Steph Kurta
NGH Consulting
Steph.K@nghconsulting.com.au

2 February 2024

Dear Steph,

RE: Sandy Hollow Battery Energy Storage System (BESS) Hazards Advice

It is understood that your client proposes to modify the approval for a 5MW solar farm at Sandy Hollow in the Muswellbrook Shire to add an ancillary 5MW/10MWh BESS.

The consent authority, Muswellbrook Shire Council (MSC), has requested this memo to discuss the hazards of the proposed modification including the State Environmental Planning Policy (Resilience and Hazards) 2021 (Resilience and Hazards SEPP).

Proposed modification

Details of the proposed BESS are presented in Table 1. The layout of the proposed BESS is presented in Figure 1.The separation distances are presented in Figure 2.

Table 1 Details of the proposed modification

Item	Description
BESS unit make and model	Sungrow ST2752UX (refer to Appendix A)
Module make and model	Sungrow M2L-M143A or E2L-M143A
Cell make and model	CATL 001CB310, CB2W0, CB310
Total capacity	5MW/10MWh
Layout	8 battery units in 4 pairs (back to back)
Separation	8 metres between BESS unit pairs
Cell chemistry	Lithium Iron Phosphate (LFP)
Cooling	Liquid cooling system including temperature monitoring and liquid cooling of batteries to prevent thermal runaway.
Fire safety	Deluge sprinkler heads (standard), Fused sprinkler heads (optional), NFPA69 explosion prevention and ventilation IDLH gases (optional)

Compliance	CE, IEC 62477-1, IEC 61000-6-2, IEC61000-6-4, IEC62619, UL9540A, UL1973, UN38.3

Figure 1 Concept layout

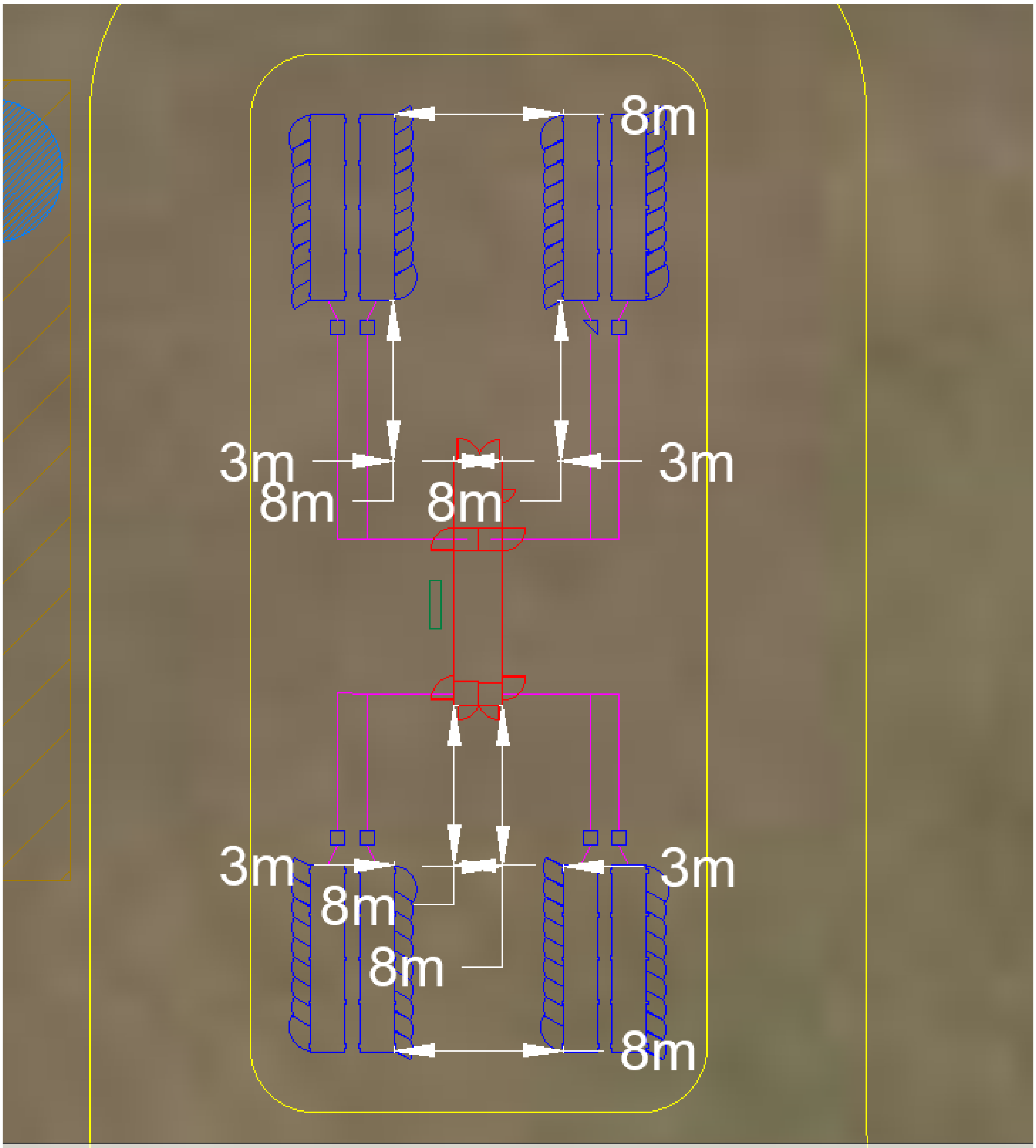


Figure 2 BESS spacing

Proposed mitigation measures

Separation between BESS units are considered the main mitigation measure to prevent fire propagation between BESS units. The Department of Planning, Housing and Infrastructure (DPHI) (formerly DPE) generally accepts that a separation distance of 3 to 4 metres is suitable to prevent the propagation of fire between BESS units. The proposed BESS includes a separation distance between BESS unit pairs of 8 metres (refer to Figure 2). Accordingly, there is a very low risk of fire propagating between BESS unit pairs.

In addition to the separation distance, the proposed BESS also adopts the BESS unit manufacturers (Sungrow) mitigation measures (refer to Appendix A), including:

- Liquid cooling system
- Battery management system
- Deluge sprinkler heads (standard)
- Fused sprinkler heads (optional)
- NFPA69 explosion prevention and ventilation IDLH gases (optional).

The use of LFP cell chemistry also reduces the risk of thermal runaway and fire propagation. If a fire occurs, LFP cells release carbon dioxide which reduces the oxygen concentration and subsequently reduces the combustion rate. A thermal runaway event and subsequent BESS unit fire for LFP cell chemistry is not generally a credible scenario.

The benefits of LFP cell chemistry can be observed in the UL9540A *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems* report (Appendix B). The summary of the thermal runaway test notes that only white smoke was observed. No external flaming, explosive discharges of gases, sparks or electrical arcs were observed.

In addition to the LFP cell chemistry, the liquid cooling system would monitor for thermal runaway and remove heat if it were to occur. The fire safety system would also be employed if a BESS unit fire were to occur.

Based on the proposed mitigation measures, the risks posed by the BESS are considered low and are unlikely to result in significant offsite impacts.

Resilience and Hazards SEPP

The Resilience and Hazards SEPP is used in New South Wales to regulate the planning approval process for developments in hazardous and offensive industries, and potentially hazardous and potentially offensive industries. Chapter 3 deals with the regulation of hazardous and offensive industries, and potentially hazardous and potentially offensive industries. It includes definitions, land to which the chapter applies, and development controls for hazardous or offensive development.

A BESS is not defined in the Resilience and Hazards SEPP. However, it might be considered *potentially hazardous industry* (without any proposed mitigation measures to reduce or minimise its impact) if it has the potential risk of fire from thermal runaway posing a significant risk to:

- Human health, life or property
- The biophysical environment.

However, when the mitigation measures included in the proposed modification, particularly the separation distances, have been employed, the proposed modification would not pose a significant risk in relation to the locality. Additionally, DPHI has an informal threshold of 30 MW for hazard assessment for BESS (i.e. Preliminary Hazard Analysis).

As the proposed BESS is less than this informal threshold and would not pose a significant risk in relation to the locality, the proposed modification is not considered to be *potentially hazardous industry.*

As the proposed modification is not classified as *potentially hazardous industry*, it is not necessary to prepare a Preliminary Hazard Analysis for the proposed modification as Chapter 3 of the Resilience and Hazards SEPP does not apply

If any changes to this letter are requested or clarity required, please do not hesitate to call Scott on 0477 343 018 or email scott@pandoconsulting.com.au.

