Tesla Megapack 2 XL



Fire Protection Engineering and
UL 9540A Interpretation Report

FIRE & RISK ALLIANCE

EXECUTIVE SUMMARY

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

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

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

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

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

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

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1. INTRODUCTION

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

1.1 Codes, Standards, and Test Methods

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

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

1.2 Reference Materials

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

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

1.3 Acronyms and Abbreviations

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

2. MP2XL DESIGN & FIRE SAFETY FEATURES

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

2.1 Cabinet Layout

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

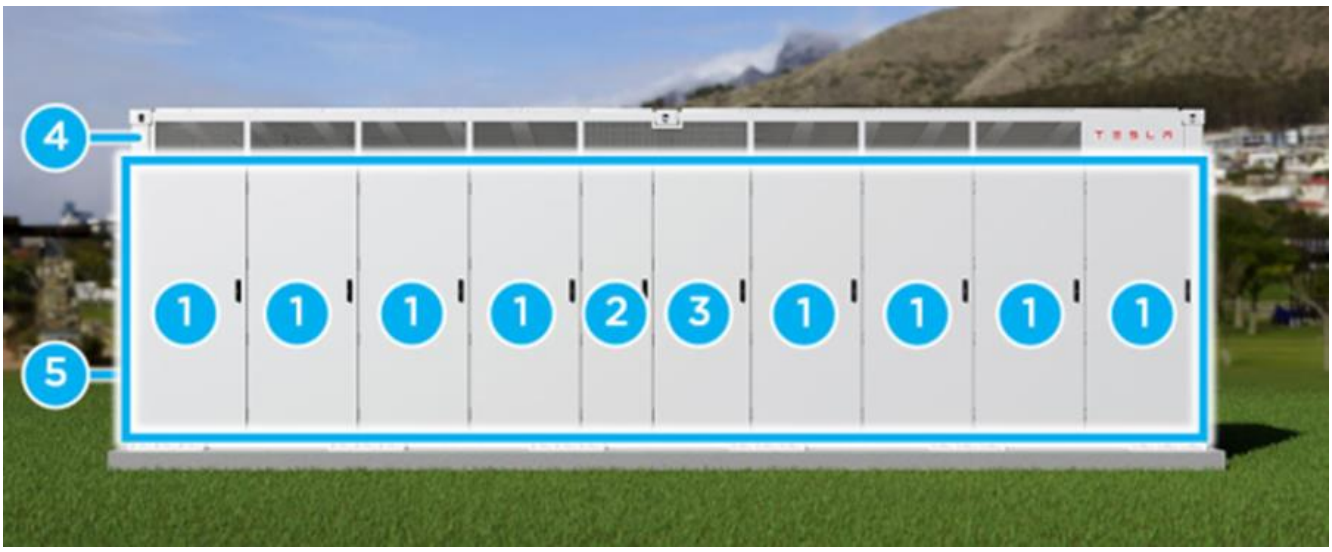


Figure 1 MP2XL internal components: (1) Battery Module Bays, (2) Thermal Cabinet, (3) Customer Interface Bay, (4) IP20 Thermal Roof Enclosure, (5) IP66 Enclosure.

The lithium-ion batteries are housed inside an IP66 steel enclosure (battery module bay) that provides protection against particle and water ingress coming into contact with the battery modules and power electronics. The IP66 enclosure is one continuous unit, meaning each of the ten bays are open to one another. However, when the MP2XL cabinet is populated with battery modules, it cannot be entered. This modular, cabinet style approach allows for the system to be easily maintained and serviced from outside the cabinets

(i.e., the battery modules, thermal management system, and power electronics are serviced through doors located on the front of the cabinets or from the top through the thermal roof), thus eliminating the need for personnel to enter an enclosure, structure, building or container to perform those activities. Since the BESS cabinets do not permit walk-in access, it is a non-walk-in style (NWI) BESS, they are not defined as occupied buildings or structures per the IBC, IFC, NFPA 1, or NFPA 855.

