
Appendix D4

Hazard Mitigation Analysis



TIDELANDS AVENUE ELECTRIC TRUCK HUB

HAZARD MITIGATION ANALYSIS (HMA)

Rev 2.0 | October 2025

SUMMARY

This document serves as a site-specific Hazard Mitigation Analysis (HMA) performed for the Tideland Avenue Electric Truck Hub using Tesla Megapack 2 XL equipment located in National City, California, United States.

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PROJECT DESCRIPTION

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1 INTRODUCTION

1.1 Background

Energy Safety Response Group (ESRG) has been retained by Skycharger to perform a site-specific Hazard Mitigation Analysis (HMA). 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.

The HMA for the Tidelands Avenue Electric Truck Hub is addressed according to the Fire Code regulatory requirements for National City, California. This report summarizes findings from a site-specific Hazard Mitigation Analysis (HMA) performed in compliance with the *2022 California Fire Code (CFC) Title 24, Part 6*, which is based off the *2021 International Fire Code (IFC)* and *NFPA 855, 2023 Edition* to assess the safety and overall effectiveness of barriers set in place to prevent and mitigate consequences of potential battery failure scenarios. The *2022 CFC* does not adopt *NFPA 855*, which is the National Fire Protection Association's Standard on Stationary Battery Energy Storage System, but this installation will still comply with this standard in addition to the *2022 CFC*.

1.2 Applicable Codes and Standards

2022 California Fire Code

The *2022 CFC §1207.1.2* requires that the design of each battery energy storage “unit” be submitted for review and approval by the local fire code official as part of the permitting process. The results of product-specific full-scale fire testing and the results of the HMA can be utilized by the local fire code official to determine acceptable terms and conditions for the installation of such systems throughout California. The *2022 CFC* prescribes the fault conditions or failure modes that shall be taken into account as part of the HMA.

Per the *2022 CFC §1207.1.4.1*, the analysis shall evaluate the consequences of a single failure :

- 1) Thermal runaway condition in a single module, array, or unit
- 2) Failure of any battery (energy) storage management system
- 3) Failure of a required ventilation or exhaust system
- 4) Voltage surges on the primary electric supply
- 5) Short circuits on the load side of the ESS
- 6) Failure of a required smoke detection, fire detection, fire suppression, or gas detection system
- 7) Required spill neutralization not being provided or failure of a required secondary containment system.

Per the 2022 CFC §1207.1.4.2, the local fire code official 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 or areas for the minimum duration of the fire-resistance-rated separations identified in CFC §1207.7.4.
- 2) Fires in occupied work centers will be detected in time to allow occupants within the room or area to safely evacuate.
- 3) Toxic and highly toxic gases released during fires will not reach concentrations in excess of the IDLH level in the building or adjacent means of egress routes during the time deemed necessary to evacuate occupants from any affected area.
- 4) Flammable gases released from ESS during charging, discharging, and normal operation will not exceed 25 percent of their lower flammability limit (LFL).
- 5) Flammable gases released from ESS during fire, overcharging, and other abnormal conditions will be controlled through the use of ventilation of the gases, preventing accumulation, or by deflagration venting.

The following codes, standards, and local requirements apply:

- *California Fire Code International Fire Code §1207 Electrical Energy Storage Systems*, 2022 Edition
- *California Electrical Code*, 2022 Edition
- *California Building Code*, 2022 Edition
- *UL 9540A Standard for Test Method for Evaluation of Thermal Runaway Fire Propagation in Battery Energy Storage Systems*, 4th Edition
- *UL 9540 Standard for Energy Storage Systems and Equipment*, 2nd Edition
- *NFPA 68 Standard on Explosion Protection by Deflagration Venting*, 2013 Edition
- *NFPA 72 National Fire Alarm and Signaling Code*, 2022 Edition
- *NFPA 76 Standard for the Fire Protection of Telecommunications Facilities*, 2016 Edition
- *NFPA 855 Standard for the Installation of Stationary Energy Storage Systems*, 2020 Edition

1.3 Summary of Findings

Based on a review of documentation provided by Skycharger and Tesla, ESRG finds that adequate protections are provided for the fault conditions listed per *2022 CFC §1207.1.4.1* and *2023 NFPA 855 §4.4*. Key findings include:

- The Tesla Megapack 2 or 2 XL is equipped with a number of protection systems (e.g., deflagration control system consisting of overpressure vents and sparker system, battery management system (BMS) control, an active liquid-cooling system for thermal management, electrical shutdowns and disconnects, etc.) that are anticipated to effectively manage all applicable fault conditions required per *2022 CFC §1207.1.4.1* and *NFPA 855 §4.4.2.1* (i.e., Table 1).
- The Tesla Megapack 2 or 2 XL is compliant with all applicable Analysis Approval requirements per *2022 CFC §1207.1.4.2* and *NFPA 855 §4.4.3* (i.e., Table 2).
- UL 9540A full-scale fire testing and performance of the Tesla Megapack 2 have shown that the system can be installed without the need for any additional passive or active fire protection features to prevent unit-to-unit propagation. Additionally, performance during UL 9540A testing indicates that nearby exposures will not be largely affected in the event of an ESS-related failure on-site.
- Additional voluntary destructive testing was conducted by Tesla on a representative Megapack 2 that utilized a more aggressive approach (than required by UL 9540A) to force the system into thermal runaway. The results of this testing showed that, due to the robustness of the system design, it was difficult to initiate and maintain any cascading thermal runaway within the unit.
- During the aforementioned testing, third-party analysis on products of combustion collected indicated no mercury (Hg) and trace levels of hydrofluoric acid (HF) far below National Institute for Occupational Safety and Health (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 XL 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.
- A site-specific draft Emergency Response Plan (ERP) must be prepared for this project, detailing emergency response procedures to guide first responders in the event of a battery-related failure on-site, and will be reviewed with the local emergency response agency.
- The proposed BESS facility and location pose minimal risk to public or life safety and property by way of being on a secured site away from public spaces or roadways with limited public access to the site. Potential nearby exposures are explained in further detail in Section 2.2. Training will be provided to the First Responders to familiarize themselves with the site and hazards associated with lithium-ion ESS, based on safe operating

procedures to address the unlikely event of an incident at this site.

These summary findings are further tabulated in *Table 1: Summary Findings of Failure Mode Consequences* and *Table 2: Summary Findings of AHJ HMA Approval Criteria*. These tables provide the direct response to each of the elements indicated.

Table 1: Summary Findings of Failure Mode Consequences

<i>Failure Mode and Consequences Evaluated by the HMA</i>	
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	Per the 2022 CFC 1207.4.7, Table 1207.6, and NFPA 855, the Megapack 2 XL is not required to have a ventilation or exhaust system. A proprietary deflagration control system is designed to mitigate the effects of flammable gases generated during an abnormal condition.
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.
Failure of a Required Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System	The project will utilize an external Infrared (IR) Fire Detection System. This system will be monitored in accordance with NFPA 72 and Chapter 9 of the CFC to include any failures or impairments to this system. A failure of the IR Detection Systems will be addressed in accordance with CFC section 901.7. Along with these safety actions, any BMS fault notifications will also be transmitted to Tesla's 24/7 Operations Center, alerting key stakeholders to any abnormal conditions.
Required spill neutralization is not being provided, or there is a failure	Spill neutralization is only required for batteries that contain acids, such as lead-acid batteries.

of the secondary containment system.	
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Table 2: Summary Findings of AHJ HMA Approval Criteria

<i>Authority Having Jurisdiction HMA Approval Criteria</i>	
Fires or explosions will be contained within unoccupied battery storage rooms for the minimum duration of the fire-resistance-rated walls identified in Table 509.1 of the <i>International Building Code</i>.	Not Applicable – The Megapack 2 XL is intended for outdoor installations.
Fires and explosions in occupied work centers will be detected in time to allow occupants within the room to evacuate safely.	Not Applicable – The Megapack 2 XL is not intended for installation within occupied work centers.
Toxic and highly toxic gases released during fires will not reach concentrations in excess of the immediately dangerous to life or health (IDLH) level in the building or adjacent means of egress routes during the time deemed necessary to evacuate any affected area.	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.
Flammable gases released from batteries during charging, discharging, and normal operation shall not exceed 25 percent of their lower flammability limit (LFL).	Not Applicable – Lithium-ion batteries do not release flammable gases during charging, discharging, or normal operations.
Flammable gases released from batteries during fire, overcharging, and other abnormal conditions shall not create an explosion hazard that will injure occupants or emergency responders.	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.

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2 SITE DESCRIPTION

2.1 Site Overview

The Tidelands Avenue Electric Truck Hub is to be located on San Diego Port Authority property at 1640 Tidelands Avenue in National City, California. The site consists of two (2) Tesla Megapack 2 XL ESS units providing approximately 1.75 MW / 7 MWh of energy storage power and capacity, respectively.

