Riskcon engineering

Preliminary Hazard Analysis

Mayfair Solar Farm

Urbis Pty Ltd
Document No. RCE-24003_MSF_PHA_Final_18Jun25_Rev(3)
Date 18/06/2025

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Prepared by

Riskcon Engineering Pty Ltd
37 Pogson Drive
Cherrybrook NSW 2126
www.riskcon-eng.com
ABN 74 626 753 820

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Quality Management

Rev	Date	Remarks	Prepared By	Reviewed By
A	24 April 2024	Draft issued for comment	Zachary Cohn	Renton Parker
0	13 August 2024	Issued final		
1	5 November 2024	Updated site layout		
2	5 June 2025	Addressed DPHI comments		
3	18 June 2025	Updated BESS layout		

Executive Summary

Background

Urbis Pty Ltd (Urbis) is preparing an Environmental Impact Statement (EIS) for the Mayfair Solar Farm which includes a Battery Energy Storage System (BESS). Risks associated with the development are required to be assessed in the form of a Preliminary Hazard Analysis (PHA) as part of the EIS. The PHA is to be prepared in accordance with the Hazardous Industry Planning Advisory Papers (HIPAP No. 6 and No. 4).

Riskcon Engineering Pty Ltd (Riskcon) has been engaged to assist with preparing the PHA for the EIS submission.

Conclusions

A hazard identification table was developed for Mayfair Solar Farm & BESS project to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with the potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

A review of the incidents carried forward for further analysis indicates that there were no observed offsite impacts; therefore, based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the project would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

Recommendations

The following recommendations have been made as a result of the analysis:

- BESS to be installed in accordance with manufacturer recommended clearances based on testing.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the project area whilst meeting the recommended clearances.
- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.

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Abbreviations

Abbreviation	Description
AC	Alternating Current
ADG	Australian Dangerous Goods Code
AS	Australian Standard
BESS	Battery Energy Storage System
DC	Direct Current
DGs	Dangerous Goods
DPHI	Department of Planning, Housing, and Infrastructure
EIS	Environmental Impact Statement
ELF	Extra Low Frequency
EMF	Electric and Magnetic Field
ERPG	Emergency Response Planning Guideline
FCAS	Frequency Control Ancillary Services
FHA	Final Hazard Analysis
HF	Hydrogen Fluoride
HIPAP	Hazardous Industry Planning Advisory Paper
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IDLH	Immediately Dangerous to Life and Health
LFP	LiFePO4 (Lithium Iron Phosphate)
MVPS	Medium Voltage Power Station
NMC	Nickel-Manganese-Cobalt
PHA	Preliminary Hazard Analysis
Pmpy	Per million per year
PO	Performance Outcome
PV	Photovoltaic
SEARs	Secretary's Environmental Assessment Requirements
SEP	Surface Emissive Power
SEPP	State Environmental Planning Policy
SOC	State of Charge
SSDA	State Significant Development Application
STEL	Short Term Exposure Limit
VBB	Victorian Big Battery

1.0 Introduction

1.1 Background

Urbis Pty Ltd (Urbis) is preparing an Environmental Impact Statement (EIS) for the Mayfair Solar Farm which includes a Battery Energy Storage System (BESS). Risks associated with the development are required to be assessed in the form of a Preliminary Hazard Analysis (PHA) as part of the EIS. The PHA is to be prepared in accordance with the Hazardous Industry Planning Advisory Papers (HIPAP No. 6 and No. 4).

Riskcon Engineering Pty Ltd (Riskcon) has been engaged to assist with preparing the PHA for the EIS submission.

1.2 Objectives

The key objectives of this PHA are to:

- Complete the PHA according to the Hazardous Industry Planning Advisory Paper (HIPAP) No. 6 – Hazard Analysis (Ref. [1]).
- Assess the PHA results using the criteria in HIPAP No. 4 – Risk Criteria for Land Use Planning (Ref. [2]).
- Demonstrate compliance of the site with the relevant codes, standards and regulations (i.e. Planning and Environment Regulation, WHS Regulation, 2017 Ref. [3]).

1.3 Scope of Services

The scope of work is to complete a PHA study for the Mayfair Solar Farm and BESS project site located approximately 5 km North of Gulgong NSW 2852.

2.0 Methodology

2.1 Multi-Level Risk Assessment

The Multi-Level Risk Assessment approach (Ref. [4]) published by the NSW Department of Planning, Housing and Infrastructure, has been used as the basis for the study to determine the level of risk assessment required. The approach considered the development in context of its location, the quantity and type (i.e. hazardous nature) of Dangerous Goods (DGs) stored and used, and the project's technical and safety management control. The Multi-Level Risk Assessment Guidelines are intended to assist industry, consultants and the consent authorities to carry out and evaluate risk assessments at an appropriate level for the project being studied.

There are three levels of risk assessment set out in Multi-Level Risk Assessment which may be appropriate for a PHA, as detailed in **Table 2-1**.

Table 2-1: Level of Assessment PHA

Level	Type of Analysis	Appropriate If:
1	Qualitative	No major off-site consequences and societal risk is negligible
2	Partially Quantitative	Off-site consequences but with low frequency of occurrence
3	Quantitative	Where 1 and 2 are exceeded

The Multi-Level Risk Assessment approach is schematically presented in **Figure 2-1**.

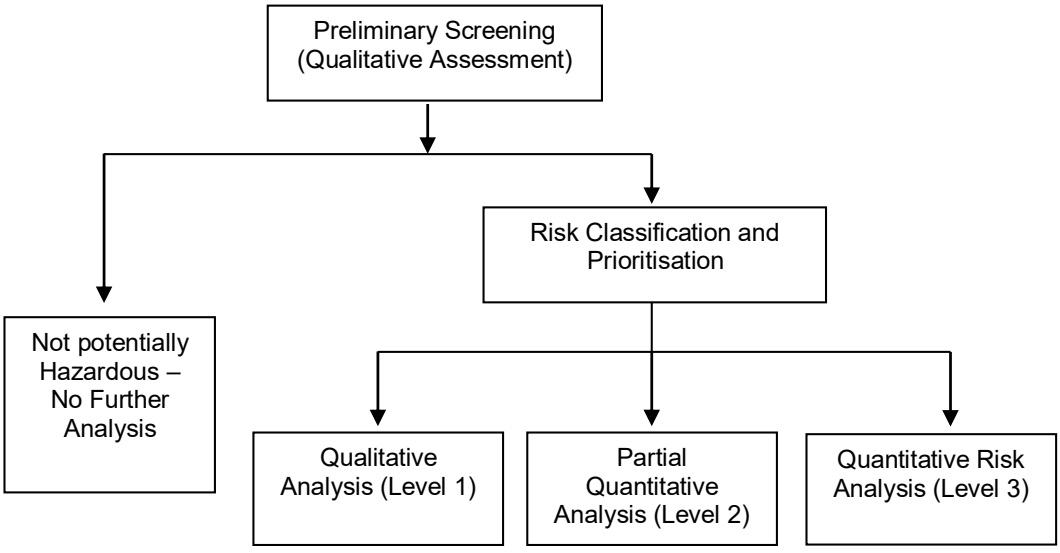


Figure 2-1: The Multi-Level Risk Assessment Approach

Based on the type of DGs to be used and handled at the proposed project, a **Level 1 Assessment** was selected for the Site. This approach provides a qualitative assessment of those DGs of lesser quantities and hazard, and a quantitative approach for the more hazardous materials to be used on-site.

1.1

2.2 Risk Assessment Study Approach

The methodology used for the PHA is as follows:

Hazard Analysis – A detailed hazard identification was conducted for the site facilities and operations. Where an incident was identified to have a potential off-site impact, it was included in the recorded hazard identification word diagram (**Appendix A**). The hazard identification word diagram lists incident type, causes, consequences and safeguards. This was performed using the word diagram format recommended in HIPAP No. 6 (Ref. [1]).

