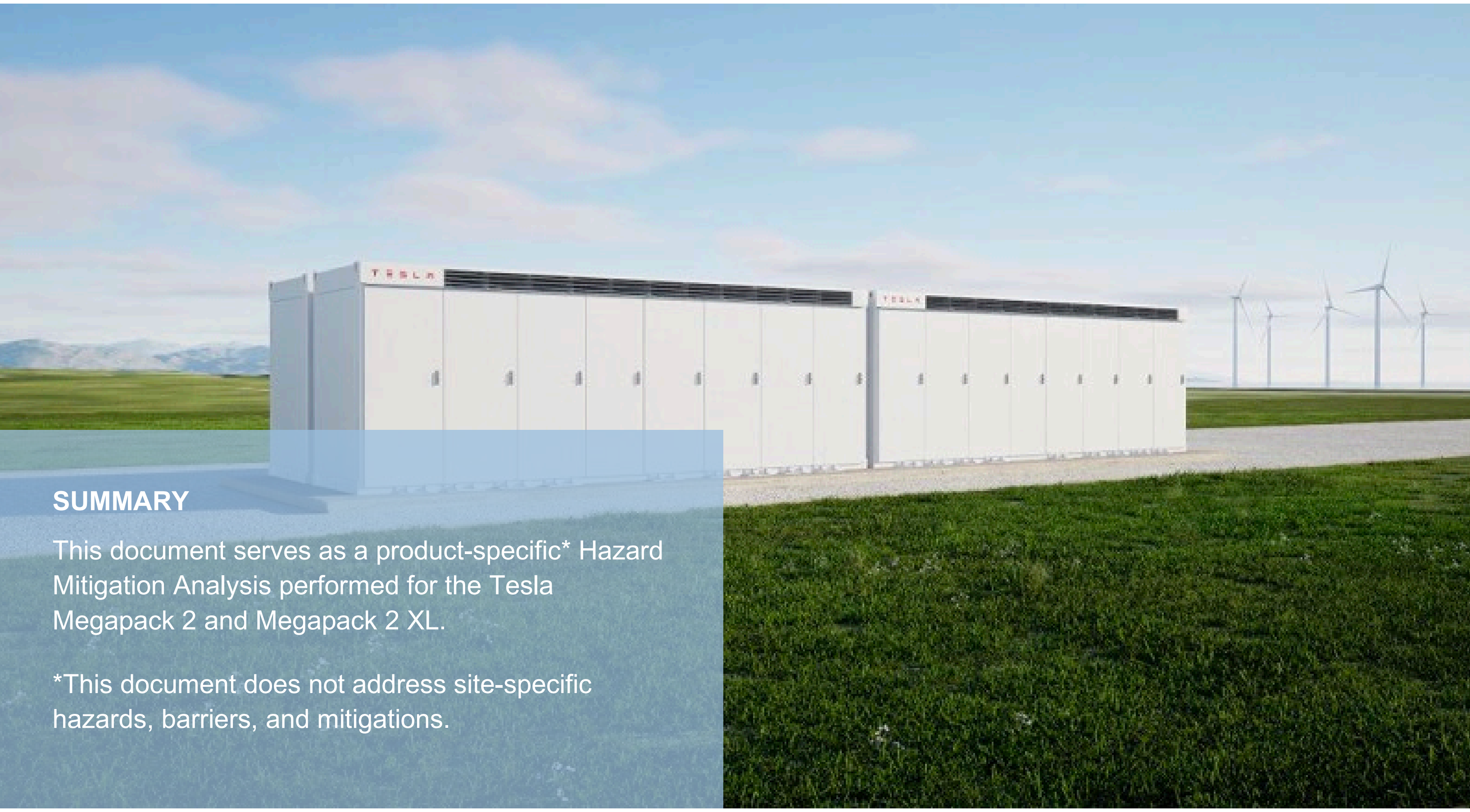
TESLA MEGAPACK 2/XL

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.

Prepared For:

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PROJECT DESCRIPTION

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Revision History

Revision No.	Date of Issue	Substance of Change	Prepared By	Reviewed By
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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.

<table>
<tr><th>Megapack 1
</th><th>Megapack 2
</th></tr>
<tr><td colspan="2">Listings and Certifications</td></tr>
<tr><td colspan="2">Component and BESS Design Certifications/Listings (UL9540 and IEC 62933-5-2)</td></tr>
<tr><td colspan="2">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>Internally Heated Cells:
Led to Cascading Thermal Runaway of All Cells</td><td>Internally Heated Cells:
Led to Thermal Runaway of One Additional Cell</td></tr>
<tr><td>Fire Propagation:
Consumed the Entire Cabinet</td><td>No Fire Propagation:
No Evidence of Sustained Flaming</td></tr>
<tr><td>Flames Observed Outside the Cabinet Exiting via the Thermal Roof</td><td>No Flames Observed Outside the Cabinet</td></tr>
<tr><td>Heat Fluxes Recorded at Distances of up to 20-30 ft From the Cabinet</td><td>No Heat Fluxes Recorded at Distances of up to 20-30 ft From the Cabinet</td></tr>
<tr><td colspan="2">Explosion hazards, including but not limited to, observations of a deflagration, projectiles, flying debris, detonation, or other explosive discharge of gases were not observed.</td></tr>
<tr><td colspan="2">No Fire Propagation to Adjacent Cabinets at 6-inch (150 mm) Spacing to the Sides and Behind</td></tr>
<tr><td colspan="2">No Fire Propagation to Adjacent Cabinets at 8 ft (2.44 m) Spacing Directly in Front</td></tr>
<tr><td colspan="2">Integral Fire Suppression Not Required to Stop Cabinet to Cabinet Fire Spread</td></tr>
<tr><td colspan="2">Manual Fire Suppression (Hose Lines) Not Required to Stop Cabinet to Cabinet Fire Spread</td></tr>
<tr><td colspan="2">No Free-Flowing Liquid Runoff Observed After the Test</td></tr>
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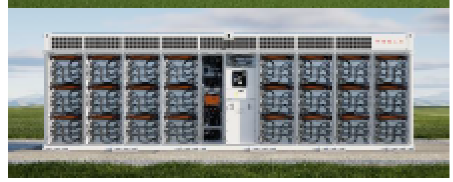
Megapack 2	Megapack 2XL
 	 
