Hazard Mitigation Analysis

for

Arlington Battery Energy Storage System

February 3, 2025

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1 Introduction

The Snohomish Public Utility District No. 1 25MW Battery Energy Storage System (BESS) project will be comprised of 38 Tesla Megapack 2XL Energy Storage Systems (hereinafter referred to as MP2XL). Ameresco is pleased to provide this Hazard Mitigation Analysis (HMA) and relevant information as it relates to the proprietary and confidential Tesla HMA[1]. This document and the referenced Tesla HMA have been prepared 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 summarized herein was performed based on the current documentation available at the time of the report.

2 Energy Storage System Description

2.1 Megapack 2XL Overview

The MP2XL is a modular, fully integrated, AC-coupled battery energy storage system. The MP2XL utilizes lithium iron phosphate ($LiFePO_4$) battery cells. The MP2XL is listed to the following standards by Occupational Safety and Health Administration (OSHA)-recognized Nationally Recognized Testing Laboratories:

- UL 1642 (cell-level certification)
- UL 1973 and IEC 62619 (battery module-level certification)
- UL 9540, IEC 62933-5-2, IEC 62109-1 (system-level certification)
- UL 1741, CSA C22.2 #107.1 (power electronics)
- UL 1998 and IEC 60730 Annex H (functional safety of software)
- International Electrotechnical Commission (IEC) 61000-6-2, and European Norm (EN) 55011 Electromagnetic Compatibility Compliance (EMC)
- United Nations (UN) Department of Transportation (DOT) 38.3 (transportation, self-certified)
- Institute of Electrical and Electronics Engineers (IEEE) 693 (seismic safety)
- UL 9540A (large-scale fire testing): Tested at the cell, module, and unit level
- And many more, including compliance to major market grid codes

MP2XL is designed to comply with major installation codes for energy storage systems, including NFPA 855, IFC 2018 and 2021, and NEC 2020. MP2XL has been reviewed and validated by an Independent Engineer, both at the product level and for the results of large-scale fire testing.

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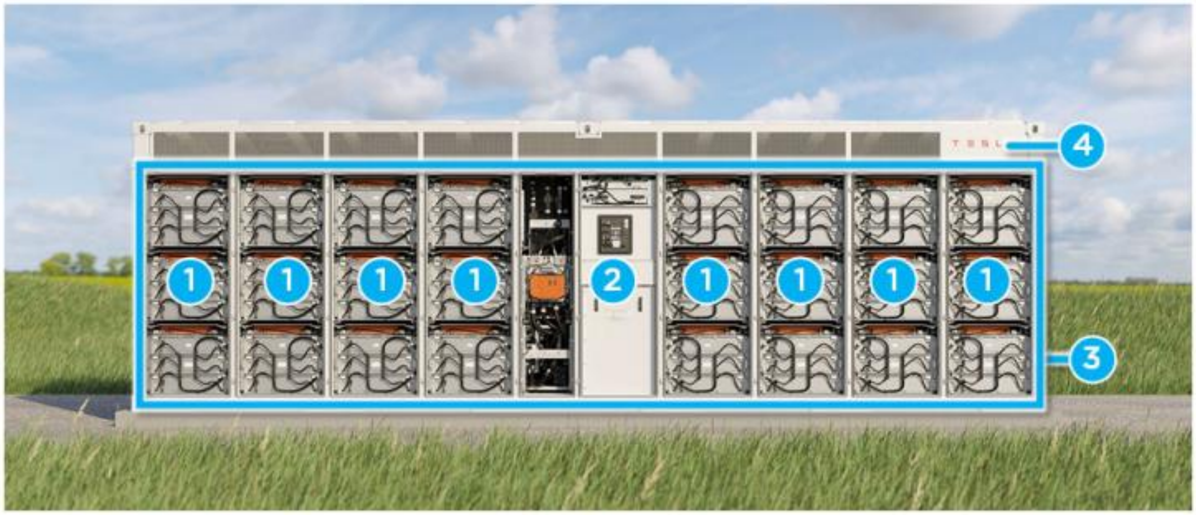
[1] Tesla commissioned an HMA for the MP2XL in 2023. The entire report is proprietary and confidential, however, the full report, including the test parameters, findings, and additional technical information is available for review, if needed.

Each MP2XL unit contains up to 24 battery 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. All components are housed in a cabinet-style enclosure, with access for maintenance provided via enclosure doors facing directly to the open air. The MP2XL, 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 the IFC. Thermal management is provided to the internal MP2XL components via active liquid cooling and heating system utilizing 50/50 ethylene glycol and water and R-134a refrigerant.