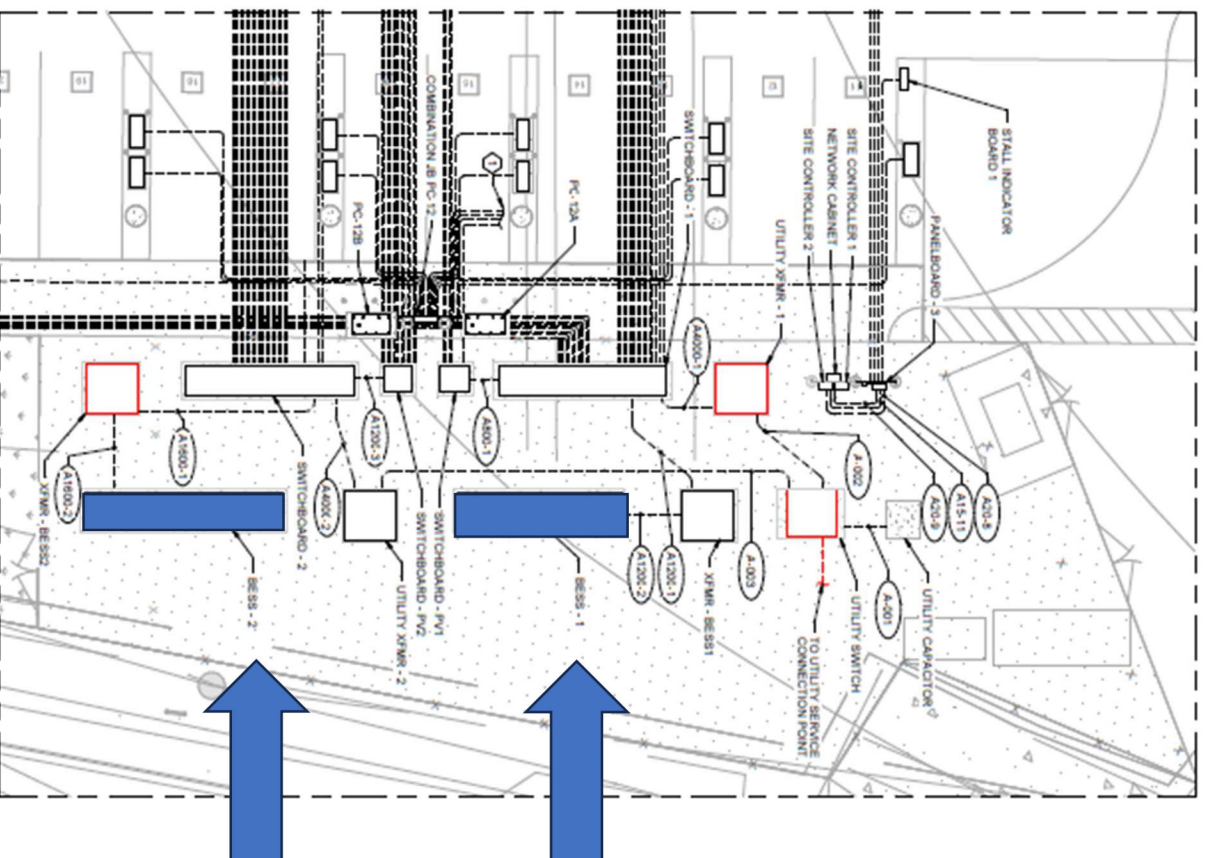
Table 3: Site Information

SITE INFORMATION	
Site Address:	1640 Tidelands Avenue National City, CA
GPS Coordinates:	32° 39' 56.15" N, 117° 06' 57.90" W

Figure 1: Aerial View



Figure 2: Layout



2.2 Nearby Exposures

The Megapack 2 XLs will be sited outdoors in non-occupiable cabinets. The project will occupy approximately 4.8 acres.

Due to the location and nature of the site, potential site risks are anticipated to be minimal and negligible; however, the following nearby exposures are noted in the general area.

- **Unified Port of San Diego to North** – The Unified Port of San Diego building is located approximately 350 feet to the north of the BESS of the site
- **San Diego Port District**– The San Diego Port is located on multiple sides of the site.
- **Harborside Gym** – The Harborside Gym is located approximately 325 feet to the west of the site.
- **Warehouses** – There are multiple warehouses and businesses located east of the site. The nearest warehouse is approximately 225 feet to the east.
- **Pacific Ocean (San Diego Bay)**– The Pacific Ocean is located approximately 800 feet to the west of the site.

2.3 Fire Department Access and Water Supply

The National City Fire Department is the fire and emergency response agency for this jurisdiction. The nearest station, Fire Station 34, is located approximately 1.4 miles away (at 343 E 16th Street in National City, CA.) to the east. They are anticipated to arrive on-scene expeditiously after receiving notification of an emergency event.

Access to/from the site will be off Tidelands Avenue and provided with two access gates. There will be an access road within the fenceline of the site. Road width and spacing will be sized in accordance with fire code requirements and allow ample room for fire apparatus. There will be hydrants on-site, but engaging a battery fire directly with water is not recommended based on best industry practice. Firefighters can utilize this water supply to protect exposures, if necessary.

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3 ENERGY STORAGE SYSTEM DESCRIPTION

3.1 Megapack 2 XL Overview

The Tesla Megapack 2 XL (a.k.a. MP2 XL) is a modular, fully integrated, AC-coupled battery energy storage system (BESS or ESS). The Megapack 2 XL is a design evolution of Megapack 2 and leverages the same core technology platform (cells, vents, sparker system, etc.). The Megapack 2 and 2 XL utilize 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. The Megapack 2 and 2 XL differ only in that the 2 XL has additional battery modules.

The Megapack 2 XL and constituent components are tested and certified to the latest editions of UL 9540, UL 1642, UL 1973, IEC 62619, and IEC 62933-5-2. UL 9540A (4th Edition) large-scale fire testing was performed at the Cell, Module, and Unit level (Note: Installation level testing was not required due to all Unit level performance criteria being met). The UL 9540A Unit level report was conducted by TUV Rheinland of North America, Inc. (TUV, a nationally recognized testing laboratory), and their conclusions state: “Based on the limited module propagation observed during MP2 testing (7 cells in runaway), the behavior would be the same with MP2 XL. 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 MP2 XL shows comparable behavior as the worst case”. (Note: the Sparker System and sparker count are explained in section 3.2.1.)

Figure 3: Megapack 2 XL Internal Architecture provides an illustration of the primary architecture of the battery units. *Figure 4: Megapack 2 XL Battery Module* illustrates the appearance of a single battery module.

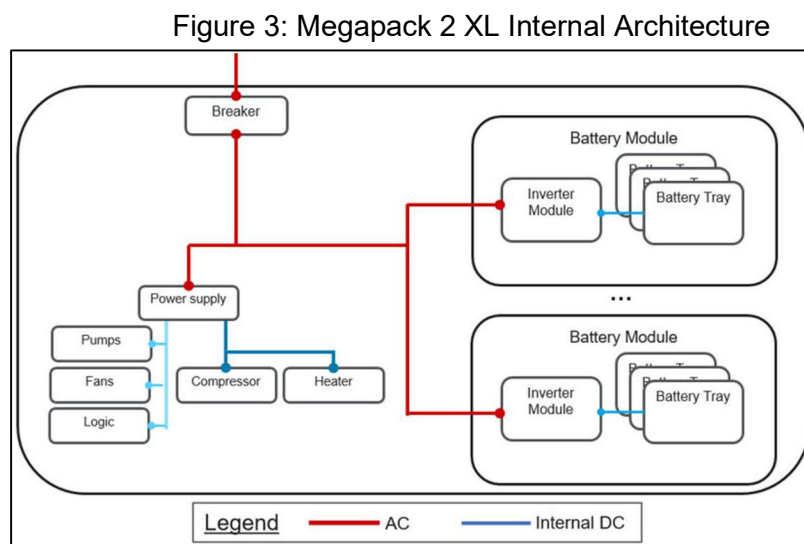


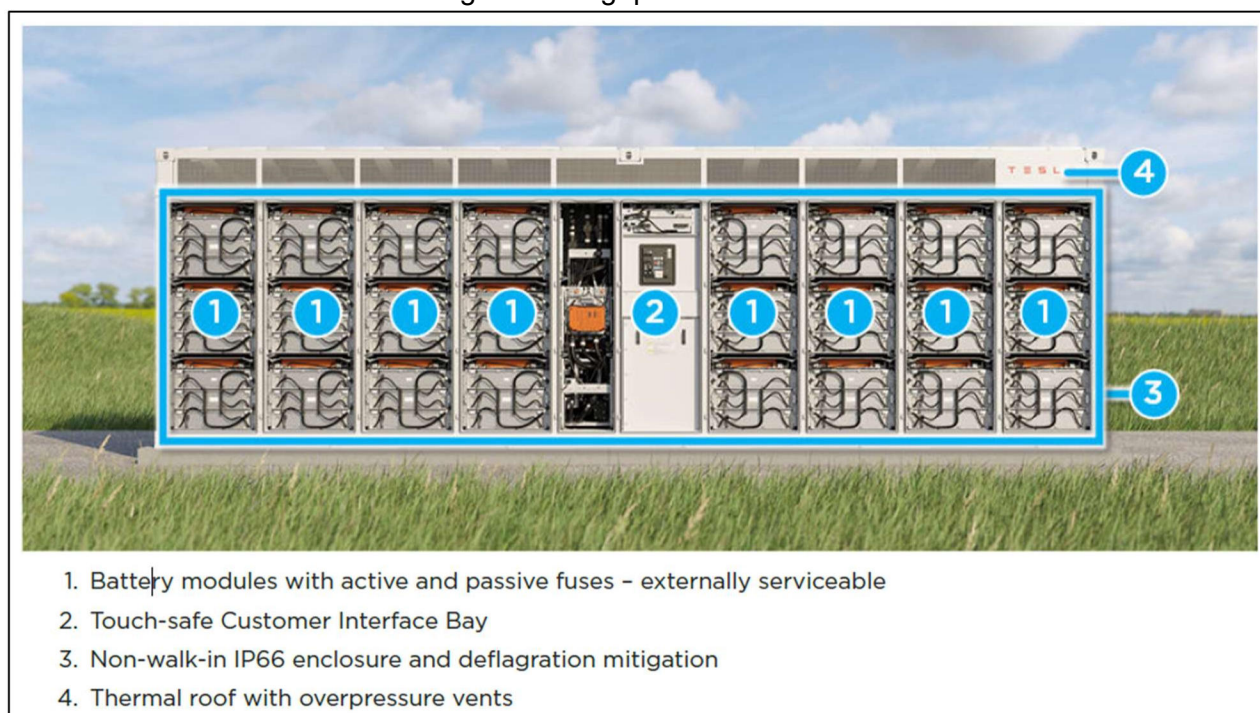
Figure 4: Megapack 2 XL Battery Module



Figure 5: Megapack 2 XL External View



Figure 6: Megapack 2 XL Internal View



3.2 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 2022 CFC and the 2023 edition of NFPA 855.