Cells and Battery Modules:	
Same Cells, Battery Modules and Integrated BMS	
Layout/Construction:	
Same Modular Cabinet Design, Not Occupiable with the Same or Substantially Similar Thermal Bay, Customer Interface Bay, IP66 Battery Module Bay, and Thermal Roof	
23.75 x 5.40 x 8.20 ft	28.83 x 5.42 x 9.17 ft
Up to 19 Battery Modules (3,100.8 kWh)	Up to 24 Battery Modules (3,854.0 kWh)
Safety Features:	
Same or Substantially Similar Thermal Management System, Customer Interface, Electrical Fault Protections and Autonomous BMS with 24/7 Remote Monitoring by Tesla Operation Facilities	
No Integral Fire Detection or Fire Suppression System	
Explosion Control System:	
22 Overpressure Vents, 12 Sparkers	26 Overpressure Vents, 12 Sparkers
Listings and Certifications	
Has the Same Component and BESS Design Certifications/Listings (UL 9540 and IEC 62933-5-2)	
Meets the Same Installation Level Codes and Standards (IFC and NFPA 855)	
UL 9540A Unit Level Test Results	
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	

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

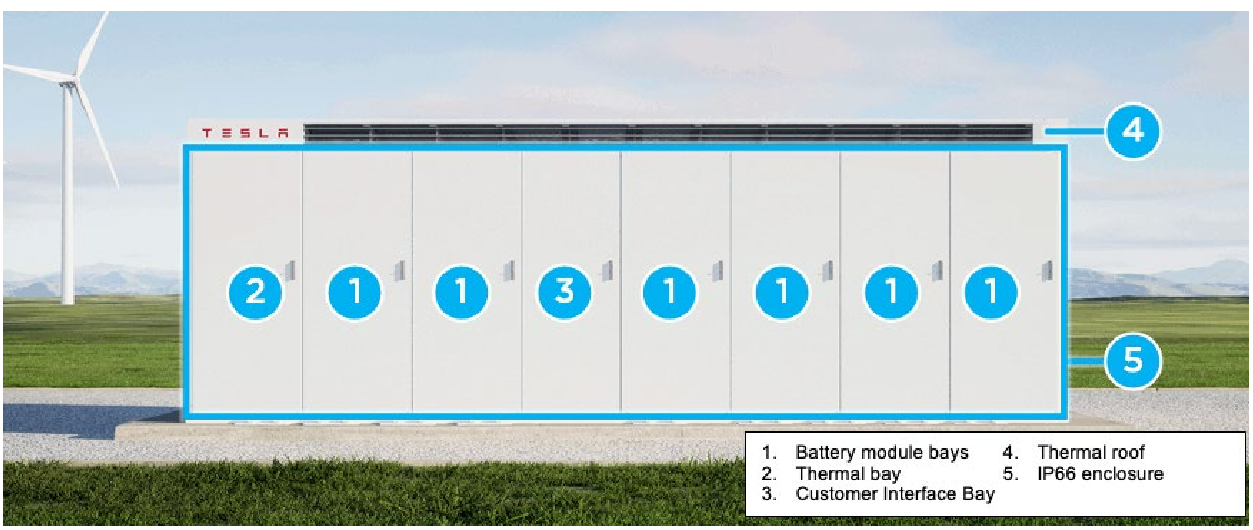


Figure 2-2 - Megapack Internal Architecture

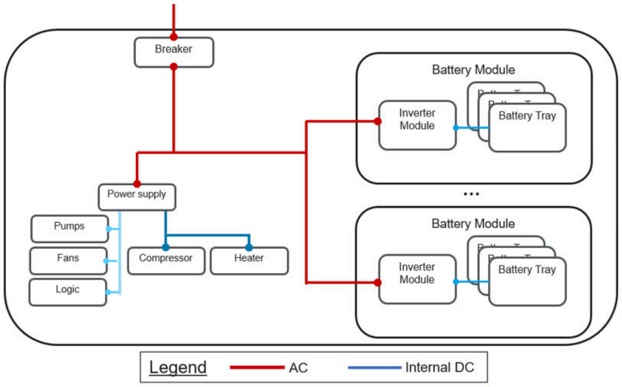
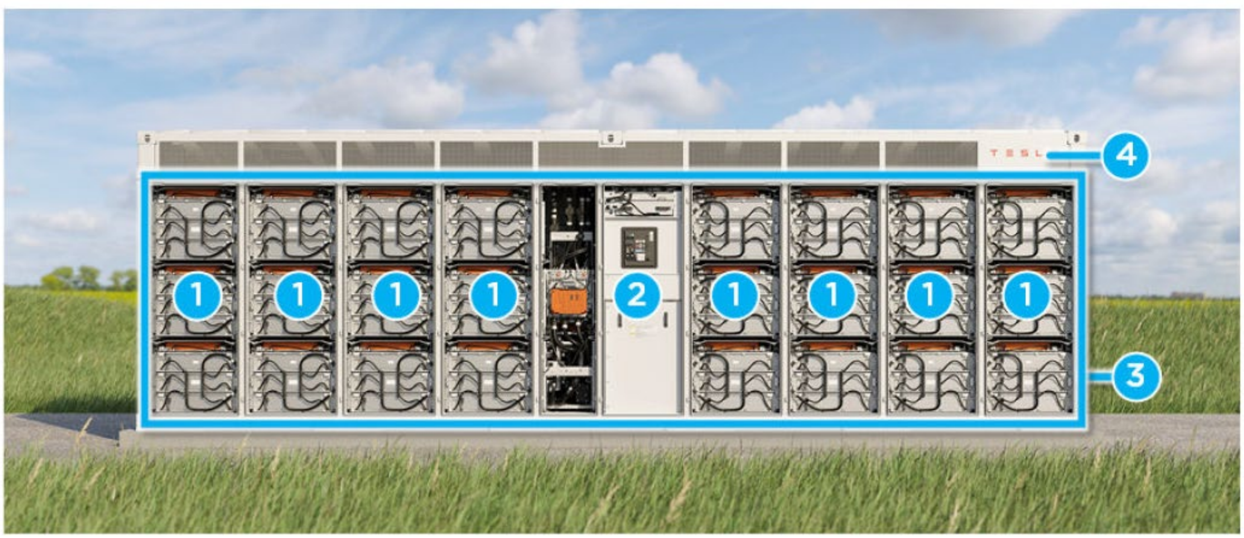


