11/10 2025 - Supplerende oplysninger Fjelstrup Batterianlæg, Vestvej

Opdateret indikativ situationsplan

Anlægget udarbejdes fortsat med maksimalt 3.400 kvm og grundet optimering opdateres effekt og kapacitet til maksimalt 44 MW og 125 MWh.

Væskehåndtering ved transformere og tekniske anlæg

Ved de tilknyttede mellemspændingstransformere og 60 kV hovedtransformeren etableres permanente opsamlingsløsninger, der forhindrer spild af olie og andre væsker til det omgivende terræn.

Transformer 60 kV – olieopsamling

Alle transformere udføres med olieopsamlingskar under selve enheden.
Opsamlingskarrene dimensioneres til at kunne rumme minimum 110 % af transformernes olievolumen og forsynes med drænlag og evt. filterlag for regnvand.
Ved eventuelt oliespild i driftsfasen tilbageholdes olien i karret, hvorfra den kan fjernes ved kontrolleret tømning via påfyldnings- eller sugepunkt.

Opsamlingskarrene udføres i beton med olie- og kemikalieresistent overfladebehandling.
Systemet sikrer, at oliespild ikke kan sive til jorden eller løbe til kloak i tilfælde af utætheder eller uheld.

Containerbaserede mellemspændingstransformere

Evt. spild af olie fra mellemspændingstransformerne vil blive opsamlet i bunden af containeren som fungerer og er designet til opsamlingskar. Olien kan fjernes ved kontrolleret tømning via påfyldnings- eller sugepunkt.

Battericontainere – håndtering af glykol

I BESS-containerne anvendes et lukket kølekredsløb med glykolholdig væske (en blanding ethylene glykol og vand).
Eventuelle spild i driftsfasen opsamles i containerens gulvkar i containeren, som fungerer og er designet til opsamlingskar.
Karrene under containerne er tætte og dimensioneret til at rumme den maksimale mængde væske fra ét samlet kølekredsløb.

Tømning foretages manuelt via aftapningsstuds eller sugeledning.

Miljø- og sikkerhedshensyn

Alle opsamlingssystemer er etableret for at forhindre udledning af olie- eller glykolholdige væsker til jord og kloak.
Løsningerne understøtter anlæggets samlede miljøsikkerhed og indgår i drifts-, kontrol- og vedligeholdelsesplanen (DKV-plan), hvor procedurer for tømning, prøvetagning og dokumentation er beskrevet.

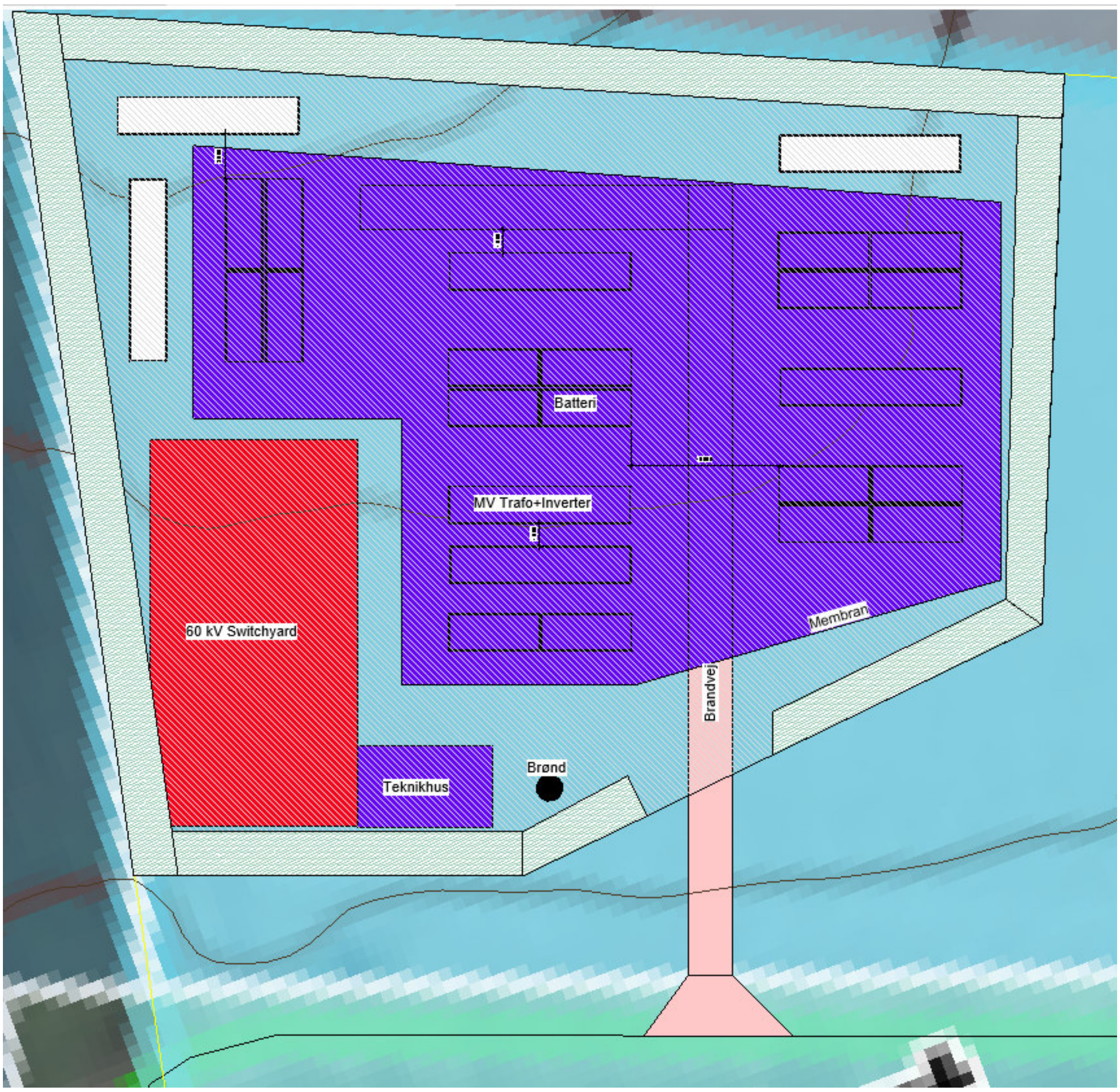
Membran- og brøndløsning ved BESS-anlæg

Under hele batteri-containerområde etableres en tæt membranløsning til opsamling og kontrol af eventuelle væsker, der måtte udledes i forbindelse med drift, service eller brandhændelser.

I tilfælde af brand oplyser Brand & Redning Sønderjylland, at de ikke forventer at bekæmpe branden med vand. Hvis de alligevel gør det, vil de tilkalde kommunens miljøvagt.

