Prüfbericht - Produkte
Test Report - Products

TÜVRheinland®

Prüfbericht-Nr.: *Test report no.*:	CN24KNIK 001	**Auftrags-Nr.:** *Order no.*:	168512245	
Kunden-Referenz-Nr.: *Client reference no.*:	2544823	**Auftragsdatum:** *Order date:*	2024-11-06	

Auftraggeber: *Client*:	Discover Energy Systems corp. 320 - 13711 International Place, Richmond, B.C., V6V 2Z8, Canada
Prüfgegenstand: *Test item*:	Rechargeable Li-ion battery
Bezeichnung / Typ-Nr.: *Identification / Type no.*:	48-48-5120-H / 900-0067
Auftrags-Inhalt: *Order content*:	Test report
Prüfgrundlage: *Test specification*:	UL 9540A: 2019 (Fourth Edition)

Wareneingangsdatum: *Date of sample receipt*:	2024-06-12
Prüfmuster-Nr.: *Test sample no:*	A003742002-006
Prüfzeitraum: *Testing period*:	2024-08-13 - 2024-08-16
Ort der Prüfung: *Place of testing*:	See to clause 1.1 of main report
Prüflaboratorium: *Testing laboratory:*	See to clause 1.1 of main report
Prüfergebnis*: *Test result**:	See main report

geprüft von: tested by:		**genehmigt von:** *authorized by*:	
Datum: *Date:* 2024-12-04	Lemon Diao	**Ausstellungsdatum:** *Issue date:* 2024-12-04	Xun Yu
Stellung / Position:	Sachverständige(r)/Expert	**Stellung** / Position:	Sachverständige(r)/Expert

Sonstiges / *Other*:

This report is based on previous report CN2490MD 001. The changes as follow:

1. The Client name and address are changed.
2. The Cell's model number are changed.

In addition to the above changes, no additional tests needed.

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*

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Remarks

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

Testing period: 2024-08-13 to 2024-08-16

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 2 directions were provided in .mp4 format.

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 to 7°C per minute until the cell thermal runaway.

White smoke was observed 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 43.05kg (before test) and 41.05kg (after test).

Measured peak chemical heat release rate HRR was 2.482 kW.

Measured total heat release through the test THR was 1.250 MJ.

Measured peak smoke release rate SRR was 0.458 m^2/s

Total smoke release TSR was 103.34m^2

Total hydrocarbons gas (equivalent to CH_4, measured by FID) was 59.8L.

Detail information see relevant clause of this report.

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.

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 Cell

2.1.1 Product information and parameters

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

Manufacturer plant:	**ZHUHAI GREAT POWER ENERGY CO., LTD.** (BULDING A, WORKSHOP) NO.2 XINQING FIFTH ROAD, JING'AN TOWN, DOUMEN DISTRICT, ZHUHAI CITY, GUANDONG	
Model number:	GSP50160119F	
Chemistry:	☒ $LiFePO_4$ ☐ NMC ☐ NCA ☐ LTO ☐ Other:	
Physical configuration:	☒ Prismatic ☐ Cylindrical ☐ Pouch	
	Weight(kg):	1.92±0.05kg
Electrical rating:	Rated capacity(Ah):	100
	Nominal voltage(V):	3.2
Standard charge method:	Charge current(A):	33
	Standard Charge Voltage:	3.65
	Cut off current(A):	5
Standard discharge method:	Discharge current(A):	33
	End of discharge voltage(V):	2.5
Compliance with UL 1973:	☒ Yes UL certificate: MH64562 ☐ No	

2.1.2 Cell level test information

Cell level thermal runaway test information is copy from Intertek cell level test report No.: 220808098GZU-001.

Thermal Runaway Methodology:	External heater applied on one side of the cell with surface heating rate at about of 5.5°C per minute until thermal runaway triggered.

Average Cell Surface Temperature at Gas Venting...:	251.0°C
Average Cell Surface Temperature Start Thermal Runaway:	280.2°C

2.2 Module

2.2.1 Product information and parameters

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

Manufacturer plant:	**Dongguan LongTTech Company Ltd.** No.38 Lianhu Road, Laozhongkeng, Sanzhong Village, Qingxi Town, Dongguan, Guangdong, P.R. China	
Model number:	1) 48-48-5120-H / 900-0067 2) 48-48-5120 / 900-0062	
Physical configuration:	Metal enclosure	
	Weight:	Approx. 43 kg
	Cells in series/parallel:	1P16S
Cooling method:	Air cooling	
Separation between cells:	-	
Electrical rating:	Rated capacity:	100 Ah
	Nominal voltage:	51.2 Vdc
Standard charge method:	Charge Current:	70A
	End of charge:	The highest voltage reaches 55.2V
Standard discharge method:	Disharge Current:	70A
	End of discharge:	The lowest voltage reaches 48 V
Compliance with UL 1973:	☒ Yes	☐ No TUV Rheinland: CN249WXG 002
Remark: The model 48-48-5120-H / 900-0067 is same as the model 48-48-5120 / 900-0062, except the model 48-48-5120 / 900-0062 is not mounted the temperature heater of cells between the cells, test was performed on model 48-48-5120-H / 900-0067.		

2.2.2 Diagram with overall dimension

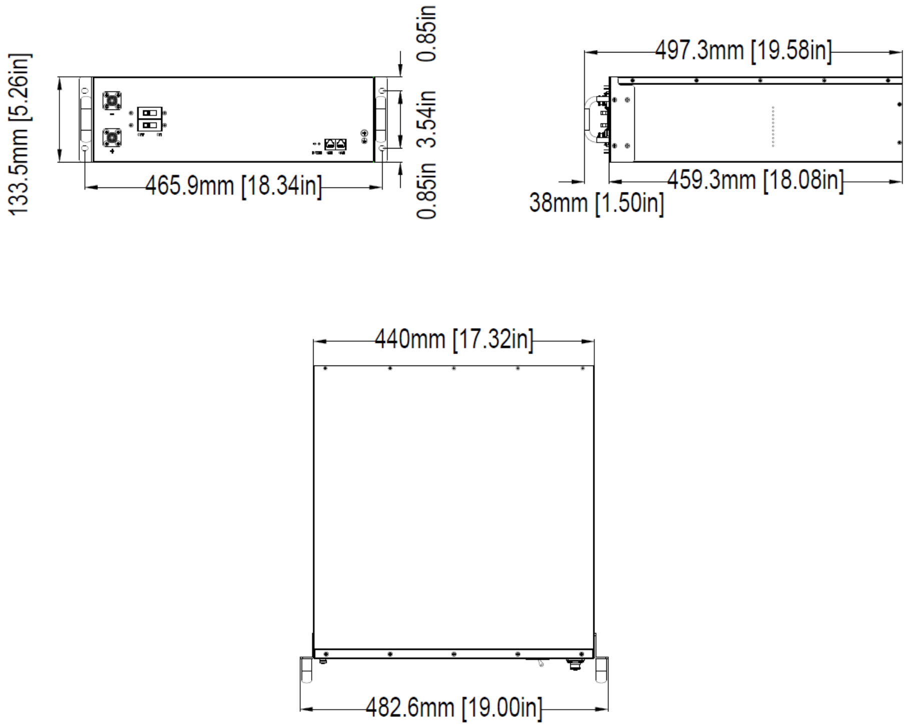


Figure 1. Diagram with overall dimension (Unit: mm)

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, smoke 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. Testing can be discontinued after the module level testing if the effects of thermal runaway (fire and explosion) are contained by the module design and the cell vent gas (as determined by the cell level testing) is non-flammable.

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 2.2.1 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 2. Sample cycling curve

3.3 Module level thermal runaway test

3.3.1 Thermal runaway test method description

The module to be tested was charged to 100% SOC and allow stabilizing for a minimum of 1 h and a maximum of 8 h before the start of the test.

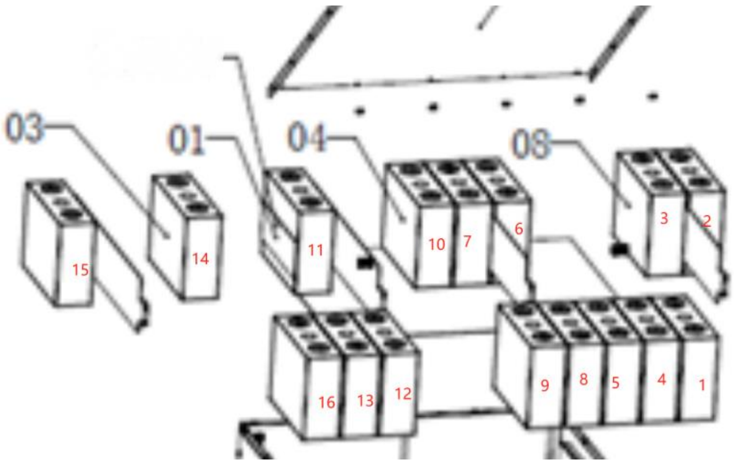
The module consisted of 16 cells (1P16S). All cells in the pack were numbered from #1 to #16 as below.

