
Appendix I

Hazard Mitigation Analysis

FIRE PROTECTION

HAZARD MITIGATION ANALYSIS (HMA)

for AES Corporation

Lithium-Ion Battery Energy Storage Enclosures

Double Butte Outdoor Energy Storage System

Address:
Menifee, CA

Prepared by: Coffman Engineers

Date: April 19, 2024



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List of Abbreviations & Definitions

AHJ	Authority Having Jurisdiction
BESS	Battery Energy Storage System
BMS	Battery Management System
BOL	Beginning of Life
CFC	California Fire Code
CFD	Computational Fluid Dynamics
CFM	Cubic Feet per Minute
DC	Direct Current
EMCU	Emergency Management Control Unit
EMS	Emergency Management System
EOL	End of Life
ERP	Emergency Response Plan
ESS	Energy Storage System
E-STOP	Emergency Stop
FACP	Fire Alarm Control Panel
FCC	Fire Command Center
FMEA	Failure Mode and Effects Analysis
HMA	Hazard Mitigation Analysis
HVAC	Heating Ventilation Air Conditioning
IDLH	Immediate Danger to Life and Health
kWh	Kilowatt hours
LFL	Lower Flammability Limit
LFP	Lithium Iron Phosphate
LPC	Local Plant Controller
MW	Mega-Watt
MWH	Mega-Watt Hours
Module	Assembly of cells. Multiple modules comprise a unit.
NFPA	National Fire Protection Association
PCS	Power Conversion System
UL9540A	Underwriter Laboratories 9540A
Unit	A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such as cells, modules, battery management systems, ventilation devices and other ancillary equipment.
UPS	Uninterruptible Power Supply

1. INTRODUCTION

This battery electrochemical Energy Storage System (ESS) Hazard Mitigation Analysis (HMA) is provided by Coffman Engineers, Inc. (Coffman) in accordance with the 2022 California Fire Code (CFC). This HMA is required per CFC 1207.1.4 because the ESS exceeds the maximum allowable quantity limit of 600 kWh for a lithium-ion ESS, as listed by CFC 1207.5.2. The CFC allows maximum energy storage quantities to be increased when supported by an approved HMA.

This HMA report provides a technical opinion prepared by a qualified professional fire protection engineer compliant with CFC 104.8.2 to evaluate the consequences of the single failure modes listed below in Table 1 as required by CFC 1207.1.4.1.

Requirement	HMA Section	Failure Mode Consequence Considered
Single Failure modes CFC 1207.1.4.1	6.1	Thermal runaway condition in a single ESS rack, module, or unit
	6.2	Failure of any battery management system
	6.3	Failure of the site energy management system
	6.4	Voltage surges on the primary electric supply.
	6.5	Short circuits on the load side of the ESS.
	6.6	Failure of Multi-Criteria Fire/CO Detection.
	6.7	Required spill neutralization not being provided or failure of a required secondary containment system.

Table 1. Summary of CFC 1207.1.4.1 Requirements

Per CFC 1207.1.4.2, the HMA shall demonstrate the following:

1. **Requirement:** Fires or explosions will be contained within unoccupied battery storage rooms for the minimum duration of the fire-resistance rated walls identified in Section 1207.7.4.

Compliance: This provision is not applicable to this project as the ESS is an outdoor installation and is not a room within a building. There is no requirement for fire-resistance rated separations.

2. **Requirement:** Fires in occupied work centers will be detected in time to allow occupants within the room or area to safely evacuate.

Compliance: This provision is not applicable to this project as the ESS is an outdoor, unoccupied installation.

3. **Requirement:** Toxic and highly toxic gases released during fires will not reach concentrations in excess of the IDLH level in the building or adjacent means of egress routes during the time deemed necessary to evacuate occupants from any affected area.

Compliance: The ESS enclosures are not in a building, are non-occupiable, and are accessed from the exterior (not walk-in). The UL9540A test results include a summary of the cell gas chemical composition.

4. **Requirement:** Flammable gases released from ESS during charging, discharging, and normal operation will not exceed 25 percent of their lower flammability limit (LFL).

Compliance: The batteries are hermetically sealed and do not vent under normal charging or discharging operating conditions. Flammable gases are not released during normal operations.

5. **Requirement:** Flammable gases released from ESS during fire, overcharging, and other abnormal conditions will be controlled through the use of ventilation of the gases, preventing accumulation, or by deflagration venting.

Compliance: There is potential that the battery cells will vent flammable gases in the event of an internal short within a battery cell, overcharging, in the event of a BMS or EMS failure, or other abnormal conditions. Fires or explosion hazards will be mitigated through the use of deflagration panels on the top of each enclosure to direct any explosion up and away from personnel or emergency responders in the surrounding area.

2. PROJECT DESCRIPTION

The site for the Double Butte ESS project is located in Menifee, California. The project includes the installation of a new 495 MW / 2,705 MWh Energy Storage System facility on an existing 23-acre site. The site is planned to accommodate 2,466 ESS enclosures.

The battery cells used in the ESS enclosures are Contemporary Amperex Technology Co., Limited (CATL) Model CB310, which uses Lithium Iron Phosphate (LFP) chemistry. The ESS enclosures are produced by Fluence, consisting of the Fluence Cube modular energy storage system (Model Number 06-01-0005-16). The Fluence Cube configuration has been tested to the UL 9540A standard at the cell, module, and unit levels.

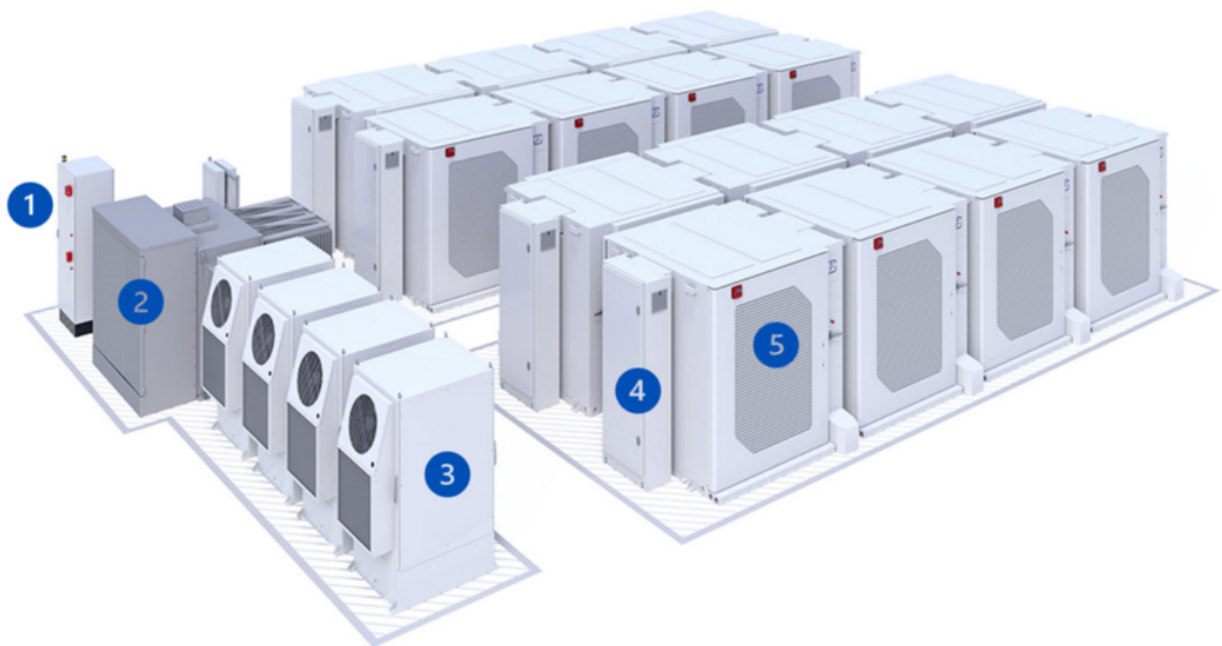
The Fluence Cubes are an outdoor installation and are not considered a room within a dedicated-use or non-dedicated-use building. Code requirements for outdoor installations for non-walk-in units are applicable to this project and associated HMA. The enclosures are not intended to be occupiable and will primarily be accessed and maintained from the exterior of the enclosure. The details of the ESS facility at the Double Butte site are captured in the table below.

Site Name	Double Butte ESS
Owner	AES Clean Energy
Overall ESS Capacity	495 MW / 2,705 MWh
Enclosures at BOL	2,466
Battery	Fluence Cube
Total Area	~23 acres

Table 2. Double Butte Battery Project Summary



Figure 1. Fluence Cube Enclosure



1. Outdoor Core Telco Enclosure (OCTE)
2. Core Transformer
3. Power Conversion System (PCS)
4. Cube Row Termination (CRT)
5. Cube

Figure 2. Fluence Battery Energy Storage System

3. CODE SUMMARY

3.1 Applicable Codes

The Authority Having Jurisdiction (AHJ) for the project is the City of Menifee Fire Department. The applicable codes and standards for the project include the following, with local amendments:

- California Electrical Code (CEC), 2022 Edition
- California Fire Code (CFC), 2022 Edition
- NFPA 24 – Standard for the Installation of Private Fire Service Mains and Their Appurtenances, 2019 Edition
- NFPA 69 – Standard on Explosion Prevention Systems, 2019 Edition
- NFPA 72 – National Fire Alarm and Signaling Code, 2022 Edition
- NFPA 1142 – Standard on Water Supplies and Rural Firefighting, 2017 Edition

The requirements of CFC 1207, Electrical Energy Storage Systems, are applicable for this project.

3.2 Available Guidance Standards

- FM Global Property Loss Prevention Data Sheet 5-33 – Electrical Energy Storage Systems
- NFPA 855 – Standard for the Installation of Stationary Energy Storage Systems, 2023 Edition
- UL 9540 – Standard for Energy Storage Systems and Equipment, 2020 Edition

4. UL 9540A TESTING

4.1 Thermal Runaway Protection

The consequence of a thermal runaway single-fault condition is required to be evaluated by this HMA. Large-scale fire testing, as required by CFC 1207.1.5 and compliant with the UL9540A test standard, has been conducted for the proposed ESS at the cell, module, and unit level. The UL9540A test results provide a basis for evaluation of thermal runaway fire propagation in the ESS enclosure and the effectiveness of the fire protection strategy in mitigating potential harmful conditions arising from a thermal runaway event.

4.2 UL 9540A Test Results

This HMA has been prepared after review of the UL9540A reports, which are referenced in the appendix of this report. Tests were conducted to the 4th edition of the UL9540A test standard. Key results of the UL9540A testing are detailed in this section of the report, including summaries of the gas composition released during the various tests.

4.3 UL 9540A Cell Test Results

The cell test was conducted by forcing the test cell into thermal runaway by inducing heat via a film heater.

- The UL9540A cell level test includes five different samples which produced similar results.
- Average cell venting was observed to occur after approximately 33 minutes.
- Average cell thermal runaway was observed to occur after approximately 53 minutes after the test started.
- The average temperature of the cell surface at which gases were first vented was 168°C.
- The average temperature of the cell surface at thermal runaway was 240°C.
- Based on the gas composition measured during the cell test the Lower Flammability Limit (LFL) at ambient temperature (25°C) is 7.85%. The LFL at average venting temperature (168°C) is 6.47%.
- Gas composition was measured during the cell test and the results are shown in the table below.

Gas Component	Chemical Formula	% Concentration
Carbon Monoxide	CO	11.086
Carbon Dioxide	CO ₂	33.290
Hydrogen	H ₂	35.698
Methane	CH ₄	10.075
Acetylene	C ₂ H ₂	0.164
Ethylene	C ₂ H ₄	5.259
Ethane	C ₂ H ₆	1.089
Propadiene	C ₃ H ₄	0.000
Propene	C ₃ H ₆	0.571
Propane	C ₃ H ₈	0.232
-	C4 (Total)	0.382
-	C5 (Total)	0.091
-	C6 (Total)	0.060
-	C7 (Total)	0.005
Benzene	C ₆ H ₆	0.023
Toluene	C ₇ H ₈	0.002
Dimethyl Carbonate	C ₃ H ₆ O ₃	1.879
Ethyl Methyl Carbonate	C ₄ H ₈ O ₃	0.091
Diethyl Carbonate	C ₅ H ₁₀ O ₃	0.000

Table 3. Cell Level Test – Gas Composition Results

4.4 UL 9540A Module Test Results

The module test was conducted with a single cell being forced into thermal runaway by inducing heat via a film heater.

- Thermal runaway occurred in the initiating cell 1 hour and 14 minutes after heater activation. Thermal runaway propagated to 2 adjacent cells 7 minutes after thermal runaway of initiating cell. No other cells within the module went into thermal runaway and thermal runaway subsided without any external intervention.
- No external flaming was observed from the module during the venting/off-gassing of the cells indicating unburned battery gas was released for the duration of the test which passes the UL 1973 requirements. Gas composition was analyzed showing the primary flammable gas constituents as hydrogen, methane and carbon ethylene. The primary toxic gas was carbon monoxide.
- No flying debris, explosive discharge of gas, sparks or electrical arcs were observed during the test.

4.5 UL 9540A Unit Level Test Results (CSA Group)

The unit level test was completed on a single Fluence Cube (Model 06-01-0005-16). A single enclosure accommodates a total of 16 modules. The size of the rack is approximately 89" (L) by 101" (W) by 100" (H). The rack is constructed out of noncombustible carbon steel.

The initiating cube was surrounded by two target cubes, Target Cube 1 and Target Cube 2, placed on adjacent corners with approximately 7" of separation, as annotated in Figure 3. Target Cube 3 was placed approximately 7 ft in front of the initiating unit to represent an accessible means of egress path. The initiating cube and target cubes were separated approximately 10 ft away from the instrumented wall, refer to Figure 3. All of the target cubes were filled with battery modules. Refer to Figure 3/4 for the test layout.

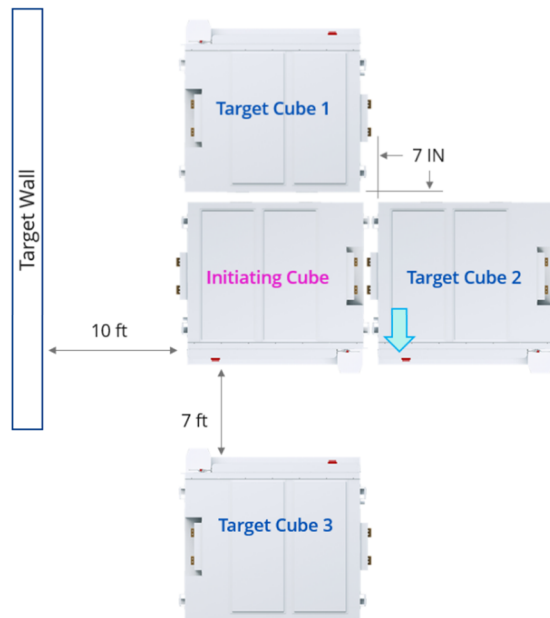


Figure 3. UL 9540A Unit Level Test Diagram



Figure 4. UL 9540A Unit Level Test Layout

Thermal runaway was induced in the initiating ESS unit in one module, using the same approach from the module level test. The test measured heat release rates, heat flux, and surface temperatures of walls and modules in the target ESS unit.

Results from the unit level UL 9540A test include:

- Thermal runaway did not propagate beyond the initiation module. Only the initiating module within the unit experienced thermal runaway.
- No flying debris, explosive discharge of gas or electrical arcs were observed.
- Modules within target unit did not exceed 135°C, which is below the temperature required to trigger thermal runaway.
- The maximum heat flux in the center of the accessible means of egress path was measured to be 0.3 kW/m², which is below the maximum allowable heat flux of 1.3 kW/m².
- Within the initiating ESS unit, the maximum surface temperature of modules adjacent to the initiating module and within the target ESS was 38°C. The cell venting temperature is 168°C; therefore, the test results demonstrate that risk of module-to-module thermal runaway propagation is low.
- Heat flux measurements at the instrumented walls and the adjacent target units did not exceed 0.4 kW/m², which is below the threshold that could potentially ignite combustible materials.
- ESS Fire Alarm System activated upon 1st full vent from initiating module and deactivated once presence of smoke reduced. A fire suppression system was not installed for the unit test.
- The UL9540A test demonstrates that fire suppression protection features would not be necessary to limit a thermal runaway event from propagating outside of a single module, as well as to adjacent ESS enclosures. The unit level test results support the proposed layout and spacing of ESS enclosures.

4.6 UL 9540A Testing Summary

As reported from the cell, module, and unit level UL 9540A testing, thermal runaway occurred within the initiating module but did not otherwise propagate between adjacent modules. There was no flying debris or explosive discharge of gases, no external flaming, and no sparks, electrical arcs, or other abnormal electrical events that occurred during the fire testing. Temperature and heat flux measurements at exposures were recorded as limited, below thresholds that would threaten the integrity of adjacent battery modules and/or would be capable of igniting combustible materials. Flammable gases were observed to be vented into the enclosure from the cells whose temperature exceeded ~200°C.

5. FIRE PROTECTION SYSTEMS

5.1 CFC Required Fire Protection Systems

5.1.1 Fire Suppression System

Per CFC 1207.5.5, an automatic sprinkler system is required for rooms and areas within building and walk-in units containing electrochemical ESS. These outdoor enclosures are not walk-in enclosures, nor are they considered a battery storage room within a building. The ESS enclosures can be accessed, serviced, and maintained from the exterior of the enclosures and are not considered an occupiable space; therefore, CFC Section 1207.5.5 does not require a fire suppression system to be installed for the Fluence Cube enclosures.

5.1.2 Fire Detection / Fire Alarm System

Although not required by CFC 1207.5.4 as an outdoor, non-walk-in unit, the Fluence Cube enclosures will be pre-installed with an automatic detection system compliant with NFPA 72. The enclosure will also be equipped with a multi-criteria fire/ CO detector located in front of the battery racks. The UL 9540A unit level test was performed with these devices deactivated.

Each Fluence Cube enclosure is provided with an exterior wall mounted fire alarm combination horn/strobe notification appliance.

5.1.3 Vegetation control

Per CFC 1207.5.7, areas within 10 feet of each side of the ESS shall be cleared of combustible vegetation and other growths. Single specimens of trees, shrubbery, or cultivated plants are exempt, if they do not form a means for spreadable combustion.

5.1.4 Clearance to exposures

Per CFC 1207.9.3, outdoor ESS shall have a minimum separation distance of 10 feet from following exposures:

- Lot lines
- Public ways
- Buildings
- Stored combustible materials
- Hazardous material
- High-piled stock
- Other exposure hazards

5.2 Hazard Mitigation Analysis Required Systems

This HMA is required to demonstrate, per CFC 1207.1.4.2, that fires will be contained within the electrochemical ESS, toxic gases released will not reach concentrations in excess of 50% of the Immediately Dangerous to Life or Health (IDLH) levels, and flammable gases released from batteries during normal and abnormal (e.g. fire condition) operation will not exceed 25% of their LFL. The following systems described in this section are included in the electrochemical ESS design to meet these requirements.

5.2.1 Thermal Runaway Precluded by Battery Module Design

Per CFC Table 1207.6, lithium-ion battery technology must be protected by a listed device or other approved method to prevent, detect, and minimize the impact of thermal runaway in accordance with CFC 1207.6.5. The battery module design has integrated safety features that preclude thermal runaway to address the hazard of battery fires or electrochemical ESS explosions that are the result of uncontrolled thermal runaway of the lithium-ion batteries. As noted by Footnote E to CFC Table 1207.6, the thermal runaway protection is permitted to be part of a battery management system that has been evaluated with the battery as part of the evaluation to UL 1973.

Each rack of battery modules is equipped with a Battery Protection Unit (BPU). The BPU continuously monitors voltage, temperature, state of charge, insulation, and also continuously performs maintenance functions such as cell balancing as part of the safety operating features set by the system Battery Management System (BMS). When the BMS detects a fault condition or a monitored operational parameter exceeds an acceptable range via the BPU, the BMS isolates the impacted battery string by opening the integrated DC contractors and sends an alarm signal to the site Emergency Management System (EMS).

The UL9540A unit level test results demonstrate that the ESS design will control thermal runaway within a module, preventing the development of a large thermal event and satisfying the requirement of CFC 1207.6.5. The UL 9540A test results demonstrate the following:

- Neither thermal runaway nor fire propagation occurred between adjacent modules within the enclosure cabinets. The results demonstrate that a thermal runaway event will be contained within the module and will not propagate to adjacent modules within the ESS unit or beyond to adjacent units.
- There was no observation of deflagration, external flaming, explosive projectiles, debris, or discharge of gases during the fire tests.
- Sparks, electrical arcs, or other abnormal electrical events were not observed during the fire tests.
- External heat flux and wall surface temperatures were measured at minimal levels that are not capable of igniting combustibles or creating temperature/heat flux exposure hazards to personnel near the battery enclosures.

5.2.2 Explosion Control Systems

CFC Table 1207.6 requires explosion control for lithium-ion battery technology. Explosion protection via deflagration venting compliant with NFPA 68 is the selected design approach over gas concentration reduction. In the event of cascading thermal runaway within a battery enclosure and the build-up of flammable gases, there are 2 deflagration panels atop and tethered to the enclosure that will vent an explosion up and away from service personnel and emergency responders.

6. FAULT CONDITION CONSEQUENCE ANALYSIS

6.1 Thermal runaway condition in a single ESS rack, module, or unit.

If one or more lithium-ion cells within a module fail and create a thermal event, it is unlikely that a module-to-module thermal runaway event will occur based on the UL9540A test results. The module design, as previously described, limits the potential for module-to-module thermal runaway propagation as well as propagation to adjacent ESS units.

The UL 9540A unit level test demonstrates a single module entering a thermal runaway condition will not produce external heat flux and exposure temperatures that could threaten adjacent ESS units or exposures.

If one or more lithium-ion cells within a module fails and continues to increase in internal temperature, then a thermal runaway event could occur. Each battery enclosure is equipped with multiple Battery Protection Unit (BPU), which continuously monitors the temperature and other parameters of the cells. If a cell is operating outside of the acceptable operational parameters, the BPU will send a signal to the Battery Management System (BMS) to isolate the impacted battery string and will send an alarm signal to the site Emergency Management System (EMS). The BPU will be able to detect the rise in temperature prior to the cell reaching a temperature where thermal runaway occurs. Additionally, individual battery cells off-gassing is generally the first visual cue that a cell has failed. The smoke and/or toxic gas detection system within the cube will initiate based on the presence of smoke and activate the alarm system at the cube's respective Outdoor Core Telco Enclosure (OCTE) and at its respective Master Fire Control Panel located at the Fire Command Center.

Each Fluence Cube is equipped with a Fast Stop (F-Stop) button located on the exterior of the Cube. An additional F-Stop button is located on the exterior of each OCTE as well. When the F-Stop buttons are manually activated, the ESS in that enclosure will immediately commence shut down, all BPU within the ESS unit will isolate their battery strings from the main system which stops all charging and discharging, and an alarm signal will be sent to the site EMS.

6.2 Failure of any battery or energy management system

The Battery Protection Unit (BPU) protects the battery from over/under voltage, over/under temperature, and faults. The BPU is controlled by the voltage, current and temperature limits set by the Battery Management System (BMS). Failure of the Battery Management System (BMS) will result in an immediate shutdown of charging or discharging of the affected battery modules. This will help to mitigate electrical conditions that could induce off-gassing or thermal runaway. Electrically isolated batteries may still contain electrochemical energy.

The BPU has two redundant protection devices:

- Main Contactor: Opens to protect the battery from over/under voltage and over/under temperature.
- Fuses: Opens to protect the battery against a failure of the of the BMS or the BPU which results in an overcurrent condition or a short circuit.

6.3 Failure of the Site Energy Management System (EMS)

This BESS site operates with the user interface Fluence OS (6.0 or later release) and the distributed control system (DCS). Together, the OS and DCS monitor the site and can control operations depending on charging grid and BESS conditions. Operators can select the following operating modes through the Fluence OS user interface:

6.3.1 Manual Control

When the system is in Manual Operation, the operator will have the ability to: start and stop units, change unit modes, open and close DC contactors and/or AC breakers, Real and Reactive power commands, and fault reset.

6.3.2 Automatic Resource Control (ARC)

When the system is in Automatic Resource Control, the system responds to external dispatch signals.

6.3.3 Idle

Idle pauses operation of the control program without disconnecting from any devices attached to the program.

6.3.4 Disconnect

Disconnect pauses operation of the control program and disconnects from all devices attached to the program.

6.3.5 Reset

Reset stops and restarts the control program.

6.3.6 Redundancy

BESS enclosures will be connected with Class X wiring so that if one BESS enclosure is lost there will still be communications with the other BESS enclosures. A redundant telecommunication pathway will also be provided, consisting of fiber optic cable connections between fire alarm control panels as well as Modbus Gateway devices for wireless communication from OCTE fire alarm control panels to the Fire Command Center.

6.3.7 Backup Power

Each enclosure and each OCTE will be equipped with its own Uninterruptible Power Supply (UPS). The UPS systems shall provide enough power to allow for an orderly shutdown of the project equipment.

6.4 Voltage surges on the primary electric supply

Voltage surges can occur on the primary electric supply due to multiple factors, including high voltage switching, lightning, ground faults and transformer inrush. Surge arresters shall be employed at the substation end and remote end of battery storage feeder circuits to limit the magnitude and duration of surges by shunting current to ground when the surge arrester's threshold voltage is exceeded.

6.5 Short circuits on the load side of the ESS

Short circuits on the load side of the stationary battery storage system are interrupted by fuses on the positive pole of each battery string. If a short circuit develops on the battery side of a fuse, the current in parallel strings will quickly melt the fuse, isolating the fault from the parallel strings.

6.6 Failure of Multi-Criteria Fire/CO Detection

If the multi-criteria fire/CO detector fails, then it is possible elevated levels of flammable gas or toxic gas may be present.

First responders should maintain a significant distance from the enclosure and remotely monitor data and information from the battery management system (BMS) and the fire alarm panel to assess the conditions internal to the enclosure. The BMS and fire alarm panel are designed to report the following information before, during, and after a thermal runaway event unless compromised. Available information includes: alarm status of smoke detectors, carbon monoxide alarm, battery voltage from the BMS, internal temperature and location information if thermal runaway has occurred, as well as elevated temperature information for cells that may be at risk of entering thermal runaway. Fire alarm devices will be of the latching type in case its compromised. An enclosure whose fire alarms have been activated should be assumed to contain CO, fire, and/or electrical hazards until serviced or replaced. DO NOT open the doors until it has been determined that a pre-determined amount of time has passed to ensure no hazards are present, and with approval of emergency personnel and Subject Matter Expert.

The following describes the consequences of a gas detector equipment failure and the events that would occur prior to a thermal runaway event.

- A trouble signal will be generated.
- Visual and audible notification will still be active.
- Alarm signals during this condition will transmit to the site's fire alarm panel as well as an approved 24-hour monitoring station.

The first responders while onsite will also be able to monitor gas levels outside of the BESS enclosures with their own equipment to maintain a safe working distance.

6.7 Required spill neutralization not being provided or failure of a required secondary containment system.

Although other battery types are required by the CFC to provide spill control and neutralization of electrolyte or other hazardous materials, lithium-ion batteries are not required to have this design feature. Each battery pack includes an integrated special tray that is intended to capture electrolyte in the event of a battery cell or pack rupture. As this feature is not required by the CFC for lithium-ion batteries, failure of this feature is not considered to pose an immediate concern that will require shutdown of battery operations or special action, besides normal maintenance to remedy the issue.

End of Report

7. APPENDIX

- 7.1 UL 9540A Cell Test Report, 4th Edition
- 7.2 UL 9540A Module Test Report, 4th Edition
- 7.3 UL 9540A Installation Test Report, 4th Edition
- 7.4 Overall Site BESS Electrical Plan

APPENDIX 7.1

UL 9540A Cell Test Report, 4th Edition



CELL TEST REPORT
UL 9540A

**Test Method for Evaluating Thermal Runaway Fire Propagation
in Battery Energy Storage Systems (AACD)**

Project Number 4789764715
Date of issue 2021.04.27
Total number of pages 39

UL Report Office UL-CCIC Company Limited Guangzhou Branch

Applicant's name Contemporary Amperex Technology Co., Limited
Address..... No.2 Xiangang Road, Zhangwan Town, Jiaocheng Distict
Nindde, Fujian, 352100 CN

Test specification: 4th Edition, Section 7, November 12, 2019
Standard..... UL 9540A, Test Method for Evaluating Thermal Runaway Fire
Propagation in Battery Energy Storage Systems
Test procedure..... 7.1 – 7.8
Non-standard test method N/A

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General disclaimer:

The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments.

