DOCKETED	
Docket Number:	26-OPT-01
Project Title:	Vaca Dixon Power Center Project
TN #:	268171-3
Document Title:	Appendix W Arges BESS Hazard Consequence Analysis_VDPC
Description:	The Hazard Consequence Analysis evaluates potential fire and safety risks for the Project, detailing mitigation measures, distances to sensitive receptors, and modeling of hazardous gas releases during thermal runaway events using UL 9540A test data and PHAST software to ensure compliance with fire codes and protect life safety. W.A SYL SU3794U3794KC UL 9540A Cell Level Test Result
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Submission Date:	1/6/2026 2:55:00 PM
Docketed Date:	1/6/2026

Appendix W

Arges BESS Hazard Consequence Analysis

COFFMAN ENGINEERS

VACA DIXON POWER CENTER PROJECT

Hazard Consequence Analysis

COFFMAN PROJECT NO. 251796

IFP SUBMITTAL

December 19, 2025

Prepared for: Arges BESS LLC

HAZARD CONSEQUENCE ANALYSIS

FOR

ARGES BESS

Vacaville, California

Project Number: 251796

Revision	Date	Description
A	11/11/2025	Issued for Review
B	12/19/2025	Issued for Permit

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TABLE OF CONTENTS

APPENDICES

ABBREVIATIONS

AHJ	Authorities Having Jurisdiction
BESS	Battery Energy Storage System
BMS	Battery Management System
CFC	California Fire Code
DC	Direct Current
EMS	Energy Management System
ESS	Energy Storage System
FACP	Fire Alarm Control Panel
FCC	Fire Command Center
HMA	Hazard Mitigation Analysis
HVAC	Heating, Ventilation, and Air Conditioning
IDLH	Immediately Dangerous to Life and Health
kV	Kilovolt
LFL	Lower Flammability Limit
LPC	Local Plant Controller
MW	Megawatt
MWh	Megawatt-hour
MV	Medium Voltage
NEC	National Electric Code
NESC	National Electric Safety Code
PCS	Power Conversion System
PEL	Permissible Exposure Limits
SCADA	Supervisory Control and Data Acquisition
UPS	Uninterruptible Power Supply
VDPC	Vaca Dixon Power Center

1 INTRODUCTION

This Hazard Consequence Analysis (HCA) is provided by Coffman Engineers, Inc. (Coffman) for the Arges Battery Energy Storage System (BESS) facilities associated with the Vaca Dixon Power Center (VDPC) project located in Vacaville, California. This document is to be used in conjunction with the Emergency Response Plan (ERP) so that the Operator and First Responders understand the practices and procedures to be followed to provide immediate and effective response to emergencies that may arise.

The purpose of this HCA is to identify the distance from the project site to the nearest sensitive receptors, and identify and characterize the quantities and locations of hazardous chemicals that could be released during a thermal runaway and/or fire event. This HCA is based on the specific project system design including equipment specifications, location, and plume dispersion modeling using PHAST™ Version 8.9 software from DNV®.

Spill control and neutralization is not required as fire suppression using fire sprinkler systems interior to the Energy Storage System (ESS) enclosures is not the fire protection design approach for this site and spill control and neutralization is not required for lithium-ion battery installations per CFC § 1207.6.2. Three (3) fire hydrants are provided within the site near to the site entrances for dedicated emergency operations only.

2 PROJECT DESCRIPTION

2.1 Project Site

The Arges BESS yard will contain 128 SYL SU5016U1250KC enclosures (including augmentation) for an approximate total energy capacity of 100 MW / 400 MWh. The BESS yard portion is located within Vacaville, California. The site will include enclosures manufactured by SYL, containing lithium-ion battery technology.

The details of the Arges BESS facilities associated with the project are discussed in the Hazard Mitigation Analysis (HMA) in detail and summarized in this section. A separate HMA will be prepared for the Vaca Dixon BESS facilities associated with the project. A vicinity map is provided in Figure 2.1(a). The site will include one-hundred twenty-eight (128) SYL SU5016U1250KC enclosures (including augmentation enclosures) installed over a footprint of approximately 5.75 acres within a 10-acre parcel (APN 0133-060-060). The Vaca Dixon 57 Mwh BESS site is located to the south within the same parcel and occupies approximately 4.25 acres. The Vaca Dixon 57 MWh BESS project is assessed in a separate report. The project site will be provided with fire department access, three (3) fire hydrants, transformers, and the necessary infrastructure for connection to the utility.

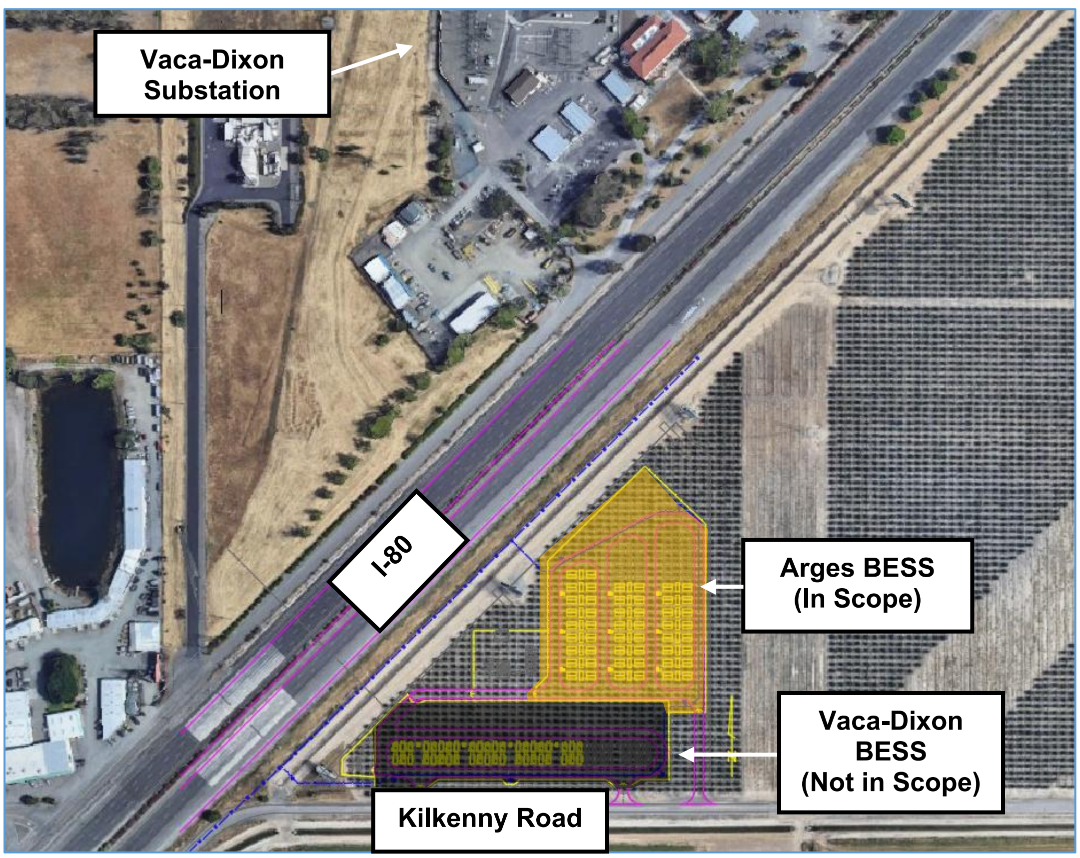


Figure 2.1(a) - Arges BESS Vicinity Map (North ↑)

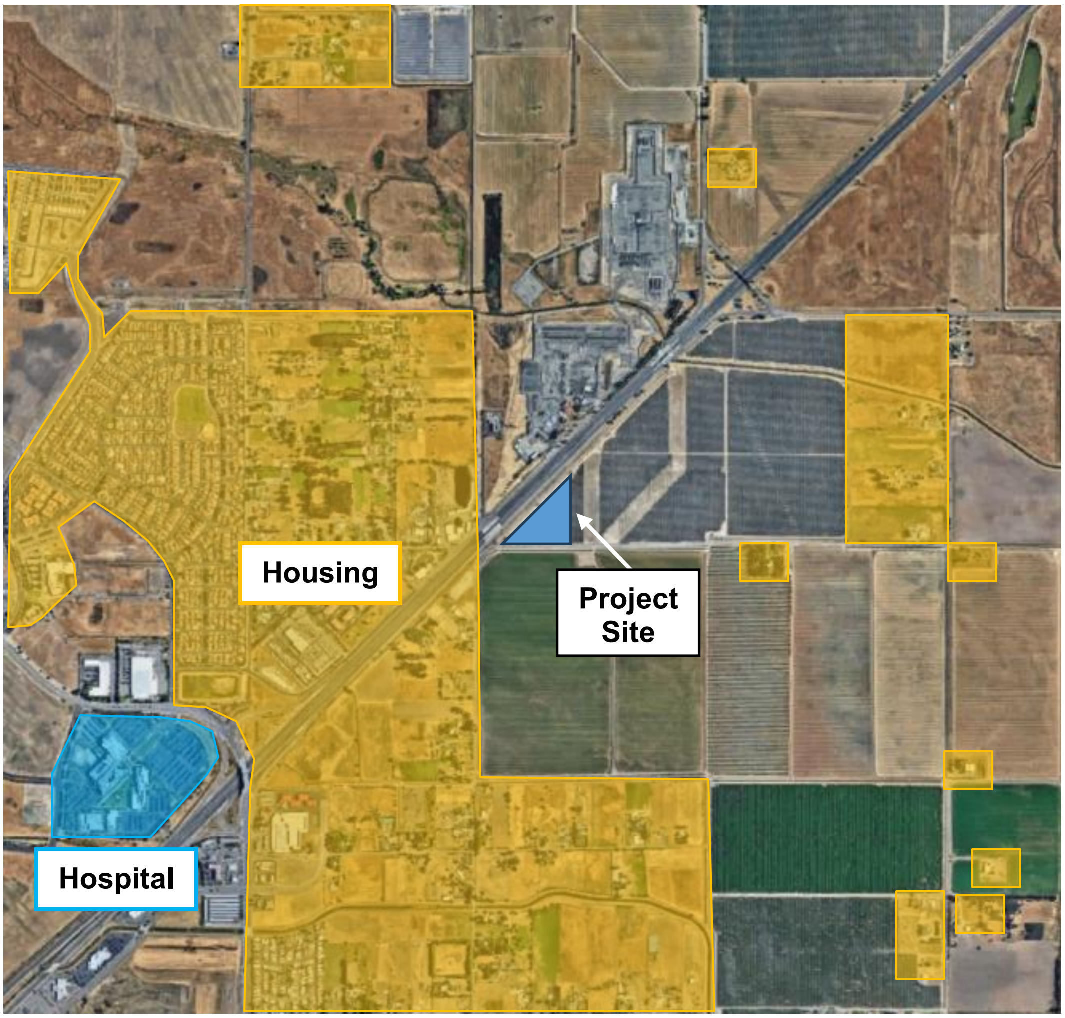


Figure 2.1(b) – Sensitive Receptors within 1 Mile of ESS Yard (North ↑)

2.2 Surrounding Area

The BESS yard is located in a mixed agricultural, commercial, and residential area within Vacaville, California. The landscape is typical of the Central Valley with low foliage, agricultural fields, and scattered trees. The adjacent properties are zoned for Agriculture, Business Park, and Public/Institutional uses. Additional occupancies including schools and hospitals are discussed later in the document.

Select nearby locations of sensitive receptors beyond one mile away from the site are provided below including approximate straight-line distances with compass headings. A zero-degree heading starts at magnetic North and rotates clockwise. Sensitive receptors are considered within this document as children, elderly, or others at a heightened risk of negative effects because of air pollutants.

2.2.1 Schools:

- The Academy of 21st Century Learning – 0.92 miles away Southwest at a 249-degree heading
- Vacaville Unified School District – 2.66 miles away Southwest at a 218-degree heading
- Edwin Markham Elementary School – 3.39 miles away Southwest at a 240-degree heading
- Browns Valley Elementary School – 3.22 miles away Southwest at a 255-degree heading
- Golden Hills School – 3.63 miles away Southwest at a 235-degree heading
- Cooper Elementary School – 2.81 miles away Southwest at a 202-degree heading

2.2.2 Hospitals/Health Centers:

- Kaiser Permanente Vacaville Medical Center – 0.77 miles away Southwest at a 236-degree heading

2.2.3 Daycare Facilities:

- Growing Cubs Daycare – 1.24 miles away Northwest at a 301-degree heading
- Millenium Child Development Center – 2.98 miles away West at a 260-degree heading
- Childtime of Vacaville – 3.01 miles away Southwest at a 219-degree heading
- Paula’s Happy Vacaville Daycare – 2.88 miles away South at a 197-degree heading

2.2.4 Residential Housing:

- There are concentrated and dispersed housing areas in all directions around the project site, with the closest ones being located 0.24 miles away to the west

3 CODE STUDY

3.1 Applicable Codes

The Authority Having Jurisdiction (AHJ) for the Arges BESS facility is the Vacaville Fire Department. The applicable codes with regards to fire protection and life safety, with local amendments, are listed below.

- CFC, California Fire Code, (2025 Edition), as adopted by the City of Vacaville
- NFPA 72, National Fire Alarm and Signaling Code (2025 Edition)
- NFPA 70, National Electrical Code (NEC) (2023 Edition)
- NFPA 855, Standard for the Installation of Stationary Energy Storage Systems (2023 Edition)
- UL 9540, Standard for Energy Storage Systems and Equipment (2023 Edition)
- UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (2019 Edition)

The following standards, not adopted by the CFC are used as guidance:

- Pre-incident planning per NFPA 1620, Standard for Pre-incident Planning (2020 Edition)

4 SYSTEM EQUIPMENT

4.1 Main ESS Components

The following section provides a description of the SYL SU5016U1250KC (referred to in this document as "enclosure") is 8-ft wide x 19.9-ft long x 9.5-ft tall. Enclosures are in groups of 4, together with the ancillary equipment (e.g., transformers). See the figure below for an image of a SYL SU5016U1250KC enclosure. Figure 4.1(a) below provides a visual of the general arrangements. The ESS enclosures are organized in rows with fire department access roads as shown in Figure 4.1(b).

Figure 4.1(a) – SYL SU5016U1250KC Enclosure

Each enclosure is self-contained with its own integrated battery modules, battery management systems, thermal management systems, and explosion prevention system. A simplified arrangement of the Arges BESS facility for reference is shown below in Figure 4.1(b) with the Fire Command Center (FCC). Note that an FCC has the same function as a First Responder Station.

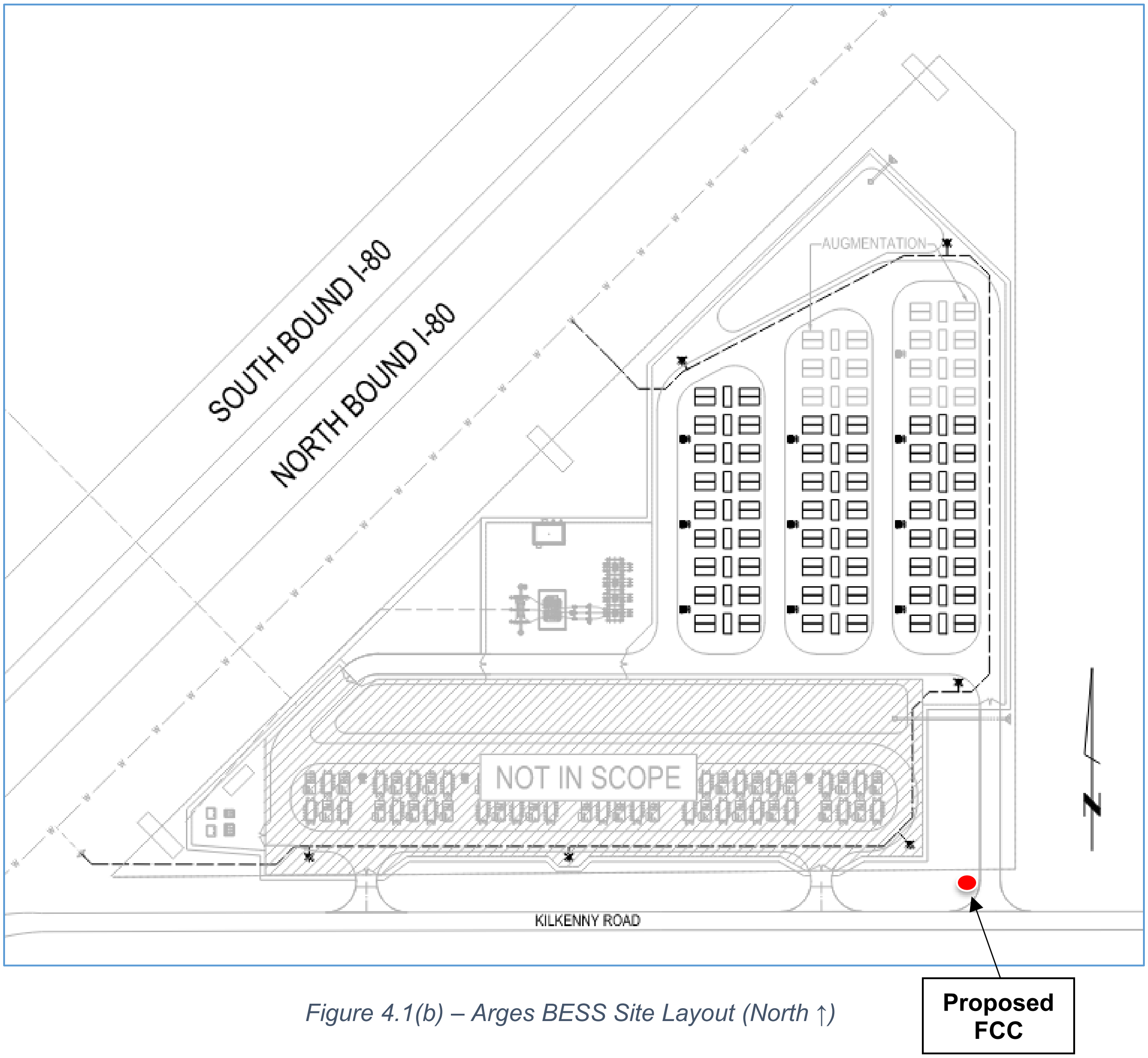


Figure 4.1(b) – Arges BESS Site Layout (North ↑)

4.2 Battery Arrangement and Quantities

The Arges BESS portion of the Vaca Dixon Power Center (VDPC) contains 128 SYL SU5016U1250KC BESS enclosures (including augmentation). One battery bay, or the accessible portion of battery modules behind one enclosure door, is shown in Figure 4.2 below. Each SU5016U1250KC BESS enclosure has 6 battery bays, and each battery bay contains 2 racks. One rack is a collection of 4 modules and within each module there are 104 battery cells. Including augmentation, Arges BESS will utilize 638,976 battery cells.