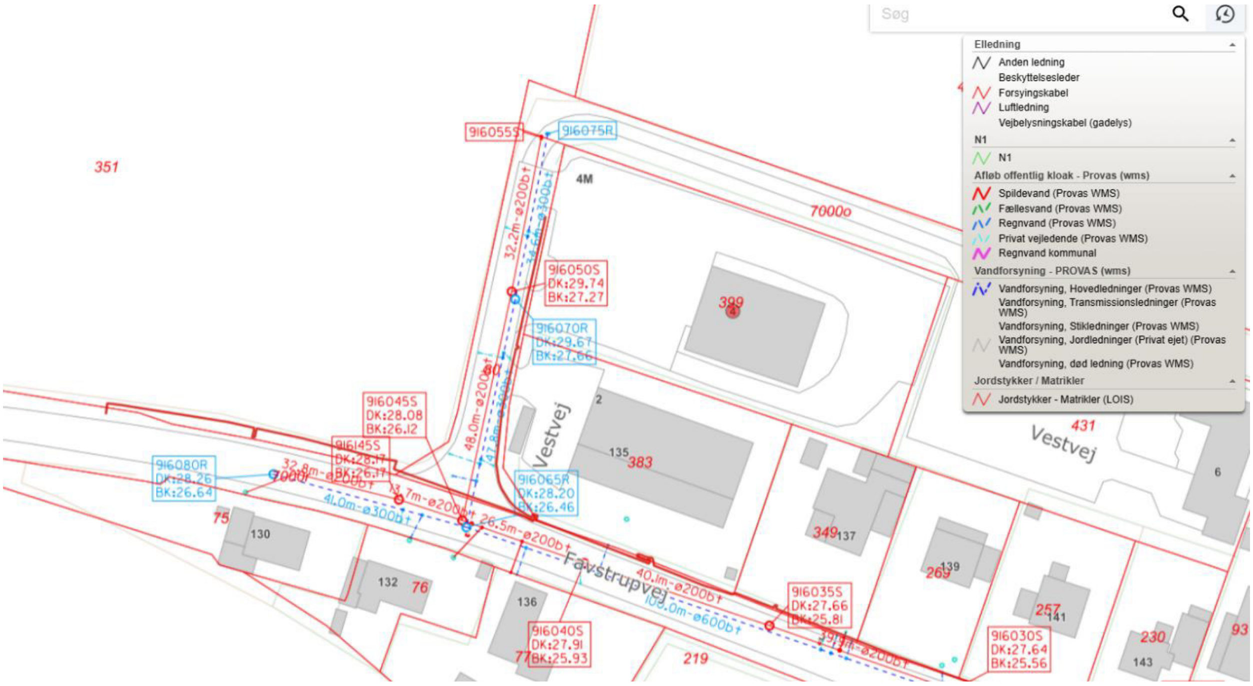
Membranen udføres som en fulddækkende flade under samtlige battericontainere samt med minimum 2 meters udlæg ud over containernes yderkanter.
Under membranen etableres beskyttelsesdug, og ovenpå membranen placeres en dræn- og beskyttelsesmåtte (f.eks. Enkadrain), som sikrer effektiv afvanding og mekanisk beskyttelse.

Indikativ placering af membran:



Membranområdet tilkobles en drænbrønd med automatisk spjæld, der lukker for udledning til kloak i tilfælde af brandalarm.
Spjældet aktiveres elektrisk via signal fra anlæggets brandalarm, således at potentielt forurenet vand eller brandslukningsvand tilbageholdes inden for det membraninddækkede område. I sådanne tilfælde tømmes brønden med slamsuger.

Under normal drift udledes overfladevand til regvandskloak i Vestvej.



Brønden udføres som en såkaldt "smartbrønd", forsynet med elektrisk motorventil og mulighed for fjernstyring eller manuel betjening.
Brønden tilsluttes anlæggets drænsystem (typisk Ø200–Ø250 mm rørføring) og dimensioneres efter forventet vandmængde ved regn- og brandsituationer.

Det samlede system omfatter:

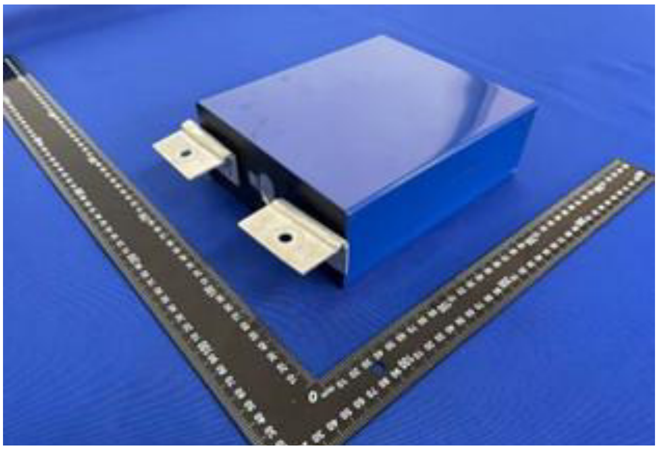
- Tæt membran under og omkring alle battericontainere (mindst 2 m udenom)
- Beskyttelsesdug under og dræn-/beskyttelsesmåtte over membranen
- Automatisk spjældbrønd (smartbrønd) koblet til brandalarm
- Tæt tilslutning til anlæggets afvandingssystem
- Styreenhed og UPS-backup for sikring af funktion under strømsvigt

Løsningen sikrer, at eventuelt udtrængende væske under brand eller fejltilstand bliver inddæmmet og ikke siver til det omkringliggende terræn, i overensstemmelse med miljø- og beredskabsmæssige krav.

Kloaktilslutningen udføres efter kommunale spildevandskrav og i samråd med Haderslev Kommune og Brand & Redning Sønderjylland for at sikre, at både miljø- og beredskabsmæssige forhold tilgodeses.

Til overvågning kan der installeres niveausensor i brønden, som alarmerer driftsansvarlig ved høj vandstand eller fejl på spjældfunktionen.

Prüfbericht-Nr.: *Test report no.*:	CN23F118 001	**Auftrags-Nr.:** *Order no.*:	168441619	Seite 1 von 36 *Page 1 of* 36
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*

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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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.