UL LLC did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).

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Cell level information	
Model No	CB310, CB2W0
Ratings (Vdc, Ah)	3.2 Vdc, 280 Ah
Chemistry of test item.....	Lithium iron phosphate
Original Equipment Manufacturer (OEM):	Contemporary AmpereX Technology Co., Limited
Branding Manufacturer (if not OEM):	N/A
Was the cell certified?	Yes
Standard test item certified to	UL 1973
Organization that certified test item	UL (MH62898)
Average Vent Temperature, °C:	168.2
Average Onset of Thermal Runaway Temperature, °C:	239.6
Gas Volume:	221.3 L
Lower flammability level (LFL), % volume in air at the ambient temperature	7.85
Lower flammability level (LFL), % volume in air at the venting temperature	6.47
Burning velocity (S_u) cm/s:	64
Maximum pressure (P_{max}) psig:	103

Cell Gas composition:

Gas		Measured %
Carbon Monoxide	CO	11.086
Carbon Dioxide	CO ₂	33.290
Hydrogen	H ₂	35.698
Methane	CH ₄	10.075
Acetylene	C ₂ H ₂	0.164
Ethylene	C ₂ H ₄	5.259
Ethane	C ₂ H ₆	1.089
Propadiene (Allene)	C ₃ H ₄	0.000
Propyne	C ₃ H ₄	0.000
Propene	C ₃ H ₆	0.571
Propane	C ₃ H ₈	0.232
-	C4 (Total)	0.382
-	C5 (Total)	0.091
-	C6 (Total)	0.060
-	C7 (Total)	0.005
-	C8 (Total)	0.000
Benzene	C ₆ H ₆	0.023
Toluene	C ₇ H ₈	0.002
Dimethyl Carbonate	C ₃ H ₆ O ₃	1.879
Ethyl Methyl Carbonate	C ₄ H ₈ O ₃	0.091
Diethyl Carbonate	C ₅ H ₁₀ O ₃	0.000
Total	-	100

Cell failure test method performed (summary of method and test clause):

- ☒ External heating using thin film with 4°C to 7°C thermal ramp.
☐ Nail Penetration
☐ Overcharge
☐ External short circuit (*X Ω external resistance*)
☐ Flow Battery with 2 active electrolyte methods
☐ Flow Battery with 1 active electrolyte methods
☐ Others

Description of method used to fail cells if other than external thin film heater with thermal ramp, :N/A

Summary of testing:**Performance Criteria in accordance with Clause 7.7 and Figure 1.1:**

- ☐ Thermal runaway was not induced in the cell; and
☐ The cell vent gas did not present a flammability hazard when mixed with any volume of air, as determined in accordance with ASTM E918 at both ambient and vent temperatures.

Necessity for a module level test

[X] The performance criteria of the cell level test as indicated in 7.7 of UL 9540A 4th edition has not been met, therefore a module level testing in accordance with UL 9540A will need to be conducted on a complete module employing this cell.

[] The performance criteria of the module level tests as indicated in 7.7 of UL 9540A 4th edition has been met, therefore a module level testing in accordance with UL 9540A need not be conducted.

Testing Laboratory information

Testing Laboratory and testing location(s):		
Testing Laboratory:	UL(Changzhou) Quality Technical Service Co., LTD	
Testing location/ address	21 Longmen Rd, National High-Tech Industrial Development District, Wujin, Changzhou, Jiangsu, China	
Tested by (name, signature).....	Jax Gao	
Witnessed by (for 3rd Party Lab Test Location) (name, signature)	N/A	N/A
Project Handler (name, signature).....	Benjamin Liu	
Reviewer (name, signature)	Rebecca Le	
Gas Analysis Testing Laboratory:	DEKRA Services, Inc.	
Testing location/ address	Forreston, Illinois	
Project Handler (name, signature).....	Abdollah Kashani	
Reviewer (name, signature)	Bernadette N. Reyes	
List of Attachments (including a total number of pages in each attachment):		
Attachment A: Cell Conditioning (Charge/discharge) Profiles - (<i>Pages 17 through 19</i>) Attachment B: Cell Instrumentation Photos - (<i>Pages 20 through 23</i>) Attachment C: Cell Temperature Profiles during testing - (<i>Pages 24 through 26</i>) Attachment D: Cell Testing Photos - (<i>Pages 27 through 36</i>) Attachment E: Cell vent gas test chamber photo and profile of chamber gas analysis (O ₂ and Pressure) – (<i>Page 37</i>) Attachment F: Cell Gas Analysis Report - (<i>Pages 38 through 39</i>)		

Photo of cell/Stack:



**Test Item Charge/Discharge Specifications:**

• Charge current, A:	140 A
• Maximum charge voltage, Vdc:	3.65 V
• Charge temperature range, °C:	5-60 °C
• End of charge current, A:	N/A
• Discharge current, A:	140 A
• End of discharge voltage, Vdc:	2.5 V
• Discharge temperature range, °C:	-20-60 °C

Test item particulars : See below for details	
Possible test case verdicts:	
- test case does not apply to the test object	N/A
- test object does meet the requirement	P (Pass)
- test object does not meet the requirement	F (Fail)
- test object was completed per the requirement....	C(Complete)
- test object was completed with modification.....	M(Modification)
Testing	Cell Model CB310
Date of receipt of test item	2020.12.24
Date (s) of performance of tests.....	2020.12.26 to 2021. 01.18
General remarks:	
"(See Enclosure #)" refers to additional information appended to the report. "(See appended table)" refers to a table appended to the report. Throughout this report a point is used as the decimal separator.	
Manufacturer's Declaration of samples submitted for test:	
The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided.....	☐ Yes ☒ Not applicable
Name and address of factory (ies).....	Contemporary Amperex Technology Co., Limited No.2 Xiangang Road, Zhangwan Town, Jiaocheng Distict Nindde, Fujian, 352100 CN
General product information and other remarks:	
The tested cell is a Lithium-ion battery cell, Model CB310. Each cell has a capacity of 280 Ah and nominal voltage 3.2 Vdc. The overall dimensions of cell are 207.2 mm (Height) by 173.9 mm (Width) by 71.65 mm (Depth). The height of cell includes the terminals. The weight of cell is 5450±300 g. Model CB2W0 is identical to model CB310 except for model name and declared charge/discharge current. Model CB310, normal charge and normal discharge current are 140A. Model CB2W0, normal charge and normal discharge current are 280A.	

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

5.0	CONSTRUCTION		Verdict
5.1. 5.4	Cell/Stack Construction		—
5.1.1, 5.4.1	Generic Chemistry:	Lithium iron phosphate / C	—
	Electrolyte Chemistry:	LiPF6 with additives	—
	Flow Battery Electrolyte No. 1 Chemistry:		N/A
	Max volume of system electrolyte No. 1, L:		N/A
	Flow Battery Electrolyte No. 2 Chemistry:		N/A
	Max volume of system electrolyte No. 2, L:		N/A
	Separator Melt Temperature, °C:	Not used during test	—
	Format: Cylindrical /Prismatic /Pouch Flow Battery Stack	Prismatic	—
	Overall Dimensions, mm	207.2 x 173.9 x 71.65 mm	—
	Cell Weight, g	5450 ± 300 g	—
5.1.2	Cell Certification:		—
	Standard Used for Cell Certification:	UL 1973	—
	Organization that Certified Cell:	UL	—
5.1.1, 5.4.1	Cell/Stack Ratings: • Nominal Voltage, Vdc • Nominal Capacity, Ah	3.2 Vdc	—
		280 Ah	—
5.4.1	Flow Battery: No. of Cells per Stack:		N/A
	Flow battery system manufacturer:		N/A
	Flow battery system model:		N/A
	Flow battery system ratings, Vdc, Ah:		N/A
5.4.2	Flow battery system certified to UL 1973:		N/A
	Organization that certified flow battery system:		N/A
7.0	PERFORMANCE – CELL LEVEL		Verdict
7.1	General		P
7.2	Samples		P

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
7.2.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles.	See Attachment A for profiles See Table 1 for specifications	P
7.2.2	100% SOC and stabilize from 1h to 8 h before testing		
7.2.3	Pouch Cells constrained per end use during testing.		N/A
7.3	Determination of thermal runaway methodology		P
7.3.1	General		P
7.3.1.1	Ambient indoor laboratory conditions: 25 ±5°C (77 ±9°F) ≤50 ±25% RH at the initiation of the test.	See Attachment C and Table 3	P
7.3.1.2	Heat the cell to thermal runaway by externally applied flexible film heaters	See Attachment B	P
	Heater Dimension	two pieces of 203.0 by 152.4 mm and two pieces of 203.0 by 50.8 mm for each sample	-
	A surface heating rate of 4° C (7.2° F) to 7° C (12.6° F) per minute was applied to the cell.	See Attachment C, D, and E See Table 4.	P
	Maximum surface end point temperature, °C	Not used, heated until thermal runaway achieved	-
	The following method(s) was employed to cause thermal runaway: ☐ Mechanical (e.g. nail penetration); ☐ Electrical stress in the form of overcharging, ☐ Electrical stress in the form of over discharging ☐ Electrical stress in the form of external short-circuiting ☐ Use of alternate heating sources (e.g. oven). ☐ Other (explain)	Only external heating using film heaters was used.	N/A
7.3.1.3	Detail of test method when using another cell abuse method to initiate thermal runaway		N/A
7.3.1.4	Monobloc batteries such as a lead acid battery		N/A
7.3.1.5	Estimated surface temperature at which internal short circuiting within the cell will occur that could lead to a thermal runaway condition.	Not used, heated until thermal runaway achieved	N/A
7.3.1.6	The cell was heated until thermal runaway has occurred.	Refer to Attachment C	P
	Another external heating method was used to cause cell thermal runaway		N/A
7.3.1.7	The cell's exterior surface temperature was measured	See Attachment B	P

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
7.3.1.8	The temperature at which the cell case vents due to internal pressure rise was documented.	See Table 3 and 4 See Attachment C and D	P
7.3.1.9	The temperature at the onset of thermal runaway was documented.	See Table 3 and 4 See Attachment C and D	p
	If cell venting occurs first, the cell was heated continuously until thermal runaway occurs.	See Attachment C	P
7.3.1.10	When using methods other than the heater method, the stresses were applied to the cell until thermal runaway occurs.		N/A
7.3.1.11	3 additional samples were tested using the same method and exhibited thermal runaway	See Table 3, 4 and 5 See Attachment C and D	P
7.3.2	Flow battery thermal runaway determination tests		N/A
7.3.2.1	The test methods of 7.3.2.2 through 7.3.2.6 were used for the flow battery technology.		N/A
7.3.2.2	The flammability of the electrolytes was determined		N/A
	For liquids with anticipated higher flashpoints and viscosities at or below 9.5×10^{-6} m ² /s (9.5 cSt) at 25°C (77°F): • ASTM D3828 or • ASTM D93 was used.		N/A
	The flash point temperature was recorded for each electrolyte tested.		N/A
7.3.2.3	For flow battery systems with two electrolytes, each electrolyte was subjected to the appropriate test method outlined in 7.3.2.2.		N/A
	The test of 7.3.2.4 was conducted if a flash point had been observed in 7.3.2.2		N/A
7.3.2.4	The energy reservoir in a test flow battery assembly was charged to 100% SOC, and then the two electrolyte materials were mixed in a closed container within approximately 1 min. The mixed solution temperature was measured during the test.		N/A
	A test battery representative of the flow battery system was subjected to an overcharge test and short circuit test in accordance with UL 1973, the temperature of the energy reservoirs during the testing were recorded.		N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
7.3.2.5	For flow battery technologies with one active electrolyte containing solid metal particles, the appropriate test method of 7.3.2.2 was conducted to determine the flash point temperature		N/A
	If a flash point had been observed in 7.3.2.2, the propensity for thermal runaway was demonstrated by the test methods of 7.3.2.6		N/A
7.3.2.6	If a flash point had been observed, a test battery representative of the flow battery system was subjected to an overcharge test and short circuit test in accordance with UL 1973, and the maximum temperature of the energy reservoir during testing was recorded.		N/A
7.4	Cell vent gas composition test		P
7.4.1	Cell vent gas was generated and captured by forcing a cell into thermal runaway with the methodology developed in 7.3, inside a pressure vessel	Size of pressure vessel used: 100L (26.4gal) Refer to Attachment E	P
	The test was initiated with an initial condition of atmospheric pressure and less than 1% oxygen by volume.	Refer to Attachment E Atmospheric pressure (psig): 0.26 psig above the atmospheric pressure Oxygen concentration measured (% volume): <0.1% Inert gas used: Nitrogen	P
7.4.2	Cell vent gas composition was determined using Gas Chromatography (GC)	Refer to Table 6 Refer to Attachment F	P
	Hydrogen gas was measured	Refer to Table 6	P
	The initial atmospheric conditions prior to testing were noted.	Refer to Table 3 and 6 Refer to attachment C and E	P
7.4.3	The lower flammability limit of the cell vent gas was determined on samples of the synthetically replicated gas mixture in accordance with ASTM E918, testing at both ambient and cell vent temperatures.	Refer to Table 6 and 7 Refer to attachment F	P
7.4.4	The gas burning velocity of the synthetically replicated cell vent gas was determined in accordance with the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817.	Refer to Table 6 and 7 Refer to attachment F	P

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
7.4.5	P_{max} of the synthetically replicated cell vent gas was determined in accordance with EN 15967.	Refer to Table 6 and 7 Refer to attachment F	P
7.5	Off gas composition for flow battery systems		N/A
7.5.1	The off gas composition from the flow battery testing of 7.3.2 was determined by conducting the test method of 7.3.2.2: • In a closed container and capturing the off gasses generated, and • By collecting the off gasses generated at vent openings and vent ducts during the overcharge and short circuit testing of 7.3.2.4 and 7.3.2.6.		N/A
	Gas composition and flammability limit were determined through the methods outlined in 7.4.2 and 7.4.3 at both ambient temperature and the maximum temperature measured.		N/A
7.5.2	The volume of flammable gases measured during the testing were scaled to the maximum energy reservoir for the intended flow battery system		N/A
7.6	Cell Level Test Report Information		P
7.6.1	Minimum information provided in the report for items a) through m)		P
7.6.2	Minimum information of items a) through k) was provided in the report for flow battery		N/A
7.7	Performance – cell level test		F
7.7.1	a) Thermal runaway cannot be induced in the cell; and	'F' in this clause indicates that module level testing is required	F
	b) The cell vent gas does not present a flammability hazard when mixed with any volume of air, at both ambient and vent temperatures.	'F' in this clause indicates that module level testing is required	F
7.8	Performance – flow battery thermal runaway determination tests		N/A
7.8.1	a) The electrolyte(s) subjected to the test method in accordance with 7.3.2.2 does not ignite; or		N/A
	b) The flash point temperature(s) measured in the test of 7.3.2.2 exceed the maximum temperature measured on the energy reservoir during the overcharge and short circuit tests of 7.3.2.4 or 7.3.2.6 by at least 5°C (9°F); and		N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	c) The flash point temperature(s) measured in the test of 7.3.2.2 exceed the maximum temperature of the mixed solution measured in accordance with 7.3.2.4 by at least 5°C (9°F) for systems with two active electrolytes.		N/A
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UL 9540A, Edition 4,

Clause	Requirement + Test	Result - Remark	Verdict
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Table 1 – Specified conditioning parameters

Charging:		Discharging	
Current (CC), A	140	Current (CC), A	140
Max Charge Voltage (CV), Vdc	3.65	Voltage at start of discharge, Vdc	3.65
End of charge current, A	14A	End of discharge voltage, Vdc	2.5
Charging Test Ambient, °C	25 ± 5	Discharging Test Ambient, °C	25 ± 5
Refer to Attachment A for charge/discharge profiles for each cell.			

Table 2 – Charge completion and cell test initiation times

Cell Test Number	Cell Number	Charge Completion Date and Time	Cell test Date and Time
1	3548329-003	2020/12/26 06:20 AM	2020/12/26 04:39 PM
2	3548329-005	2021/01/05 09:04 AM	2021/01/05 03:53 PM
3	3548329-006	2021/01/05 07:51 AM	2021/01/06 05:01 PM
4	3581515-001	2021/01/15 07:23 AM	2021/01/15 02:05 PM
5	3581515-002	2021/01/15 07:23 AM	2021/01/18 01:42 PM

Table 3 - Test Initiation Details

	Cell Test 1	Cell Test 2	Cell Test 3	Cell Test 4	Cell Test 5
Test Date	2020/12/26	2021/01/05	2021/01/06	2021/01/15	2021/01/18
Test Start Time	04:39 PM	03:53 PM	05:01 PM	02:05 PM	01:42 PM
Initial Lab Temperature	26.6 °C	27.0 °C	24.4 °C	25.8 °C	22.8 °C
Initial Relative Humidity	35%	33%	31%	33%	29%

Table 4 - Thermal Runaway Results

	Cell Test 1	Cell Test 2	Cell Test 3	Cell Test 4	Cell Test 5
OCV at start of test, Vdc	3.38	3.42	3.44	3.40	3.37
Average Heating Rate, °C/min	4.3	4.3	4.3	4.3	4.3
Venting Time after the test start, secs	1910	1927	2026	1871	2091
Venting Temperature, °C	156.0	183.9	174.8	158.3	171.8
Thermal Runaway Time after the test start, secs	3272	3423	3434	3353	2262
Thermal Runaway Temperature, °C	234.1	262.3	237.5	224.3	192.8

Refer to Attachment C for surface temperature profiles during testing

Table 5 – Average Vent and Thermal Runaway Temperatures#

Average of Cell Vent Temperatures, °C	168.2
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UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Average of Cell Thermal Runaway Temperatures, °C	239.6
#Averages of cell tests other than the cell gas analysis test	

Table 6 – Results of Gas Analysis			
Gas		Measured %	Component LFL
Carbon Monoxide	CO	11.086	10.9
Carbon Dioxide	CO ₂	33.290	N/A
Hydrogen	H ₂	35.698	4.0
Methane	CH ₄	10.075	4.4
Acetylene	C ₂ H ₂	0.164	2.3
Ethylene	C ₂ H ₄	5.259	2.4
Ethane	C ₂ H ₆	1.089	2.4
Propadiene (Allene)	C ₃ H ₄	0.000	1.9
Propyne	C ₃ H ₄	0.000	1.8
Propene	C ₃ H ₆	0.571	1.8
Propane	C ₃ H ₈	0.232	1.7
-	C4 (Total)	0.382	N/A
-	C5 (Total)	0.091	N/A
-	C6 (Total)	0.060	N/A
-	C7 (Total)	0.005	N/A
Benzene	C ₆ H ₆	0.023	1.2
Toluene	C ₇ H ₈	0.002	1.0
Dimethyl Carbonate	C ₃ H ₆ O ₃	1.879	N/A
Ethyl Methyl Carbonate	C ₄ H ₈ O ₃	0.091	N/A
Diethyl Carbonate	C ₅ H ₁₀ O ₃	0.000	N/A
Total	-	100	-

Table 7 – Properties of Vent Gas Analysis	
Lower Flammability Analysis at Ambient Temperature, 25°C (% vol in air)	7.85
Lower Flammability Analysis at Vent Temperature, [168°C] (% vol in air)	6.47
Burning Velocity Measurement, S _u cm/sec	64
Maximum Pressure P _{max} , psig	103

TABLE: Critical components information					
Object / part No.	Manufacturer/ trademark	Type / model	Technical data	Standard	Mark(s) of conformity ¹⁾
Cell Model	Contemporary Ampere Technology Co., Limited	CB310, CB2W0	3.2Vdc, 280Ah, LFP	UL 1973	MH62898
Separator	Vendor code, 7647	N/A	PE	UL 1973	MH62937

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Electrolyte	Vendor code, 9869	N/A	LiPF6+EC/EMC/DEC/DMC	—	—
Case	Vendor code, 1970	N/A	AL3003	—	—
Insulators/ location in cell	Vendor code, 7929	N/A	Bottom-plate, material: PC	—	—
	Vendor code, 10766		Top-paper, material: PC		
	Vendor code, 7929		Blue-film, material: PET		

Attachment A: Cell Conditioning (Charge/discharge) Profiles - (Pages 17 through 19)

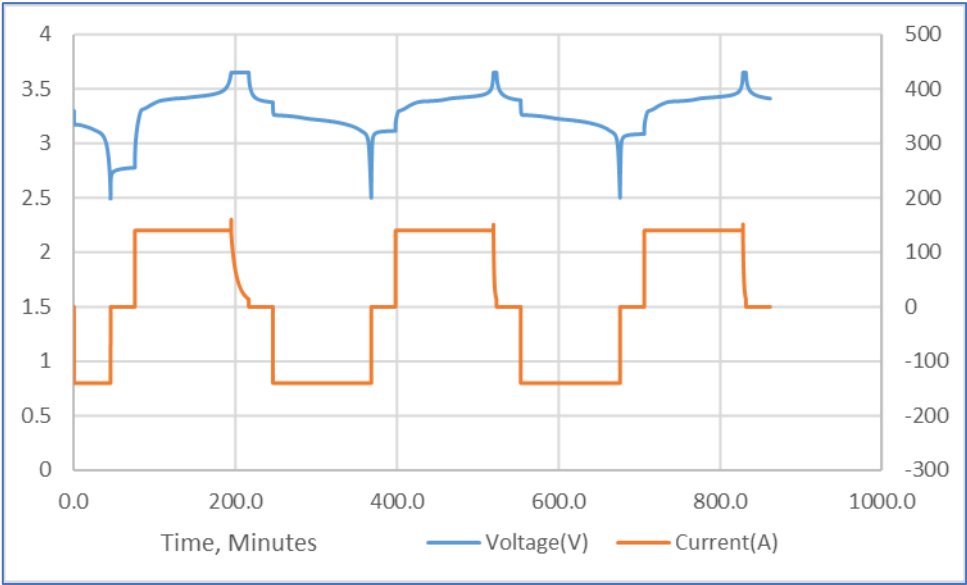


Figure 1: Cell 1 Conditioning (Charge/discharge) Profiles

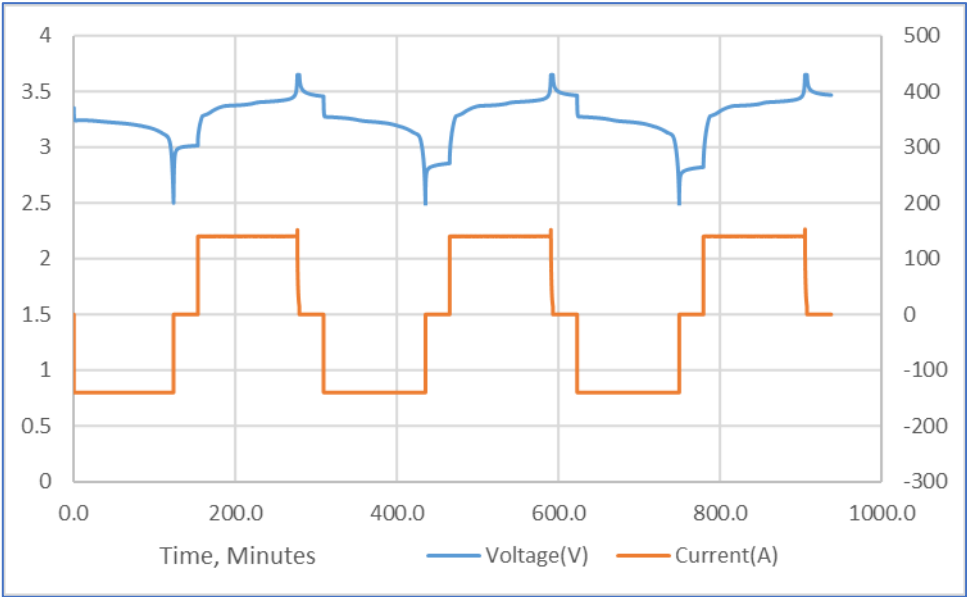


Figure 2: Cell 2 Conditioning (Charge/discharge) Profiles

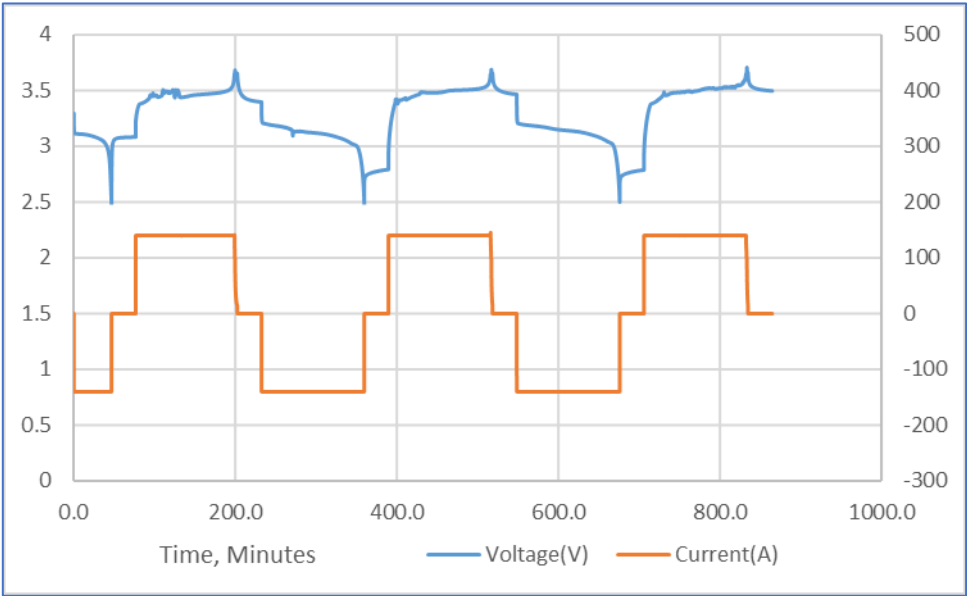


Figure 3: Cell 3 Conditioning (Charge/discharge) Profiles

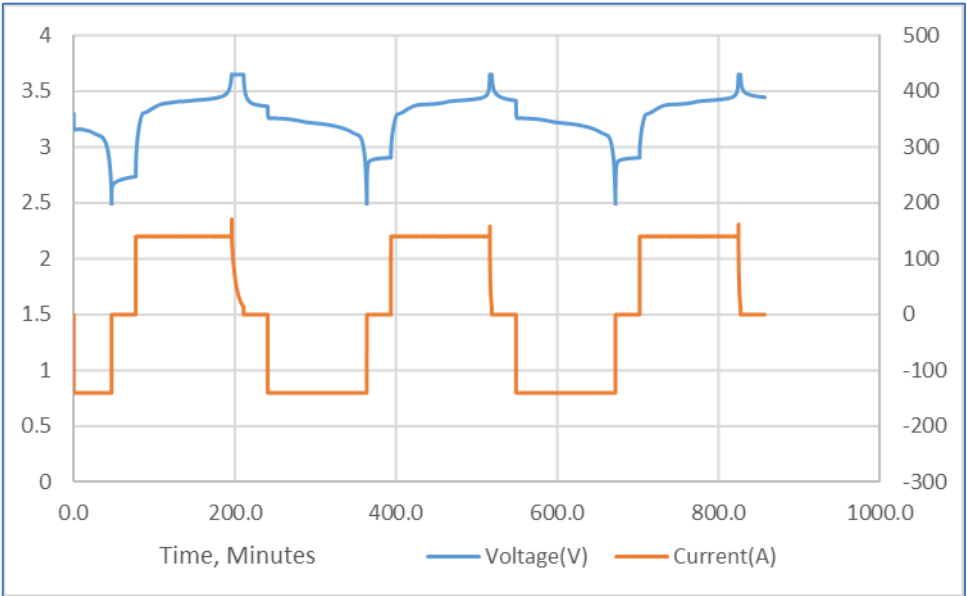


Figure 4: Cell 4 Conditioning (Charge/discharge) Profiles

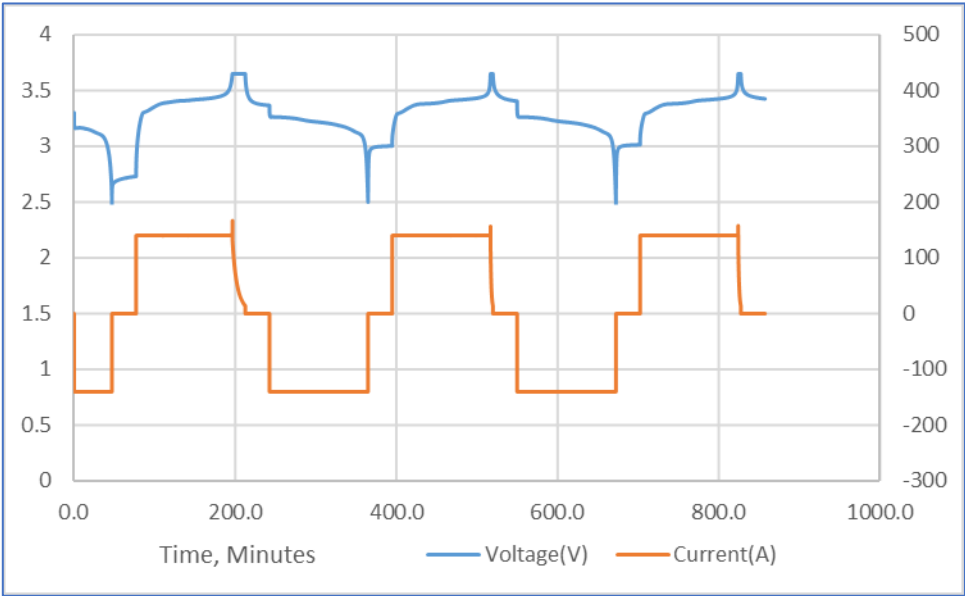


Figure 5: Cell 5 Conditioning (Charge/discharge) Profiles

Attachment B: Cell Instrumentation Photos - (Pages 20 through 23)