Figure 4.2 – View of single SYL SU5016U1250KC battery bay housing 8 modules.

5 LARGE SCALE FIRE TESTING

5.1 UL 9540A Fire Test

This HCA has been prepared after reviewing the UL 9540A test result reports. The unit-level test is included in Appendix A of this report. Tests were conducted to the 4th edition of the UL 9540A test procedures. Key results of the UL 9540A testing are shown in the following sections.

5.1.1 Cell Level Test

The cell level test document that was referenced for this report was published by TÜV Rheinland (Shenzhen) Co., Ltd. Dated 12/06/2023, Test Report No. CN23F118 001.

The cell test included the same test repeated 5 times with a separate cell each time. Each time, the single cell was forced into thermal runaway by inducing heat via a single film heater at a rate between 4°C/min and 7°C/min.

- On average, cell venting occurred at 203.7°C (398.66°F) and thermal runaway occurred at 295.7°C (564.26°F).
- Gas composition was analyzed showing the primary flammable gas constituents as hydrogen, methane and ethylene. The primary toxic gas was carbon monoxide.

5.1.2 Module Level Test

The module level test document that was referenced for this report was published by TÜV Rheinland (Shanghai) Co., Ltd. Dated 6/28/2024, Report No. CN248UKE 001.

The module test was conducted with 3 cells being forced into thermal runaway by inducing heat via 2 film heaters between the 3 initiating cells.

- Thermal runaway propagated to 1 non-induced cell within the initiating module, resulting in a total of 4 cells in thermal runaway.
- Gas composition was analyzed showing the primary flammable gas constituents as hydrogen, methane and other hydrocarbons described as “Propane Equivalent”. The primary toxic gas was carbon monoxide.
- No flying debris, explosive discharge of gas, sparks or electrical arcs were observed during the test.

5.1.3 Unit Level Test

- The unit test was conducted with a single module being forced into thermal runaway with 2 film heaters used to simultaneously heat 3 cells within the module. No fire suppression system was installed for any test.
- Thermal runaway of a single module occurred approximately 54 minutes after heater activation. At approximately 2 hours and 45 minutes temperature readings inside the initiating module showed it had cooled to approximately the same temperature as when thermal runaway initiated. Cooling continued for the duration of the test.
- Thermal runaway propagated to 1 non-induced cell within the initiating module, resulting in a total of 4 cells in thermal runaway.

- The unit test results demonstrate that the thermal runaway event was limited to a single module within the initiating rack unit and there was no propagation to other modules within the initiating rack unit or any of the target rack units. There were no observations of a deflagration or explosive discharge of gases.
- The maximum external heat flux detected was 0.0061 kW/m^2. This level of heat flux is below the level that can ignite combustibles.
  - For perspective on the effects of thermal radiation at various radiant heat flux values are provided below.
    - 1 kW/m^2 – Solar radiation (sunny day)
    - 10 kW/m^2 – Pain after 2 seconds of skin exposure (SFPE Handbook, 4th ed. Table 2-6.19, Perkins)
    - 29 kW/m^2 – Wood ignites spontaneously after prolonged exposure (Drysdale, 2005)
- The UL 9540A unit test demonstrates that the ESS enclosure design will limit a thermal runaway event from propagating outside of a single enclosure with a clearance distance of 40mm (1.58 inches) to adjacent units. This testing supports the proposed layout and spacing of rack units at the site.
- Additional thermal runaway prevention will be provided via a Battery Management System (BMS) that monitors battery voltage, temperature, etc. to detect irregularities and disconnect power if needed. Note that the BMS may cease charging and discharging, but will not dissipate stranded energy.

6 FIRE PROTECTION FEATURES

6.1 Fire Suppression / Thermal Runaway Mitigation System

The failure of a battery module could lead to a thermal runaway event. UL 9540A testing has demonstrated that the failure and thermal runaway of one module is likely to be contained within the ESS enclosure. A clean agent suppression system is provided inside the enclosure, however UL9540A testing was conducted without this suppression system and a thermal runaway event will likely be contained to one module. If thermal runaway and cell venting occurs, the enclosure's exhaust ventilation system is expected to activate if LFL concentration above 10% is detected.

Three (3) fire hydrants are provided within the site for fire department use and exterior fire protection. In addition, each enclosure is equipped with smoke, heat, and combustible gas detectors to trigger a fire alarm in the event of fire or thermal runaway. The features are discussed in the Hazard Mitigation Analysis (HMA) for the project.

6.2 Smoke, Heat, and Gas Detection

Each SYL SU5016U1250KC ESS enclosure will contain smoke detectors, heat detectors, and combustible gas detectors. If respective detection criteria are reached within the enclosure, these detectors will send either level 1 (single smoke/heat detector) or level 2 (multiple smoke/heat detectors) or Gas Concentration (gas detector) alarm signals to the enclosure's internal fire alarm panel. These signals will activate the alarm bell, horn/strobe, or exhaust ventilation of the ESS enclosure and individual alarm signals will also be sent to the site FCC and relayed via a cellular communicator to a central station and then to the responding fire department. For additional information on the fire alarm system, reference the fire alarm drawings, HMA, & ERP.

6.3 Explosion Protection

The explosion prevention system within the SYL SU5016U1250KC ESS enclosures employs an automatic approach that integrates gas detection devices, ventilation system, and operational safeguards:

- Gas Detection: Each enclosure houses two gas detectors specifically designed to detect flammable gases (e.g., H_2, hydrocarbons) typically released during lithium-ion battery thermal runaway. The detectors are calibrated to activate at a threshold of 10% LFL.
- Exhaust Ventilation (NFPA 69): Upon gas detection, one exhaust fan (697 cfm) activates to remove flammable gases from the enclosure.
- Operational Controls: Detection triggers several actions: alarms are sent, charging/discharging processes halt, off-gassing valves open, and exhaust ventilation activates.

6.4 Fire Alarm System/Fire Command Center

A networked site fire alarm panel and a Fire Command Center (FCC) is provided at the site entrance and connected to each remote fire alarm panel located throughout the site. The fire alarm panels monitor fire alarm devices within the ESS enclosures and interface with the FCC. These systems provide current information on active alarms and system telemetry to the responding fire department without approaching the battery enclosure.

The fire alarm system is monitored through a cellular connection and transmits supervisory, trouble and alarm signals to a constantly attended central station contracted by the project owner.

6.5 Battery Management System

A Battery Management System (BMS) is provided for each SYL SU5016U1250KC enclosure. The total BMS system is comprised of three (3) components known as the Module Battery Management Unit (BMU), Battery Cluster Unit (BCU), and Battery Array Unit (BAU). Each BMU monitors one (1) module, which supplies enclosure level information to the BCU, and finally that information is processed within the BAU. Together, these components act as the BMS which monitors state of charge (SOC), temperature, and voltage to identify modules and cells that are not operating within acceptable ranges. The BMS can disconnect module clusters by switching the DC contactor from the BCU to cease charging/discharging. The BMS communicates with the Energy Management System (EMS) which may shut down the affected SYL SU5016U1250KC if needed and alert the Network Operator and SCADA monitors. The actions of the BMS system are not functionally tested in UL 9540A testing.

6.6 Signage

Approved signage shall indicate the type of lithium batteries in the enclosure, identify that the enclosure contains energized battery systems, and that the enclosure contains energized electrical circuits in accordance with CFC Section 1207.4.8.

7 POTENTIALLY HAZARDOUS EMISSIONS

7.1 Characterization of Potential Hazards

The UL 9540A cell level test report identifies thirteen (13) hazardous substances captured during the thermal runaway that may have an impact on nearby receptors described earlier. The hazardous substances include carbon monoxide, carbon dioxide, hydrogen, methane, ethylene, ethane, propene, propane, butane, butene, pentane, isopentane and cyclopentane.

The following describes the potential air toxics, and potential effects from acute inhalation exposure: Acute Exposure Guideline Levels (AEGLs), Emergency Response Planning Guidelines (ERPGs), Temporary Emergency Exposure Limits (TEELs), Immediately Dangerous to Life and Health (IDLH), and Protective Action Criteria for Chemicals (PACs). Descriptions of health effects are summarized from the National Institute of Health PubChem database. ERPGs are developed by the Emergency Response Planning committee of the American Industrial Hygiene Association (AIHA).

AEGLs are developed by the National Academy of Sciences. TEELs are derived by the U.S. Department of Energy Subcommittee on Consequence Assessment and Protective Actions (SCAPA) according to a specific, standard methodology. IDLH limits are derived by the National Institute of Occupational Safety and Health (NIOSH). The public exposure guideline systems use a three-tier system to differentiate severity levels except for IDLH which has one level per substance. The tier levels for each system are described below as published by the EPA:

The AEGL values are defined as:

- AEGL-1 is the airborne concentration (expressed as parts per million [ppm] or milligrams per cubic meter [mg/m^3]) of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.
- AEGL-2 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
- AEGL-3 is the airborne concentration, (expressed as ppm or mg/m^3), of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

The ERPG values are defined as follows:

- ERPG-1 is the maximum airborne concentration below which nearly all individuals could be exposed to for up to one hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odor.
- ERPG-2 is the maximum airborne concentration below which nearly all individuals could be exposed to for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

- ERPG-3 is the maximum airborne concentration below which nearly all individuals could be exposed to for up to one hour without experiencing or developing life-threatening health effects.

The TEEL values are defined as:

- TEEL-1 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, when exposed for more than one hour, could experience notable discomfort, irritation, or certain asymptomatic, non-sensory effects. However, these effects are not disabling and are transient and reversible upon cessation of exposure.
- TEEL-2 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, when exposed for more than one hour, could experience irreversible or other serious, long-lasting, adverse health effects or an impaired ability to escape.
- TEEL -3 is the airborne concentration (expressed as ppm or mg/m^3) of a substance above which it is predicted that the general population, including susceptible individuals, when exposed for more than one hour, could experience life-threatening adverse health effects or death.

The PACs dataset is a hierarchy-based system composed of the public exposure guideline systems. The PACs dataset prioritizes AEGLs (final or interim), followed by ERPGs, and lastly TEELs when determining values for levels of concern. The distance of toxic endpoints uses the PAC-2 values per EPA guidance to evaluate potential risk to nearby receptors or first responders.

The IDLH level is defined as:

- The airborne concentration (expressed as ppm or mg/m^3) from which a worker could escape without injury or irreversible health effects from an exposure in the event of the failure of respiratory protection equipment. The IDLH considered a maximum concentration above which only a highly reliable self-contained breathing apparatus (SCBA) providing maximum worker protection should be permitted.

The table below summarizes the individual values for each gas species measured in the UL 9540A cell level test.

Table 7.1 – Summary of Hazardous Thresholds

			EPA[1] (1 hour)			**Cameo Chemicals[2] (NOAA)**			**U.S. Dept. of Energy[3]**				**NIOSH[4]**
Gas Species	**Formula**	**CAS #**	**AEGL-1**	**AEGL-2**	**AEGL-3**	**ERPG**	**ERPG**	**ERPG**	**PAC-1**	**PAC-2**	**PAC-3**	**LFL %**	**IDLH**
Carbon Monoxide	CO_2	630-08-0	-	**83**	**330**	200	350	500	75	83	330	12.5	**1,200**
Carbon Dioxide	CO_2	124-38-9	-	-	-	-	-	-	30,000	40,000	50,000	-	40,000
Hydrogen	H_2	1333-74-0	-	-	-	-	-	-	65,000	230,000	400,000	**4**	-
Methane	CH_4	74-82-8	-	-	-	-	-	-	65,000	230,000	400,000	**5**	-
Ethylene (Ethene)	C_2H_4	74-85-1	-	-	-	-	-	-	600	6,600	40,000	**2.7**	-
Ethane	C_2H_6	74-84-0	-	-	-	-	-	-	65,000	230,000	400,000	**3**	-
Propane	C_3H_8	74-98-6	5,500	17,000	33,000	-	-	-	5,500	17,000	33,000	**2.3**	2,100
Propylene (Propene)	C_3H_6	115-07-1	-	-	-	-	-	-	1,500	2,800	17,000	**2**	-
Butane	C_4H_{10}	106-97-8	5,500	17,000	33,000	-	-	-	5,500	17,000	53,000	**1.9**	1,600
1-Butene	C_4H_8	106-98-9	-	-	-	-	-	-	750	2,900	17,000	**1.6**	-
Pentane	C_5H_{12}	109-66-0	-	-	-	-	-	-	3,000	33,000	200,000	**1.5**	1,500
Isopentane	C_5H_{12}	78-78-4	-	-	-	-	-	-	3,000	33,000	200,000	**1.4**	-
Cyclopentane	C_5H_{12}	287-92-3	-	-	-				590	3,800	23,000	**1.5**	-
Mixture Total	-	-	-	-	-	-	-	-	-	-	-	**6.5**	-

[1] https://www.epa.gov/aegl/access-acute-exposure-guideline-levels-aegls-values
[2] https://cameochemicals.noaa.gov/search/simple
[3] https://emhub1.energy.gov/pacteel
[4] https://www.cdc.gov/niosh/idlh/intridl4.html

8 ESTIMATED THERMAL RUNAWAY EMISSIONS

A UL 9540A cell-level test was conducted by a cell being forced into thermal runaway by inducing heat via a film heater. The UL 9540A cell-level test captured the total volume of gas, in liters (L), vented during the thermal runaway event over a collection time which was analyzed to be approximately 15 minutes. The assumed release duration for a single cell was based on the UL 9540A cell-level test report by averaging the difference between cell venting time and thermal runaway time based upon the values of section 3.3.2 and the graphs in section 3.3.3. This time is also supported by the module-level and unit-level UL 9540A tests in each test reports respective “Test overview timeline” tables, showing 15 minutes between vent start and thermal runaway.

Although this estimation is based on the initiating time of thermal runaway and may not include its total duration, a shorter emissions duration of 15 minutes in the PHAST™ model is a more conservative approach than a longer duration. The gases recorded during the cell-level UL 9540A test are used in this report. These gases were collected in a fixed-volume vessel and include all pre-flaming gases released from a battery cell. The vented gases measured in the cell-level test do not indicate volume, only concentration in percentage.

During the UL 9540A module-level test, thermal runaway was initiated in 3 cells and propagated to 1 additional cell within the module, resulting in a total of 4 cells in thermal runaway. This result was repeated in the UL 9540A unit-level test which involved thermal runaway in 3 initiating cells and propagation to 1 additional cell, resulting again in a total of 4 cells in thermal runaway.

Based on the UL 9540A module and unit level tests, the off-gas plume resulting from the thermal runaway of 4 cells may be described as a “credible event”. A safety factor of 2 would then be applied, resulting in a plume analysis “credible event” based upon 8 cells in thermal runaway.

Emissions from all 8 cells were modeled simultaneously rather than sequentially, which gives a more conservative result.