Each postulated hazardous incident was assessed qualitatively in light of proposed safeguards (technical and management controls). Where a potential offsite impact was identified, the incident was carried into the main report for further analysis. Where the qualitative review in the main report determined that the safeguards were adequate to control the hazard, or that the consequence would obviously have no offsite impact, no further analysis was performed. **Section 3.1** of this report provides details of values used to assist in selecting incidents required to be carried forward for further analysis.

Consequence Analysis – For those incidents qualitatively identified in the hazard analysis to have a potential offsite impact, a detailed consequence analysis was conducted. The analysis modelled the various postulated hazardous incidents and determined impact distances from the incident source. The results were compared to the consequence criteria listed in HIPAP No. 4 (Ref. [2]). The criteria selected for screening incidents is discussed in **Section 3.1**.

Where an incident was identified to result in an offsite impact, it was carried forward for frequency analysis. Where an incident was identified to not have an offsite impact, and a simple solution was evident (i.e. move the proposed equipment further away from the boundary), the solution was recommended, and no further analysis was performed.

Frequency Analysis – In the event a simple solution for managing consequence impacts was not evident, each incident identified to have potential offsite impact was subjected to a frequency analysis. The analysis considered the initiating event and probability of failure of the safeguards (both hardware and software). The results of the frequency analysis were then carried forward to the risk assessment and reduction stage for combination with the consequence analysis results.

Risk Assessment and Reduction – Where incidents were identified to impact offsite and where a consequence and frequency analysis was conducted, the consequence and frequency analysis for each incident were combined to determine the risk and then compared to the risk criteria published in HIPAP No. 4 (Ref. [2]). Where the criteria were exceeded, a review of the major risk contributors was performed, and the risks reassessed incorporating the recommended risk reduction measures. Recommendations were then made regarding risk reduction measures.

Reporting – On completion of the study, a draft report was developed for review and comment. A final report was then developed, incorporating the comments received for submission to the regulatory authority.

3.0 Site Description

3.1 Site Location

The site is located on Jackson Lane off Barneys Reef Road approximately 5 km north of Gulgong in Stubbo, NSW 2852. The closest sensitive receptor in the surrounding area is approximately 500 m away from the solar farm 1,400 m away from the BESS. There is a rail corridor to the immediate West of the site.

Figure 3-1 shows the regional location of the site. **Figure 3-2** and **Figure 3-3** respectively show the preliminary site layout of the full development and an indicative layout for the BESS based on a similar site. Please note the exact number and arrangement of battery storage units and inverters in this BESS layout varies from the final arrangement.

Figure 3-1: Site Location

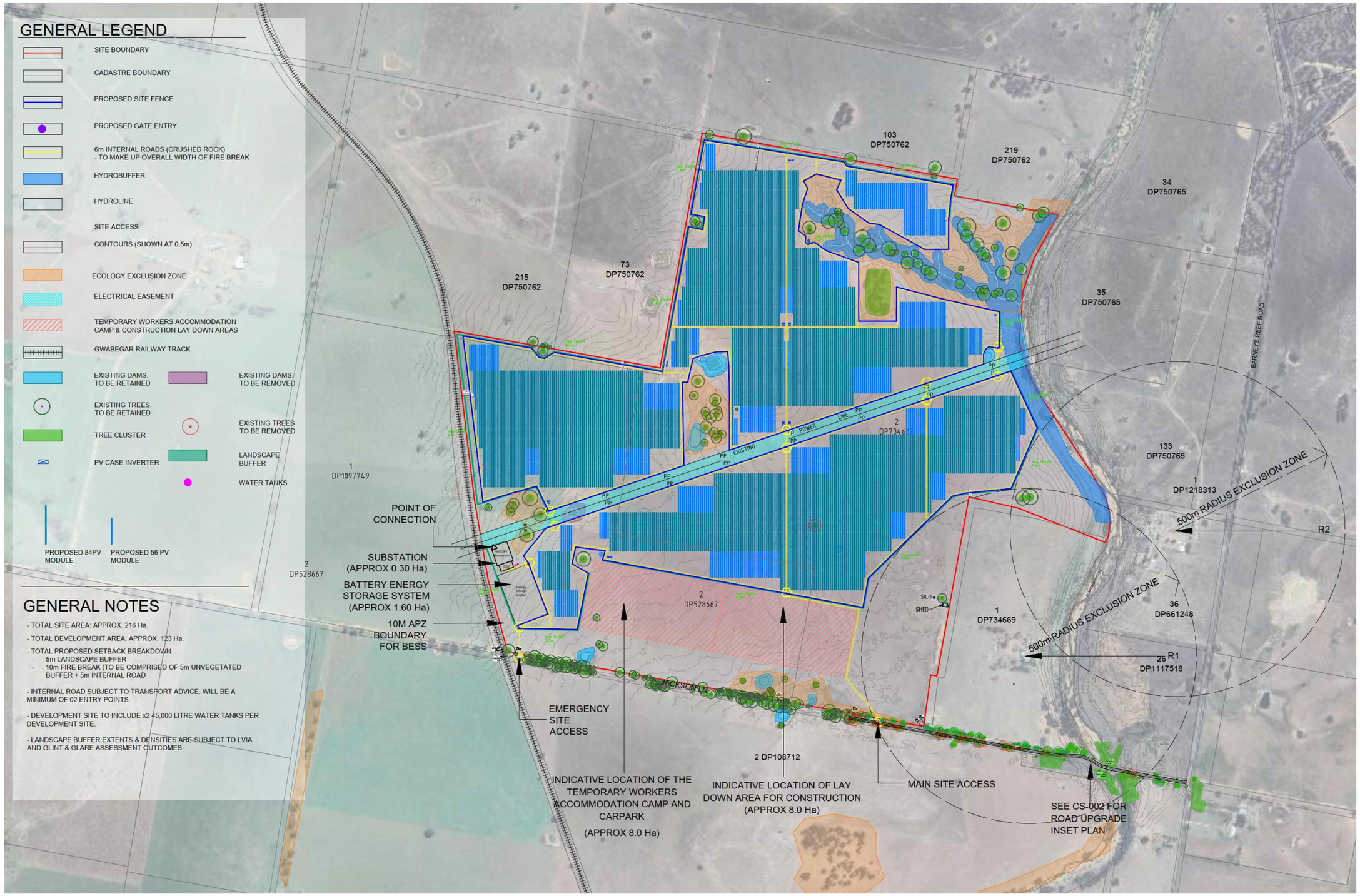
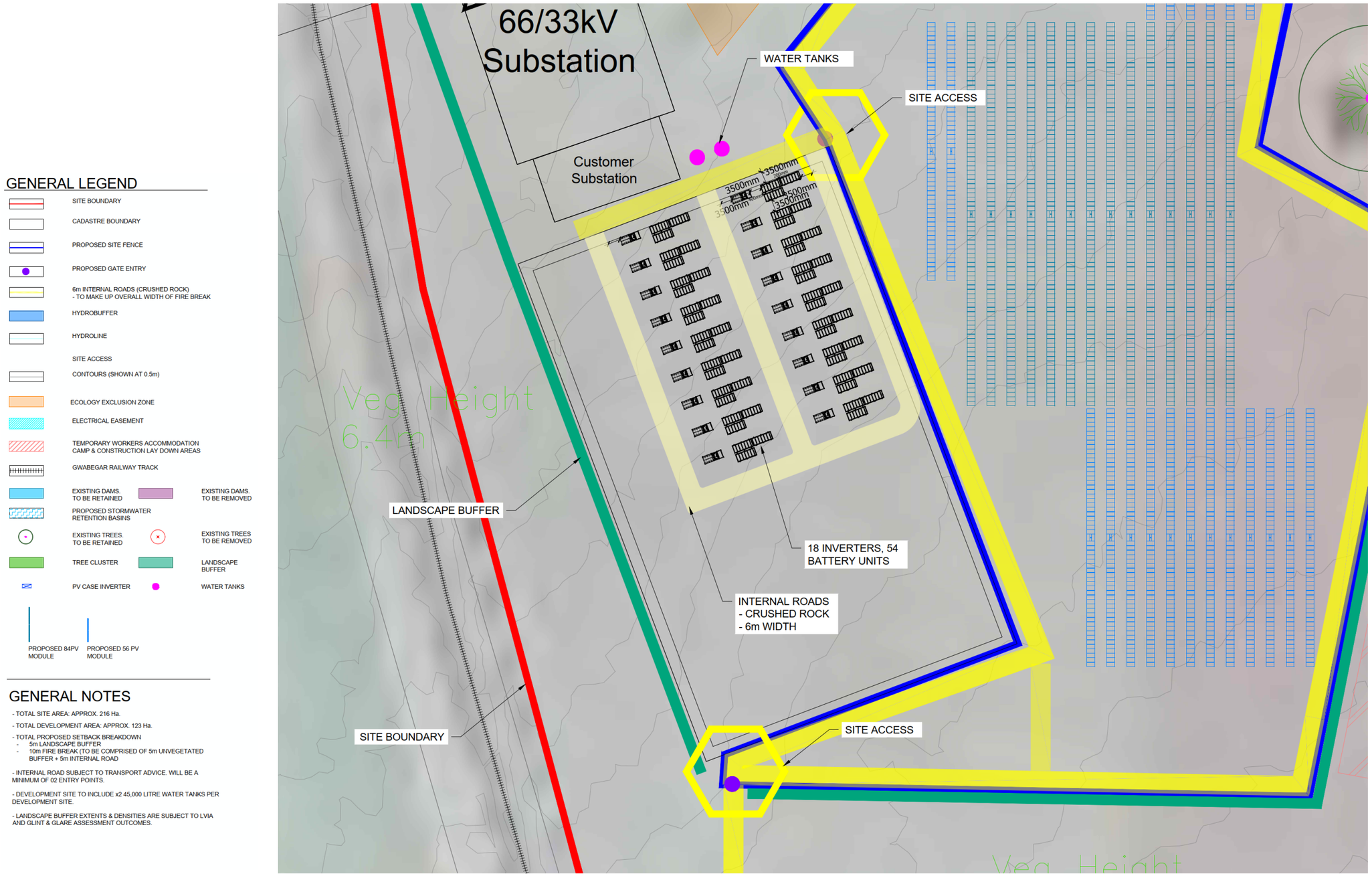