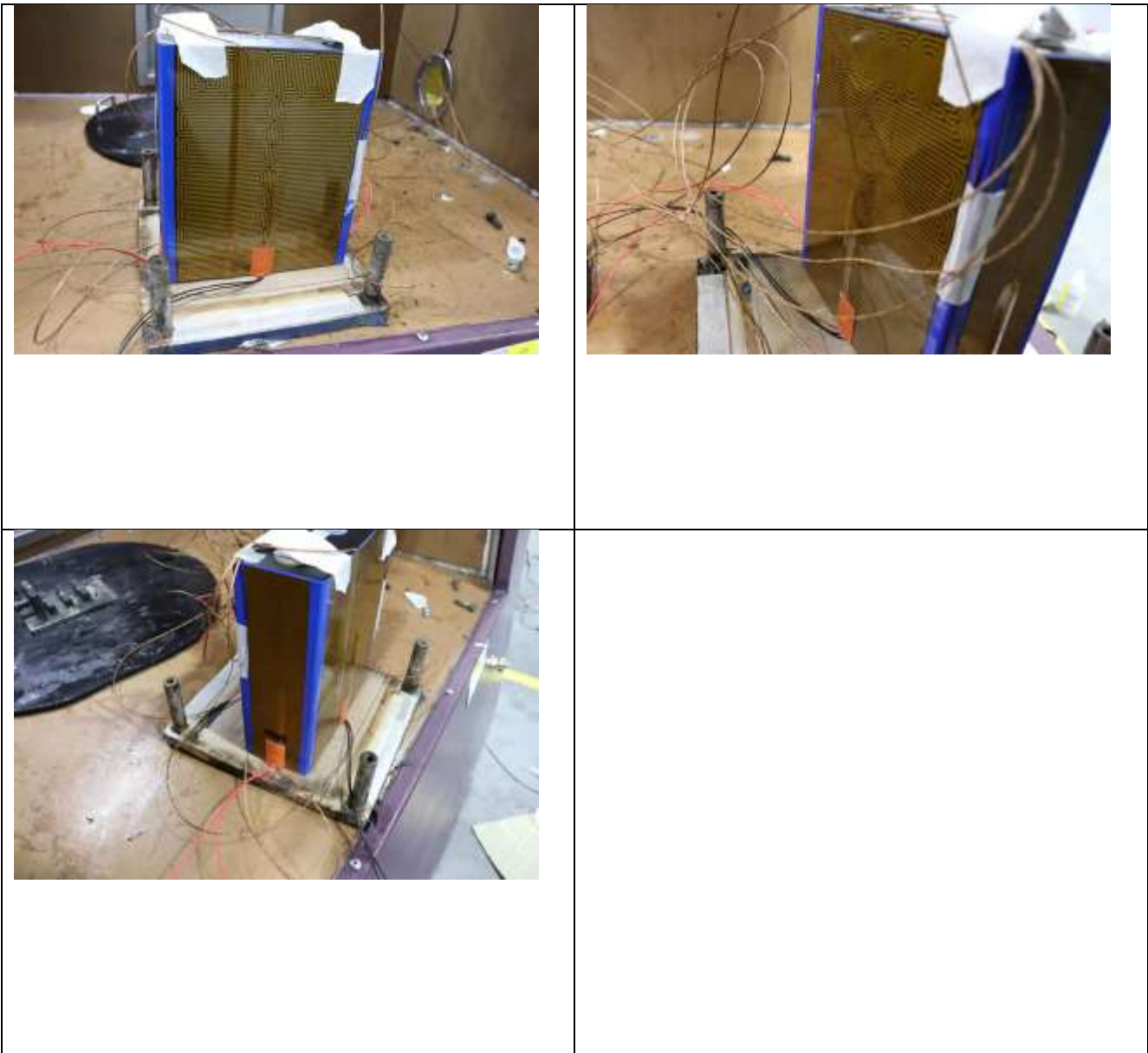
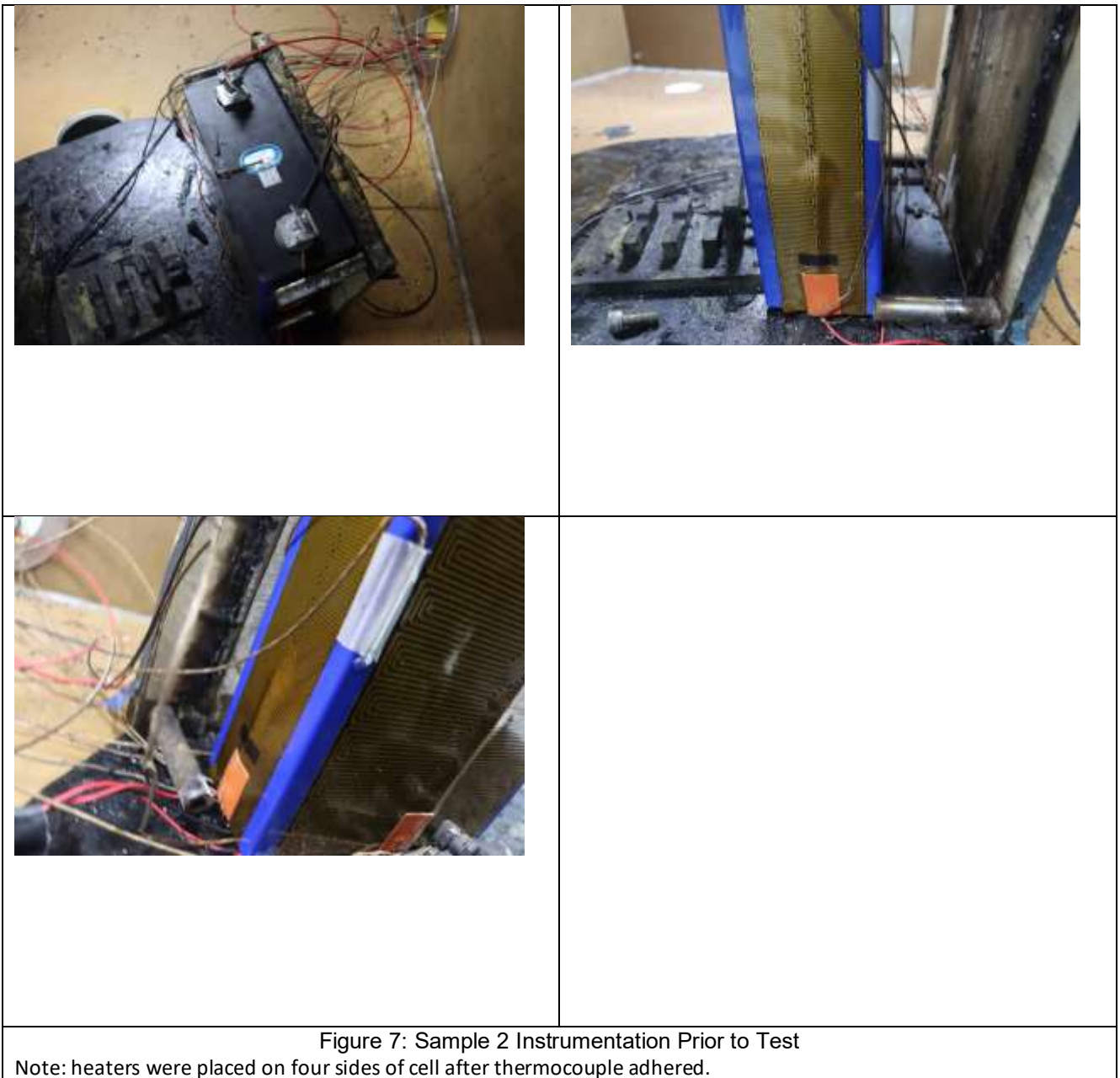
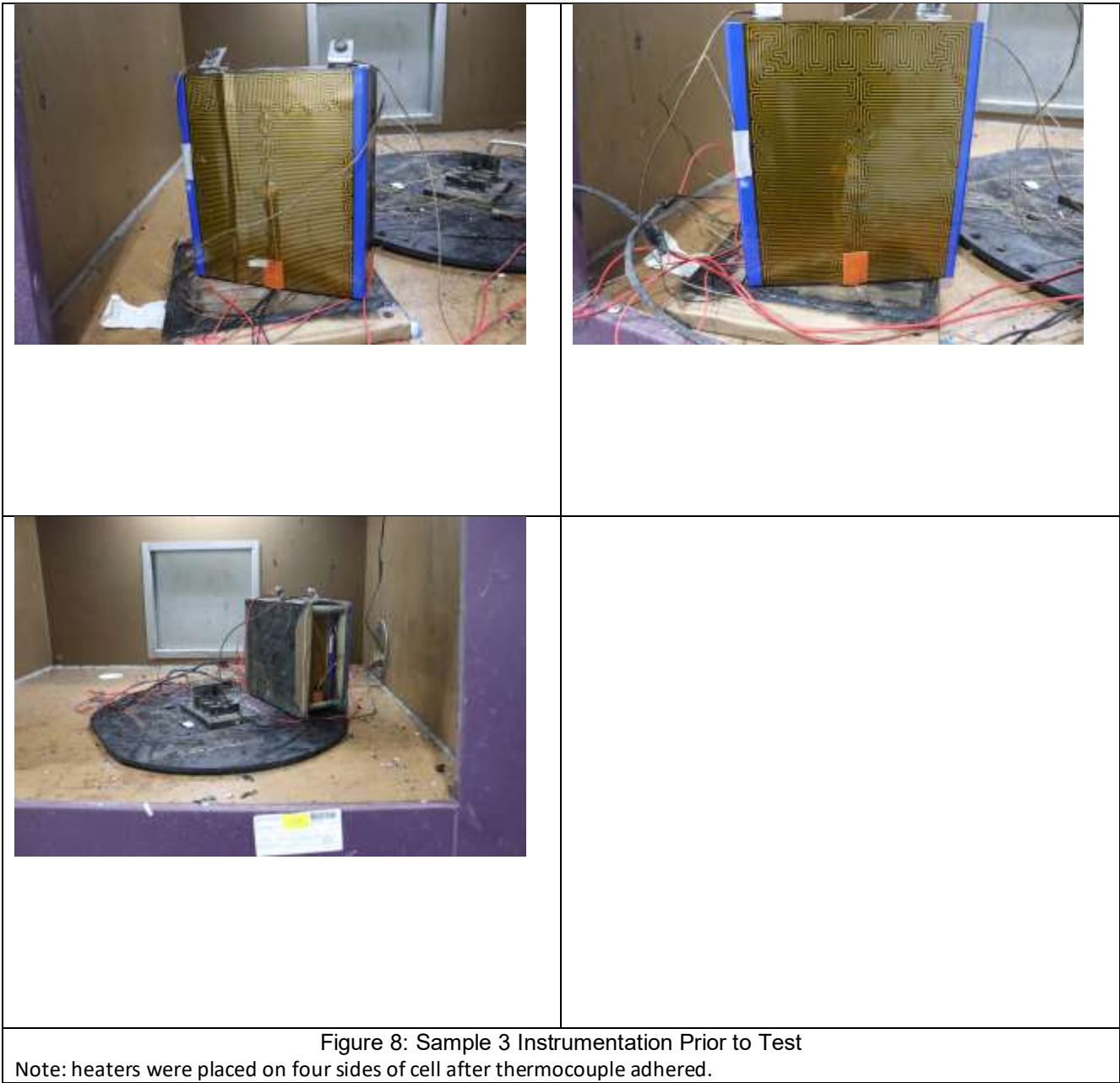
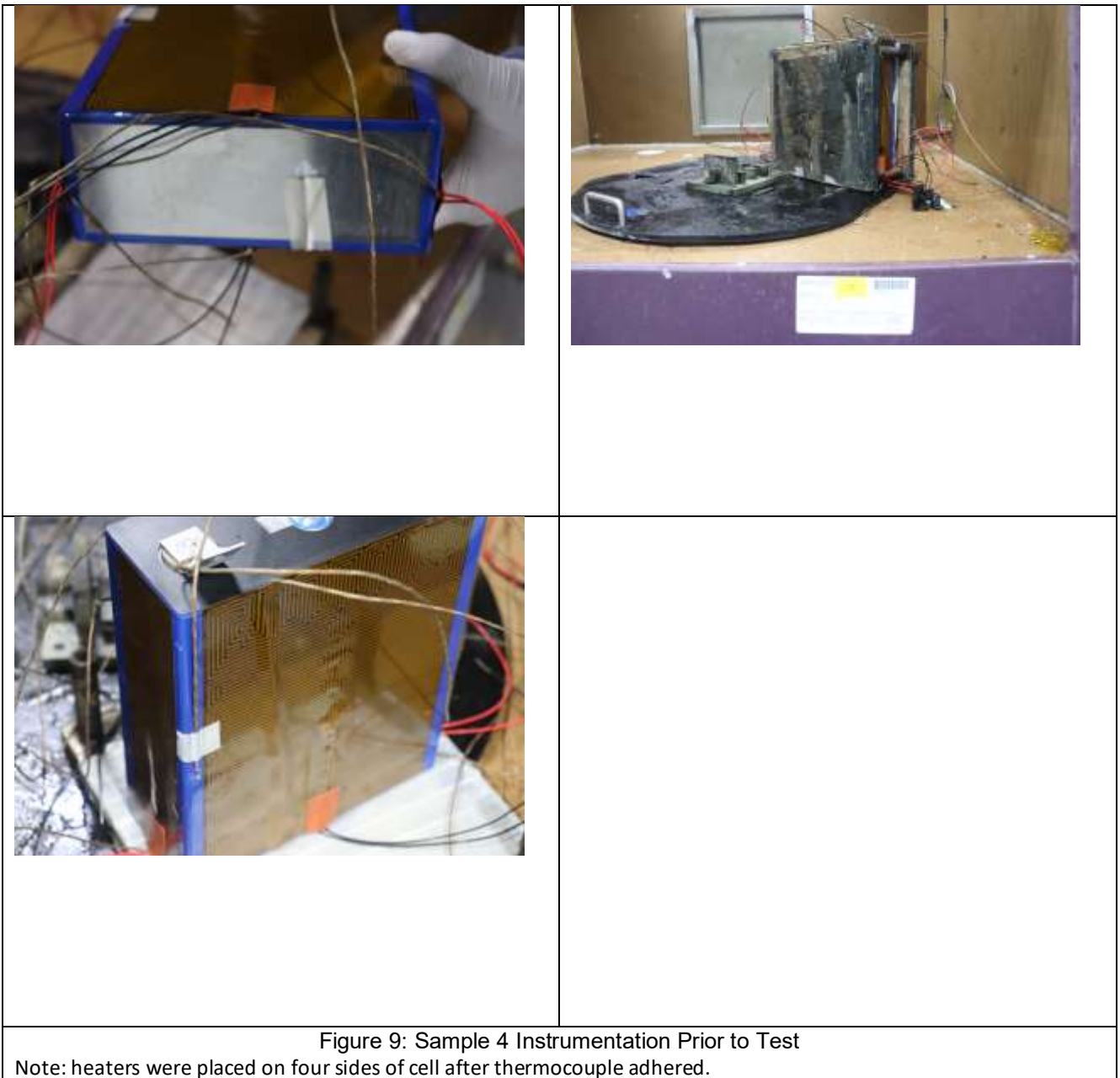


Figure 6: Sample 1 Instrumentation Prior to Test
Note: heaters were placed on four sides of cell after thermocouple adhered.







Attachment C: Cell Temperature Profiles during testing - (Pages 24 through 26)

Note: TC01 under heater; TC02 on the cell positive; TC03 at the cell bottom; TC04 on the cell body not cover by heater; TC05 Ambient temperature; V1 cell voltage

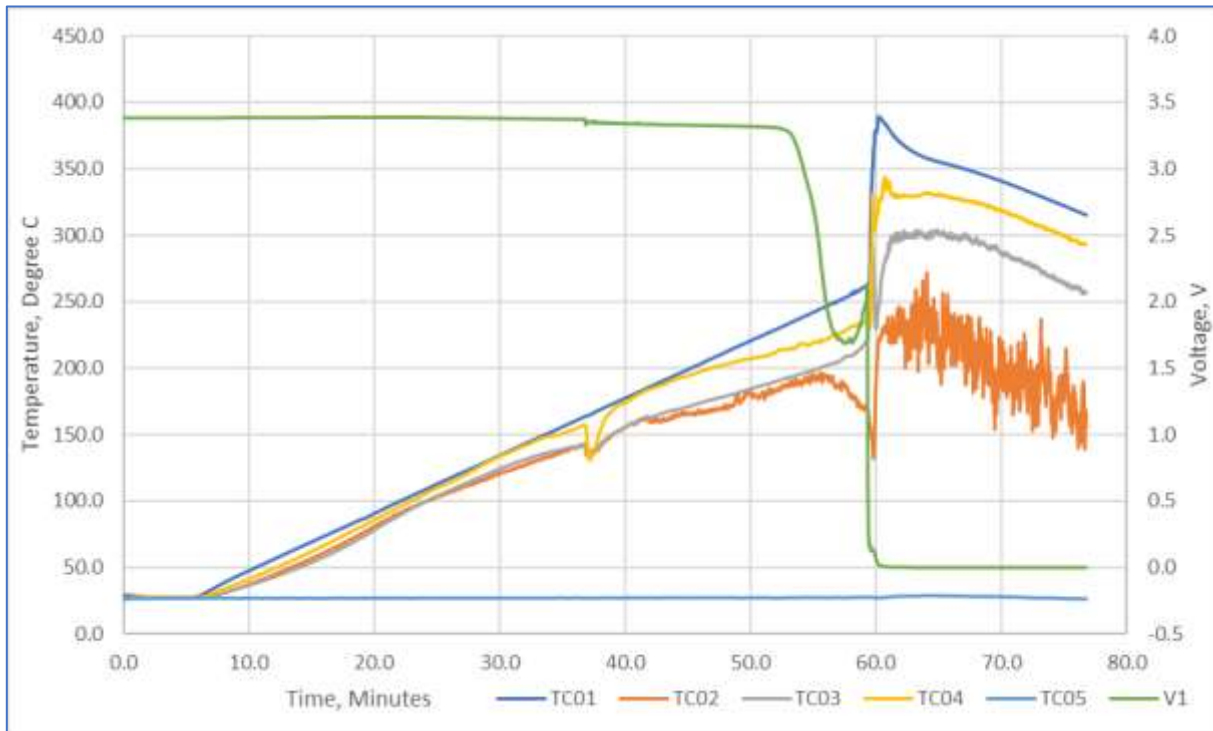


Figure 10: Cell 1 – External Heating 4.3°C per minute

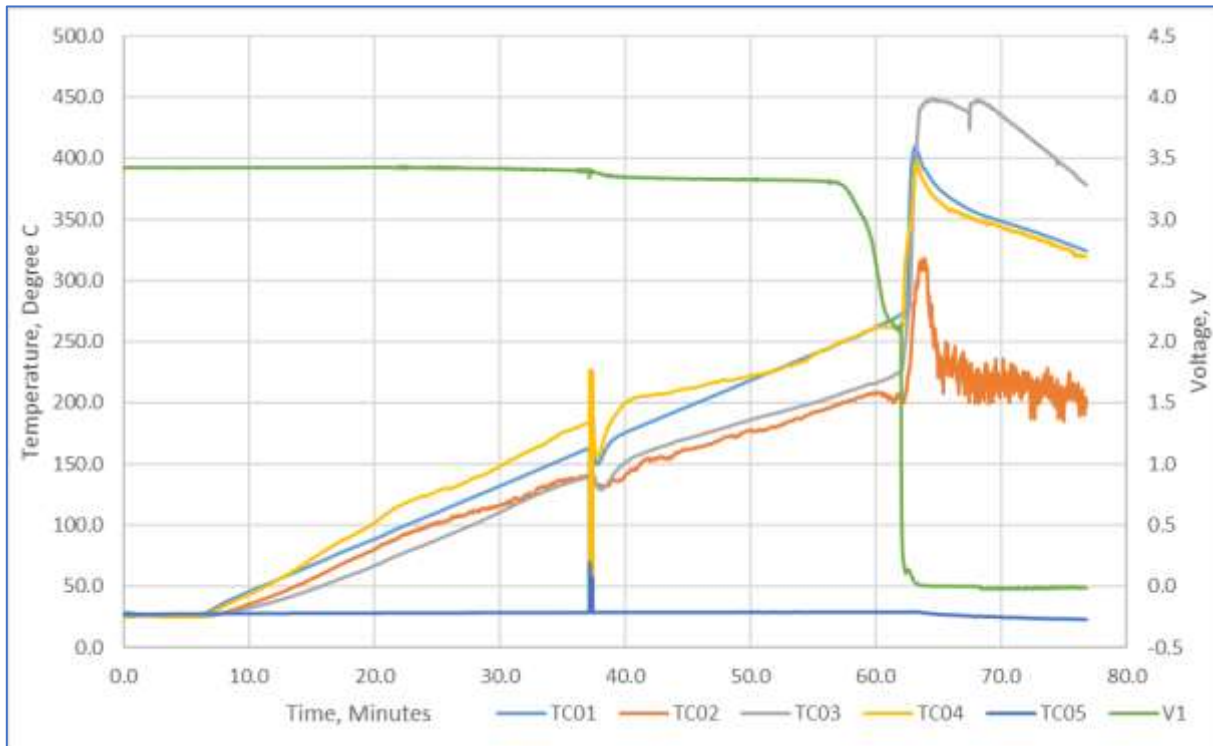


Figure 11: Cell 2 – External Heating 4.3°C per minute

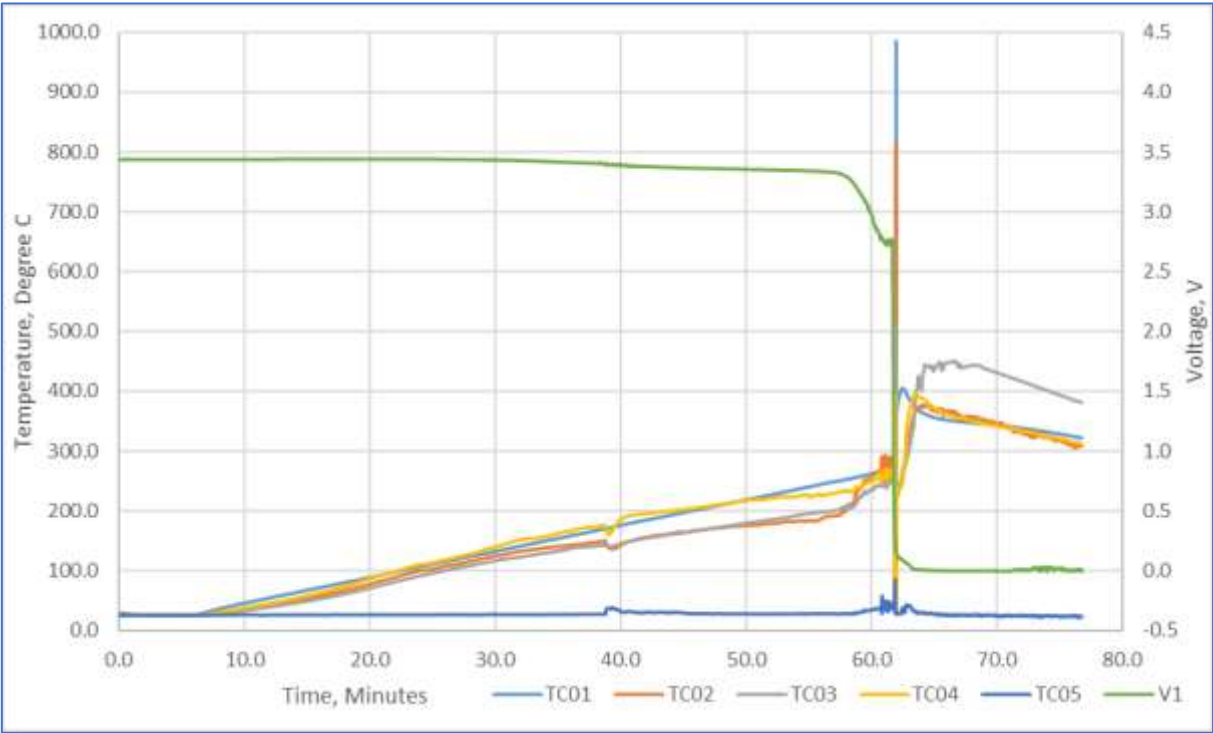


Figure 12: Cell 3 – External Heating 4.3°C per minute

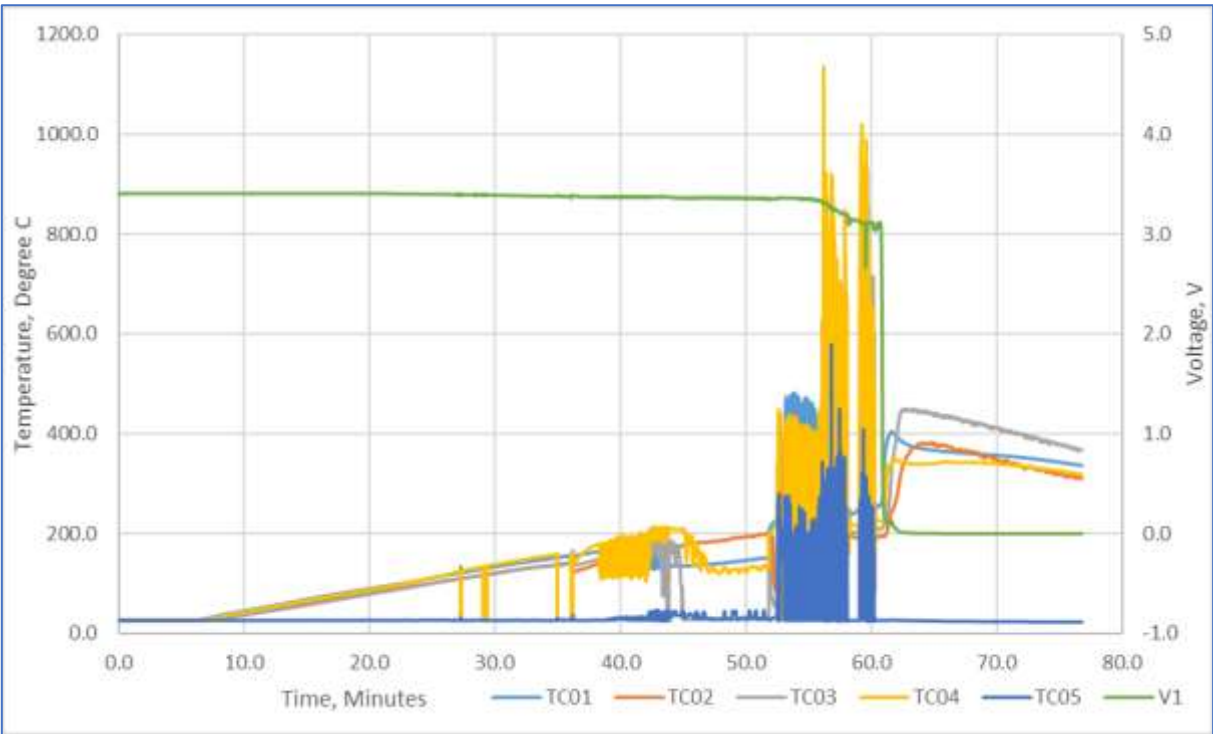


Figure 13: Cell 4 – External Heating 4.3°C per minute

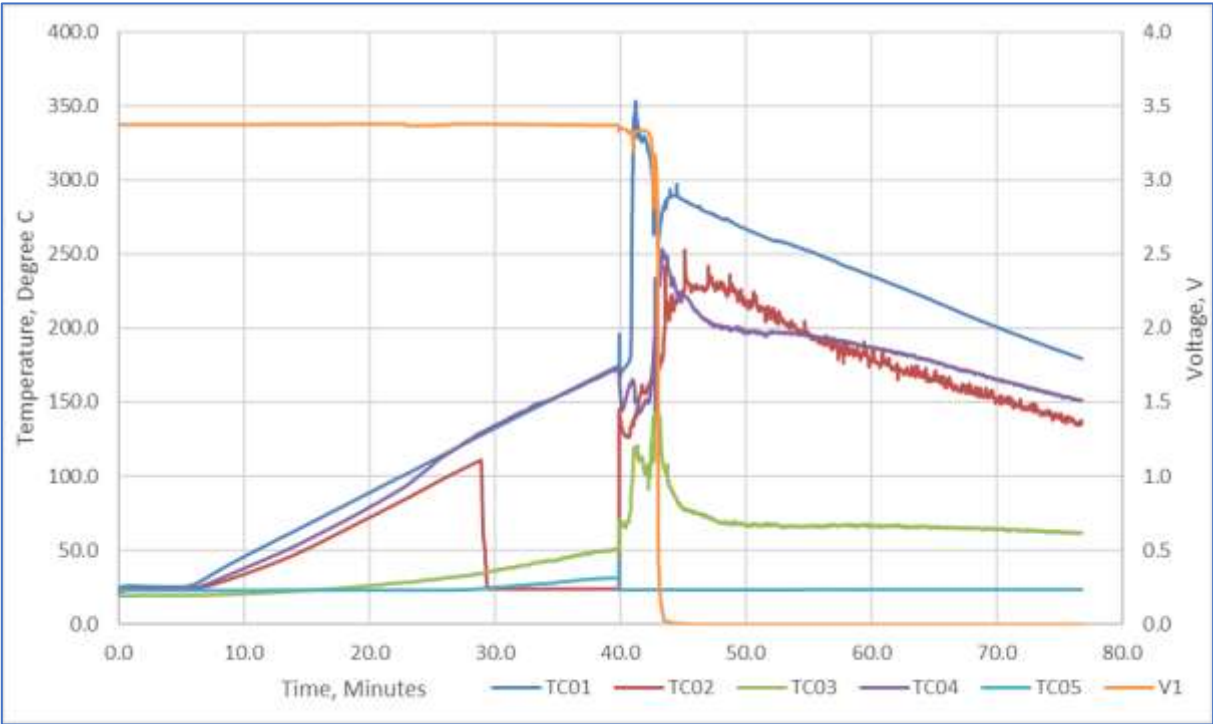


Figure 14: Cell 5 – External Heating 4.3°C per minute

Attachment D: Cell Testing Photos - (Pages 27 through 36)

Cell Sample 1 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.