3.2.1 Deflagration Control System

Each Megapack 2 XL is provided with an integral and proprietary deflagration prevention system (deflagration control). This deflagration prevention 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 gases that could be generated within the unit during a failure event.

The Megapack 2 XL is provided with twelve (12) sparkers and twenty-six (26) overpressure vents. 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. Any overpressures generated from the ignition of flammable gases 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.

3.2.2 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 overtemperature, temperature signal loss, and battery module overcurrent. In the event of any abnormal conditions, the BMS will first raise an information warning alert, and then trigger a corresponding corrective action should certain levels be reached.

3.2.3 Fire Detection

The Megapack 2 XLs will be sited outdoors in non-occupiable cabinets, in a remote location as defined by the applicable codes (*2022 CFC* and *2023 NFPA 855*). This project will utilize the Viking VSF 303 Multi-Spectrum external UV/IR flame detection system, which will be designed in accordance with CFC Chapter 9 and NFPA 72. The UV/IR flame detection system will be monitored by the Notifier 320SYS Fire Alarm Control Panel (FACP). Specification sheets for the fire detection system can be found in Appendix C. (The type of detector will be updated if it changes before commissioning.)

As additional information, during UL 9540A unit-level testing for the Megapack 2 XL, the radiant energy sensing detectors used in the tests were not activated since no fire occurred. Subsequent supplemental full-scale (more aggressive) testing of Megapack systems showed that these external UV/IR detectors effectively detected failure conditions that initiated within the unit.

3.2.4 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 is communicated to the Fire Department to provide guidance to emergency response personnel.

The site controller and monitoring are significantly sophisticated in the levels, numbers, and types of issues it monitors, and further, this is monitored and processed 24/7. While this is a key feature for the ongoing maintenance of all units to assure optimal

performance, this detailed monitoring serves the additional purpose of effective fire alarm notification for all maintenance alerts that escalate beyond pre-defined thresholds.

3.2.5 Fire Suppression Systems

The Tesla Megapack 2 XL does not rely on any external or internal fire suppression systems to mitigate cascading thermal runaway, nor is this required in accordance with the applicable code requirements (e.g., CFC and NFPA 855). Additional full-scale testing and subsequent fire modeling have indicated that the Megapack's construction provides a robust thermal resistance from the impacts of an adjacent Megapack during a large-scale failure.

3.2.6 Electrical Fault Protection Devices

Multiple levels of passive and active electrical protection 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 a high-speed pyrotechnic fuse for passive or active isolation of the battery module, as well as a 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 a DC ground fault detection system and an AC circuit breaker with ground fault trip settings for distribution system protection.

Protection from direct lightning strike. Megapack enclosures have internal frames that act like a Faraday cage, diverting currents to flow around the internal components but not through them to ground. There is no expected significant impact to MegaPack functionality due to a direct lightning strike. Hence, air terminations or lightning masts are not required to protect MegaPack enclosures.

Protection from Indirect Lightning Strikes. MegaPacks are designed with adequate power electronic component sizing and creepage in addition to monitored surge protection on the load side of the MegaPack breaker. Tests, in accordance with Institute of Electrical and Electronics Engineers (IEEE) C62.45, demonstrate that internal circuits and components of MegaPack are protected from induced overvoltage from indirect lightning strikes. There is no expected impact on MegaPack functionality due to an indirect lightning strike.

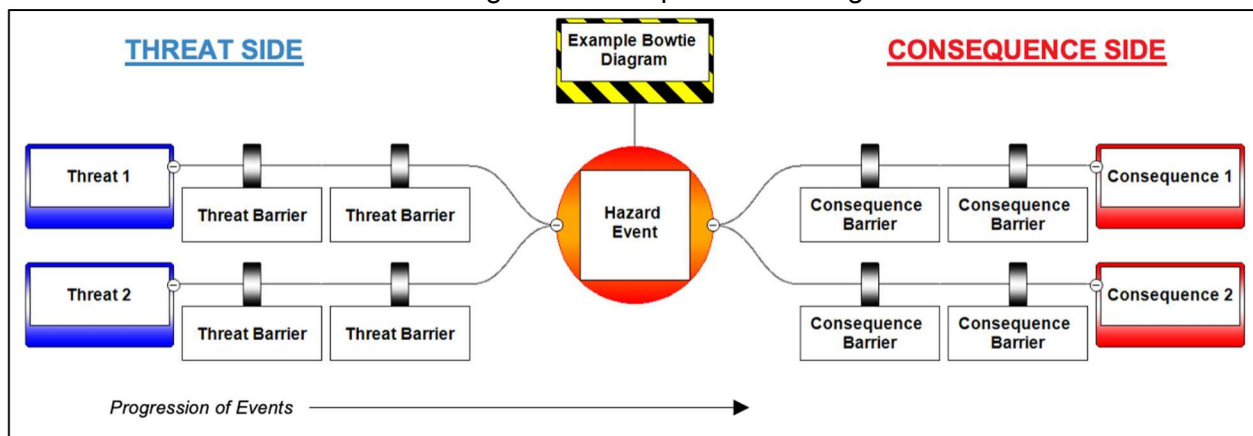
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4 HAZARD MITIGATION ANALYSIS

4.1 HMA Methodology

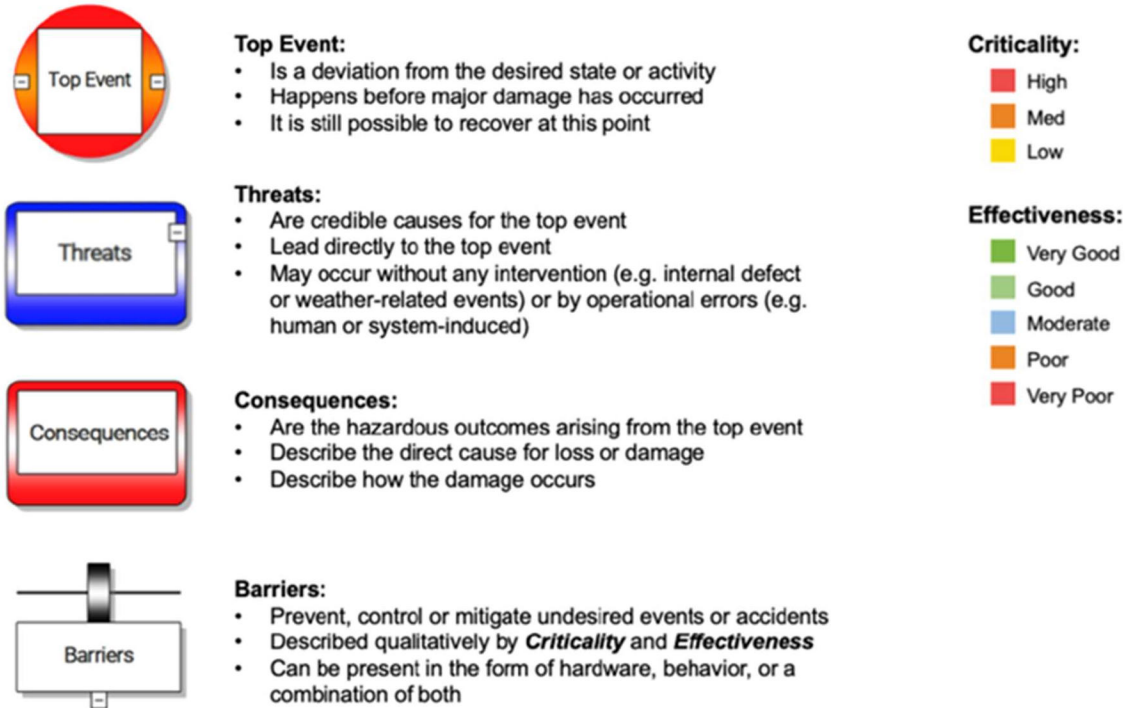
ESRG utilizes the bowtie methodology for hazard and risk assessments, as described in *ISO IEC 31010 §B.21*. This allows for in-depth analysis of individual mitigative **barriers** and serves as a strong tool for visualizing the chronological pathway of **threats** leading to critical hazard events, and ultimately to greater potential **consequences**, as depicted in Figure 13 below. This simple diagrammatic way of describing and analyzing the pathways of a risk from hazards to outcomes can be considered a combination of the logic of a fault tree, analyzing the cause of an event, and an event tree, analyzing the consequences.

Figure 7: Example Bowtie Diagram



Each fault condition per the 2022 CFC and the 2023 edition of *NFPA 855*, assessed in Sections 4.4.1 – 4.4.6 below, is accompanied by a corresponding bowtie diagram indicating critical *threat* and *consequence* pathways and the mitigative barriers between them. Since the most critical risk posed by lithium-ion battery cells involves 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 the 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. For more on the methodology and relevant terminology, see [Appendix B](#) of this report.