Warm Regards,

Scott McGrath

Principal Environmental Consultant

Scott@pandoconsulting.com.au

0477 343 018

Appendix A Sungrow ST2752UX datasheet

ST2752UX

Liquid Cooling Energy Storage System

LOW COSTS

- Highly integrated ESS for easy transportation and O&M
- All pre-assembled, no battery module handling on site
- 8 hours from installation to commissioning, drop on a pad and make electrical connections

SAFE AND RELIABLE

- DC electric circuit safety management includes fast breaking and anti-arc protection
- Multi level battery protection layers formed by discreet standalone systems offer impeccable safety

EFFICIENT AND FLEXIBLE

- Intelligent liquid cooling ensures higher efficiency and longer battery cycle life
- Modular design supports parallel connection and easy system expansion
- IP54 outdoor cablinet and optional C5 anti-corrosion

SMART AND ROBUST

- Fast state monitoring and fault record enables pre-alarm and fault location
- Integrated battery performance monitoring and logging

SUNGROW
Clean power for all

Type designation	ST2752UX
Battery Data	
Cell type	LFP
Battery capacity (BOL)	2752 kWh
System output voltage range	500 – 1500 V
C-rate	≤0.5C
General Data	
Dimensions of battery unit (W * H * D)	9340*2600*1730 mm
Weight of battery unit	26,400 kg
Degree of protection	IP54
Operating temperature range	-30 to 50 ℃ (> 45 ℃ derating)
Relative humidity	0 – 95 % (non-condensing)
Max. working altitude	3000 m
Cooling concept of battery chamber	Liquid cooling
Fire safety standard/Optional	Deluge sprinkler heads (standard), Fused sprinkler heads (optional), NFPA69 explosion prevention and ventillation IDLH gases (optional)
Communication interfaces	RS485, Ethernet
Compliance	CE, IEC 62477-1, IEC 61000-6-2, IEC61000-6-4, IEC62619, UL9540A, UL1973, UN38.3

Appendix B CATL UL9540A test report

GProdukte
Products

TÜVRheinland®

Prüfbericht-Nr.: *Test Report No.:*	**CN214A4R 001**	**Auftrags-Nr.:** *Order No.:*	244329098	**Seite 1 von 36** *Page 1 of 36*
Kunden-Referenz-Nr.: *Client Reference No.:*	2182037	**Auftragsdatum:** *Order date.:*	May 06, 2021	
Auftraggeber: *Client:*	**Sungrow Energy Storage Technology Co., Ltd.** No. 788, Mingchuan Road, Boyan Technology Park, Hi-tech Zone, Hefei City, 230088 Anhui, P.R. China			
Prüfgegenstand: *Test item:*	LFP battery module			
Bezeichnung / Typ-Nr.: *Identification / Type No.:*	M2L-M143A E2L-M143A			
Auftrags-Inhalt: *Order content:*	Test report			
Prüfgrundlage: *Test specification:*	UL 9540A: 2019 (Fourth Edition)			
Wareneingangsdatum: *Date of receipt:*	Aug 29, 2021			
Prüfmuster-Nr.: *Test sample No.:*	Engineering sample			
Prüfzeitraum: *Testing period:*	Aug 29, 2021 ~ Aug 30, 2021			
Ort der Prüfung: *Place of testing:*	See clause 1.1 of main report			
Prüflaboratorium: *Testing laboratory:*	See clause 1.1 of main report			
Prüfergebnis*: *Test result*:*	See main report			

geprüft von / *tested by:*

September 16, 2021	Marvin Peng / Engineer	
Datum *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*

kontrolliert von / *reviewed by:*

September 16, 2021	Bowen Dong / Reviewer	
Datum *Date*	**Name/Stellung** *Name/Position*	**Unterschrift** *Signature*

Sonstiges / *Other:*

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

* Legende:	1 = sehr gut	2 = gut	3 = befriedigend	4 = ausreichend	5 = mangelhalt
	P(ass) = entspricht o.g. Prüfgrundlage(n)		F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet
Legend:	1 = very good	2 = good	3 = satisfactory	4 = sufficient	5 = poor
	P(ass) = passed a.m. test specifications(s)		F(ail) = failed a.m. test specifications(s)	N/A = not applicable	N/T = not tested

V04

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 module level tests of UL 9540A: 2019.

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

Testing period: Aug 29, 2021 ~ Aug 30, 2021

All tests were under supervision of TÜV Rheinland's engineer.

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 Revision information

New report, not applicable

1.4 Summary of the test

Video records of the test from 1 direction were provided in .mp4 format. Complete records were provided in 1 separate document, file number listed as below:

One external heater was place in the module to initiating the thermal runaway inside module. The initiating cells were heated at a rate of 4°C~7°C per minute until the cell thermal runaway.

White smoke was observe during test. No flying debris or explosive discharge of gases during test. No sparks, electrical arcs, or other electrical events during test. No external flaming observed.

The battery pack weight measured was 107.8 kg (before test) and 92.8 kg (after test).

Measured peak chemical heat release rate HRR was 19.39 KW

Measured peak smoke release rate SRR was 27.2 m^2/s

Total smoke release TSR was 17002.7 m^2

Total hydrocarbons gas was 1092 L

Detail information see relevant clause of this report.

1.5 List of attachments

Video records of the test from 1 direction was provided in .mp4 format.

Complete records was provided in document, file number listed as below:

NY20210830Sungrow Module.mp4;

2. General Product Information

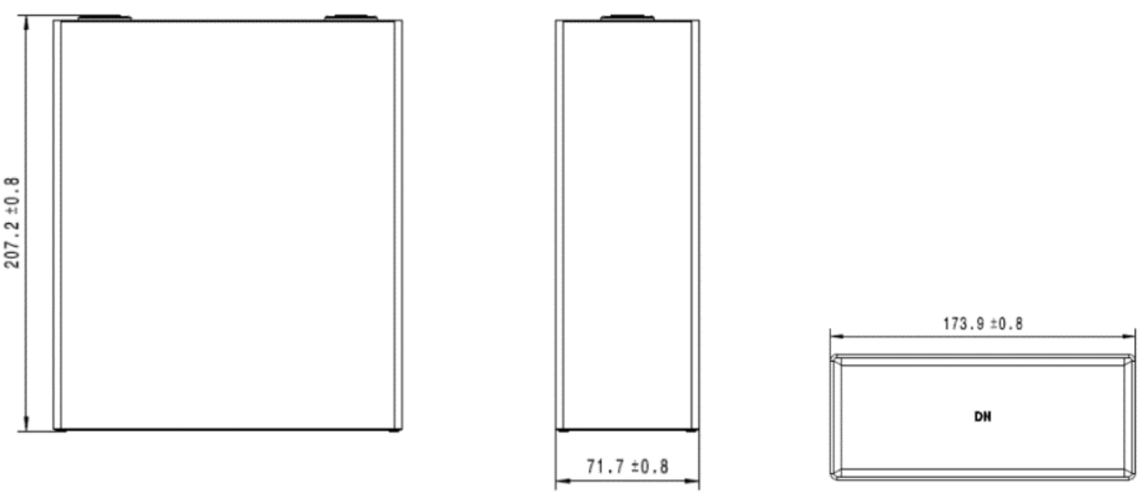
2.1 Cell

2.1.1 Product information and parameters

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

Manufacturer .... :	CATL	
Model number .... :	001CB310, CB2W0, CB310	
Chemistry .... :	LiFePO4	
Physical configuration........................ :	Prismatic	
	Weight:	5410 ± 300 g
Electrical rating .... :	Rated capacity:	280 Ah
	Nominal voltage:	3.2 V
Standard charge method .... :	Charge current:	280 A
	End of charge voltage:	3.65 V
	Cut off current:	14 A
Standard discharge method .... :	Discharge current:	280 A
	End of discharge voltage:	2.5 V

Diagram with overall dimension



2.1.2 Cell level test information

Cell level thermal runaway test information is from CSA cell level test report 80008629 provided by the client.

Thermal Runaway Methodology .... :	External heating method with ceramic heater 1 PCS, rated 220/230V, 500W
Cell Surface Temperature at Gas Venting .. :	143.3°C
Cell Surface Temperature at Thermal Runaway .... :	209.8°C

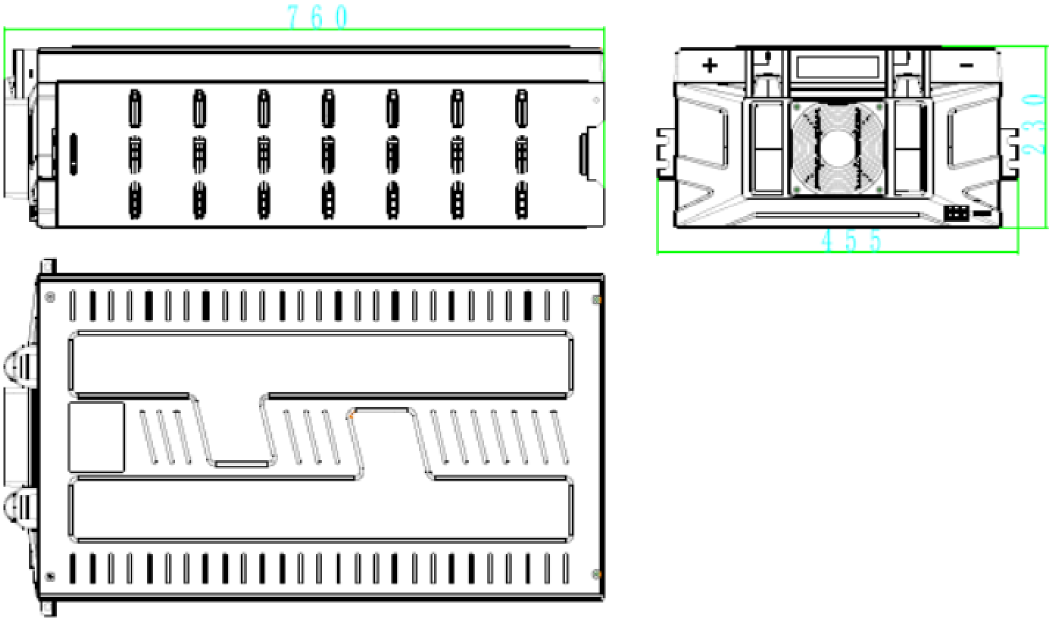
2.2 Module

2.2.1 Product information and parameters

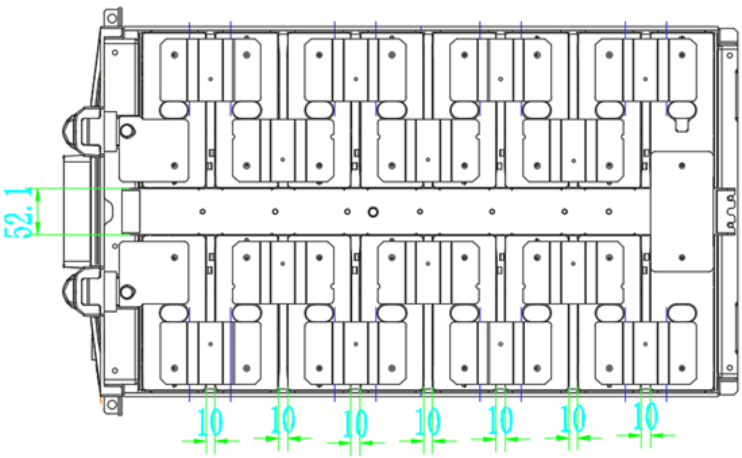
The product information and parameters are provided by the client as below.