2.2 Cells and Battery Modules

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

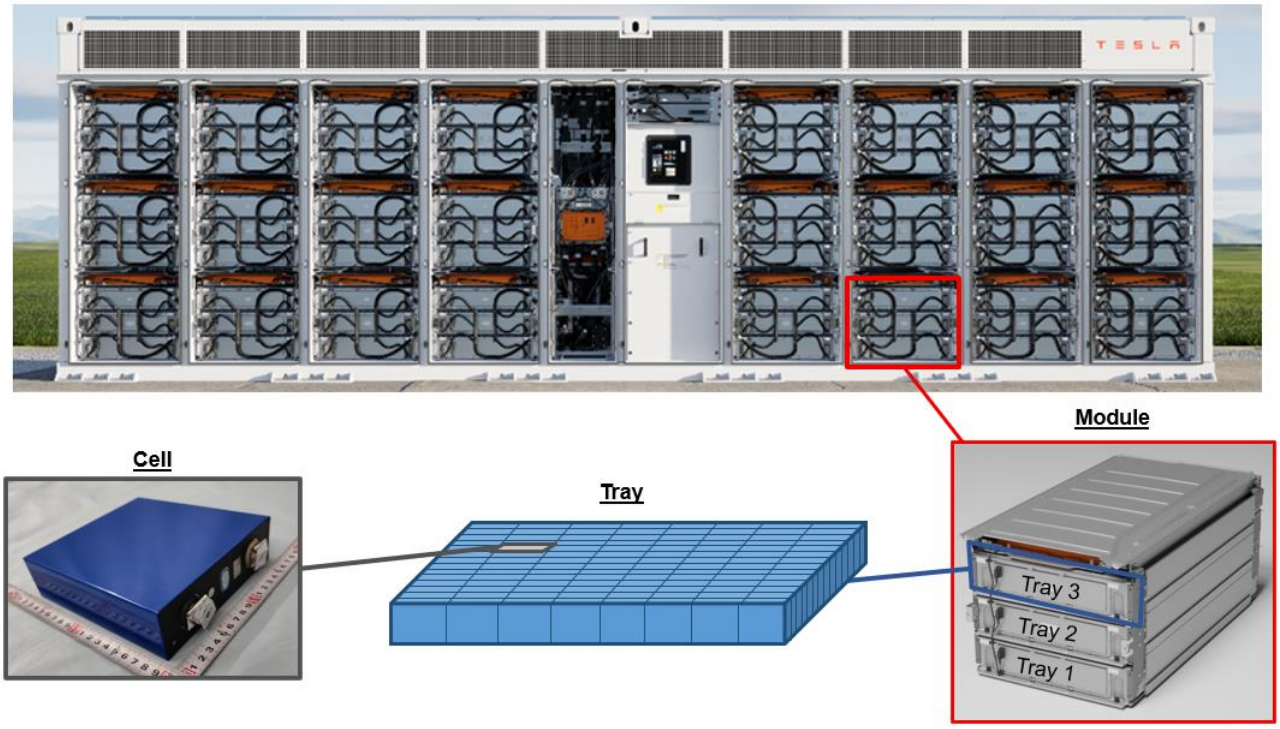


Figure 2 MP2XL, module, generalized tray, and an individual cell layout.

2.3 Customer Interface Bay

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

2.4 Thermal Management System

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

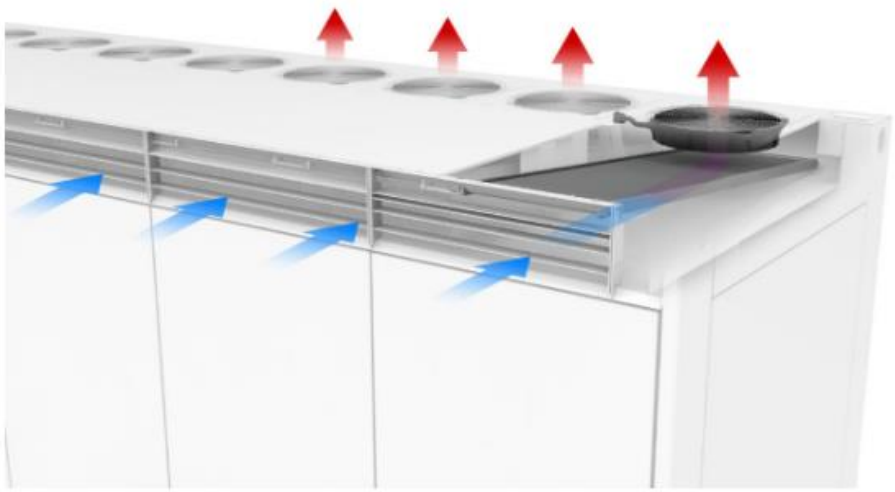


Figure 3 Airflow through the thermal roof.

2.5 Battery Management System

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

2.6 Site Controller and Monitoring

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

2.7 Electrical Fault Protection Devices

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

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

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

2.8 Explosion Control System

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

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

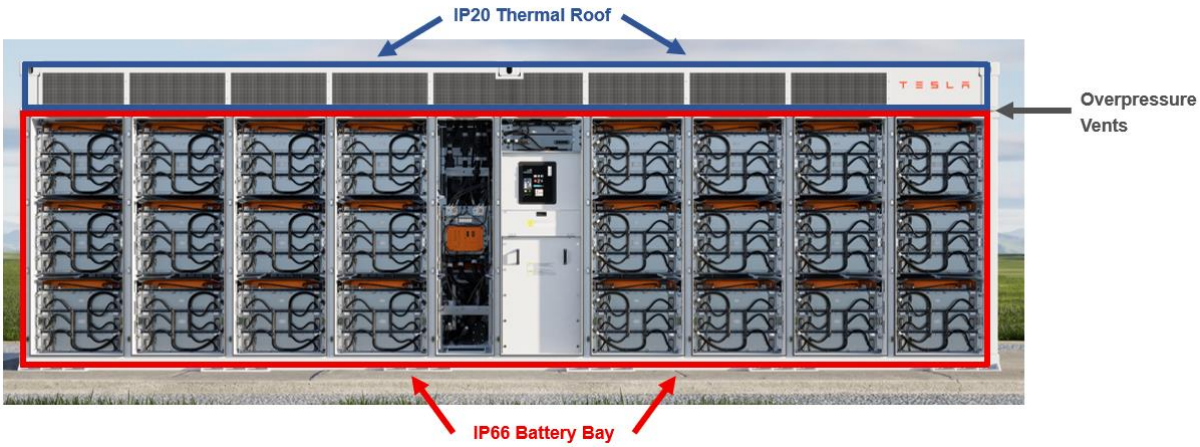


Figure 4 Location of overpressure vents in between the IP66 battery bay and the IP20 thermal roof