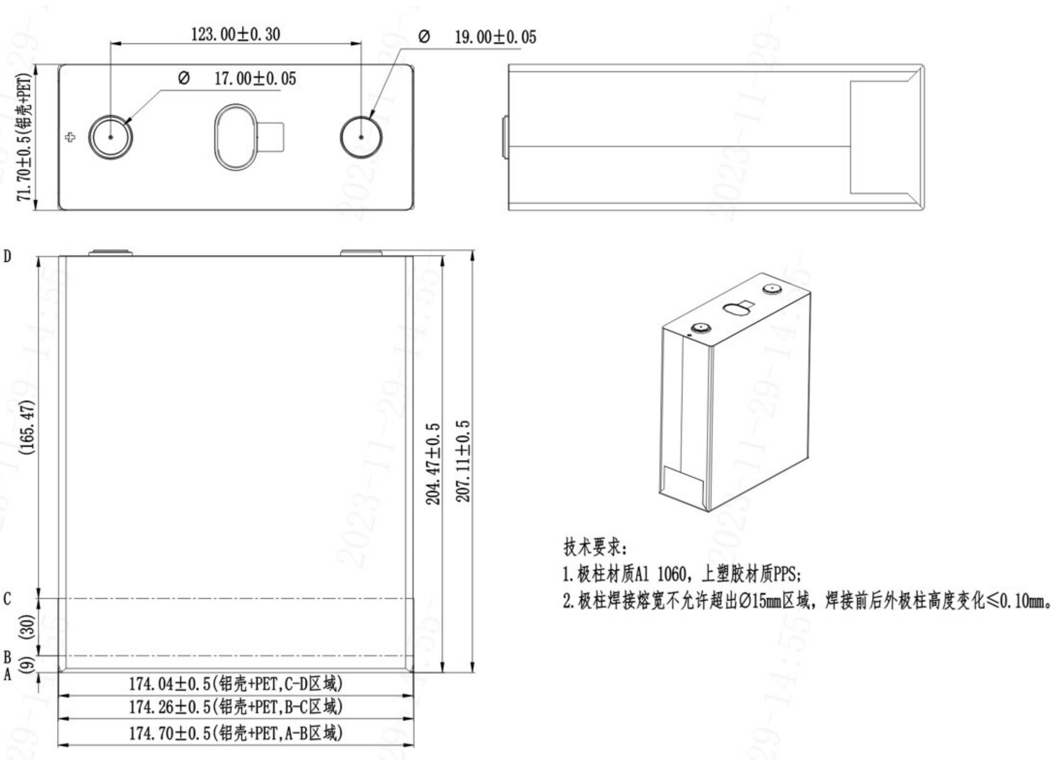
2 General Product Information

2.1 Product information and parameters

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

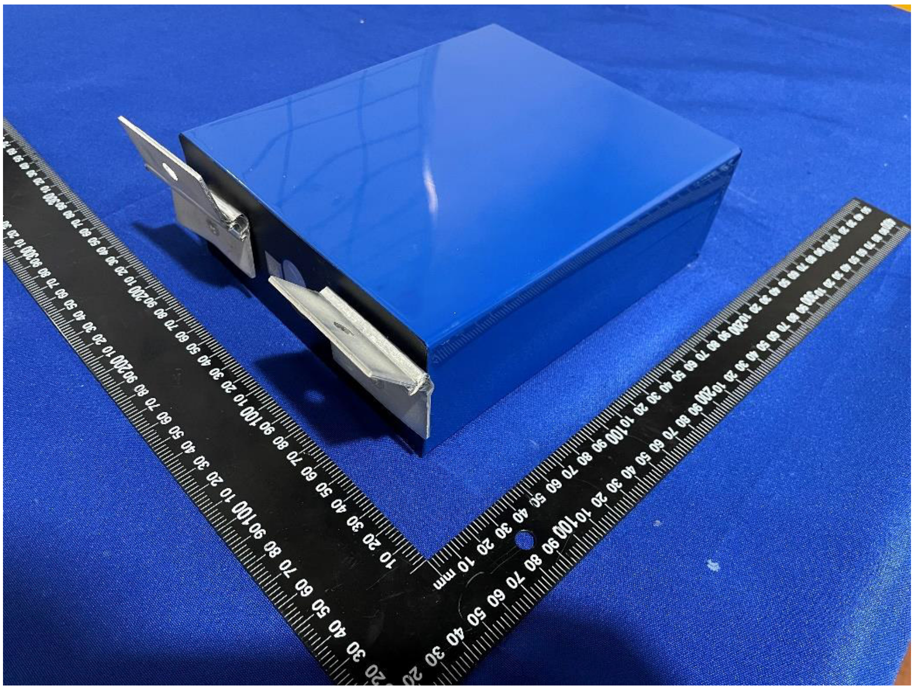
Manufacturer ....:	Xiamen Hithium Energy Storage Technology Co., Ltd. 201-1, Comprehensive Building 5, No.11, Butang Middle Road, Industrial Base Of Xiamen Torch High Tech Zone (Tongxiang), Xiamen, Fujian, P.R. China	
Model number...................................:	LFP71173207/314Ah	
Chemistry ....:	☒ $LiFePO_4$ ☐ 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:		