Figure 3-2: Preliminary Site Layout



GENERAL LEGEND

- SITE BOUNDARY
- CADASTRE BOUNDARY
- PROPOSED SITE FENCE
- PROPOSED GATE ENTRY
- 6m INTERNAL ROADS (CRUSHED ROCK) - TO MAKE UP OVERALL WIDTH OF FIRE BREAK
- HYDROBUFFER
- HYDROLINE
- SITE ACCESS
- CONTOURS (SHOWN AT 0.5m)
- ECOLOGY EXCLUSION ZONE
- ELECTRICAL EASEMENT
- TEMPORARY WORKERS ACCOMMODATION CAMP & CONSTRUCTION LAY DOWN AREAS
- GWABEGAR RAILWAY TRACK
- EXISTING DAMS. TO BE RETAINED / EXISTING DAMS. TO BE REMOVED
- PROPOSED STORMWATER RETENTION BASINS
- EXISTING TREES. TO BE RETAINED / EXISTING TREES TO BE REMOVED
- TREE CLUSTER / LANDSCAPE BUFFER
- PV CASE INVERTER / WATER TANKS
- PROPOSED 84PV MODULE
- PROPOSED 56 PV MODULE

GENERAL NOTES

- TOTAL SITE AREA: APPROX. 216 Ha.
- TOTAL DEVELOPMENT AREA: APPROX. 123 Ha.
- TOTAL PROPOSED SETBACK BREAKDOWN
  - 5m LANDSCAPE BUFFER
  - 10m FIRE BREAK (TO BE COMPRISED OF 5m UNVEGETATED BUFFER + 5m INTERNAL ROAD
- INTERNAL ROAD SUBJECT TO TRANSPORT ADVICE. WILL BE A MINIMUM OF 02 ENTRY POINTS.
- DEVELOPMENT SITE TO INCLUDE x2 45,000 LITRE WATER TANKS PER DEVELOPMENT SITE.
- LANDSCAPE BUFFER EXTENTS & DENSITIES ARE SUBJECT TO LVIA AND GLINT & GLARE ASSESSMENT OUTCOMES.

URBIS

MAYFAIR SOLAR FARM
SITE LAYOUT PLAN

Angel Place, Level 8, 123 Pitt Street | Sydney NSW 2000 Australia | +61 2 8233 9900 | URBIS Pty Ltd | ABN 50 105 256 228

REV	DESCRIPTION	DWN	CHK	DATE
B	ISSUED FOR SSDA	LB	YV	12.06.2025
A	ISSUE FOR SSDA	HS	YV	02.09.2024

CLIENT
ELGIN ENERGY

1:5,000 @ A1
1:10,000 @ A3
0 50 100 250m

PROJECT NO. P0046824
DATE 12.06.2025
DRAWING NO. CS-001
REVISION B

Figure 3-3: Indicative BESS Layout

3.2 Project Description

The proposed Project includes a solar farm with a capacity of approximately 60 MW AC and will include a hybrid battery energy storage system (BESS) of approximately 60 MW capacity and 270.8 MWh (4 hour) storage. Associated infrastructure to be constructed as part of the Project includes a substation to connect the project to the electricity network, all associated power conversion equipment such as inverters and transformers and internal access tracks.

The BESS comprises 54 containerised battery storage units (HiTHIUM LFP314-2P52S). Each unit has an energy capacity of 5.015 MWh. Each unit employs lithium iron phosphate (LFP) battery modules and is equipped with a liquid cooling mechanism and a Battery Management System for operational control. Each containerised battery storage unit is to be separated by at least 3 m end-to-end and 3.5 m side-to-side as selected based on a similar project to allow access for maintenance and operations without introducing risk of fire propagation between units. The site layout in **Figure 3-3** presents the proposed layout in accordance with these separation distances, demonstrating that there is sufficient space on site to house all containerised units with this separation.

Each container measures approx. 6.0 by 2.4 by 2.9 m, with a total weight under 45,000 kilograms and an IP55 rating. The energy storage system includes one transformer with a capacity of 70 megavolt-amperes (MVA) for voltage transformation from 33 kilovolts (kV) to 66 kV.

The containers conform to IEC 62619, IEC 62477, IEC 63056, IEC 61000, UL 1973, UL 9540A, NFPA 855, and UN 38.3 standards which govern the safety and performance of the included batteries. This includes the installation of a multistage active fire protection system within each container (**Appendix B**).