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

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

2.9 Fire Detection

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

2.10 Clearances

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

2.11 Emergency Response

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

3. MP2XL PRODUCT LISTINGS

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

3.1 Cell and Module Level

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

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

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

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

3.2 Unit Level

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

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

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

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

3.3 Installation Level

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

4. UL 9540A TESTING

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

4.1 UL 9540A Cell Level Testing

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

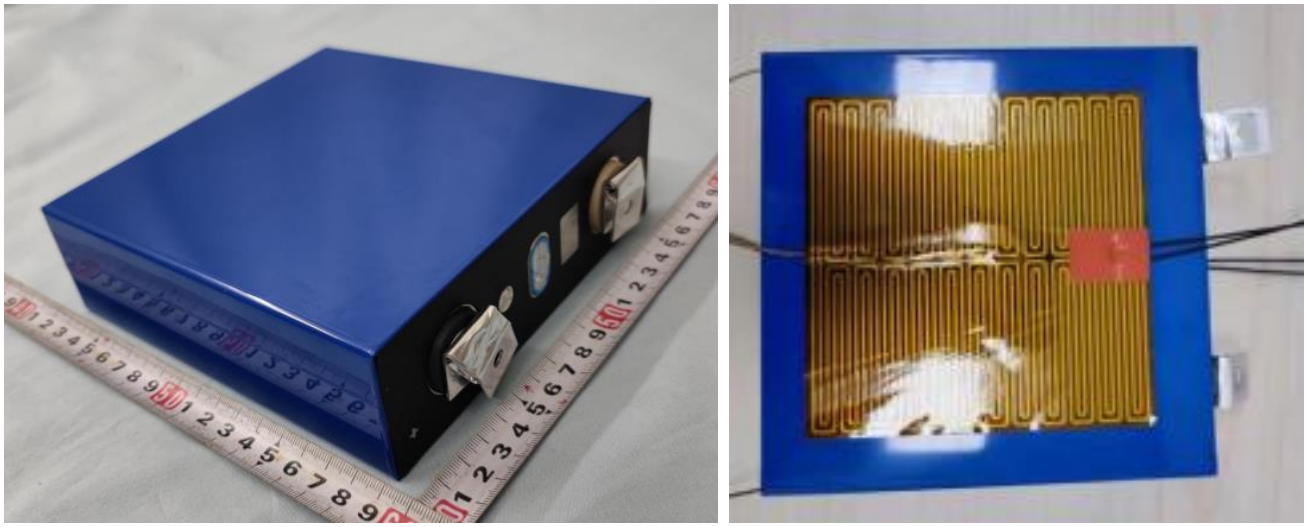


Figure 5 Individual cell tested to UL 9540A (left) and installed film strip heater (right).

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

4.1.1 Test Results

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

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

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

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

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

4.1.2 Key Takeaways

Key takeaways from the tests include:

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

4.1.3 Performance Criteria

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

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

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

4.2 UL 9540A Module Level Testing

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

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

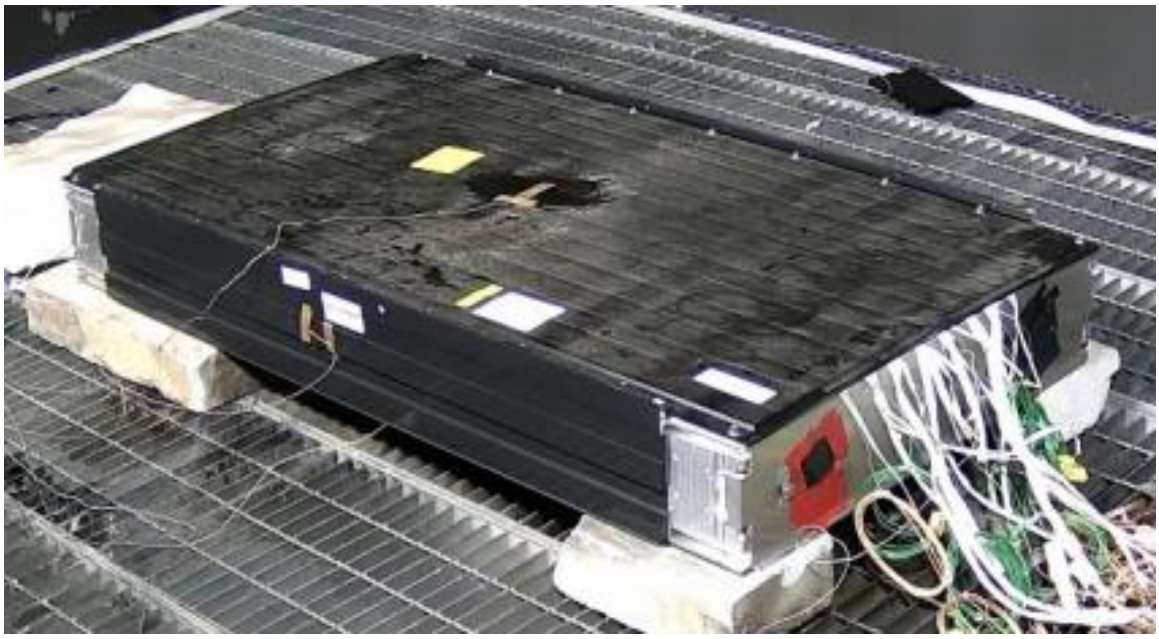


Figure 6 Tray tested to UL 9540A module level testing.

4.2.1 Test Results

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

4.2.2 Key Takeaways

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

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

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

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

4.2.3 Performance Criteria

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

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

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

4.3 UL 9540A Unit Level Testing

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

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

4.3.1 Test Unit

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

4.3.2 Test Setup

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

4.3.3 Initiation

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



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

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

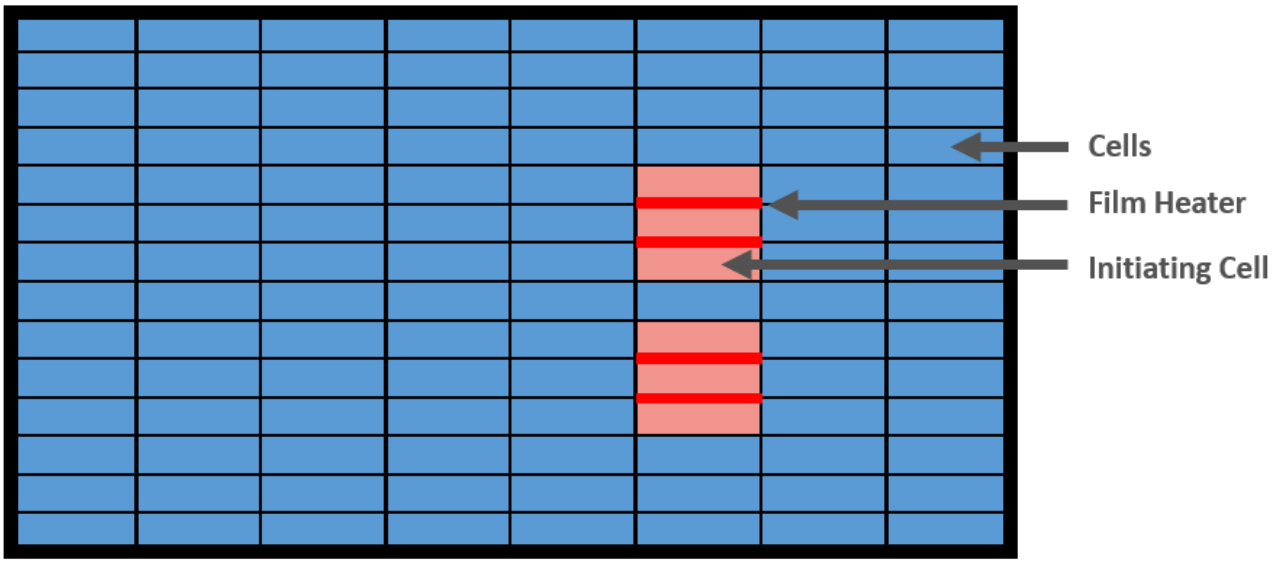


Figure 8 Film heater locations within the initiating tray (top view).