Figure 2-3 - Battery Module

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

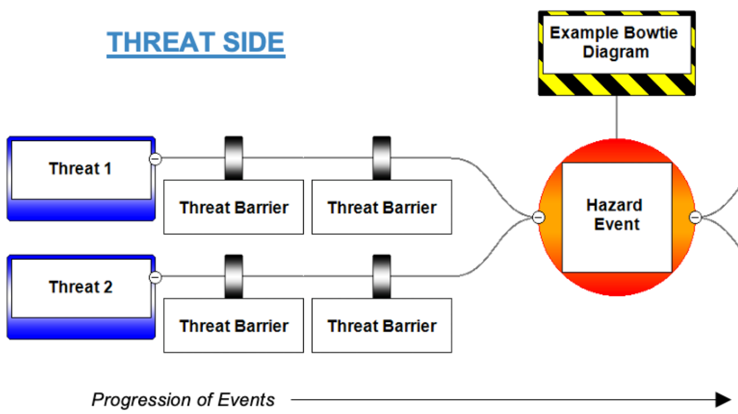
Multiple levels of passive and active electrical protections are provided for the Megapack 2/XL. At the battery module level, overcurrent protection is provided for each module in the form of single-use fusible links, providing interruption of overcurrent in the battery module in the case of an abnormal 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.

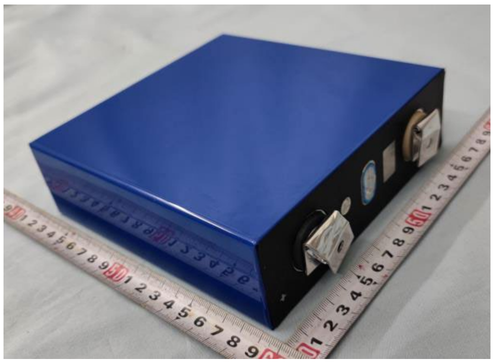
Thermal runaway was initiated via film strip heater, resulting in average cell surface temperature of 174°C and average cell surface temperature at thermal runaway of 239°C. Gas analysis of the gas generated from the well were identified as flammable. As these performance criteria per *UL 9540A Clause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

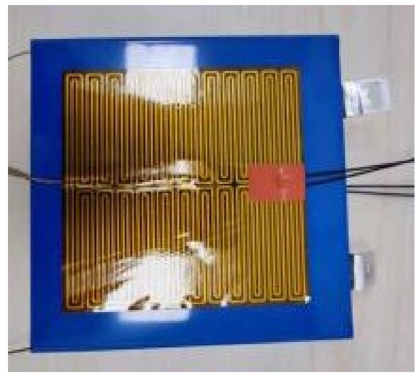
Table 3-1 – Results of Gas Analysis (Excluding O_2 and N_2)

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.

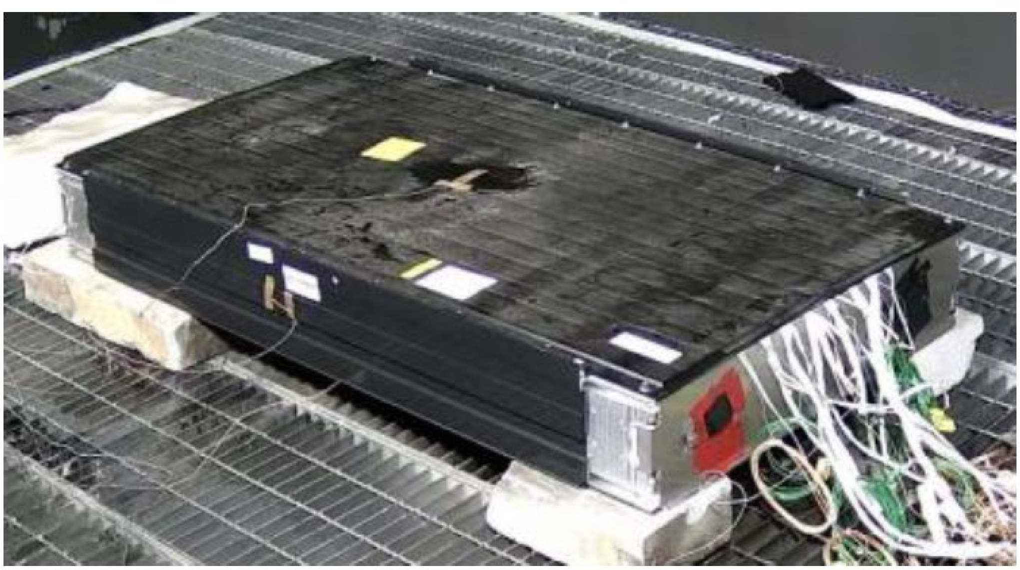
Thermal runaway was initiated via film strip heaters installed on both of the wide side surfaces of each cell, similar to the cell level test. In the module level test, however, two cells were heated simultaneously to force multiple cells into thermal runaway at the same time.

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 (4^{th} 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