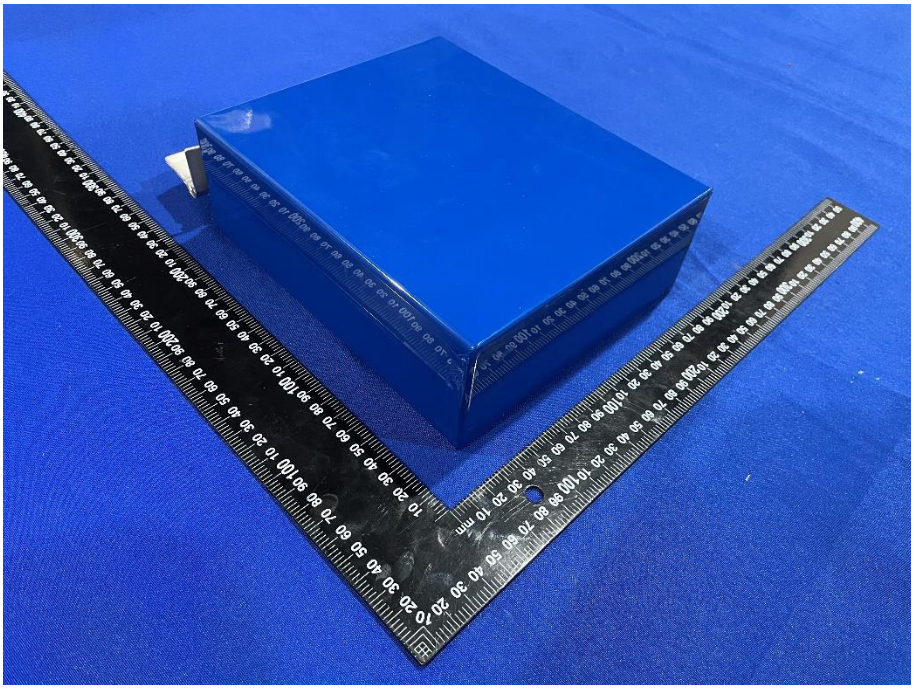
2.2 Diagram with overall dimension

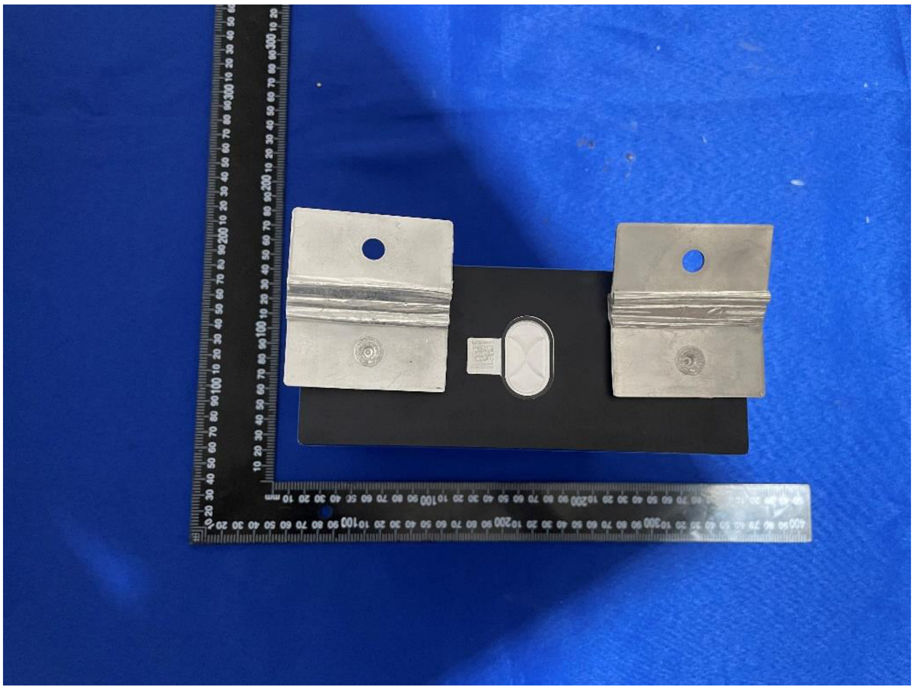


Unit: mm

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

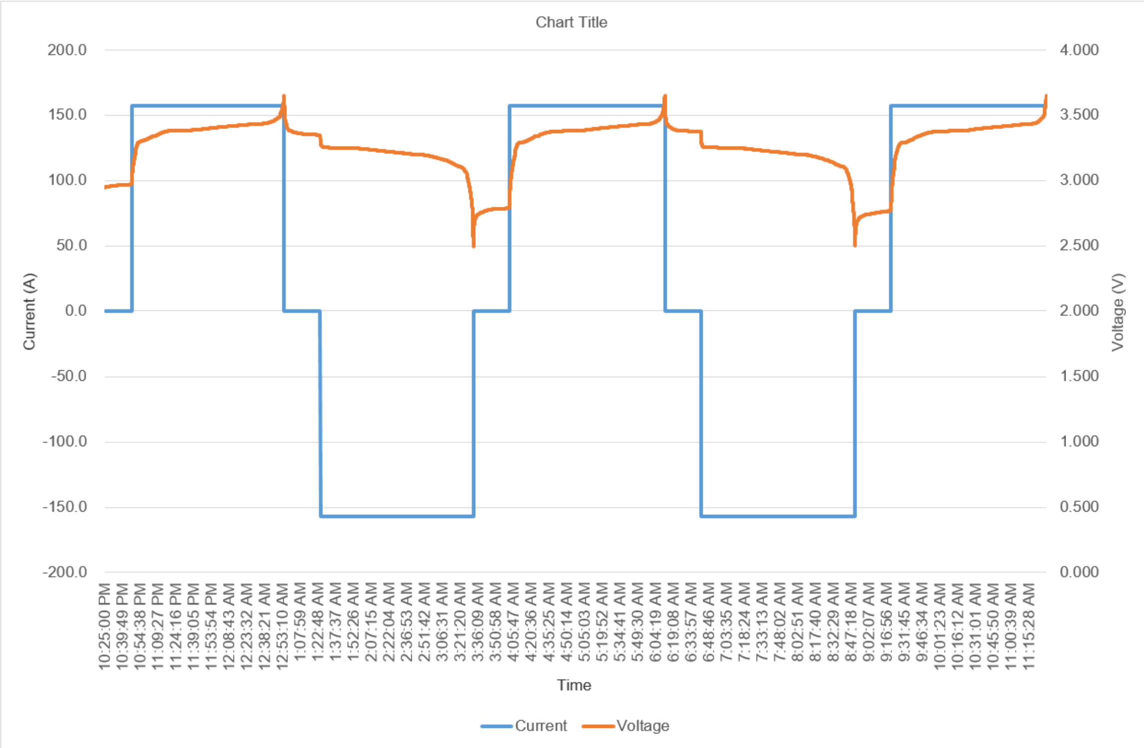
3.2.1 Test method and description

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



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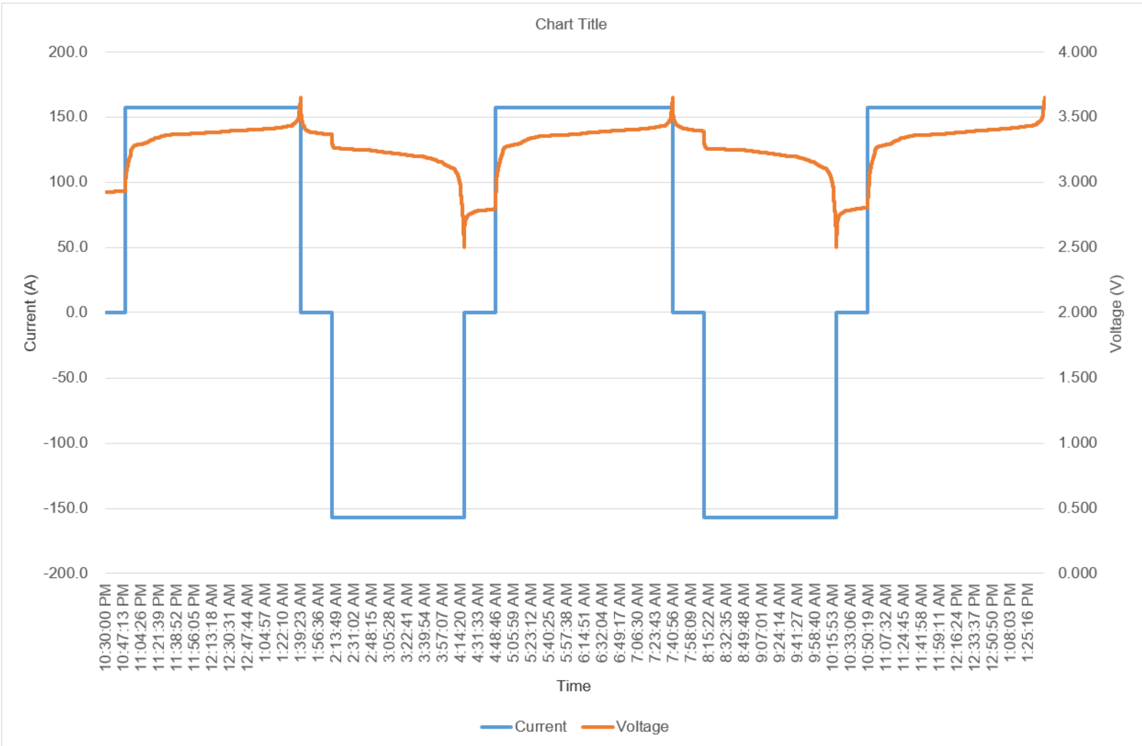