4.2 Relevant Supporting Information

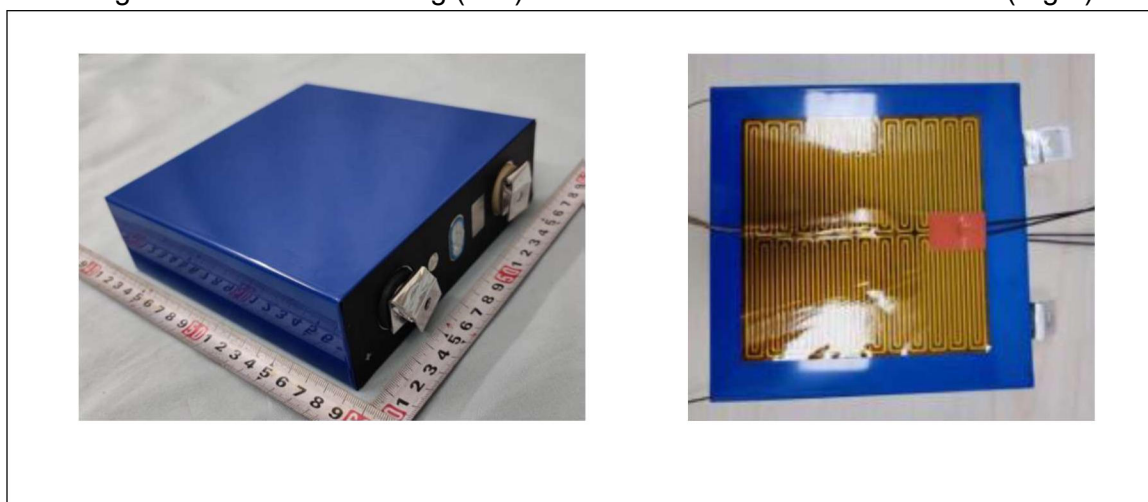
4.2.1 UL 9540A Large-Scale Fire Testing

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

4.2.1.1 Cell Level and Module Level Test Report

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. (project number 4790205409 [1]). Thermal runaway was initiated via the film strip heater. Since the performance criteria per *UL 9540A Clause 7.7* were not met, module-level testing was required.

Figure 8: Cell Level Testing (Left) and Flexible Film Heater Installation (Right)



(Source: Fisher Engineering, Fire Protection Engineering Analysis, Megapack 2 XL, Jan 23, 2023)

4.2.1.2 Module Level Test Report

UL 9540A (4th Edition) Module level testing was performed on the Contemporary Amperex Technology Co., Ltd. (CATL) MP2 360.64Vdc, 157.2 Ah battery module at TÜV SÜD New Energy Testing (Guangdong) Co., Ltd. (Report number 64.280.22.60133.01 [2])

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 gases generated being flammable.

Additional information regarding Cell and Module level testing can be found in the MP2 and MP2 XL FPE report by Fisher Engineering.

Figure 9: Tray Tested to UL 9540A Module Level Testing



4.2.1.3 Unit Level Test Report

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. (Report number NN22GLCI.003 [3]).

Burn marks were observed on the initiating AC battery module, though no external damage was observed. No damage to target units or adjacent walls was 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.

4.2.2 Tesla Megapack 2 XL: Fire Protection Engineering Analysis

A fire protection engineering analysis was provided by Fisher Engineering, Inc. (FEI), which includes a review of the Megapack 2 and Megapack 2 XL construction, design, fire safety features, and large-scale fire test data [4]. A brief summary of key takeaways is provided below.

Key takeaways from the report include:

- 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 MP2 XL was not performed. The UL 9540A unit-level fire test results, described above for the MP2, can be applied to the MP2 XL.
 - a. Similarly, after reviewing the MP2 unit-level fire test results and comparing the MP2 and MP2 XL to one another, TÜV determined that the MP2 UL 9540A unit-level fire test results can be applied to the MP2 XL, and an additional UL 9540A unit-level fire test for the MP2 XL was not required for its listing.
- 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.
- All unit-level performance criteria outlined in UL 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 were 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, were 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 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.

- 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 the 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.
- 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.) to the larger capacity 3,100 kWh MP2 cabinet tested and described in the Fisher report.
- 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.
- 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.
- Manual fire suppression (hose lines) is not required to stop propagating thermal runaway and the spread of fire from an 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.

4.2.3 Tesla Megapack 2 XL: Internal Fire Testing and Modeling

4.2.3.1 Destructive Unit Level Testing

Voluntary destructive unit-level testing was conducted by Tesla on a representative and fully populated Megapack 2 XL [4]. 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.

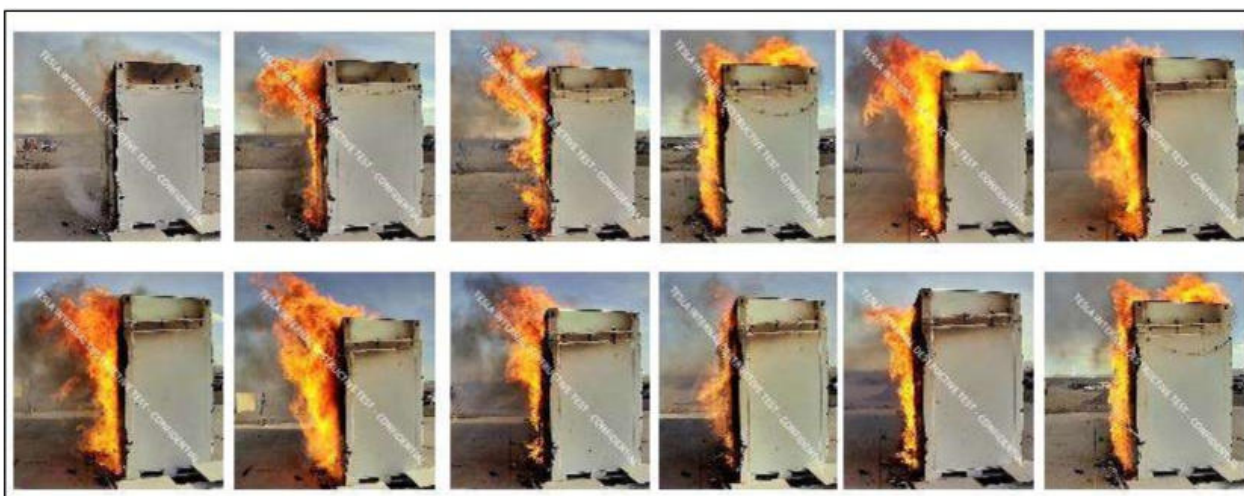
This testing was conducted at the Northern Nevada Research Center on May 19th, 2022. The test utilized film heaters to simultaneously heat forty-eight (48) cells within a module, creating a severe failure scenario that is well beyond what is contemplated by the UL 9540A test method. The goal of this 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 it reached 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).

4.2.3.2 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.

Figure 10: Fire Progression During Unit Level Destructive Testing



(Source: Fisher Engineering, Fire Protection Engineering Analysis, Megapack 2 XL, Jan 23, 2023)

4.2.3.3 Product of Combustion - Unit Level Testing

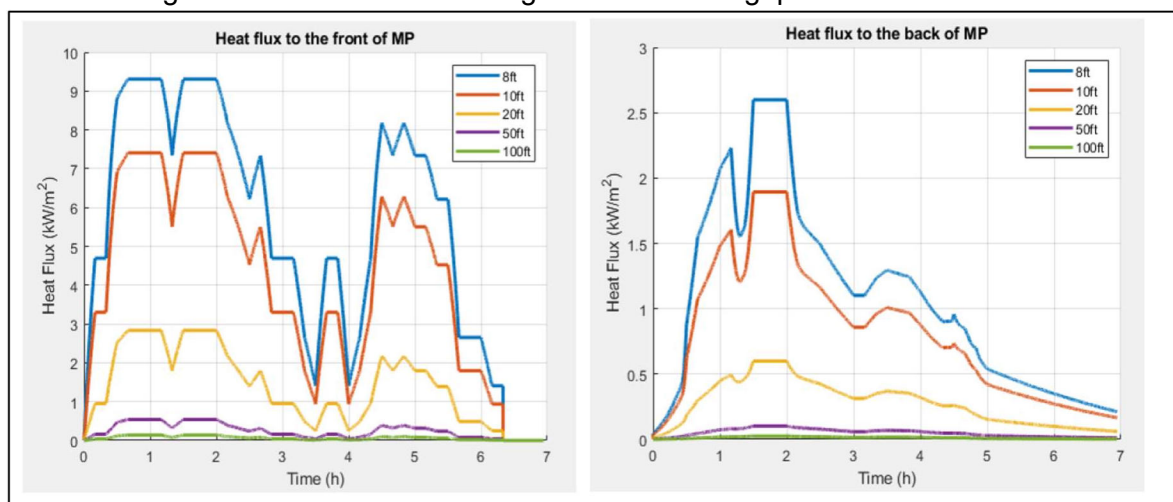
Tesla conducted additional internal unit-level testing to obtain and analyze the products of combustion from a failing Megapack Unit. The products of combustion were collected at locations 5 ft upwind and 20 ft downwind from the initiating unit to assess airborne contaminants that may be present during an incident. Subsequent third-party analysis concluded that no traces of Mercury were 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 the accepted NIOSH Immediately Dangerous to Life or Health (IDLH) value of 30 ppm for HF. These results can be extrapolated to the Tesla Megapack 2 XL, as TUV indicated in the UL 9540A unit report that the testing performed on the Megapack 2 is considered “harsher with higher gas concentrations, and fundamental engineering analysis for the Megapack 2 XL shows comparable behavior as worst case”.

4.2.3.4 Tesla Megapack 2 XL: Heat Flux Analysis

The subsequent fire propagation modeling was conducted to assess the fire propagation risk to adjacent Megapack 2 XL units during a more severe event. As mentioned in the report, the heat flux model was also utilized to determine the estimated heat fluxes at distances further from the Megapack 2 XL cabinet. These values can be utilized to analyze the risk of flame spreading to exposures in proximity to the MP2 XL installation.

The peak heat flux values were utilized for this analysis, utilizing the higher values that are expected at the front of the Megapack 2 XL. For conservativeness, it is assumed that the higher heat flux values (front) are experienced at all orientations from the Megapack 2 XL.