External heating method was used to initiate thermal runaway in the module. One PET heater, rated 220V ac/1000 W, size 100 x 150 x 0.34 mm, was fitted on cell.

1 PTFE insulated thermocouples, Type K, 24AWG, were attached between the cells and under the heating surface. See Figure 3 and Figure 4 for the detail locations.

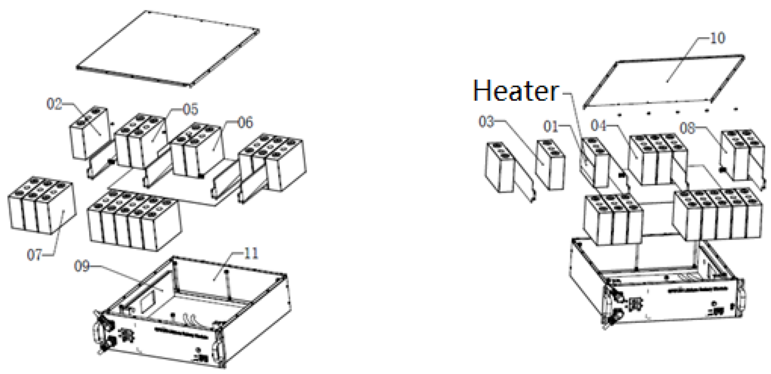
Voltage of the module was monitored during test.

Figure 3 and Figure 4 Cell numbering, heater location and thermocouples locations.



Remark: The number 1~16 means Cell #1~#16 distributed in modules.

Figure 3. Internal view of module



Remark: The number 1~10 means Thermocouple no. T1~T10 distributed in modules.

Figure 4. Location of heater and thermocouple

A PID controller was used to control the voltage supply to the heater and maintain a 4°C/min to 7°C/min heating rate. Additional one thermocouple on the center of initiating cell surface below heater was used to feedback the cell surface temperature to the controller.

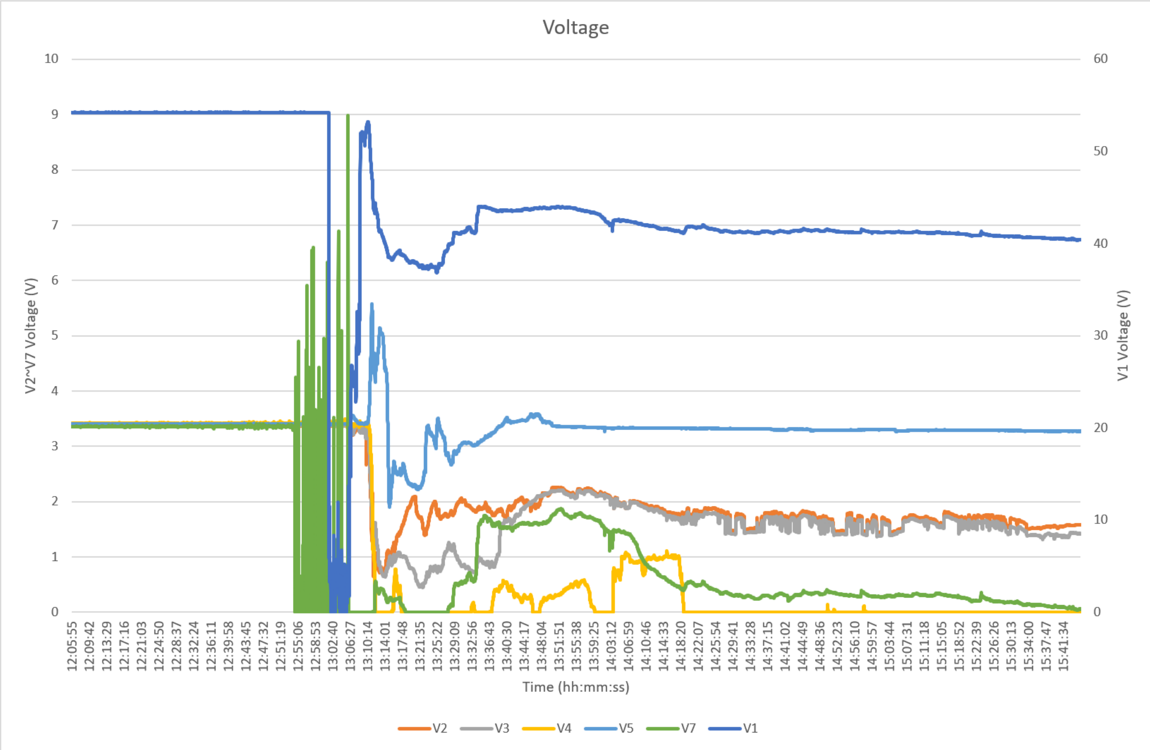
The initiating cells were heated at a rate of 4°C to 7°C per minute until the cell thermal runaway.

Once the measured temperature exceed the set heating rate, the heaters were immediately de-energized.

3.3.2 Observations and records

Ambient conditions at the initiation of the test . :	28.5°C, 70.5% R.H.
Sample number :	A003742002-006
Open circuit voltage before test (V) :	54.24
Weight before test (kg) :	43.05
Time initiating the test :	2024-08-15 12:05:55
Observations during test :	The first thermal runaway cell (#11) and smoke release at 13:10. Then stop heating. The second thermal runaway cell (#14) at 13:12. No flying debris or explosive discharge of gases during test. No sparks, electrical arcs, or other electrical events during test. No external flaming observe.
Posttest evaluation :	Two cells (#11, #14) went into thermal runaway during test. One cells (#14) was into thermal runaway by cell to cell propagation.
Open circuit voltage after test (V) :	40.427
Weight after test (kg) :	41.05
Weight loss (kg) :	2.0

3.3.3 Temperature measurements



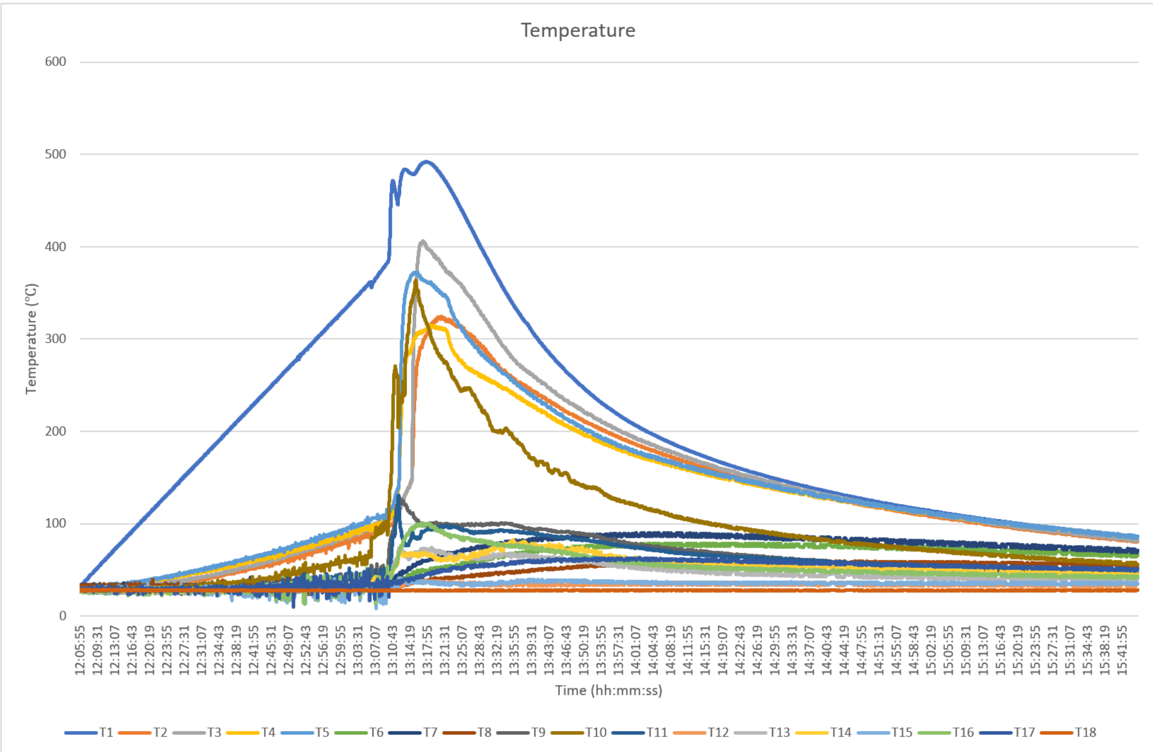


Figure 5. The voltage and temperatures curve

Thermocouple no.	Location	Maximum temp. °C
T1	Between cell_11 and Heater	492.0
T2	Right surface of cell_15	324.3
T3	Left surface of cell_14	406.2
T4	Left surface of cell_10	314.5
T5	Right surface of cell_11	372.3
T6	Right surface of cell_07	78.9
T7	Right surface of cell_12	90.0
T8	Left surface of cell_03	59.3
T9	Left surface of the internal Enclosure	128.1
T10	Top surface of the internal Enclosure	363.3
T11	Back surface of the internal Enclosure	130.4
T12	Front surface of the Enclosure	38.7
T13	Back surface of the Enclosure	73.9
T14	Left surface of the Enclosure	82.1
T15	Right surface of the Enclosure	49.1
T16	Top surface of the Enclosure	100.4
T17	Bottom surface of the Enclosure	62.9
T18	Ambient temperature	28.7