Manufacturer name............................ :	SUNGROW ENERGY STORAGE TECHNOLOGY CO., LTD.		
Model number .... :	M2L-M143A	E2L-M143A	
Physical configuration......................... :	Metal enclosure with plastic cover		
	Weight:	105 ± 3.2 kg	
	Cells in series/parallel:	16 in series	
Cooling method .... :	Electric fan	Air flow: Outward	
Separation between cells .... :	10 mm separation between cells by plastic bracket		
Electrical rating .... :	Rated capacity:	280 Ah	
	Nominal voltage:	51.2 V	
Standard charge method .... :	Charge current:	280 A	140A
	End of charge voltage:	58.4 V	
	Cut of current:	14 A	
Standard discharge method .... :	Discharge current:	280 A	140A
	End of discharge voltage:	43.2 V	
Compliance with UL 1973 .... :	Under certification, not finished		

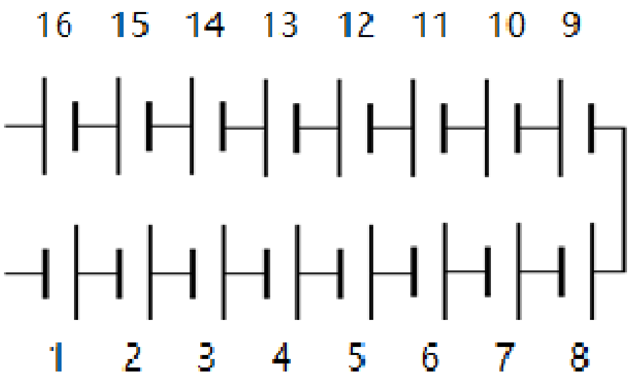
2.2.2 Diagram with overall dimension

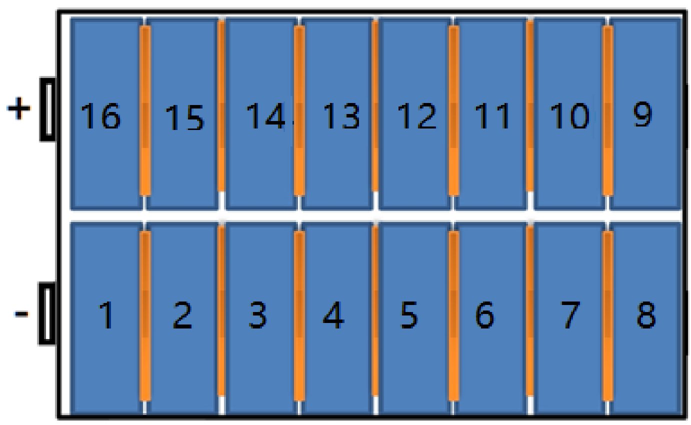


2.2.3 Layout of the module contents



Configuration diagram of the module





2.3 Photos

3. Module level test (section 8 of UL 9540A)

3.1 General

This testing is conducted on battery modules, which are in turn installed in an enclosure or in an open rack system to form a BESS unit.

This test uses applied stresses determined during the cell level test to force a selected number of battery cells within the module into thermal runaway. If there is fire that results from the cell being driven into thermal runaway, the fire is allowed to progress within the module.

The test measures the chemical heat release rate, maximum temperature, and vent gas composition; and documents the module enclosure integrity after the test, any explosions or hazardous ejection of parts outside of the module enclosure, and the extent and duration of any flame propagation outside of the module.

The module level testing establishes a base line fire test performance that can be evaluated against the fire performance of other battery modules the BESS manufacturer may choose to use within the system.

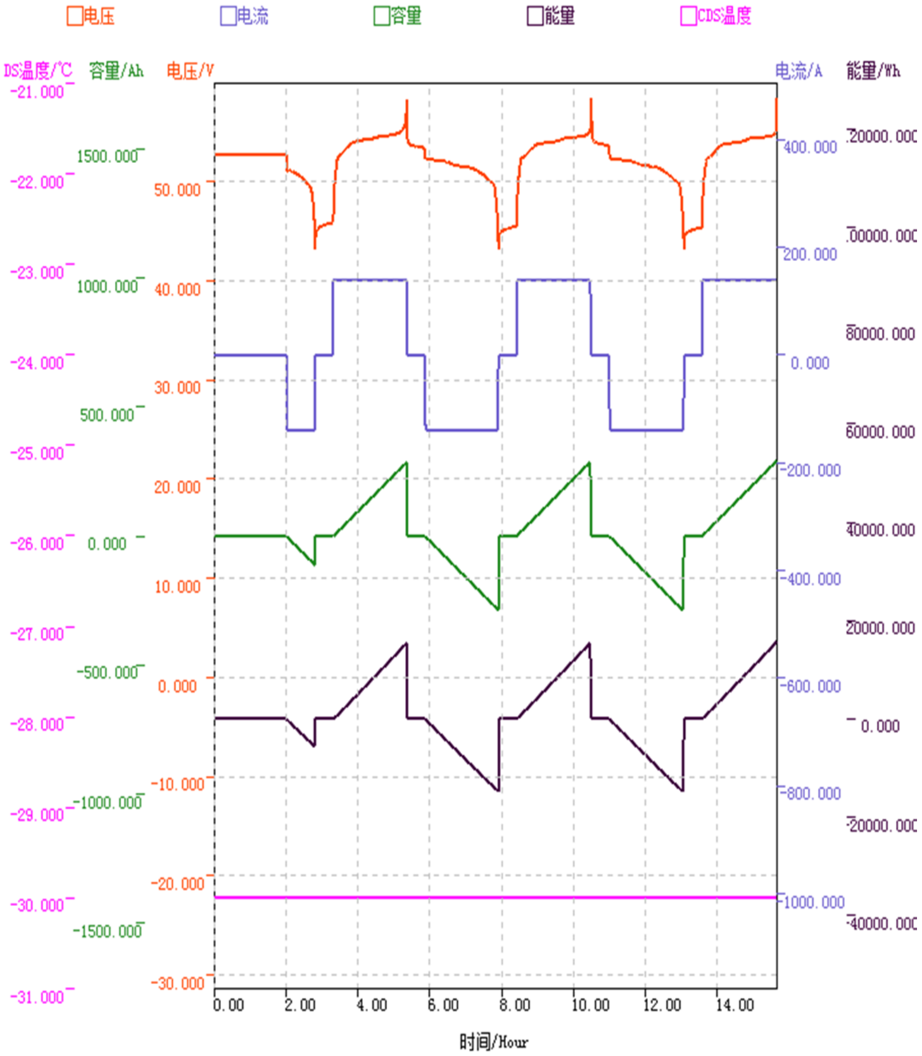
3.2 Sample preparation

Module sample was conditioned, prior to testing, through charge and discharge cycles of 2 cycles to verify that the module was functional.

Each cycle was defined as a charge to 100% SOC and allowed to rest several minutes and then discharged to an end of discharge voltage (EODV) determined by the manufacturer. Refer to 2.1 for charge and discharge profile.

The module sample was put in a climate chamber during charge and discharge. The ambient is kept at 25°C±2°C and 50%± 5% R.H.

Figure 1. Module charge and discharge voltage/current profiles



3.3 Module level thermal runaway test

3.3.1 Thermal runaway test method description

The module 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.

The external heating method used for initiating thermal runaway in cell level test was used to initiate thermal runaway within the module.

Consider the unit level installation and airflow of the fan cooling in the module. #8 cell located in the back side of the module was chose as target cell to be forced into thermal runaway.

The cells was heated by three external heater rated 220VAC/512 W (size 202*169*0.36mm). One layer 2 mm glass fiber heat insulation sheet was placed between the heater and metal enclosure to limit the heat transfer to enclosure.

10 armored thermocouples with diameter 0.1mm (external diameter 0.5mm) were attached on the center of each wide surface of #1 ~ #8 cells. (See 3.3.2 figure 1)

10 armored thermocouples with diameter 0.1mm (external diameter 0.5mm) were attached on the center of each narrow surface of #9 ~ #16 cells closed to heated cell. (See 3.3.2 figure 1)

T12 to T19 located on negative electrode of #1 ~ #8 cells.

10 thermocouples were located on top of the module enclosure.

A PID controller was used to control the voltage supply to the heater and maintain a 5°C/min to 7°C/min heating rate.

Once thermal runaway was observed, the heaters were immediately de-energized.

Three thermocouples located below the heater at the center of #5 cell and #6 cell surface was used to feedback the temperature to the controller. (See 3.3.2 figure 1)

Voltage of the module are monitored during test.