Figure 11: Heat Flux Modelling Vs Time for Megapack Front and Back



(Source: Fisher Engineering, Fire Protection Engineering Analysis, Megapack 2 XL, Jan 23, 2023)

The heat flux values are estimated (and rounded up for conservativeness) from the peak values of the chart and are prescribed as the following discrete values:

- Approximately 9.5 kW/m² at 8ft (radius) from the Megapack 2 XL
- Approximately 7.5 kW/m² at 10ft (radius) from the Megapack 2 XL
- Approximately 3 kW/m² at 20ft (radius) from the Megapack 2 XL
- Approximately 0.5 kW/m² at 50ft (radius) from the Megapack 2 XL
- Approximately 0.1 kW/m² at 100ft (radius) from the Megapack 2 XL

4.2.3.5 Failure Criteria and Thresholds

There are numerous sources of impacts from heat flux, depending on the data source. The information from NIST utilizes the following information:

Table 4: Heat Flux Examples

Heat Flux is the rate of heat energy transferred per surface unit area - kW/m ² .	
Heat Flux (kW/m ²)	Example
1	Sunny day
2.5	Typical firefighter exposure
3-5	Pain to skin within seconds
20	Threshold flux to floor at flashover
84	Thermal Protective Performance Test (NFPA 1971)
60 - 200	Flames over surface

(Source: NIST Fire.Gov, Engineering Laboratory, Fire Research Division)

In a conservative manner, the minimum acceptable heat flux shall not exceed 2.5 kW/m² where Emergency Responders are expected to stage for an extended duration of time.

Additionally, the SFPE Fire Protection Handbook references the maximum allowable heat flux to determine tenability for exposure of skin to radiant heat. That value is 2.5 kW/m² as well. It is expected that exposure can be tolerated for at least several minutes at heat flux values below this level. This would allow time for people (without PPE) to egress to a safe location.

The City University of New York (CUNY) UL 9540A data utilization guidelines reference the SFPE handbook for radiant heat flux values and their observed effects (Table below). As indicated, a critical heat flux of 12.5 kW/m² can be utilized as a failure threshold to assess the threshold for the potential ignition of combustibles.

Table 5: Radiant Heat Flux Observations

Approximate Radiant Heat Flux (kW/m ²)	Comment or Observed Effect
170	Maximum heat flux as currently measured in a postflashover fire compartment.
80	Heat flux for protective clothing Thermal Protective Performance (TPP) Test. ^a
52	Fiberboard ignites spontaneously after 5 seconds. ^b
29	Wood ignites spontaneously after prolonged exposure. ^b
20	Heat flux on a residential family room floor at the beginning of flashover. ^c
20	Human skin experiences pain with a 2-second exposure and blisters in 4 seconds with second-degree burn injury. ^d
15	Human skin experiences pain with a 3-second exposure and blisters in 6 seconds with second-degree burn injury. ^d
12.5	Wood volatiles ignite with extended exposure ^c and piloted ignition.
10	Human skin experiences pain with a 5-second exposure and blisters in 10 seconds with second-degree burn injury. ^d
5	Human skin experiences pain with a 13-second exposure and blisters in 29 seconds with second-degree burn injury. ^d
2.5	Human skin experiences pain with a 33-second exposure and blisters in 79 seconds with second-degree burn injury. ^d
2.5	Common thermal radiation exposure while fire fighting. ^f This energy level may cause burn injuries with prolonged exposure.
1.0	Nominal solar constant on a clear summer day. ^g

4.2.3.6 Heat Flux and Conclusions

Extrapolating the heat flux data, the 2.5 kW/m² threshold is located at approximately 28 feet from the front of the nearest Megapack 2 XL unit. All exposures indicated in section 4.2.3.6 are expected to experience negligible heat flux in the rare event of a full Megapack failure and are all outside of the 28-foot boundary.

In addition, it is noted that the Megapack units themselves are well insulated and are not adversely impacted by a fully involved adjacent unit. This alleviates the concerns for

possible fire propagation from unit to unit in the rare event that a single unit becomes fully involved.

4.2.4 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.

4.3 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 the associated threat or consequence pathway.

Figure 12: Primary Consequence Diagram

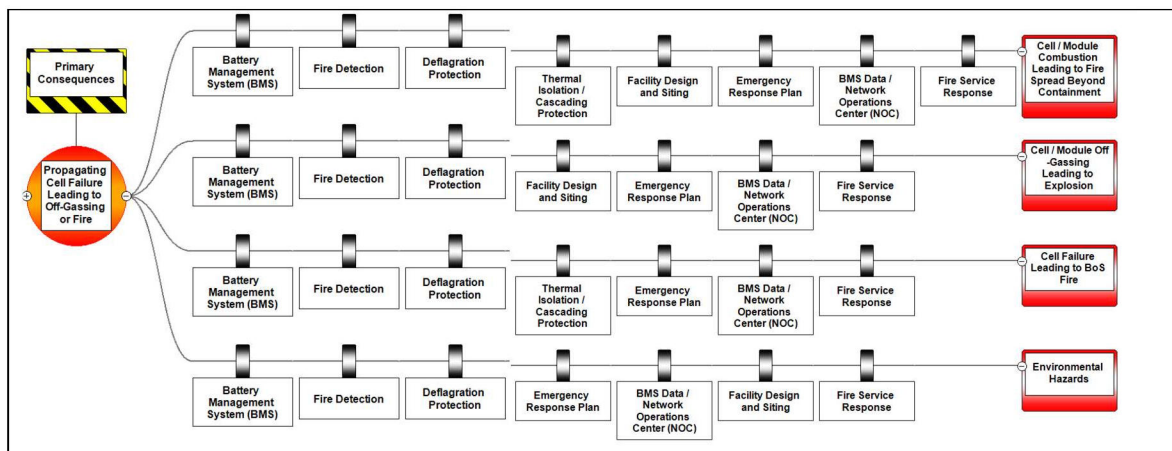


Table 6: Primary Consequence Barriers

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	The Megapack 2 XL in outdoor cabinets is protected by an external IR fire detection system in accordance with the automatic fire detection requirements of the CFC and NFPA 855.
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 a sparker system designed to ignite any flammable gases and release them 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 protections in the form of battery module overcurrent protection, inverter DC and AC protection, and ground fault protection.
Facility Design and Siting	The facility is sited with adequate separation distances from sensitive occupancies that may be affected. The BESS installation is provided with adequate separation distances from the nearest exposures. The BESS facility is bounded by a chain-link fence to prevent unauthorized access to the facility.
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) will provide an additional level of safety for the installation utilizing the Megapack 2 XL.
BMS Data Availability / Operations Center	Tesla Site Controller provides a 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 will be provided.

Fire Service Response	As recommended in Tesla's Emergency Response Guide (ERG), a defensive firefighting approach shall be utilized 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 fire department equipment and capabilities will be strengthened with this familiarization.
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4.4 Fault Condition Analysis

Per 2022 CFC§1207.2.3.1 (and Table 1 above), 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-battery storage rack, module, or array.*
2. *Failure of any energy management system.*
3. *Failure of any required ventilation system.*
4. *Voltage surges on the primary electric supply.*
5. *Short circuits on the load side of the ESS.*
6. *Failure of the smoke detection, fire detection, fire suppression, or gas detection system.*
7. *Required spill neutralization not being provided or failure of a required secondary containment system.*

For the purposes of this report, it is assumed that all construction, equipment, and systems that are required for the ESS are 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 Plus Power at the time of this report.

The following table provides a summary of findings from the hazard mitigation analysis performed in fulfillment of the 2022 CFC§1206.2.3.1, 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 7: Summary of Fault Condition Analysis

Compliance Requirement	Comments
1. Thermal runaway condition in a single-battery storage rack, module, or array.	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 of 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 4.3 above for a list of all consequence barriers).
2. Failure of any battery (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 affected 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 3.2.6 above.
3. Failure of any required ventilation or exhaust system	The Megapack 2 XL does not utilize a system to exhaust flammable gases, as lithium-ion batteries do not release flammable gases during normal operations. Flammable gases generated during abnormal operations are mitigated by the Megapack 2 XL’s proprietary explosion mitigation system.
4. Voltage surges on the primary electric supply	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 3.2.6 of this report.
5. Short circuits on the load side of the ESS	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 3.2.6 of this report.

6. Failure of the smoke detection, fire detection, fire suppression, or gas detection system	The project will utilize an external Infrared (IR) Fire Detection System. This system will be monitored in accordance with NFPA 72 and Chapter 9 of the CFC to include any failures or impairments to this system. A failure of the IR Detection Systems will be addressed in accordance with CFC section 901.7. Along with these safety actions, any BMS fault notifications will also be transmitted to Tesla's 24/7 Operations Center, alerting key stakeholders to any abnormal conditions. Data from the BMS is expected to be communicated to the Subject Matter Expert to provide guidance to the fire department in case of an emergency. The Megapack 2 XL does not rely on an integrated fire suppression system (such as an internal water-based or gas-phase suppression system) to mitigate the hazards associated with propagating thermal runaway. Destructive fire testing and subsequent fire modeling have 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. It is anticipated that sufficient water will be accessible for defensive operations by firefighters arriving on-site, due to the robust municipal water supply that is provided in proximity to the installation.
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4.4.1 Thermal Runaway Condition

Thermal runaway is defined as the "self-heating of an electrochemical system in an uncontrollable fashion" (2023 edition of *NFPA 855* §3.3.26). 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 an 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 the propagation of failure throughout the system, leading to more severe consequences, which are described in detail in Section 4.3 of this report above.

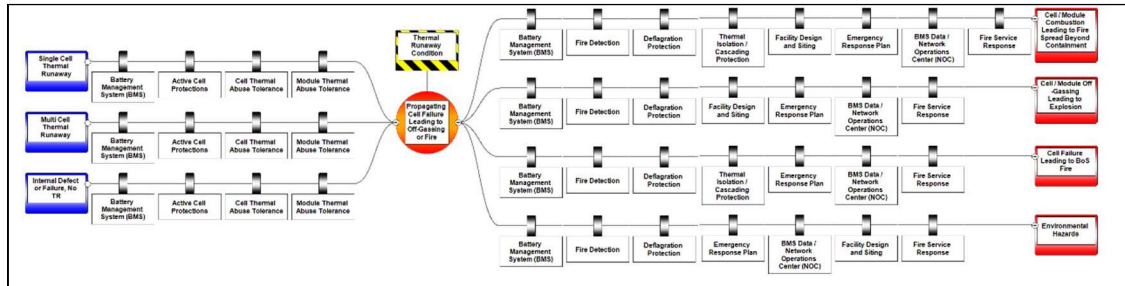


Figure 19: Thermal Runaway Condition Diagram

Table 10: 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 the system is operating outside 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	The active thermal management system provides liquid cooling to internal components within the Megapack 2 XL to limit heat diffusion.
Cell Thermal Abuse Tolerance	The cell has been tested and listed to UL 1973, in which thermal abuse tolerance was tested.
Module Thermal Abuse Tolerance	The module has been tested and listed to UL 1973, in which thermal abuse tolerance was tested.
CONSEQUENCE BARRIERS	
See Section 4.3 above for the list of primary consequence barriers.	