The MP2XL and constituent components are tested and certified to 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, battery 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 1 – Tesla MP2XL Exterior View

Figure 2 – Tesla MP2XL Partial Interior View



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

2.2 Fire Safety Features

The Tesla MP2XL 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 IFC §1207 Electrical Energy Storage Systems.

2.2.1 Deflagration Control System

Each MP2XL 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 MP2XL 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 or Energy Storage Management System ESMS) 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 battery 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, external multi-spectrum infrared (IR) flame detectors will be provided to comply with prescriptive requirements for automatic fire detection systems

While the IR detectors were not activated during UL 9540A unit level testing for the MP2XL (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 MP2XL 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 MP2XL has 24/7 remote monitoring, diagnostics, and troubleshooting capabilities. In the event of an emergency, this information may be made available to an 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 in certain installation conditions for battery BESS. 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 MP2XL are housed in a cabinet-style enclosure, with access for maintenance provided via enclosure doors that cannot be physically entered by any person. Thus, the installation codes and standards would not consider the Tesla MP2XL as a walk-in container, occupied building, or structure as defined by NFPA 855 and IFC.

The Tesla MP2XL 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 MP2XL. At the battery module level, overcurrent protection is provided for each battery 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 MP2XL is equipped with DC ground fault detection system and AC circuit breaker with ground fault trip settings for distribution system protection

3 Applicable Codes and Standards

The 2020 edition of NFPA 855 Standard for the Installation of Energy Storage Systems §4.1.4 Hazard Mitigation Analysis states that it 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 IFC §1207.1.4.1:

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

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 Authority Having Jurisdiction (AHJ) is permitted to approve the hazardous mitigation analysis as documentation of the safety of the BESS installation, provided the consequences of the analysis demonstrate the following:

1) Fires will be contained within unoccupied BESS 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) BESS 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 Permissible Exposure Limit (PEL) in the area where the BESS 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 Lower Flammable Limit (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
- Underwriter's Laboratory (UL) 9540A Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 4th Edition
- UL 9540 Standard for Energy Storage Systems and Equipment, 2nd Edition

4 Summary of Findings

Based on the Tesla HMA, adequate protections are provided in the MP2XL 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 MP2XL 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, 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	
Failure Mode	Design Response
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 battery module and the 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 MP2XL 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 MP2XL 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 BESS	Short circuits on the load side are mitigated by BMS controls and automatic safety actions.

- The Tesla MP2XL 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 BESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 §4.3.6.	N/A – The MP2XL is intended for outdoor installations and is used outdoors for this project.
Suitable deflagration protection is provided where required.	The MP2XL is provided with a proprietary explosion protection system. The effectiveness of the explosion protection system was validated during destructive fire testing.
BESS cabinets in occupied work centers allow occupants to safely evacuate in fire conditions.	N/A – The MP2XL is not intended for installation within occupied work centers, nor will it be used in occupied spaces in this entirely outdoor application.
Toxic and highly toxic gases released during normal charging, discharging, and operation will not exceed the PEL in the area where the BESS is contained.	N/A – The lithium iron phosphate ($LiFePO_4$) batteries in this project 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 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.	Internal Unit level testing conducted on the products of combustion from the MP2XL indicated that there was no Mercury (Hg) observed, and trace levels of Hydrogen Fluoride (HF) far below NIOSH IDLH levels.
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 MP2XL's proprietary explosion mitigation system has been validated by UL 9540A Unit level testing 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 battery 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 Rheinland, "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 MP2XL. The MP2XL does not rely on any internal or external fire suppression systems to prevent cascading thermal runaway propagation at the battery module and unit (Megapack-to-Megapack) level.
- Additional voluntary destructive testing was conducted by Tesla on a representative MP2XL. This testing utilized a more aggressive approach than typical UL 9540A testing by initiating a thermal runaway of all 48 cells within a battery 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 mercury (Hg) and trace levels of HF far below National Institute for Occupational Safety and Health (NIOSH) IDLH levels.
- Voluntary fire propagation modeling was conducted by Tesla to determine the potential 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 MP2XL fire, the model shows that thermal runaway would not propagate to the adjacent units that are installed as per Tesla's site design requirements. Furthermore, Ameresco will provide more space between units than Tesla requires to deliver greater risk mitigation.

