module level testing was conducted at a TÜV SÜD (TÜV) laboratory in May 2022. TÜV is an OSHA-approved NRTL and offers the cTÜVus mark, which is equivalent to other NRTL marks such as UL, ETL or CSA. Testing was performed on a 360.64 V, 157.2 Ah, MP2/2XL tray (model MP2 Module), manufactured by CATL.[2] Each tray consists of 112, CATL model CB5T0 LFP cells that were charged to 100% SOC prior to testing. During the test, the MP2XL tray is not connected to the BMS or TMS; meaning, they are not actively operating to prevent thermal runaway in a cell or to prohibit the propagation of thermal runaway from cell to cell. Thermal runaway was initiated via film strip heaters installed on both of the wide side surfaces of two cells, similar to the cell level test (see Figure 5). This resulted in the simultaneous heating of six cells forcing multiple cells into thermal runaway at approximately the same time. The heaters were programmed to increase the temperature of the cell's surface by approximately 4.17 - 4.52°C per minute until the cells vented and went into thermal runaway. The tray was placed under an instrumented hood and the products released during combustion were collected for analysis.

[2] Note, as described in Section 2.2, the MP2 and MP2XL utilize the same cells and battery modules.

Figure 6 Tray tested to UL 9540A module level testing.

4.2.1 Test Results

This simultaneous heating of six cells forced multiple cells to go into thermal runaway that propagated from the initiating cells to all the cells in the MP2/2XL tray. Once ignited, the MP2/2XL tray fire appears to be a slow-progressing thermal event that took approximately 30-35 minutes to burn itself out. Sparks and flying debris were observed during the test; however, there were no explosive discharges of gases. Products of combustion were collected in the hood and flammable gases were identified, as listed in Table 3. However, toxic gases sometimes associated with lithium-ion batteries, such as HF, HCL, and HCN, were not detected during the combustion of the MP2/2XL tray.

4.2.2 Key Takeaways

Key takeaways from the UL 9540A module level test include:

- Thermal runaway propagated from the initiating cells to all the cells in the MP2/2XL tray.
- The MP2/2XL tray fire appears to be a slow-progressing thermal event requiring over 30 minutes to burn itself out.
- Sparks and flying debris were observed, however, there were no explosive discharges of gases.
- Products of combustion were collected and were identified as flammable.
- Toxic gases sometimes associated with lithium-ion batteries, such as HF, HCL, and HCN, were not detected during the combustion of the MP2/2XL tray.

Table 3 UL 9540A Module Level Testing: Products of Combustion

Gas Name	Chemical Structure	Measurement Peak (ppm)
Carbon Monoxide	CO	205
Carbon Dioxide	CO2	6721
Methane	CH4	68.8
Acetylene	C2H2	17.1
Ethene	C2H4	Not Detected
Ethane	C2H6	Not Detected
Propane	C3H8	Not Detected
Butane	C3H4	Not Detected
Pentane	C3H6	Not Detected
Benzene	C6H6	9.0
Hexane	C7H14	Not Detected
Hydrofluoric Acid	HF	Not Detected
Hydrogen Chloride	HCL	Not Detected
Hydrogen Cyanide	HCN	Not Detected
Hydrogen	H2	446
Total Hydrocarbons	(Propane Equivalent)	247

4.2.3 Performance Criteria

UL 9540A, Section 8.4 outlines the performance criteria for the module level test. If all these conditions are met, further testing (such as unit or installation level tests) are not required. The acceptable performance criteria during the UL 9540A module level test are as follows:

1. Thermal runaway is contained by module design.
2. Cell vent gas is nonflammable as determined by the cell level test.

Given the cell vent gases are flammable (as summarized previously) and thermal runaway was not contained by the module design, UL 9540A unit level testing was required.

4.3 UL 9540A Unit Level Testing

The unit level fire test was conducted at the Northern Nevada Research Center on March 9, 2022, and was certified by TÜV. TÜV is an OSHA-approved NRTL and offers the cTÜVus mark, which is equivalent to other NRTL marks such as UL, ETL or CSA. Note, the MP2XL design is almost identical to the MP2 other than being greater in length to accommodate the additional battery modules. It uses the exact same cells, battery modules, and power electronics (i.e., all the same internal components) that the MP2 utilizes in its design. In addition, the design of the cabinet itself, enclosure strength, and fire safety features, such as the BMS, site controller, monitoring, electrical fault protections, and explosion control system are nearly identical for the two products.

After reviewing the MP2 unit level fire test results and comparing the MP2 and MP2XL products to one another, TÜV determined the MP2 UL 9540A unit level fire test results can be applied to the MP2XL and an additional UL 9540A unit level fire test for the MP2XL was not required for its listing. As such, given all these factors, a stand-alone MP2XL unit level fire test was not performed, nor required. Therefore, the UL 9540A unit level fire test results, described below for the MP2, can be applied to the MP2XL.

4.3.1 Test Unit

The test was performed on a fully populated MP2, consisting of nineteen battery modules, with a capacity of 3,100.8 kWh, tested at 100% SOC. Of all the MP2 variations, the unit tested during UL 9540A unit level testing is the largest capacity variation Tesla manufactures. In addition, during the test, the BMS and TMS are disabled; meaning, they are not actively operating to prevent thermal runaway in a cell or to prohibit the propagation of thermal runaway from cell to cell, or module to module. As such, the UL 9540A unit level fire test can be considered a worst-case fire scenario, where: (1) the unit tested was the largest variation in terms of energy capacity; (2) the unit tested was at the highest energy density possible (100% SOC); and (3) the BMS and TMS were disabled and, therefore, unable to actively respond to the thermal runaway condition. As such, any tests performed on a smaller capacity MP2, at a lower SOC, or on an operating MP2 (one with an active BMS and TMS) would be expected to perform similarly, if not better, than this worst-case scenario. Below is a summary of the UL 9540A unit level fire test results as well as a description of the performance of key fire safety features/systems during the test.