3.3 Project Overview

The proposed Project seeks consent for the following:

- Ground mounted solar/photovoltaic (PV) modules. PV modules would be mounted on single axis tracking systems with a maximum height up to 3.5 metres above ground
- A series of power conversion units (PCU)/ inverters, with underground cabling connecting each PCU to the on-site substation
- A hybrid BESS with approximately 60MW capacity and 240MWh (4 hour) storage. The BESS would be in containerised modules adjacent to the on-site substation
- An on-site 33/66 kV substation to connect the Project to the distribution network via an existing overhead 66 kV powerline
- Upgrade and sealing of Jacksons Lane from Barney's Reef Road to site access (approximately 1km), including replacement of the existing vehicle crossing over Slapdash Creek with a new culvert
- Permanent supporting infrastructure including:
    - Internal access tracks
    - Security fencing and lighting
    - Operations and maintenance buildings
    - Operational vehicle access points

- Water tanks
- 33,400 m^3 stormwater retention basin
- Landscaping

Temporary construction facilities may include:

- Construction compound
- Laydown area
- Construction materials storage
- Site office buildings, amenities and temporary workforce accommodation camp

Subject to final design, the temporary workforce accommodation camp, with a capacity of up to 150 workers, will include:

- Demountable single-storey 2 or 4-person demountable air-conditioned buildings
- Various single-storey buildings for supporting facilities including kitchen and dining, amenities, laundry, library, gymnasium, site shop, licenced premises, administration and services, a medical room, cold stores, industrial freezers, storage rooms
- Temporary on-site utilities
- Covered recreational areas
- Car parking

3.4 Quantities of Dangerous Goods

The classes and quantities of DGs are provided in **Table 3-1**. The type of transformer oil is not yet confirmed; hence it is conservatively assumed as a C1 combustible liquid for the purposes of this PHA.

Table 3-1: Maximum Quantities of Dangerous Goods Stored

Area	Class	Description	Quantity
Workers Camp Kitchen	2.1	LPG Bottles	8 x 45 kg
BESS	9	Lithium Batteries	2,430 t
Transformer oil	C1	Combustible liquid	40 kL

4.0 Hazard Identification

4.1 Introduction

A hazard identification table has been developed and is presented at **Appendix A**. This table has been developed following the recommended approach in Hazardous Industry Planning Advisory Paper No. 6, Hazard Analysis Guidelines (Ref. [1]). The Hazard Identification Table provides a summary of the potential hazards, consequences and safeguards at the site. The table has been used to identify the hazards for further assessment in this section of the study. Each hazard is identified in detail and no hazards have been eliminated from assessment by qualitative risk assessment prior to detailed hazard assessment in this section of the study.

In order to determine acceptable impact criteria for incidents that would not be considered for further analysis, due to limited impact offsite, the following approach has been applied:

- *Fire Impacts* - It is noted in HIPAP No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible heat radiation at the site boundary (4.7 kW/m^2) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in a heat radiation less that at 4.7 kW/m^2, at the site boundary, are screened from further assessment.

  Those incidents exceeding 4.7 kW/m^2 at the site boundary are carried forward for further assessment (i.e. frequency and risk). This is a conservative approach, as HIPAP No. 4 (Ref. [2]) indicates that values of heat radiation of 4.7 kW/m^2 should not exceed 50 chances per million per year at sensitive land uses (e.g. residential).

- *Explosion* - It is noted in HIPAP No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible explosion over pressure at the site boundary (7 kPa) above which the risk of injury may occur and therefore the risk must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk, for this study, incidents that result in an explosion overpressure less than 7 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 7 kPa, at the site boundary, are carried forward for further assessment (i.e. frequency and risk).

- *Toxicity* – Toxic by-products of combustion may be generated by a BESS fire; hence, toxicity has been assessed with criteria based upon the Emergency Response Planning Guidelines (ERPG).

- *Property Damage and Accident Propagation* - It is noted in HIPAP No. 4 (Ref. [2]) that a criterion is provided for the maximum permissible heat radiation/explosion overpressure at the site boundary (23 kW/m^2/14 kPa) above which the risk of property damage and accident propagation to neighbouring sites must be assessed. Hence, to assist in screening those incidents that do not pose a significant risk to incident propagation, for this study, incidents that result in a heat radiation heat radiation less than 23 kW/m^2 and explosion over pressure less than 14 kPa, at the site boundary, are screened from further assessment. Those incidents exceeding 23 kW/m^2 at the site boundary are carried forward for further assessment with respect to incident propagation (i.e. frequency and risk).

- *Societal Risk* – HIPAP No. 4 (Ref. [2]) discusses the application of societal risk to populations surrounding the Project. It is noted that HIPAP No. 4 (Ref. [2]) indicates that where a development proposal involves a significant intensification of population, in the vicinity of such a project, the change in societal risk needs to be taken into account. In the case of the project,

there is currently no significant intensification of population around the proposed site; hence, societal risk has not been considered in this assessment.

4.2 Properties of Dangerous Goods

The type of DGs and quantities stored and used at the site has been described in **Section 3**. **Table 4-1** provides a description of the DGs to be stored and handled at the site, including the Class and the hazardous material properties of the DG Class.

Table 4-1: Properties* of the Dangerous Goods and Materials Stored at the Site

Class	Hazardous Properties
2.1 – Flammable Gases	Class 2.1 includes flammable gases which are ignitable when in a mixture of 13 per cent or less by volume with air or have a flammable range with air of at least 12 percentage points regardless of the lower flammable limit. Ignited gas may result in explosion or flash fire. Where gas released under pressure from a hole in a pressurised component is ignited, a jet fire may occur.
9 – Miscellaneous DGs	Class 9 substances and articles (miscellaneous dangerous substances and articles) are substances and articles which, during transport present a danger not covered by other classes. Releases to the environment may cause damage to sensitive receptors within the environment. It is noted that the Class 9s stored within this project are lithium-ion batteries which may undergo thermal runaway (i.e. escalating reaction resulting in heat which ultimately leads to failure of the battery and a fire).
Combustible Liquids	Combustible liquids are typically long chain hydrocarbons with flash points exceeding 60.5°C. Combustible liquids are difficult to ignite as the temperature of the liquid must be heated to above the flash point such that vapours are generated which can then ignite. This process requires either sustained heating or a high-energy ignition source.

* The Australian Code for the Transport of Dangerous Goods by Road and Rail (Ref. [6])

4.3 Hazard Identification

Based on the hazard identification table presented in **Appendix A**, the following hazardous scenarios have been developed:

- LPG release, ignition and fire.
- Li-ion battery fault, thermal runaway and fire.
- Victorian Big Battery fire review.
- Li-ion battery fire and toxic gas dispersion.
- Electrical equipment failure and fire.
- Transformer internal arcing, oil spill, ignition and bund fire.
- Transformer electrical surge protection failure and explosion
- Electromagnetic field impacts.

Each identified scenario is discussed in further detail in the following sections.

4.4 LPG Release, Ignition and Fire

Minor quantities of LPG are to be stored at the workers camp kitchen area in 8 x 45 kg bottles. These bottles are regularly tested and designed to withstand impacts associated with regular transport, filling and handling, hence a release is unlikely. However, should a release occur from a

bottle valve or connected piping for whatever reason, there is potential for a flammable atmosphere to develop which upon exposure to an ignition source may result in a fire. Due to the small quantities involved, a fire is expected to be handled by personnel using first attack firefighting equipment (fire blanket/extinguisher). In the unlikely event that the fire is not controlled and propagates to involve all gas bottles, due to the small quantities present and location of the camp, the resulting fire would not pose an offsite impact. Therefore, this scenario has not been carried forward for further analysis.

4.5 Li-Ion Battery Fault, Thermal Runaway and Fire

Lithium ion (Li-ion) batteries are composed of a metallic anode and cathode which allows for electrons released from the anode to travel to the cathode where positively charged ions in the solute migrate to the cathode and are reduced. The flow of electrons provides the source of energy which is discharged from a battery and used for work. In a Li-ion battery, the lithium metal composites (a composite of lithium with other metals such as cobalt, manganese, nickel, or any combination of these metals) oxidises (loses an electron) becoming a positively charged ion in solution which migrates through the battery separator to the cathode. At the same time, the lost electron travels through the circuit to the cathode. The lithium ions in solution then recombine with the electron at the cathode forming lithium metal within the cathodic metal composite. This process is shown in **Figure 4-1**.