	
(a) Test Start [00:00]	(b) Cell Venting [36:52]
	
(c) Thermal runaway behavior [59:34]	
Figure 15: Highlights of Cell 1 Testing	

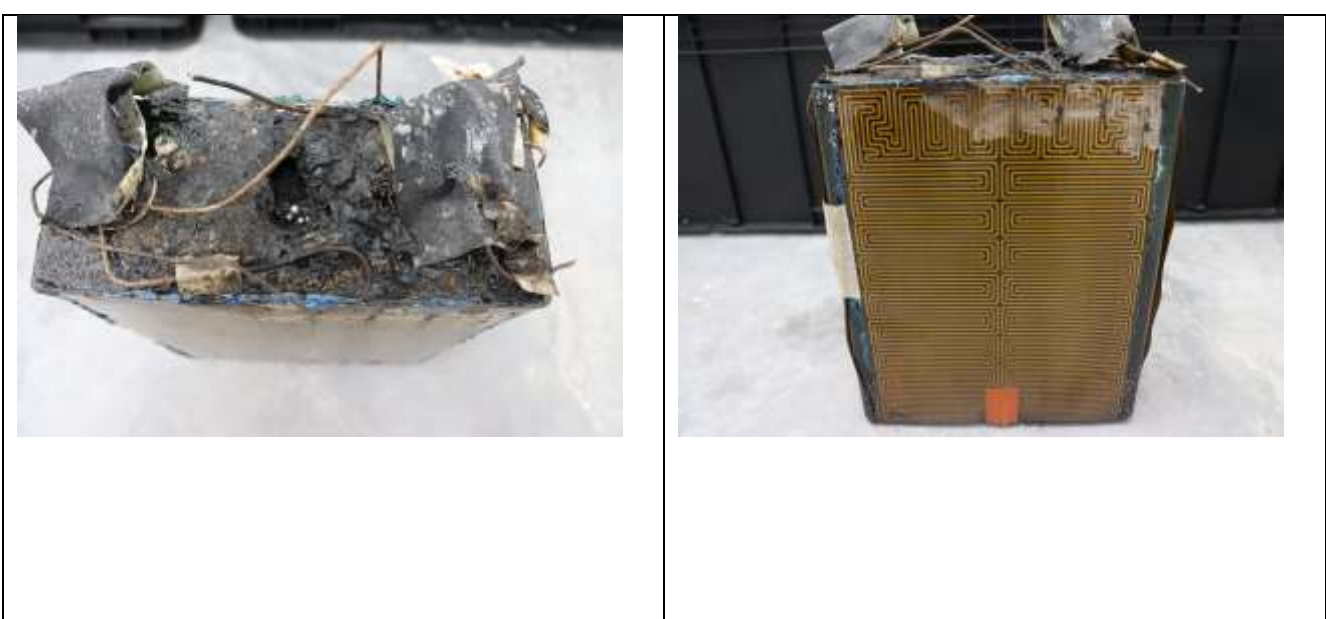


Figure 16: Sample 1 Post Test Photos

Cell Sample 2 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.

	
(a) Test Start [00:00]	(b) Cell Venting [37:10]
	
(c) Thermal runaway behavior [62:12]	
Figure 17: Highlights of Cell 2 Testing	

	
Figure 18: Sample 2 Post Test Photos	

Cell Sample 3 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.

	
(a) Test Start [00:00]	(b) Cell Venting [38:48]
	
(c) Thermal runaway behavior [62:16]	
Figure 19: Highlights of Cell 3 Testing	



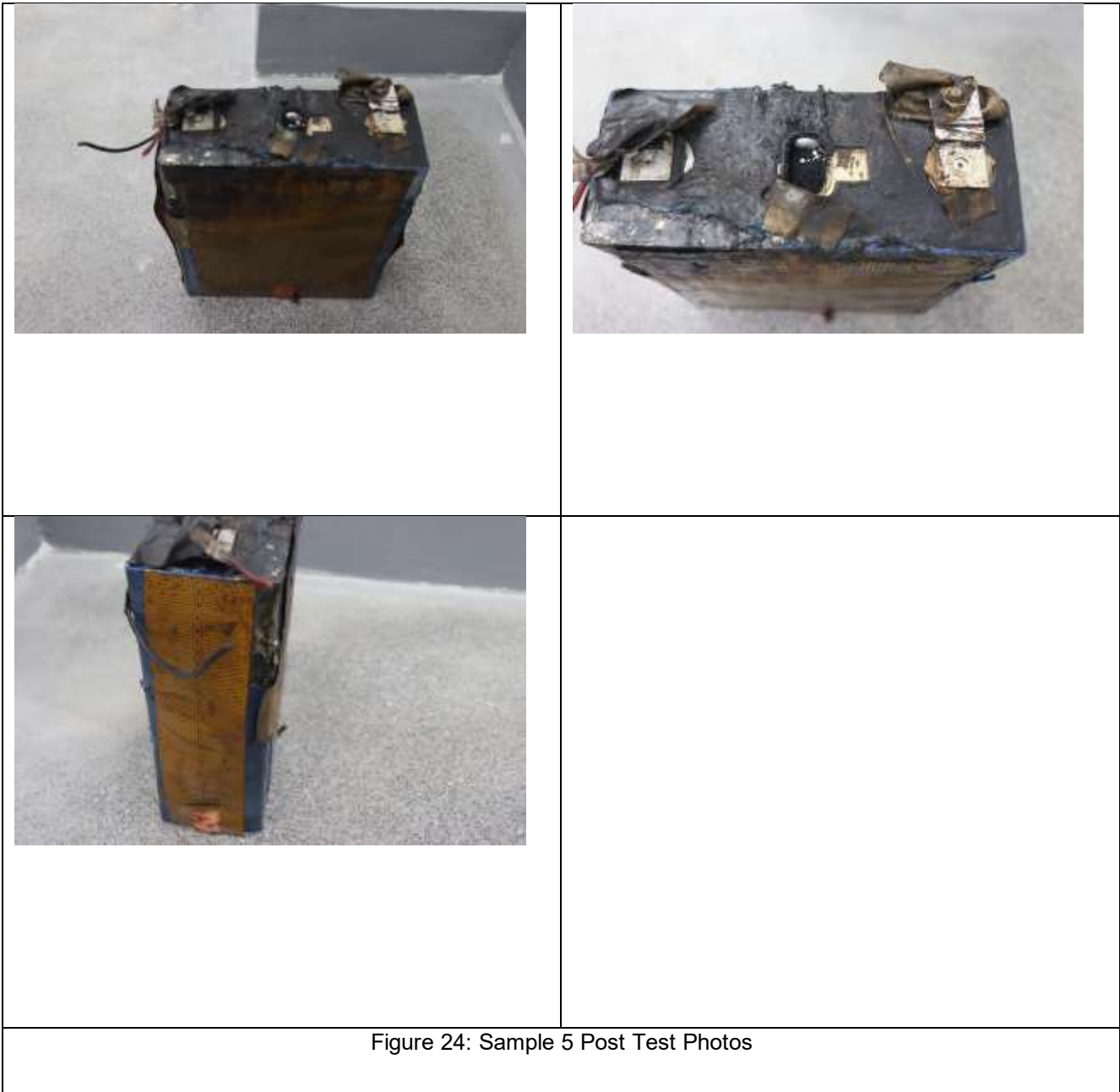
Cell Sample 4 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.

	
(a) Test Start [00:00]	(b) Cell Venting [36:13]
	
(c) Thermal runaway behavior [60:56]	
Figure 21: Highlights of Cell 4 Testing	



Cell Sample 5 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.

	
(a) Test Start [00:00]	(b) Cell Venting [39:53]
Too much gas in the chamber, without video	
(c) Thermal runaway behavior [42:45]	
Figure 23: Highlights of Cell 5 Testing	



Attachment E: Cell vent gas test chamber photo and profile of chamber gas analysis (O₂ and Pressure) - (Pages 37)



Figure 25: Sample 5 instrumented and inside gas test chamber

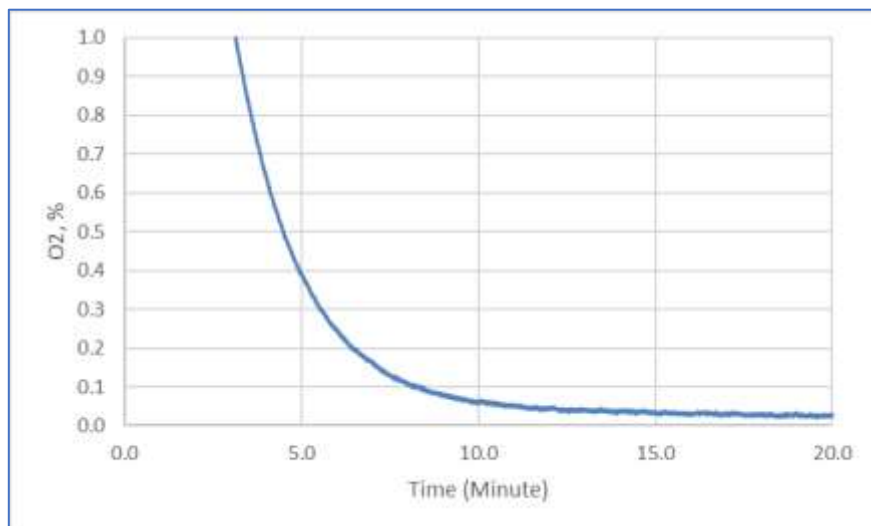


Figure 26: Profile of gas test chamber (O₂ Concentration)

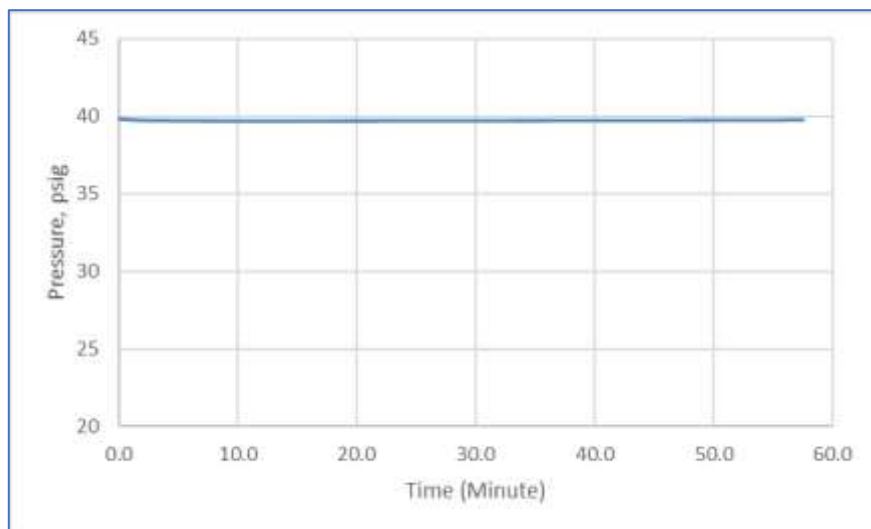


Figure 27: Profile of gas test chamber (Pressure)

Attachment F: Cell Gas Analysis Report - (Pages 38 through 39)

Table Re-normalized Gas Quantification, excluding N ₂ and O ₂ , and unknown compounds.			
Item	Measure	Chemical formula	Conc.(%)
1	Carbon Monoxide	CO	11.086
2	Carbon Dioxide	CO ₂	33.290
3	Hydrogen	H ₂	35.698
4	Methane	CH ₄	10.075
5	Acetylene	C ₂ H ₂	0.164
6	Ethylene	C ₂ H ₄	5.259
7	Ethane	C ₂ H ₆	1.089
8	Propadiene (Allene)	C ₃ H ₄	0.000
9	Propyne	C ₃ H ₄	0.000
10	Propene	C ₃ H ₆	0.571
11	Propane	C ₃ H ₈	0.232
12	C4 (Total)	-	0.382
13	C5 (Total)	-	0.091
14	C6 (Total)	-	0.060
15	C7 (Total)	-	0.005
16	C8 (Total)	-	0.000
17	Benzene	C ₆ H ₆	0.023
18	Toluene	C ₇ H ₈	0.002
19	Dimethyl Carbonate	C ₃ H ₆ O ₃	1.879
20	Ethyl Methyl Carbonate	C ₄ H ₈ O ₃	0.091
21	Diethyl Carbonate	C ₅ H ₁₀ O ₃	0.000
Total		Measurement result	100.000

Figure 28: Gas composition analysis result

The lower flammability limit testing was performed using ASTM E918, *Standard Practice for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure*. The results from these tests are summarized in Table 1-3.

Table 1-3: Executive Summary of Lower Flammability Limit Test Results

Sample Name	LFL at Ambient Temp (vol.%)	LFL at 168°C (vol.%)
Custom Gas Mix Ref #4789764715	7.85	6.47

Proprietary Property of Fauske & Associates, LLC

Figure 29: Flammability characteristics test result – Lower flammability level (LFL)

Material Tested: Gas-Mixture Part # SG HYULMX26-150A, Cylinder/Serial # CC152640
Certification of Analysis (COA): COA of Gas mixture formulation is shown in section 4 below
Reference Material Tested: R-32 (difluoromethane)

Parameter Tested/Analyzed	Results
Explosion Severity Output	
Maximum Pressure (psig)	103
Maximum Pressure Rise Rate (psi/sec)	7649
Maximum Reaction Temperature in chamber (°C)	196
Deflagration Index; K_G (bar·m/sec)	91
Flame Speed and Burning Velocity	
Gas Mixture Linear Flame Speed (cm/sec)	133
Gas Mixture Burning Velocity (cm/sec)	64
R-32 Linear Flame Speed (cm/sec)	25.0
R-32 Burning Velocity (cm/sec)	6.67

Figure 30: Flammability characteristics test result – Maximum pressure (P_{max}) and Burning velocity (S_u)

APPENDIX 7.2

UL 9540A Module Test Report, 4th Edition

	MODULE TEST REPORT UL 9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)
Project Number. : 4790241748 Date of issue : 2022.02.28 Total number of pages : 28	
UL Report Office	UL(Changzhou) Quality Technical Service Co., LTD
Applicant's name : Contemporary Amperex Technology Co Limited Address : No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, FuJian 352100 China	
Test specification: 4 th Edition, Section 8, November 12, 2019 Standard : UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems Test procedure : 8.1 – 8.4 Non-standard test method : N/A	
Copyright © 2020 UL LLC All Rights Reserved.	
General disclaimer: The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments. UL LLC did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s). The issuance of this report in no way implies Listing, Classification or Recognition by UL and does not authorize the use of UL Listing, Classification or Recognition Marks or any other reference to UL on the product or system. UL LLC authorizes the above named company to reproduce this Report provided it is reproduced in its entirety. UL's name or marks cannot be used in any packaging, advertising, promotion or marketing relating to the data in this Report, without UL's prior written permission. UL LLC, its employees, and its agents shall not be responsible to anyone for the use or non-use of the information contained in this Report, and shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use of, or inability to use, the information contained in this Report.	

Cell level information	
Cells in Module: •Manufacturer Name •Part Number •Chemistry •Format	
	Contemporary Amperex Technology Co Limited
	CB310, CB2W0
	Lithium iron phosphate
	Prismatic
Ratings (Vdc, Ah) :	3.2V, 280Ah
Was the cell certified? :	Yes
Standard the cell was certified to:	UL1973
Organization that certified the cell:	UL (MH62898)
Average cell surface temperature at gas venting, °C:	168.2
Average cell surface temperature at thermal runaway, °C:	239.6
Gas Volume:	221.3L
Lower flammability limit (LFL), % volume in air at the ambient temperature:	7.85
Lower flammability limit (LFL), % volume in air at the venting temperature:	6.47
Burning velocity (S_u) cm/s:	64
Maximum pressure (P_{max}) psig:	103

Cell Gas Composition:		
	Gas	Measured %
Carbon Monoxide	CO	11.086
Carbon Dioxide	CO ₂	33.290
Hydrogen	H ₂	35.698
Methane	CH ₄	10.075
Acetylene	C ₂ H ₂	0.164
Ethylene	C ₂ H ₄	5.259
Ethane	C ₂ H ₆	1.089
Propadiene (Allene)	C ₃ H ₄	0.000
Propyne	C ₃ H ₄	0.000
Propene	C ₃ H ₆	0.571
Propane	C ₃ H ₈	0.232
-	C4 (Total)	0.382
-	C5 (Total)	0.091
-	C6 (Total)	0.060
-	C7 (Total)	0.005
-	C8 (Total)	0.000
Benzene	C ₆ H ₆	0.023
Toluene	C ₇ H ₈	0.002
Dimethyl Carbonate	C ₃ H ₆ O ₃	1.879
Ethyl Methyl Carbonate	C ₄ H ₈ O ₃	0.091
Diethyl Carbonate	C ₅ H ₁₀ O ₃	0.000
Total	-	100

Module level Information	
Model No:	M52280-E, M52280-P
Ratings (Vdc, Ah) :	166.4V 280Ah
Module cell configuration (xS/yP):	52S/1P
Module dimensions (W x D x H (mm)) :	810±5mm*1155±5mm*243.4±5mm
Module weight (kg) :	320±10kg
Module enclosure material:	Top enclosure is made of plastic bottom enclosure is made of aluminium alloy
Was the module certified? :	No
Standard the module was certified to:	N/A
Organization that certified test item:	N/A
Cell failure test method performed for the module level (summary of method and test clause):	
☒ External heating using thin film with 4°C to 7°C thermal ramp.	
☐ Nail Penetration ☐ Overcharge	
☐ External short circuit (<i>X Ω external resistance</i>)	
☐ Others	

Description of method used to fail cells if other than external thin film heater with thermal ramp, : N/A																													
Description of components employed within the module that serve to suppress propagation (fire protection features). There is no mica sheet in this test.																													
Number of initiating cells failed to achieve propagation.				1																									
Thermal Runaway Propagation:				Initiating cell went into thermal runaway and propagated to one adjacent cell																									
Maximum Smoke Release Rate (m²/s)				4.9																									
Total Smoke Released: (m²)				376.7																									
Total smoke released duration				00:42:00 to 2:00:00																									
Peak Chemical Heat Release Rate: (kW):				No flaming occurred																									
External Flaming:				No external flaming occurred.																									
Location(s) of Flame Venting:				No flaming occurred																									
Flying Debris:				No flying debris occurred.																									
Re-ignitions:				No further re-ignitions were observed during post test observation.																									
Summary of Module level test Gas Analysis Data:																													
Gas Analysis: ☒ Flame ionization detection ☐ Fourier-Transform infrared Spectrometer ☒ Hydrogen Sensor (palladium-nickel, thin-film solid state sensor) ☒ White light source with photo detector (smoke release rate)																													
Gas Composition & Volume for Each Compound (Pre-flaming and After flame): <table border="1"> <thead> <tr> <th>Gas Compound</th> <th>Gas Type</th> <th>Pre-Flaming (L)</th> <th>Flaming (L)</th> <th>Minimum detectable limit(LPM)</th> </tr> </thead> <tbody> <tr> <td>Total Hydrocarbons (Propane Equivalent)</td> <td>Hydrocarbons</td> <td>150</td> <td>No flaming</td> <td>0.52</td> </tr> <tr> <td>Carbon Monoxide</td> <td>Carbon Containing</td> <td>53</td> <td>No flaming</td> <td>0.68</td> </tr> <tr> <td>Carbon Dioxide</td> <td>Carbon Containing</td> <td>143</td> <td>No flaming</td> <td>2.98</td> </tr> <tr> <td>Hydrogen</td> <td>Hydrogen</td> <td>189</td> <td>No flaming</td> <td>8.79</td> </tr> </tbody> </table>					Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable limit(LPM)	Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	150	No flaming	0.52	Carbon Monoxide	Carbon Containing	53	No flaming	0.68	Carbon Dioxide	Carbon Containing	143	No flaming	2.98	Hydrogen	Hydrogen	189	No flaming	8.79
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Carbon Dioxide	Carbon Containing	143	No flaming	2.98																									
Hydrogen	Hydrogen	189	No flaming	8.79																									
Summary of Module testing:																													
Performance Criteria in accordance with Clause 8.4 and Figure 1.1: [] The effects of thermal runaway was contained by the module design;																													

☐ Cell vent gas (based upon the cell level test) was non-flammable		
Necessity of a unit level test		
☒ The performance criteria of the module level test as indicated in 8.4 and as shown in Figure 1.1 of UL 9540A 4th edition has not been met, therefore unit level testing in accordance with UL 9540A will need to be conducted on a complete unit employing this module. ☐ The performance criteria of the module level test as indicated in 8.4 and as shown in Figure 1.1 of UL 9540A 4th edition has been met, therefore unit level testing in accordance with UL 9540A need not be conducted.		
Testing Laboratory information		
Testing Laboratory and testing location(s):		
Testing Laboratory:	Beijing Building Materials Testing Academy	
Testing location/ address	#17 Raxin Road, Doudian Town, Fangshan district, Beijing 102402, CN	
Tested by (name, signature)	Zhang Qi	
Witnessed by (for 3rd Party Lab Test Location) (name, signature)	Albert He	Albert He
Project Handler (name, signature).....	Benjamin Liu	BENJAMIN LIU
Reviewer (name, signature)	Sean Yang	
List of Attachments (including a total number of pages in each attachment):		
Attachment A: Module Conditioning (Charge/discharge) Profiles - (Page 17) Attachment B: Module Construction Photos - (Page 18) Attachment C: Module Instrumentation Photos - (Pages 19 through 20) Attachment D: Module and Initiating Cell(s) Temperature Profiles During Testing - (Pages 21 through 22) Attachment E: Module Testing Photos - (Pages 23 through 25) Attachment F: Module Gas Flow Rate and Heat Release Profiles – (Pages 26 through 28)		

Photo(s) of module:



Test Item Charge/Discharge Specifications:

- Charge current A:
- Charge power W:
- Standard Full charge Voltage, Vdc:
- Charge temperature range, °C:
- End of charge current, A¹:
- Discharge current A:
- Discharge power W:
- End of discharge voltage, Vdc:
- Discharge temperature range, °C:

M52280-E

140

23296

187.2

0~55

N/A

140

23296

145.6

0~55

M52280-P

280

46592

187.2

0~55

N/A

280

46592

145.6

0~55

¹ No constant voltage charge is not applicable for these cells of interest

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Test item particulars	
Possible test case verdicts:	
- test case does not apply to the test object..... :	N/A
- test object does meet the requirement	P (Pass)
- test object does not meet the requirement..... :	F (Fail)
- test object was completed per the requirement....:	C(Complete)
- test object was completed with modification.....:	M(Modification)
Testing..... :	
Date of receipt of test item	2022.01.05
Date (s) of performance of tests	2022.01.08
General remarks:	
"(See Enclosure #)" refers to additional information appended to the report. "(See appended table)" refers to a table appended to the report. Throughout this report a point is used as the decimal separator.	
Manufacturer's Declaration of samples submitted for test:	
The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided:	☒ Yes ☐ Not applicable

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Name and address of factory (ies)..... :	Factory_1: Contemporary Amperex Technology Co Limited Factory_1 address: No.2 Xingang Road Zhangwan Town, Jiaocheng District, Ningde, 352100 Ningde, Fujian, PEOPLE'S REPUBLIC OF CHINA Factory_2: Ningde Jiaocheng Contemporary Amperex Technology Co., Limited Factory_2 address: No.2 Xingang Road, Zhangwan Town, Jiaocheng District, 352100 Ningde, Fujian, PEOPLE'S REPUBLIC OF CHINA Factory_3: Sichuan Contemporary Amperex Technology Limited Factory_3 address: Room 502,Enterprise Service Center, No. 17, Fusan Road, West Section of North Yangtze Road, Lingang Economic Development Zone, Yibin City, Sichuan Province, PEOPLE'S REPUBLIC OF CHINA Factory_4: Guangdong Ruiqing Contemporary Amperex Technology Limited Factory_4 address: Room 1507, 15th Floor, Jianmin Building, No. 18, Beijiang Avenue, Zhaoqing Hi-tech Zone, Zhaoqing City, Guangdong Province, PEOPLE'S REPUBLIC OF CHINA
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General product information and other remarks:

Battery Module Model M52280-E employs cell Models CB310 manufactured by Contemporary Amperex Technology Co Limited.

Battery Module Model M52280-P employs cell Model CB2W0 manufactured by Contemporary Amperex Technology Co Limited.

The cell Model CB2W0 is identical to model CB310 in construction except for the declared charge and discharge current rating.

The normal charge and normal discharge current rating for Model CB310 are 140A.

The normal charge and normal discharge current rating for Model CB2W0 are 280A.