The module was placed on top of a lift with the module orientation representative of its intended final installation.

The module was located under the smoke collection hood of the calorimeter measurement system.

Ambient conditions were within 25±5 °C and 50±25% RH at the initiation of the test.

3.3.2 Location of thermocouples

Figure 2. Cell numbering, heater location and thermocouples (no. xx) locations inside the sub-module

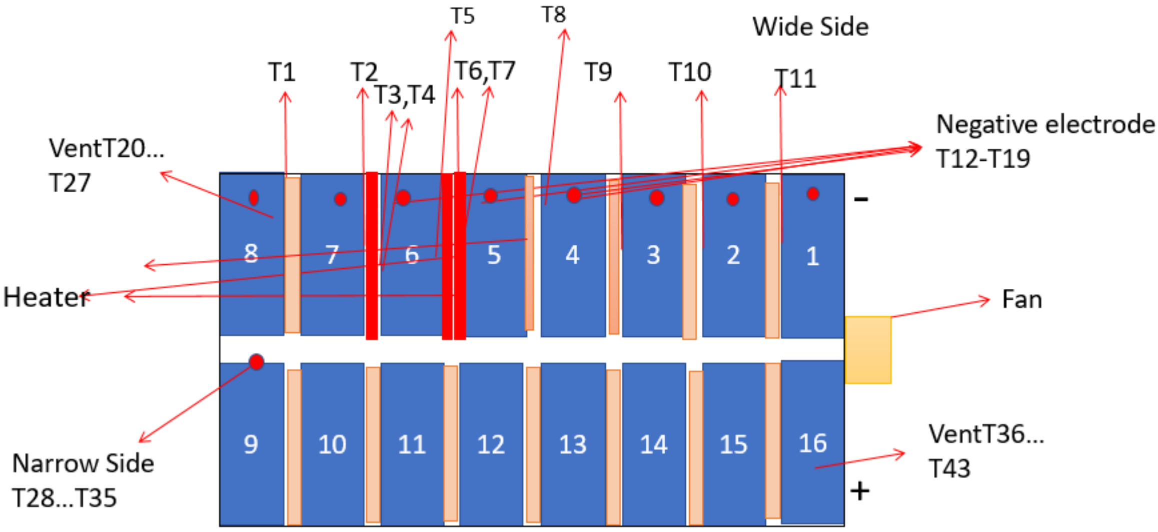
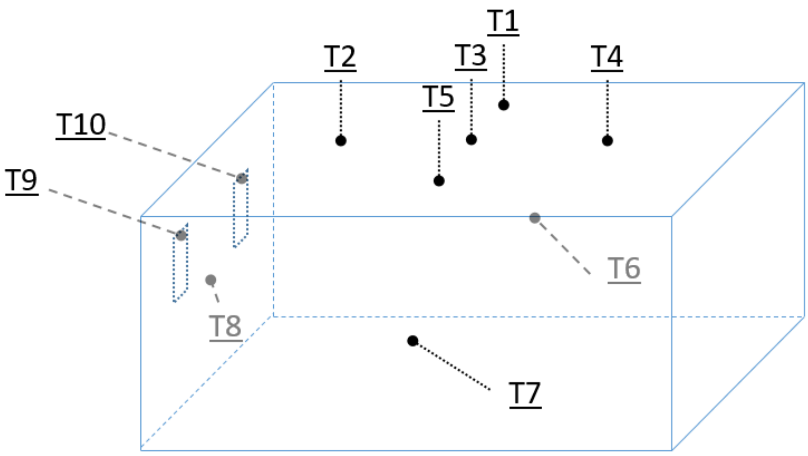


Figure 3. Thermo-couples locations outside module



3.3.3 Observations and records

Ambient conditions at the initiation of the test...:	27.0°C, 59% R.H.
Sample number ....:	#NY202108383
Open circuit voltage before test (V) .....:	53.67
Weight before test (kg) ....:	104.4 (with thermal couplers)

Time initiating the test ....:	11:34 start to heat the cells
Observations during test ....:	Audible pop was heard on 12:18 PM (the pressure relief valve burst), followed by smoke release after several seconds. Large amount of white smoke were observed on 12:37. No flying debris or explosive discharge of gases during test. No sparks, electrical arcs, or other electrical events during test. No any flaming observed.
Posttest evaluation ....:	Posttest evaluation were performed after 24 hours of test. Eight cells were damage after test. Photos “sample after test” in page 38 show the damage of the module enclosure, electrolyte outside and damage of the components inside enclosure. 27.72V was measured on the module output terminal.
Weight after test (kg) ....:	95.20 (with thermal couplers)
Weight loss (kg) ....:	9.2

3.3.4 Temperature measurements

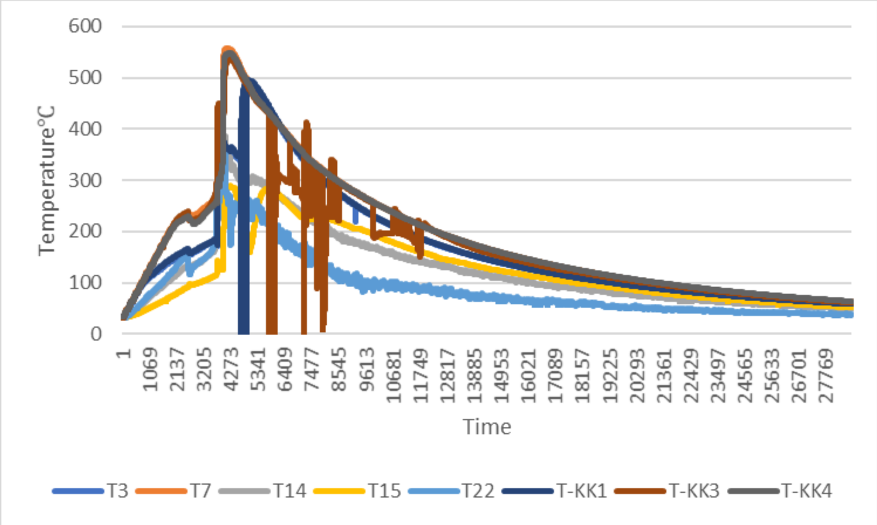
Cell to cell propagation happened during the test.

First thermal runaway occur on the cell contact the heater in 5# cell, 64 minutes after imitating the test, with maximum temperature of 557.9°C. (T7)

Second thermal runaway occur on the cell contact the heater in 6# cell, 3 minutes after first thermal runaway, with maximum temperature of 537°C. (TKK3)

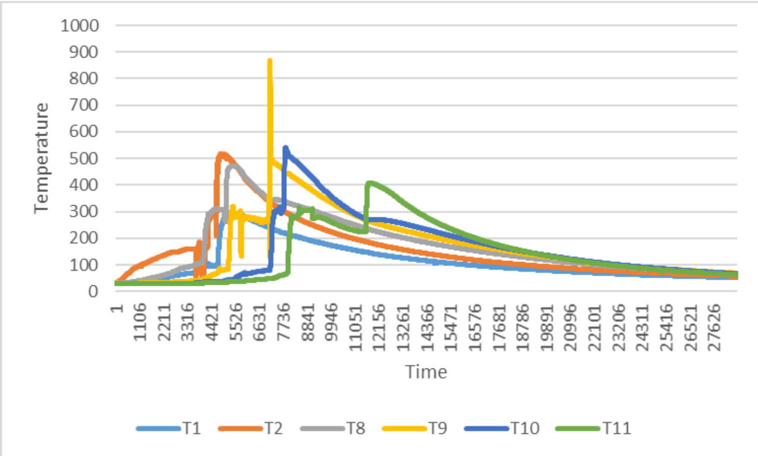
Maximum temperature measured on side of #9 cell was 146°C (TA7).

Figure 4. Temperatures of cell 5# and 6# cell



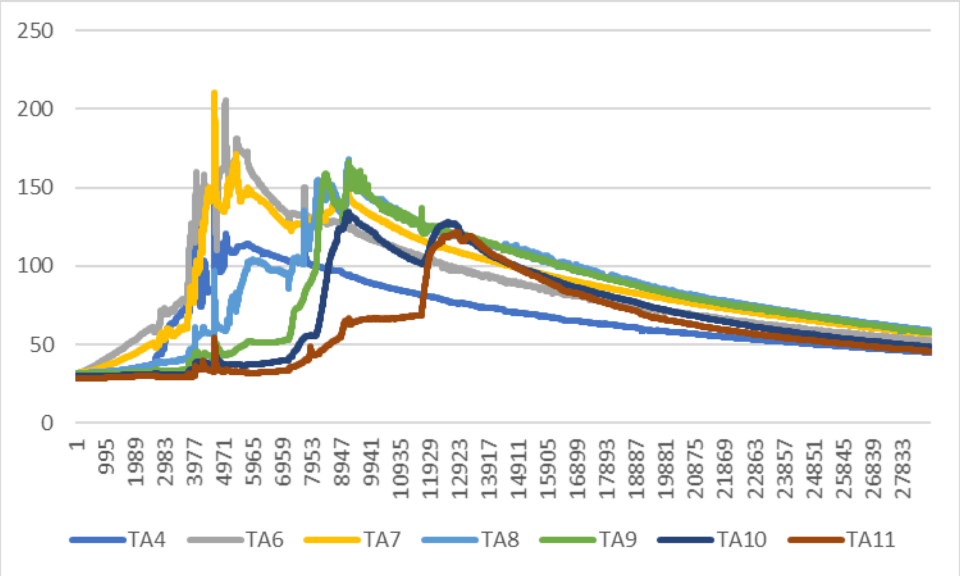
Thermocouple no.	Location	Maximum temp.(℃)
T3	Surface of cell_6 under heater T3	489.1
T7	Surface of cell_5 under heater T7	557.9
T14	Negative Electrode of cell_6	385.5
T15	Negative Electrode of cell_5	288.8
T22	Vent of cell_6	430.8
TKK1	Surface of cell_6 under heater T4	494.9
TKK3	Surface of cell_6 under heater T5	537.0
TKK4	Surface of cell_5 under heater T6	548.3