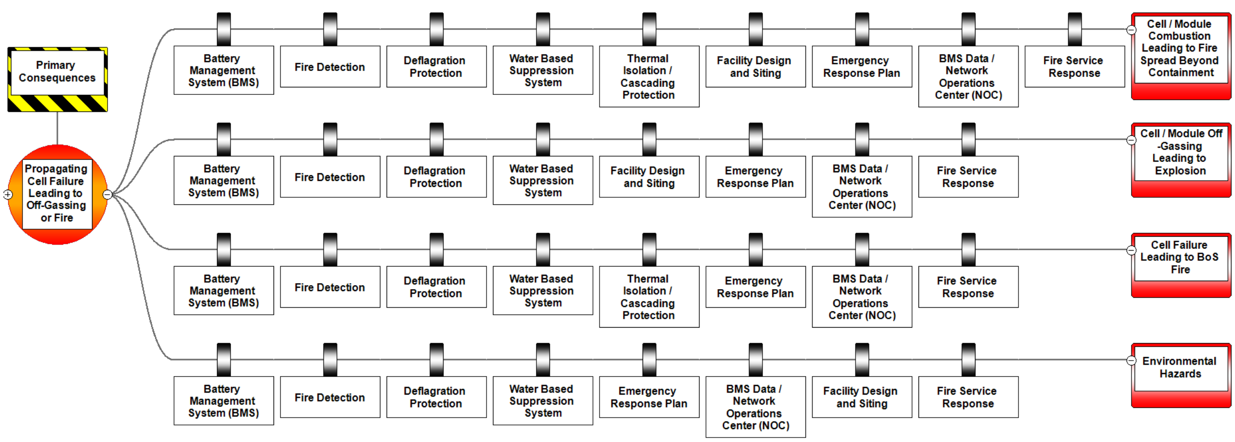


Table 3-3 - Primary Consequence Barriers

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

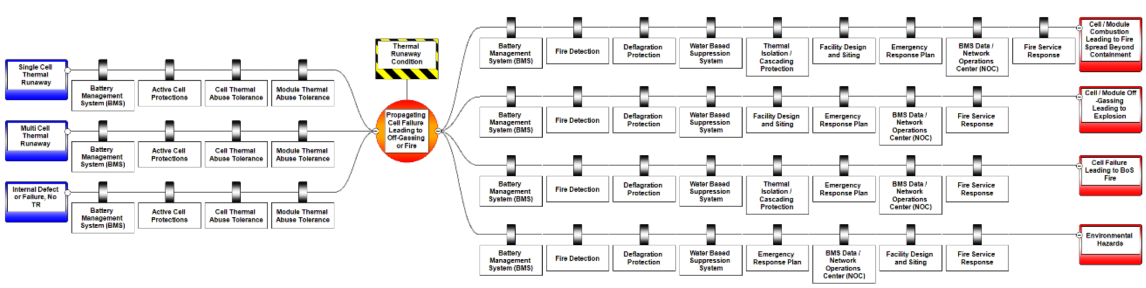


Table 3-5 - Thermal Runaway Condition Barriers

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

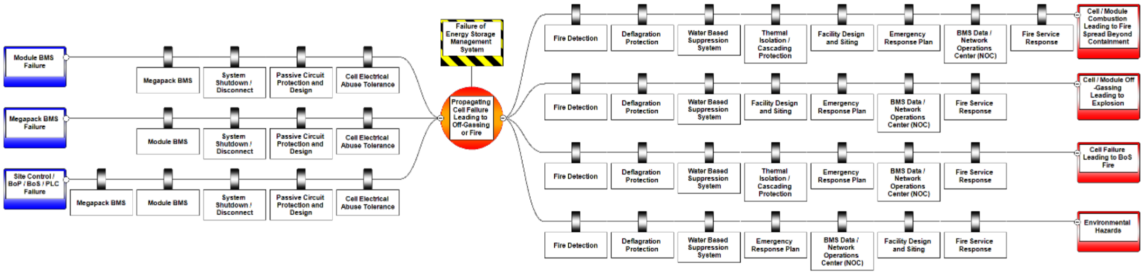


Table 3-6 - Failure of an Energy Storage Management System Barriers

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

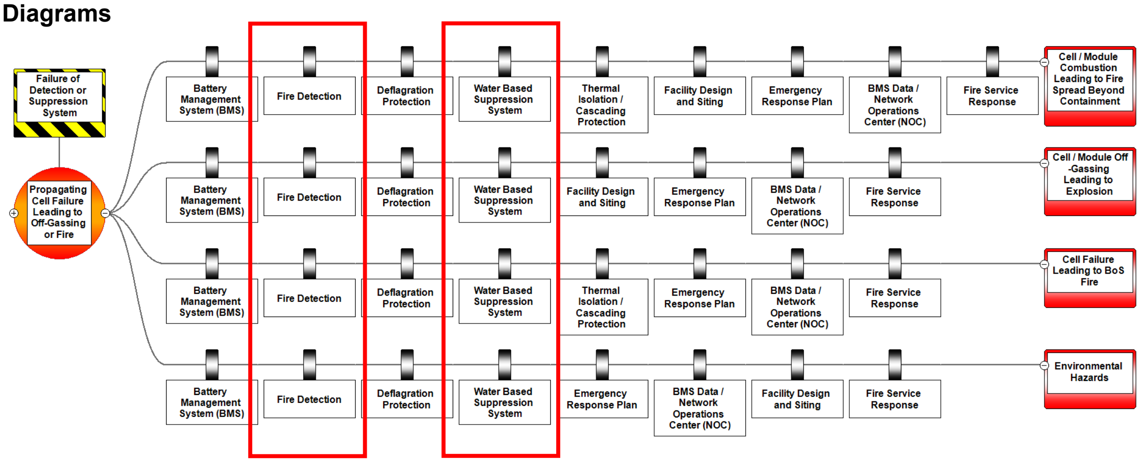


Table 3-7 - Failure of Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System Barriers