The Battery Module Model M52280-P is identical to model M52280-E in construction except for the declared charge and discharge current rating.

The module sample tested in this project was M52280-E with cell Model CB310.

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

5.0	CONSTRUCTION		Verdict
5.2	Module Construction		—
5.2.1, 5.2.3	Construction information	See Test Item Description at the beginning of this report	—
	General layout of module contents	See Attachment B	—
5.2.2	Module certified to UL 1973	No	
	Organization that certified module:	N/A	—
6.0	PERFORMANCE		Verdict
6.1	General		
8.1	Samples		
8.1.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles.	See Attachment A for profiles See Table 1 for specifications See also Table 2. The module voltage was checked before the test, and the voltage did not drop further compared to 1h to 8h after cycles, which was judged acceptable.	M
8.1.2	100% SOC and stabilize from 1h to 8 h before testing		
8.1.3	Electronic controls such as BMS not relied upon during testing.		C
8.2	Test Method		—
8.2.1	Ambient indoor laboratory conditions: 25 ±5°C (77 ±9°F) ≤50 ±25% RH at the initiation of the test.	See Table 3 The Ambient temperature 18.6°C at the initiation of the test. The engineering judgment found it acceptable.	M
8.2.2	Test conducted under a smoke collection hood appropriately sized for the module		C
8.2.3	The weight of the module was recorded before and after testing, (kg)	See Table 11	C
8,2,4	A sufficient number of cells were forced into thermal runaway to create a condition of cell to cell propagation within the module.	See Attachment C See Tables 4 and 5 One cell was forced into thermal runaway selected by client.	C
	The location of the cell(s) forced into thermal runaway were selected to present the greatest thermal exposure to adjacent cells	See Attachment C for figures showing location within the module of the cell(s) forced into thermal runaway	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
8.2.5	The method used to initiating thermal runaway in the cell(s) were in accordance with 7.2	See Summary of Cell Testing at the beginning of this report.	C
8.2.6	The occurrence of thermal runaway was verified	See Test Results from Cell Level Test from the beginning of this report See Attachments D	C
8.2.7	The module was placed on top of a non-combustible horizontal surface with the module orientation representative of its intended final installation.	See Attachment E	C
8.2.8	The chemical heat release rate of the module was measured with oxygen consumption calorimetry	See Table 10 See Attachment F	C
8.2.9	The chemical heat relate rate was measured for the duration of the test	See Attachment F	C
8.2.10	The chemical heat release rate was measured using the following equipment: • Paramagnetic oxygen analyser • Non-dispersive infrared carbon dioxide and carbon monoxide analyser • Velocity probe • Type K thermocouple	See Attachment F	C
	The instrumentation was located in the exhaust duct of the heat release rate calorimeter at a location that minimizes the influences of bends or exhaust devices.		C
8.2.11	The chemical heat release rate at each of the flows was calculated in accordance with 8.2.11.	See Attachment F	C
8.2.12	The hydrocarbon content of the vent gas was measured using flame ionization detection.	See Table 9	C
	Hydrogen gas shall be measured with a palladium-nickel thin-film solid state sensor.	See Table 9	C
8.2.13	The hydrocarbon content of the vent gas may also be measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm ⁻¹ and a path length of at least 2 m (6.6 ft), or equivalent gas analyzer.	FTIR analysis was not used in accordance with the Certification Requirement Decision: Corrections to gas measurement methods to make FTIR as an option for measuring hydrocarbon contents of gas emissions and to include Hydrogen measurements during the Unit Level Test. FTIR was considered redundant to the other gas measurement methods used.	N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	Vent gas velocity and temperature measurements respectively were obtained in the exhaust duct of the heat release rate calorimeter using equipment specified in 8.2.10.		C
8.2.14	The light transmission in the exhaust duct of the heat release rate calorimeter was measured using a white light source and photo detector for the duration of the test.		C
8.2.15	Smoke release rate was calculated as outlined in 8.2.15	See Table 10 See Attachment F	C
8.3	Module level test report		
	a. Module manufacturer and model number; b. Number of cells in module; c. Module configuration;	See Test Item Description in beginning of this report.	C
	d. Module construction features;	See Attachment C See Critical Components Table	C
	e. Module voltage corresponding to the tested SOC;	See Table 3	C
	f. Thermal runaway initiation method used;	See Attachment C	C
	g. Heat release rate versus time data;	See Table 10 See Attachment F	C
	h. Flammable gas generation and composition data;	See Attachment F See Tables 8 and 9	C
	i. Peak smoke release rate and total smoke release data.	See Table 10	C
	j. Observation(s) of flying debris or explosive discharge of gases;	See Table 12	C
	k. Observation(s) of sparks, electrical arcs, or other electrical events;	See Table 12	C
	l. Identification/location of cells(s) that exhibited thermal runaway within the module;	See Tables 4 and 5	C
	m. Locations and visual estimations of flame extension and duration from the module;	See Attachments E See Table 7	C
	n. Module weight loss;	See Table 11	C
	o. Video of the test.	The test was video recorded.	C
8.4	Performance – Module level		
8.4.1	The following performance conditions are met during the module level test: a) Thermal runaway is contained by module design;	Thermal runaway was contained by module design.	P

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	b) Cell vent gas is nonflammable as determined by the cell level test	Cell gas report show the cell gases are flammable. See Cell Gas Composition Table.	F
--	---	--	---

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 1 – Specified conditioning parameters

Charging:		Discharging:	
Current (CC), A	140	Current (CC), A	140
Standard full Charge Voltage, Vdc	187.2	End of discharge voltage, Vdc	145.6
End of charge current, A	N/A	Discharging Test Ambient, °C	0~55
Charging Test Ambient, °C	0~55		
Refer to Attachment A for charge/discharge profiles for the module.			

Table 2 – Charge completion and module test initiation times

Module No.	Charge Completion Date and Time	Module Test Date and Time
M52280-E	2022.01.07 05:20 PM	2022.01.08 3:07 PM

Table 3 - Test Initiation Details

Module No.	M52280-E
Test Date	2022.01.08
Test Start Time	3:07 PM
Initial Lab Temperature	18.6°C
Initial Relative Humidity	26%
Module OCV at Start of Test, Vdc	173.3

Table 4 – Approximate time of thermal runaway propagation through module

Time to thermal runaway	Location
01:14:26	Initiating Cell (Cell 20)
01:21:16	Cell 21
~*	Cell 19

*Note: after check the disassembly sample, there are three cells thermal runaway. The TC on cell 19 not work during the test.

Table 5 – Test overview timeline

Time (HH:MM:SS)	Event	Description
00:00:00	Test Start	The test was started and the heater was turned on to heat the initiating cell (Cell 20) at a ratio of 4 ~ 7 °C/min.
00:43:43	Venting of initiating Cell	Initiating cell (Cell 20) vented at around 147°C measured through TC 02 by an indication of sudden dip in cell's temperature curve and the bulge of top enclosure. See Figure (b)
01:14:12	Smoke released from enclosure	Obvious smoke observed from the enclosure, electrolyte leakage also observed from the side enclosure
01:14:26	Thermal runaway of initiating cell	Initiating cell (Cell 20) was at around 181°C measured through TC02. Smoke and electrolyte leakage continued from the side enclosure with no flame observed and the temperature of cell 20 began to increase in an uncontrollable manner. See Figure (c)
01:21:16	Propagation to first	Thermal runaway propagated to nearby cell (cell 21). More

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	cell	Gas released. See Figure (d)	
01:31:33	Smoke released from enclosure	Obvious smoke observed from the enclosure, Another cell venting	
02:00:00	Test Termination	Data acquisition was stopped. The module was left in the test overnight and with video monitored.	

Table 6 – Gases measured and measurement methods used in unit level testing

Measurement Method	Gases Measured	Chemical Formula	Gas Type
Flame Ionization Detection (FID)	Total Hydrocarbons	-	Hydrocarbons
Solid-state Hydrogen Sensor	Hydrogen	H ₂	-
Non-dispersive infrared spectroscopy (NDIR)	Carbon Dioxide	CO ₂	Carbon Containing
	Carbon Monoxide	CO	Carbon Containing

- This table was modified to reflect the gases measured during testing.

Table 7 - Gas generation periods

Time	Condition
00:42:00 to 2:00:00	No-Flaming
External Flaming of Gas	
Condition	Duration (s)
External Flaming of Vent Gases:	N/A

Table 9 – Summary of battery gas volumes identified during thermal runaway in module test

Gas Component	Gas Type	During Pre-flaming (L)	During Flaming (L)
Total Hydrocarbons	Hydrocarbons	150	No flaming
Carbon Dioxide	Carbon Containing	53	
Carbon Monoxide	Carbon Containing	143	
Hydrogen	Hydrogen	189	

Table 10 – Smoke and heat release rate

Heat Release Rate (HRR)		Smoke Release Rate (SRR)	
Peak Chemical HRR (kW)	No flame observed	Maximum SRR (m ² /s)	4.9
		Total Smoke Released (m ²)	376.7

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 11 – Module Weight During Test, kg

Before Test:	319.5 kg
After Test:	317.5 kg
Weight Loss:	2 kg

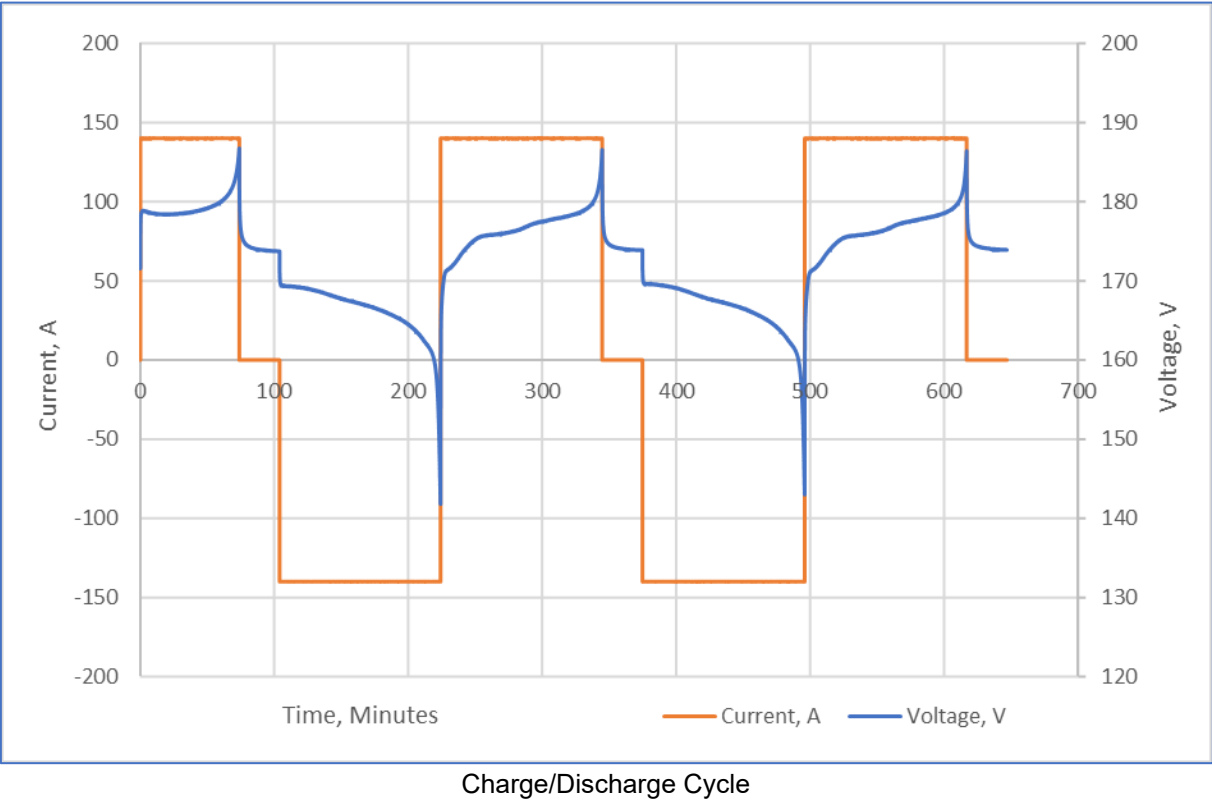
Table 12 – Other Observations during module test

	Observed, Yes/No	Location
Flying debris	No	N/A
Explosive discharge of gas	No	N/A
Sparks or electrical arcs	No	N/A

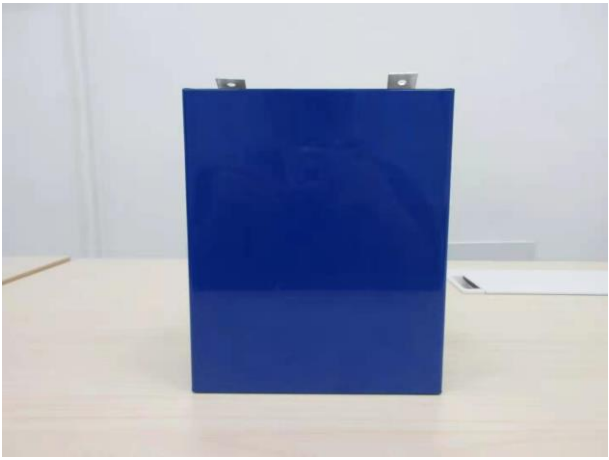
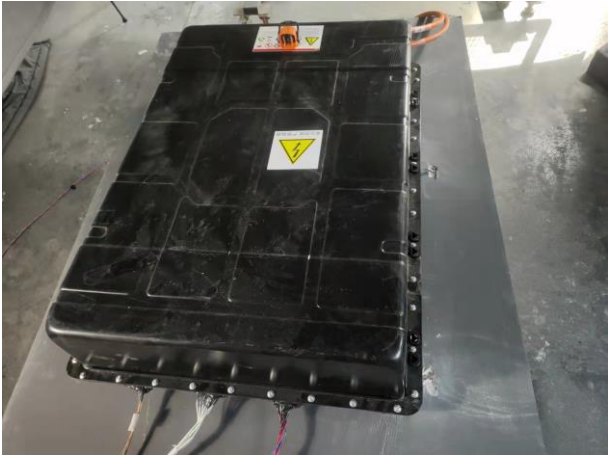
UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

TABLE: Critical components information					
Object / Part No.	Manufacturer/ trademark	Type / model	Technical data	Standard	Mark(s) of conformity ¹⁾
Cells	Contemporary Amperex Technology Co Limited	CB310, CB2W0	3.2V, 280Ah	UL1973	UL (MH62898)
Bottom enclosure	Contemporary Amperex Technology Co., Limited	--	Material: Aluminum Thickness: ≥1mm Size: 810.0mm(W)*1135.0mm(D)*55.0mm(H)	--	--
Top Plastic enclosure	Hunan Jiyongsheng Co., Limited	PP	UL94-V0, 85 °C	UL94	Intertek 20890002-MT-3
DC High Voltage connector	Sanco New Energy Technology Co., Ltd	ES095	1500 Vd.c. 310A, -40 °C to 125 °C,	EN 61984:2009/UL 1977	TUV
Plastic material for Cover of CSC_22S	CHENGDU KANGLONGXIN PLASTICS CO LTD	Polycarbonate	0.8mm, UL94-V0, 125°C	UL94&UL 746	UL (E315185)
Voltage sampling wire	DONG GUAN NISTAR TRANSMITTING TECHNOLOGY CO.,INC.	UL3666	0.35mm ² XLPE 125°C 600 Va.c.	UL 758/UL1581	UL (E214184)
NTC IC	SEMITEC CORP	HD21103C0-18010	10K	N/A	N/A
Temperature sampling wire	TAIZHOU RISHUN ELECTRIC APPLIANCE DEVELOPMENT CO LTD	UL 4484	300 V, -40°C ~150°C	UL 758/UL1581/ UL 2556	UL (E237675)
NTC Sensor	SEMITEC CORP	103AP-2	10 KΩ 3976K -40°C ~125 °C	UL 1434	UL (E92669)

Attachment A: Module Conditioning (Charge/discharge) Profiles - (Pages **17** through **17**)



Attachment B: Module Construction Photos - (Pages 18 through 18)

	
Figure 1 - Photo of cell – Wide side view	Figure 2 - Photo of cell – Narrow side view
	
Figure 3 - Photo of module – Internal view	Figure 4 - Photo of module
	
Figure 5 – Photo of module	

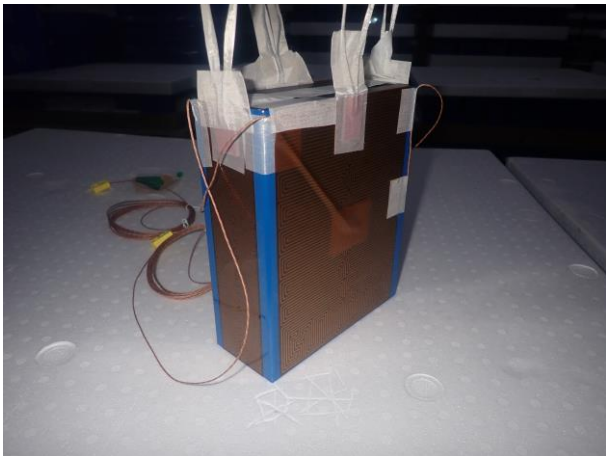
Attachment C: Module Instrumentation Photos - (Pages 20 through 21)

Figure 6 – Cell with heater. two pieces of 203.0 mm by 152.4 mm and two pieces of 203.0 mm by 50.8 mm for each sample.

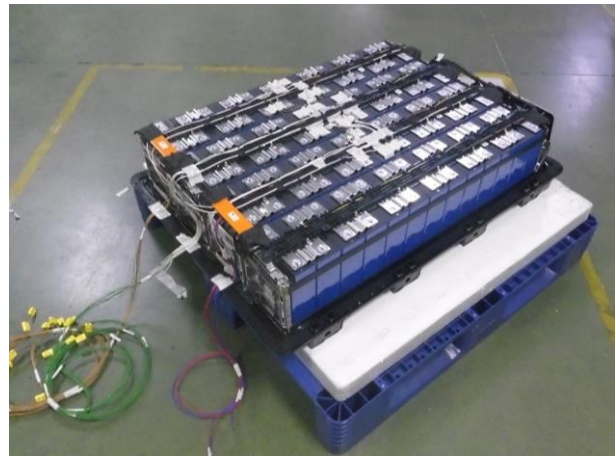


Figure 7 – Module with heater, TCs and Voltage Sampling wires

Note: The thermocouple T1-1 was used to control the supply power to the heater to keep the heating rate at 4 ~ 7 °C/min. T2 was used to represent the temperature of initiating cell. T3 was error during test. T1-1, on the wide side surface center of cell 20, between the cell and heater. T1-2 on the other wide side surface center of cell 20, between the cell and heater. T2 on the wide side surface center of cell 20, not covered by heater. V1, V2, V3, V4, V5 was the voltage of cell 20, 19, 21, 33, 7 separately. T3 to T8 were attached on the wide side surface center of cells shown in below illustration.

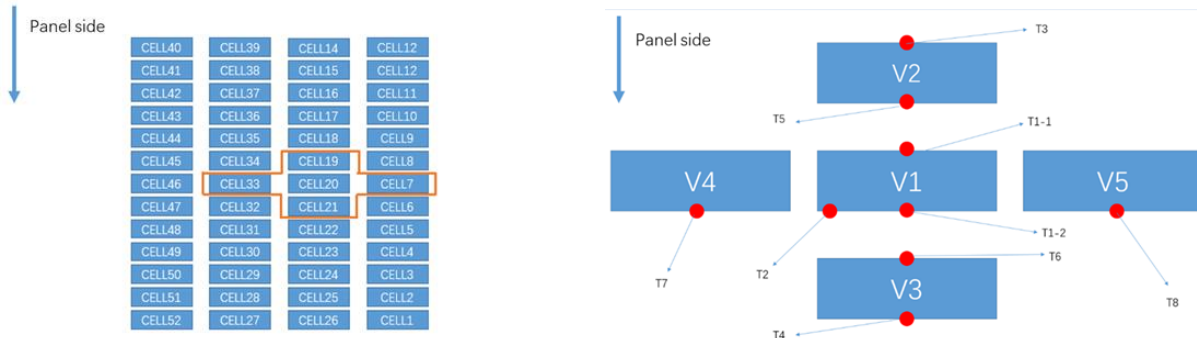


Figure 8 – Locations of TCs



Figure 9 – Module on the test platform – Side view 1



Figure 10 Module on the test platform – Side view 2

Attachment D: Module and Initiating Cell(s) Temperature Profiles During Testing - (Pages 21 through 22)

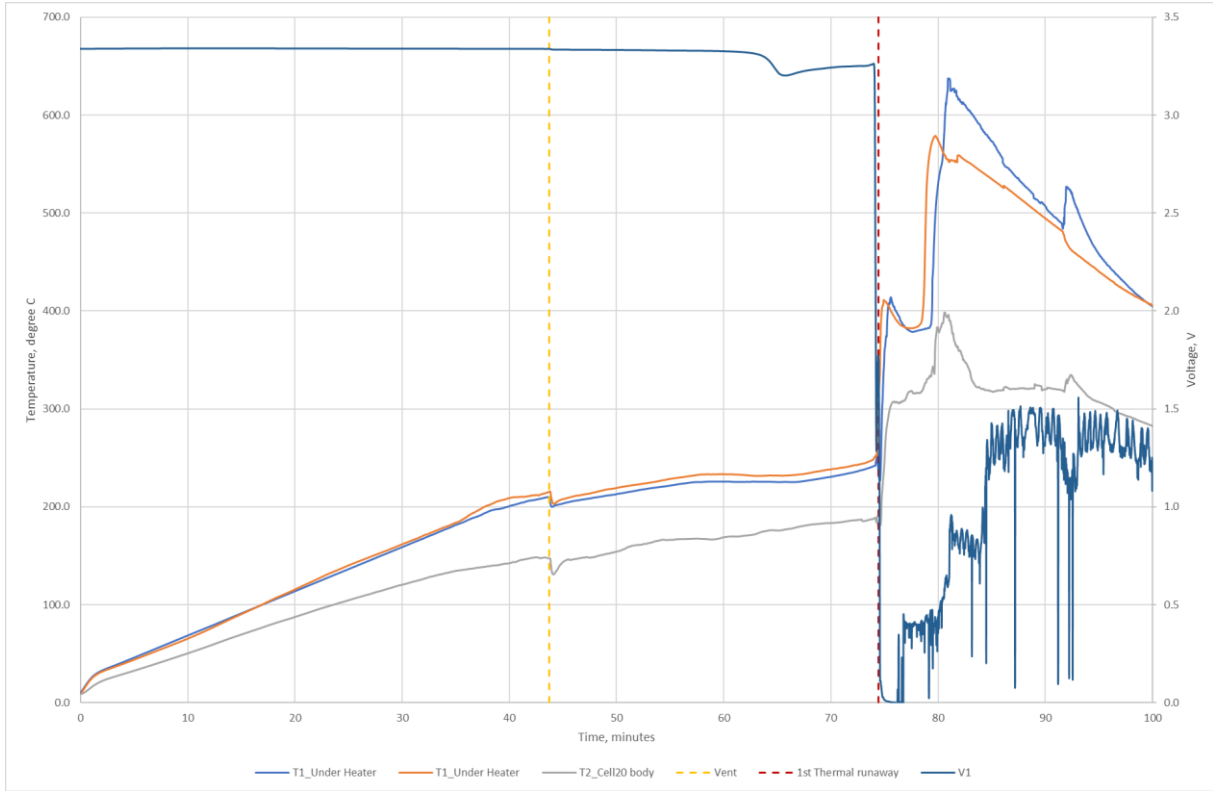
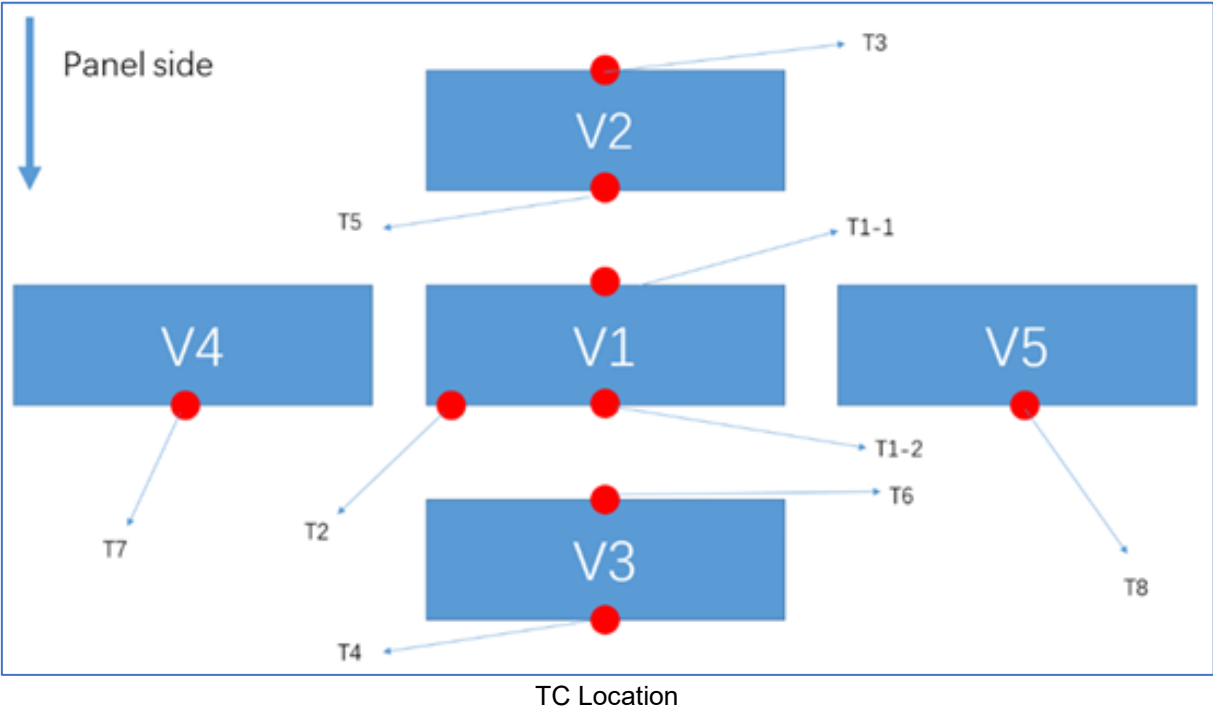


Figure 10-1, Initiating cell Temperature and Voltage Profiles During Testing

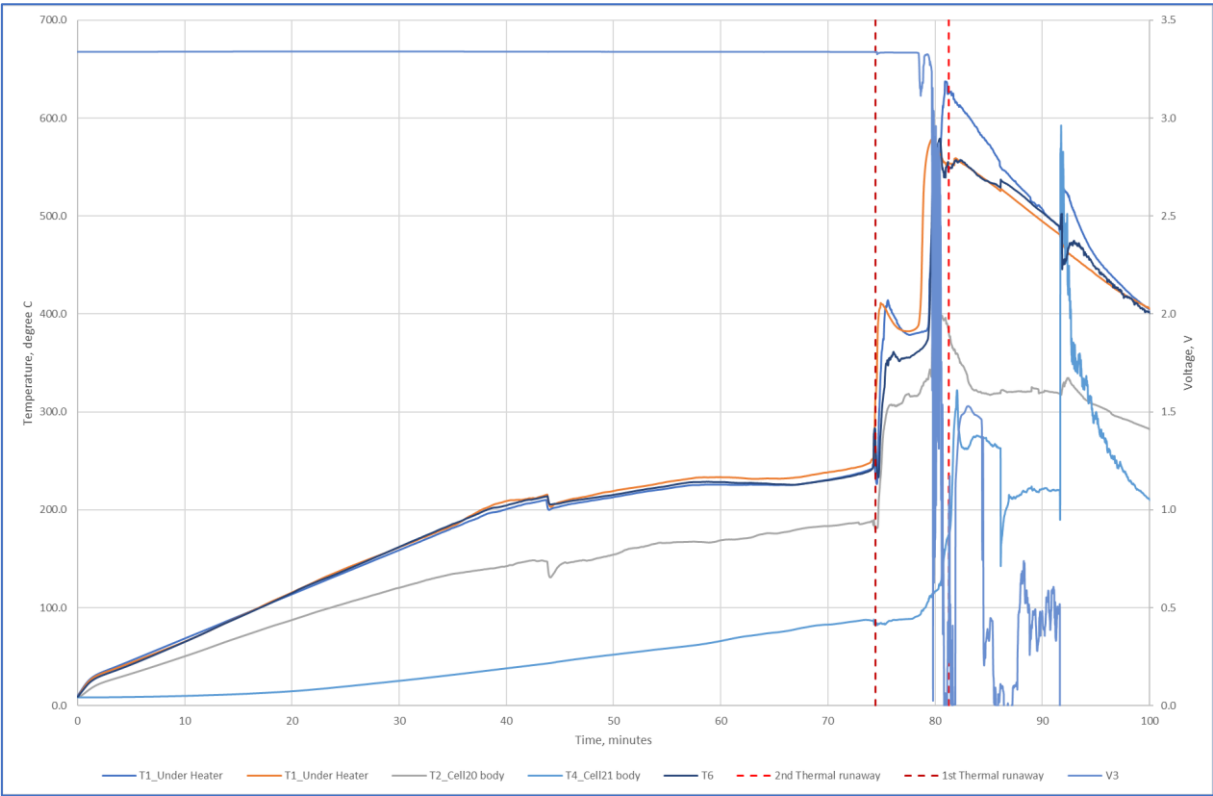


Figure 10-2, Temperature and Voltage Profiles Describing Cell to Cell Propagation