Voltage no.	Name	Voltage
V1	Voltage of Module	54.240 V to 40.427 V
V2	Voltage variety of cell 10	3.379 V to 1.585 V
V3	Voltage variety of cell 15	3.388 V to 1.419 V
V4	Voltage variety of cell 14	3.410 V to 0 V
V5	Voltage variety of cell 12	3.405 V to 3.275 V
V6	Voltage variety of cell 11	3.355 V to 0 V

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

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

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 was calibrated at 139MJ total heat release before the test. The calibration was performed using mass of 3Kg of heptane.

3.4.2 Test result

Peak chemical heat release rate HRR: 2.482KW

Total heat release through the test THR: 1.250MJ

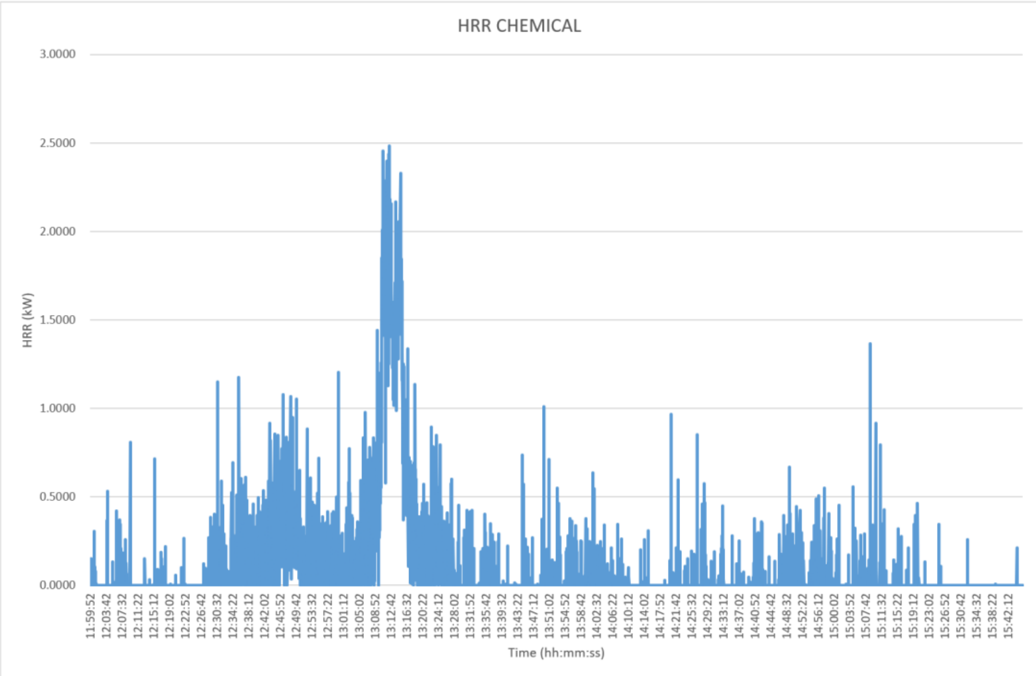


Figure 6. HRR curve

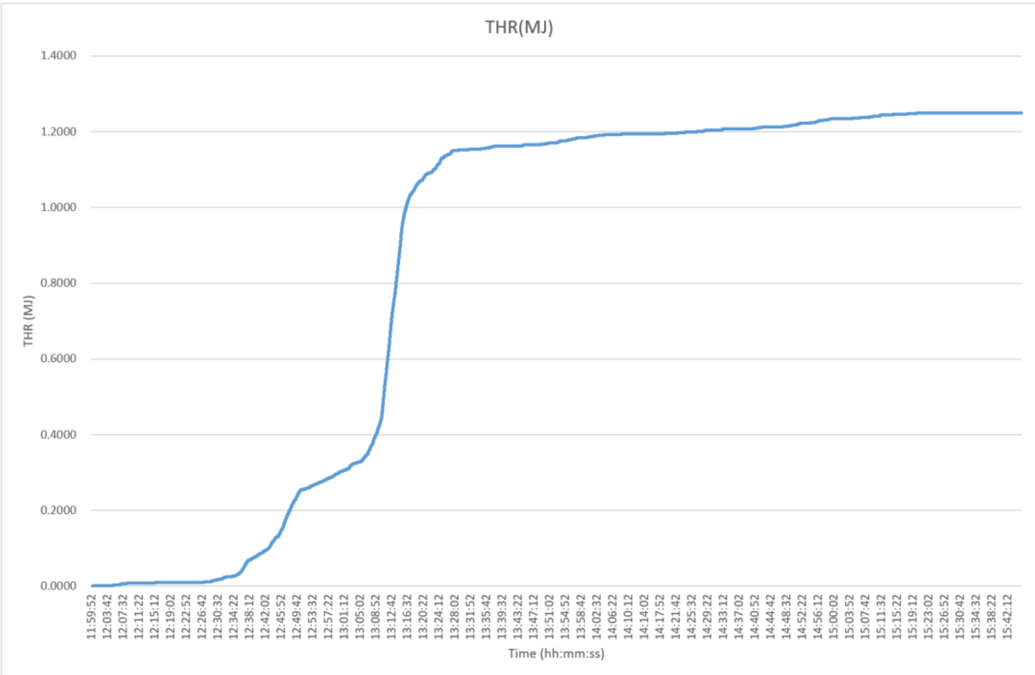


Figure 7. THR curve

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.