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

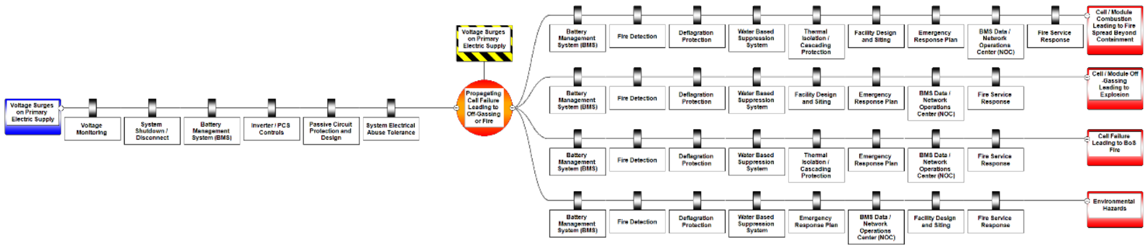


Table 3-8 - Voltage Surges on the Primary Electric Supply Barriers

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

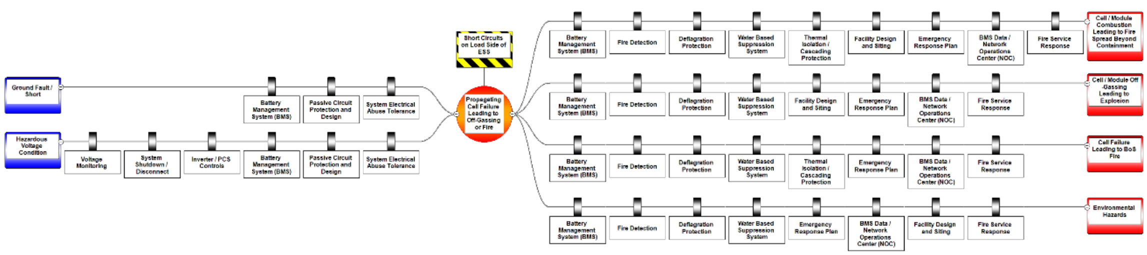


Table 3-9 - Short Circuits on the Load Side of the ESS Barriers

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.*

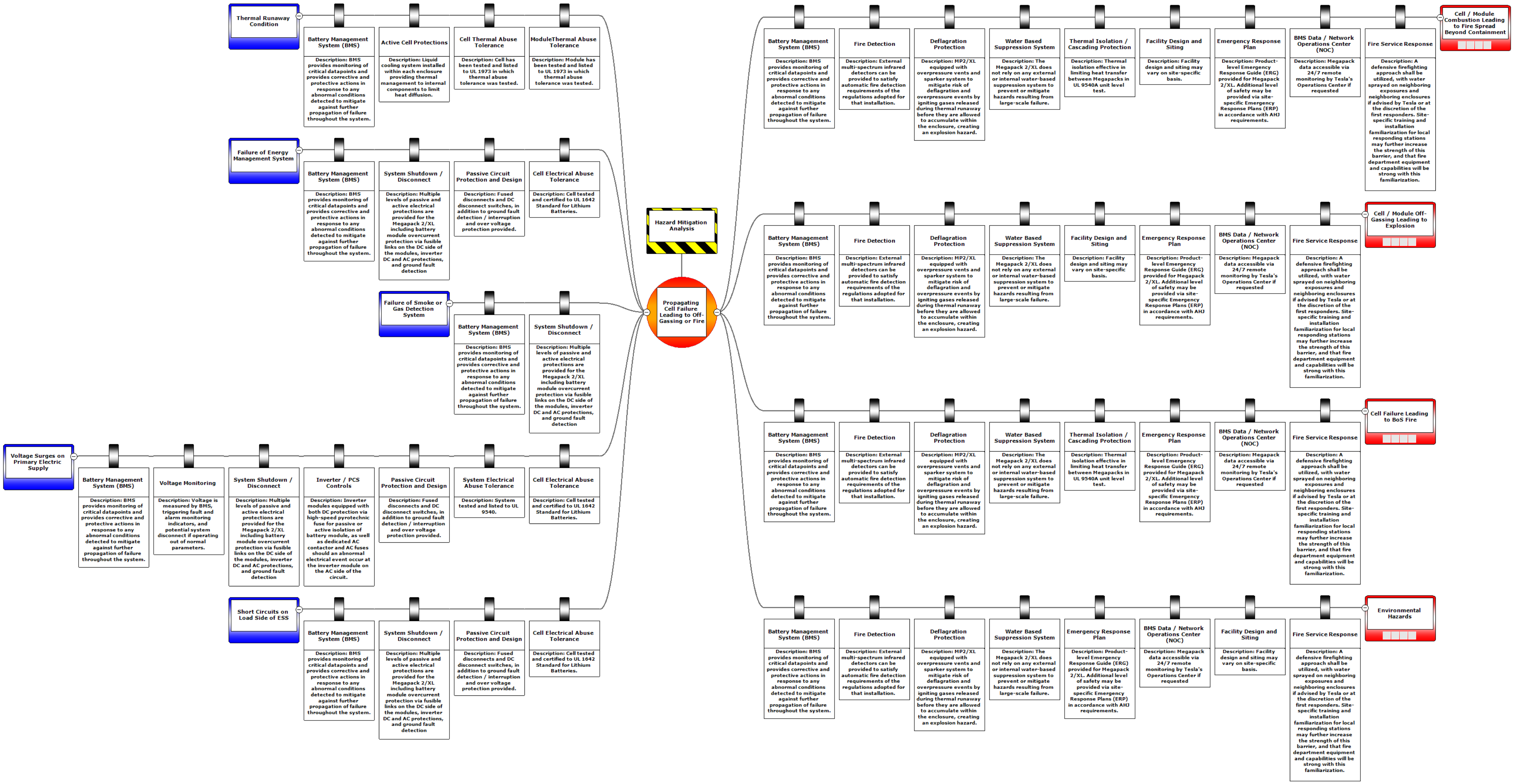
Table 3-10 - Summary of Analysis Approval

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.