4.3.2 Test Setup

The test setup included all the required instrumentation and data collection as required by UL 9540A as well as some additional measurements that go beyond what is required. These additional measurements were collected to provide additional information to project designers, installers, a FCO, or an AHJ to assist in their design, installation, or review of a MP2XL installation.

4.3.3 Initiation

The initiating battery module was chosen to be the bottom battery module from Bay 7, in the middle battery tray, as shown in Figure 7.

Figure 7 Initiation location: Bay 7, bottom battery module within tray 2.

This location was deemed to be the worst-case, given there are battery trays directly above it and below it. In addition, by initiating in the bottom battery module, there are two additional battery modules installed directly above the initiation location. Within the battery tray itself, six interior cells were simultaneously heated via four film heaters, as shown in Figure 8. The heaters were programmed to provide a heating rate of 5°C (9°F) per minute, as specified by UL 9540A. The number of cells and the location were selected to provide the greatest thermal exposure to adjacent cells to ensure cell-to-cell propagation during the test. The objective of this initiation method is to simulate a mass failure of multiple cells in a localized area within the same battery module.

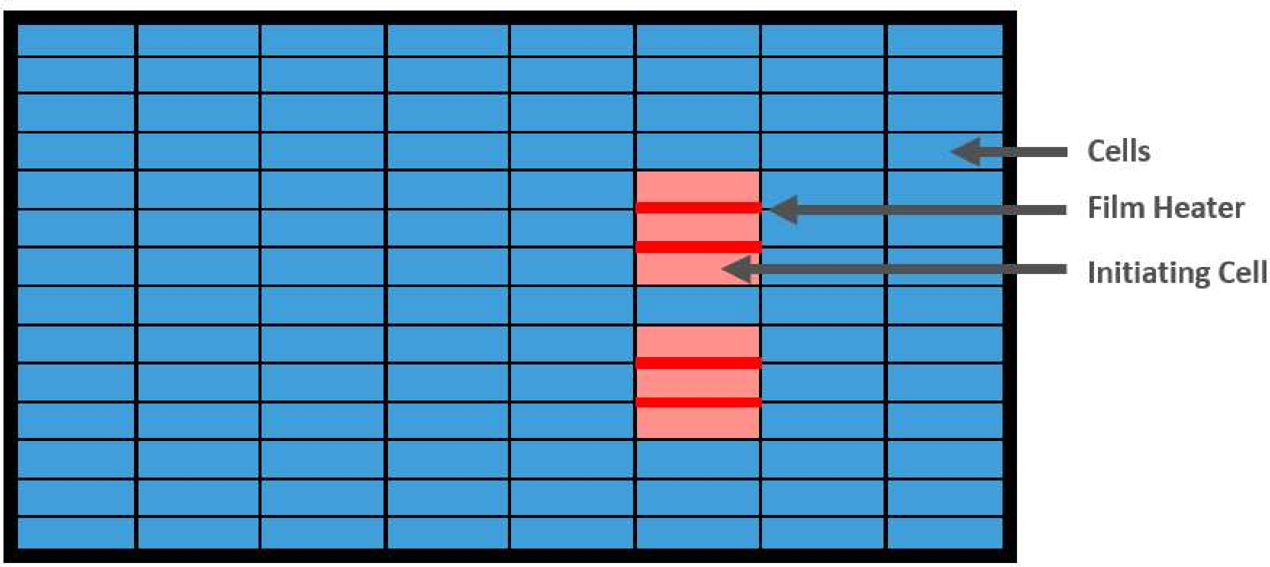

Figure 8 Film heater locations within the initiating tray (top view).

4.3.4 Instrumentation

Outside the initiating battery module and MP2 cabinet, three additional target MP2 cabinets were installed: (1) 6 inches (in) or 150 mm behind the initiating MP2; (2) 6 in (150 mm) to the side of the initiating MP2; and (3) 8 ft (2.44 m) in front the initiating MP2, as shown in Figure 9. The two target MP2 cabinets behind and to the side were populated with 100% SOC battery modules to simulate a multiple MP2 cabinet installation and to determine if thermal runaway and/or fire will propagate from one MP2 cabinet to adjacent cabinets at separation distances of 6 in (150 mm). Additionally, a combustible, instrumented wall (wood framing with plywood facing, painted black) was installed 5 ft (1.52 m) to the side of the initiating MP2 to demonstrate if fire could spread to a combustible surface (plywood wall) during the test.

Thermocouples were installed in the initiating battery module on the external surface of the initiating cells, inside the initiating MP2 cabinet, inside the target MP2 cabinets, on the instrumented wall, and on the exterior surfaces of all the MP2 target cabinets. Heat flux sensors were installed at distances of 3, 5, 8, 20, and 30 ft (0.91, 1.52, 2.44, 6.10, and 9.14 m) from the initiating MP2, as shown in Figure 9. Two external flame detectors and two thermal imagers were installed facing the initiating MP2 to demonstrate their functionality should flames exit the initiating MP2 during the test.