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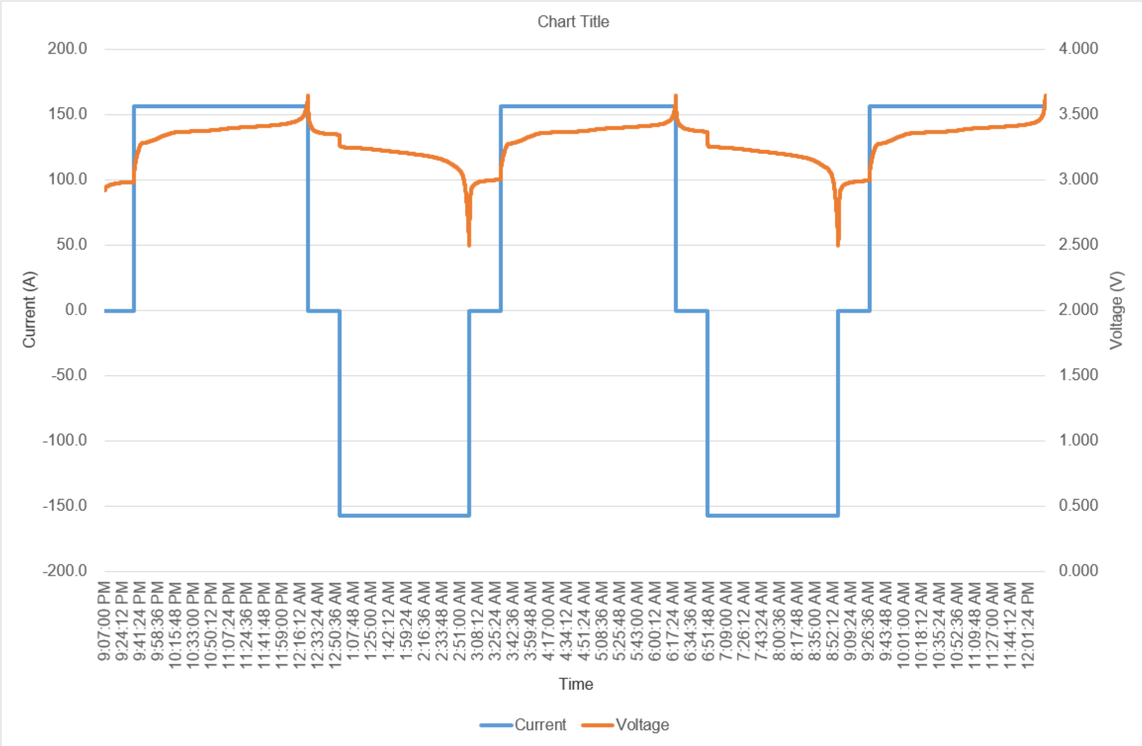