Table 8: Emission Release Rate	
Hazardous Gas Component	UL 9540A Gas Analysis (%)
Carbon Monoxide	16.202
Carbon Dioxide	26.861
Hydrogen	49.875
Methane	3.671
Ethene (Ethylene)	1.389
Ethane	0.548
Propene (Propylene)	0.745
Propane	0.18
Butane	0.068
Butene	0.22
Pentane	0.076
Isopentane	0.112
Cyclopentane	0.053
Total Cell Off-gas Volume	**130 L**
Credible Event Vent Volume	**1,040 L**
Credible Event Vent Mass	**0.8932 kg**
Mass Flow Rate*	**0.05955 kg/min**

*Note: * The emission rate was calculated for 8 cells with a conservative venting time of 15 minutes as described in Section 8.*

L = liters; min = minutes; kg = kilograms.

9 OFFSITE CONSEQUENCE ANALYSIS

An offsite consequence analysis was performed using emission rate estimates as described in Section 8 and the PHAST™ model as described in the sections below.

9.1 Methodology

The EPA's "Risk Management Program Guidance for Offsite Consequence Analysis" recommends conducting an offsite consequence analysis to represent release scenarios that are possible (although unlikely) to occur under a variety of weather and wind conditions to determine the distance to a toxic or flammable endpoint. Modeling assumptions and meteorological conditions that were used for conducting this offsite consequence analysis are described below. The offsite consequences analysis was conducted based on the following assumed conditions:

- Specific conditions –
  - Wind speed of 3.4 miles per hour (mph), 3.9 mph, 5.8 mph, 7.8 mph, and 19.9 mph were modeled based upon nearby ASHRAE weather station data.
  - Atmospheric stability class F (Stable – night with moderate clouds and light/moderate wind) and class B (Unstable – as with A/B only less sunny and more windy).
  - Release temperature of 309.2 degrees Fahrenheit (°F) for toxic and flammable gas releases.
  - Relative humidity of 53%, 66%, and 83%.
  - Height of release – 8 feet (approximate center of exhaust vent).
  - Surface roughness – PHAST™ default of "user defined" between "low crops" and "high crops"; as determined based on the density and height of obstructions.
  - No perimeter fence, barrier, or wall.

The first of the 10 weather scenarios within the model was based upon average weather conditions, with subsequent weather models changing one variable at a time. The subsequent 9 weather scenarios evaluated the effects of altering atmospheric stability class, temperature, wind speed, and humidity.

The PHAST™ model was set up to specify three toxic levels of concern, three flammable levels of concern, one heat flux level of concern, and three overpressure levels of concern. Modeling was conducted to identify maximum estimated distances to AEGL-2/PAC-2 at 1 hour, AEGL-3/PAC-3 at 1 hour, IDLH, LFL, 50% LFL, 25% LFL, 2.5 kW/m^2, 4.7 kW/m^2, 5 kW/m^2, 1.45 psi, 3 psi, and 4.35 psi. The gas cloud levels of concern were recorded from an elevation of 20 feet and below. This elevation was chosen as a worst-case flammable gas cloud in the event of any unforeseen down drafts and includes the gases found up to approximately twice the height of the enclosure. This was chosen as the hazards of flammable gases extend beyond exposure to the gases themselves, but the hazard of heat flux and overpressure in the event of ignition of the flammable gases.

Air toxics levels of concern were determined as described in section 7. Flammable levels of concern were based upon the lower flammable limit of the combined gas mixture or an individual gas. The gases analyzed were the collective gas mixture results from the UL 9540A cell-level test, carbon monoxide and hydrogen as these were determined to be the most concerning toxic and flammable gas mixture constituents. The heat flux level was based upon the NFPA 59A Table 19.8.4.2.1 threshold for "irreversible harm to persons outdoors without PPE". Overpressure levels of concern were based on values from *Guidelines for Quantitative Risk Assessment*, "Purple Book", 2005 that describe probabilities of fatalities from overpressure exposure indoors and outdoors to a vapor cloud explosion.

Table 9.1: Pressure Effects for a Vapor Cloud Explosion

Explosion Overpressure PSI (BARG)	Probability of Death	
	Indoor	Outdoor
> 4.35 (0.3)	100%	100%
> 3 (0.2)	-	50%
> 1.45 (0.1)	2.5%	0%

The offsite consequence analysis was conducted according to EPA's "Risk Management Program Guidance for Offsite Consequence Analysis". Plume analysis and exposure impacts were conducted using DNV®'s PHAST™ hazards modeling program. Based on the information from a chemical release, PHAST™ estimates how quickly the chemicals will escape from containment forming a hazardous gas cloud, and how that release rate may change over time. PHAST™ can then model how that hazardous gas cloud will travel downwind, including both neutrally buoyant and heavy gas dispersion.

Additionally, if the chemical release is flammable, PHAST™ can simulate multiple scenarios including pool fires, boiling liquid expanding vapor explosions, vapor cloud explosions, jet fires, and flammable gas clouds (where flash fires might occur). PHAST™ evaluates different types of hazards (depending on the release scenario) including toxicity, flammability, thermal radiation, and overpressure. PHAST™ produces a threat zone estimate, which shows the area where a particular hazard (such as toxicity, flammability, or thermal radiation) is predicted to exceed a specified level of concern at some time after the release begins. PHAST™ is able to determine a threat zone under different weather and wind scenarios.

10 OFFSITE CONSEQUENCE ANALYSIS

The release scenario was modeled using ASHRAE weather data from the Vacaville Nut Tree weather station located approximately 2 miles away from the Arges BESS site. The weather data represents average temperature and wind speed over an 18-year period from 2001-2019.

A toxic release from 6 battery cells was the basis for the model runs with the potential for release of Carbon Monoxide, Carbon Dioxide, Hydrogen, Methane, Acetylene, Ethane, Ethene (Ethylene), Propane, Propene (Propylene), Butane, Pentane, Hexane, Heptene, Dimethyl carbonate, and Ethyl methyl carbonate. Note that Heptene, Dimethyl carbonate, and Ethyl methyl carbonate are not material options within PHAST™. Together, these gases comprise 0.128% of the UL 9540A cell-level test gas composition and were substituted within PHAST™ for Heptane. Heptane's chemical formula is C_7H_{16}, compared to Heptene's C_7H_{14}. Heptane has a molecular mass of 100.21 grams/mol and is more similar to Heptene, Dimethyl carbonate, and Ethyl methyl carbonate compared to the other UL 9540A constituent gas species on a mass basis. Therefore, Heptane was chosen to replace the missing 0.128% gas volume that was comprised of Heptene, Dimethyl carbonate, and Ethyl methyl carbonate on the UL 9540A cell-level test. Graphical diagrams and data generated in PHAST™ are shown in the sections below.

All measurements along the X-axis in the following graphs start at 0, the modeled gas release point.

10.1 Hydrogen

The modeled percentage LFL due to the emission of hydrogen during thermal runaway is shown in the diagrams and figures below. The categories are displayed in PPM based on the following colors in the legend:

- All contours show 25% LFL (10,000 ppm)

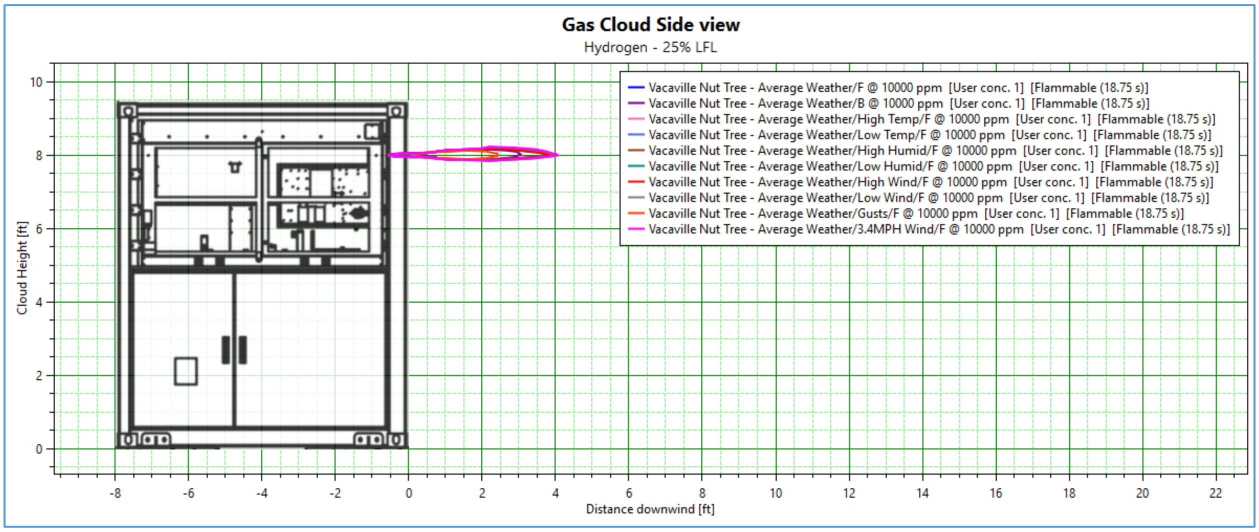


Figure 10.1(a) - Hydrogen - Gas Cloud Side View – 25% LFL with 15 minute vent duration

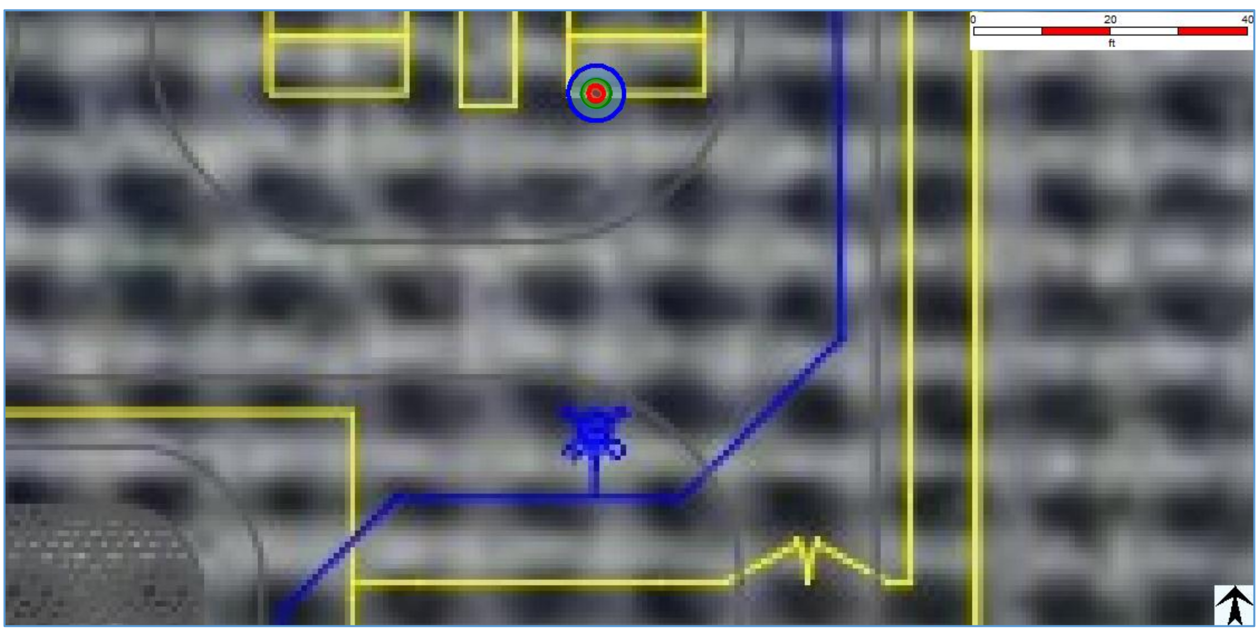


Figure 10.1(b) - Hydrogen - Gas Cloud Cross Section at 8-foot Elevation (Maximum cloud diameter below 20-feet) - LFL Concentration in PPM

10.2 Carbon Monoxide

The modeled carbon monoxide emissions due to emissions during thermal runaway is shown in the diagrams and figures below. The categories are displayed in PPM based on the following colors in the legend:

- All contours show AEGL-2 (1 hour) / PAC-2 levels of 83 ppm

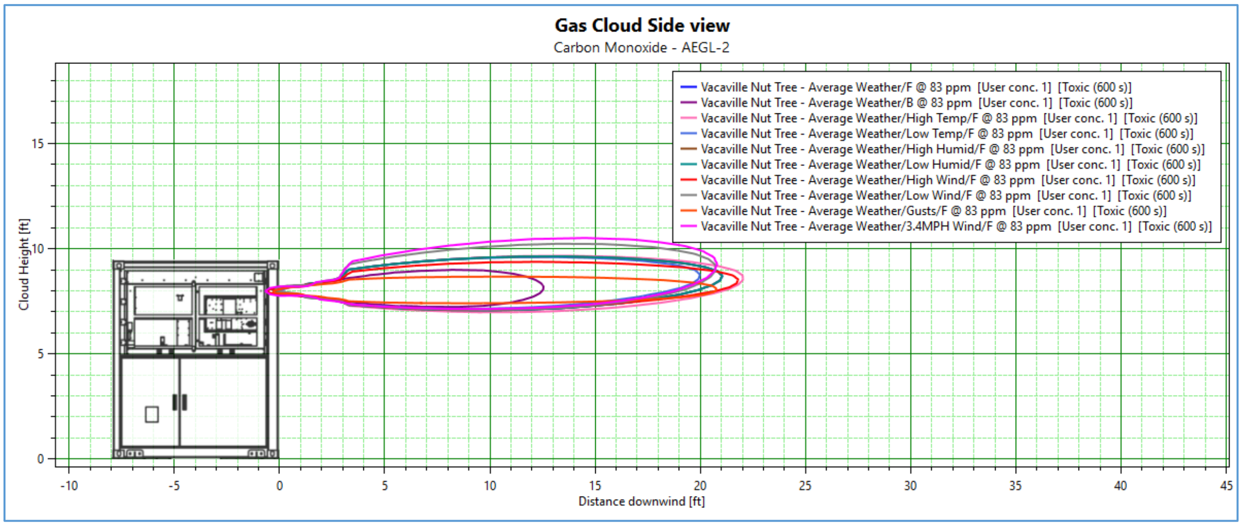


Figure 10.2(a) - Carbon Monoxide - Gas Cloud Side View – Concentration by PPM

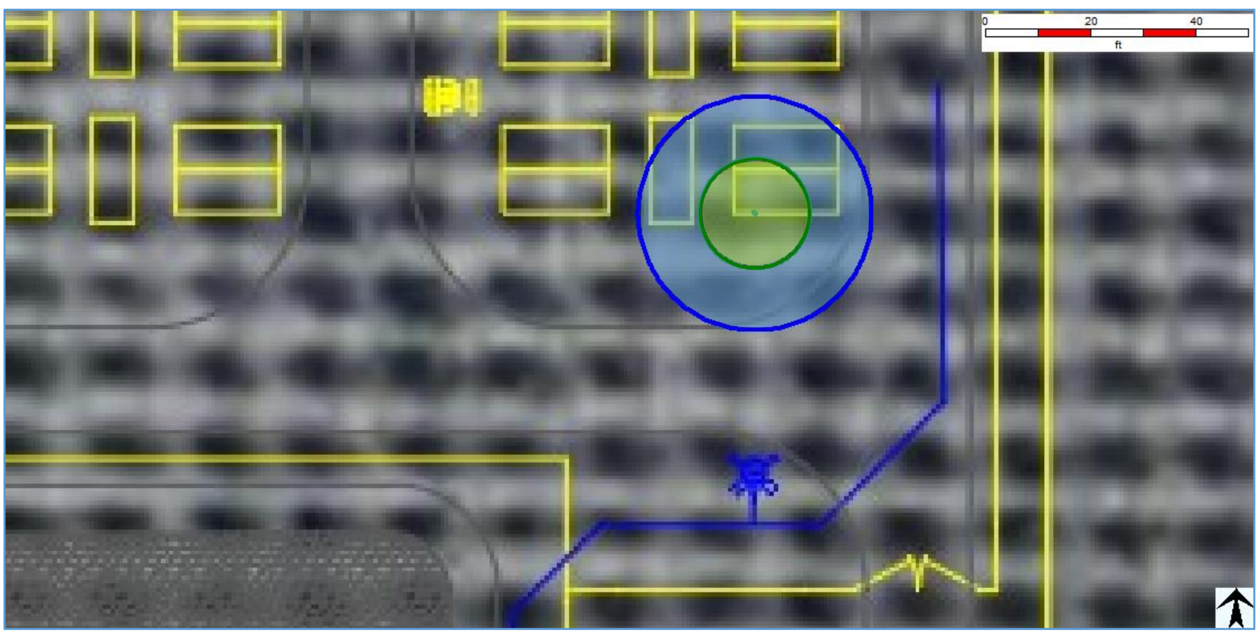


Figure 10.2(b) – Carbon Monoxide - Gas Cloud Cross Section at 8.5-foot Elevation (Greatest extent below 20 feet) - Concentration in PPM

10.3 Hydrocarbons

The modeled hydrocarbons based in the UL 9540A testing due to emissions during thermal runaway is shown in the diagrams and figures below. The categories are displayed in PPM based on the following colors in the legend:

- All contours show 25% LFL (16,250 ppm)