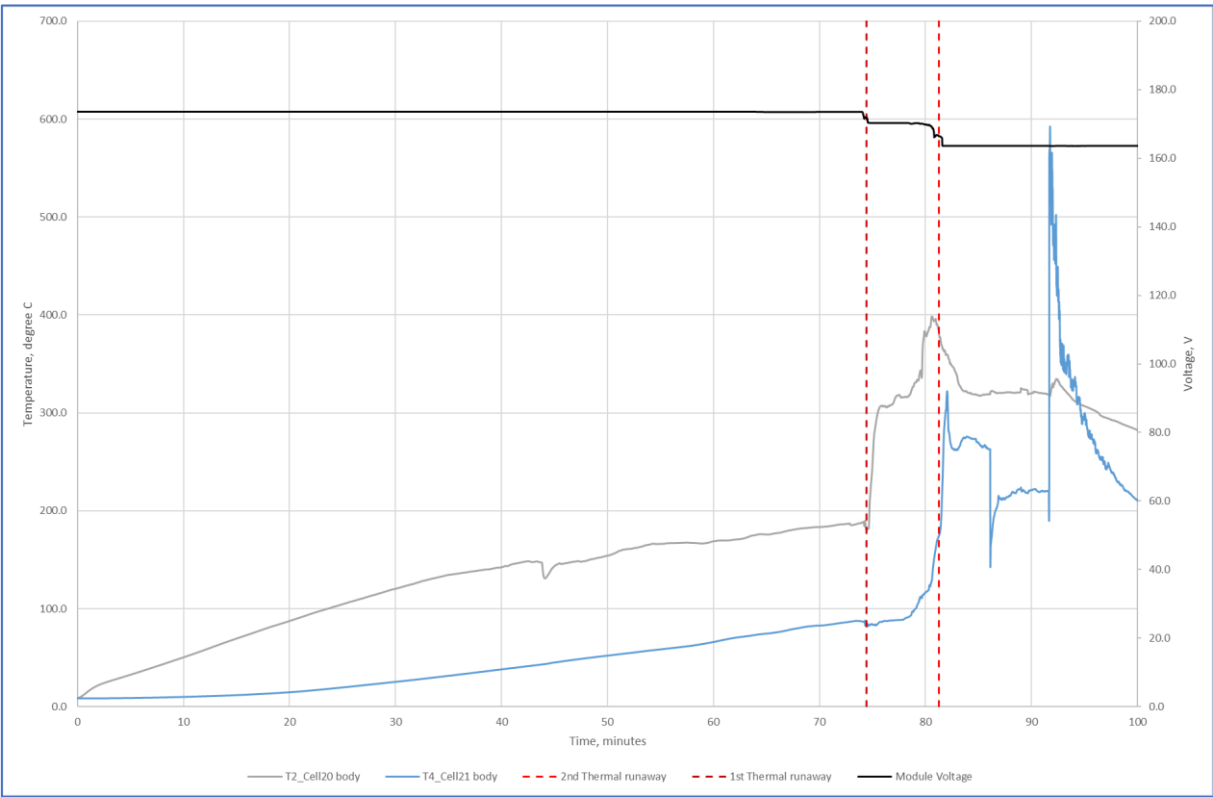
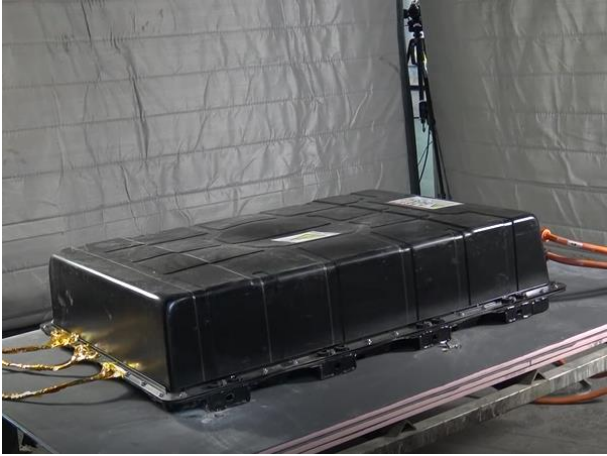


Figure 10-3, Temperature and Voltage Profiles Describing Cell to Cell Propagation

Attachment E: Module Testing Photos - (Pages 23 through 25)

	
(a) Test Start [00:00:00]	(b) Initiating cell Venting [00:43:48]
	
(c) Smoke observed out of the enclosure [01:14:12]	(d) Initiating Cell Thermal Runaway [01:14:26]



(e) Large quantities of gas poured out of the enclosure
[01:14:29]



(f) Propagation to Cell 21
(2nd Thermal Runaway)
[01:21:16]



(g) another cell venting
[01:31:33]



(h) Test Termination²
[2:00:00]

2 all cells temperature had peaked and dropped below 90°C, there is no visible smoke. THC concentration had returned back to the zero level, the test was terminated then.



Figure 11 - Post Test Photos

Attachment F: Module Gas Flow Rate and Heat Release Profiles - (Pages 26 through 28)

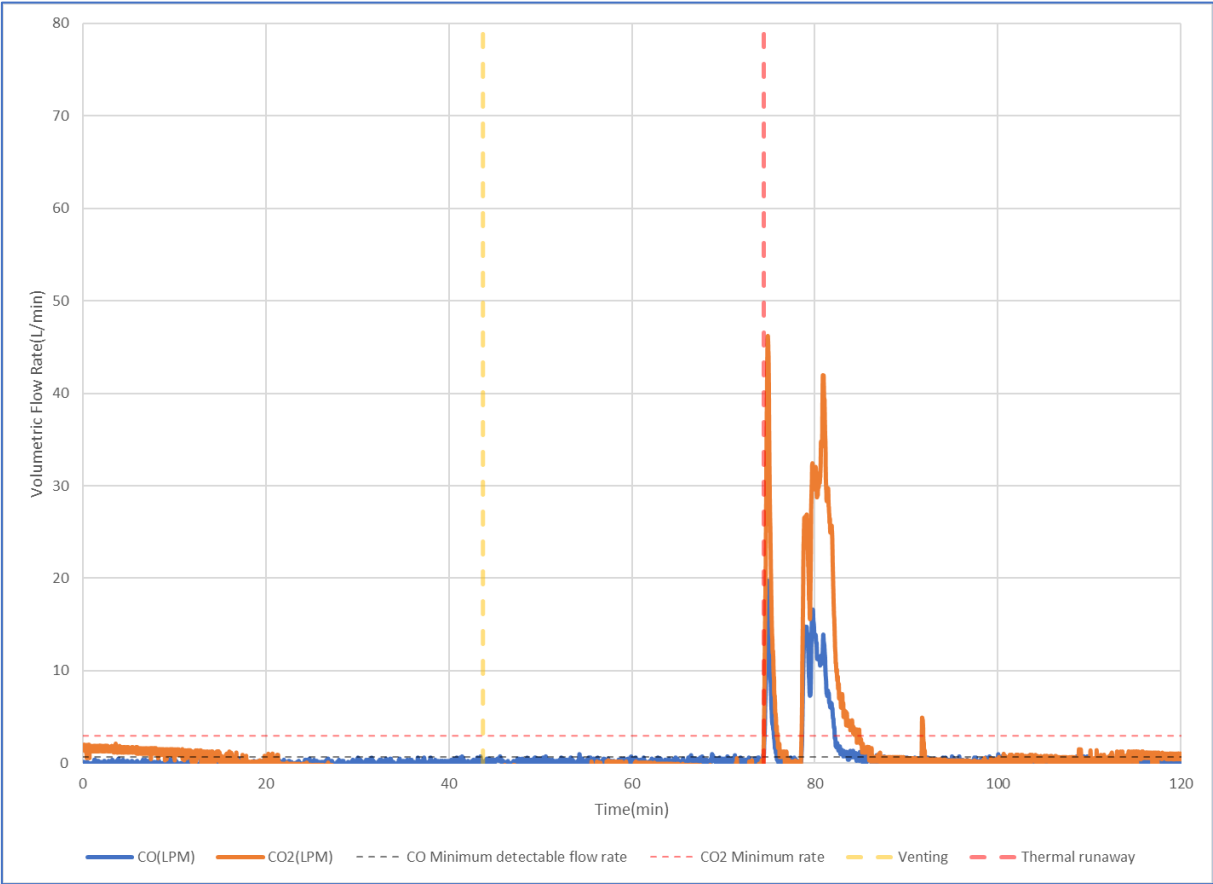


Figure 12, CO, CO2 Volumetric flow rates

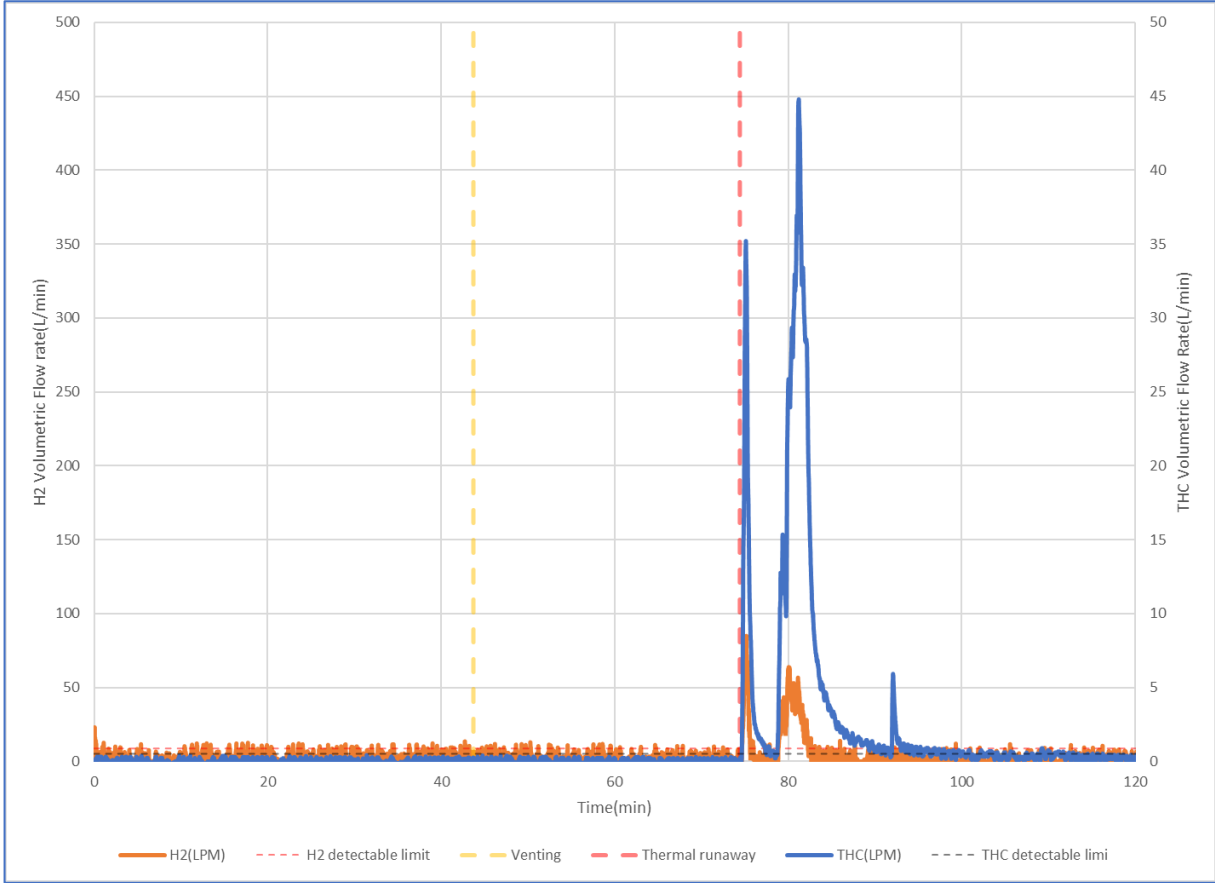


Figure 13, THC, H2 Volumetric flow rates

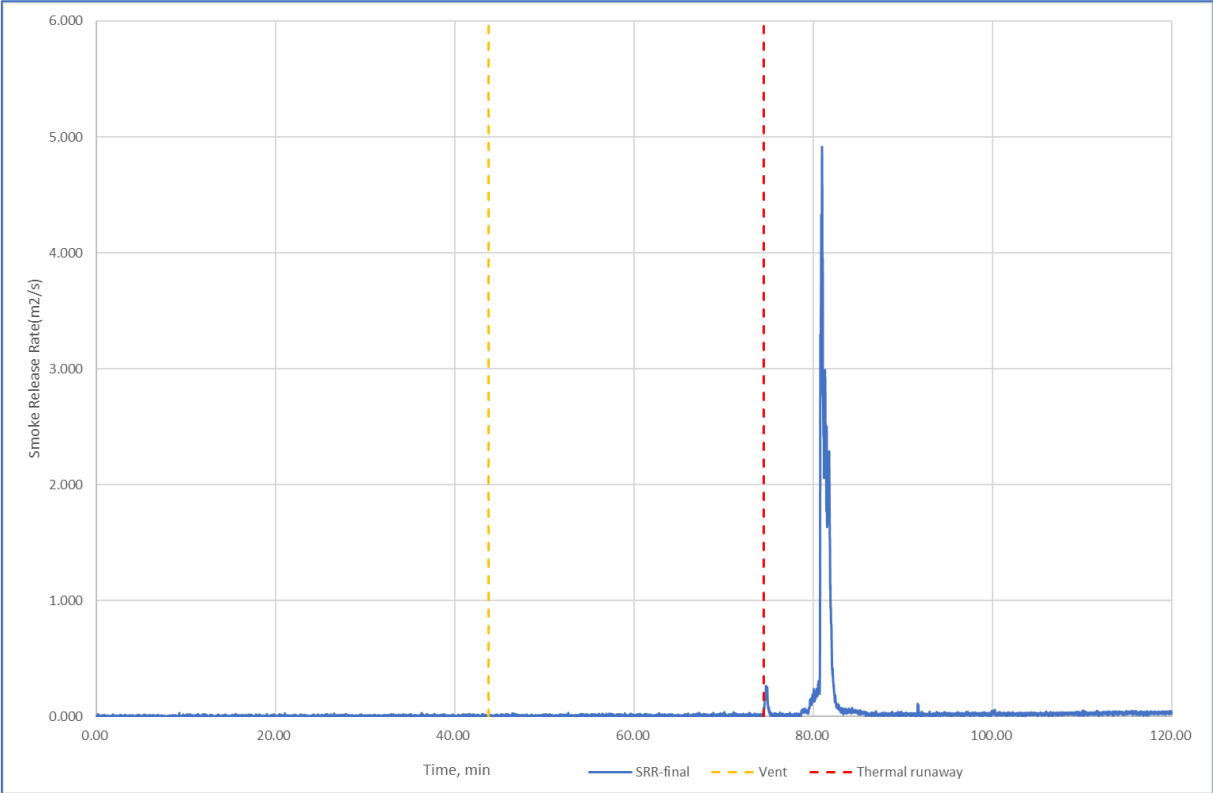


Figure 14, Smoke release rate

APPENDIX 7.3

UL 9540A Installation Test Report, 4th Edition



CSA GROUP
Laboratory Test Data - UL 9540A

Master Contract: 301546
Report: 80122674
Project: 80122674

July 27, 2022

Fluence Energy, LLC
4601 N. Fairfax Drive, Suite 600
Arlington, VA 22203
United States

Subject: 06-01-0005-16 UL 9540A Test Report

To Whom It May Concern:

We are pleased to inform you that testing of your product per UL 9540A has been completed. Applicable test(s) was witnessed at facility Right Testing Labs located at 198 Matbeth Road, Barnesville, GA 30204 USA by CSA – 8501 East Pleasant Valley Road, Independence, OH 44131 USA. Unit level testing was conducted on the sample provided and the results are enclosed in the test report.

Note: This Test Report is not an Authorization to apply the CSA Mark to the product. The results contained in the report(s) provided are contingent upon the characteristics of the actual sample(s) used in the investigation. In the absence of a continuing inspection service, CSA provides no assurance, expressed or implied, that the contents of the report are applicable to reproductions of the sample(s). Use or reproduction of the CSA name, logo, or trademark is not permitted without the prior written consent of CSA. No references can be made to this report when using the results of this investigation for the purposes of advertising, promotion or litigation, without the prior written consent of CSA.

Please examine the enclosed documents and contact me if you have any questions or would like us to make any changes.

On behalf of CSA, I would like to thank you for your business and offer our services for your future needs.

Sincerely,

Kim Sikorski
CSA – Cleveland
8501 East Pleasant Valley Road
Independence, OH 444131
USA
Encl. UL 9540A Test Report



CSA GROUP
Laboratory Test Data - UL 9540A Checklist and Test Result
ORIGINAL TEST DATA

The results relate only to the items tested.

This report shall not be reproduced, except in full, without the approval of CSA Group Testing & Certification Inc.

Master Contract:	301546	Model:	06-01-0005-16	Page number 1 of 31
Project / Network:	80122674	Description:	LFP Energy Storage System, 1500V, 745kWh	

Standard(s): ANSI/CAN/UL 9540A:2019 Fourth Edition, Dated November 12, 2019 - Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

Testing Laboratory Name:	CSA Group		
Address:	8501 East Pleasant Valley Road, Independence, OH 44131 USA		
Testing Program:	Custom Test:	Cover Letter	☒ Testing Only
Note: Mark "X" in applicable test program block			

If tests were performed at another facility, then described below:

Testing Laboratory Name:	Right Test Laboratory
Address:	198 Matbeth Road, Barnesville, GA 30204 USA
Facility Qualification Number:	N/A

Customer:	As above / or describe otherwise Fluence Energy, LLC
Address:	4601 Fairfax Drive Suite 600, Arlington, VA 22203 USA

Tested By:	Drew Mersereau, Senior Project Manager	
	Name, Title	
	On File	2022-06-24
	Signature	Date (YYYY-MM-DD)
☒ Reviewed by:	Kim Sikorski, Certifier II	
☒ Witnessed by:	Name, Title	
	Kim Sikorski	2022-06-24
	Signature	Date (YYYY-MM-DD)

Version5 : 01/05/2022



CSA GROUP
Laboratory Test Data - UL 9540A Checklist and Test Result
ORIGINAL TEST DATA

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This report shall not be reproduced, except in full, without the approval of CSA Group Testing & Certification Inc.

Master Contract:	301546	Model:	06-01-0005-16	Page number 2 of 31
Project / Network:	80122674	Description:	LFP Energy Storage System, 1500V, 745kWh	

Product Details	
Test Request:	☐ Cell Level Testing ☐ Module Level Testing ☒ Unit Level Testing ☐ Installation Level Testing
Manufacturer	☐ Cell: ☐ Module: ☒ Unit: Fluence Energy, LLC
Brand name / Trademark	☐ Cell: ☐ Module: ☒ Unit: Fluence
Model Number	☐ Cell: ☐ Module: ☒ Unit0: 6-01-0005-16
Date of receipt of test sample(s)	2022-06-16 (YYYY-MM-DD) Delivered to Right Testing Laboratory
Cell/Battery Type	LFP
Approximate Dimension (mm)	☐ Cell: ☐ Module: ☒ Unit: 2257 x 2578 x 2549 (d x w x h)
Mass (kg)	☐ Cell: ☐ Module: ☒ Unit: 8,200
DUT Sample/Serial Number	☐ Cell: ☐ Module: ☒ Unit: N/A
DUT Nominal Voltage Rating (V)	☐ Cell: ☐ Module: ☒ Unit: 1,331
DUT Nominal Charge Capacity Rating (Ah)	☐ Cell: ☐ Module: ☒ Unit: 560
Fire Mitigation Strategies: (For installation level testing)	☐ Water: ☐ Other (Specify): ☒ N/A
Additional Information	N/A



ORIGINAL TEST DATA

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Master Contract:	301546	Model:	06-01-0005-16	Page number 3 of 31
Project / Network:	80122674	Description:	LFP Energy Storage System, 1500V, 745kWh	

THE TESTING SPECIFIED IN THIS PROCEDURE IS INHERENTLY DANGEROUS

DO NOT ATTEMPT TO PERFORM THIS TEST UNLESS YOU HAVE BEEN PROPERLY TRAINED REGARDING SAFELY WORKING WITH THE HAZARDS INVOLVED

Important Test Consideration:

- As some batteries expose in test described above, it is important that personnel be protected from the flying fragments, explosive force, and sudden release of heat, chemical burns, and noise resulting from such explosions. The test area is to be well ventilated to protect personnel from possible harmful fumes or gases.
- Temperature of the surface of the battery casing shall be monitored during the tests described above. All personnel involved in the testing of batteries are to be instructed never to approach a battery until the surface temperature returns to ambient temperature.
- Test shall be conducted in separate room or equipped with an adequate safety barrier separating the test area from observer.



CSA GROUP
Laboratory Test Data - UL 9540A Checklist and Test Result
ORIGINAL TEST DATA

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Master Contract:	301546	Model:	06-01-0005-16	Page number 4 of 31
Project / Network:	80122674	Description:	LFP Energy Storage System, 1500V, 745kWh	

UL 9540 A – Definition

-**BATTERY ENERGY STORAGE SYSTEM (BESS)** - Stationary equipment that receives electrical energy and then utilizes batteries to store that energy to supply electrical energy at some future time. The BESS, at a minimum consists of one or more modules, a power conditioning system (PCS), battery management system (BMS) and balance of plant components.

NOTE: For flow battery systems the energy is stored within one or more electrolyte storage tanks.

- a) **INITIATING BATTERY ENERGY STORAGE SYSTEM UNIT (INITIATING BESS)** – A BESS unit which has been equipped with resistance heaters in order to create the internal fire condition necessary for the installation level test (Section 9).
- b) **TARGET BATTERY ENERGY STORAGE SYSTEM UNIT (TARGET BESS)** – The enclosure and/or rack hardware that physically supports and/or contains the components that comprise a BESS. The target BESS unit does not contain energy storage components, but serves to enable instrumentation to measure the thermal exposure from the initiating BESS.

-**BATTERY SYSTEM** - Is a component of a BESS and consists of one or more modules typically in a rack configuration, controls such as the BMS and components that make up the system such as cooling systems, disconnects and protection devices.

-**CELL** - The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

-**DUT** - Device under test.

-**ELECTRICAL RESISTANCE HEATERS** - Devices that convert electrical energy supplied from a laboratory source into thermal energy.

-**END OF DISCHARGE VOLTAGE (EODV)** - The manufacturer's specified minimum voltage level during discharge.

-**ENERGY RESERVOIR** - The solution which stores the active energy in the flow battery energy storage system. This can be in the form of one electrolyte, two electrolytes, or one electrolyte with solid metal particles.

-**FLEXIBLE FILM HEATERS** - Electrical resistance heaters of a film, tape or otherwise thin sheet like construction that easily conform to the surface of cells.

-**FLOW BATTERY** - A battery technology that stores its active materials in the form of one or more electrolytes (with or without solid metal particles) within one or more storage tanks, and when operating, the electrolytes are transferred between the reactor (battery stacks) and the storage tanks

NOTE 1: Three commercially available flow battery technologies are zinc air, zinc bromine and vanadium redox.

NOTE 2: Unlike a fuel cell system, a flow battery is a closed system and has no net consumption of fuel.



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Master Contract:	301546	Model:	06-01-0005-16	Page number 5 of 31
Project / Network:	80122674	Description:	LFP Energy Storage System, 1500V, 745kWh	

-**"MAXIMUM SURFACE TEMPERATURE END POINT"** - The final hold temperature measured on the cell case after conducting the thermal ramp when using the external heater method to achieve thermal runaway of the cell.

-**"MODULE"** - A subassembly that is a component of a BESS that consists of a group of cells or electrochemical capacitors connected either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry.

-**"MONOBLOC"** - A battery design with a common case containing one or more internal cells, electrolyte, a vent or pressure relief valve assembly, intercell connections and hardware. A typical example of a common monobloc battery is an SLI lead acid battery.

-**"NON-RESIDENTIAL USE"** - Intended for use in commercial, industrial or utility owned locations.

-**"RESIDENTIAL USE"** - In accordance with this standard, intended for use in one or two family homes and townhomes and individual dwelling units of multi-family dwellings.

-**"STATE OF CHARGE (SOC)"** - The available capacity in a BESS, pack, module or cell expressed as a percentage of rated capacity.

-**"THERMAL RUNAWAY"** - The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gas evolution.

-**"UNIT"** - A frame, rack or enclosure that consists of a functional BESS which includes components and subassemblies such as cells, modules, battery management systems, ventilation devices and other ancillary equipment.