Chart Title
Current (A)
Voltage (V)
Time
Current
Voltage

#4

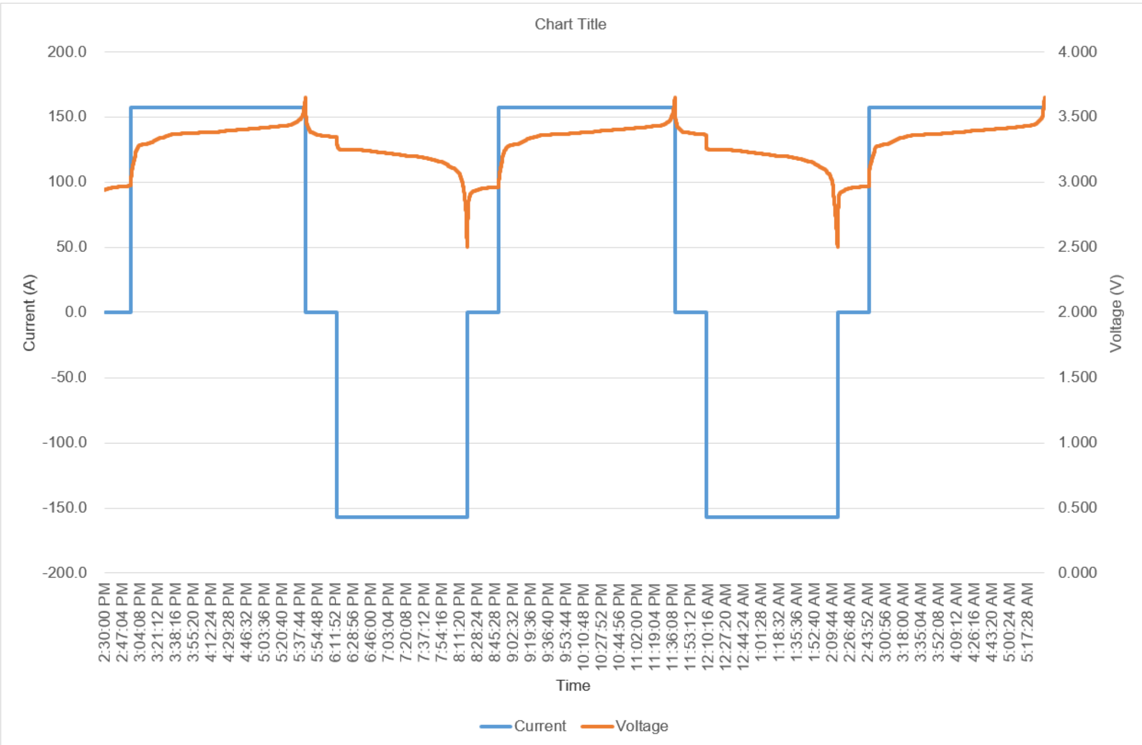


Chart Title
Current (A)
Voltage (V)
Time
Current
Voltage

#5

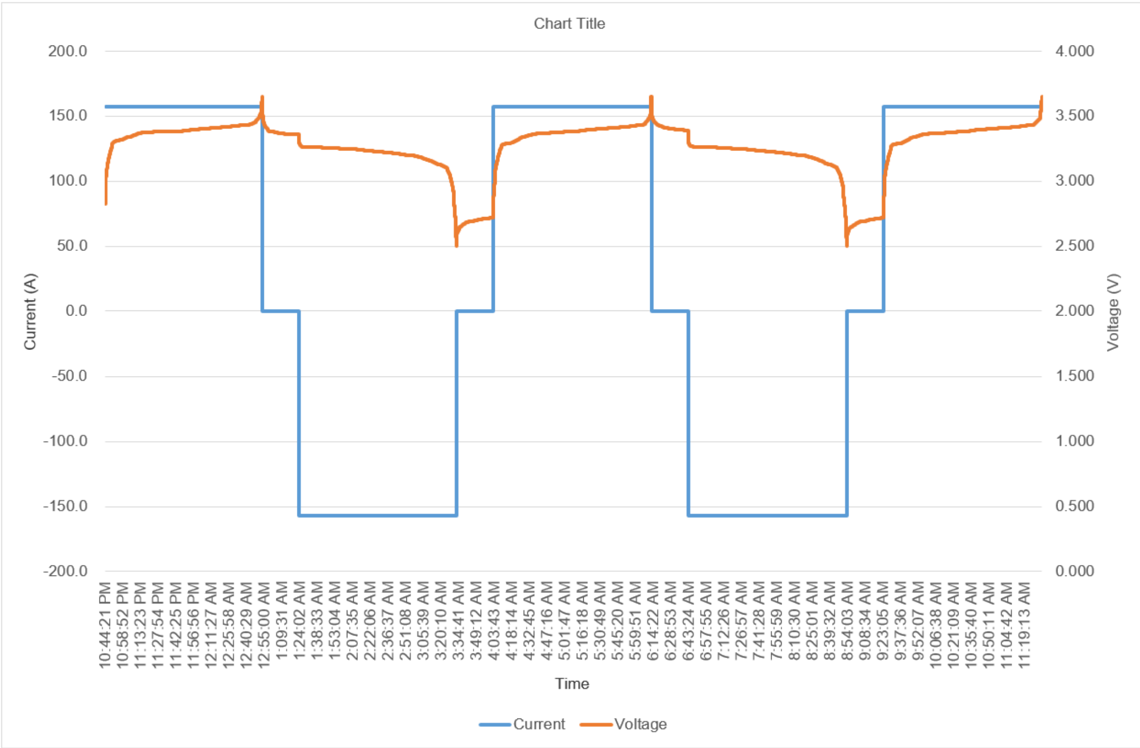


Chart Title
200.0
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
-200.0
Current (A)
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
Voltage (V)
10:44:21 PM
10:58:52 PM
11:13:23 PM
11:27:54 PM
11:42:25 PM
11:56:56 PM
12:11:27 AM
12:25:58 AM
12:40:29 AM
12:55:00 AM
1:09:31 AM
1:24:02 AM
1:38:33 AM
1:53:04 AM
2:07:35 AM
2:22:06 AM
2:36:37 AM
2:51:08 AM
3:05:39 AM
3:20:10 AM
3:34:41 AM
3:49:12 AM
4:03:43 AM
4:18:14 AM
4:32:45 AM
4:47:16 AM
5:01:47 AM
5:16:18 AM
5:30:49 AM
5:45:20 AM
5:59:51 AM
6:14:22 AM
6:28:53 AM
6:43:24 AM
6:57:55 AM
7:12:26 AM
7:26:57 AM
7:41:28 AM
7:55:59 AM
8:10:30 AM
8:25:01 AM
8:39:32 AM
8:54:03 AM
9:08:34 AM
9:23:05 AM
9:37:36 AM
9:52:07 AM
10:06:38 AM
10:21:09 AM
10:35:40 AM
10:50:11 AM
11:04:42 AM
11:19:13 AM
Time
Current
Voltage

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.

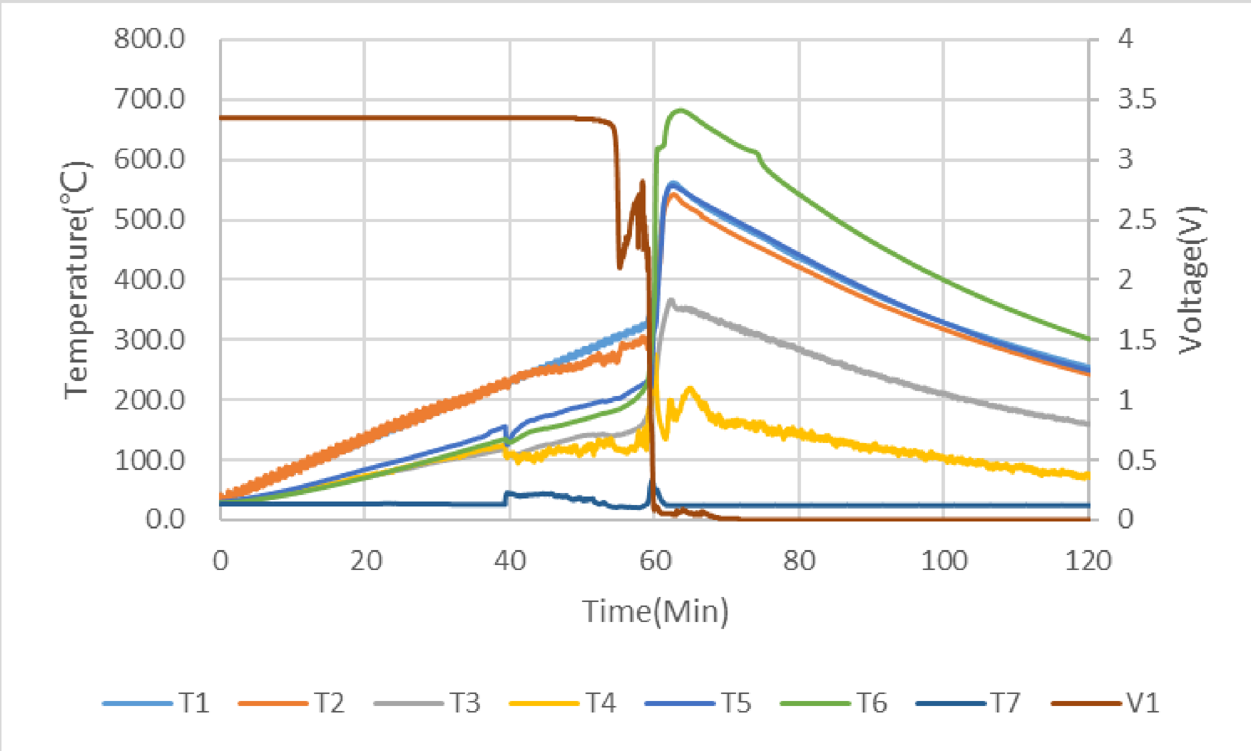
3.3.2 Test result

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).