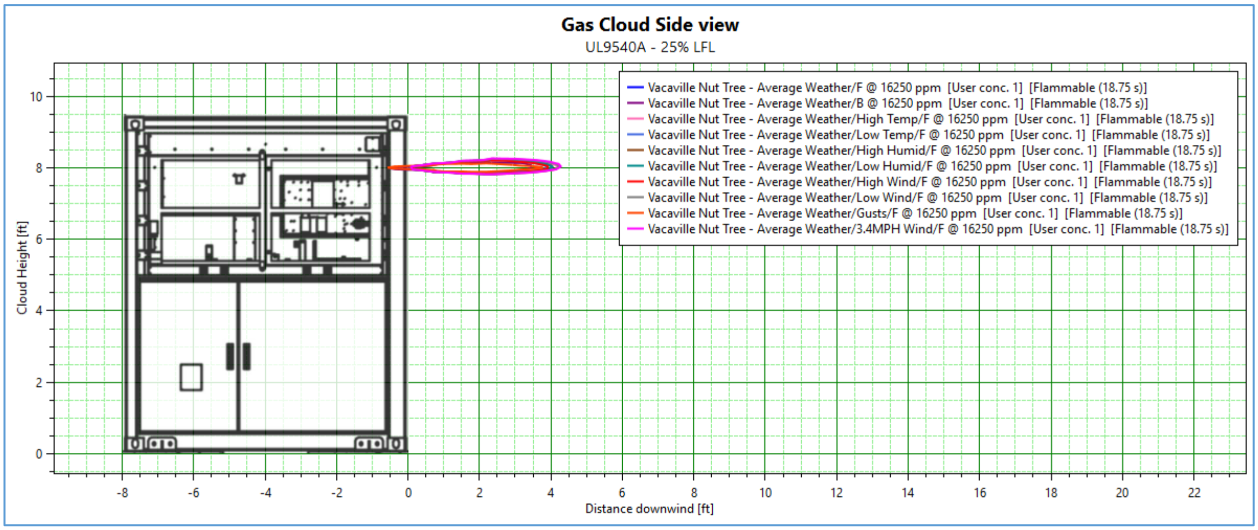


Figure 10.3(a) – UL 9540A Cell-level Hydrocarbon - Gas Cloud Side View Concentration by PPM

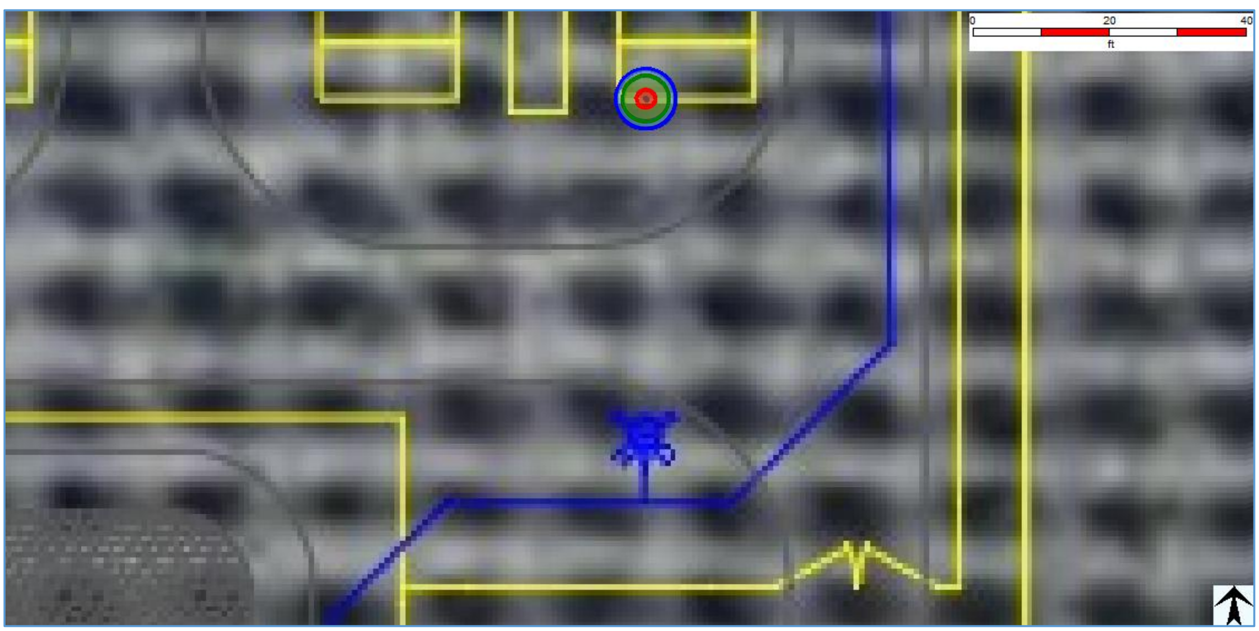


Figure 10.3(b) – UL 9540A Cell-level test Hydrocarbons - Gas Cloud Cross Section at 8-foot Elevation (Maximum cloud diameter below 20-feet) - Concentration in PPM

10.4 Radiation and Heat Flux

The modeled heat flux is based on the UL 9540A cell level testing emissions during thermal runaway and is shown in the diagrams and figures below.

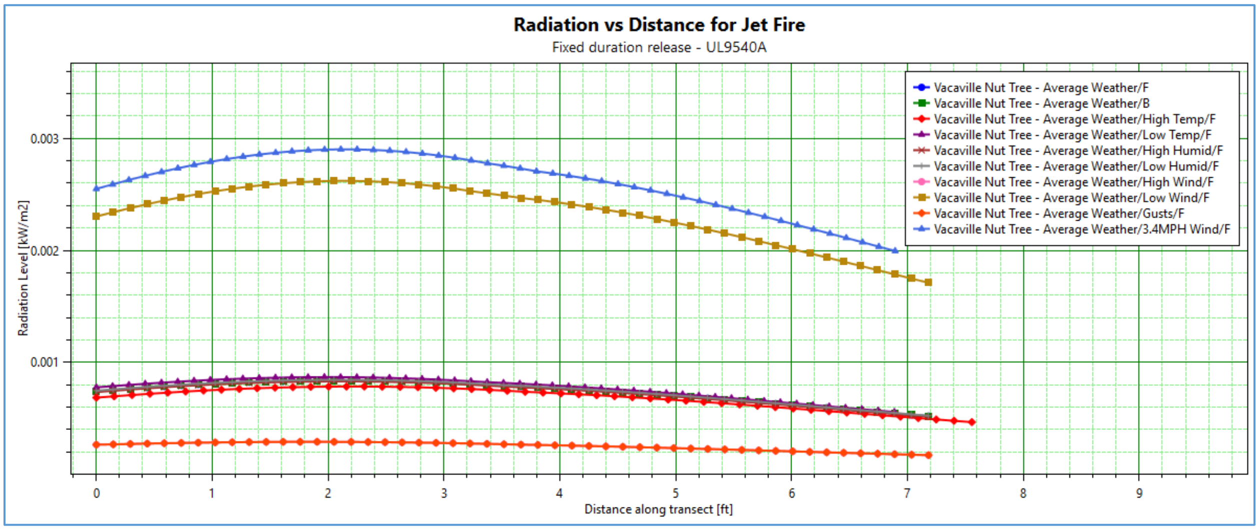


Figure 10.4(a) – UL 9540A Cell-level Test Gas Mixture - Jet Fire Heat Flux by Distance

Note that the model did not produce any contours that reached the 2.5 kW/m^2 threshold.

10.5 Explosion Effects

The modeled pressure effects are based on the UL 9540A cell level testing emissions during thermal runaway (multiplied by 6 for the number of cells in a SYL SU5016U1250KC credible thermal runaway event) and is shown in the diagrams and figures below. The categories are displayed in pounds per square inch (psi) based on the following colors in the legend:

- Blue is 1.45 psi
- Green is 3 psi
- Red is 4.35 psi

The model produced an overpressure event when a late ignition point was manually provided away from the gas release point. The late ignition point was input at 1-ft intervals, producing equivalent overpressure events at the 1-ft and 2-ft ignition points. At 3-ft, the model failed to produce an overpressure event. The 2-ft ignition point is displayed in the following figures as it is the event that occurs furthest from the gas release point.

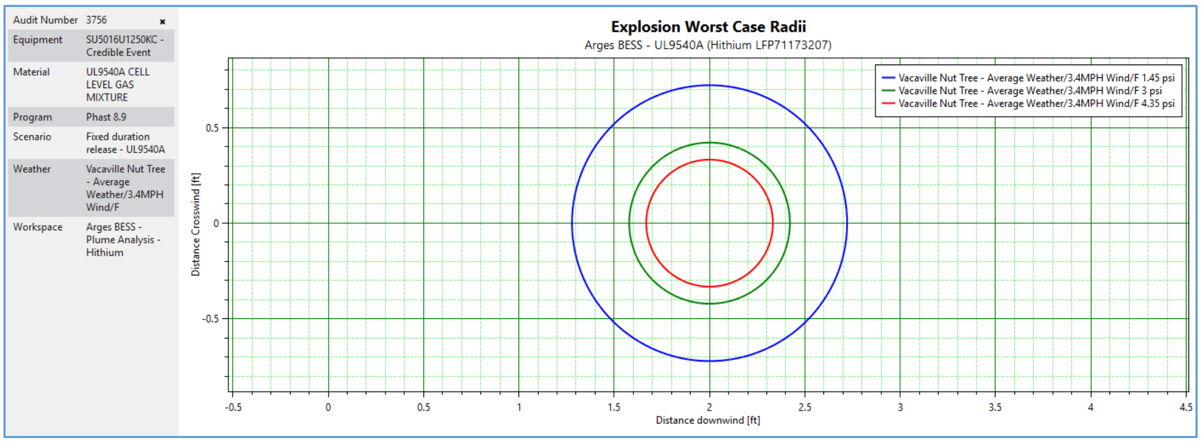


Figure 10.5(a) – UL 9540A Cell-level Test Gas Explosion - Pressure Effects

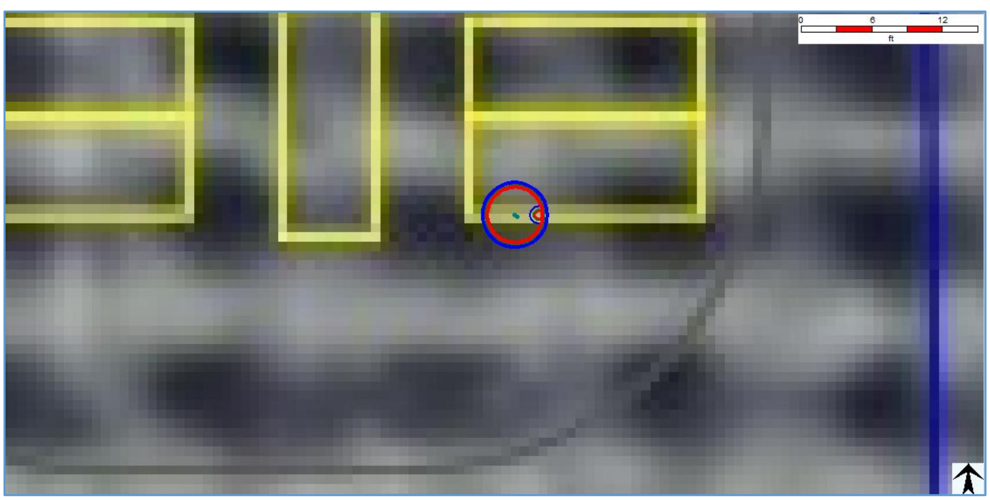


Figure 10.5(b) – UL 9540A Cell-level Test Gas Explosion – Pressure Effects (Large circles show 1.45 psi, 3 psi, 4.35 psi effect zone contours. Small circles show overpressure event 3-ft offset from gas release point)

10.6 PHAST™ Analysis Effects Summary Table

Table 10.6: PHAST™ Analysis Results Table											
#	Scenario	Gas Type	Release Type	Endpoint - Extent of Hazard at 20 ft Above Grade (ft)							
				100% LFL	50% LFL	25% LFL	IDLH	AEGL-3	AEGL-2	Heat Flux (2.5 kW/m^2)	Overpressure (1.45 psi)
1	Failure of 8 cells within SYL SU5016U1250KC (15 Minutes)	UL 9540A Cell Test Gas Composition	Flammable	**2 ft**	**3 ft**	**5 ft**	N/A	N/A	N/A	**N/A**	**3 ft**
2		Hydrogen (H_2)	Flammable	**2 ft**	**3 ft**	**5 ft**	N/A	N/A	N/A	N/A	**3 ft**
3		Carbon Monoxide (CO)	Toxic	N/A	N/A	N/A	**7 ft**	**12 ft**	**23 ft**	N/A	N/A

The modeling analysis results are as follows:

- The maximum toxic endpoint distance of Carbon Monoxide's AEGL-2 / PAC-2 value would be 23 feet.
- The maximum distance to the flammable endpoint at 25% LFL would be 5 feet, as shared by UL 9540A gas mixture and Hydrogen.
- There is no heat flux endpoint distance as a heat flux of 2.5 kW/m^2 is never reached.
- An overpressure event did not develop within the model and a distance to the overpressure endpoint of 1.45 psi was never reached.

The results of the consequence analysis show that the maximum distance of these levels of concern is 23 feet based on Carbon Monoxide. The nearest receptor (ESS enclosure to site fence) is located approximately 30 feet away.

Below is an image with a hazard extent distance of 23 feet overlaid onto the site layout.

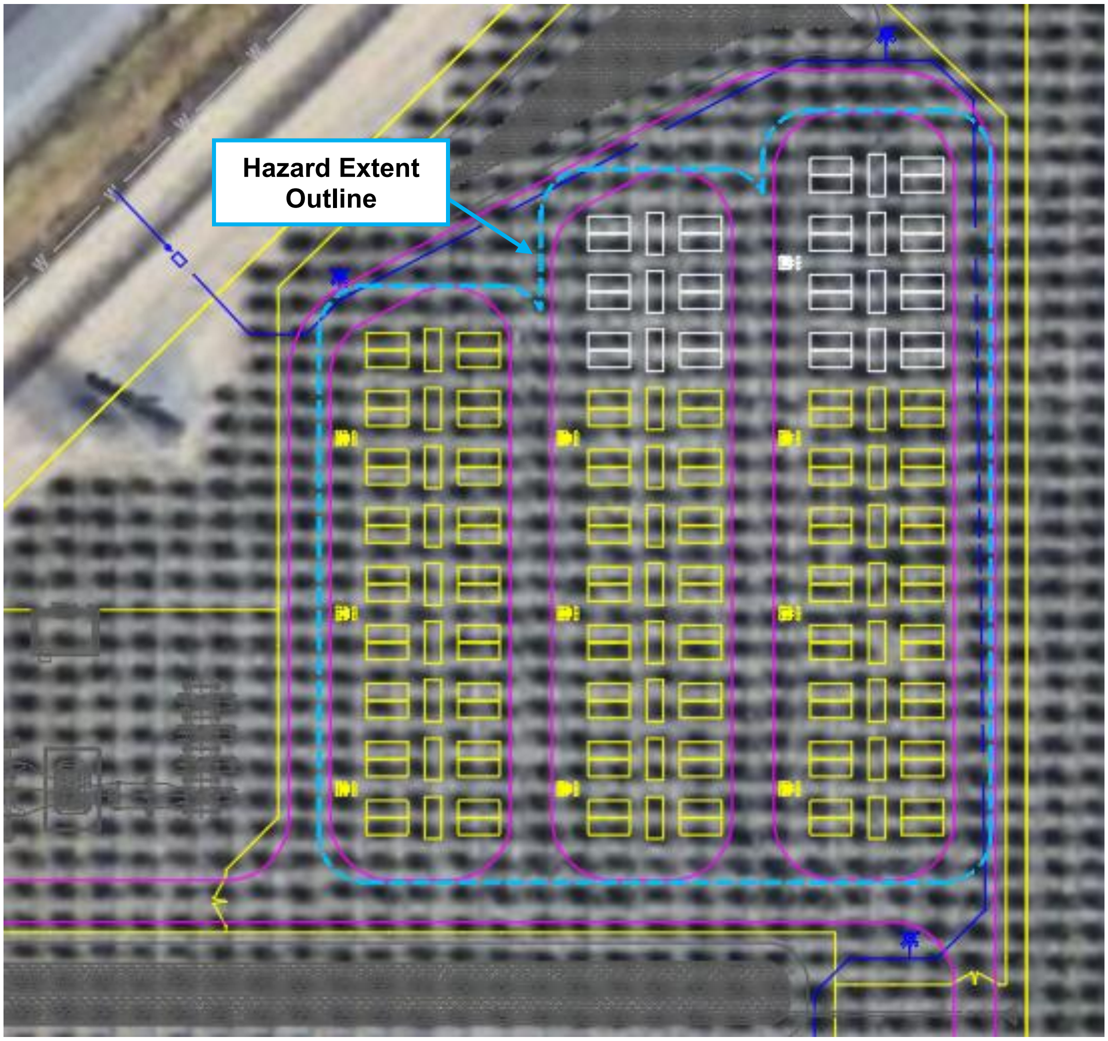


Figure 10.6 – Hazards Extent Overlay in blue (North ↑)

11 SUMMARY

Coffman has provided this HCA for the Arges BESS site. The report was conducted for the batteries planned to be implemented at the site, as well as the correct number of modules and potential toxins during a credible event. Modeling was accomplished with PHAST™ software, based on the information provided in the UL 9540A test reports, to identify and describe safety measures and fire risk mitigation measures, identify distance from the project site to the nearest sensitive receptors, and identify and characterize the quantities and locations of hazardous chemicals that could be released during a thermal runaway and/or fire event.