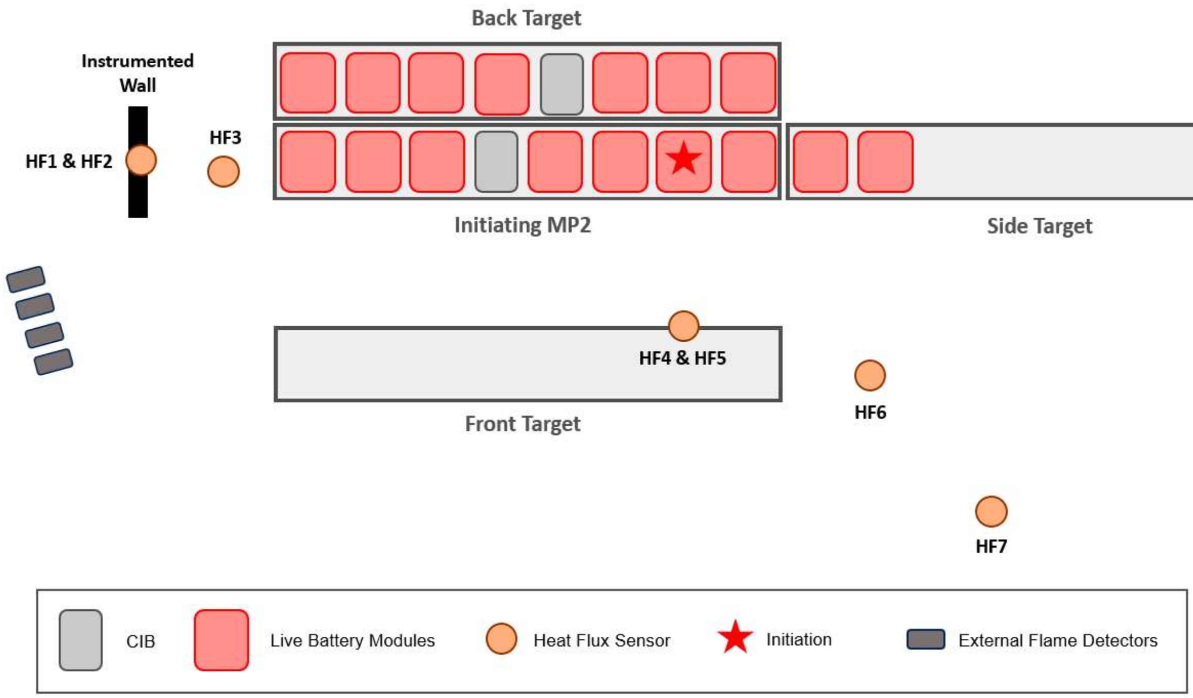

Figure 9 Instrumentation and target MP2 cabinet setup (top view).

4.3.5 Test Results

The test was performed starting around 11:30 am on March 9, 2022. The ambient temperature was between 50.5°F and 52.9°F. It was a sunny, clear day with no precipitation and a relative humidity between 14% and 19%. These outdoor environmental conditions meet the requirements of UL 9540A, Section 9.1.2. The cameras and instrumentation were turned ON at or around time 0:00:00 (hours: minutes: seconds) and the heaters within the initiating MP2 were turned ON at time 0:09:25. Six cells were heated simultaneously for over 1 hour and 18 minutes until the first initiation cell reached its thermal runaway temperature (as measured on the external surface of the cell via a thermocouple) of 239°C (462°F). Fifteen minutes later, the second group of initiating cells reached their thermal runaway temperature. Around 6 minutes later (approximately 1 hour 39 minutes into the test), light smoking/off-gassing was observed exiting the MP2 cabinet in the location where instrumentation was routed into the cabinet (i.e., where thermocouple/power wiring was in contact with the gasket that forms a tight seal for Bay 7's front door). Cell-to-cell propagation (thermal runaway spreading beyond the initial six cells being forcibly heated) was confirmed at approximately 1 hour 45 minutes when a seventh cell reached a temperature of 239°C (462°F). The heaters continued to run for an additional 5 minutes after this observation and then were turned off (at approximately 1 hour and 51 minutes into the test). Thermocouple temperatures inside the initiating MP2 subsided and no additional off-gassing, smoking, or cell thermal runaways were observed. By 2 hours and 30 minutes, the test ended. However, a period of observation and data collection continued for hours afterward to ensure the MP2 did not demonstrate any signs of distress. Table 4 provides a summary of key events from the UL 9540A unit level fire test of the MP2.

Table 4 UL 9540A Unit Level Testing: Timeline of Key Events

Elapsed Time hr:min:sec	Event
00:00:00	Start of Test. Cameras and Data acquisition system (DAQ) turned on.
0:09:25	Heaters ON.
1:18:18	First group of initiating cells reach thermal runaway temperature of 239°C (462°F).
1:33:38	Second group of initiating cells reach thermal runaway temperature of 239°C (462°F).
1:39:28	Smoke observed exiting out the bottom of the initiating MP2 cabinet's bay door where instrumentation was routed into the cabinet.
1:45:48	Confirmation of cell propagation to a 7th cell via internal thermocouple measurements.
1:51:09	Heaters turned OFF.
2:00:00	No additional smoke was observed from the initiating MP2 cabinet. Internal temperatures subside.
2:30:00	End of Test.
Post Test Overhaul	The initiating MP2 cabinet was observed for several hours afterwards and allowed to cool. No additional off-gassing, smoking, elevated temperatures, fire, thermal runaways, or signs of off-normal conditions were observed.

After 24 hours, the initiating MP2 showed no signs of abnormal conditions or distress since the test had concluded (no additional off-gassing, smoking, smells, thermal runaway, or flare-ups) and it was opened for inspection. Prior to opening the initiating MP2, handheld gas detection devices were utilized around the cabinets and did not detect the presence of flammable gases nor were flammable gases detected internally after the Bay 7 door was opened. A visual inspection of the initiating MP2 yielded the following observations:

- Seven cells had gone into thermal runaway: the six that were forcibly heated and one additional cell, as illustrated in Figure 10. This demonstrated that cell-to-cell propagation had occurred during the test, as is required by UL 9540A.