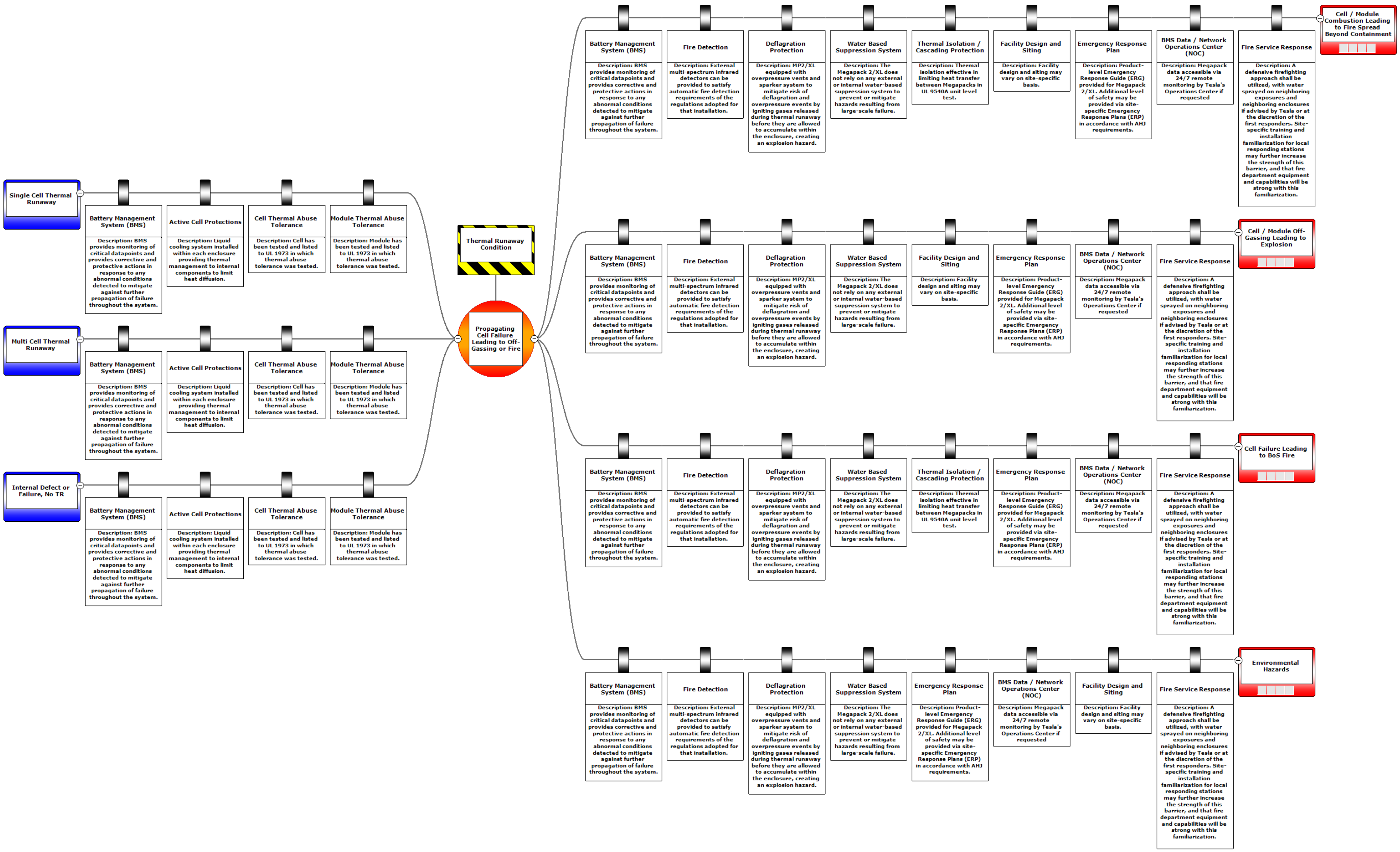
APPENDIX A – DETAILED HMA DIAGRAMS AND BARRIER DESCRIPTIONS

3.6 A.1 All Fault Conditions

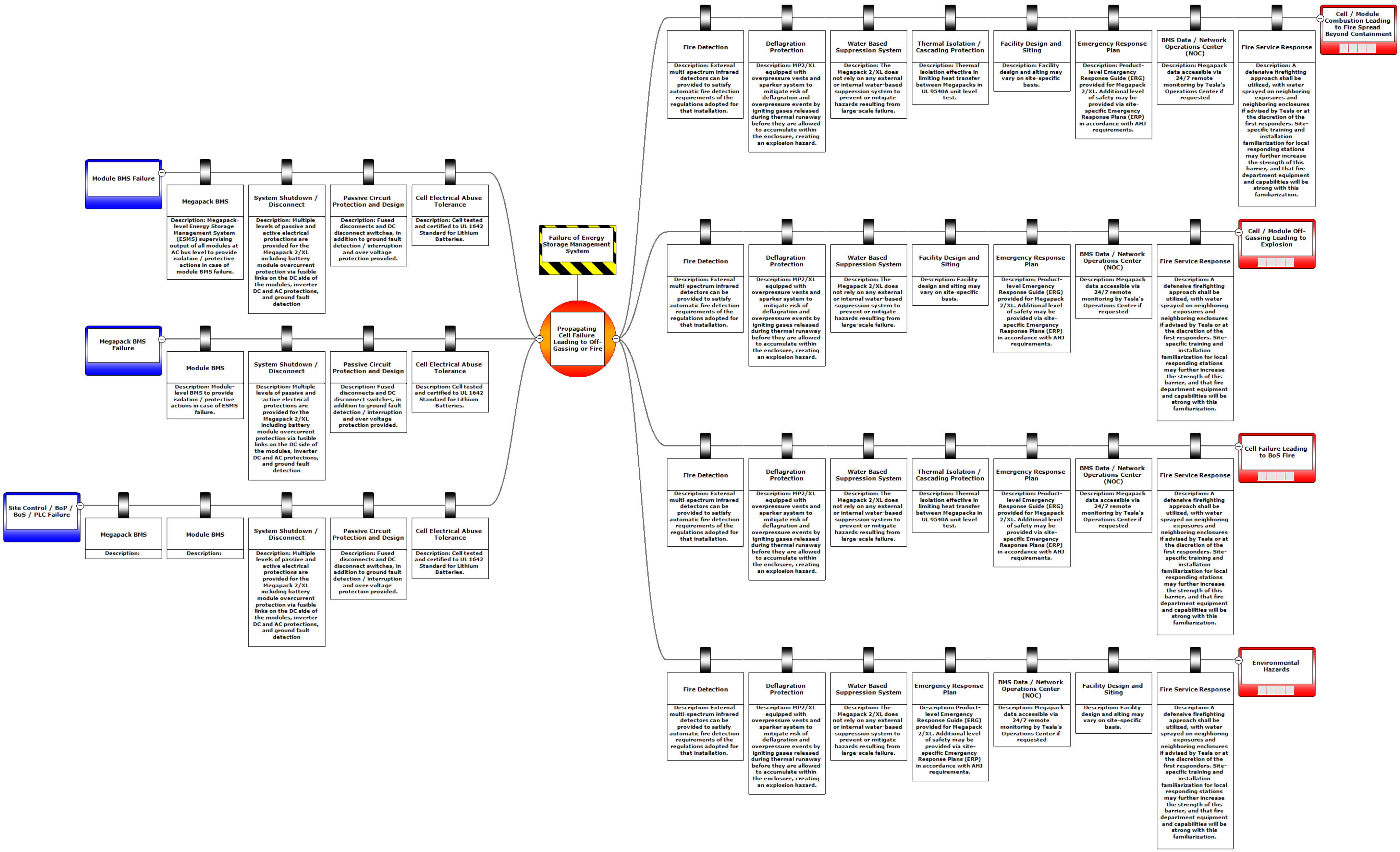


3.6.1