12 MAIN STUDY ASSUMPTIONS/REFERENCE MATERIAL

1. UL 9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, December 9, 2019.
2. DNV GL, Considerations for ESS Fire Safety, February 9, 2017, https://www.nyserda.ny.gov/-/media/Project/Nyserda/files/Publications/Research/Energy-Storage/20170118-ConEd-NYSERDA-Battery-Testing-Report.pdf
3. National Fire Protection Association, Hazard Assessment of Lithium Ion Battery Energy Storage Systems, February 26, 2016, https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Hazardous-materials/RFFireHazardAssessmentLithiumIonBattery.ashx
4. Office of Response and Restoration, Public Exposure Guidelines, July 25, 2016, https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/resources/public-exposure-guidelines.html
5. EPA, Risk Management Guidance for Offsite Consequence Analysis, March 2009, https://www.epa.gov/rmp/rmp-guidance-offsite-consequence-analysis
6. Guidelines for Quantitative Risk Assessment, “Purple Book”, 2005, International Atomic Energy Agency.

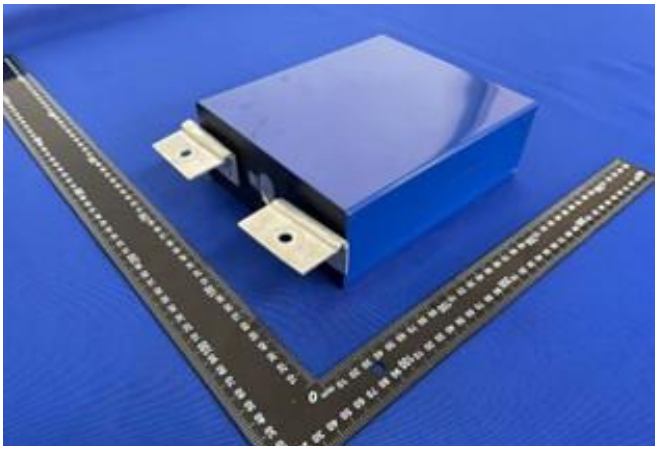
APPENDICES

Appendix A

SYL SU5016U1250KC UL 9540A CELL LEVEL TEST RESULT

Prüfbericht-Nr.: *Test report no.:*	CN23F118 001	**Auftrags-Nr.:** *Order no.:*	168441619	
Kunden-Referenz-Nr.: *Client reference no.:*	2347845	**Auftragsdatum:** *Order date:*	2023-08-29	
Auftraggeber: *Client:*	Xiamen Hithium Energy Storage Technology Co., Ltd. 201-1, Comprehensive Building 5, No.11, Butang Middle Road, Industrial Base Of Xiamen Torch High Tech Zone (Tongxiang), Xiamen, Fujian, P.R. China			
Prüfgegenstand: *Test item:*	Iron Phosphate-Lithium Cell			
Bezeichnung / Typ-Nr.: *Identification / Type no.:*	LFP71173207/314Ah			
Auftrags-Inhalt: *Order content:*	Test report			
Prüfgrundlage: *Test specification:*	UL 9540A:2019 (Forth Edition)			

Wareneingangsdatum: *Date of sample receipt:*	2023-08-30
Prüfmuster-Nr.: *Test sample no:*	Engineering sample
Prüfzeitraum: *Testing period:*	2023-09-04 - 2023-11-21
Ort der Prüfung: *Place of testing:*	See to clause 1.1 of main report
Prüflaboratorium: *Testing laboratory:*	TÜV Rheinland (Shenzhen) Co., Ltd.
Prüfergebnis*: *Test result*:*	See main report



erstellt von: *created by:*		**genehmigt von:** *authorized by:*	
Datum: *Date:* 2023-12-06	Jason Zhu	**Ausstellungsdatum:** *Issue date:* 2023-12-06	Xun Yu
Stellung / Position:	Project Engineer	**Stellung** / Position:	Reviewer

Sonstiges / *Other:*

This report does not evidence compliance of the provided sample with the relevant standards but only with the referred tests. This test report documents the findings of examination conducted on the delivered product mentioned above only. This report does not entitle the applicant to carry any safety mark on this or similar products. Further for sales or other application purposes of the tested product, any reference to TÜV Rheinland or a test through TÜV Rheinland is only permissible with prior written consent of TÜV Rheinland.

Zustand des Prüfgegenstandes bei Anlieferung: *Condition of the test item at delivery:*	Prüfmuster vollständig und unbeschädigt *Test item complete and undamaged*

* Legende:	P(ass) = entspricht o.g. Prüfgrundlage(n)	F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
** Legend:*	*P(ass) = passed a.m. test specification(s)*	*F(ail) = failed a.m. test specification(s)*	*N/A = not applicable*	*N/T = not tested*

Dieser Prüfbericht bezieht sich nur auf das o.g. Prüfmuster und darf ohne Genehmigung der Prüfstelle nicht auszugsweise vervielfältigt werden. Dieser Bericht berechtigt nicht zur Verwendung eines Prüfzeichens.
This test report only relates to the above mentioned test sample. Without permission of the test center this test report is not permitted to be duplicated in extracts. This test report does not entitle to carry any test mark.

Anmerkungen
Remarks

1	Alle eingesetzten Prüfmittel waren zum angegebenen Prüfzeitraum gemäß eines festgelegten Kalibrierungsprogramms unseres Prüfhauses kalibriert. Sie entsprechen den in den Prüfprogrammen hinterlegten Anforderungen. Die Rückverfolgbarkeit der eingesetzten Prüfmittel ist durch die Einhaltung der Regelungen unseres Managementsystems gegeben. Detaillierte Informationen bezüglich Prüfkonditionen, Prüfequipment und Messunsicherheiten sind im Prüflabor vorhanden und können auf Wunsch bereitgestellt werden. *The equipment used during the specified testing period was calibrated according to our test laboratory calibration program. The equipment fulfils the requirements included in the relevant standards. The traceability of the test equipment used is ensured by compliance with the regulations of our management system.* *Detailed information regarding test conditions, equipment and measurement uncertainty is available in the test laboratory and could be provided on request.*
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3	Prüfklausel mit der Note * wurden an qualifizierte Unterauftragnehmer vergeben und sind unter der jeweiligen Prüfklausel des Berichts beschrieben. Abweichungen von Prüfspezifikation(en) oder Kundenanforderungen sind in der jeweiligen Prüfklausel im Bericht aufgeführt. *Test clauses with remark of * are subcontracted to qualified subcontractors and descripted under the respective test clause in the report.* *Deviations of testing specification(s) or customer requirements are listed in specific test clause in the report.*
4	Die Entscheidungsregel für Konformitätserklärungen basierend auf numerischen Messergebnisen in diesem Prüfbericht basiert auf der "Null-Grenzwert-Regel" und der "Einfachen Akzeptanz" gemäß ILAC G8:2019 und IEC Guide 115:2021, es sei denn, in der auf Seite 1 dieses Berichts genannten angewandten Norm ist etwas anderes festgelegt oder vom Kunden gewünscht. Dies bedeutet, dass die Messunsicherheit nicht berücksichtigt wird und daher auch nicht im Prüfbericht angegeben wird. Zu weiteren Informationen bezueglich des Risikos durch diese Entscheidungsregel siehe ILAC G8:2019. *The decision rule for statements of conformity, based on numerical measurement results, in this test report is based on the “Zero Guard Band Rule” and “Simple Acceptance” in accordance with ILAC G8:2019 and IEC Guide 115:2021, unless otherwise specified in the applied standard mentioned on Page 1 of this report or requested by the customer. This means that measurement uncertainty is not taken in account and hence also not declared in the test report. For additional information to the resulting risk based of this decision rule please refer to ILAC G8:2019.*

Introduction

Model fire codes and energy storage system standards require energy storage systems to comply with UL 9540, which in turn requires battery cells and modules to comply with UL 1973. Compliance with these standards reduces the risk of batteries and battery energy storage systems (BESS) creating fire, shock or personal injury hazards. However, they don't evaluate the ability of the BESS installed as intended and with fire suppression mechanisms in place if necessary, from contributing to a fire or explosion in the end use installations.

To address these fire and explosion hazards associated with the installation of a BESS, the fire and other codes require energy storage systems to meet certain location, separation, fire suppression and other criteria. Those codes also provide a means to provide an equivalent level of safety based on large scale fire testing of anticipated BESS installations.

UL 9540A is intended to provide a test method that can be used as a basis for validating the safety of a BESS installation in lieu of meeting the specific criteria provided in those codes. The data generated can be used to determine the fire and explosion protection required for installation of a BESS.

The test method is initiated through the establishment of a thermal runaway condition that leads to combustion within the BESS. The test method outlined in UL 9540A consists of several steps – cell level testing, module level testing, unit level testing and installation level testing. The cell and module level testing steps are information gathering steps to inform the unit and installation level testing.

The following outlines the information that may gathered as part of the testing:

a) Cell level – An individual cell fails in a manner that leads to thermal runaway and fire through a suitable method such as external heating. Data such as off-gassing contents, temperatures at venting and temperatures at thermal runaway are recorded.

b) Module level – One or more cells within a BESS module fail in the manner determined during the cell level testing. Data such as fire propagation in the module, temperatures on the failed cells and surrounding cells, off-gassing contents and heat release data are gathered.

c) Unit level – A complete BESS is installed surrounded by target (e.g. dummy) BESS and walls separated at a distance as intended in its installation. The module level test is repeated on a module located in the BESS in the most unfavorable location. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; observation of fire propagation from BESS to target units and walls as well as observance of explosions or evidence of re-ignition within the BESS; and heat release and off-gassing contents are gathered.

d) Installation level – This test is a repeat of the unit level test with the test conducted within a test room and with the intended fire suppression system installed as well as any overhead cables (that can lead to fire propagation) installed. This test is intended to validate the fire suppression system for the BESS installation. Data such as temperature within the BESS, on surrounding walls and target BESS; incident heat flux on walls and target BESS; fire propagation from the BESS to target units, walls or overhead cables and any observable explosion incidents or re-ignition within the BESS; and off-gassing contents (if needed) and heat release are gathered.

Contents

1 General information

1.1 Test specification

Standard: ANSI/CAN/UL 9540A:2019 (Fourth Edition)

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

This report presents the result of cell level tests of UL 9540A: 2019.

All tests were conducted at TUV Rheinland (Shenzhen) Co., Ltd. and TUV Rheinland's partner labs that were under supervision of TÜV Rheinland's engineer.

Testing period: 2023-09-04 to 2023-11-17

Refer to Clause 4 for test and measurement instruments.

1.2 General remarks

This report is descriptive and provide the test data only.

The test results presented in this report relate only to the object tested.

This report shall not be reproduced, except in full, without the written approval of the testing laboratory.

Throughout this report a ☐ comma / ☒ point is used as the decimal separator.

1.3 List of attachments

The following attachments resulting from the tests, provided with separate page number, are included in this report.

Appendix A: Cell vent gas lower flammability limit (LFL) test

Appendix B: Cell vent gas burning velocity (S_u) test

Appendix C: Cell vent gas maximum pressure (P_{max}) test

1.4 Revision information

New report, not applicable

1.5 Definitions

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.

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

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

BATTERY SYSTEM (BS) – 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.

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.

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.

Note: Depending upon the configuration and design of the BESS (e.g. the BESS is composed of multiple separate parts within separate enclosures), the unit level test can be done at battery system level. In such case, the BESS is be read as BS throughout this report.

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 town homes and individual dwelling units of multi-family dwellings.

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.

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

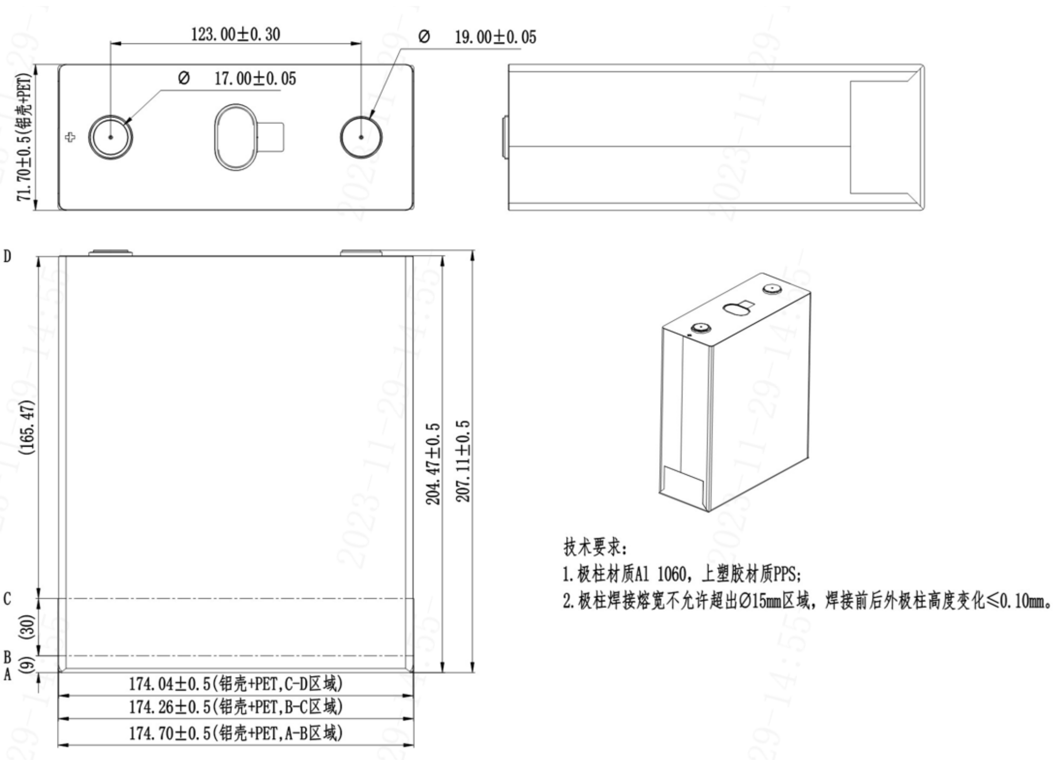
2 General Product Information

2.1 Product information and parameters

The product information and parameters are provided by the client as below.