3.5.2 Test result

Peak smoke release rate SRR: 0.458 m^2/s

Total smoke release TSR: 103.34m^2

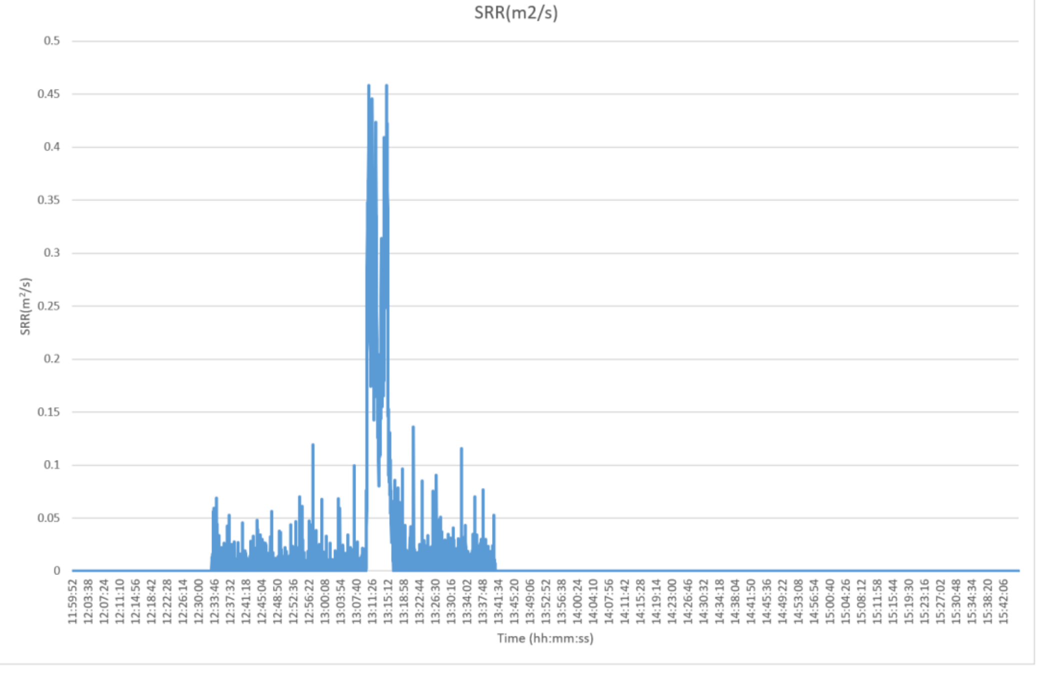


Figure 8. SRR curve

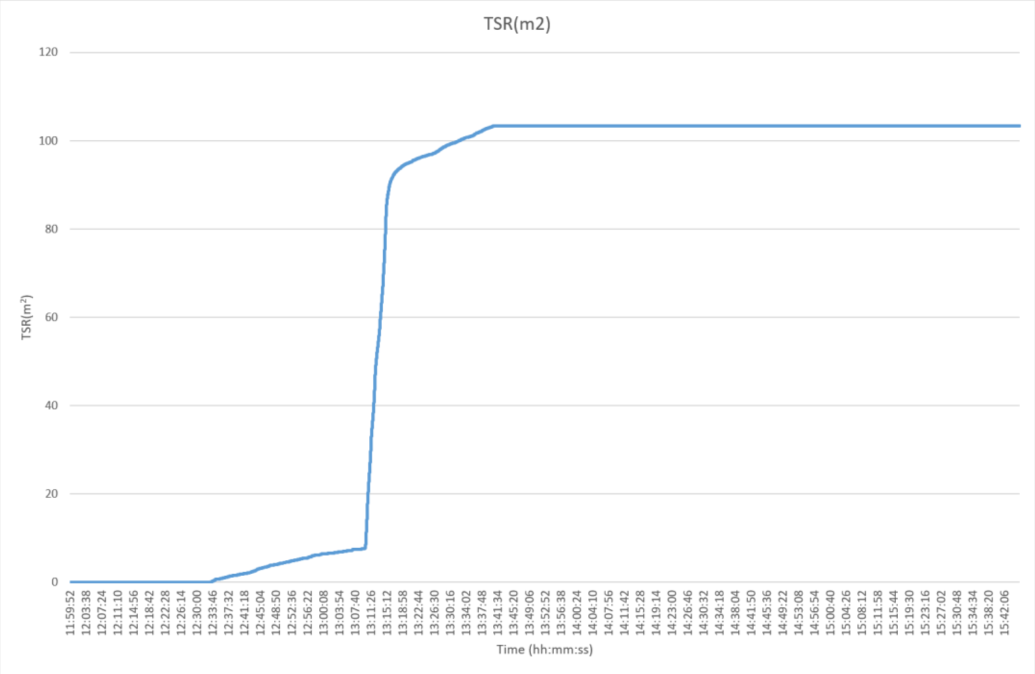


Figure 9. TSP curve

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 5 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.

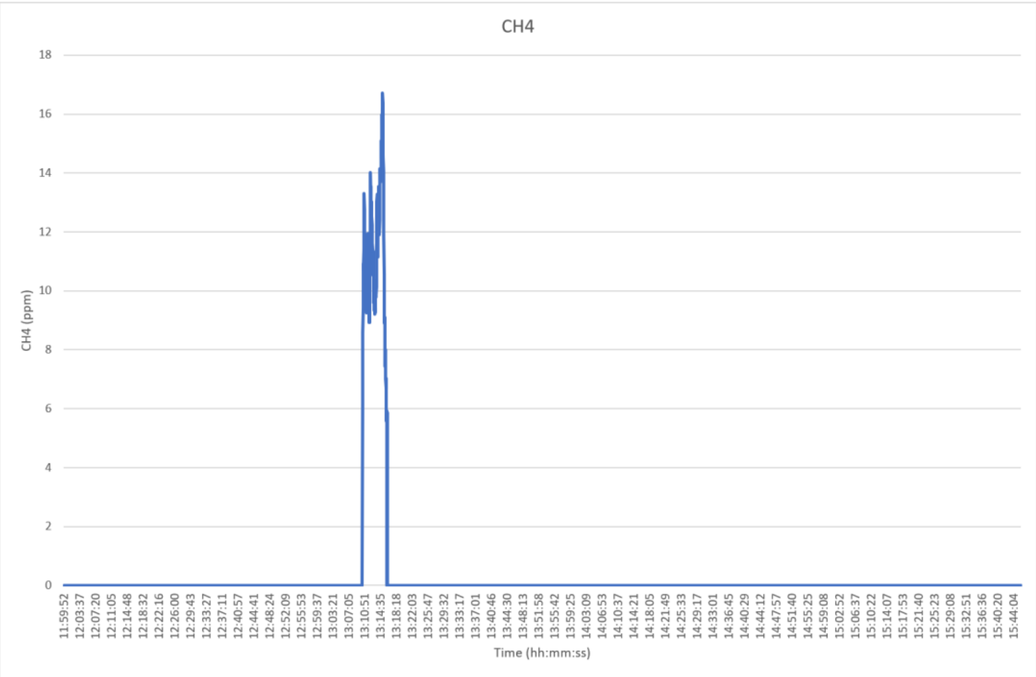
3.6.2 Total gas release

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 were presented in below table.

Gas type	Gas components		Total volume of gas (L)
Hydrocarbon species	Methane	CH_4	8.1
	Ethylene	C_2H_4	6.6
Others	Carbon Monoxide NDIR/FTIR	CO	9.0
	Carbon Dioxide NDIR/FTIR	CO_2	30.0
	Hydrogen (Palladium nickel thin film solid state sensor)	H_2	Below detectable limit
Total Hydrocarbons (equivalent to CH_4, measured by FID)			59.8

3.6.3 Gas components

Concentration of different gas components were present according to gas species classification in Figures 10 to 14. Average flow rate was 1.552 m^3/s during test.