5 Hazard Mitigation Analysis

5.1 HMA Methodology

The Tesla HMA utilizes a bowtie methodology for hazard and risk assessments, as is described in ISO.IEC IEC 31010 §B.21, allowing 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. This simple 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.

Each fault condition per NFPA 855 and IFC is assessed in Sections 5.4.1 – 5.4.6 below. 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, the consequence barriers (e.g., explosion protection) also contribute added layers of safety on top of the main threat barriers. It is important to note that the barriers along a threat path, are intended to keep the threat from becoming a thermal runaway, while the barriers 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.

5.2 Relevant Supporting Information

5.2.1 UL 9540A Large-Scale Fire Testing

UL 9540A (4th Edition) testing was performed for the constituent cell, battery module, and unit levels of the Tesla MP2XL.

<u>Cell Level Test Report</u>

Cell level testing was conducted at UL in December 2021. UL is an OSHA-approved Nationally Recognized Testing Laboratory (NRTL) and offers the UL mark for products. Testing was performed on five 3.22 V, 157.2 Ah, LFP cells for use in the MP2/2XL. Each cell was charged to 100% State of Charge (SOC) prior to testing. Thermal runaway was initiated. Gas analysis of the gas generated from the well were identified as flammable. As these performance criteria per UL 9540A Clause 7.7 were not met, module level testing was required.

<u>Battery Module Level Test Report</u>

Battey module level testing was conducted at a TÜV Rheinland (TÜV) laboratory in May 2022. TÜV is an OSHA approved NRTL and offers the cTUVus mark, which is equivalent to other NRTL marks such as UL, Electrical Testing Labs (ETL) or CSA. Testing was performed on an entire MP2/2XL tray of LFP cells. The test results summarized below are from the May 2022 test.

Thermal runaway was initiated, similar to the cell level test. 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 (hydrochloric acid), and HCN (hydrogen cyanide). Unit level testing to the UL 9540A test method is required due to the fact that the gases generated are flammable.

Unit Level Test Report

UL 9540A (4th Edition) Unit level testing was performed for the Tesla MP2XL model 1748844-XX-Y at TUV Rheinland of North America, Inc. May 9, 2022.

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

5.2.2 Tesla MP2XL: 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 MP2XL construction, design, fire safety features, and large-scale fire test data.

Key takeaways from the report include:

1. The MP2XL design is almost identical to the MP2 other than being greater in length to accommodate the additional battery modules. As such, a stand-alone UL9540A unit level fire test for the MP2XL was not performed. FEI determined that 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 MP2XL 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) using the UL 9540A Unit level fire test method in which *six cells* within a battery module of the initiating MP2 unit were forced into thermal runaway by using a thermal heat source on each battery. 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 BESS 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 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.
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.

4. 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 an adjacent unit at a distance of 8 ft or more is not possible.
5. 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.
6. An internal fire suppression system or an external fire suppression system is not required to stop propagating thermal runaway from cell to cell, battery module to battery module, or MP2 unit to unit when near simultaneous failure of up to six cells occurs within the same battery module.
7. Manual fire suppression (hose lines) is not required to stop propagating thermal runaway and the spread of fire from a MP2 unit to adjacent MP2 unit 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.

5.2.3 Tesla MP2XL: Internal Fire Testing

5.2.3.1 Destructive Unit Level Testing

Voluntary destructive testing was conducted by Tesla on a representative and fully populated MP2XL. 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 MP2XL'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 MP2XL 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 battery 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 MP2XL during a thermal runaway event propagating to an adjacent MP2XL. The results of this testing show some key takeaways:

- 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 Customer Interface Bay (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.
- 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. 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).

5.2.3.2 Fire Modeling – Propagation Model

Subsequent fire propagation modeling was conducted to assess the fire propagation risk to adjacent MP2XL units during a more severe event such as what was observed during the internal destructive testing referenced **in Section 5.2.3.1**. This fire propagation model showed that due to the robustness of the system design, it is unlikely that a fire from an initiating MP2XL would propagate to the adjacent MP2XL, 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 MP2XL as well as a flaming event and the impact of radiative heat transfer on a target MP2XL installed per Tesla's recommendations.

5.2.3.3 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 were present over the entire 2.5-hour test duration. 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. 53.2.4 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

5.3 Primary Consequences of BESS Failure and Mitigative Barriers

The dynamics of lithium-ion BESS 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 detailed in the table below (though other scenarios not listed may certainly also occur).