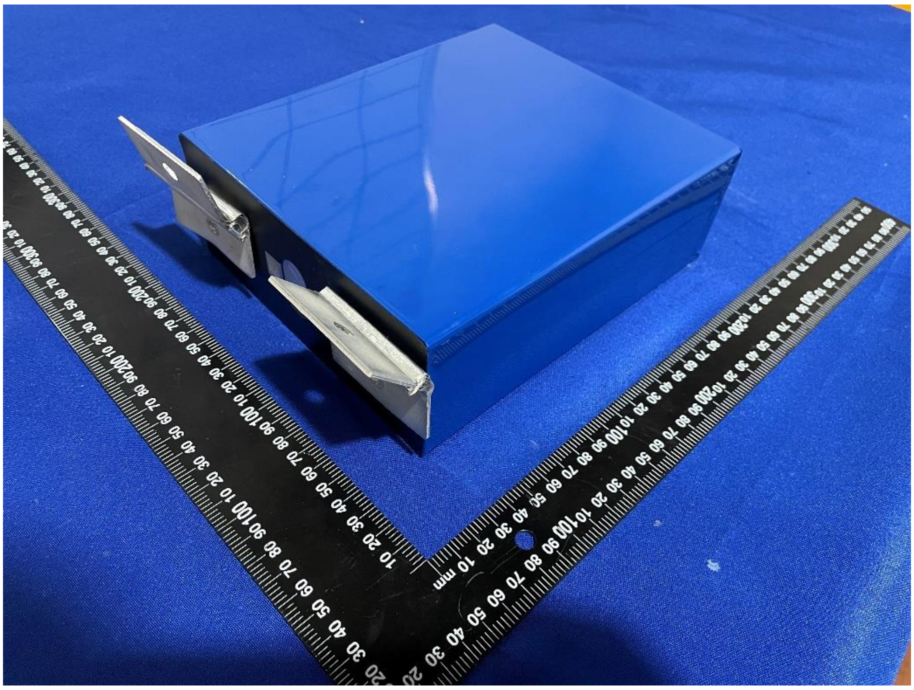
Manufacturer ....:	Xiamen Hithium Energy Storage Technology Co., Ltd. 201-1, Comprehensive Building 5, No.11, Butang Middle Road, Industrial Base Of Xiamen Torch High Tech Zone (Tongxiang), Xiamen, Fujian, P.R. China	
Model number...................................:	LFP71173207/314Ah	
Chemistry ....:	☒ $LiFePO_4$ ☐ NMC ☐ NCA ☐ LTO ☐ Other:	
Physical configuration.......................:	☒ Prismatic ☐ Cylindrical ☐ Pouch	
	Weight(kg):	5.6±0.2
Electrical rating ....:	Rated capacity(Ah):	314 (25°C±2°C)
	Nominal voltage(V):	3.2
Standard charge method ....:	Charge current(A):	157 (25°C±2°C)
	Standard Charge Voltage(V):	3.65
	Cut off current(A):	/
Standard discharge method..............:	Discharge current(A):	157 (25°C±2°C)
	End of discharge voltage(V):	2.5V (T>0°C) 2.0V (T≤0°C)
Maximum continuous charge current :	314A	
Maximum continuous discharge current ....:	314A	
Compliance with UL 1973.................:	☒ Yes, TUV Report No.: CN23RGEH 001 ☐ No	
Note:		

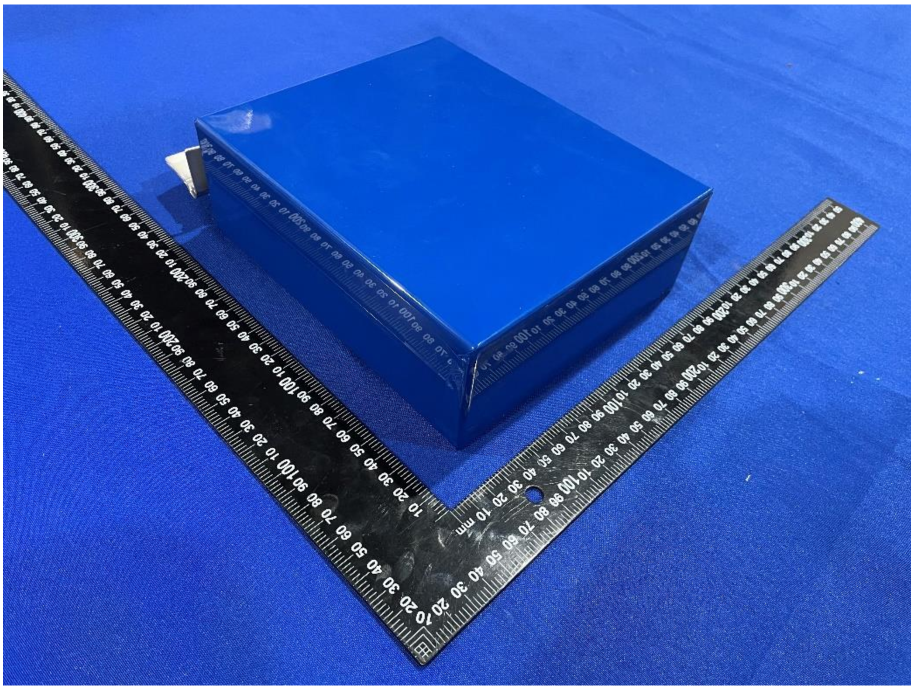
2.2 Diagram with overall dimension

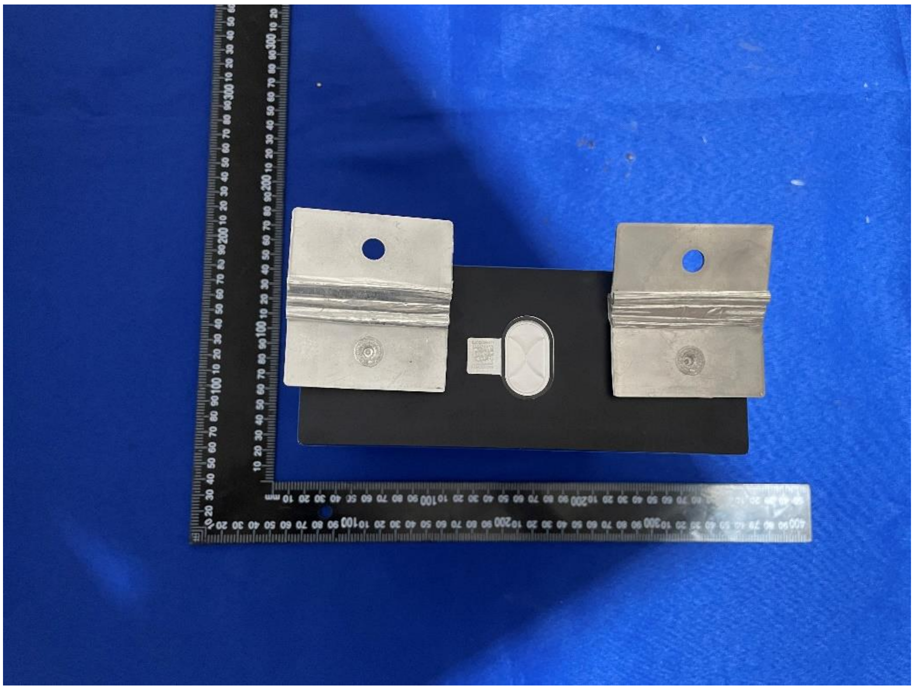


Unit: mm

Photos







3 Cell level test (section 7 of UL 9540A)

3.1 General

This testing is conducted on individual cells and uses various stress conditions such as external heating to force the cells into thermal runaway.

Once the stress mechanism is induced, the test measures the temperature at which the cell vents and then the temperature at which thermal runaway occurs.

The test also measures the volume and pressure of the vent gases that are released from the cells, and the composition of the vent gases.

Cell vent gas with flammable components in its composition should have the following parameters characterized in order to enable deflagration venting design:

a) Measurement of fundamental burning velocity by the vertical tube method described in the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817; and

b) Maximum pressure developed in a contained deflagration of an optimum mixture per EN 15967.

Cell level testing performed on the cells used within a BESS module establishes a base line fire test performance that can be evaluated against the fire performance of other battery cells the BESS manufacturer may choose to use within the unit's modules.

If none of the cell samples can be forced into thermal runaway and none of the cell samples vent flammable gases as determined by the ASTM E918 test, during any of the cell level tests, it is not necessary to conduct additional module or unit level testing on BESS that utilize these cells.

3.2 Sample preparation

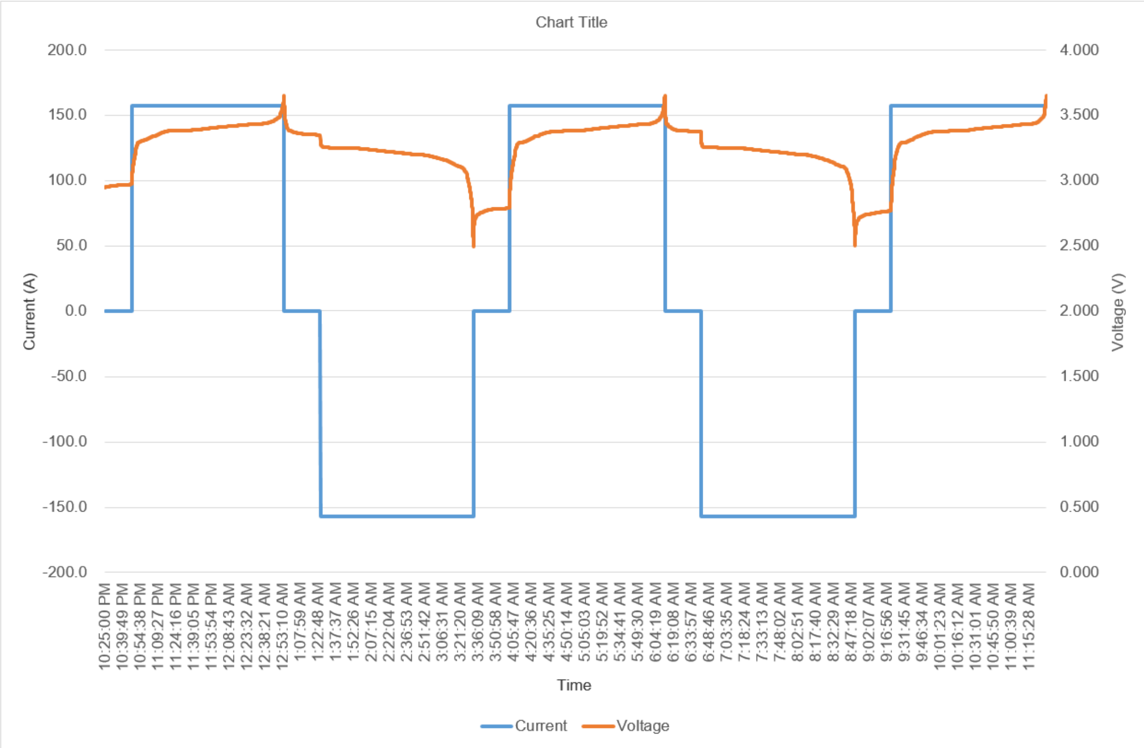
3.2.1 Test method and description

The cells were conditioned, prior to testing, through charge and discharge cycles for 2 cycles using a manufacturer specified methodology (refer to 2.1.1).

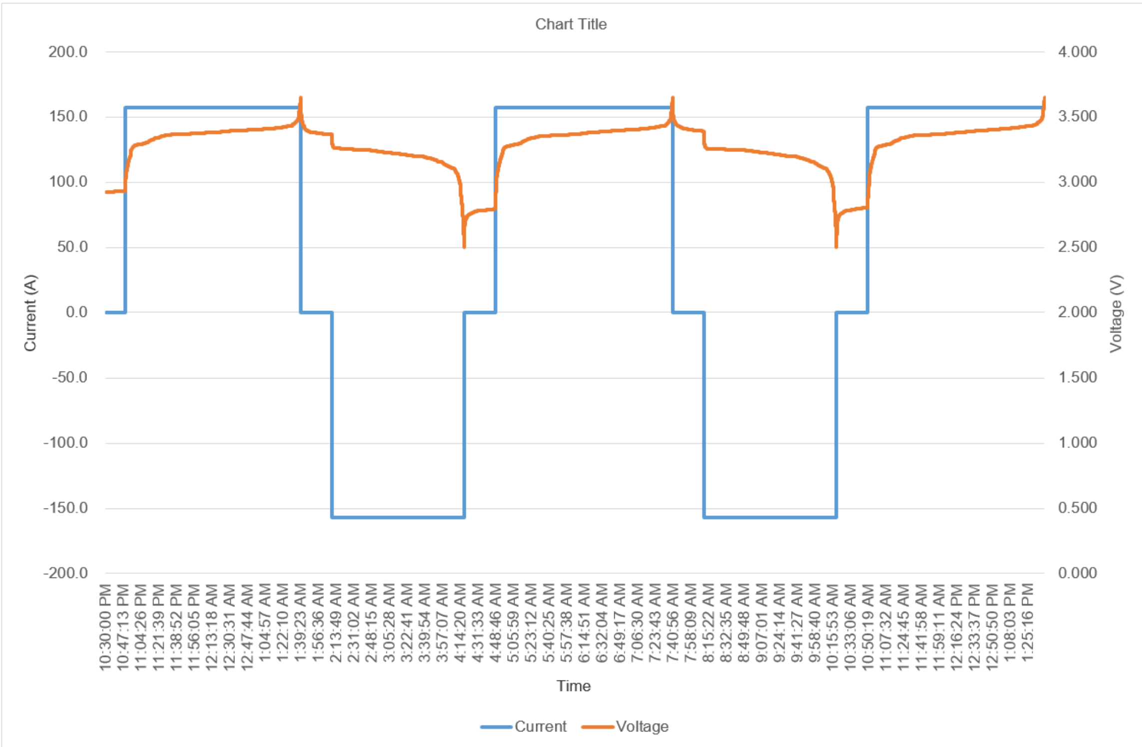
During the cycling, ambient condition is maintained within 25°C±2°C and R.H. 50±25 %.