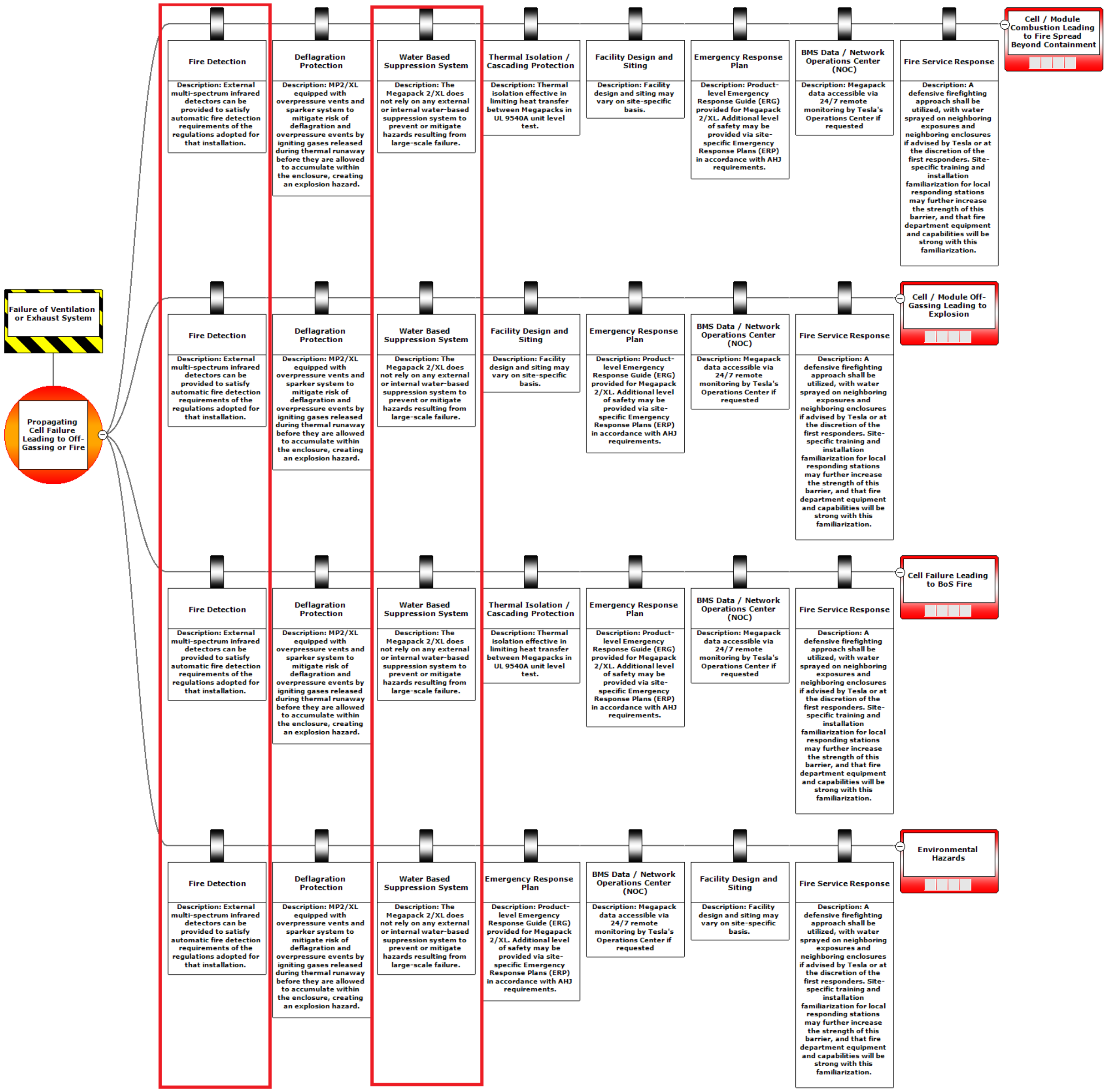
3.7 A.2 Thermal Runaway Condition



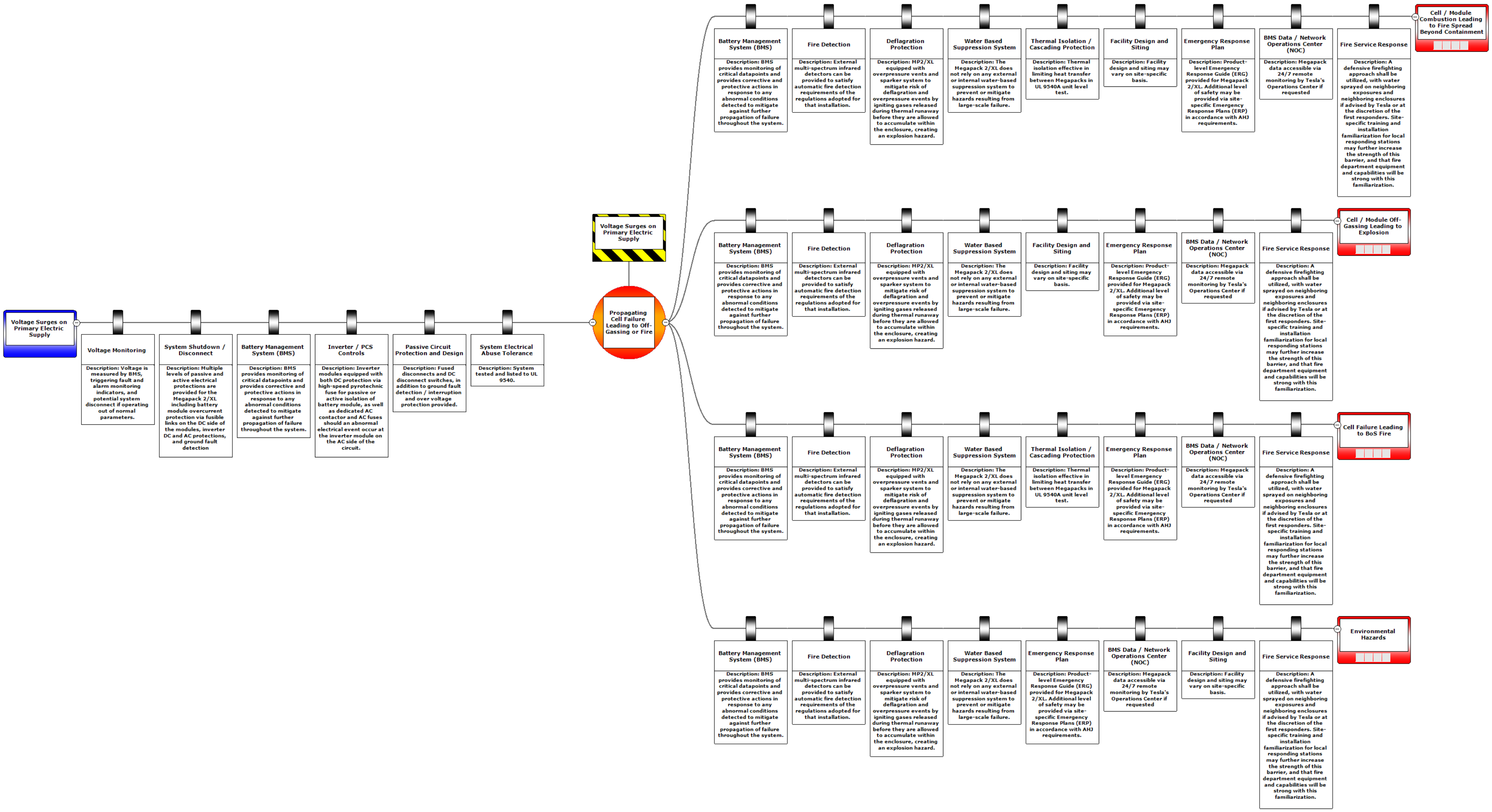
3.8 A.3 Failure of an Energy Storage Management System