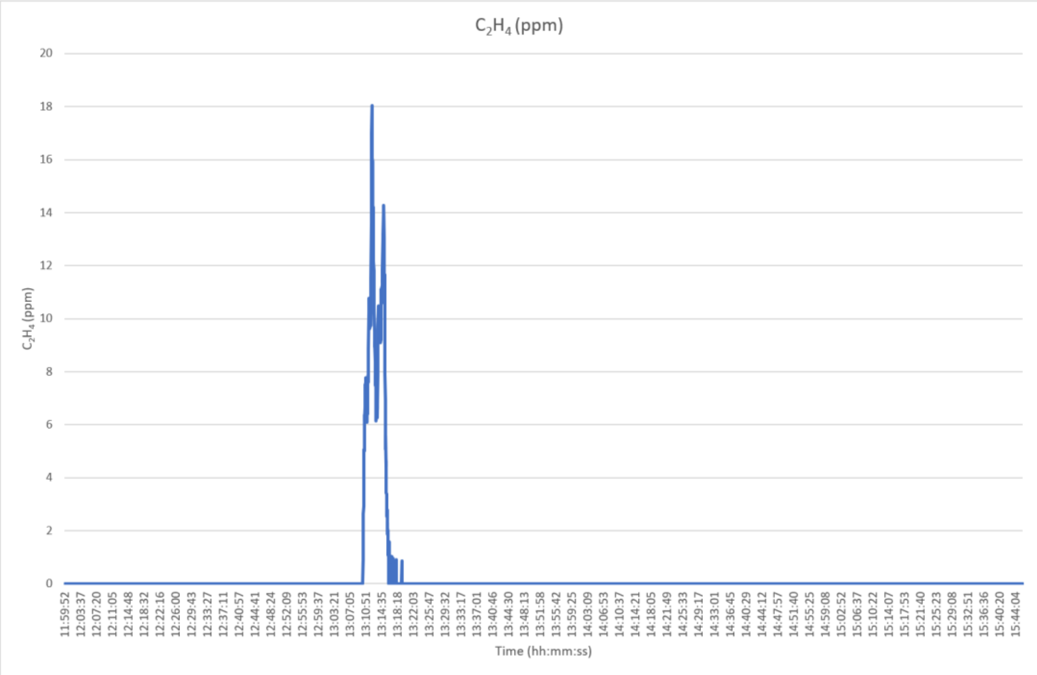
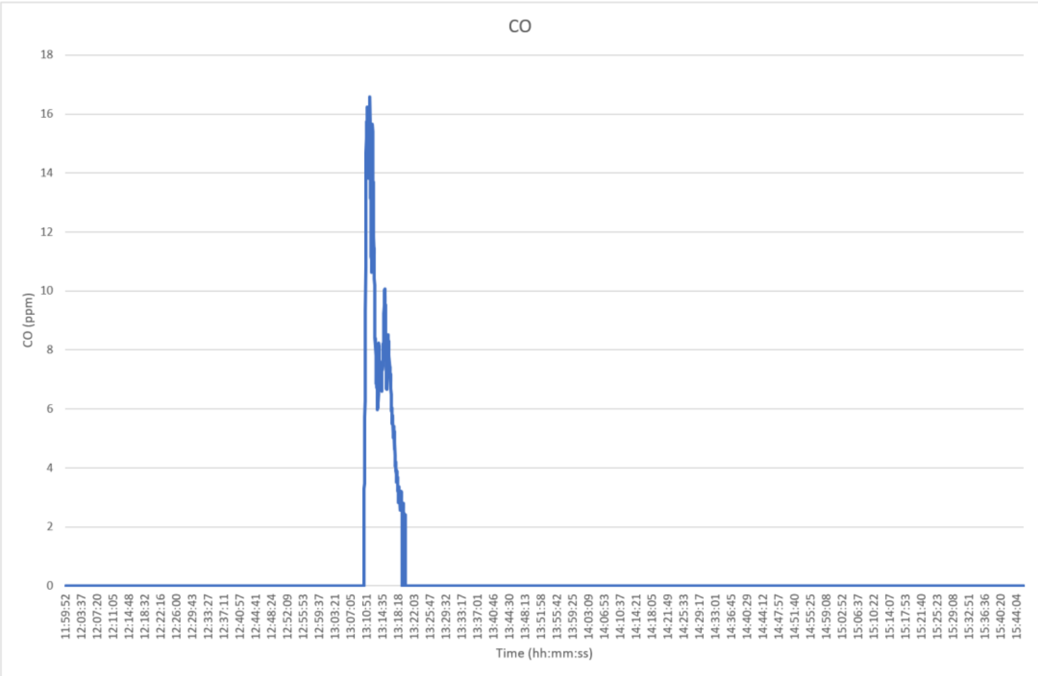
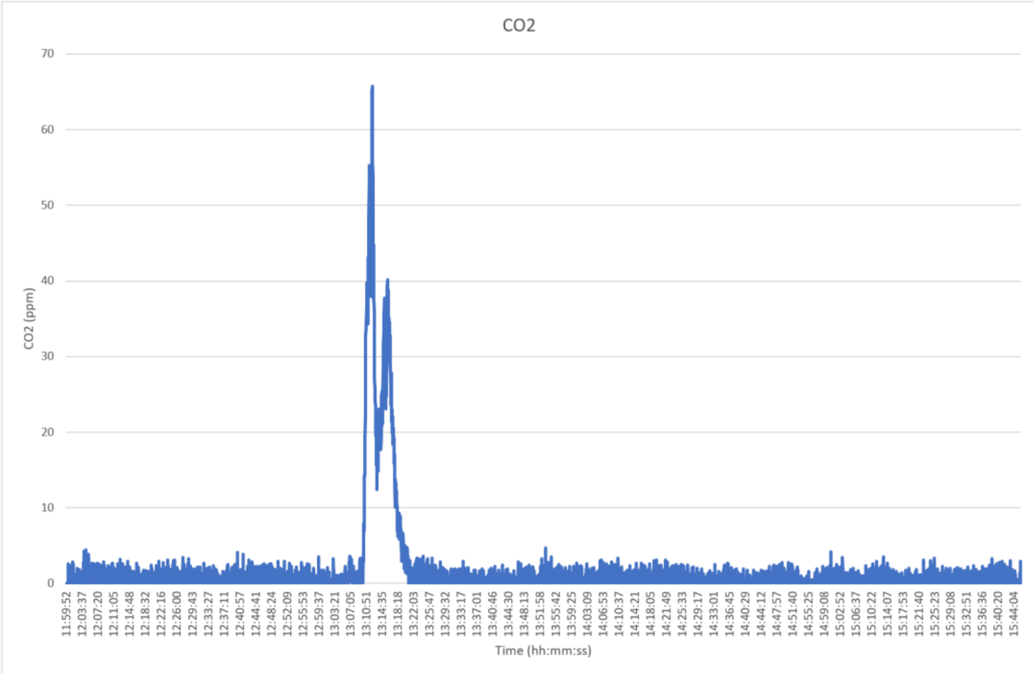