4.3.4 Instrumentation

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

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

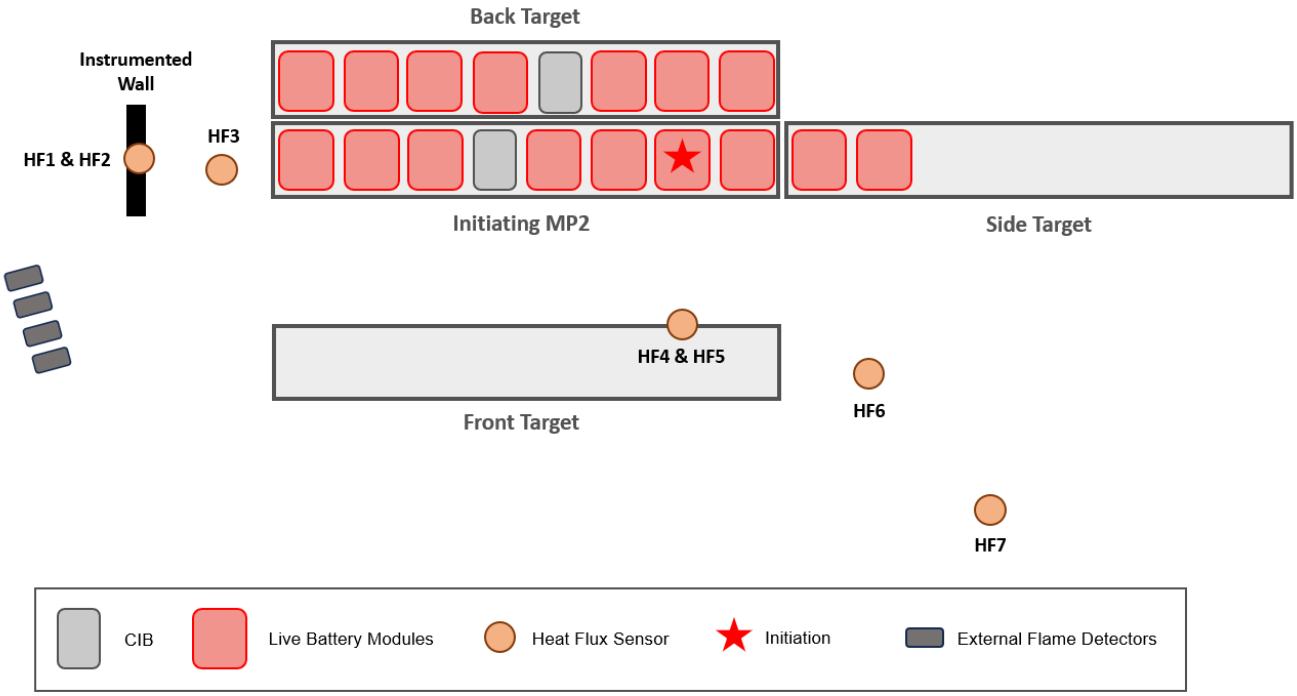


Figure 9 Instrumentation and target MP2 cabinet setup (top view).

4.3.5 Test Results

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

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

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

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

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

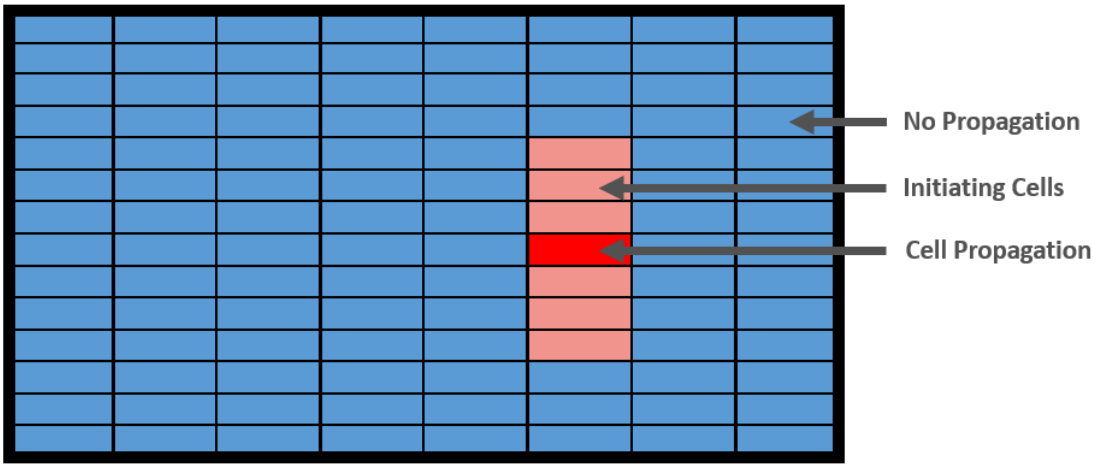


Figure 10 Cell propagation during UL 9540A unit level fire testing (top view).