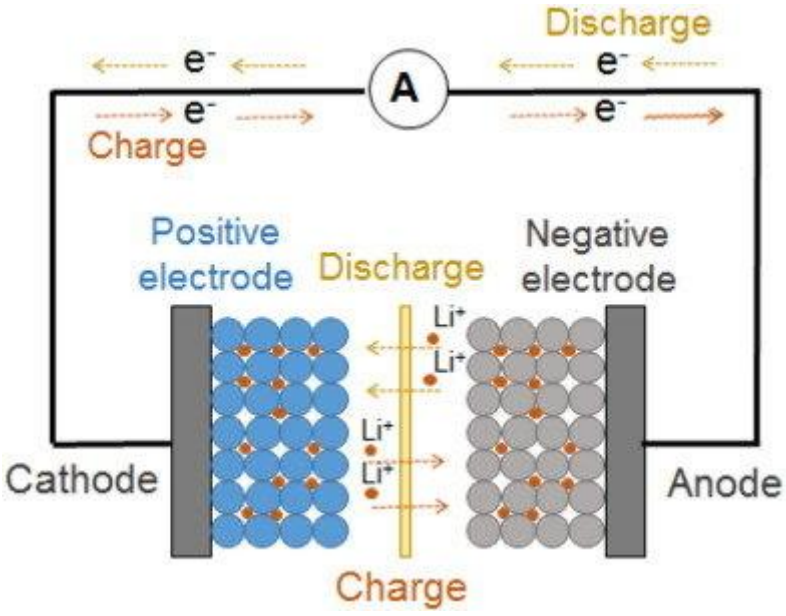


Figure 4-1: Cathode and Anode of a Battery (Source Research Gate)

Initial lithium batteries were designed around lithium metal (i.e. no composite structure) due to the high energy density yielded by the metal. However, when overcharging a battery, lithium ions can begin to plate on the anode in the form of lithium dendrites. Eventually, the dendrites pierce the separator within the battery resulting in a short of the battery which could result in heat, fire, or explosion of the battery. The technology evolved to move away from lithium metal to lithium ions (held within composite materials) which reduced the incidence of lithium dendrites forming resulting in an overall safer battery.

Despite the improvement in battery technology, there are several degradation mechanisms that are still present within the battery which can result in thermal runaway. These include:

- Chemical reduction of the electrolyte at the anode

- Thermal decomposition of the electrolyte
- Chemical reduction of the electrolyte at the cathode
- Thermal decomposition of the cathode and the anode
- Internal short circuit by charge effects

These effects arise primarily as a result of high discharge, overcharging, or water ingress into the battery which results in a host of biproducts being formed within the battery during charge and discharge cycles.

As a result, Li-ion batteries are equipped with several safety features to prevent the batteries from charging or discharging at voltages which result in battery degradation, leading to shorting of the battery and thermal runaway. Safety features generally include:

- Shut-down separator (for overheating)
- Tear-away tab (for internal pressure relief)
- Vent (pressure relief in case of severe outgassing)
- Thermal interrupt (overcurrent/overcharging/environmental exposure)

These features are designed to prevent overcharging or excessive discharge, pressurisation arising from heat generated at the anode or from battery contamination. Protection techniques for Li-ion batteries are standard; hence, the potential for thermal runaway to occur in normal operation is very low with the only exceptions being due to manufacturing faults or battery damage (i.e. battery cell is ruptured as this can short circuit the battery resulting in thermal runaway).

In terms of physical damage, the batteries are contained within in modules which are located within a fenced area; therefore, there is a low potential for damage to occur to the batteries which may initiate an incident.

A review of the batteries proposed to be used as part of this project indicates the battery chemistry is anticipated to be lithium iron phosphate (LiFePO4, or simply LFP) which are considered to be one of the safest battery chemistries within the industry. When exposed to external heat the thermal rise of typical lithium-ion battery chemistries is 200-400 ºC/min resulting thermal run away and fire which can then propagate to adjacent batteries escalating the incident to a full container fire. For LFP batteries, the thermal rise of the batteries at peak is 1.5ºC/min which results in a gradual temperature rise and does not result in fire and thus avoiding incident propagation to other batteries. The thermal rise of various battery chemistries is provided in **Figure 4-2** with a zoomed in temperature rise for LFP provided in the top right of **Figure 4-2**. The stability of the batteries is due to the cathode which does not release oxygen therefore preventing violent redox reactions resulting in rapid temperature rise as the oxygen oxides the electrolyte.

Additional testing for shock and damage to batteries (i.e. nail puncture test) has been shown that LFP batteries when punctured through membranes which typically results in a shorting of the battery does not result in ignition of the battery demonstrating that the battery chemistry is protected against shock damage.

In the event that LFP chemistries do ignite by artificial means, the combustion by products release carbon dioxide which reduces the oxygen concentration within a confined space reducing the combustion rate. Finally, the containers are fitted with fire suppression systems which will activate to suppress and control a fire preventing escalation to other battery units (**Appendix B**).

NMC batteries (nickel-manganese-cobalt) are also considered viable due to their high energy density relative to LFP batteries, however operation of NMC does result in oxygen release, potentially increasing fire risks. For this reason, LFP batteries are advised as the industry standard for safety in lithium-ion battery technology.

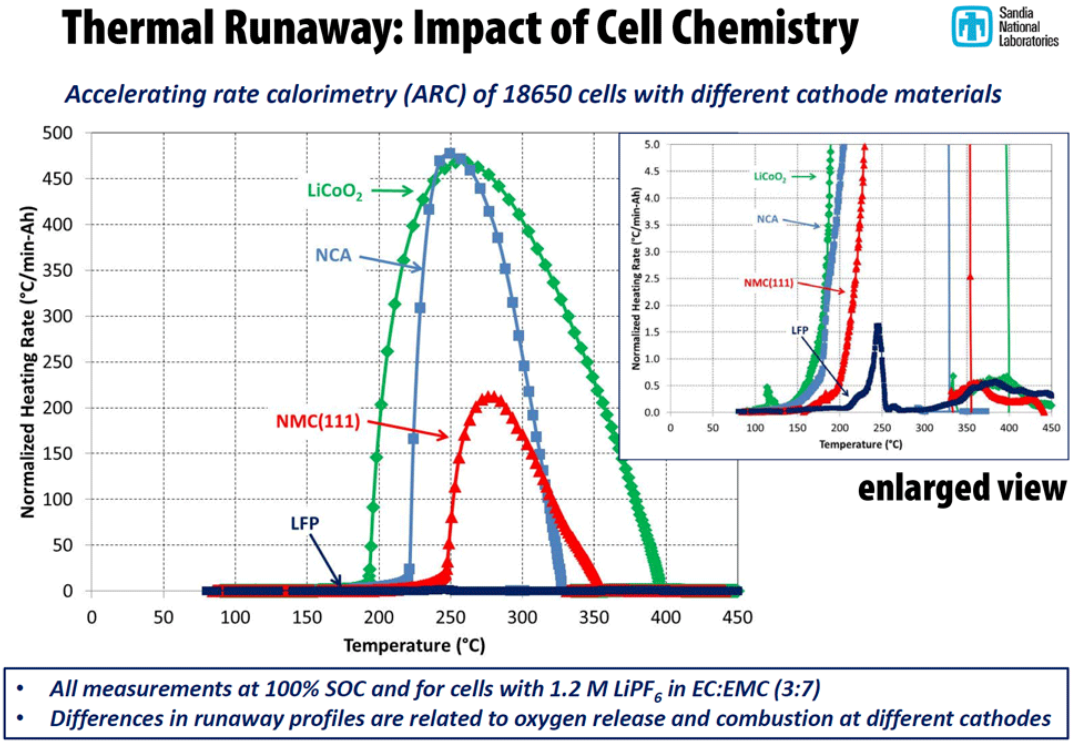


Figure 4-2: Temperature Rise of Lithium-Ion Battery Chemistries (Ref. [7]).