Figure 5. Temperatures of cell 1# ~ 4# and cell 7# ~ 8#



Thermocouple no.	Location	Maximum temp.(℃)
T11	Surface of cell_1 under heater	407.7
T10	Surface of cell_2 under heater	541.3
T9	Surface of cell_3 under heater	869.2
T8	Surface of cell_4 under heater	472.7
T2	Surface of cell_7 under heater	518.2
T1	Surface of cell_8 under heater	297.6

Figure 6 Temperatures of the opposite side cells



Thermocouple no.	Location	Maximum temp.(℃)
TA4	Surface of cell_9 under heater	143.6
TA6	Surface of cell_11 under heater	205.6
TA7	Surface of cell_12 under heater	210.3
TA8	Surface of cell_13 under heater	168.1
TA9	Surface of cell_14 under heater	166.3
TA10	Surface of cell_15 under heater	134.5
TA11	Surface of cell_16 under heater	121.5

3.4 Chemical heat release rate measurement

3.4.1 Test method

The chemical heat release rates were measured by an oxygen consumption calorimeter measurement system consisting of a paramagnetic oxygen analyzer, non-dispersive infrared carbon dioxide and carbon monoxide analyzer, velocity probe, and a Type K thermocouple.

The instrumentations are located in the exhaust duct of the heat release rate calorimeter.

The chemical heat release rate was calculated at each of the flows as follows:

$$HRR_1 = \left[E \times \varphi - (E_{co} - E) \times \frac{1-\varphi}{2} \times \frac{X_{co}}{X_{O_2}}\right] \times \frac{\dot{m}_e}{1 + \varphi \times (\alpha - 1)} \times \frac{M_{O_2}}{M_a} \times (1 - X^o_{H_2O}) \times X^o_{O_2}$$

In which:

HRR_t = total heat release rate, as a function of time (kW)

E = Net heat released for complete combustion per unit of oxygen consumed (adjusted for oxygen contained within cell chemistry, 13,100 kJ/kg)

E_{CO} = Net heat released for complete combustion per unit of oxygen consumed, for CO (adjusted for oxygen contained within cell chemistry, 17,600 kJ/kg)

φ = Oxygen depletion factor (non-dimensional), where:

$$\varphi = \frac{X^o_{O_2} \times [1 - X_{CO_2} - X_{CO}] - X_{O_2} \times [1 - X^o_{CO_2}]}{X^o_{O_2} \times [1 - X_{O_2} - X_{CO_2} - X_{CO}]}$$

X_{CO} = Measured mole fraction of CO in exhaust flow (non-dimensional)

X_{CO_2} Measured mole fraction of CO_2 in exhaust flow (non-dimensional)

$X°_{CO_2}$ = Measured mole fraction of CO_2 in incoming air (non-dimensional)

$X°_{H_2O}$ = Measured mole fraction of H_2O in incoming air (non-dimensional)

X_{O_2} = Measured mole fraction of O_2 in exhaust flow (non-dimensional)

$X°_{O_2}$ = Measured mole fraction of O_2 in incoming air (non-dimensional)

α = Combustion expansion factor (non-dimensional; normally a value of 1.105)

M_a = Molecular weight of incoming and exhaust air (29 kg/kmol)

M_{O_2} = Molecular weight of oxygen (32 kg/kmol)

$\dot{m}_e$ = Mass flow rate in exhaust duct (kg/s), in which:

$$\dot{m}_e = C \times \sqrt{\frac{\Delta p}{T_e}}$$

or

$$\dot{m}_e = 26.54 \times \frac{A \times k_c}{f(\mathrm{Re})} \times \sqrt{\frac{\Delta p}{T_e}}$$

C = Orifice plate coefficient (in $kg^{1/2}m^{1/2}K^{1/2}$)

Δp = Pressure drop across orifice plate or bidirectional probe (Pa)

T_e = Combustion gas temperature at orifice plate or bidirectional probe (K)

A = Cross sectional area of the duct (m^2)

k_c = Velocity profile shape factor (non-dimensional)

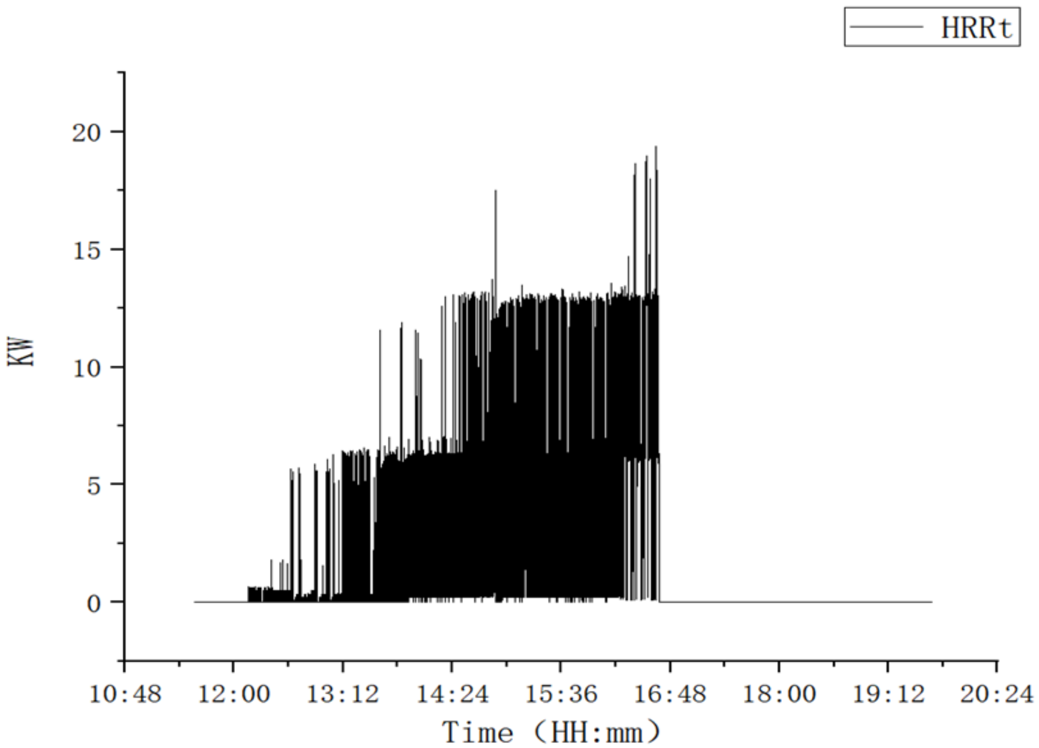
f(Re) = Reynolds number correction (non-dimensional)

The whole heat release rate measurement system were calibrated using an atomized heptane diffusion burner before the test. The calibration were performed using flows of 1078mg/s and 1510mg/s of propane (corresponding to 50kW and 70kW heat release rate).

3.4.2 Test result

Peak chemical heat release rate HRR: 19.39KW

Figure 7 HRR curve



3.5 Smoke release rate measurement

3.5.1 Test method

The light transmission in the calorimeter's exhaust duct was measured using a white light source and photo detector for the duration of the test.

The smoke release rate was calculated as follows:

$$SRR = 2.303\left(\frac{V}{D}\right)Log_{10}\left(\frac{I_o}{I}\right)$$

Where:

SRR = Smoke release rate (m^2/s)

V = Volumetric exhaust duct flow rate (m^3/s)

D = duct diameter (m)

I_o = Light transmission signal of clear (pre-test) beam (V)

I = Light transmission signal during test (V)

The whole smoke release rate measurement system were self-checked using calibrated light filter before test. The self-check were performed at 100%, 79%, 50%, 32%, 16%, 10%, 1% and 0% light transmittance.