Table 1 – Primary Consequence Barriers

Primary Consequence Barriers	
Battery Management System (BMS)	Critical BMS sensing parameters for the MP2XL 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	Infrared detectors will be provided to satisfy automatic fire detection requirements of the regulations adopted for that installation.
Water-Based Suppression System	The MP2XL 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 MP2XL is equipped with deflagration protection in the form of pressure-sensitive vents and sparker system designed to ignite any flammable gases and release those gasses in a controlled manner before they are allowed to accumulate and create an explosive atmosphere within the enclosure.
Electrical Fault Protection Devices	The MP2XL is equipped with a number of electrical fault protection devices 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 increases the strength of this barrier. Ameresco is building the project with spacing that is greater than Tesla recommended installation guidelines.
Emergency Response Plan/First Responders	A product-level Emergency Response Guide (ERG) is provided for the Tesla MP2XL, outlining key product information, safety hazards, and general emergency response procedures.
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 will be provided.
Fire Service Response	A fire hydrant is located adjacent to the project site. 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 will further increase the strength of this barrier.

5.4 Fault Condition Analysis

Per NFPA 855 §4.1.4.2, the analysis shall evaluate 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

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 BESS For the purposes of this report, it shall be assumed that all construction, equipment, and systems that are required for the BESS will 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.

Table 2 – 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 5.3** above for list of all consequence barriers).
2. Failure of an energy storage management system	In the event of a failure of battery module-level BMS, the Megapack-level BMS (which may be considered an energy storage management system) shall isolate effected battery modules, mitigating against further propagation of failure across the system. Should a failure of the Megapack-level BMS occur, each battery 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 MP2XL 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 MP2XL's proprietary explosion mitigation system.
4. Failure of a required smoke detection, fire detection, fire suppression, or gas detection system	The Tesla MP2XL 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 BMS fault notifications will be transmitted to Tesla's 24/7 Operations Center, alerting system owner to abnormal conditions. Data from the BMS may be communicated to the appropriate party to provide guidance to the fire department in case of emergency. The MP2XL 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 MP2XL 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 / battery modules reached levels capable of initiating cell venting or thermal runaway in the adjacent units.
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 BESS (IFC §1207.1.4.1(5))	Short circuits on the load side of the BESS 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

5.4.1 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 MP2XL 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. 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 5.3** of this report above.

5.4.2 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 MP2XL utilizes a tiered hierarchy of controls starting at the module level up to the site level.

In the event of a failure of battery module-level BMS, the Megapack-level BMS (which may be considered an energy storage management system) shall electrically isolate effected modules, mitigating against further propagation of failure across the system. Should a failure of the Megapack-level BMS occur, each battery 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 5.3** of this report above.

5.4.3 Failure of a Required Ventilation or Exhaust System

The MP2XL 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 MP2XL’s proprietary explosion mitigation system.

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

The Tesla MP2XL does not rely on a dedicated smoke detection, fire detection, or gas detection system. Multi-spectrum infrared (IR) detection will be provided to satisfy the automatic fire detection requirements of the locally adopted codes/standards. Furthermore, BMS fault notifications will be transmitted to the 24/7 Operations Center, alerting the operations team to abnormal conditions. Data from the BMS will be communicated to a Subject Matter Expert to provide guidance to the fire department in case of emergency.

The MP2XL 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 / battery 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 MP2XL 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.

5.4.5 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 MP2XL, as are briefly described in **Section 2.2.6** of this report.

5.4.6 Short Circuits on the Load Side of the BESS

Short circuits on the load side of the BESS 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 MP2XL 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 5.3** of this report above.

5.5 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 BESS installation provided the consequences of the analysis demonstrate the following:

1) Fires will be contained within unoccupied BESS 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) BESS 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 BESS 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 – Summary of Analysis Approval

Compliance Requirement	Comments
1. Fires will be contained within unoccupied BESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 §4.3.6.	**Not Applicable.** The MP2XL is intended for outdoor installations only and for the proposed project, it will not be installed within any BESS rooms or structures
2. Suitable deflagration protection is provided where required.	**Compliant.** The MP2XL 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. BESS cabinets in occupied work centers allow occupants to safely evacuate in fire conditions.	**Not Applicable.** The MP2XL is not intended for installation within occupied work centers and it will not be installed within occupied work centers for the proposed project.
4. Toxic and highly toxic gases released during normal charging, discharging, and operation will not exceed the PEL in the area where the BESS is contained.	**Not Applicable.** Lithium-ion batteries do not release toxic or highly toxic gases during normal charging or discharging operations.
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 MP2XL 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.
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 MP2XL 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.