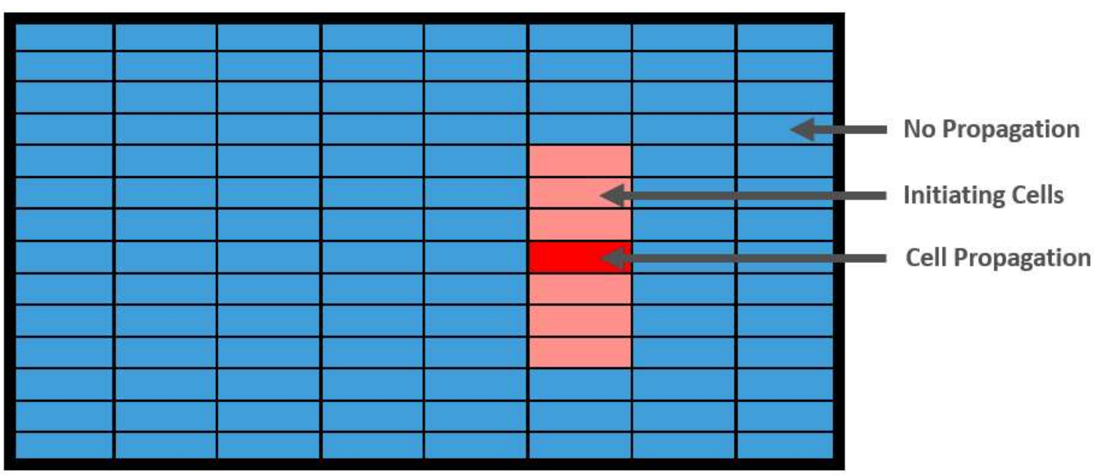

Figure 10 Cell propagation during UL 9540A unit level fire testing (top view).

- No other signs of distress were observed in the initiating battery module. Thermal runway had not propagated beyond the seven cells within Tray 2, nor had it spread to the tray above or below it within the battery module.
- Internal cell components were observed inside the initiating MP2 cabinet in the area of the initiating battery module and around Bay 7's front door; however, no free-flowing liquid or runoff was observed.
- The overpressure vents in Bay 7 had not opened, indicating that the internal pressure within Bay 7 did not see a significant rise during the failure of the seven cells.
- Visible clues of fire damage to surrounding components (plastics, electronics, etc.) were not observed. Based on this observation, it is likely that a sustained fire did not occur around the initiating battery module, even with the failure of seven cells occurring.
- The battery modules within the target MP2 cabinets installed 6 in (150 mm) behind and to the sides were also unaffected.

4.3.6 Fire Propagation

UL 9540A unit level fire testing of the MP2 demonstrated that an internal failure event causing thermal runaway of six cells nearly simultaneously will not propagate thermal runaway throughout the battery module. The nearly simultaneous failure resulted in thermal runaway propagating only to one additional cell and no further. The first group of initiating cells went into thermal runaway approximately 1-hour and 18 minutes into the test, as shown in Figure 11. This observation is based on internal thermocouple measurements installed on the surface of the cells within the initiating battery module.

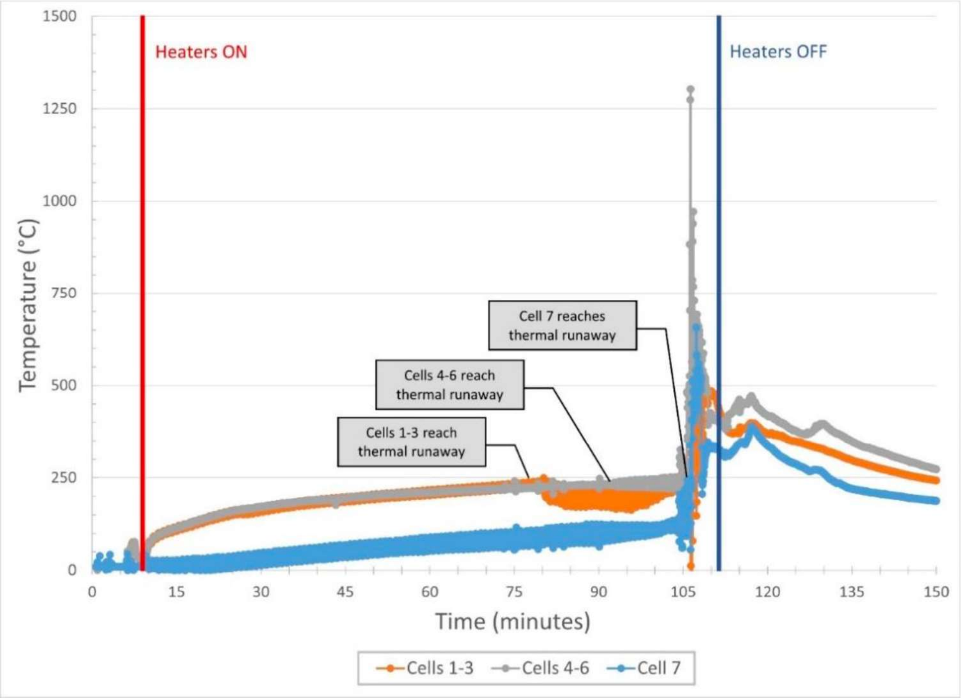

Figure 11 Cell surface temperatures recorded during UL 9540A unit level fire testing.

Fifteen minutes later the second group of initiating cells went into thermal runaway and cell-to-cell propagation was confirmed at approximately 1 hour 45 minutes when a seventh cell reached 239°C (462°F). Note, this result was with a disabled BMS and TMS (i.e., no safety protections were in place). Thermal runaway did not propagate beyond the seventh cell within Tray 2 of the initiating module, nor did it propagate to the battery modules installed above. In addition, thermal runaway did not propagate to the target MP2 cabinets installed 6 in (150 mm) behind and to the sides of the initiating MP2 cabinet. Lastly, no flaming was observed outside of the unit during the test.