3.2.2 Cell cycling curves

#1



#2



#3

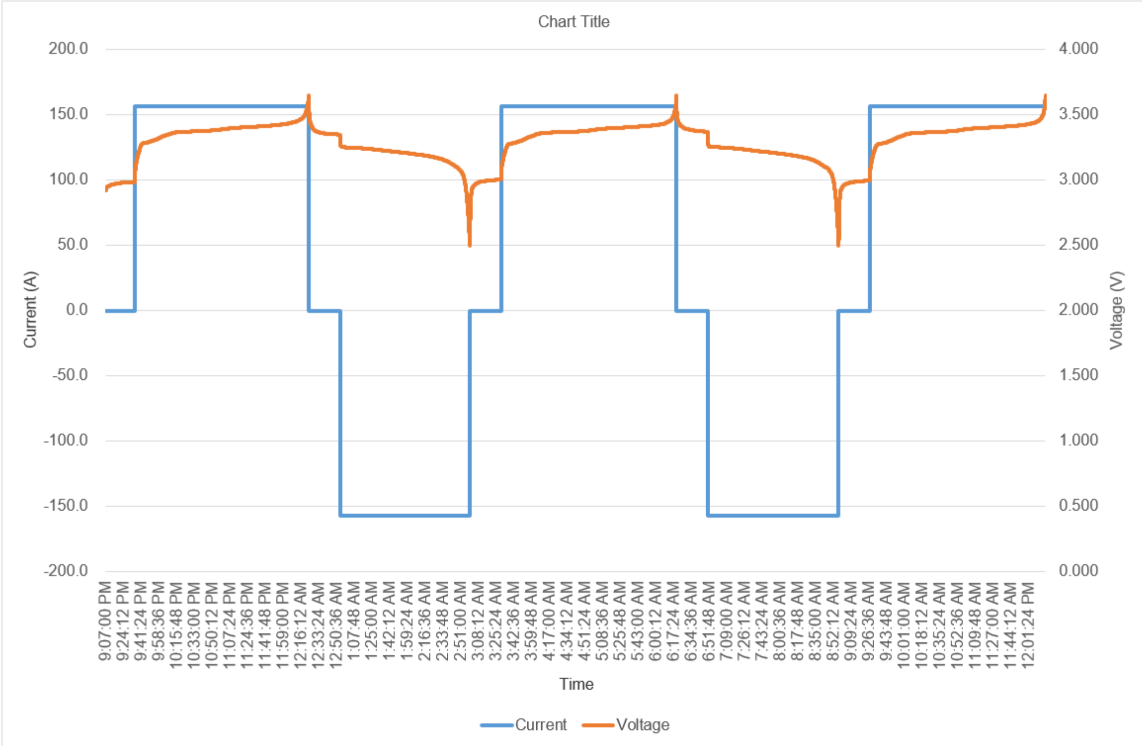


Chart Title
Current (A)
Voltage (V)
Time
Current
Voltage

#4

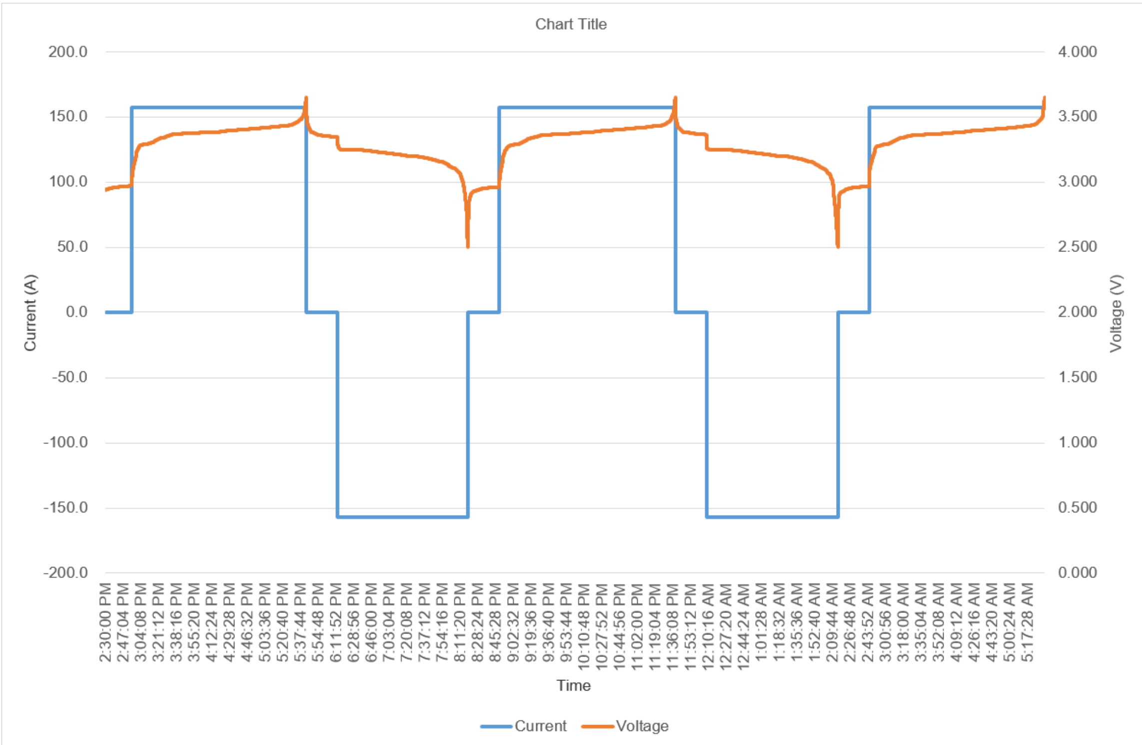
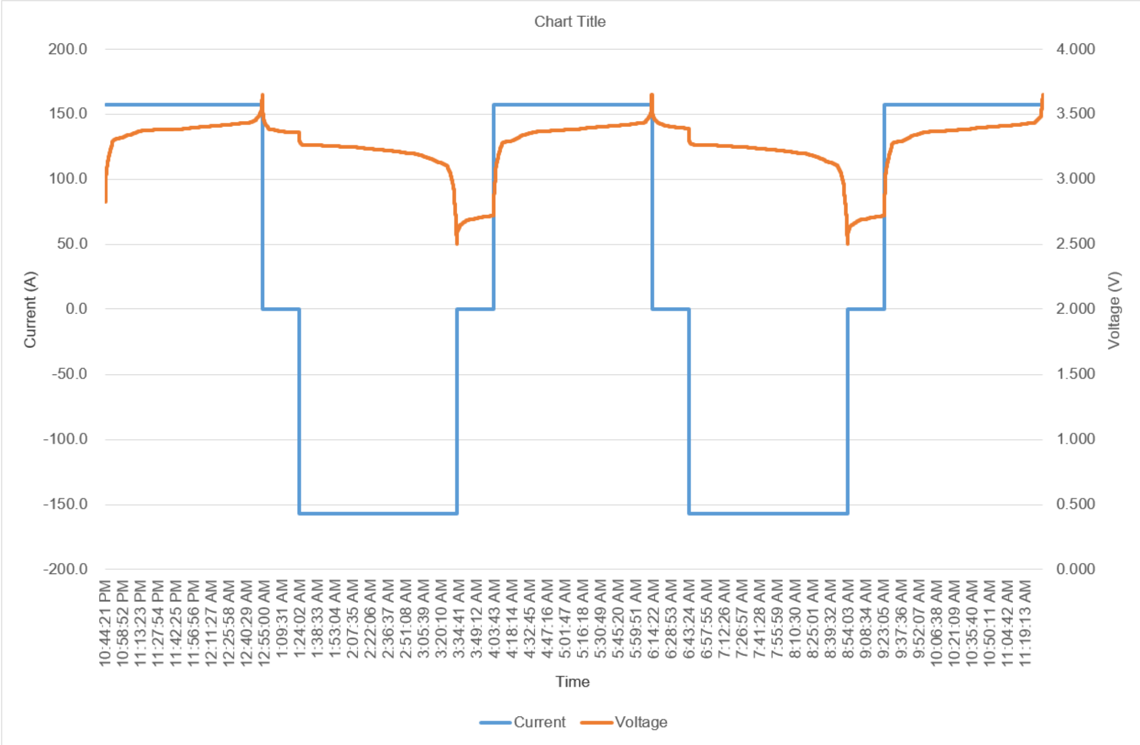


Chart Title
Current (A)
Voltage (V)
Time
Current
Voltage

#5



3.3 Determination of cell thermal runaway methodology

3.3.1 Test method and description

The cells to be tested were charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

External film heater rated 220Vac/429W was put below the cell to induce the cell thermal runaway.

The cell sample and heater were clamped by two steel plate together using four bolts during test to simulate the constraint in the BESS module to prevent excessive swelling during the test.

The thermocouple (type K, 24AWG) was located below the heater that used to measure vent and thermal runaway onset temperature.

An AC power supply controller was used to control the voltage supply to the heater and maintain a 4°C/min to 7°C/min heating rate. Once thermal runaway was observed, the heaters were immediately de-energized.

The cell exhibits thermal runaway after establishing the heating rate. 3 additional samples were repeated to demonstrate repeatability.

The vent temperature and thermal runaway onset temperatures were averaged over the tested samples.

3.3.2 Test result

Ambient conditions at the initiation of the test...:	26.1°C, 51%R.H.	27.9°C, 51%R.H.	26.1°C, 52%R.H.	27.9°C, 50%R.H.	26.1°C, 51%R.H.
Sample number ....:	#1[1)]	#2	#3	#4	#5
Open circuit voltage before test (V) :	3.35	3.37	3.36	3.35	3.35
Cell vent temperature (°C) ....:	231.4	201.8	200.7	208.5	203.6
Thermal runaway onset temperature (°C) ....:	328.8	306.3	283.5	291.4	301.6
Average cell vent temperature (°C)[2)] ....:	--	203.7			
Average thermal runaway onset temperature (°C) [2)] ....:	--	295.7			

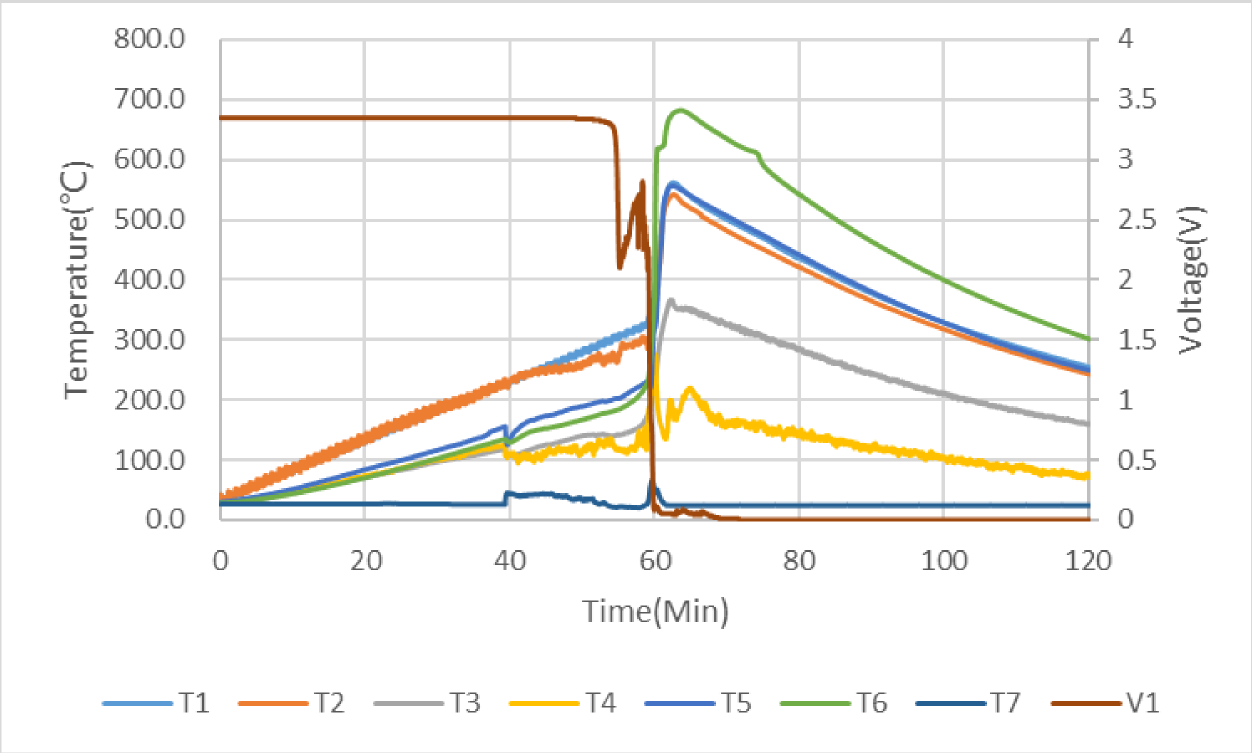
Note:

1) The sample (#1) is for gas vent capture.

2) The temperatures were averaged over the tested samples (#1, #2, #3, #4, #5) excluding the gas vent capture sample (#1).

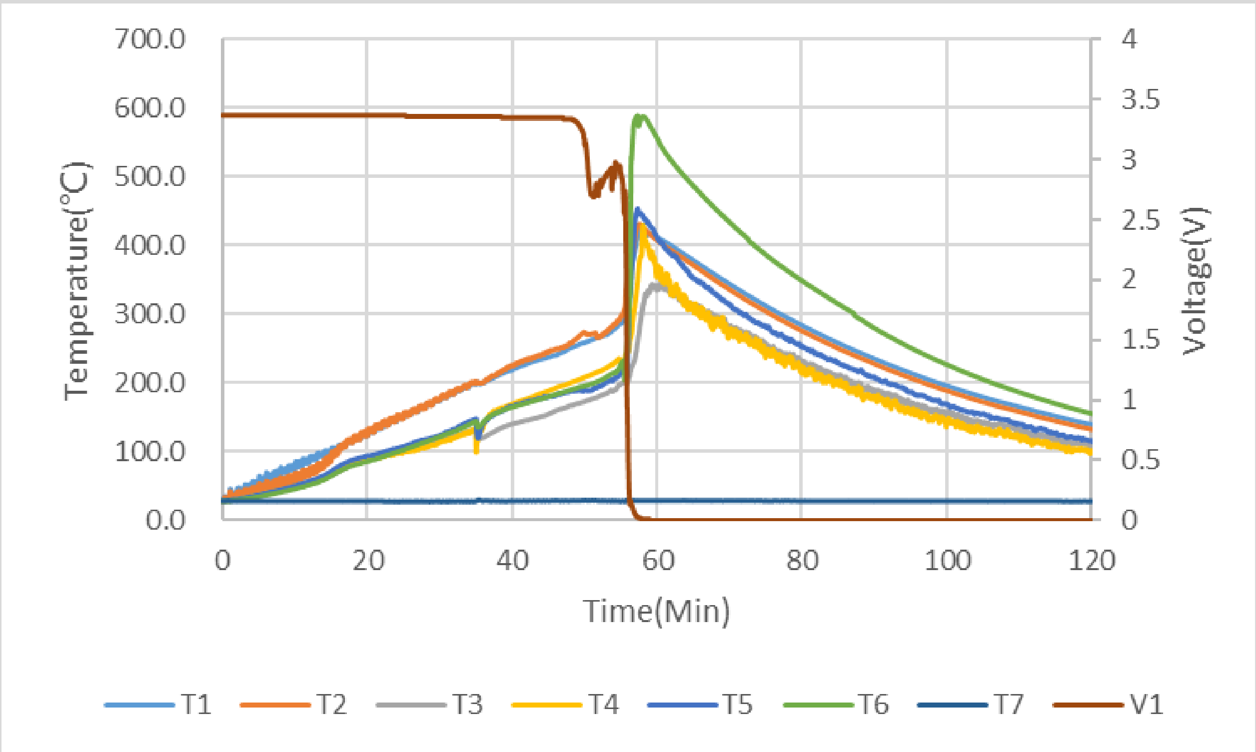
3.3.3 Temperature/voltage vs time curve

#1



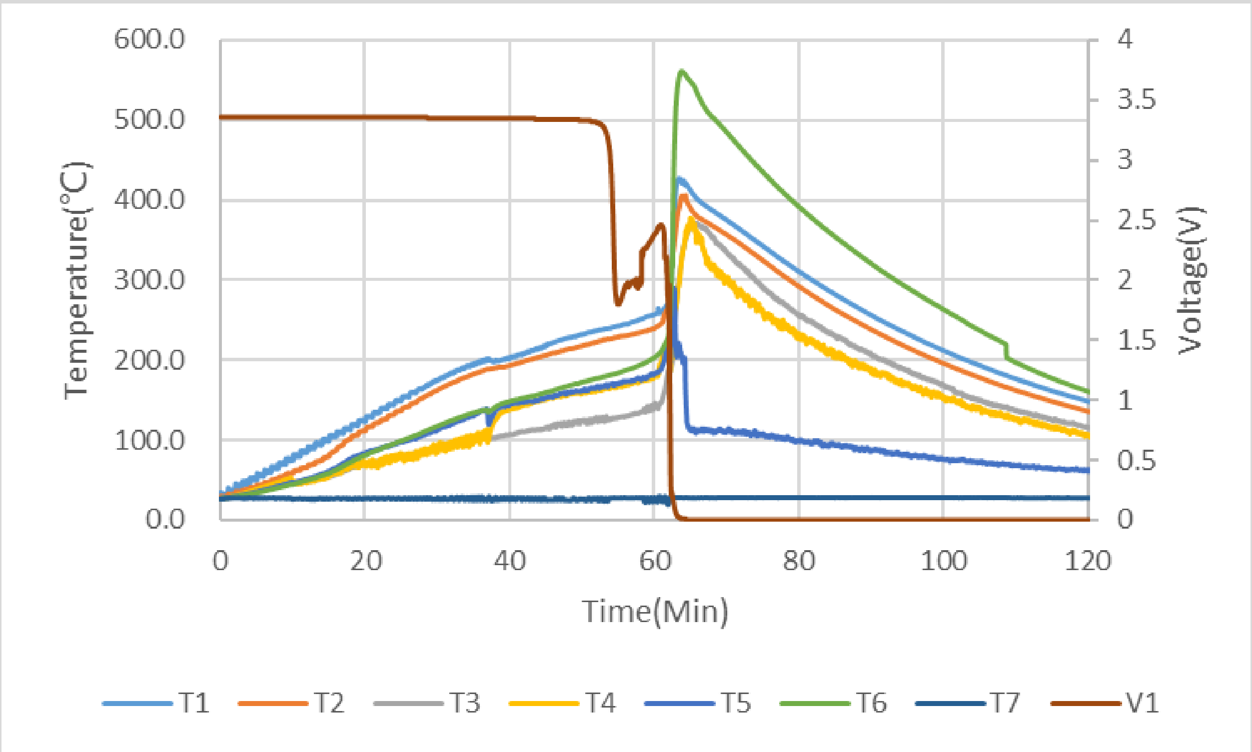
Thermalcouple No.	Location
T1	Cell center below the heater(A side)
T2	Cell center below the heater(B side)
T3	Positive eletrode tap
T4	Near pressure relief valve
T5	Cell narrow side
T6	Cell bottom
T7	Ambient temperature (Inside of pressure vessel)
V1	Cell Voltage

#2



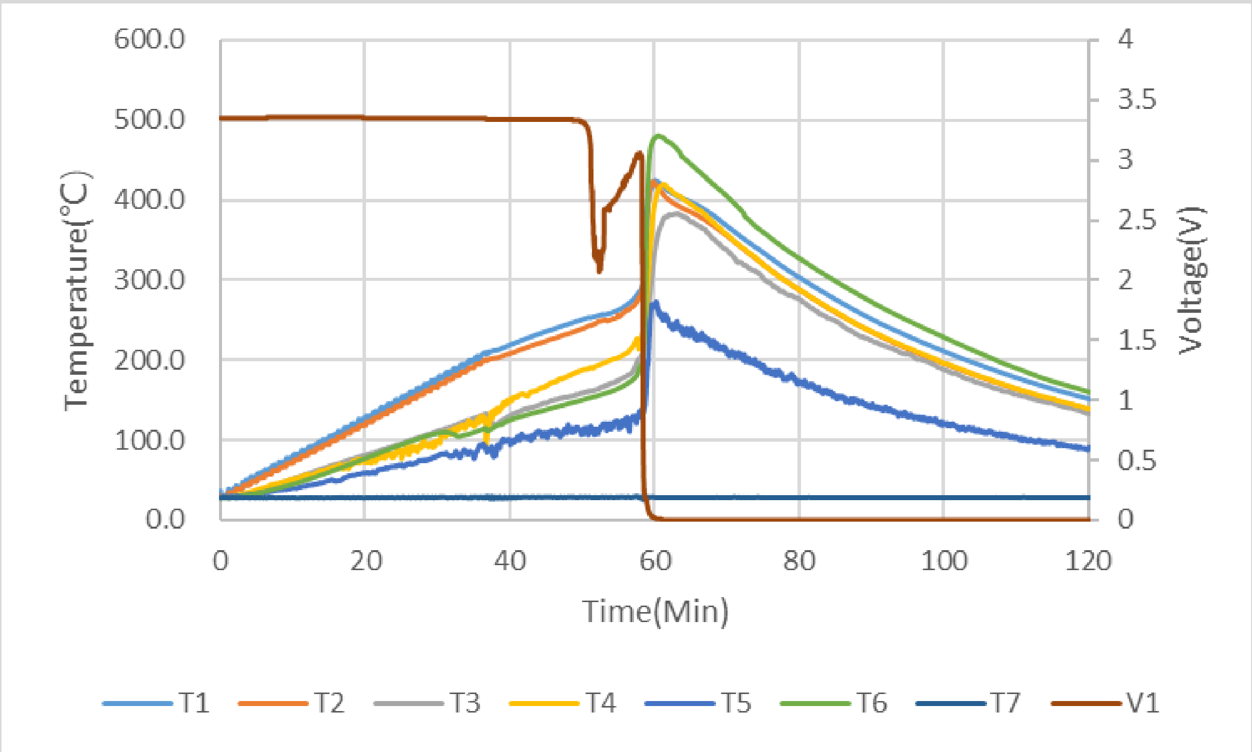
Thermalcouple No.	Location
T1	Cell center below the heater(A side)
T2	Cell center below the heater(B side)
T3	Positive eletrode tap
T4	Near pressure relief valve
T5	Cell narrow side
T6	Cell bottom
T7	Ambient temperature
V1	Cell Voltage