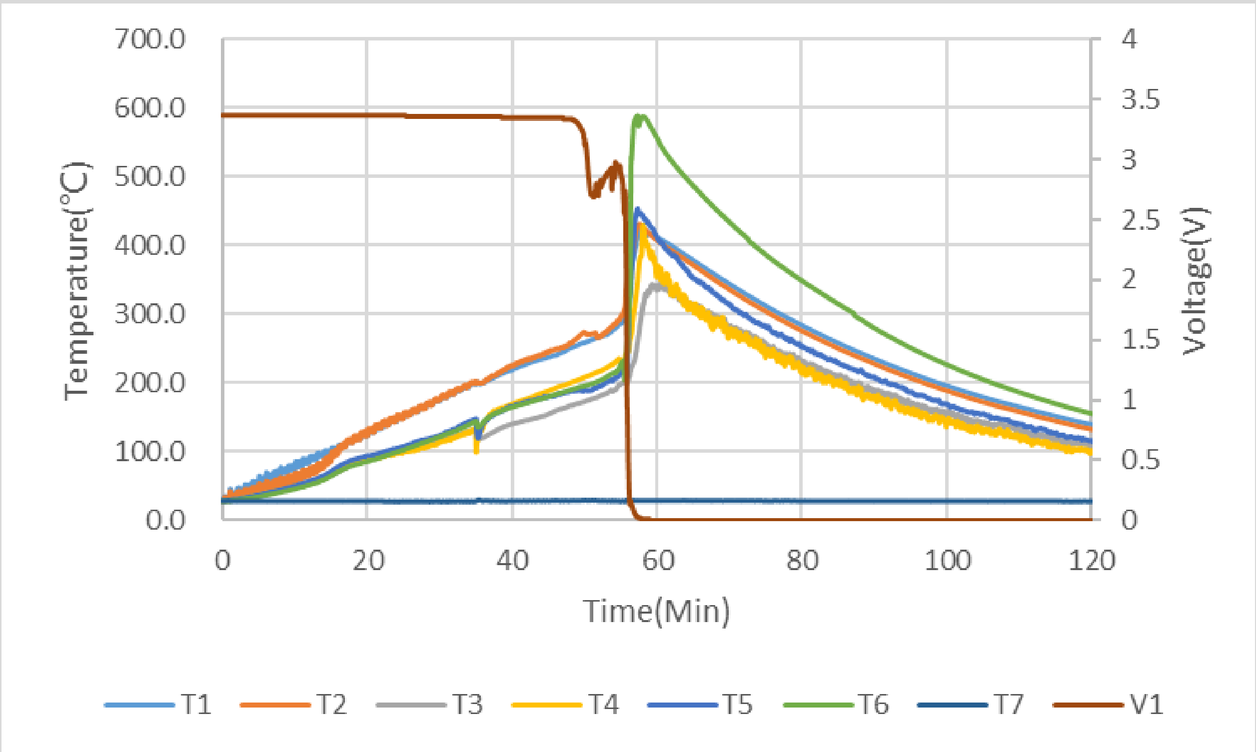
3.3.3 Temperature/voltage vs time curve

#1



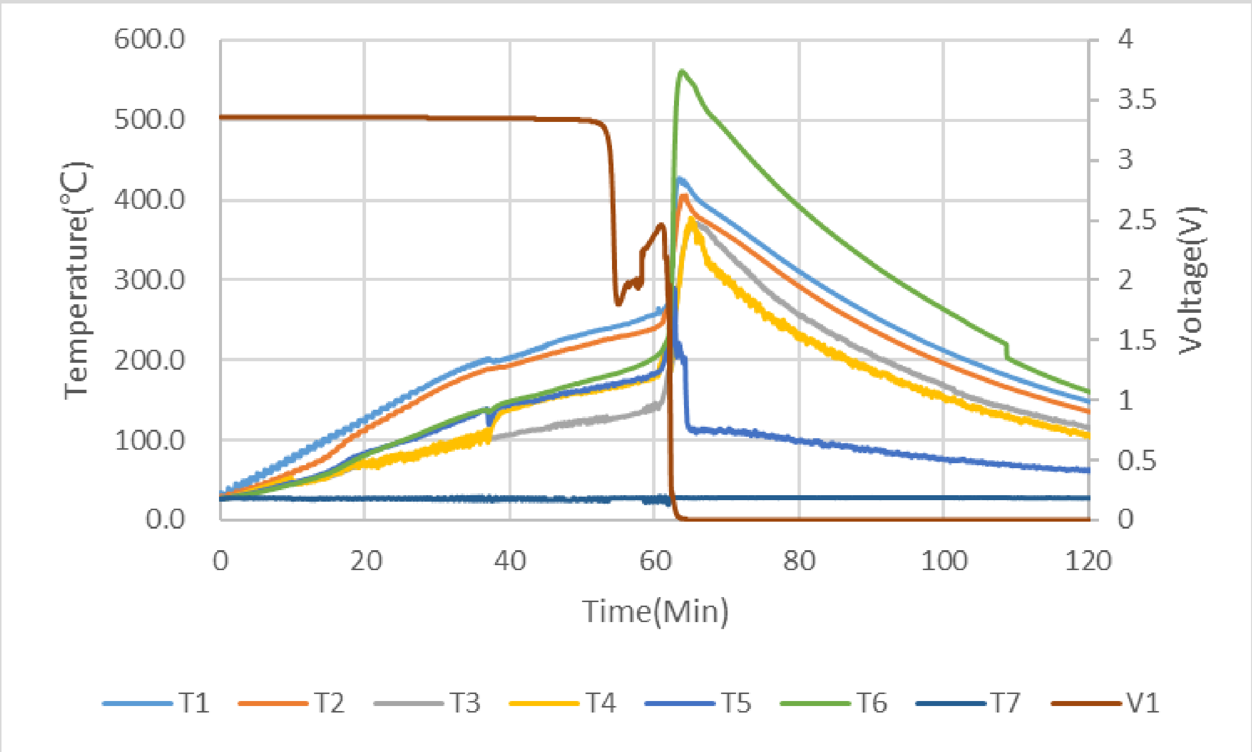
Thermalcouple No.	Location
T1	Cell center below the heater(A side)
T2	Cell center below the heater(B side)
T3	Positive eletrode tap
T4	Near pressure relief valve
T5	Cell narrow side
T6	Cell bottom
T7	Ambient temperature (Inside of pressure vessel)
V1	Cell Voltage