4.3.7 Target Battery Module Surface Temperatures

As shown in Table 5, surface temperatures of battery modules within the target MP2 cabinets did not exceed 174°C (345°F), the temperature at which thermally initiated cell venting occurs (as determined during UL 9540A cell level testing).

Table 5 UL 9540A Unit Level Testing: Target Battery Module Surface Temperatures

Location	Maximum Battery Module Temperature Recorded	Ambient Temperature at the Start of Test	Cell Venting Temperature	Cell Thermal Runaway Temperature
Back Target Modules	13.8°C (56.4°F)	10.2°C (50.4°F)	174°C (345°F)	239°C (462°F)
Side Target Modules	13.2°C (55.8°F)	8.0°C (46.4°F)	174°C (345°F)	239°C (462°F)

These temperatures were recorded at the battery modules closest to the initiating battery module, as shown in Figure 12. As plotted in Figure 13, the internal temperature of the target battery modules gently rose throughout the 2½-hour test as the ambient, outdoor temperature also increased from 10.3°C to 11.6°C. These temperature measurements indicate the target battery modules were not affected by the thermal runaway of the seven cells within the initiating battery module.

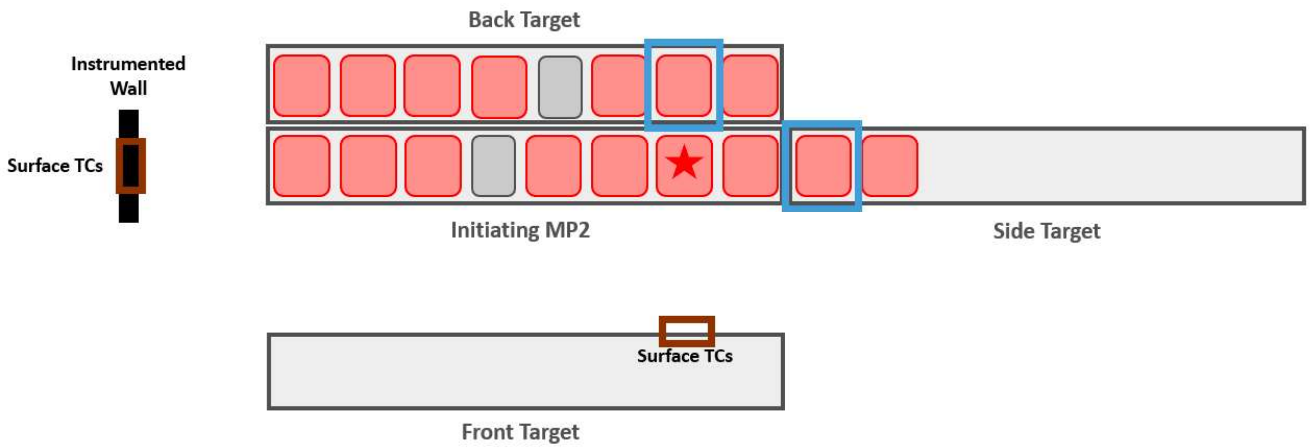

Figure 12 Temperature measurement locations: at side and back target battery modules (blue boxes) and the front target and instrumented wall surface temperatures (brown boxes).

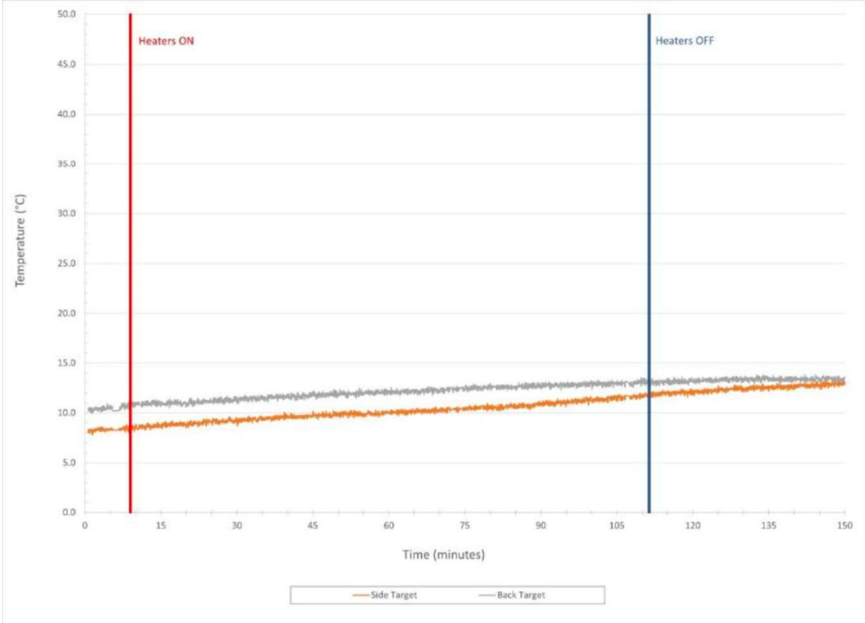

Figure 13 Side and back target battery module temperatures during UL 9540A unit level fire testing.

4.3.8 Exposure Surface Temperatures

As shown in Table 6, surface temperatures on exposures 5 ft (1.52 m) to the side (instrumented wall) and 8 ft (2.44 m) directly in front of the initiating MP2 cabinet (front target) did not exceed 97°C (175°F) above ambient.