3.5.2 Test result

Peak smoke release rate SRR: 27.2 m^2/s

Total smoke release TSR: 17002.7 m^2

Figure 8 SRR curve

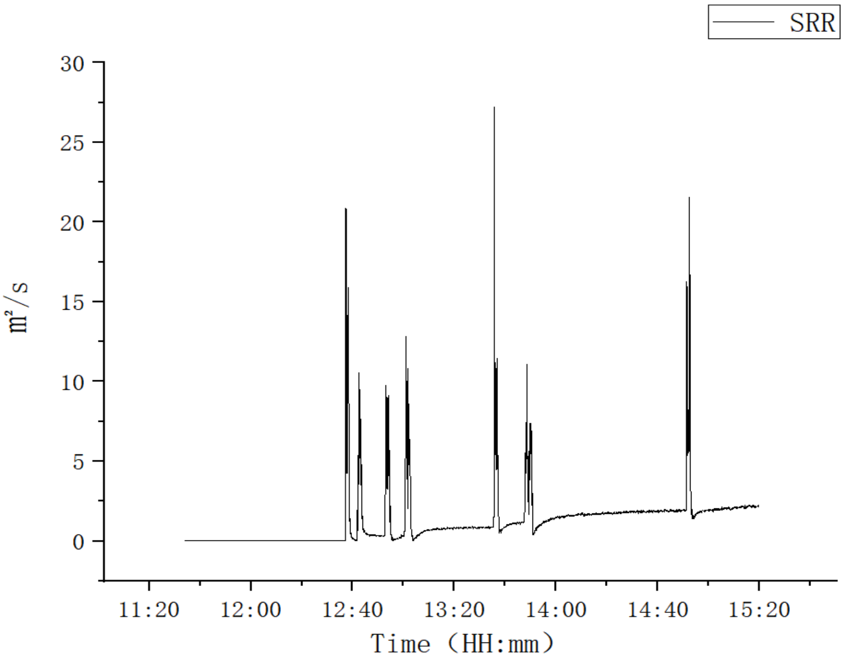
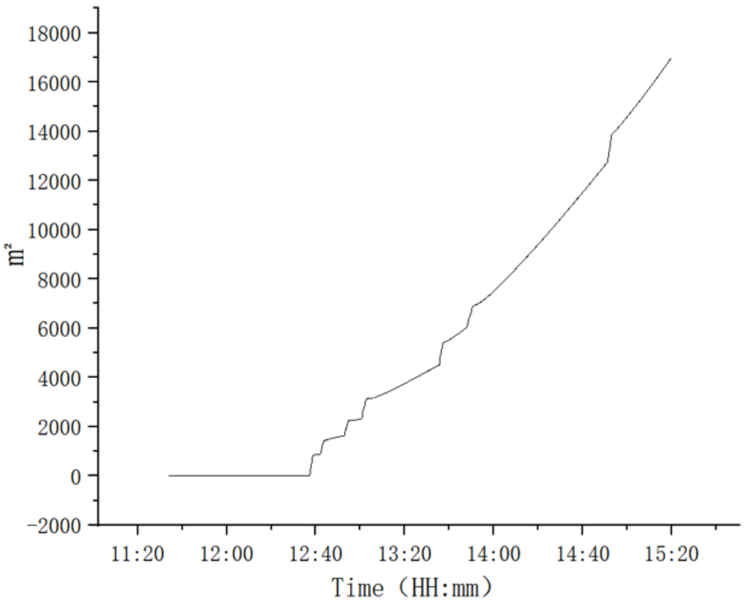


Figure 9 TSR curve



3.6 Gas generation measurement

3.6.1 Test method

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

Gas composition were measured using a Fourier-Transform Infrared Spectrometer with a resolution of 1 cm^{-1} and a path length of 4.2 m within the calorimeter's exhaust duct.

The hydrocarbon content of the vent gas was measured using flame ionization detection.

Hydrogen gas was measured with a palladium-nickel thin-film solid state sensor.

Composition, velocity and temperature instrumentation were collocated with heat release rate calorimetry instrumentation.

3.6.2 Total gas release

The flow rates of various gases were integrated over the test duration and the total cumulative volume of gas calculated for the total test duration (11:34~19:56) were presented in below table.

Total cumulative volume of gases before cell venting (11:34 ~ 12:18) were also presented in table for reference. Which may be considered as ambient gases background before test.

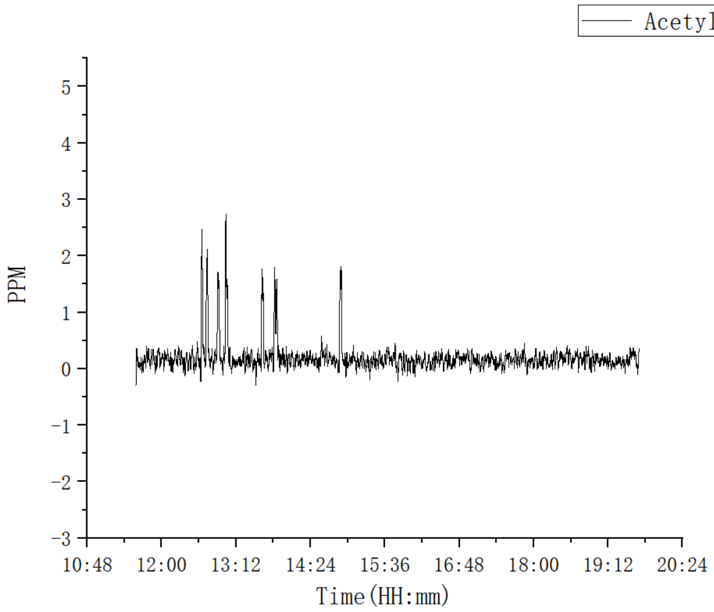
Gas type	Gas components		Total volume of gas (L)	
			Before cell venting	Throughout the test
Hydrocarbon species	Methane	CH_4	1.6	75.6
	Acetylene	C_2H_2	0.7	9.4
	Ethylene	C_2H_4	2.0	111
	Ethane	C_2H_6	1.2	32.1
	Propane	C_3H_8	2.1	122.6
	Propylene	C_3H_6	0.7	225.9
Hydrogen halide species	Hydrogen Fluoride	HF	0.2	138.6
Nitrogen containing species	Nitrogen Monoxide	NO	0	114
Others	Carbon Monoxide	CO	23.2	201.3
	Carbon Dioxide [1)]	CO_2	4981	39727
	Hydrogen	H_2	0	1182
	Dimethyl carbonate(DMC)	$C_3H_6O_3$	0.6	754.8
	Diethyl carbonate(DEC)	$C_5H_{10}O_3$	1.7	28.3
	Ethylmethyl carbonate	$C_4H_8O_3$	0	138.2
	Formaldehyde	CH_2O	1.2	7.2
	Ethylene oxide	C_2H_4O	0.2	2.8
	Ammonia	NH_3	0.2	6.4
	Methanol	CH_4O	1.2	42.1
	Oil as octane		0	48
Total Hydrocarbons				1092

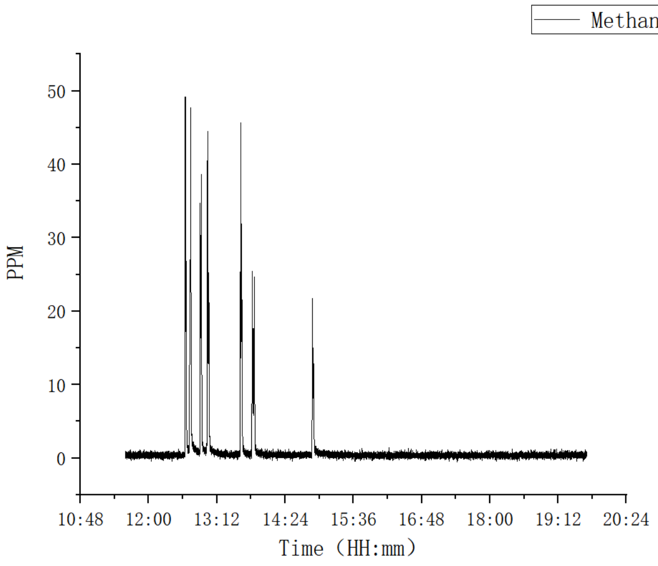
Note:
1)The collection time is from 11:34 to 19:56
2)The carbon dioxide in the air during this period[1)] was also counted

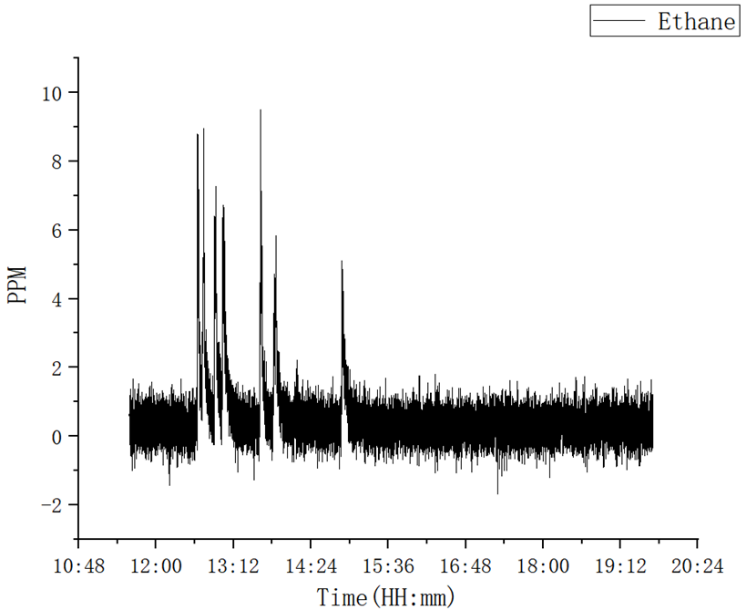
3.6.3 Gas components

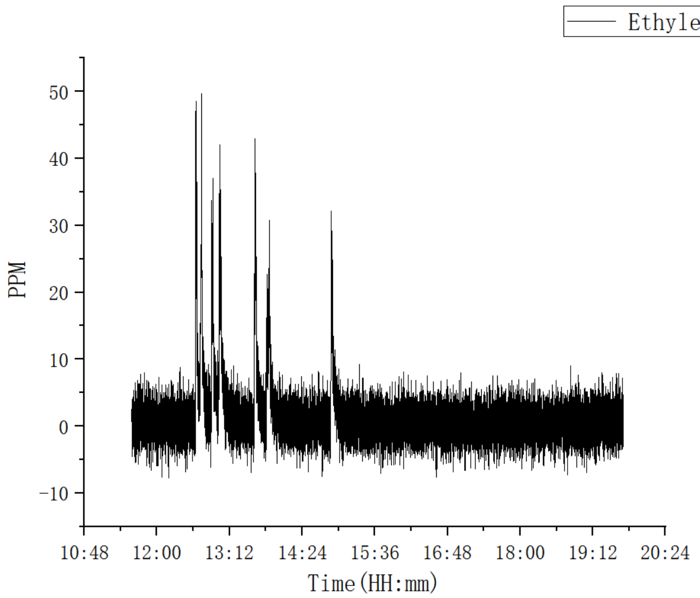
Concentrations of the gases were scaled based on the measured flow rate of the exhaust system and were presented in standard volume flow rate of gas ventilated in Figures 10 to