Figure 10. Hydrocarbon species





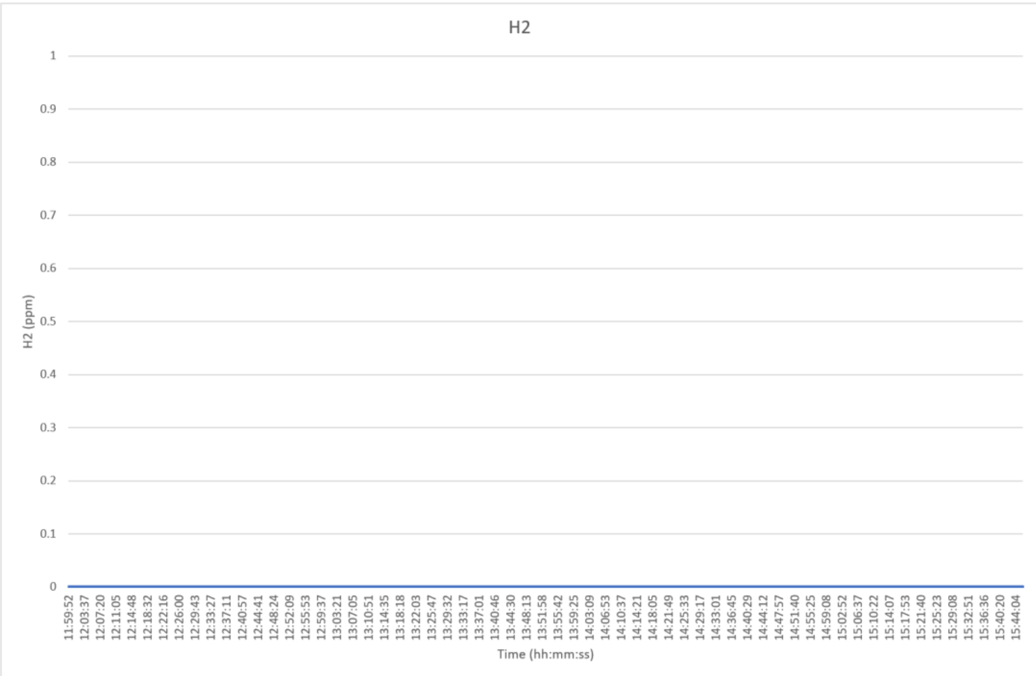


Figure 13. Others

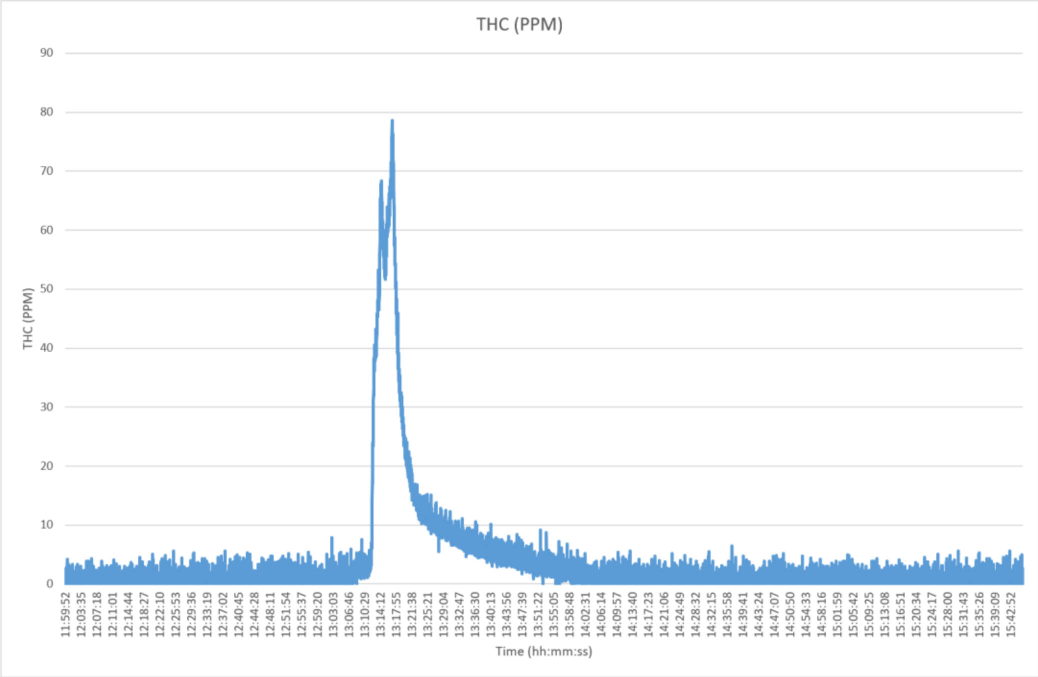
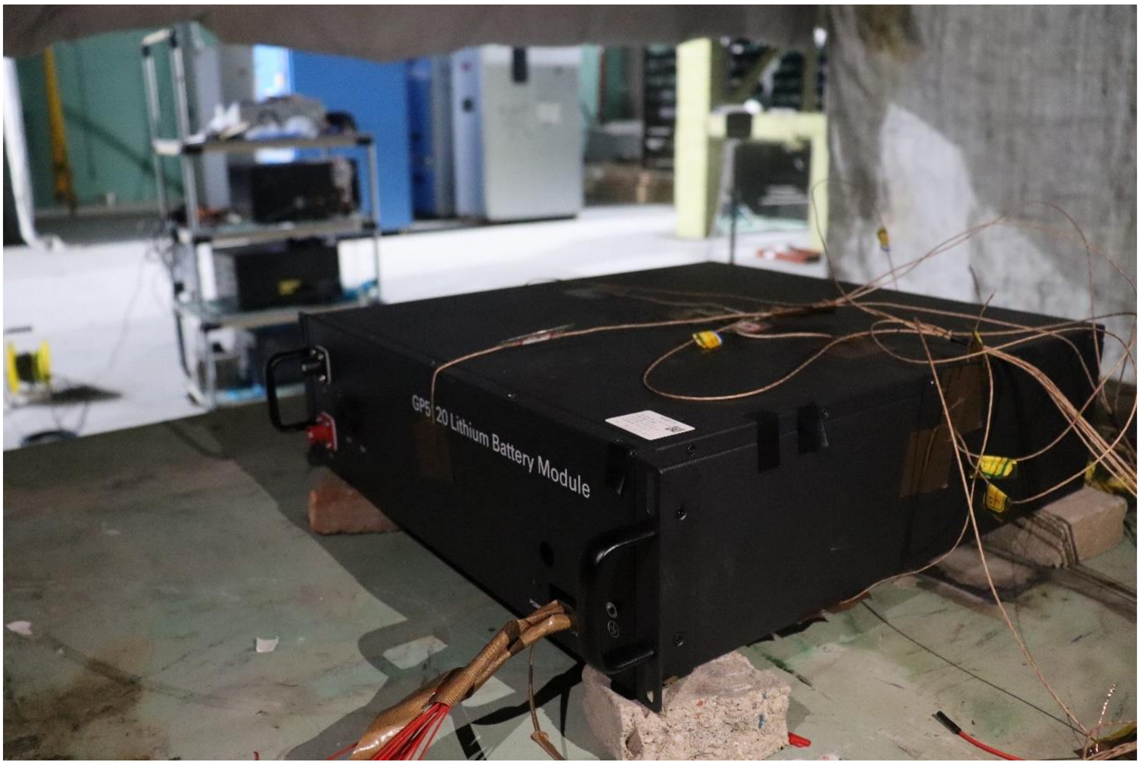
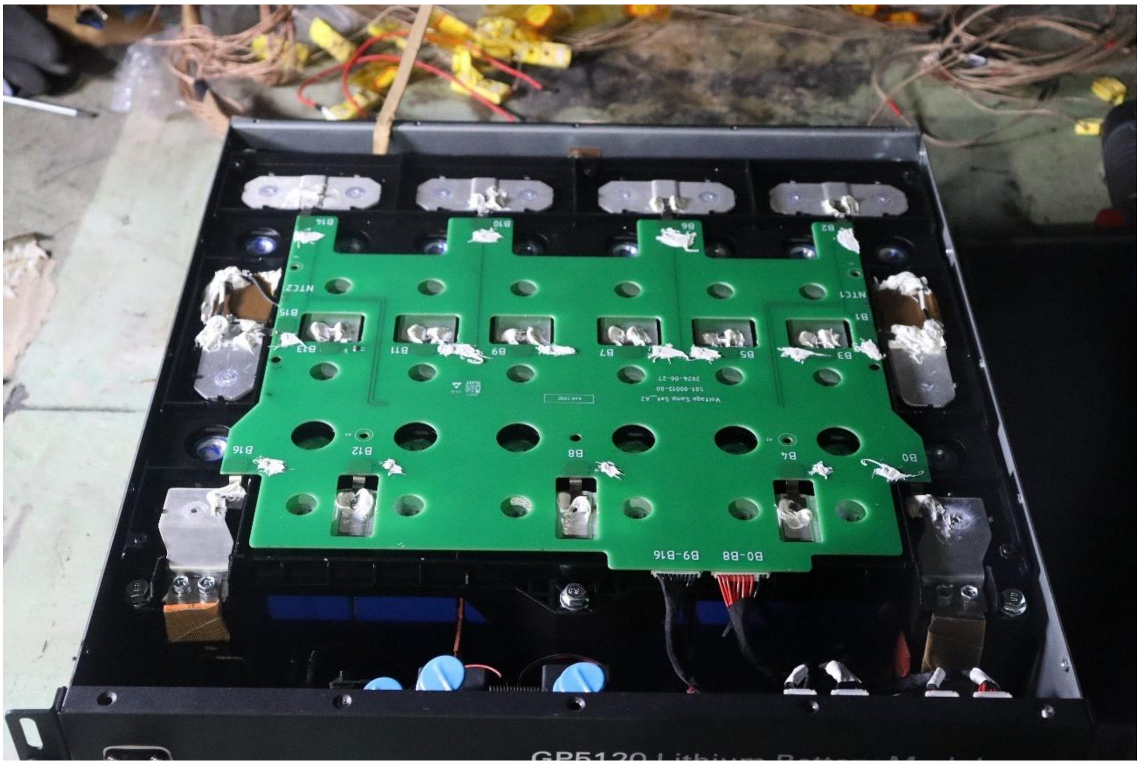


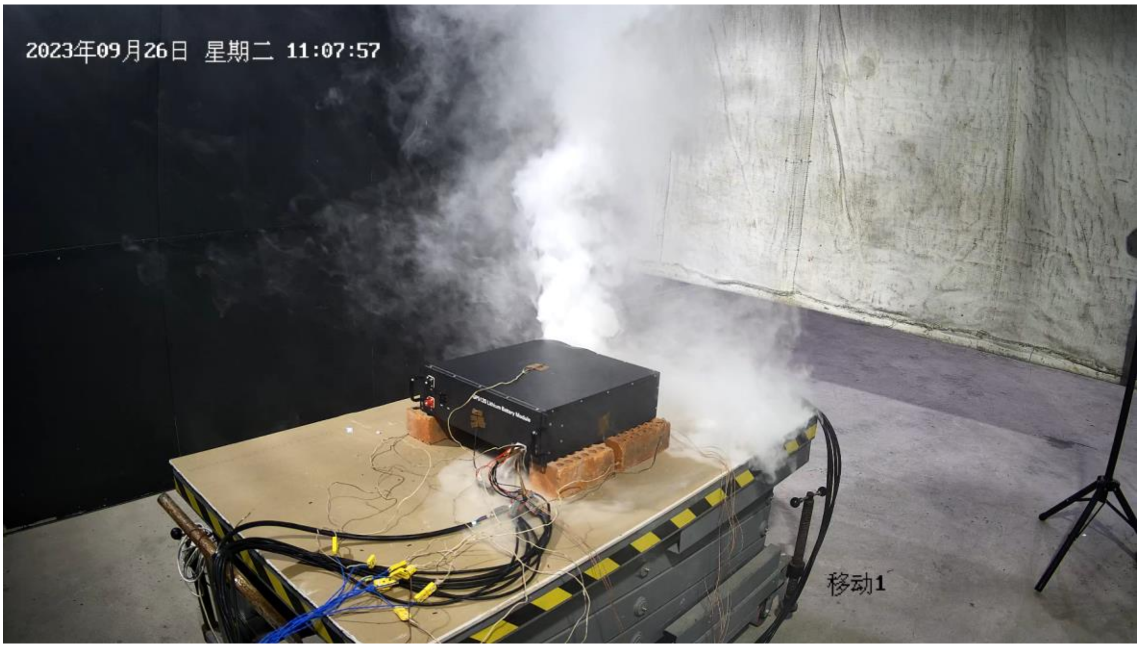
Figure 14. Total Hydrocarbons (equivalent to CH_4, measured by FID)