4.4.2 Failure of any Battery (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 affected 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 3.2.6 above.

Finally, should a propagating thermal runaway occur, a number of key barriers are provided to mitigate against the propagation of failure throughout the system, leading to more severe consequences, which are described in detail in Section 4.3 of this report above.

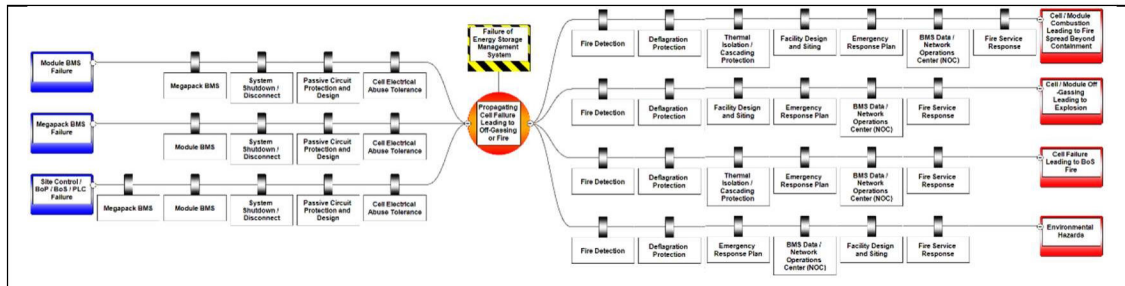


Figure 20: Failure of an Energy Storage Management System Diagram

Table 11: 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 the 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 4.3 above for the list of primary consequence barriers.	

4.4.3 Failure of any Required Ventilation or Exhaust System

The Megapack 2 XL does not utilize a system to exhaust flammable gases, as lithium-ion batteries do not release flammable gases during normal operations. Flammable gases generated during abnormal operations and explosion hazards are mitigated by the Megapack 2 XL's proprietary deflagration prevention system.

4.4.4 Failure of the Smoke/Fire/Gas Detection or Fire Suppression

The project will utilize an external Infrared (IR) Fire Detection System. This system will be monitored in accordance with NFPA 72 and Chapter 9 of the CFC to include any failures or impairments to this system. A failure of the IR Detection Systems will be addressed in accordance with CFC section 901.7. Along with these safety actions, any BMS fault notifications will also be transmitted to Tesla's 24/7 Operations Center, alerting key stakeholders to any abnormal conditions. Data from the BMS is expected to be communicated to the Subject Matter Expert to provide guidance to the fire department in case of an emergency.

The Megapack 2 XL does not inherently rely on an integrated or external fire suppression system to mitigate a thermal runaway failure event. 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. Destructive fire testing and subsequent fire modeling have further assessed the robustness of the Megapack 2 XL system design and resistance to propagating failures. Furthermore, the fire department's response is expected to be strong based on training, robust firefighting capabilities, and timely response.

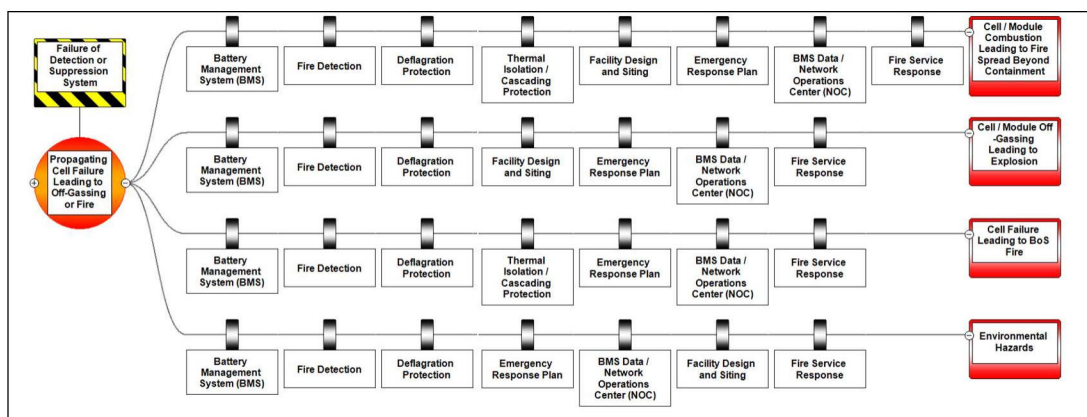


Figure 21: Failure of the Smoke/Fire/Gas Detection or Fire Suppression Diagram

Table 12: Failure of the Smoke/Fire/Gas Detection or Fire Suppression 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 the system is operating outside 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 a sparker system designed to ignite any flammable gases and release them in a controlled manner before they are allowed to accumulate and create a combustible atmosphere within the enclosure.
Thermal Isolation / Cascading Protection	Thermal isolation has been shown to be effective in limiting heat transfer between Megapacks in UL 9540A unit-level testing.

Facility Design and Siting	Facility design and siting are strong. The system is proposed to be installed in a secure area. The Megapack 2 XLs are provided with the minimum required separation distances from the adjacent exposures.
Emergency Response Plan / First Responders	Product-level Emergency Response Guide (ERG) provided by Tesla. An additional level of safety will be provided via site-specific Emergency Response Plans (ERP) in accordance with the requirements of the CFC.
BMS Data / Operations Center	Megapack data is 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 strengthened with this familiarization. Given the adequate water supply within the vicinity of the installation, water will be available for defensive firefighting tactics such as cooling of nearby enclosures or other high-risk exposures (if warranted).

4.4.5 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 3.2.6 of this report.

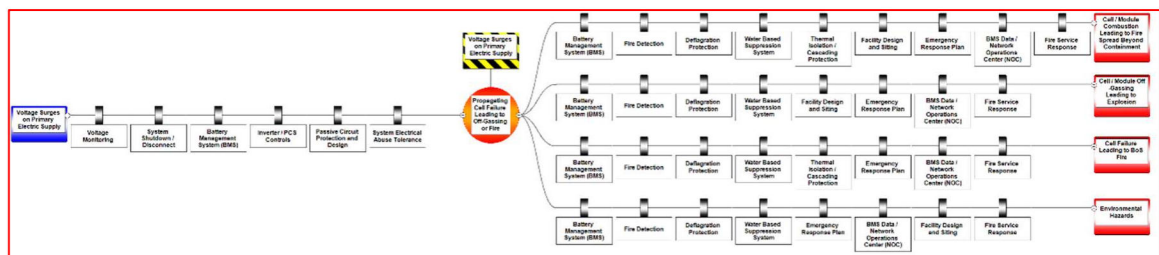


Figure 22: Voltage Surges on the Primary Electric Supply Diagram

Table 13: Voltage Surges on the Primary Electric Supply Barriers

Barrier	Barrier Description
THREAT BARRIERS	
Voltage Monitoring	Voltage is measured by the 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 the system is operating outside 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 a high-speed pyrotechnic fuse for passive or active isolation of the 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 4.3 above for the list of primary consequence barriers.	

4.4.6 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 the propagation of failure throughout the system, leading to more severe consequences, which are described in detail in [Section 3.3](#) of this report above.

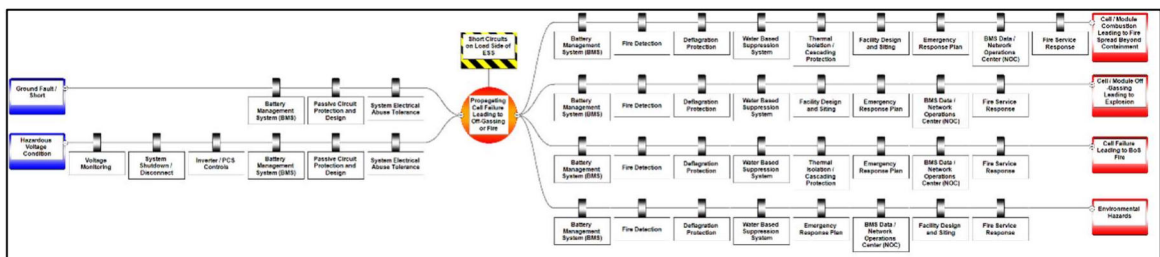


Figure 23: Short Circuits on the Load Side of the ESS Diagram

Table 14: 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 the system is operating outside 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 the 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 4.3 above for the list of primary consequence barriers.	

4.5 Analysis Approval

As per the 2022 CFC and 2023 edition of NFPA 855, the fire code official 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 or explosions will be contained within unoccupied ESS rooms for the minimum duration of the fire-resistance-rated separation identified in 1207.7.4.*
2. *Fires in occupied work centers will be detected in time to allow occupants within the room to evacuate safely.*
3. *Toxic and highly toxic gases released during fires will not reach concentrations in excess of the IDLH level in the building or adjacent means of egress routes during the time deemed necessary to evacuate occupants from any affected area.*
4. *Flammable gases released from ESS during charging, discharging, and normal operation will not exceed 25 percent of their lower flammability limit (LFL).*
5. *Flammable gases released from ESS during fire, overcharging, and other abnormal conditions will be controlled through the use of ventilation of the gases, preventing accumulation or by deflagration venting.*

Table 15: Summary of Analysis Approval

Compliance Requirement	Comments
1. Fires or explosions will be contained within unoccupied ESS rooms for the minimum duration of the fire-resistance-rated separation identified in 1207.7.4.	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. Fires in occupied work centers will be detected in time to allow occupants within the room to evacuate safely.	Not applicable. The Megapack 2 XL is not intended to be installed in any occupied work centers.
3. Toxic and highly toxic gases released during fires and other fault conditions will not reach concentrations in excess of the 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 the accepted NIOSH Immediately Dangerous to Life or Health (IDLH) value of 30 ppm for HF.