Table 6 UL 9540A Unit Level Testing: Exposure Surface Temperatures

Location	Maximum Temperature Recorded	Ambient Temperature Recorded by the TC at the Start of Test	Temperature Rise Above Ambient
Front Target Surface	16.8°C (62.2°F)	11.3°C (52.3°F)	5.5°C (9.9°F)
Instrumented Wall Surface	25.9°C (78.6°F)	20.4°C (68.7°F)	5.5°C (9.9°F)

These temperatures were recorded directly in front of the initiating battery module and at the instrumented wall, as shown in Figure 12. The surface temperature of the front target gently rose throughout the 2½-hour test from a starting temperature of 11.3°C (52.3°F) to a maximum surface temperature of 16.8°C (62.2°F), as shown in Figure 14. Similarly, the 24 thermocouples installed on the instrumented wall also gently rose throughout the test and fluctuated slightly with the outdoor environmental conditions (i.e., wind blowing, sun exposure, increasing ambient temperatures), as shown in Figure 15. The maximum temperature measured on the instrumented wall was 25.9°C (78.6°F), which was a temperature rise of 5.5°C (9.9°F) above its ambient temperature at the start of the test. Note, the temperature rise above ambient can be attributed to the environmental conditions during the 2½-hour test and is not directly related to the thermal runaway of the seven cells within the initiating MP2. As these measurements are surface temperatures, the temperature rise within the front target surface and the instrumented wall surface is predominantly due to the sun heating up those surfaces during the test (the test was run between 11 am and 1:30 pm on a mostly sunny day). These temperature measurements indicate an exposure surface 5 ft (1.52 m) to the side and adjacent MP2 cabinets 8 ft (2.44 m) in front, were not affected by the thermal runaway of the seven cells within the initiating battery module.

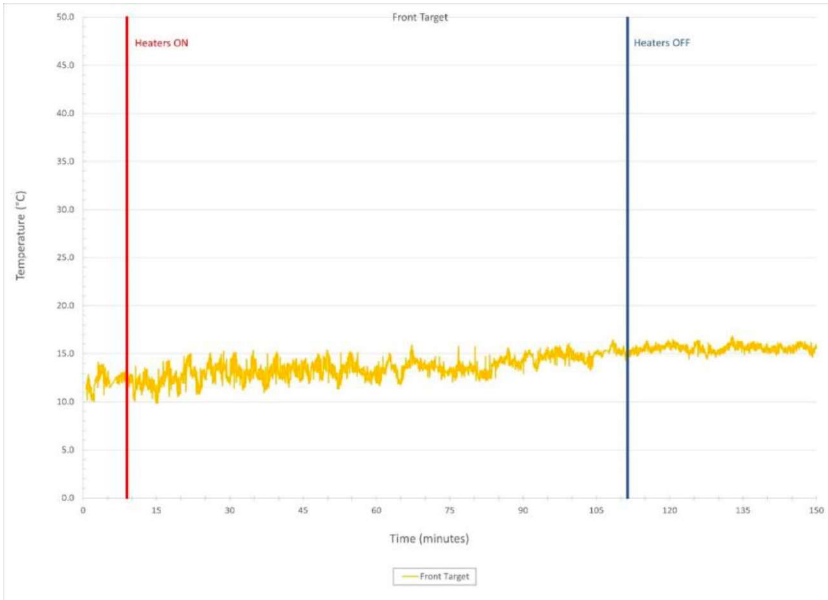

Figure 14 Front target external surface temperature 8 ft (2.44 m) directly in front of the initiating module.

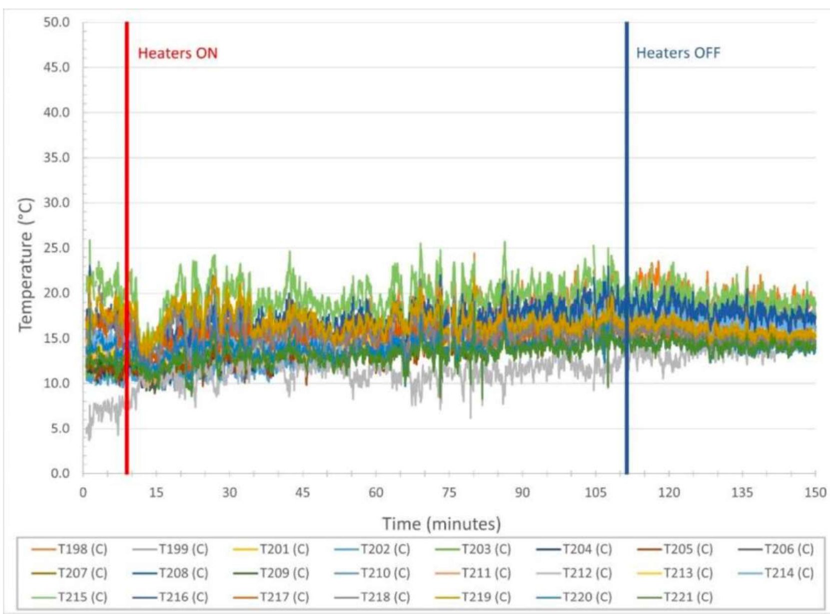

Figure 15 Instrumented wall surface temperatures during UL 9540A unit level fire testing.

Note: T200, the 24th thermocouple installed on the instrumented wall, did not work during testing, and was therefore removed from this plot as the measurements recorded were erroneous.

4.3.9 Heat Flux Measurements

Heat flux measurements were recorded throughout the UL 9540A unit level fire test at distances of 3, 5, 8, 20, and 30 ft (0.91, 1.52, 2.44, 6.10, and 9.14 m). Since flames did not occur outside the initiating MP2 cabinet, predictably, these measurements were essentially 0.00 kW/m^2 throughout the entire test, as summarized in Table 7 and plotted in Figure 16.