3.7 Photos

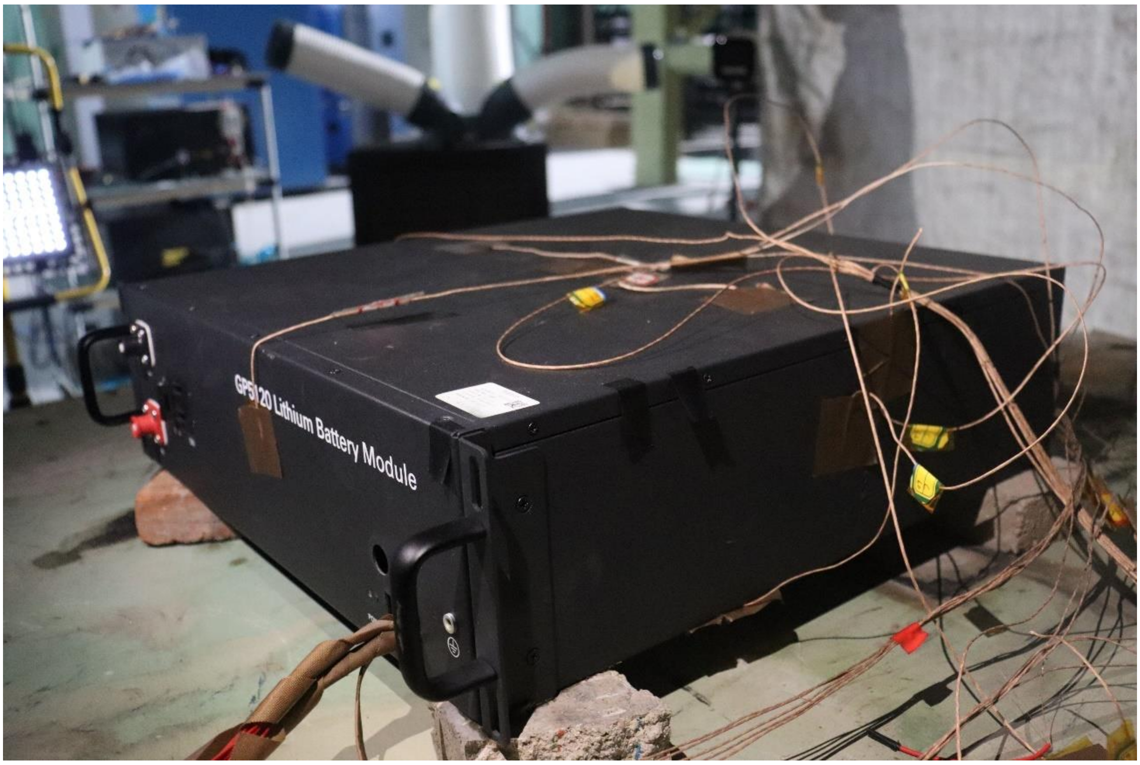


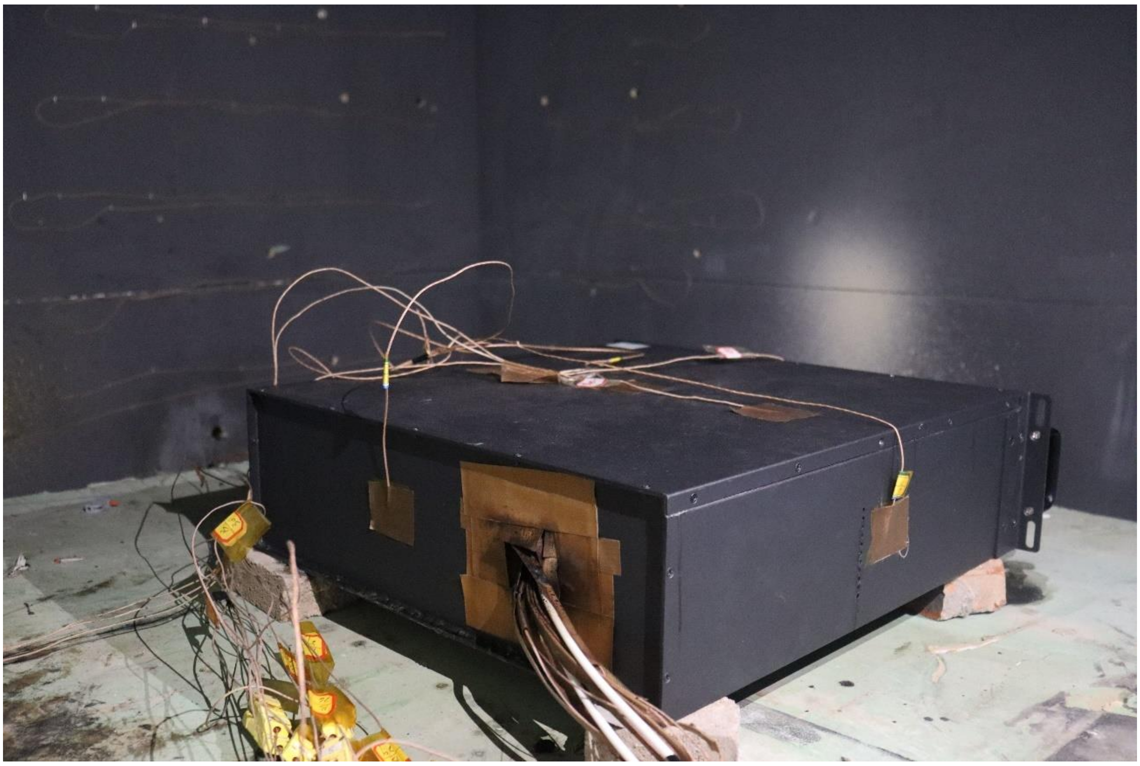


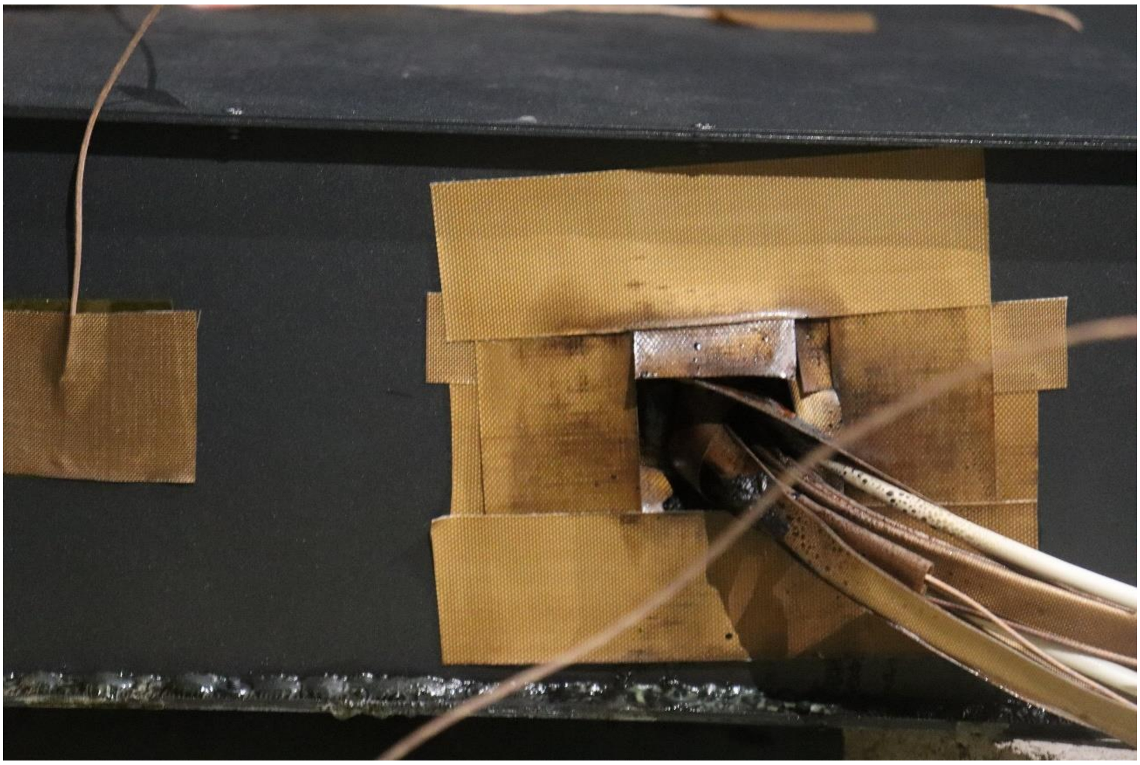
Module before test



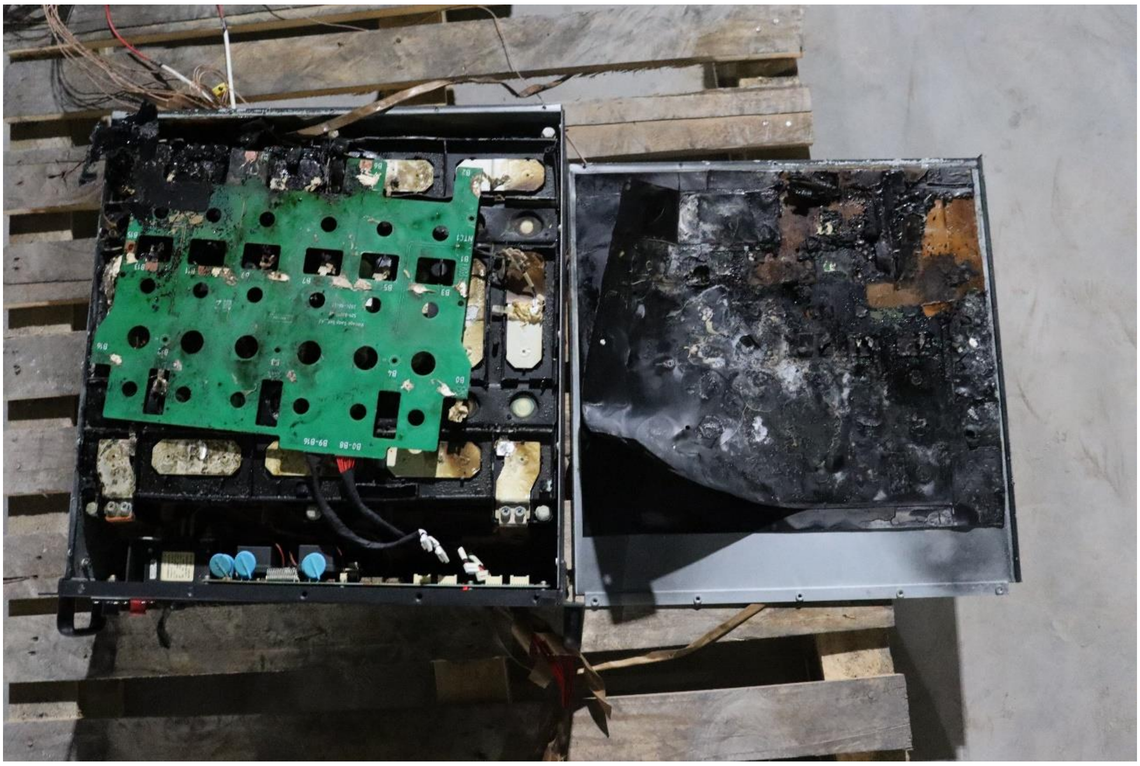