The preliminary battery product considered for the purposes of a preliminary hazard analysis for the project is a BESS with LFP technology. A UL9540A report (test standard report with a systematic evaluation of thermal runaway and propagation in energy storage system at cell, module, unit, and installation levels) has been completed for the module (Model Number LFP71173207/314Ah) used in the containerised battery unit (HiTHIUM LFP314-2P52S) and is attached in **Appendix B**. The testing involved initiating thermal runaway by placing an external heater within a module and heating at a rate of 4 to 7 ºC per minute until cells exhibited 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 was observed. Given these results, propagation between modules and therefore between containerised battery units would not be expected to occur in the selected product. These results align with data shown from UL9540A reports for similar LFP systems. This is attributed to the nature of LFP technology as well as the sheer mass of the battery module (heavier objects have higher thermal capacity). As such, separation between each containerised battery unit is not required to prevent propagation, and the proposed separation distances of approximately 3 m end-to-end and 3.5 m side-to-side is deemed acceptable to allow for operation and maintenance activities.

Although the LFP technology does not cause fire, there can be circumstances where battery modules catch fire due to leaking coolant or electric faults. In those cases, fire will be constrained by the stainless-steel enclosure. Large scale fire testing for similar systems show that generally the container wall remains intact after sustaining heating in a furnace to over 900°C.

Furthermore, each container has multiple built-in fire protection devices that work collaboratively, including smoke and thermal sensors, combustible gas detector, pressure relief system, and aerosol E-Stop buttons. Safety systems include fire and smoke detectors, explosive gas detectors, active ventilation, dry piping for water suppression and 2-hour firewall. Therefore, a container is expected to automatically detect an internal fire in the first instance.

In conclusion, the LFP technology does not cause fire during thermal runaway. Should fire be developed within one BESS container it would not transfer to nearby containers due to the fire safety design features; hence, this incident has not been carried forward for further analysis.

Notwithstanding, based on conversations with and review by NSW Department of Planning, Housing, and Infrastructure (DPHI) on other BESS projects, the following recommendations have been made:

- BESS to be installed in accordance with manufacturer recommended clearances.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the project area whilst meeting the intended clearances.

4.6 Victorian Big Battery Fire Review

Notwithstanding the findings of **Section 4.5**, it is necessary to review recent large scale BESS fires to determine whether similar incidents could occur with the present project.

The present project has thoroughly considered the separation distance considering fire safety, and operation and maintenance. The fire safety assessment is essentially around heat transfer which has been discussed in detail in **Section 4.5**.

The Victorian Big Battery (VBB) experienced a fire in July 2021 which also has a back-to-back layout. According to the independent investigation report on its fire incidence, the back-to-back layout was not the cause for propagation. The main reason for fire propagation was strong wind blowing flames from one Megapack into the unprotected vent atop of an adjacent Megapack which resulted in the ignition of the plastic fan which was able to impact the battery modules directly beneath the fan.

Lessons learnt from the VBB incident results in fire safety precautions on the design of the present project. The vent atop the containers shall be made of metal instead of plastic and covered by a metallic mesh shield. Furthermore, the placement of the fans shall be such that batteries or flammable materials shall not be located directly beneath ventilation openings. To ensure the above are captured the following recommendations have been made:

- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.

Based upon the designs incorporated with the container based upon the VBB fire, the available area assessment and the separation distance assessment, it is considered that the propagation between two units is considered unlikely; hence, this incident has not been carried forward for further analysis.

4.7 Li-ion Battery Fire and Toxic Gas Dispersion

If a BESS failure occurs resulting in a fire, toxic biproducts of combustion may form. A literature review was conducted on lithium-ion battery fires to identify the toxic gases which may be generated in the event of a fire. The review identified the following gases or classes of gases can form:

- Carbon dioxide;
- Carbon monoxide; and
- Fluorine gases.

Each of these have been discussed in further detail in the following subsections.

4.7.1 Carbon Dioxide

Carbon dioxide is a colourless, odourless, dense gas which is naturally forming and is present in the atmosphere at concentrations around 415 ppm (0.0415%). At low concentrations carbon dioxide is physiologically impotent and at low concentrations does not appear to have any toxicological effects. However, as the concentration grows it increases the respiration rate with short term Exposure Limit (STEL) occurring at 30,000 ppm (3%), above 50,000 ppm (5%) a strong respiration effect is observed along with dizziness, confusion, headaches, and shortness of breath. Concentrations in excess of 100,000 ppm (10%) may result in coma or death.

Carbon dioxide is a by-product of combustion where hydrocarbon or carbon-based materials are involved. A typical combustion reaction producing carbon from a hydrocarbon has been provided in **Equation 4-1**. This reaction proceeds when there is an excess of oxygen to the fuel being consumed and is known as complete combustion as it is the most efficient reaction pathway.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3Co_2(g) + 4H_2O(g)$$ **Equation 4-1**

The lithium-ion batteries are predominantly composed of metal structures. However, during a fire event ancillary equipment and materials within the batteries will be involved in the fire including wiring, plastics, anodes, etc. which will liberate carbon dioxide. However, a review of the toxicological impacts indicates high concentrations would be required to result in injury or fatality. Based upon a review of the sensitive areas, and the similar BESS fires (i.e. Victoria BESS fire), it is not considered that the formation of carbon dioxide in a fire would be sufficient to result in downwind impacts sufficient to cause injury or fatality. In other words, there would be insufficient production of carbon dioxide to generate a plume of sufficient concentration to displace the required oxygen for a significant downwind consequence to occur. Therefore, this incident has not been carried forward for further analysis.

4.7.2 Carbon Monoxide

Carbon monoxide is an odourless, colourless gas which is slightly denser than air and occurs naturally in the atmosphere at concentrations around 80 ppb. Carbon monoxide is a toxic gas as it irreversibly binds with haemoglobin which prevents these molecules from carrying out the function of oxygen / carbon dioxide exchange. The loss of 50% of the haemoglobin may result in seizures, coma or death which can occur at concentration exposures of approximately 600 ppm (0.06%).

Carbon monoxide is by-product of combustion if there is insufficient oxygen to enable complete combustion. The reaction pathway for the formation of carbon monoxide is provided in **Equation 4-2**.

$$2C_3H_8(g) + 7O_2(g) \rightarrow 6CO(g) + 8H_2O(g)$$ **Equation 4-2**

As noted, in **Section 4.7.1** there is the potential for a fire to occur with the BESS units which could form carbon monoxide if there is insufficient oxygen to sustain complete combustion. However, it is noted that the combustible load within the BESS which could result in the formation of carbon monoxide is relatively low compared to the available oxygen in the surrounding atmosphere. Therefore, it is considered that the formation of carbon monoxide at levels which would result in a substantial downwind impact are not considered credible and subsequent analysis of, this incident is not required.

4.7.3 Fluoride Gases

The electrolyte used in Li-ion batteries typically is lithium hexafluorophosphate ($LiPF_6$) or other li-salts containing fluorine. In the event of a thermal runaway, the electrolyte will expand and be vented from the battery. In the event of a fire, the vented gas and other components such as the polyvinylidene fluoride binders may form gases such as hydrogen fluoride (HF), phosphorous pentafluoride (PF_5) and phosphoryl fluoride (POF_3) (Ref. [8]).