Table 7 UL 9540A Unit Level Testing: Maximum Recorded Heat Fluxes

Location	Maximum Heat Flux Recorded (W/m^2)
HF1	0.0000013
HF2	0.0000013
HF3	0.0000014
HF4	0.0000016
HF5	0.0000014
HF6	0.0000016
HF7	0.0000013

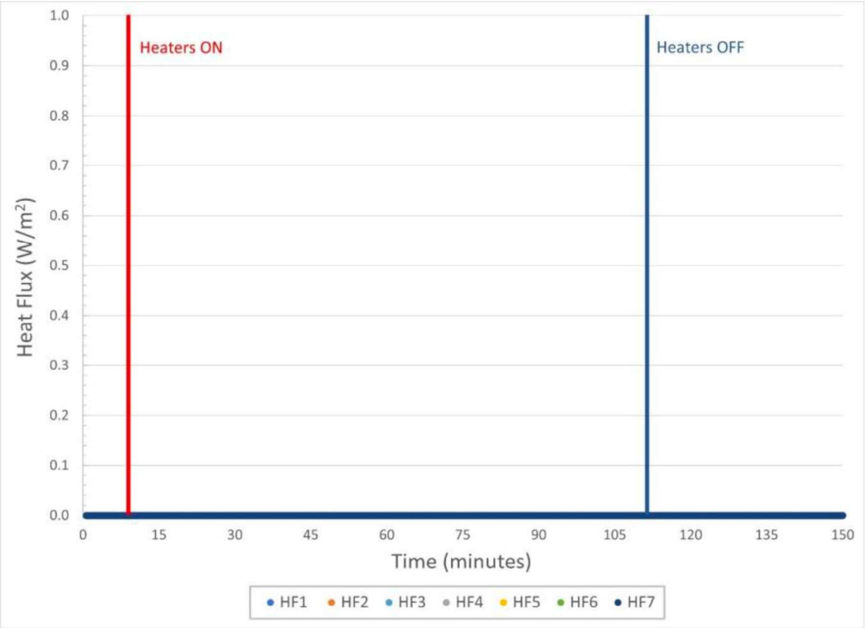

Figure 16 Heat flux measurements recorded during UL 9540A unit level fire testing.

The maximum heat flux recorded was 0.0000016 W/m^2, which was recorded at both the front target and at a distance of 20 ft from the initiating MP2. Note, these heat flux values, in W/m^2, are essentially reading no heat flux values at all, as would be expected given no flaming was observed outside the MP2 cabinet nor was the cabinet itself warmed enough to impose a heat flux on the sensors. These heat flux measurements indicate an exposure surface 3-5 ft (0.91-1.52 m) to the side, an adjacent MP2 cabinet 8 ft (2.44 m) in front, and other exposures further away at 20-30 ft (6.10-9.14 m), were not affected by the thermal runaway of the seven cells within initiating battery module. Furthermore, the heat flux measurements in front of and to the side of the initiating MP2 cabinet did not exceed 1.3 kW/m^2 at any time during the test.

4.3.10 External Fire Detection System

The MP2 does not have an internal fire detection system or one that is integral to its design/construction. During the UL 9540A unit level fire test, two multi-spectrum IR flame detectors and two thermal imagers from differing manufacturers were installed pointing directly at the front and top of the initiating MP2 cabinet. None of the detectors were activated during the fire test. This result is expected, as no flames were observed during the test. However, previous testing by Tesla on the MP1 has demonstrated that multi-spectrum IR flame detectors can detect a fire should flames exit the cabinet through the thermal roof and can be incorporated into a site design, if required.

4.3.11 Fire Suppression System

The MP2 does not have an internal fire suppression system or one that is integral to its design/construction. The UL 9540A unit level test results demonstrate that a suppression system is not required to stop the spread of fire from cell to cell, module to module, or MP2 cabinet to cabinet when a near-simultaneous failure of up to six cells occurs within the same battery module.

The UL 9540A unit level fire test also demonstrated that manual fire suppression (hose lines) is not required to stop the spread of fire from a MP2 cabinet to adjacent MP2 cabinets installed 6 in (150 mm) behind and to the sides when a near-simultaneous failure of up to six cells occurs within the same battery module.

4.3.12 Explosion Control

UL 9540A unit level fire testing of the MP2 demonstrated that a failure event causing the near-simultaneous thermal runaway of six cells will not cause a deflagration. During the test, pressure transducers were installed within the battery module bay to monitor overpressures within the MP2 cabinet. After the test, no pressure spikes were observed in the data, indicating no sudden increases in pressure, consistent with a deflagration, occurred within the MP2 cabinet during the UL 9540A unit level test. In addition, the overpressure vents did not open, the MP2 cabinet doors were not forced open, nor did the MP2 cabinet fail to hold containment. Meaning, no visual indications of an overpressure event occurring inside the MP2 cabinet were observed. Light smoking/off-gassing (i.e., not a pressurized discharge or deflagration) did escape the initiating MP2 during the test, likely through pathways created by the required instrumentation (thermocouples, film heaters, etc.) for the test; however, explosion hazards, including but not limited to, observations of a deflagration, projectiles, flying debris, detonation, hazardous pressure waves, shrapnel, or other explosive discharge of gases, were not observed.

4.3.13 Runoff/Products of Combustion

UL 9540A unit level fire testing does not require the collection of runoff or products of combustion as part of an outdoor installation test. However, during the unit level test, and afterwards during cleanup, no liquid runoff (such as the water-glycol solution from the TMS) was observed. Internal cell components were observed after the test on the interior of the cabinet around the Bay 7 door, as would be expected after the failure of seven cells. However, no free-flowing liquid, or runoff was observed once the MP2 doors were opened. If necessary, should a failure event occur, internal cell components/electrolytes can be disposed of in an appropriate manner as specified by Tesla's ERG and Safety Data Sheets (SDS).