Smoke release during test

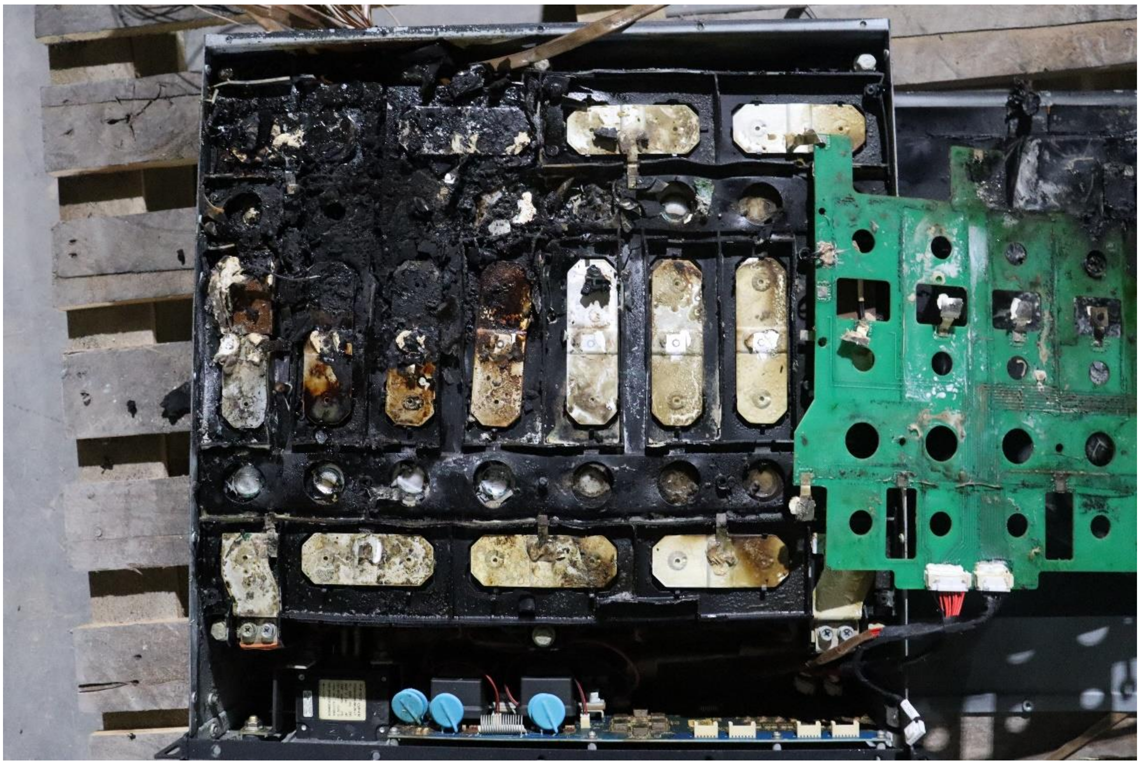

GP5120 Lithium Battery Module

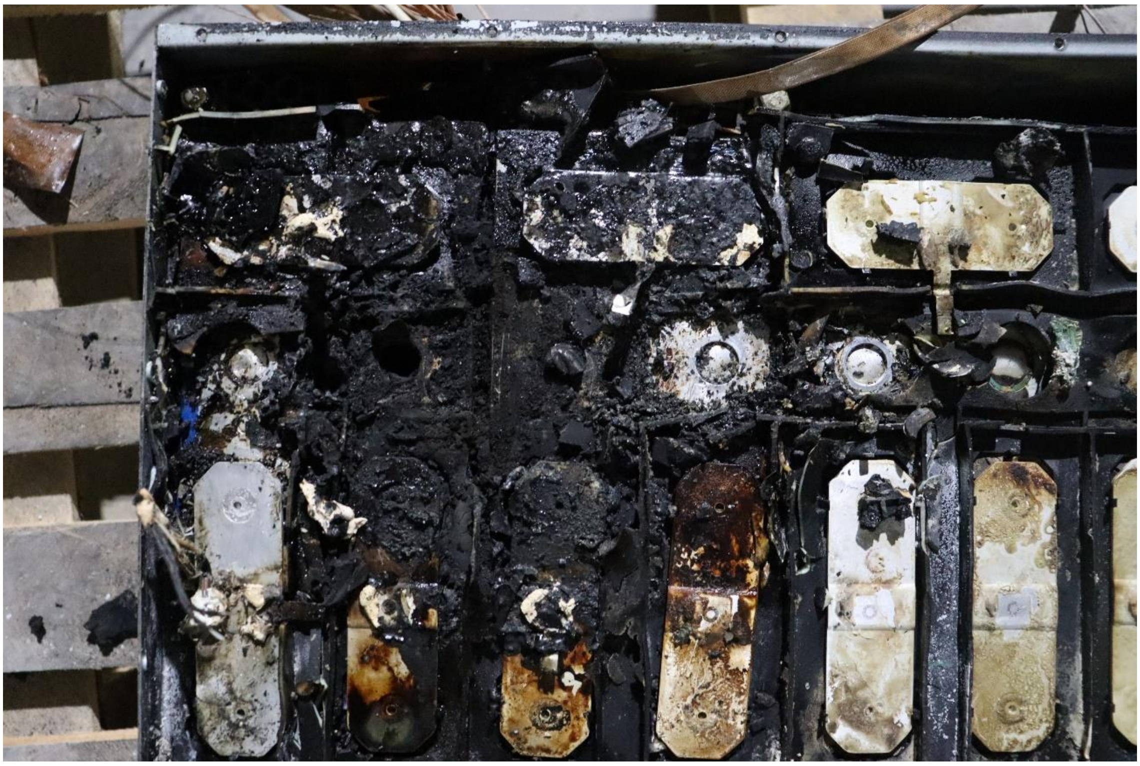




Sample after test







Damage of the internal components

End of Test Report