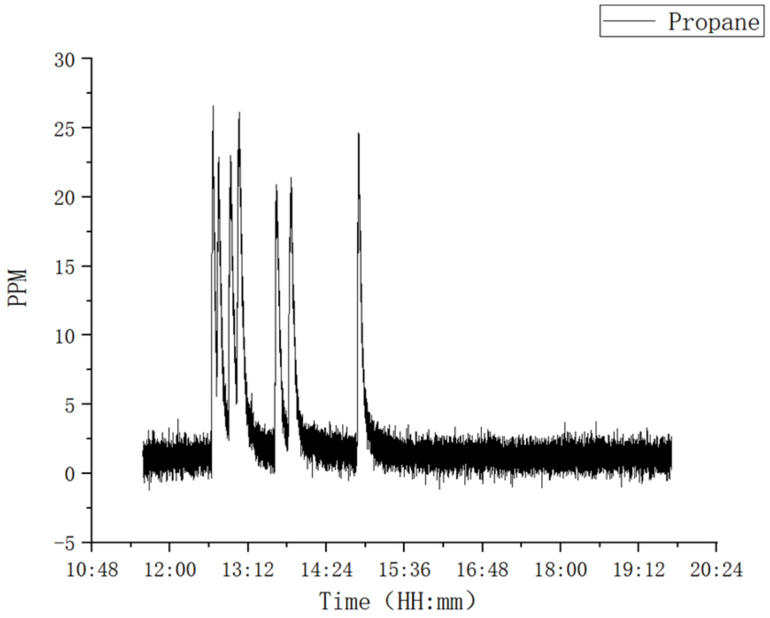
Figure 10. Hydrocarbon species






Ethane
PPM
10
8
6
4
2
0
−2
10:48
12:00
13:12
14:24
15:36
16:48
18:00
19:12
20:24
Time(HH:mm)


Ethylene
PPM
50
40
30
20
10
0
−10
10:48
12:00
13:12
14:24
15:36
16:48
18:00
19:12
20:24
Time(HH:mm)


Propane
PPM
30
25
20
15
10
5
0
−5
10:48
12:00
13:12
14:24
15:36
16:48
18:00
19:12
20:24
Time (HH:mm)

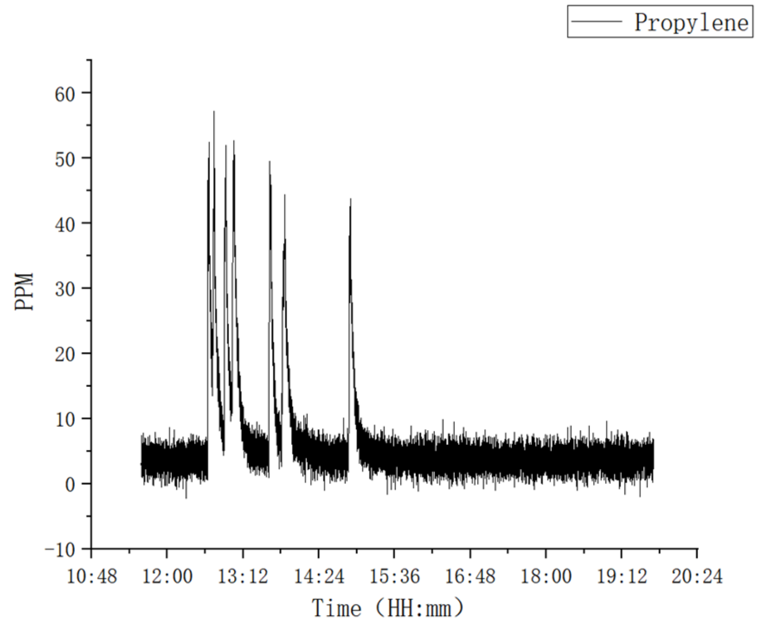

Propylene
PPM
60
50
40
30
20
10
0
−10
10:48
12:00
13:12
14:24
15:36
16:48
18:00
19:12
20:24
Time (HH:mm)

Figure 11. Hydrogen halide species

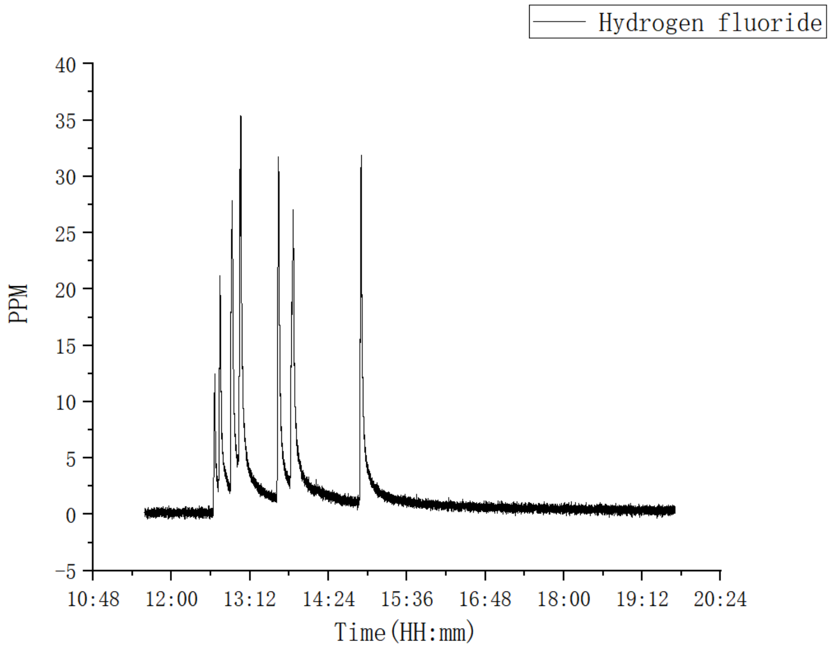


Figure 12. Nitrogen containing species

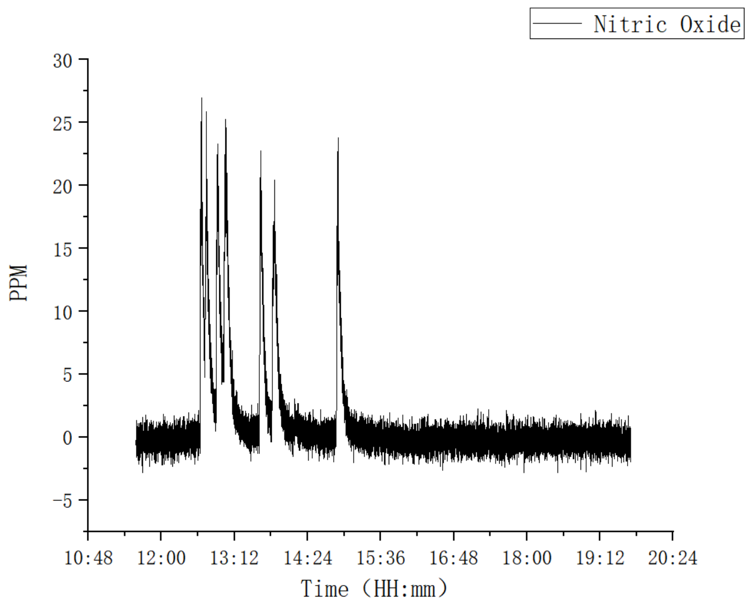
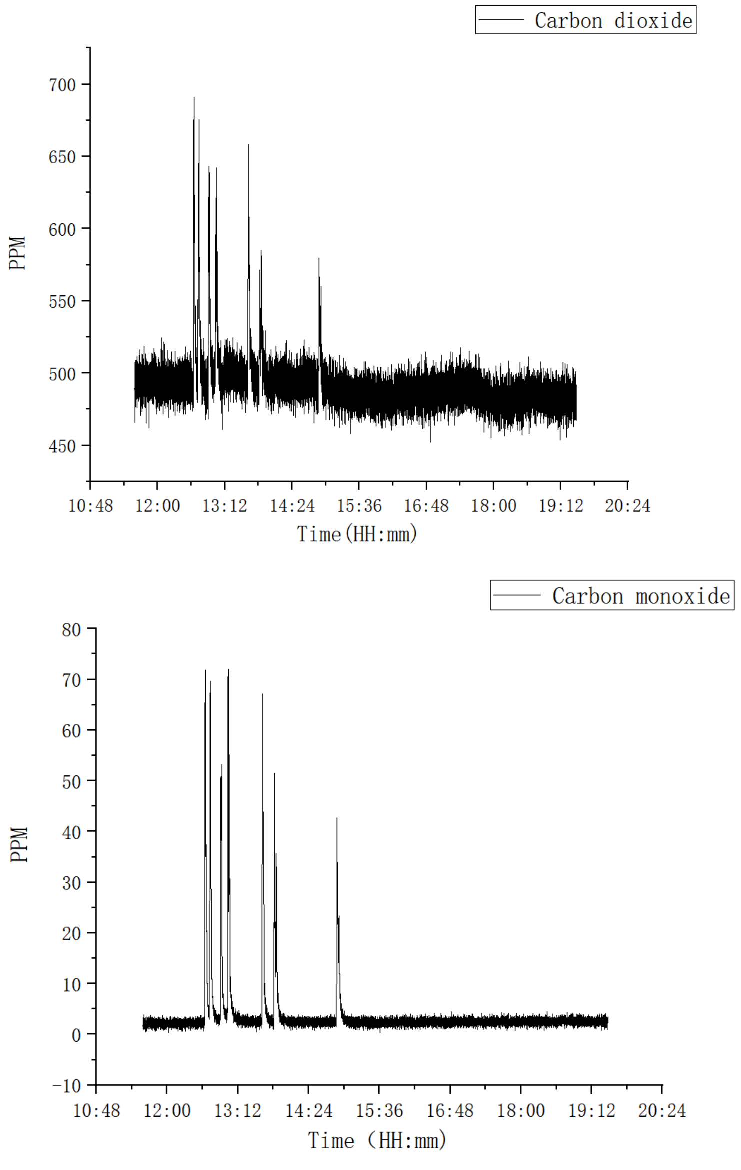