	The installation is proposed to be sited in an area with adequate separation distances.
4. 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 a sparker system designed to ignite any flammable gases and release them in a controlled manner before they are allowed to accumulate and create an explosive atmosphere within the enclosure.
5. Flammable gases released from ESS during fire, overcharging, and other abnormal conditions will be controlled through the use of ventilation of the gases, preventing accumulation or by deflagration venting.	Compliant. The Megapack 2 XL is equipped with deflagration protection in the form of pressure-sensitive vents and a sparker system designed to ignite any flammable gases and release them in a controlled manner before they are allowed to accumulate and create an explosive atmosphere within the enclosure.

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APPENDIX A – DETAILED HMA DIAGRAMS AND BARRIER DESCRIPTIONS

A.1 All Fault Conditions

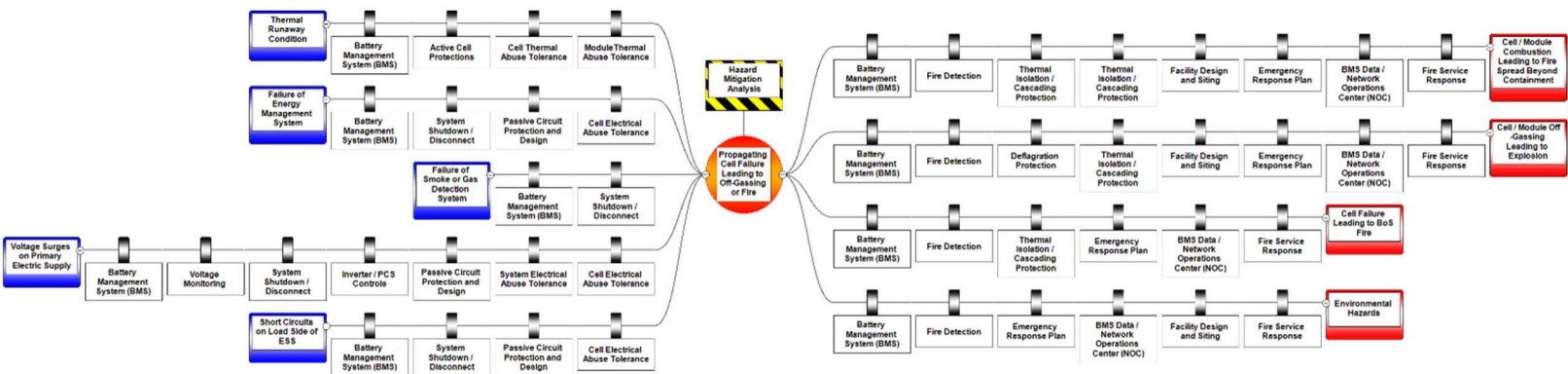


Figure A-1: All Fault Conditions

A.2 Thermal Runaway Condition

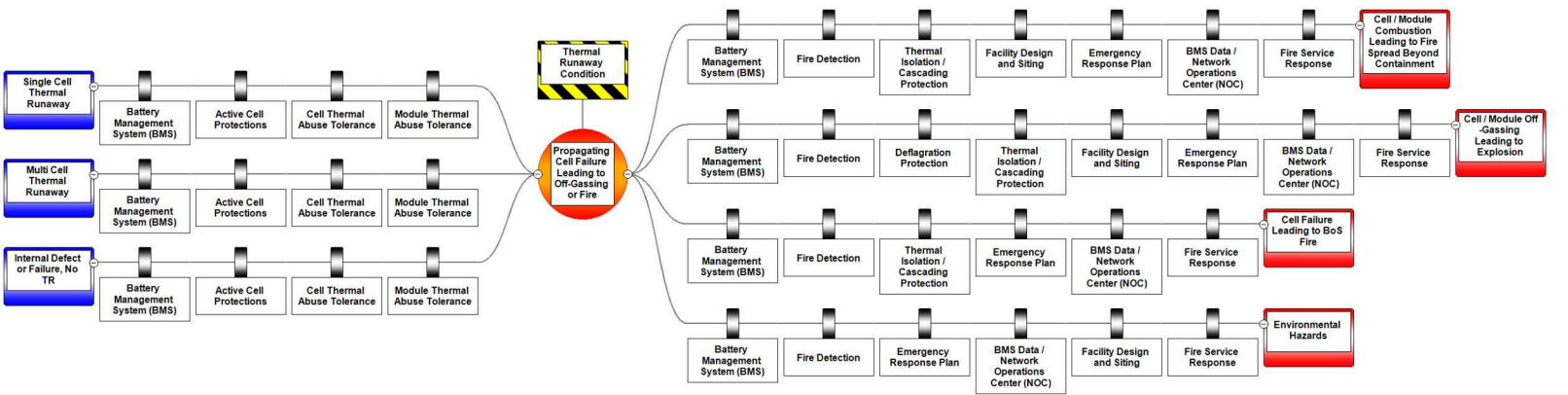


Figure A-2: Thermal Runaway Condition

A.3 Failure of an Energy Storage Management System

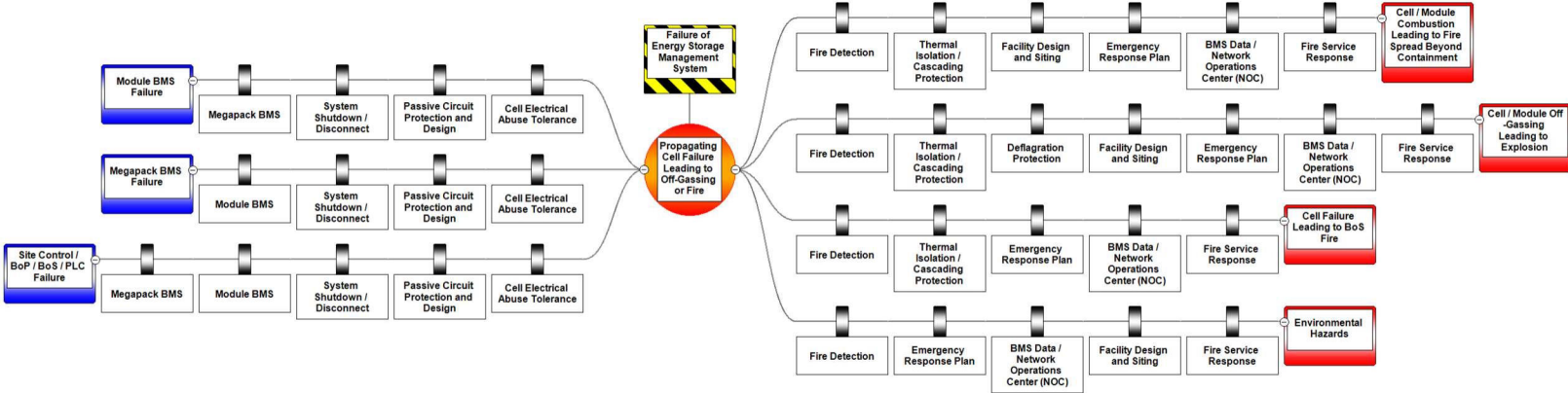


Figure A-3: Failure of an Energy Storage Management System

A.4 Failure of a Required Smoke/Fire/Gas Detection or Fire Suppression

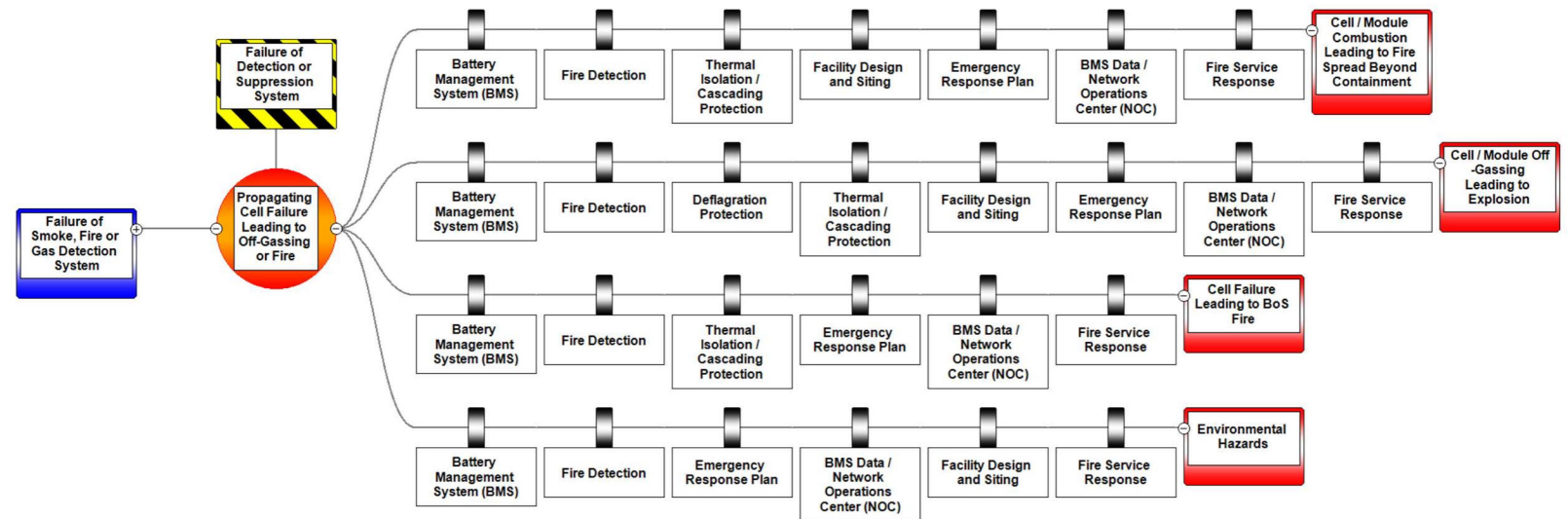


Figure A-4: Failure of a Required Smoke/Fire/Gas Detection or Fire Suppression

A.5 Voltage Surges on the Primary Electric Supply

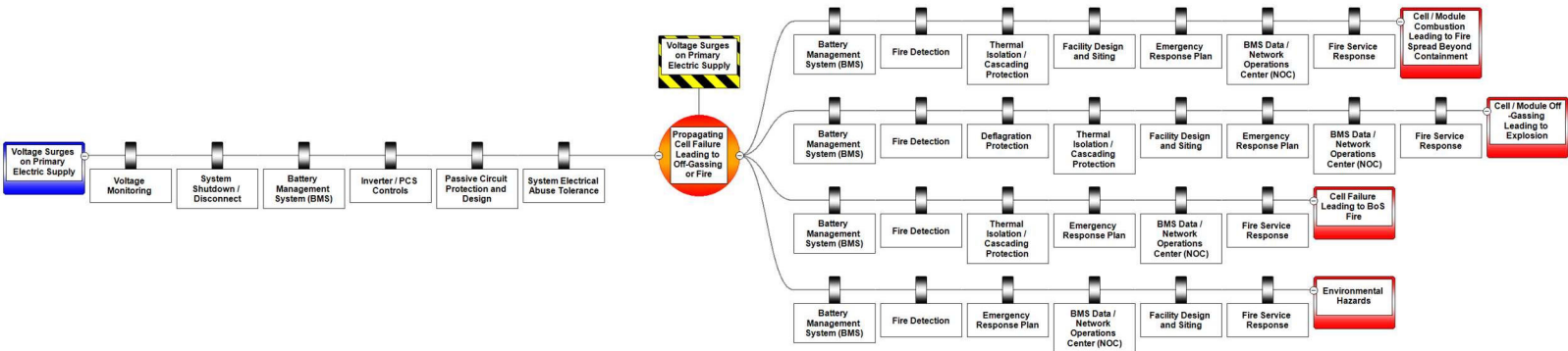


Figure A-5: Voltage Surges on the Primary Electric Supply

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

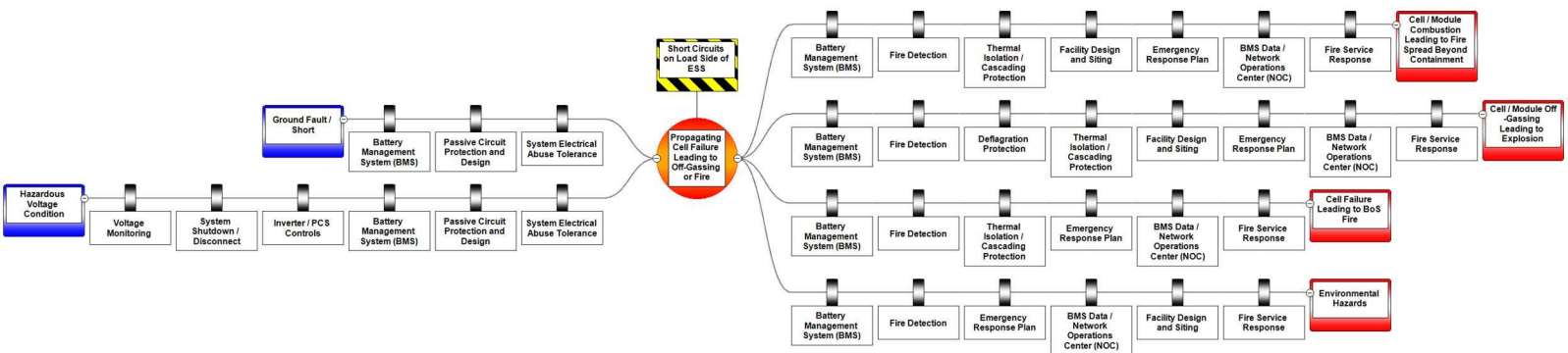


Figure A-6: Short Circuits on the Load Side of the ESS

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 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 Figure B-1 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 that 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 that 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.

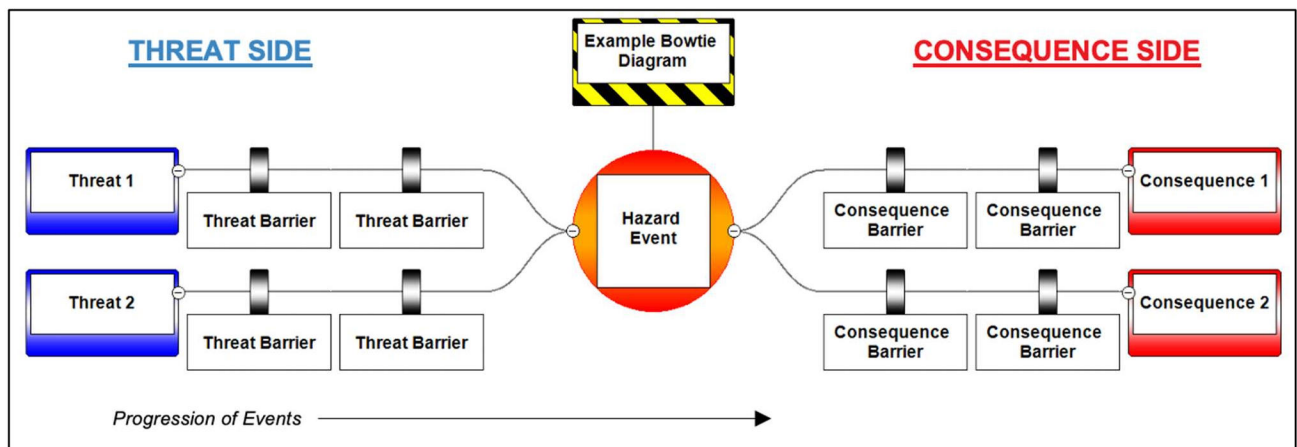


Figure B-1: Basic Bowtie Diagram

- **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, 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 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 the 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, shut down the system, or otherwise prevent thermal runaway from occurring, the hazard may persist.

APPENDIX C – FLAME DETECTION SYSTEM

1. INTENDED USE