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

4.3.6 Fire Propagation

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

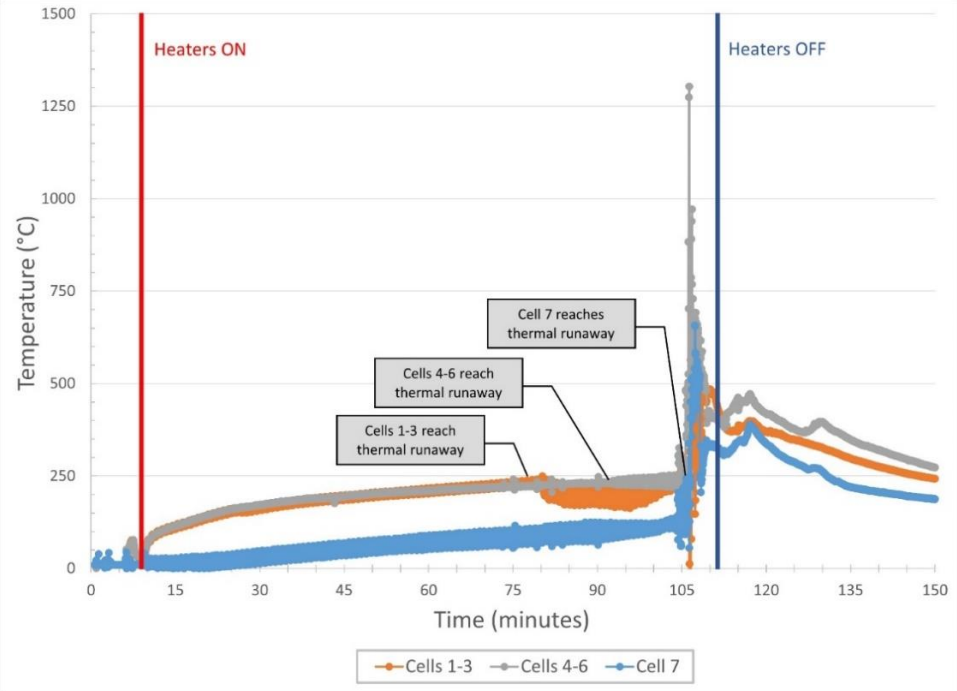


Figure 11 Cell surface temperatures recorded during UL 9540A unit level fire testing.

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

4.3.7 Target Battery Module Surface Temperatures

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

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

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

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

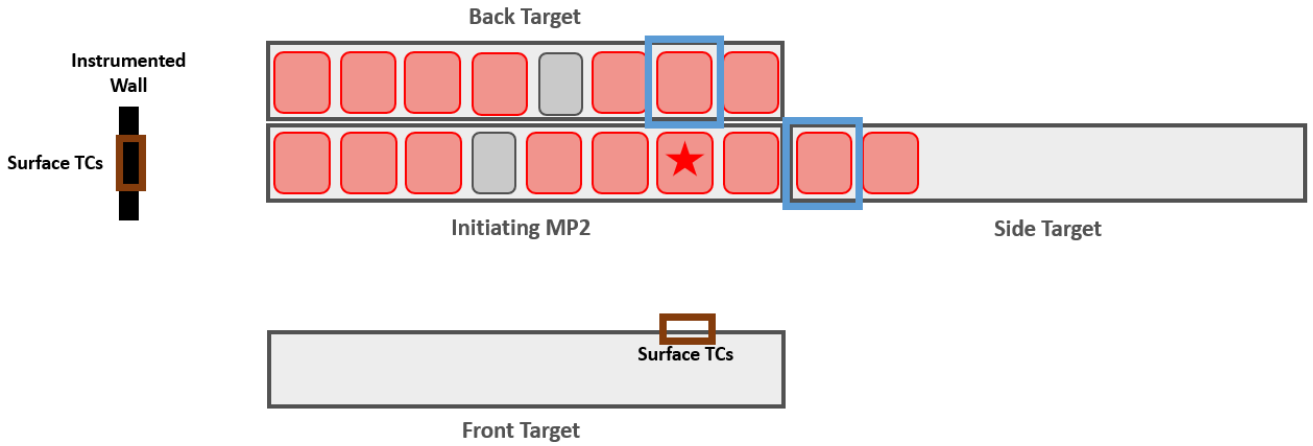


Figure 12 Temperature measurement locations: at side and back target battery modules (blue boxes) and the front target and instrumented wall surface temperatures (brown boxes).

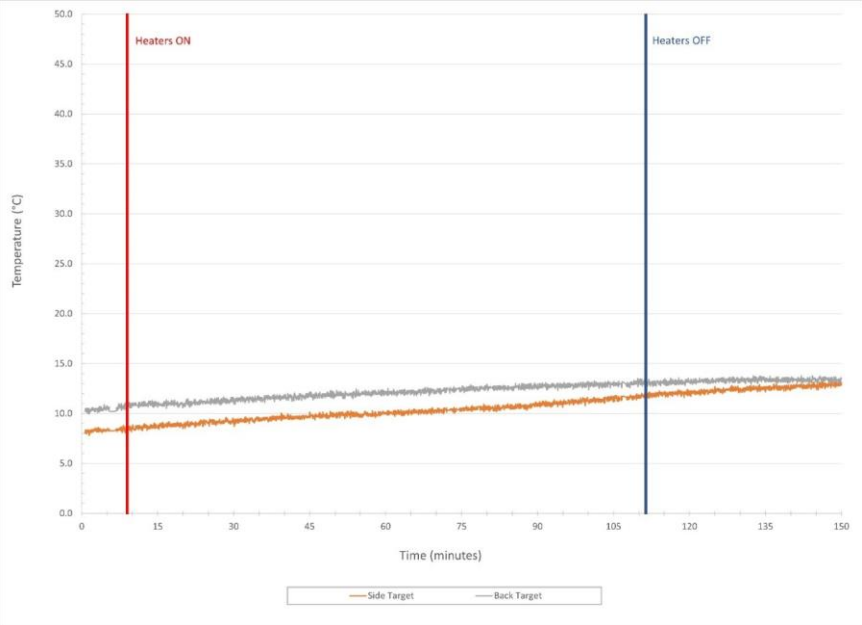


Figure 13 Side and back target battery module temperatures during UL 9540A unit level fire testing.