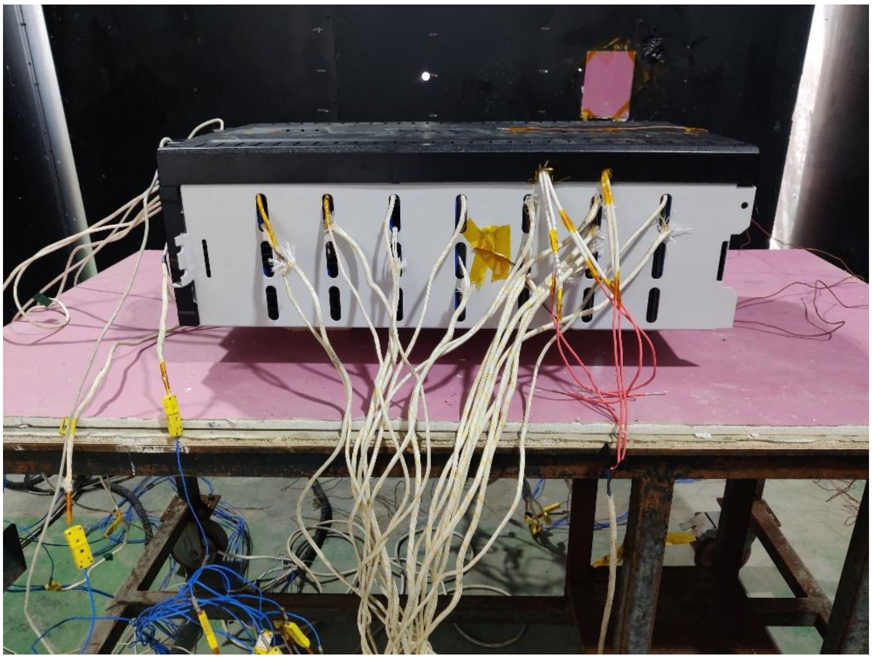
Figure 25. CO concentration



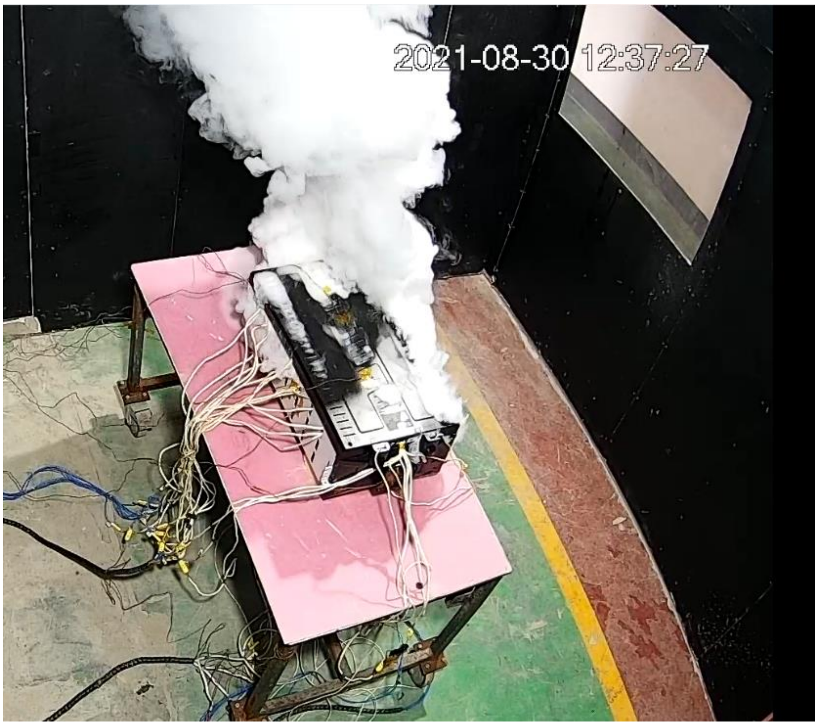
3.7 Photos

Sample before test

Test setup

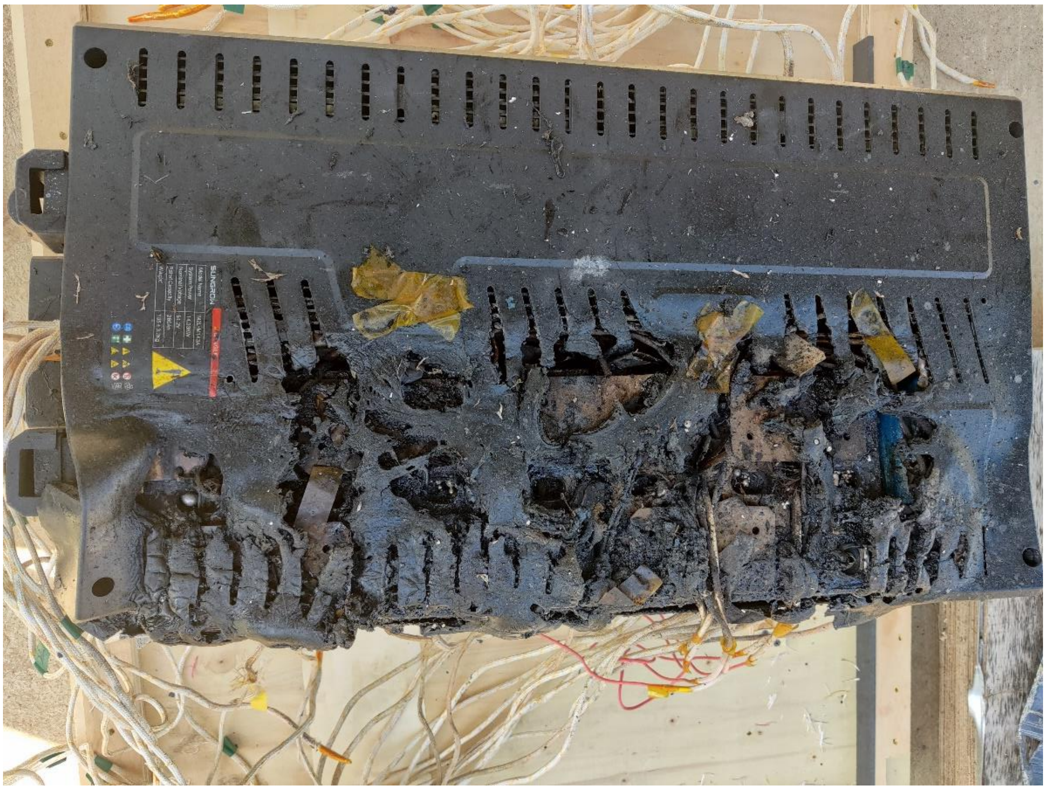


Smoke release during test



Smoke release during test

Sample after test



Sample after test

List of Test and Measurement Instruments

No.	Equipment		Manufacture/ Model	Rating	Inventory no.	Latest Cal. date
1.	Ambient monitor		testo/ 175H1	-20°C to +55°C 0 to 100%RH	PVE-018	20201203
2.	Data acquisition equipment		Delta/ DTM series	0 to 1500°C	S-029	20201203
3.	Digital multi-meter		Fluke/ F101	0-600V	S-038	20201203
4.	Tape		Kaptaen	0-300°C	S-040	/
5.	Electronic scale		Shanghai Xiangxu/ TCS-500	0-500kg	S-039	20201203
6.	Oxygen consumption calorimeter measurement system	Paramagnetic oxygen analyzer	Servomex/ 4100	0-21%	S-024	20210319
7.		Velocity probe	Motis Fire Technology	0-200Pa		20210308
8.		Photo detector	Motis Fire Technology	0-100%		20210319
9.		Light filter	Motis Fire Technology	25%,50%,75%		20210308
10.		CO and CO_2 sensor	Servomex/ 4100	CO 0-1% CO_2 0-10%		20210319
11.	Palladium-nickel thin-film solid state sensor		H2SCAN 740B	0.5%-100%	S-023	20210319
12.	H2 sensor		Suzhou Chint	0%-100%	S-22	20210319
13.	Fourier-Transform Infrared Spectrometer		MultiGas/ MKS6030	/	S-019	20210319
14	Flame Ionization Detector		ABB/ AO2040	0-600mgC/m^3	S-025	20210319
15	Heat flux measurement equipment		Medtherm	0-50kW	S-031	20201203
16	Thermopile		Omega/ No.24	0-1040°C	S-026	20210308

End of Test Report