Designed for hazardous industries where fast fire detection is critical and nuisance alarms are not an option. The Viking VSF303 UVIR is an explosion proof ultraviolet-infrared flame detector. The device delivers superior performance, responding to hydrocarbon liquid fuel and gas fires at long distances. The VSF303 UVIR has been independently tested to demonstrate it can detect a hydrocarbon fuel pan fire at over 128 feet in less than 5 seconds.

Typical applications include:

- On/Offshore Oil and Gas Processing Facilities
- Refineries
- Petrochemical Plants
- Chemical Facilities
- Pharmaceutical
- Aircraft Hangars
- Road Tunnels
- Power Generation
- Tank Farms
- Road & Rail Loading Racks
- LNG / LPG
- Warehouses/ Storage Areas
- Waste Recycling/ Biomass Plants
- Printing Industry



2. APPROVALS AND CERTIFICATIONS



FMus Approved
Class 1 Div 1 Groups B, C, D T4
Ambient
-58 °F to +185 °F
(-50 °C to +85 °C)

Class 1 Zone 1
AEx/Ex db IIC T4
Ambient
-58 °F to +185 °F
(-50 °C to +85 °C)



ATEX II 2 G Ex db IIC T4
IECEX Ex db IIC T4
Ambient -76 °F to +185 °F
(-60 °C to +85 °C)



INMETRO Ex db IIC T4*
PESO Ex db IIC T4*
Ta=-76 °F to +185 °F (-60 °C to +85 °C)



Performance approvals
FM3260
EN 54-10



Ingress NEMA type 4X/ 4P IP66/67
IEC 61508 SIL 2 Capable*
Marine ABS Product Assessment*

*Designed to meet



The NFS-320SYS intelligent Fire Alarm Control Panel is part of the ONYX® Series of Fire Alarm Controls from NOTIFIER. The panel can be configured with just a few devices for small building applications, or networked with many devices to protect a large campus or a high-rise office block.

Features & Benefits:

- High-speed network for up to 200 nodes
- Standard network for up to 103 nodes
- Autoprogramming and Walk Test reports
- Multiple central station communication options
- Listings: Seismic Certified, Marine Approved

APPENDIX D – REFERENCED DOCUMENTATION

- [1] *Megapack 2XL_- _ANSI-UL_9540A_Cell_Level_Report.pdf*
- [2] *Megapack 2XL_- _ANSI-UL_9540A_Module_Level_Report-1.pdf*
- [3] *Megapack_2_and_XL_- _ANSI-UL_9540A_Unit_Level_Report-1.pdf*
- [4] *Tesla_Megapack_2_and_XL_FPE_Report_Final.-1pdf*

APPENDIX E – REFERENCED CODES AND STANDARDS

- *California Fire Code International Fire Code §1207 Electrical Energy Storage Systems, 2022 Edition*
- *California Electrical Code, 2022 Edition*
- *California Building Code, 2022 Edition*
- *UL 9540A Standard for Test Method for Evaluation of Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 4th Edition*
- *UL 9540 Standard for Energy Storage Systems and Equipment, 2nd Edition*
- *NFPA 68 Standard on Explosion Protection by Deflagration Venting, 2013 Edition*
- *NFPA 72 National Fire Alarm and Signaling Code, 2022 Edition*
- *NFPA 76 Standard for the Fire Protection of Telecommunications Facilities, 2016 Edition*
- *NFPA 855 Standard for the Installation of Stationary Energy Storage Systems, 2020 Edition*