#3



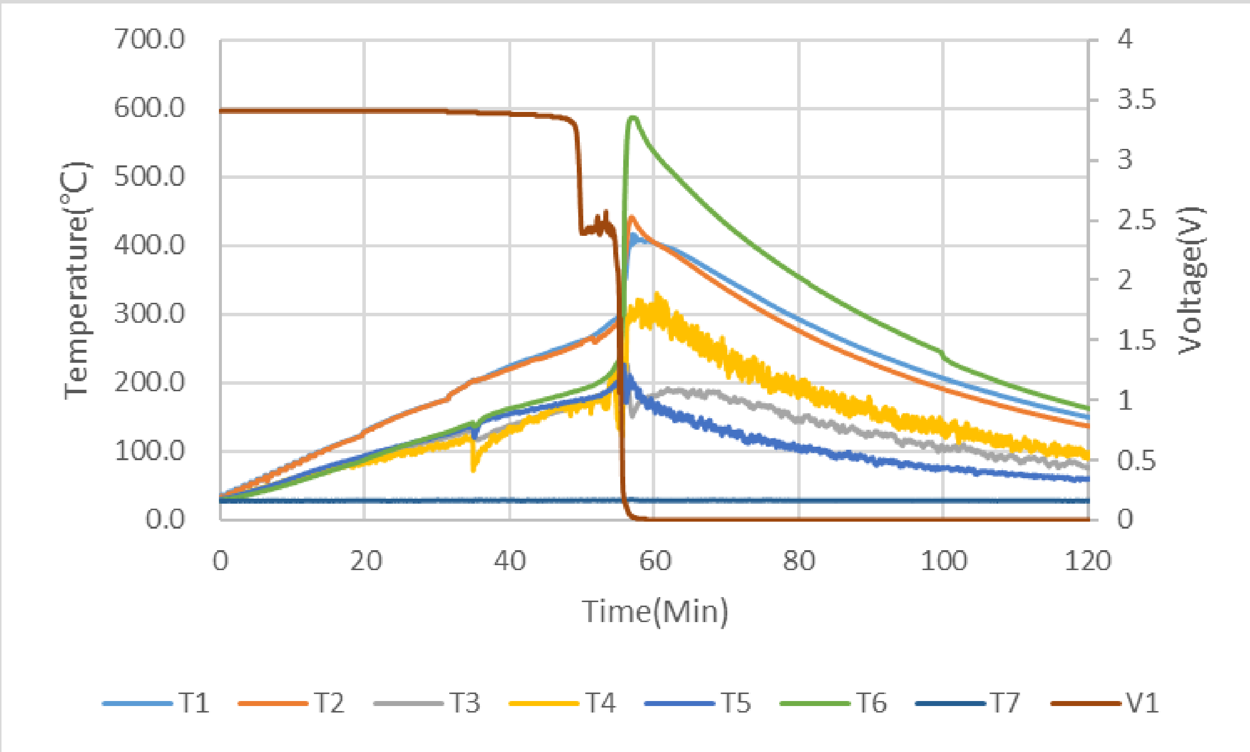
Thermalcouple No.	Location
T1	Cell center below the heater(A side)
T2	Cell center below the heater(B side)
T3	Positive eletrode tap
T4	Near pressure relief valve
T5	Cell narrow side
T6	Cell bottom
T7	Ambient temperature
V1	Cell Voltage

#4



Thermalcouple No.	Location
T1	Cell center below the heater(A side)
T2	Cell center below the heater(B side)
T3	Positive eletrode tap
T4	Near pressure relief valve
T5	Cell narrow side
T6	Cell bottom
T7	Ambient temperature
V1	Cell Voltage

#5



Thermalcouple No.	Location
T1	Cell center below the heater(A side)
T2	Cell center below the heater(B side)
T3	Positive eletrode tap
T4	Near pressure relief valve
T5	Cell narrow side
T6	Cell bottom
T7	Ambient temperature
V1	Cell Voltage

3.4 Cell vent gas generation and capturing

3.4.1 Test method and description

The cells to be tested were charged to 100% SOC and allowed to stabilize for a minimum of 1 h and a maximum of 8 h before the start of the test.

A cell was forced into thermal runaway by the external heating as determined in cell thermal runaway methodology test inside an 280L pressure vessel.

Before testing, the vessel was purged with N_2 to reduce the oxygen content below 1% by volume.

Gas mixtures were collected before and after thermal runaway testing. 0.3L gas collection bag with two valve were used for the gas collection.

Two bags after thermal runaway were used to determine the vent gas composition.

Cell weight was measured before and after test for reference.

Pressure was measured before and after thermal runaway to calculate the total gas produced for reference.

3.4.2 Test result

Ambient conditions .... :	26.1 °C, 51 % R.H
Sample number .... :	#1
Open circuit voltage before test (V) .... :	3.35
Pressure vessel size........................... :	280L
Initial oxygen content by volume (%) .. :	< 0.1%
Cell weight before test (g)................... :	5626.0
Cell weight after test (g)...................... :	4474.1
Total vent gas produced (L)................	130

3.5 Determination of cell vent gas composition

3.5.1 Test method

Cell vent gas composition was determined using Gas Chromatography (GC) with detection techniques for quantifying component gases.

The gases make up in table 1 is the gas composition after cell thermal runaway.

Table 2 contains normalized volumetric gas compositions by removing the N_2 contributions. This information was used to synthetically replicated gas mixture for further flammability character parameter tests.

3.5.2 Test result

Table 1: Vent gas components

Gas component	Concentration (v, %)
CH_4	1.1092
C_2H_6	0.1655
C_2H_4	0.4196
C_3H_8	0.0545
C_3H_6	0.2250
n-C_4H_{10}	0.0207
n-C_4H_8	0.0666
n-C_5H_{12}	0.0230
iso- C_5H_{12}	0.0339
n-C_5H_{10}	0.0160
CO	4.8960
CO_2	8.1173
H_2	15.0719
N_2	69.7808

Table 2: Vent gas components (normalized)

The gas components N_2 was removed.

Gas component	Concentration (v, %)
CH_4	3.671
C_2H_6	0.548
C_2H_4	1.389
C_3H_8	0.18
C_3H_6	0.745
n-C_4H_{10}	0.068
n-C_4H_8	0.22
n-C_5H_{12}	0.076
iso-C_5H_{12}	0.112
n-C_5H_{10}	0.053
CO	16.202
CO_2	26.861
H_2	49.875

3.6 Flammability character parameters of the cell vent gas

3.6.1 Test method

Upon determination of the cell vent gas composition, the flammability character parameters were determined on sample of the synthetically replicated gas mixture with maximum uncertainty 2%.

Lower flammability limit (LFL) of the cell vent gas was determined in accordance with ASTM E918, testing at both ambient and cell vent temperatures.

The gas burning velocity was determined in accordance with the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817.

The maximum explosion pressure P_{lax} was determined on samples of the synthetically replicated gas mixture in accordance with EN 15967.

Below table show the test result only. Detailed test report refer to Appendix A, Appendix B and Appendix C.

References:

ASTM E 918-19 – Standard Practice for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure

ISO 817: 2014/Amd 1: 2017 – Refrigerants- Designation and safety classification

EN 15967: 2011 – Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours

3.6.2 Test result

LFL at 25°C±5°C and 101±5kPa .... :	8.1%	(see Appendix A for details)
LFL at 205°C±5°C and 101±5kPa ...... :	6.5%	(see Appendix A for details)
Burning Velocity S_u(m/s) at room temperature .... :	0.779	(see Appendix B for details)
P_{max} (MPa) at room temperature .... :	0.78	(see Appendix C for details)

3.7 Photos

Sample #1: Gas generation and capturing setup

Sample #1: After thermal runaway test

Sample #2: Thermal runaway test setup

Sample #2: After thermal runaway test

4 List of Test and Measurement Instruments

No.	Equipment	Model	Rating	Last Cal. date
1	Gas Chromatography	8890	--	2023.09.06
2	Hybrid Recorder	TWC-2A	-50~700°C	2023.03.17
3	Data Acquisition	34970A	10mA-1000mA 0.1-300V	2023.07.06
4	Battery Testing System	CT-4004-5V200A-ATL	5V/200A	2023.07.10
5.	Digital multi-meter	15B+	400mVdc~100Vdc	2023.07.10
6.	Electronic Weight	CHS-D	0-10kg	2023.03.17
7.	Gas acquisition system	WRNK-191 HM90-H3-2-BD-801KZ DTM	0-1200°C -0.1~1.5 MPa 0-1000°C	2023.09.07 2023.09.07 2023.09.07
8.	Oxygen analyzer	HG-BX-O2	0-30%	2023.09.07
9.	Gas lower flammability limit test system			
	Temperature measurement	TJ120-CAXL-116U-10-SPW-M	0-300°C	2023.09.07
	Pressure transducer	PTX50G2-TC-A3-CA-H0-PB	-100~150KPa	2023.09.07
10.	Gas explosion test system			
	Temperature measurement	TJ120-CAXL-116U-10-SPW-M	0-300°C	2023.09.07
	Pressure transducer	Kistler 603CAA	0~100MPa	2023.09.07
	Pressure sensor	HM90-H3-2-V2-F1-W2	-0.1~2.0 MPa -0.1~0.15 MPa	2023.09.07
11.	High speed camera	MV-XG1205GC/M-T MV-XG280GC-T	90fps 409fps	--
12.	Combustible gas combustion rate device			
	Temperature measurement	TJ120-CAXL-116U-10-SPW-M	0-300°C	2023.09.07
	straight steel ruler	dawn 1m	1000mm	2023.09.07

Appendix A: Cell vent gas lower flammability limit (LFL) test

Test Method	ASTM E918-19 Standard Practice for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure
Test Item	The lower flammability of gas mixture
Test Apparatus	Test Vessel: 5L closed sphere Ignition system: Fusing Wire
Preparation of Test Mixture	Partial pressure method used inside the vessel; Accuracy: within 0.2% absolute
Symbol and definition	The symbols used in this report are defined as below except otherwise defined: c_s —— Concentration of sample; T_i —— Initial temperature in each trial; p_i —— Initial pressure in each trial; p_{ex} —— Overpressure in each trial; It is considered flame occurred, if pex / pi ≥ 1.07. L_1 —— The minimum sample concentration that gives flame propagation; L_2 —— The maximum sample concentration that does not give flame propagation; LFL —— Lower flammable limit; LFL is expressed as: LFL = (L1+ L2)/2 Concentration defined in this report means volume percentage.
Remark	This report is effective under the specific condition; please seek for the advice of expert for risk assessment in producing, processing, transportation and storage.

LFL test data at room temperature (part)						
Test Condition	Initial Temperature: 25(±5)°C Initial Pressure: 101(±5)kPa					
No.	cs [%]	Ti [°C]	p_i [kPa]	p_{ex} [kPa]	p_{ex} / p_i	Ignition?
1	7.8	22	101.98	108.35	1.062	N
2	8.0	22	101.73	107.67	1.058	N
3	8.0	23	101.88	108.50	1.065	N
4	8.0	23	101.92	108.31	1.063	N
5	8.2	23	102.04	109.65	1.075	Y
6	8.2	23	101.88	109.98	1.080	Y
7	8.2	23	101.54	109.06	1.074	Y
Test result	L1=8.2 %, L2=8.0%, LFL=8.1 % at 25(±5)°C and 101(±5)kPa					

LFL test data at cell vent temperature (part)						
Test Condition	Initial Temperature: 205(±5)°C Initial Pressure: 101(±5)kPa					
No.	cs [%]	Ti [°C]	p_i [kPa]	p_{ex} [kPa]	p_{ex} / p_i	Ignition?
1	6.2	205	101.00	105.12	1.041	N
2	6.4	206	101.46	107.17	1.056	N
3	6.4	207	100.83	107.69	1.068	N
4	6.4	206	101.60	106.46	1.048	N
5	6.6	206	101.21	108.56	1.073	Y
6	6.6	207	101.33	110.73	1.093	Y
7	6.6	203	100.98	109.44	1.084	Y
Test result	L1=6.6%, L2=6.4%, LFL=6.5% at 205(±5)°C and 101(±5)kPa					

Appendix B: Cell vent gas burning velocity (S_u) test

Same synthetically replicated gas mixture as LFL test was used for the test.

Test Method	ISO 817: 2014 / Amd 1: 2017 Refrigerants - Designation and safety classification
Test Item	Burning velocity of flammable gases
Test Apparatus	Test vessel: Glass tube; length 1500 mm; inner diameter 40 mm Ignition system: Electric spark Recorder: High speed camera
Preparation of Test Mixture	Partial pressure method used inside the vessel; Accuracy: within 0.2% absolute
Symbol and definition	The symbols used in this report are defined as below except otherwise defined: c_S —— Concentration of sample; S_S —— Flame propagation speed； a_f —— Cross-sectional area of flame bottom； A_f —— Flame surface area； S_u is calculated as： $$S_u = S_S \times \frac{a_f}{A_f}$$
Remark	This report is effective under the specific condition; please seek for the advice of expert for risk assessment in producing, processing, transportation and storage.

Burning velocity test data (part)				
Test Condition	Initial temperature: room temperature Initial pressure: atmospheric pressure The oxidant used: synthetic air Smallest flammable substance content increment: 1.0% volume			
No	c_S [%]	S_S [m/s]	a_f/ A_f [m^2]	S_u [m/s]
1	21%	1.032	0.492	0.508
2	22%	1.267	0.510	0.646
3	23%	1.366	0.511	0.698
4	24%	1.426	0.506	0.722
5	25%	1.483	0.509	0.755
6	26%	1.524	0.511	0.779
7	27%	1.467	0.506	0.742
8	28%	1.432	0.504	0.722
9	29%	1.393	0.501	0.698
Test result	Su= 0.779m/s at room temperature and atmosphere pressure.			

Appendix C: Cell vent gas maximum pressure (P_{max}) test

Same synthetically replicated gas mixture as LFL test was used for the test.

Test Method	EN 15967:2011 Determination of maximum explosion pressure and the maximum rate of pressure rise of gases and vapours
Test Item	Maximum explosion pressure of the gas mixture
Test Apparatus	Test Vessel: 5L closed sphere Ignition system: Fusing Wire
Preparation of Test Mixture	Partial pressure method used inside the vessel; Accuracy: within 0.2% absolute
Symbol and definition	The symbols used in this report are defined as below except otherwise defined: c_s—— Content of flammable substance by volume; p_{exn} —— Explosive overpressure in the n^{th} ignition test at a certain concentration; p_{ex} —— Highest pressure occurring in a closed vessel during the explosion of a specific mixture of flammable substances with air or air and inert gases determined under specified test conditions; P_{Mean}——The average value of the explosion overpressure at a certain concentration; P_{max} —— Maximum explosion pressure; $p_{max}$is expressed as the maximum value of p_{ex}.
Remark	This report is effective under the specific condition; please seek for the advice of expert for risk assessment in producing, processing, transportation and storage.

P_{max} test data (part)						
Test Condition	Initial Temperature: 25(±2)°C Initial Pressure: 101(±5)kPa					
Part of Test Data						
No.	c_s [%]	p_{ex1} [MPa]	p_{ex2} [MPa]	p_{ex3} [MPa]	p_{ex4} [MPa]	p_{ex5} [MPa]
1	19	0.6106	0.6213	0.6119	--	--
2	21	0.6593	0.6599	0.6587	--	--
3	23	0.7070	0.6801	0.6942	--	--
4	25	0.7319	0.7286	0.7308	--	--
5	27	0.7571	0.7565	0.7562	--	--
6	29	0.7550	0.7691	0.7644	--	--
7	29.8	0.7667	0.7693	0.7713	0.7702	0.7688
8	31	0.7796	0.7805	0.7784	0.7815	0.7820
9	31.2	0.7764	0.7782	0.7758	0.7773	0.7672
10	31.4	0.7745	0.7675	0.7583	0.7726	0.7747
11	33	0.7562	0.7517	0.7537	--	--
12	35	0.7350	0.7351	0.7355	--	--

Determination of the explosion pressure			
No.	c_S [%]	P_{Mean} [MPa]	P_{max} [MPa]
1	19	0.6146	0.6213
2	21	0.6593	0.6599
3	23	0.6938	0.7070
4	25	0.7304	0.7319
5	27	0.7566	0.7571
6	29	0.7628	0.7691
7	29.8	0.7693	0.7713
8	31	0.7804	0.7820
9	31.2	0.7750	0.7782
10	31.4	0.7695	0.7747
11	33	0.7539	0.7562
12	35	0.7352	0.7355

Test result	
Content of flammable substance	31 % volume
Smallest flammable substance content increment	0.2% absolute
Maximum explosion pressure (P_{max})	0.78 MPa

End of Test Report