The decomposition of $LiPF_6$ can be promoted by the presence of water / humidity according to reactions **Equation 4-3** to **Equation 4-5**.

$$LiPF_6 \rightarrow LiF + PF_5$$ **Equation 4-3**

$$PF_5 + H_2O \rightarrow POF_3 + 2HF$$ **Equation 4-4**

$$LiPF_6 + H_2O \rightarrow LiF + POF_3 + 2HF$$ **Equation 4-5**

Of the fluorine gases formed, PF_5 is a short-lived gas while POF_3 is a reactive intermediate. Thermal destruction of a several battery chemistry, configurations and State of Charge (SOC) indicated the vast majority of these did not produce observable POF_3 with the only observance occurring in a specific battery chemistry at 0% SOC (Ref. [8]). Therefore, the main fluorine gas of concern in a Li-ion battery fire is HF.

HF gas is hydroscopic readily dissolving into water vapour / humidity or moisture in airways forming hydrofluoric acid. Hydrofluoric acid is a weak acid although is highly corrosive and may result in chemical burns. In addition, it is calcium scavenging. Hence, it will readily bind with calcium in cells and tissues disrupting the nerve signalling. The immediately dangerous to life or Health (IDLH) for HF is 30 ppm and the 10-minute lethal concentration is 170 ppm.

For a toxic gas dispersion, a battery container fire is necessary as the initiating event. As discussed in **Section 4.4** the potential for a fire to occur is considered negligible due to the highly stable and safe battery chemistries used. Therefore, a toxic gas dispersion impacting sensitive receptors is not deemed a credible scenario and this incident has not been carried forward for further analysis.

4.8 Electrical Equipment Failure and Fire

Electrical equipment is located within the switch room which may fail resulting in overheating, arcing, etc. which could initiate a fire. In the event of a fire, it may begin to propagate to adjacent combustible materials (i.e. wiring). It is noted that electrical equipment fires typically start by smouldering before flame ignition occurs resulting in a slow fire development.

The type of equipment used within the Project is ubiquitous throughout the world and across industry segments and is therefore not a unique fire scenario. Based upon fire development within

switch rooms the fire would be considered to be relatively slow in growth and would be unlikely to result in substantial impacts in terms of offsite impact or incident propagation. Therefore, this incident has not been carried forward for further analysis.

4.9 Transformer Internal Arcing, Oil Spill, Ignition and Bund Fire

Transformers contain oil which is used to insulate the transformers during operation. If arcing occurs within the transformer (e.g. due to a low oil level), the high energy passing through the coolant vaporises the oil into light hydrocarbons (methane, ethane, acetylene, etc.) resulting in rapid pressurisation within the reservoir. It is noted that non-mineral oil is to be used with a high flashpoint (KNAN ester-based oil) which provides an increased safety margin, however arcing may still provide sufficient energy to vaporise this oil.

Notwithstanding the protection systems, if the pressure rise exceeds the structural integrity of the reservoir, and the installed pressure relief devices, the reservoir can rupture allowing the release of oil into the bund. The rupture also allows oxygen to enter the reservoir. The temperature of the gases is anticipated to be above the auto ignition point, but this does not occur until oxygen is present. When oxygen enters the reservoir, the gases auto ignite which generates sufficient heat to ignite the oil in the bund.

Notwithstanding this, transformers are ubiquitous units with a low potential for failure and every transformer is to be self-bunded on a skid or have a concrete bund, limiting the spread of an oil pool fire. Additionally, the separation distance to the site boundary and other adjacent units would be unlikely to result in incident propagation and offsite impacts. Nevertheless, it has been decided to quantitatively determine the risk of such a fire, hence this incident has been carried forward for further analysis.

4.10 Transformer Electrical Surge Protection Failure and Explosion

Transformers generate large amounts of heat as a result of the high electrical currents that pass through them; hence, as described in **Section 4.8**, oil is used as an insulating material within the transformers to protect the mechanical components. However, if the transformer gets an extreme surge of energy, such as that which could occur due to a lightning strike, and the electrical surge protection measures fail, the ester oil may start to decompose and vapourise, resulting in flammable gas bubbles including hydrogen and methane (Ref. [9]) at temperatures above the autoignition of the gases.

The formation of gases will increase the pressure within the transformer which can result in the transformer structure rupturing which allows the ingress of oxygen. As the oxygen enters, the concentration of flammable gases falls within the explosive limits which are above their autoignition temperatures which ignite resulting in increased formation of hot gaseous products resulting in an explosion. The explosion may generate significant overpressure, sparks and fire and would result in a whole transformer fire, as discussed in **Section 4.9**.

In order to protect against overheating and explosions, transformers generally have surge protection devices which shunt electrical surges safely to ground. However, this surge detection and protection devices are not universally installed nor do they protect against all events such as in the case of a major lightning strike or significant oil deterioration, leakage of water into the transformer, and physical damage such as a fallen tree (Ref. [10]). Therefore, while transformers are ubiquitous units with a low potential for failure, there is the potential for an explosion to occur

which may result in offsite impacts. Hence, this incident has been carried forward for further analysis.

4.11 Electromagnetic Field Impacts

4.11.1 Introduction

Electric and Magnetic Fields (EMFs) are associated with a wide range of sources and occur both naturally as well as man-made. Naturally occurring EMFs, occurring during lightning storms, are generated from Earth's magnetic field. Man-made EMFs are present wherever there is electricity; hence, EMFs are present in almost all built environments where electricity is used.

Extremely low frequency (ELF) electric and magnetic fields (EMF) occupy the lower part of the electromagnetic spectrum in the frequency range 0-3,000 Hz which is the current will change direction 0-3,000 times a second. ELF EMF result from electrically charged particles. Artificial sources are the dominant sources of ELF EMF and are usually associated with the generation, distribution and use of electricity at the frequency of 50 Hz in Australia. The electric field is produced by the voltage whereas the magnetic field is produced by the current.

BESS create EMFs from operational electrical equipment, such as transmission lines, transformers and the electrical components found within BESS units, inverters, etc. This equipment has the potential to produced ELF EMF's in the range of 30 to 300 Hz.

4.11.2 Existing Standards

There are currently no existing standards in Australia for governing the exposure limits to ELF EMFs; however, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) has provided some guidelines around exposure limits for prolonged exposure which limits the exposure to 2,000 milligauss (mG) for members of the public in a 24 hour period (Ref. [11]).

Table 4-2 provides typical magnetic field measurements and ranges associated with EMF sources. It is noted that electric fields around devices are generally close to 0 due to the shielding provided around the equipment. In addition, EMF levels drop away quickly with distance; hence, while a value may be measurable at the source, within a short distance the EMF is undetectable.

Table 4-2: EMF Sources and Magnetic Field Strength

Source	Typical Measurement (mG)	Measurement Range (mG)
Television	1	0.2 – 2
Refrigerator	2	2 – 5
Kettle	3	2 – 10
Personal computer	5	2 – 20
Electric blanket	20	5 – 30
Hair dryer	25	10 – 70
Distribution powerline (under the line)	10	2 – 20
Transmission power line (under the line)	20	10 – 200
Edge of easement	10	2 – 50

4.11.3 Exposure Discussion

A review of the site indicates there are no immediate residences adjacent to the area where the BESS will be developed providing substantial distance for attenuation of EMFs. Based upon the typical levels which may be generated by transmission equipment the cumulative effect would not exceed the 2,000 mG limit for prolonged exposure. In addition, the closest residence is over 1,400 m away from the EMF generating sources at the BESS; hence, the potential for the EMF to exceed the accepted levels is considered negligible.

As the potential for exposure to EMF exceeding the international guidelines is negligible, this incident has not been carried forward for further analysis.

5.0 Conclusion and Recommendations

5.1 Conclusions

A hazard identification table was developed for Mayfair Solar Farm & BESS project to identify potential hazards that may be present at the site as a result of operations or storage of materials. Based on the identified hazards, scenarios were postulated that may result in an incident with the potential for offsite impacts. Postulated scenarios were discussed qualitatively and any scenarios that would not impact offsite were eliminated from further assessment. Scenarios not eliminated were then carried forward for consequence analysis.