ORIGINAL TEST DATA

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Master Contract:	301546	Model:	06-01-0005-16	Page number 6 of 31
Project / Network:	80122674	Description:	LFP Energy Storage System, 1500V, 745kWh	

ANSI/CAN/UL 9540A:2019 Fourth Edition, Dated November 12, 2019 - Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

Section	Requirement	Test (T) / Waive (W) / Not App. (N/A)	Comments																																												
5	General																																														
5.1	Cell	N/A	Cell testing conducted by UL during project no. 4789764715, issue date 2021/04/27.																																												
5.1.1	The cells associated with the BESS were tested.	---	Chemistry: LFP Physical Format: Prismatic Capacity (Ahr): 280 Nominal Voltage (Vdc): 3.2 Approximate Dimension (mm): 207.2 x 173.9 x 71.65 (HxWxD) Weight (g): 5450 ± 300 Cell Thermal runaway methodology: Film Heater Cell Surface temperature at gas venting (°C): 168.2 Cell Surface temperature at thermal runaway(°C): 239.6 Total Gas Generation Volume (Liter): 221.3 Gas Composition (%): <table><tr><td>CO</td><td>11.086</td></tr><tr><td>CO₂</td><td>33.290</td></tr><tr><td>H₂</td><td>35.698</td></tr><tr><td>CH₄</td><td>10.075</td></tr><tr><td>C₂H₂</td><td>0.164</td></tr><tr><td>C₂H₄</td><td>5.259</td></tr><tr><td>C₂H₆</td><td>1.089</td></tr><tr><td>C₃H₄</td><td>0.000</td></tr><tr><td>C₃H₄</td><td>0.000</td></tr><tr><td>C₃H₆</td><td>0.571</td></tr><tr><td>C₃H₈</td><td>0.232</td></tr><tr><td>C4 (Total)</td><td>0.382</td></tr><tr><td>C5 (Total)</td><td>0.091</td></tr><tr><td>C6 (Total)</td><td>0.060</td></tr><tr><td>C7 (Total)</td><td>0.005</td></tr><tr><td>C8 (Total)</td><td>0.000</td></tr><tr><td>C₆H₆</td><td>0.023</td></tr><tr><td>C₇H₈</td><td>0.002</td></tr><tr><td>C₃H₆O₃</td><td>1.879</td></tr><tr><td>C₄H₈O₃</td><td>0.091</td></tr><tr><td>C₅H₁₀O₃</td><td>0.000</td></tr><tr><td>-</td><td>100</td></tr></table> LFL limit at Ambient Temperature (%):7.85	CO	11.086	CO ₂	33.290	H ₂	35.698	CH ₄	10.075	C ₂ H ₂	0.164	C ₂ H ₄	5.259	C ₂ H ₆	1.089	C ₃ H ₄	0.000	C ₃ H ₄	0.000	C ₃ H ₆	0.571	C ₃ H ₈	0.232	C4 (Total)	0.382	C5 (Total)	0.091	C6 (Total)	0.060	C7 (Total)	0.005	C8 (Total)	0.000	C ₆ H ₆	0.023	C ₇ H ₈	0.002	C ₃ H ₆ O ₃	1.879	C ₄ H ₈ O ₃	0.091	C ₅ H ₁₀ O ₃	0.000	-	100
CO	11.086																																														
CO ₂	33.290																																														
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CSA GROUP
Laboratory Test Data - UL 9540A Checklist and Test Result
ORIGINAL TEST DATA

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Master Contract:	301546	Model:	06-01-0005-16	Page number 7 of 31
Project / Network:	80122674	Description:	LFP Energy Storage System, 1500V, 745kWh	

Section	Requirement	Test (T) / Waive (W) / Not App. (N/A)	Comments
			LFL limit at Cell Vent Temperature (%): 6.47 Gas Burning Velocity (cm/sec): 64 Gas Vent Pmax (psig): 103 See Attachment 1 for Cell Level testing data provided by manufacturer
5.1.2	Cells associated with the BESS comply with UL 1973	---	Cells comply with UL 1973, UL file number MH62898
5.1.3	Cell level test report	---	Cell testing conducted by UL during project no. 4789764715, issue date 2021/04/27.
5.2	Module	N/A	Module testing conducted by UL during project no. 4790087185, issue date 2022/01/27.
5.2.1	The module associated with the BESS were tested.	---	Enclosure Material: Non-metallic Cell Configuration: 52S-1P Quantity of Cell: 52 Chemistry: LFP Capacity (Ahr): 280 Energy (Whr): 46,592 Nominal Voltage: 166.4 Approximate Dimension (mm): 810 x 1152 x 243.4 (WxDxH) Weight (kg): 304.5 Cell Thermal Runaway Methodology: Film Heater Module Thermal Runaway Methodology: Film Heater Cell Surface Temperature at Gas Venting (°C): 168.2 Cell Surface temperature at thermal runaway(°C): 239.6 Module Heat Release Rate (kW/m ²): No flaming occurred Cell/Module Gas Generation and Composition: Cell:



ORIGINAL TEST DATA

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Master Contract:	301546	Model:	06-01-0005-16	Page number 8 of 31
Project / Network:	80122674	Description:	LFP Energy Storage System, 1500V, 745kWh	

Section	Requirement	Test (T) / Waive (W) / Not App. (N/A)	Comments																																												
			<table><tr><td>CO</td><td>11.086</td></tr><tr><td>CO₂</td><td>33.290</td></tr><tr><td>H₂</td><td>35.698</td></tr><tr><td>CH₄</td><td>10.075</td></tr><tr><td>C₂H₂</td><td>0.164</td></tr><tr><td>C₂H₄</td><td>5.259</td></tr><tr><td>C₂H₆</td><td>1.089</td></tr><tr><td>C₃H₄</td><td>0.000</td></tr><tr><td>C₃H₄</td><td>0.000</td></tr><tr><td>C₃H₆</td><td>0.571</td></tr><tr><td>C₃H₈</td><td>0.232</td></tr><tr><td>C4 (Total)</td><td>0.382</td></tr><tr><td>C5 (Total)</td><td>0.091</td></tr><tr><td>C6 (Total)</td><td>0.060</td></tr><tr><td>C7 (Total)</td><td>0.005</td></tr><tr><td>C8 (Total)</td><td>0.000</td></tr><tr><td>C₆H₆</td><td>0.023</td></tr><tr><td>C₇H₈</td><td>0.002</td></tr><tr><td>C₃H₆O₃</td><td>1.879</td></tr><tr><td>C₄H₈O₃</td><td>0.091</td></tr><tr><td>C₅H₁₀O₃</td><td>0.000</td></tr><tr><td>-</td><td>100</td></tr></table> Module: THC: 147L CO: 37L CO₂: 111L H₂: 136L Module External Flaming and Flying Debris Hazard: No Module Location of Flame Venting: No flames emitted See Attachment 2 for Module Level testing data provided by manufacturer	CO	11.086	CO ₂	33.290	H ₂	35.698	CH ₄	10.075	C ₂ H ₂	0.164	C ₂ H ₄	5.259	C ₂ H ₆	1.089	C ₃ H ₄	0.000	C ₃ H ₄	0.000	C ₃ H ₆	0.571	C ₃ H ₈	0.232	C4 (Total)	0.382	C5 (Total)	0.091	C6 (Total)	0.060	C7 (Total)	0.005	C8 (Total)	0.000	C ₆ H ₆	0.023	C ₇ H ₈	0.002	C ₃ H ₆ O ₃	1.879	C ₄ H ₈ O ₃	0.091	C ₅ H ₁₀ O ₃	0.000	-	100
CO	11.086																																														
CO ₂	33.290																																														
H ₂	35.698																																														
CH ₄	10.075																																														
C ₂ H ₂	0.164																																														
C ₂ H ₄	5.259																																														
C ₂ H ₆	1.089																																														
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C ₇ H ₈	0.002																																														
C ₃ H ₆ O ₃	1.879																																														
C ₄ H ₈ O ₃	0.091																																														
C ₅ H ₁₀ O ₃	0.000																																														
-	100																																														
5.2.2	Modules associated with the BESS comply with UL 1973	---	Module complies with UL 1973, TUV Rheinland Certificate Number CU 72200221 0002 issued on 2022/09/22																																												
5.2.3	Module level test report	---	Module testing conducted by UL during project no. 4790087185, issue date 2022/01/27.																																												
5.3	Battery energy storage system unit	T	Test Conducted																																												
5.3.1	BESS were tested.	---	Manufacturer Name: Fluence Energy, LLC Model: 06-01-0005-16																																												



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Project / Network:	80122674	Description:	LFP Energy Storage System, 1500V, 745kWh	

Section	Requirement	Test (T) / Waive (W) / Not App. (N/A)	Comments
			Nominal Voltage: 1500 BESS Energy (kWhr): 745.4
5.3.2	BESS comply with UL 9540	---	See Attachment 3 for BESS certificate complying UL 9540 provided by manufacturer Number of modules in the BESS: 16 Electrical configuration of the module: 52S - 1P Physical layout of the modules in the BESS: 2P-8S BESS enclosure overall dimensions (mm): 2, 549 x 2, 578 x 2,257 (HxWxD) BESS Enclosure Material: Metallic
5.3.3	Fire detection and suppression systems	---	Fire Detection System(mandatory): Siemens Fire System, consists of minimum of smoke and CO detectors, horn and strobe alarm. Fire Suppression System(optional): Aerosol fire suppression system consisting of a single canister Fire Detection/Suppression System: Part of System Manufacturer request to perform test with Fire Detection/suppression System (Yes/No): No
5.3.4	BESS test report	---	See Unit level test section below
5.4	Flow Batteries	N/A	EUT is not flow battery
5.4.1		N/A	EUT is not flow battery
5.4.2	Flow battery comply with UL 1973	N/A	EUT is not flow battery
5.4.3	Flow battery thermal runaway determination level test report	N/A	EUT is not flow battery

Attachments

No.	Name	Number of Pages
1	Cell Level Testing	39
2	Module Level Testing	29
3	UL 9540 Certificate	1
4	UL 1973 Certificate	2



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ANSI/CAN/UL 9540A:2019 Fourth Edition, Dated November 12, 2019 - Section 7 Cell Level Testing

Cell level testing completed by UL, report number 4789764715

ANSI/CAN/UL 9540A:2019 Fourth Edition, Dated November 12, 2019 - Section 8 Module Level Testing

Module level testing completed by UL, report number 4790087185

ANSI/CAN/UL 9540A:2019 Fourth Edition, Dated November 12, 2019 - Section 9 Unit Level Testing

Section	Requirement	Comments
9	Unit Level Testing	
9.1	Sample and test configuration	
	The unit level test conducted with BESS units installed as described in the manufacturer's instructions and this section.	Test Configuration: Outdoor ground mounted non-residential use BESS
	Unit level test required one initiating BESS unit in which an internal fire condition in accordance with the module level test is initiated and target adjacent BESS units representative of installation.	☒ Conformed
	Test conducted for indoor floor mounted installations with fire propagation hazards and separation distances between initiating and target units representative of the installation.	BESS is not indoor floor mounted
	Exception: Testing can be conducted outdoors for outdoor only installations if there are the following controls and environmental conditions in place:	
	a) Wind screens are utilized with a maximum wind speed maintained at ≤ 12 mph;	Conformed, average speed 3mph with maximum gust of 5.7mph
	b) The temperature range is within 10°C to 40°C (50°F to 104°F);	Conformed
	c) The humidity is $< 90\%$ RH;	Conformed
	d) There is sufficient light to observe the testing;	Conformed
	e) There is no precipitation during the testing;	During active testing no precipitation occurred. Approximately 5 hours following peak temperatures and again approximately 20 hours following peak temperatures precipitation was observed.



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Section	Requirement	Comments
		This did not impact the temperature measurements from within the cube.
	f) There is control of vegetation and combustibles in the test area to prevent any impact on the testing and to prevent inadvertent fire spread from the test area; and	Conformed
	g) There are protection mechanisms in place to prevent inadvertent access by unauthorized persons in the test area and to prevent exposure of persons to any hazards as a result of testing.	Conformed, area is restricted access.
	Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), this testing to determine fire characterization can be done at the battery system level. Note: The suitability of this approach shall be determined based upon the overall design of the BESS and an analysis of the battery system as representative of the overall BESS for fire characterization concerns.	BESS is composed of multiple separate parts within separate enclosures. Test performed on battery system. It contains modules, BMS, and chillers and other supporting component. PCS and transformer are separate components, Not considered during this testing.
	The initiating BESS unit shall contain components representative of a BESS unit in a complete installation.	☒ Conformed
	Target BESS units shall include - the outer cabinet (if part of the design), racking, - module enclosures, and - components that retain cells components.	☒ Conformed
	Initiating BESS sample tested within 8 hrs. after charging BESS as per manufacturer specification to obtain maximum operating state of charge.	☒ Conformed Charging was completed with manufacturer's specified and provided charger. Manufacturer: Fuguang Electronics Model Number: FCF-651CT Max Charging: 260Vdc Max Discharging: 260V



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Section	Requirement	Comments
		All modules within the initiating BESS completed a charge cycle, completed by the Fluence Technician, between the hours of 07:33:00am and 08:18:01am on 2022/06/27, with OCV being checked to confirm 100% SOC. Testing started at 09:46:00am
	BESS unit includes an integral fire suppression system.	Integral fire suppression system : ☒ Optional ☐ Part of BESS Evaluation ☐ DUT tested with Integral fire suppression system ☒ DUT tested without Integral fire suppression system
	Electronics and software controls such as the battery management system (BMS) in the BESS are not relied upon for this testing.	☒ Conformed
9.2	Test method – Indoor floor mounted BESS units	
	During the test, the test room environment shall be controlled to prevent drafts that may affect test results.	Temperature(°C): 21 to 33 Humidity (% RH): 52 to 90
	Any access door(s) or panels on the initiating BESS unit and adjacent target BESS units closed, latched and locked at the beginning and duration of the test.	☒ Conformed
	The initiating BESS unit positioned adjacent to two instrumented wall sections.	Outdoor ground mounted installation, only one instrumented wall used. See test arrangement below. Additional unit was placed instead of additional wall to simulate a typical installation.
	Instrumented wall sections extend not less than 1.6 ft. (0.49 m) horizontally beyond the exterior of the target BESS units.	☒ Conformed Instrumented wall extended 1.6ft beyond posterior target cube. Anterior target cube is not required for testing; therefore wall does not extend beyond this cube.
	Instrumented wall sections was at least 0.61-m (2-ft) taller than the BESS unit height, but not less than 3.66 m (12 ft) in height above the bottom surface of the unit	☒ Conformed
	The surface of the instrumented wall sections were covered with 5/8-in (16-mm) gypsum wall board and painted flat black.	☒ Conformed Note: plywood was used as per outdoor ground mounted, non-residential test



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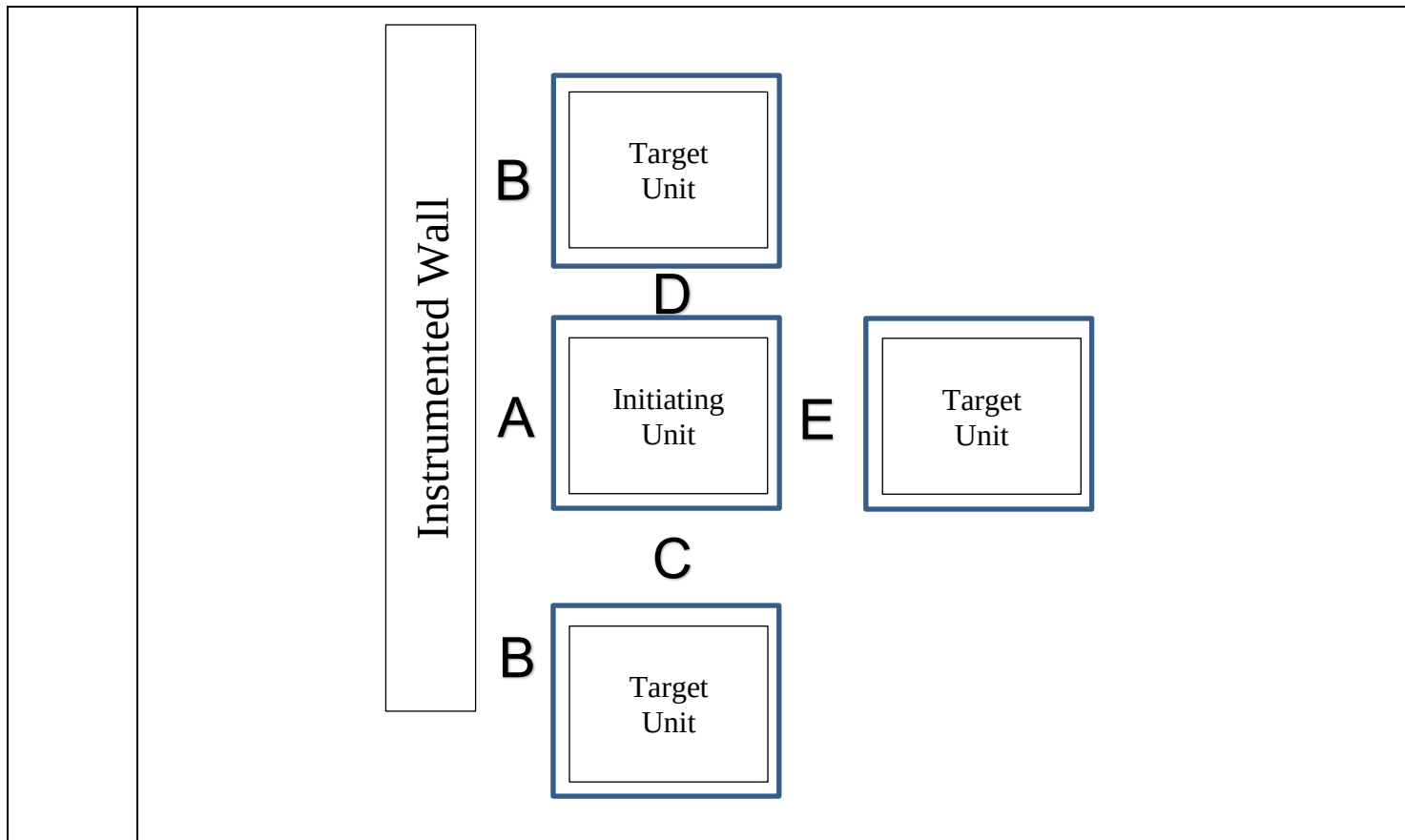
Section	Requirement	Comments
	The initiating BESS unit was centred underneath an appropriately sized smoke collection hood of an oxygen consumption calorimeter	N/A, not required for Outdoor Only installations
	The light transmission measured in the calorimeter's exhaust duct of the heat release rate calorimeter.	N/A, not required for Outdoor Only installations
	The smoke release rate calculated.	N/A, not required for Outdoor Only installations
	The chemical and convective heat release rates shall be measured for the duration of the test	N/A, not required for Outdoor Only installations
	The heat release rate measurement system was calibrated using an atomized heptane diffusion burner.	N/A, not required for Outdoor Only installations
	The convective heat release rate shall be measured using 1. Thermopile, 2. Velocity probe, and 3. Type K thermocouple, located in the exhaust system of the exhaust duct	N/A, not required for Outdoor Only installations
	Following test configuration used for testing.	
	- Installation of BESS unit with two or more rows	See below for test configuration
	- Installation of BESS units with a single row	N/A, two rows used

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ID	Location	Required Value	Measured Value
A	Separation distance between the initiating BESS unit and instrumented wall section beside initiating BESS unit.	10 Ft.	10 Ft.
B	Separation distance between the target BESS unit and instrumented wall section to the side of target BESS unit.	10 Ft.	10 Ft.
C	Separation distance between the initiating BESS unit and target BESS in front.	7 Ft.	7 Ft.
D	Separation distance between initiating BESS unit and target BESS unit behind.	7 in.	7 in.
E	Separation distance between initiating BESS unit and target BESS unit on the side.	7 in.	7 in.
Note: The physical spacing between BESS units (both initiating and target) and adjacent walls shall be representative of the intended installation. For example, the left side of Figure 9.1 shows a layout of BESS units of two or more rows. The right side of Figure 9.1 shows a layout of BESS units of a single row, with an instrumented wall taking place of the target BESS units as the nearest potential item exposed to thermal energy from the initiating BESS unit in thermal runaway			
Wall surface temperature measurements collected for BESS intended for installation in locations with combustible construction.		☒ Conformed	
Wall surface temperatures measured in vertical array(s) at 152-mm (6-in) intervals for the full height of the instrumented wall sections using - No. 24-gauge or smaller, - Type-K exposed junction thermocouples.		☒ Conformed	
Thermocouples shall be secured to gypsum surfaces.		Confirmed, plywood walls were used instead of gypsum	
Heat flux measured with at least two water-cooled Schmidt- Boelter gauges at the surface of each instrumented wall:		☒ Conformed	
a) Both are collinear with the vertical thermocouple array;		Conformed	
b) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module; and		Conformed	
c) One is positioned at the elevation estimated to receive the greatest heat flux during		Conformed	



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potential propagation of thermal runaway within the initiating BESS unit.	
Heat flux measured with at least two water-cooled Schmidt-Boelter gauges at the surface of each adjacent target BESS unit that faces the initiating BESS unit:	☒ Conformed
a) One is positioned at the elevation estimated to receive the greatest heat flux due to the thermal runaway of the initiating module within the initiating BESS; and	Conformed
b) One is positioned at the elevation estimated to receive the greatest surface heat flux due to the thermal runaway of the initiating BESS.	Conformed
For non-residential use BESS, heat flux measured with at least one water-cooled Schmidt-Boelter gauge positioned at the mid height of the initiating unit in the center of the accessible means of egress.	Conformed
No. 24-gauge or smaller, Type-K exposed junction thermocouples installed to measure the temperature of the surface proximate to the cells and between the cells and exposed face of the initiating module. Each non-initiating module enclosure within the initiating BESS unit instrumented with at least one No. 24-gauge or smaller Type-K thermocouple(s) to provide data to monitor the thermal conditions within non-initiating modules. Additional thermocouples placed to account for convoluted enclosure interior geometries.	Conformed
For residential use BESS, the DUT covered with a single layer of cheese cloth ignition indicator.	N/A, BESS is intended for non-residential installations only
An internal fire condition in accordance with the module level test created within a single module in the initiating BESS unit:	☒ Conformed
a) The position of the module selected to present the greatest thermal exposure to adjacent modules (e.g. above, below,	Conformed

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laterally), based on the results from the module level test; and



b) The setup (i.e. type, quantity and positioning) of equipment for initiating thermal runaway in the module is same as that used to initiate and propagate thermal runaway within the module level test (Section 8).

Conformed

The composition, velocity and temperature of the initiating BESS unit vent gases measured within the calorimeter's exhaust duct.

N/A, Outdoor only installations



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	Gas composition measured using a Fourier-Transform Infrared Spectrometer with a minimum resolution of 1 cm ⁻¹ and a path length of at least 2.0 m (6.6 ft), or equivalent gas analyzer.	N/A, Outdoor only installations
	The hydrocarbon content of the vent gas shall be measured using flame ionization detection.	N/A, Outdoor only installations
	Hydrogen gas measured with a palladium-nickel thin-film solid state sensor.	N/A, Outdoor only installations
	The test shall be terminated if:	
	a) Temperatures measured inside each module within the initiating BESS unit return to ambient temperature;	☒ Conformed
	b) The fire propagates to adjacent units or to adjacent walls; or	N/A, fire did not propagate outside of the unit
	c) A condition hazardous to test staff or the test facility requires mitigation.	N/A, a hazardous test condition did not occur
9.3	For residential use systems, the gas collection data gathered in 9.2 shall be compared to the smallest room installation specified by the manufacturer to determine if the flammable gas collected exceeds 25% LFL in air.	BESS is intended for non-residential installation only
	Test method – Outdoor ground mounted units	
	Outdoor ground mounted non-residential use BESS being evaluated for installation in close proximity to buildings and structures shall use the test method described in Section 9.2.	BESS is intended for installation in close proximity to building or structures. Requirements from 9.2 used as applicable for outdoor installation.
	If intended for outdoor use only installations, following measurements are not needed. - the smoke release rate, - the convective and chemical heat release rate and content, - velocity - temperature of the released vent gases	
	Outdoor ground mounted residential use BESS being evaluated for installation in close proximity to buildings and structures.	N/A, BESS is intended for non-residential installations only



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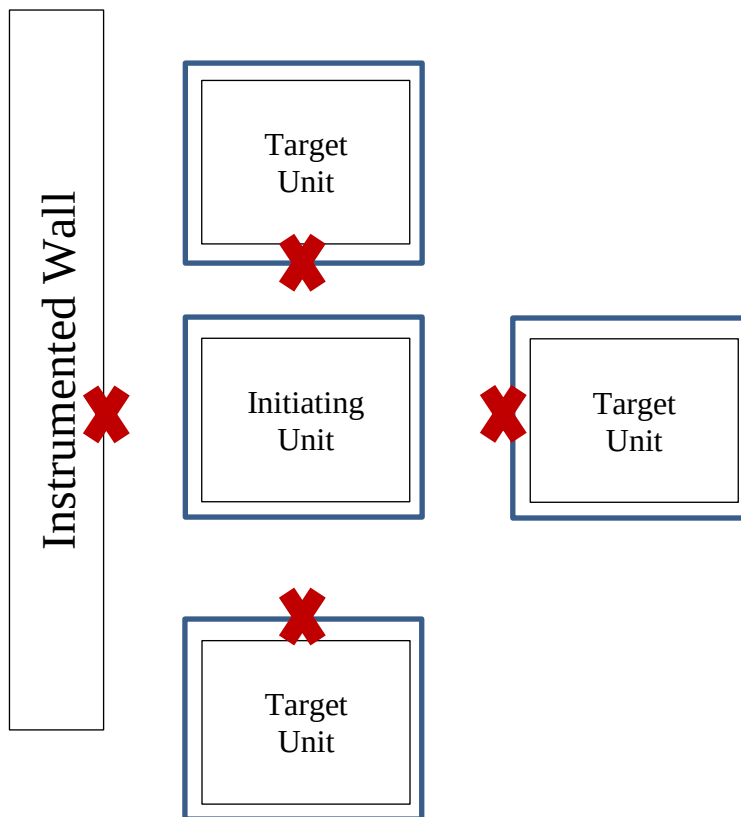
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Heat flux measurements for the accessible means of egress.	☒ Heatflux measured ☐ No accessible egress path
Test samples installed as shown in Figure 9.2 in proximity to an instrumented wall section that is 3.66-m (12-ft) tall with a 0.3-m (1-ft) wide horizontal soffit (under surface of the eave shown in Figure 9.2). The sample mounted on a support substrate and spaced from the wall in accordance with the minimum separation distances specified by the manufacturer.	☒ Conformed D – Distance of ESS from external wall Required by manufacturer (ft): 10 Measured during testing (ft): 10
Exception: If the manufacturer requires installation against non-flammable material	☐ Test perform with manufacturer recommended backing material ☒ Test performed without manufacturer recommended backing material

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X – Denotes typical thermocouple locations, specific positions dependent on installation details.





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	Target BESS installed on each side of the initiating BESS in accordance with the manufacturer's installation specifications.	☒ Conformed
9.4	Test Method – Indoor wall mounted units	
	Indoor wall mounted BESS tested in accordance with Section 9.2, except as modified in this section.	N/A, BESS is intended for non-residential outdoor ground mounted installation only.
9.5	Test Method – Outdoor wall mounted units	
	Outdoor wall mounted BESS tested in accordance with Section 9.2, except as modified in this section.	N/A, BESS is intended for non-residential outdoor ground mounted installation only.
9.6	Rooftop and open garage installations	
	Non-residential use rooftop or open garage installations BESS tested be in accordance with 9.2.	BESS is not intended for rooftop or open garage installation

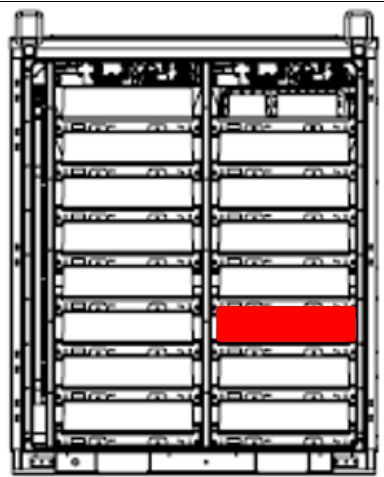
Section 9	TABLE: Unit Level Test
Sample No	DUT 1
Type of Installation:	Outdoor ground mounted, non-residential
Representative of Other Type of Installation:	None
Open Circuit Voltage of Initiating BESS Before Test(Vdc):	1466*
Open Circuit Voltage of Module 1 with BESS Before Test (Vdc):	181.7
Open Circuit Voltage of Module 2 with BESS Before Test (Vdc):	183.1
Open Circuit Voltage of Module 3 with BESS Before Test (Vdc):	182.0
Open Circuit Voltage of Module 4 with BESS Before Test (Vdc):	182.1
Open Circuit Voltage of Module 5 with BESS Before Test (Vdc):	183.0
Open Circuit Voltage of Module 6 with BESS Before Test (Vdc):	183.1
Open Circuit Voltage of Module 7 with BESS Before Test (Vdc):	183.4
Open Circuit Voltage of Module 8 with BESS Before Test (Vdc):	183.6
Open Circuit Voltage of Module 9 with BESS Before Test (Vdc):	182.3
Open Circuit Voltage of Module 10 with BESS Before Test (Vdc):	182.4
Open Circuit Voltage of Module 11 with BESS Before Test (Vdc):	183.4
Open Circuit Voltage of Module 12 with BESS Before Test (Vdc):	183.3
Open Circuit Voltage of Module 13 with BESS Before Test (Vdc):	184.1

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Open Circuit Voltage of Module 14 with BESS Before Test (Vdc):	183.5
Open Circuit Voltage of Module 15 with BESS Before Test (Vdc):	183.9
Open Circuit Voltage of Module 16 with BESS Before Test (Vdc):	183.1
Thermal runaway initiation Method:	Film Heater
Location of Initiating module within BESS:	

*Maximum Voltage is 1497.6

Heat Release Data

N/A, not required for outdoor only installations.

Observation of Flying Debris or Explosive Discharge of Gases

Time (H:MM:SS)	Observation
0:00:00	Test Start / Heater Activated
0:30:00	No Observations
1:00:00	No Observations
1:08:14	1st full vent from front of initiating module, Audible alarm sounding, flashing light on front of container door.
1:08:31	Slight Smoke exiting from door seal and cabling conduit, strong electrolyte smell present.
1:11:05	Additional Puff with continued Slight Smoke exiting from door seal and cabling conduit, strong electrolyte odor present.
1:12:00	Additional Puff with continued Slight Smoke exiting from door seal and cabling conduit, strong electrolyte odor present.
1:15:30	Smoking reduced, slight odor present.
2:30:00	No Signs of Smoke, All Thermocouples are decreasing.
2:36:48	Test Video Stopped
7:37:10	Rain observed over test site and specimen
22:53:10	Rain observed over test site and specimen
26:14:04	Data Acquisition Stopped, Test Complete

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Smoke exiting cube

Flammable Gas Generation and Composition Data

N/A, not required for outdoor only installations.