4.3.8 Exposure Surface Temperatures

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

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

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

These temperatures were recorded directly in front of the initiating battery module and at the instrumented wall, as shown in Figure 12. The surface temperature of the front target gently rose throughout the 2½-hour test from a starting temperature of 11.3°C (52.3°F) to a maximum surface temperature of 16.8°C (62.2°F), as shown in Figure 14. Similarly, the 24 thermocouples installed on the instrumented wall also gently rose throughout the test and fluctuated slightly with the outdoor environmental conditions (i.e., wind blowing, sun exposure, increasing ambient temperatures), as shown in Figure 15. The maximum temperature measured on the instrumented wall was 25.9°C (78.6°F), which was a temperature rise of 5.5°C (9.9°F) above its ambient temperature at the start of the test. Note, the temperature rise above ambient can be attributed to the environmental conditions during the 2½-hour test and is not directly related to the thermal runaway of the seven cells within the initiating MP2. As these measurements are surface temperatures, the temperature rise within

the front target surface and the instrumented wall surface is predominantly due to the sun heating up those surfaces during the test (the test was run between 11 am and 1:30 pm on a mostly sunny day). These temperature measurements indicate an exposure surface 5 ft (1.52 m) to the side and adjacent MP2 cabinets 8 ft (2.44 m) in front, were not affected by the thermal runaway of the seven cells within the initiating battery module.

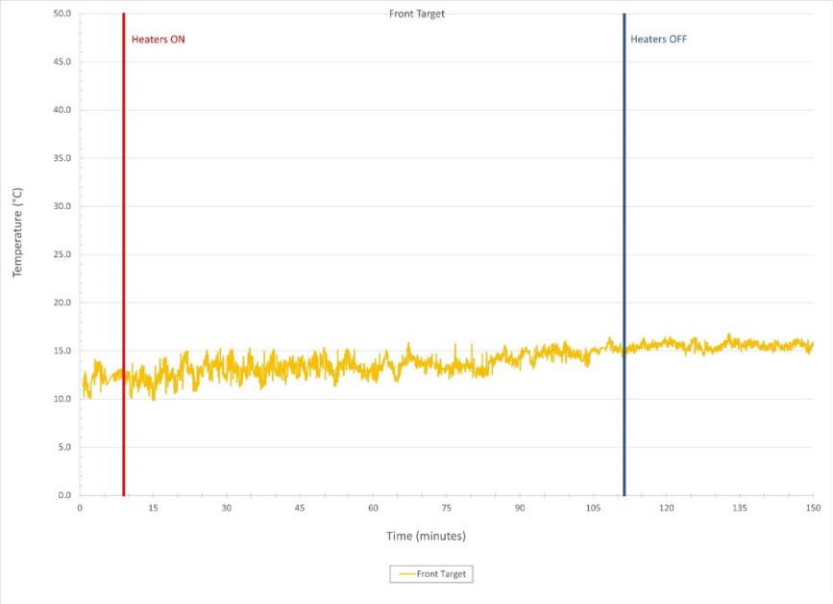


Figure 14 Front target external surface temperature 8 ft (2.44 m) directly in front of the initiating module.

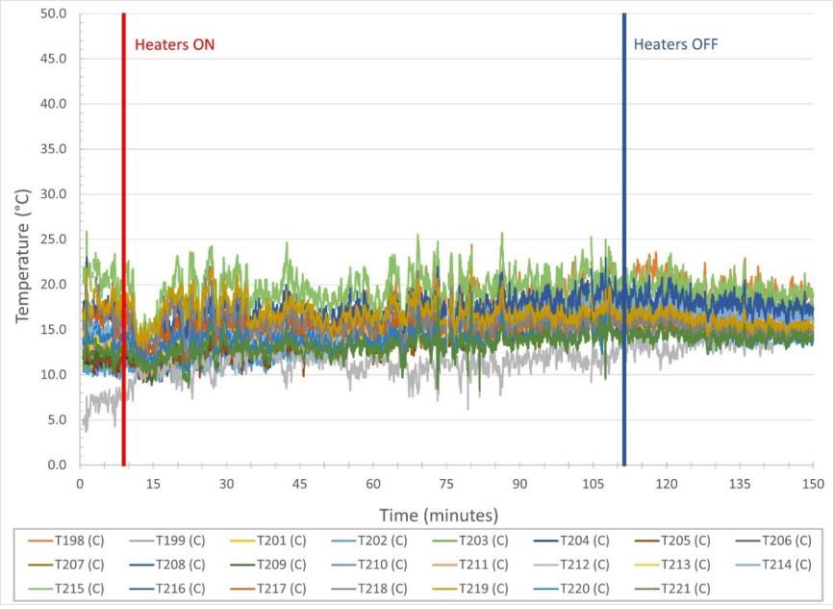


Figure 15 Instrumented wall surface temperatures during UL 9540A unit level fire testing.