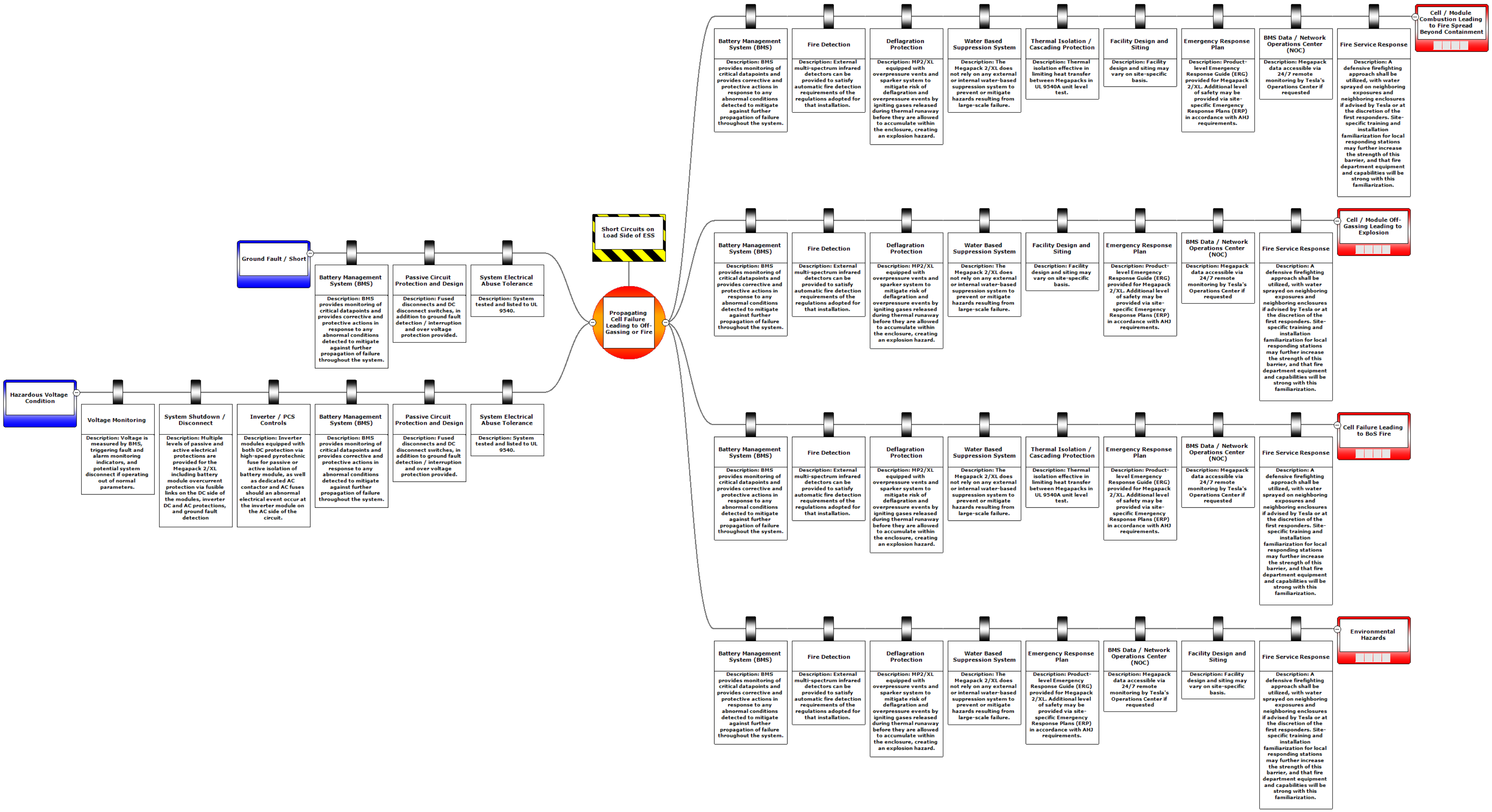
3.9 A.4 Failure of a Required Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System



3.10 A.5 Voltage Surges on the Primary Electric Supply



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

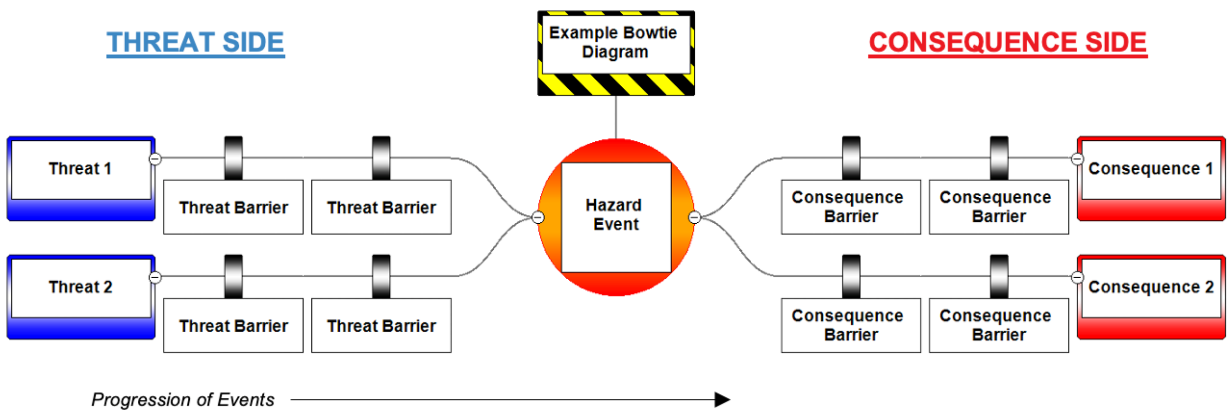


APPENDIX B – HMA METHODOLOGY

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