Activation of Integral Fire Protection System.

Not used.

Smoke release rate

N/A, not required for outdoor only installations.

Temperature Measurement

Thermocouple Location	Temperature Limit (°C)	Measured Maximum Temperature (°C)
Ambient Temperature Before Test	40	33
Max Wall Surface Temperature (60in. from ground)	97	49.3
Maximum Target BESS Temperature (Target across means of egress, level with initiating module of initiating BESS)	168.2	38.1



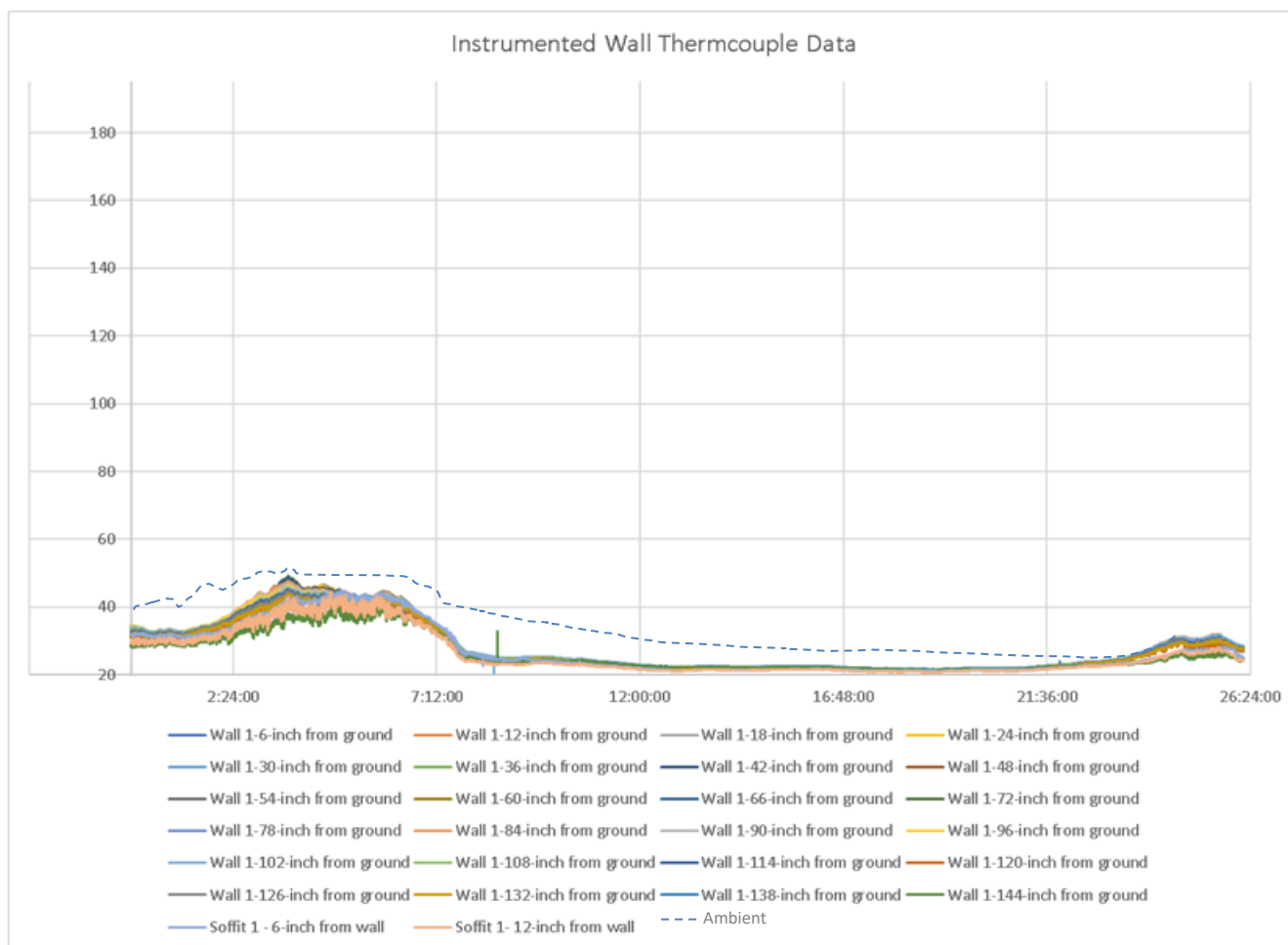
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Maximum Surface Temperature of Module within Target BESS (Target across means of egress, behind grill and level with initiating module of initiating BESS)	168.2	38.1
Maximum Ceiling or Soffit Surface Temperatures (12in. from wall)	97	47.7



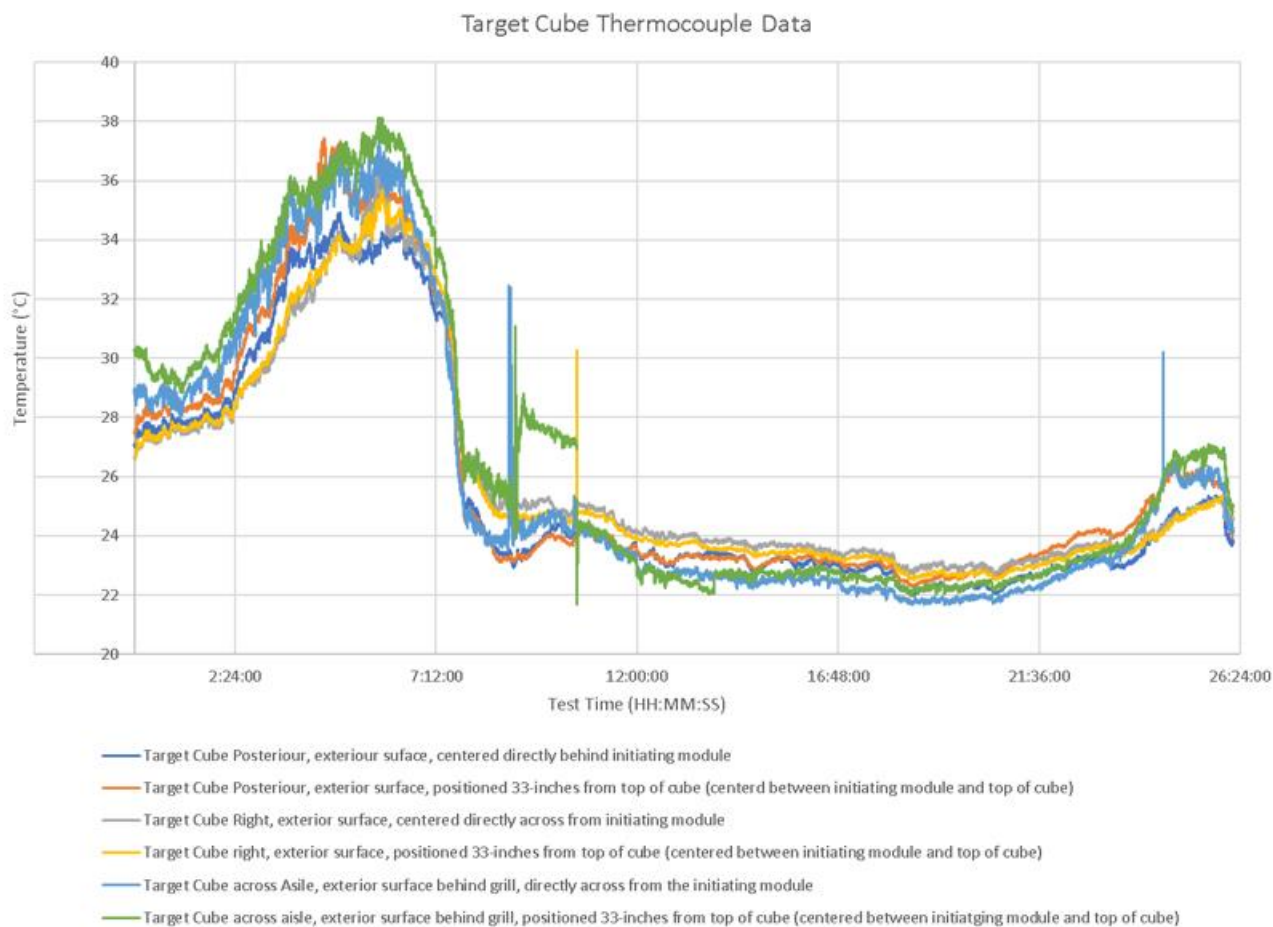


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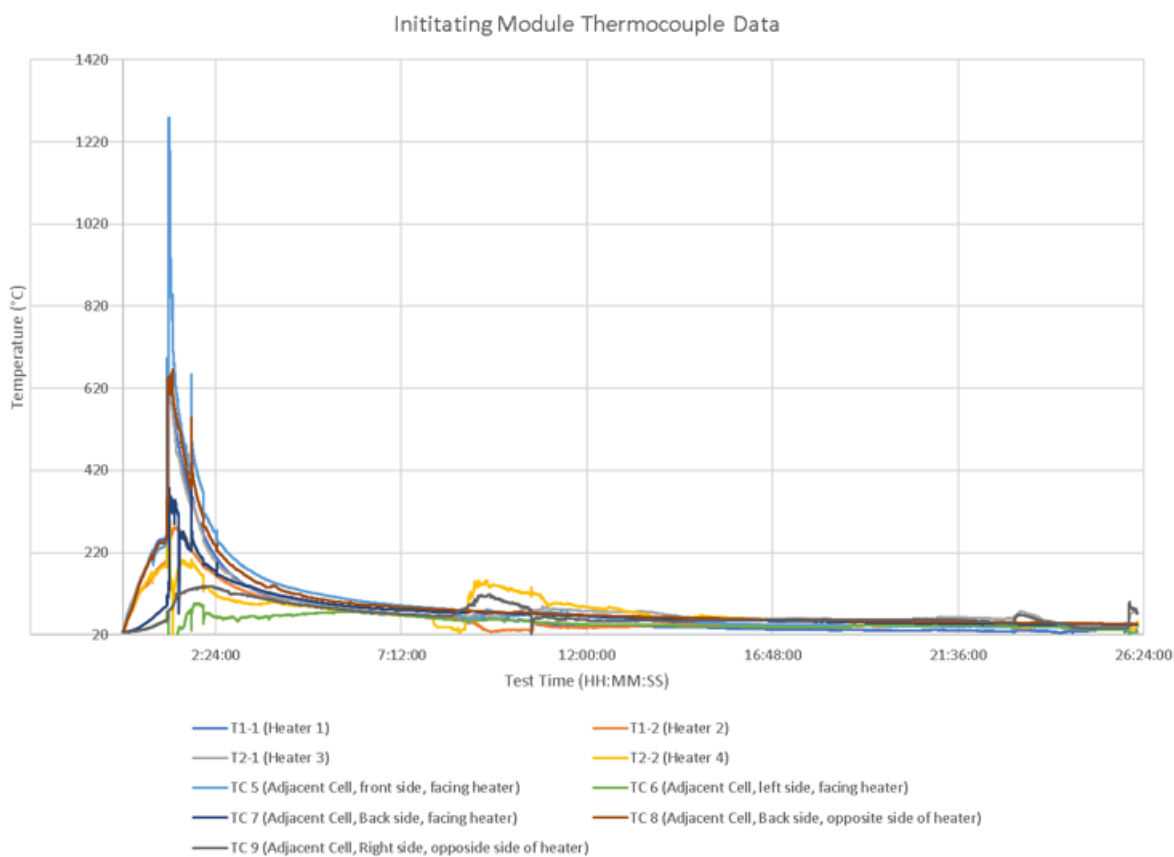


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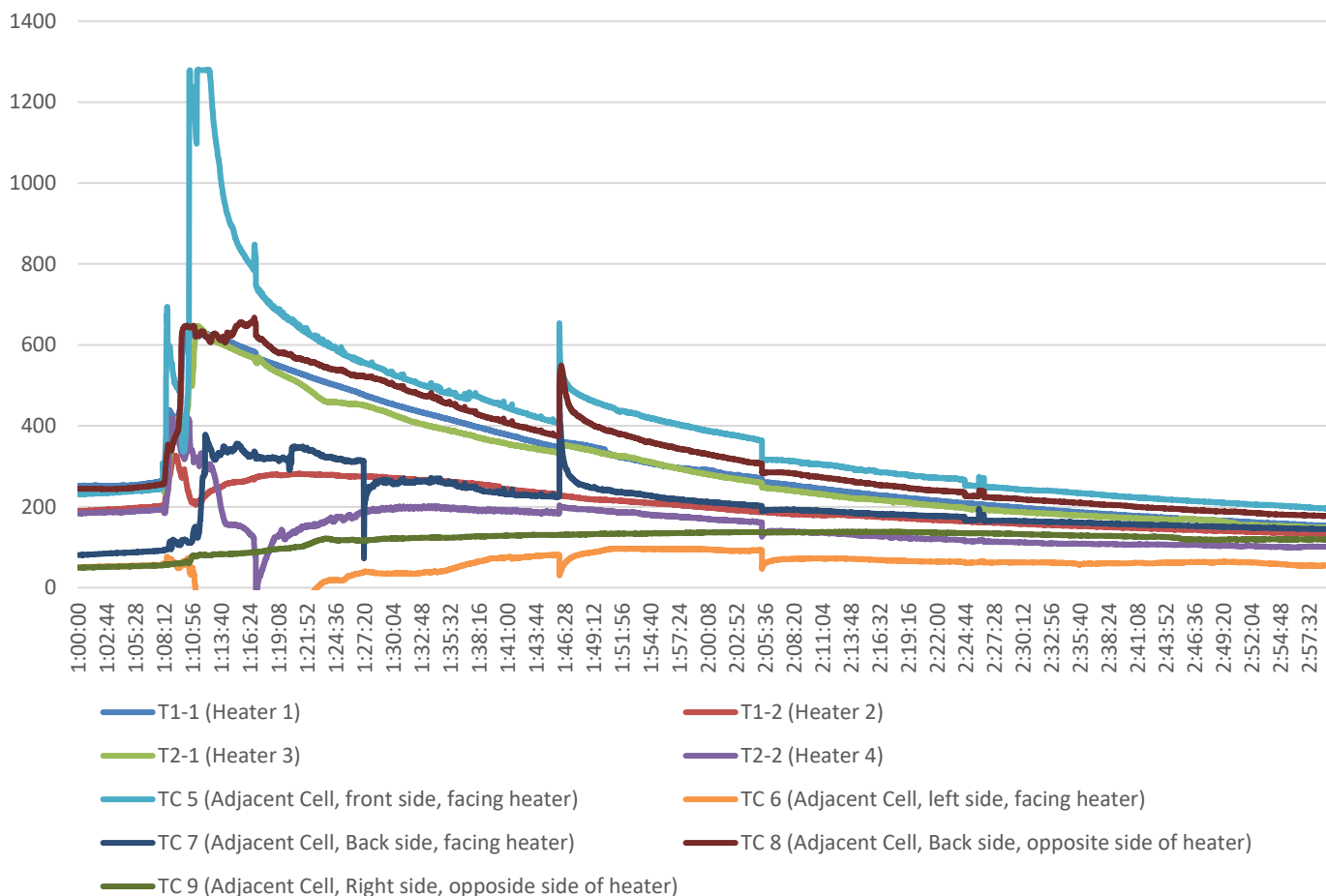
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Spotlight View - Initiating Module



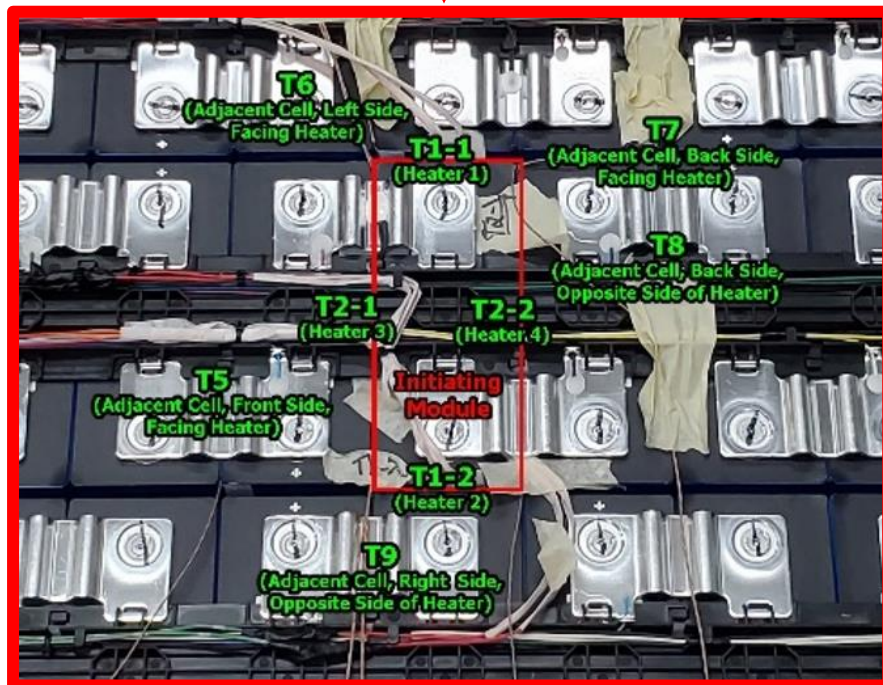
Note: TC 6 was damaged during thermal runaway, resulting in negative temperature readings.

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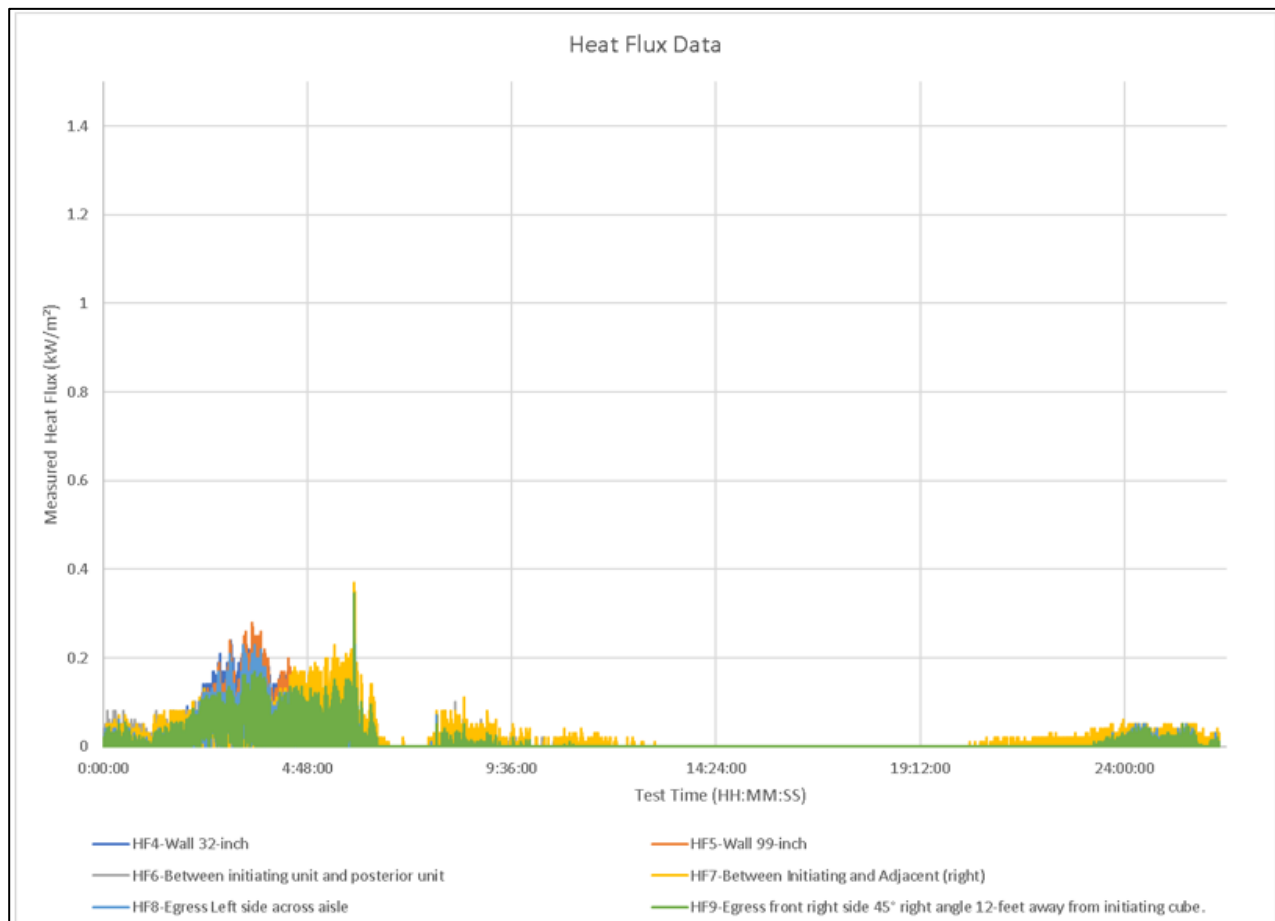
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Heat Flux Measurement

Heat flux Location	Measured Maximum Heat Flux (kW/m ²)
Target Wall Surface -32 in. from ground	0.3
Target Wall Surface -99 in. from ground	0.3
Between initiating and posterior unit	0.2
Between initiating and adjacent unit	0.4
Left side means of egress	0.3
Egress in front of initiating unit	0.3



Note: The Heat Flux Readings observed during the test were below the calibrated detectable limit of the sensors. The lower calibrated limits are 0.1 kw/m² and 1.45 kw/m²

The results relate only to the items tested.

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Master Contract: 301546	Model: 06-01-0005-16	Page number 30 of 31
Project / Network: 80122674	Description: LFP Energy Storage System, 1500V, 745kWh	

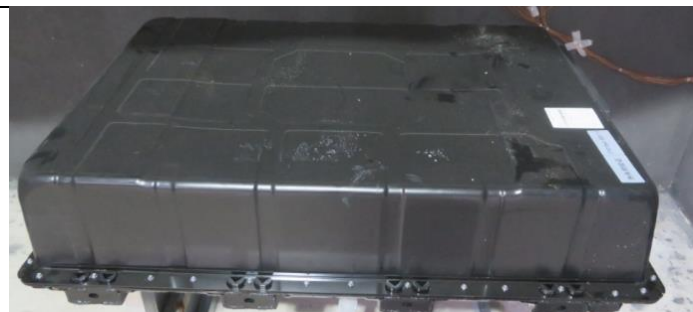
Supplementary information:



Initiating BESS with door open prior to test



Initiating BESS with door open following test



The results relate only to the items tested.

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Master Contract: 301546	Model: 06-01-0005-16	Page number 31 of 31
Project / Network: 80122674	Description: LFP Energy Storage System, 1500V, 745kWh	

Module cover before that has not gone through testing	Module cover after removed from BESS following test
 Module without cover that has not been tested	 Initiating module after being removed from the initiating BESS and having the cover removed.

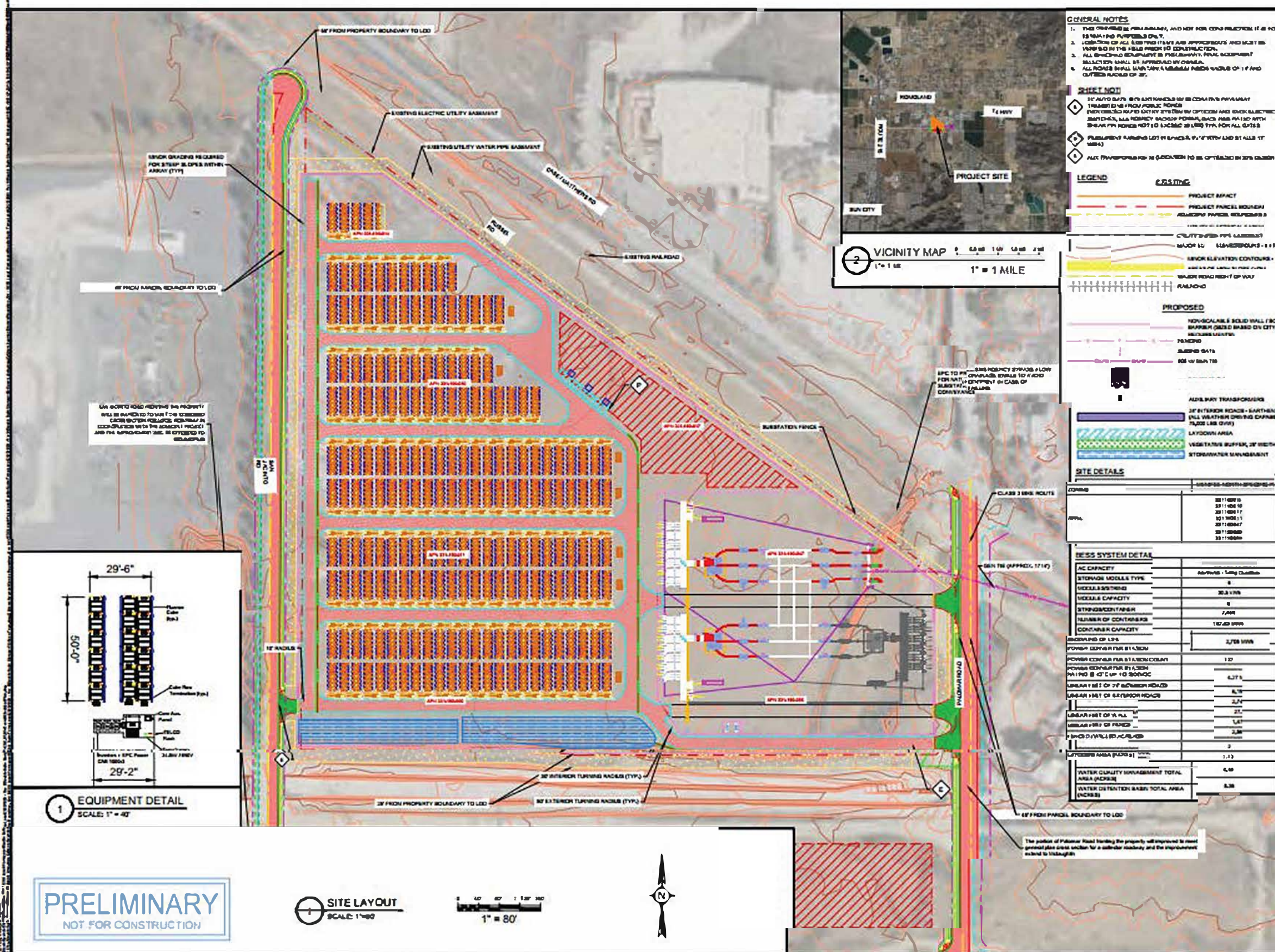
ANSI/CAN/UL 9540A:2019 Fourth Edition, Dated November 12, 2019 - Section 10 Installation Level Testing

Installation level testing not required.

End of Report....

APPENDIX 7.4

Overall Site BESS Electrical Plan

PE STAMP:

KEY PLAN:

REVISIONS:		
NO.	DATE	DESCRIPTION
0	EXP 00007	ADD PN DESIGN
1	EXP 00007	ADD PN DESIGN
2	EXP 00007	ADD PN DESIGN UPD
3	EXP 00007	ADD PN DESIGN UPD
4	EXP 00007	ADD PN DESIGN UPD
5	EXP 00007	ADD PN DESIGN UPD
6	EXP 00007	ADD PN DESIGN UPD
7	EXP 00007	ADD PN DESIGN UPD
8	EXP 00007	ADD PN DESIGN UPD

**DOUBLE BUTTE
STORAGE**

INQUIRY LOCATION
CITY OF MENIFEE, CA
RIVERSIDE COUNTY
33.7412, -117.1563

SHEET TITLE & DESCRIPTION

OVERALL BESS
ELECTRICAL PLAN

495 MW / 2.705
MWh BESS

ES12.000
V. Lolla
M. House
S. Shrestha
03/01/2022

AS NOTED

ES-E.01.01	8
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