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

4.3.9 Heat Flux Measurements

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

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

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

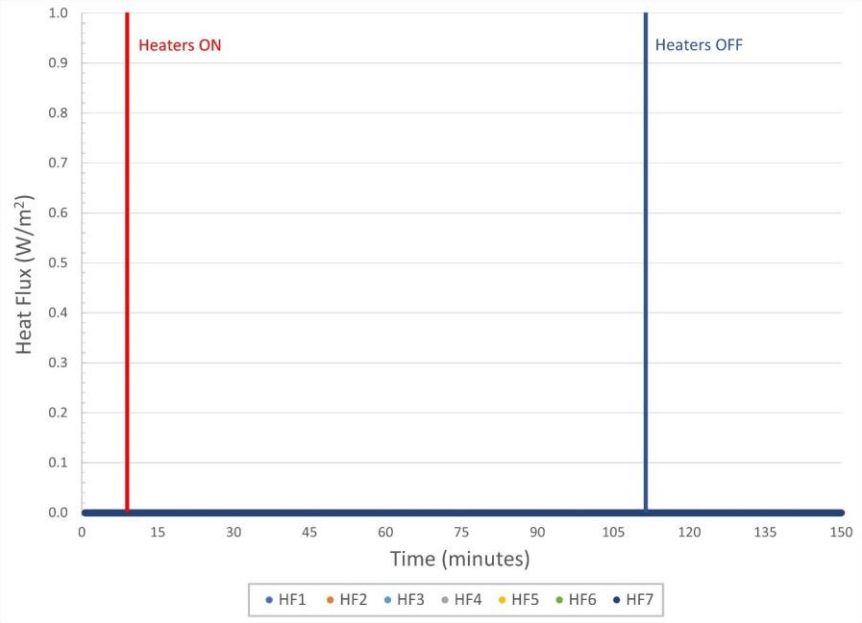


Figure 16 Heat flux measurements recorded during UL 9540A unit level fire testing.

The maximum heat flux recorded was 0.0000016 W/m^2, which was recorded at both the front target and at a distance of 20 ft from the initiating MP2. Note, these heat flux values, in W/m^2, are essentially reading no heat flux values at all, as would be expected given no flaming was observed outside the MP2 cabinet nor was the cabinet itself warmed enough to impose a heat flux on the sensors. These heat flux measurements indicate an exposure surface 3-5 ft (0.91-1.52 m) to the side, an adjacent MP2 cabinet 8 ft (2.44 m) in front, and other

exposures further away at 20-30 ft (6.10-9.14 m), were not affected by the thermal runaway of the seven cells within initiating battery module. Furthermore, the heat flux measurements in front of and to the side of the initiating MP2 cabinet did not exceed 1.3 kW/m^2 at any time during the test.

4.3.10 External Fire Detection System

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

4.3.11 Fire Suppression System

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

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

4.3.12 Explosion Control

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

4.3.13 Runoff/Products of Combustion

UL 9540A unit level fire testing does not require the collection of runoff or products of combustion as part of an outdoor installation test. However, during the unit level test, and afterwards during cleanup, no liquid runoff

(such as the water-glycol solution from the TMS) was observed. Internal cell components were observed after the test on the interior of the cabinet around the Bay 7 door, as would be expected after the failure of seven cells. However, no free-flowing liquid, or runoff was observed once the MP2 doors were opened. If necessary, should a failure event occur, internal cell components/electrolytes can be disposed of in an appropriate manner as specified by Tesla's ERG and Safety Data Sheets (SDS).

4.3.14 Performance Criteria

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

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

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

5. CONCLUSIONS

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

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

6. Based on a review of the MP2XL, its fire safety features, and the UL 9540A unit level fire test results, the MP2XL meets or exceeds all the performance criteria of UL 9540A, Table 9.1 and UL 9540A installation level testing is not required for a MP2XL installation.
7. None of the external fire detectors activated during the UL 9540A unit level fire test (two multi-spectrum IR flame detectors and two thermal imagers). This result is expected, as no flaming was observed outside of the cabinet during the test; however, previous testing by Tesla on the MP1 has demonstrated that multi-spectrum IR flame detectors can detect a fire should flames exit the cabinet through the thermal roof.
8. An integral fire suppression system or an external fire suppression system is not required to stop the spread of fire from cell to cell, module to module, or MP2XL cabinet to cabinet when a near-simultaneous failure of up to six cells occurs within the same battery module.
9. Manual fire suppression (hose lines) is not required to stop the spread of fire from a MP2XL cabinet to adjacent MP2XL cabinets installed 6 in (150 mm) behind and to the sides when a near-simultaneous failure of up to six cells occurs within the same battery module.
10. Based on a review of the MP2XL, its fire safety features, and the UL 9540A test results, the MP2XL can meet or exceed all the installation level codes and standards, such as the IFC and NFPA 855, required for outdoor, ground mounted BESS installations when installed in accordance with the MP2XL DIM.

6. REVISION CONTROL SHEET

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

Revision	Section	Changed Noted