#2



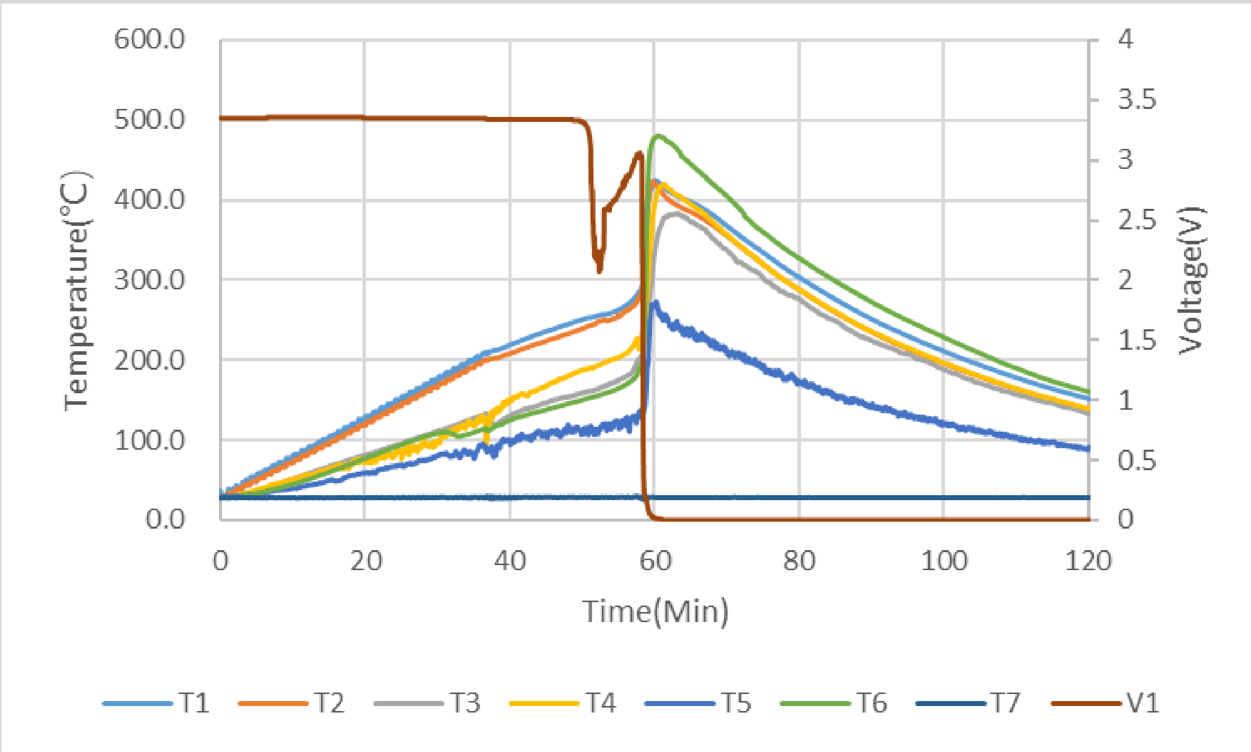
Thermalcouple No.	Location
T1	Cell center below the heater(A side)
T2	Cell center below the heater(B side)
T3	Positive eletrode tap
T4	Near pressure relief valve
T5	Cell narrow side
T6	Cell bottom
T7	Ambient temperature
V1	Cell Voltage

#3



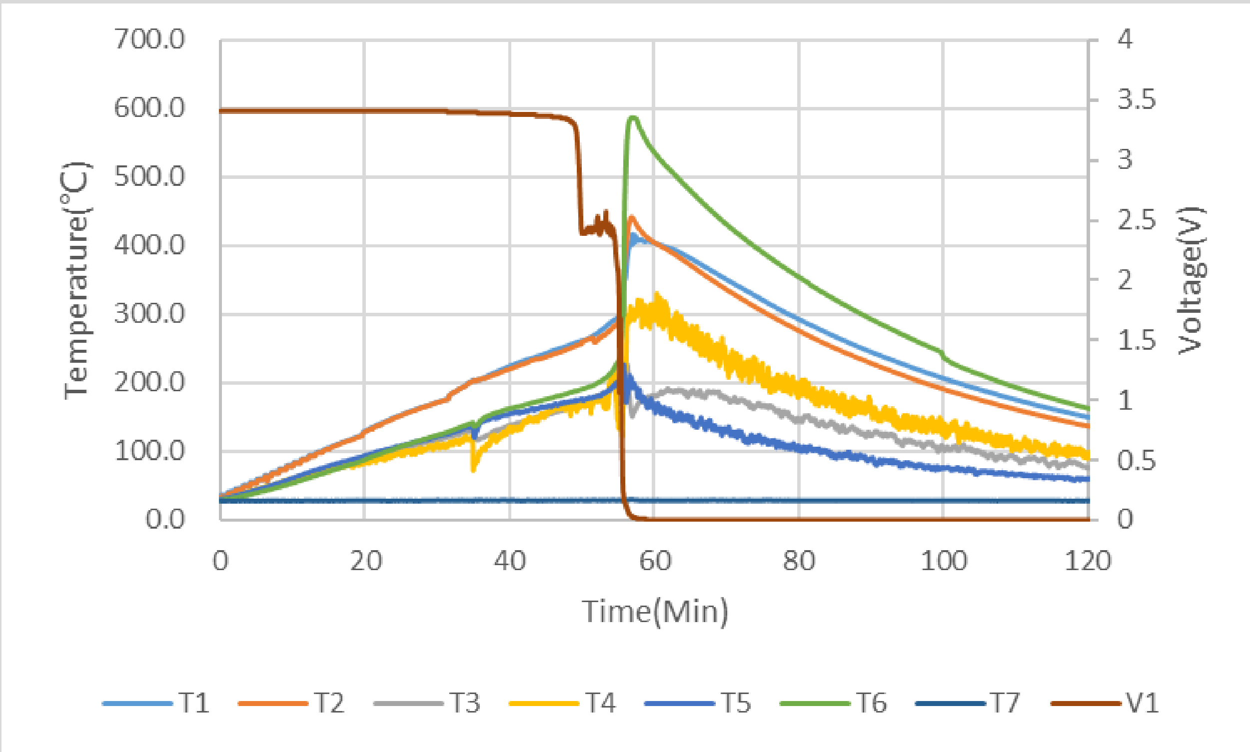
Thermalcouple No.	Location
T1	Cell center below the heater(A side)
T2	Cell center below the heater(B side)
T3	Positive eletrode tap
T4	Near pressure relief valve
T5	Cell narrow side
T6	Cell bottom
T7	Ambient temperature
V1	Cell Voltage

#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)

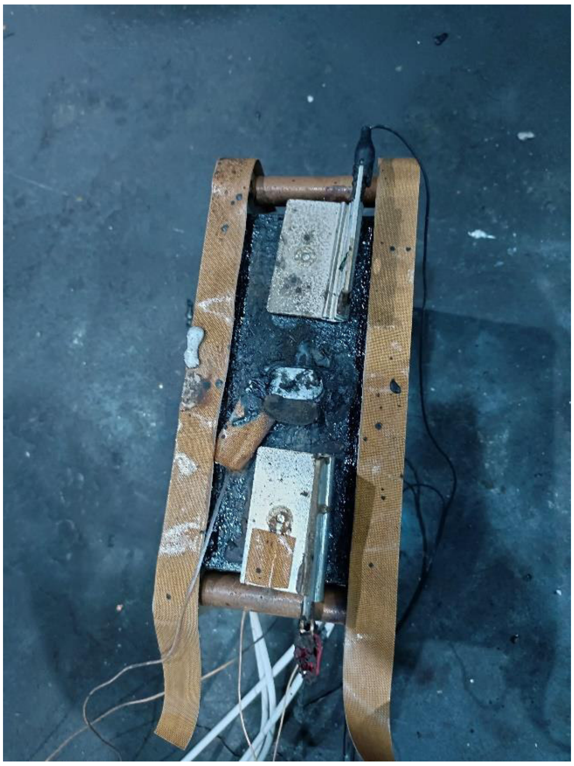
3.7 Photos

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