4.3.14 Performance Criteria

UL 9540A, Table 9.1 outlines the performance criteria for outdoor, ground-mounted BESS. If all these conditions are met, further testing (such as installation-level testing) is not required. The performance criteria during the UL 9540A unit level fire test is as follows:

1. No flaming observed outside of the unit.
2. Surface temperatures of battery modules within the targets adjacent to the initiating unit cannot exceed the temperature at which thermally initiated cell venting occurs.
3. Surface temperatures on exposures 5 ft (1.52 m) to the side and 8 ft (2.44 m) in front of the initiating unit cannot exceed 97°C (175°F) above ambient.
4. No explosion hazards, including but not limited to, observations of a deflagration, projectiles, flying debris, detonation, or other explosive discharge of gases observed.
5. Heat flux in the center of the accessible means of egress cannot exceed 1.3 kW/m^2.

As described above, no flaming was observed outside the MP2 cabinet during the unit level test. In addition, surface temperatures of the battery modules within the targets were below the temperature at which cell venting occurs (174°C or 345°F), and external surface temperatures on exposures 5 and 8 ft (1.52 and 2.44 m) away did not exceed 97°C (175°F) above ambient. Lastly, no explosion hazards were observed, and all heat fluxes remained below 1.3 kW/m^2. Based on the above UL 9540A unit level fire test results, the MP2 meets all five of the above performance criteria. By meeting the unit level performance criteria, UL 9540A installation-level testing is not required for a MP2 installation.

5. CONCLUSIONS

Based on our review of the available materials, our background, experience and training, and the analysis performed to date described above, the following conclusions are submitted within a reasonable degree of scientific and engineering certainty:

1. The MP2XL is listed to all product design standards (such as UL and IEC) required of a BESS and has been tested to UL 9540A at the cell, module, and unit level.
2. Cell and module level UL 9540A testing demonstrated that the venting and combustion of the MP2XL cells release flammable gases that are commonly detected in a vented lithium-ion cell; however, they do not release toxic gases sometimes associated with the failure of lithium-ion batteries, such as HCN, HCL, and HF.
3. The largest variant of the MP2, a 3,100.8-kWh unit, was tested at a worst-case scenario (i.e., 100% SOC with the BMS and TMS disabled) to the UL 9540A unit level fire test method where six cells within the same battery module were forced into thermal runaway.
4. The MP2XL design is almost identical to the MP2 other than being greater in length to accommodate the additional battery modules. It uses the exact same cells, battery modules, and power electronics (i.e., all the same internal components) that the MP2 utilizes in its design. In addition, the design of the cabinet itself, enclosure strength, and fire safety features, such as the BMS, site controller, monitoring, electrical fault protections, and explosion control system are nearly identical for the two products. As such, TÜV determined the MP2 UL 9540A unit level fire test results summarized below can be applied to the MP2XL.
5. The performance criteria outlined in UL 9540A, Table 9.1 for outdoor, ground-mounted BESS were all met during the unit level test. Specifically, the performance criteria results were:
    a. No flaming was observed outside of the unit.
    b. Surface temperatures of battery modules within the target MP2 cabinets adjacent to the initiating MP2 cabinet did not exceed the temperature at which thermally initiated cell venting occurs. The maximum temperatures recorded at the battery modules of the adjacent MP2 cabinets were 13.8°C (56.4°F) and 13.2°C (55.8°F). These temperatures are significantly below the temperature at which cell venting occurs (174°C or 345°F).
    c. Surface temperatures on exposures 5 ft (1.52 m) to the side and 8 ft (2.44 m) in front of the initiating MP2 cabinet did not exceed 97°C (175°F) above ambient. The maximum external surface temperatures recorded at the instrumented wall 5 ft (1.52 m) to the side was 25.9°C (78.6°F) with a temperature rise above ambient of 5.5°C (9.9°F). The maximum external surface temperatures recorded at the front target 8 ft (2.44 m) directly in front of the initiating MP2 was 16.8°C (62.2°F) with a temperature rise above ambient of 5.5°C (9.9°F). These temperatures are significantly below the maximum permitted temperature rise above ambient of 97°C (175°F).
    d. Explosion hazards, including but not limited to, observations of a deflagration, projectiles, flying debris, detonation, or other explosive discharge of gases were not observed.
    e. Heat flux measurements did not exceed 1.3 kW/m^2. The maximum heat flux recorded was 0.0000016 W/m^2, which was the sensor installed on the front target MP2 cabinet and was the ambient heat flux the sensor was exposed to throughout the test.

6. Based on a review of the MP2XL, its fire safety features, and the UL 9540A unit level fire test results, the MP2XL meets or exceeds all the performance criteria of UL 9540A, Table 9.1 and UL 9540A installation level testing is not required for a MP2XL installation.
7. None of the external fire detectors activated during the UL 9540A unit level fire test (two multi-spectrum IR flame detectors and two thermal imagers). This result is expected, as no flaming was observed outside of the cabinet during the test; however, previous testing by Tesla on the MP1 has demonstrated that multi-spectrum IR flame detectors can detect a fire should flames exit the cabinet through the thermal roof.
8. An integral fire suppression system or an external fire suppression system is not required to stop the spread of fire from cell to cell, module to module, or MP2XL cabinet to cabinet when a near-simultaneous failure of up to six cells occurs within the same battery module.
9. Manual fire suppression (hose lines) is not required to stop the spread of fire from a MP2XL cabinet to adjacent MP2XL cabinets installed 6 in (150 mm) behind and to the sides when a near-simultaneous failure of up to six cells occurs within the same battery module.
10. Based on a review of the MP2XL, its fire safety features, and the UL 9540A test results, the MP2XL can meet or exceed all the 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 MP2XL DIM.

6. REVISION CONTROL SHEET

Date	Revision	Reason for Issue	Developed By	Reviewed By	Approved By
04/03/2024	Rev0	Initial Report	AFB	BA	NLR

Revision	Section	Changed Noted