A review of the incidents carried forward for further analysis indicates that there were no observed offsite impacts; therefore, based on the analysis conducted, it is concluded that the risks at the site boundary are not considered to exceed the acceptable risk criteria; hence, the project would only be classified as potentially hazardous and would be permitted within the current land zoning for the site.

5.2 Recommendations

The following recommendations have been made as a result of the analysis:

- BESS to be installed in accordance with manufacturer recommended clearances based on testing.
- BESS to be installed with fire protection systems specified by the manufacturer and UL9540A report.
- Before construction, detailed design to validate the system can be installed in the project area whilst meeting the recommended clearances.
- The vent covers of the BESS shall be constructed of non-combustible material.
- The vents shall not be located above battery packs within the BESS container.

6.0 References

[1] Department of Planning, Industry and Environment, “Hazardous Industry Planning Advisory Paper No. 6 - Guidelines for Hazard Analysis,” Department of Planning, Industry and Environment, Sydney, 2011.

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[6] Power Tech Systems, “Safety of Lithium-Ion batteries,” Power Tech Systems, 2022. [Online]. Available: https://www.powertechsystems.eu/home/tech-corner/safety-of-lithium-ion-batteries/. [Accessed 13 April 2022].

[7] F. Larson, P. Andersson, P. Blomqvist and B.-E. Mellander, “Toxic fluoride gas emissions from lithium ion battery fires,” Nature: Scientific Reports, 2017.

[8] Y. F. K. L. H. Y. Y. Z. G. W. Bo Gao, “Molecular dynamics study on thermal decomposition characteristics of synthetic ester oil,” *Chemical Physics Letters,* vol. 813, 2023.

[9] P. Hoole, S. Rufus, N. Hashim, M. Saad, S. Abdullah, A. Othman, K. Piralaharan, A. CV and S. Hoole, “Power Transformer Fire and Explosion: Causes and Control,” *International Journal of Control Theory and Applications,* vol. 10, no. 16, pp. 211-219, 2017.

[10] International Commission on Non-Ionizing Radiation Protection, “ICNIRP Guideline for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1-100 Hz),” International Commission on Non-Ionizing Radiation Protection, 2010.

[11] Standards Australia, “AS/NZS 3000:2007 - Wiring Rules,” Standards Australia, Sydney, 2007.

Appendix A

Hazard Identification Table

Appendix A

A1. Hazard Identification Table

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
Workers Camp Kitchen	• Release from LPG bottles	• Ignition and fire	• Minor storage quantities • First attack fire fighting equipment to be available
Battery Storage	• Failure of Li-ion battery protection systems	• Thermal runaway resulting in fire or explosion • Incident propagation through battery cells • Toxic smoke dispersion	• Batteries are tested by manufacturer prior to sale / installation • Overcharging and electrical circuit protection • Battery monitoring systems • Batteries composed of subcomponents (i.e. BBU, cells) reducing risk of substantial component failure • Batteries are not located in areas where damage could easily occur (i.e. within the fenced property) • Electrical systems designed per AS/NZS 3000:2018 (Ref. [11]) • CATL EnerOne cooling • Aerosol fire suppression • UL9540A testing
Switch rooms, communications, etc.	• Arcing, overheating, sparking, etc. of electrical systems	• Ignition of processors and other combustible material within servers and subsequent fire	• Fires tend to smoulder rather than burn • Isolated location • Switch room separation from other sources of fire
Transformers	• Arcing within transformer, vaporisation of oil and rupture of oil reservoir	• Transformer oil spill into bund and bund fire	• Bunded • Isolated location
	• Power surge to transformers (e.g. from lightning)	• Major failure of surge protection in transformer, vapourisation of oil, ignition and explosion	• Transformers have surge protection system to shut down upon detection of extreme energy input • Lightning protection to prevent lightning strikes impacting transformers

Area/Operation	Hazard Cause	Hazard Consequence	Safeguards
			• Control of ignition sources – no smoking / open flames around the transformers • KNAN high flash point ester-oil • Isolated location
EMF	• Electric and magnetic equipment	• Generation of ELF EMF and injury / nuisance to surrounding area	• Large separation distances allow for attenuation of EMFs • Cumulative impacts from equipment below acceptable thresholds. • Low occupancy density within vicinity of the development

Appendix B

Supporting Information

Fire Protection System of ESS Container

1. Introduction

This document describes the layout and the control logic of various fire protection systems in the ESS container (INF5015K050PG1-EU).

Xiamen Hithium Energy Storage Technology Co., Ltd. (“Hithium’) offers this document as the standard limited document. The content of this document is supposed to be checked and updated when necessary. Please contact Hithium or your distributors for the latest version.

2. Layout and Descriptions

The fire protection system is designed following the NFPA855 installation standard for stationary energy storage system.

The fire protection system includes FACP (Fire alarm control panel), automatic alarm system, ventilation system, aerosol fire extinguishing system and water spray system (Optional).

The ESS container enclosure plates are three-layer structure composed of double steel plate and fireproof rock wool, and the fire resistance rating is greater than 1h.

The interior and exterior decoration materials are all flame retardant materials, and the fire protection grade of the materials is UL94-V0. The combustible gas concentration reduction system is provided with a minimum of 2 hours of standby power according to NFPA 855-2023 section 9.6.5.6.7 (3). The gas detection system is provided with a minimum of 24 hours of standby power and 2 hours in alarm according to NFPA 855-2023 section 9.6.5.6.7 (4).

A secondary power supply is provided for smoke and fire detection systems in accordance with NFPA 72 capable of 24 hours in standby and 2 hours in alarm according to NFPA 855-2023 section 4.8.3.

Table2-1 Introduction of fire protection system button

No.	Item	Quantity	Function
1	Ventilation system emergency start/stop button	1	Manually Start or Stop the Fan.
2	Manual release button	1	When a fire has occurred, aerosol can be manually released.
3	Fire protection emergency stop button	1	During the delay release period, it can abort the execution of the firefighting operation.

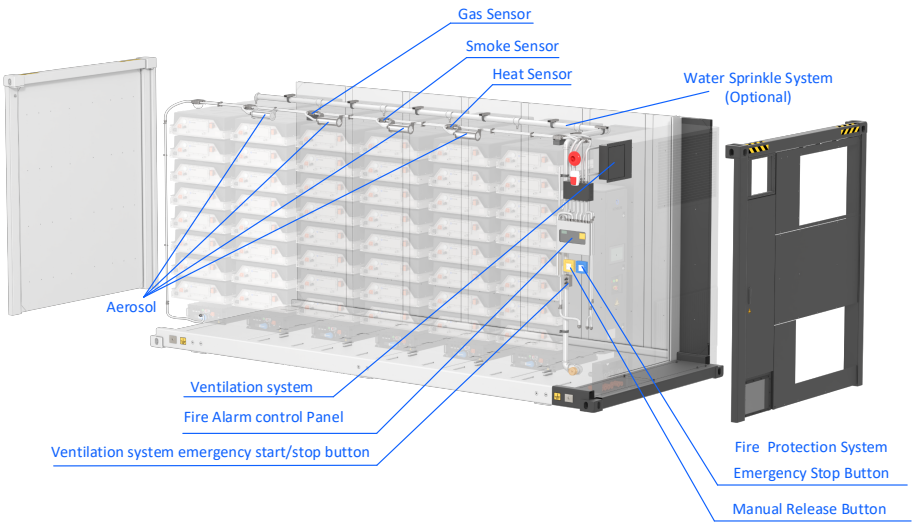


Fig 2-1 Fire Protection System

2.1. Automatic Alarm System

The automatic alarm system is mainly composed of FACP, heat detector, smoke detector, alarm bell, horn/strobe, fire protection emergency stop button and manual release button.

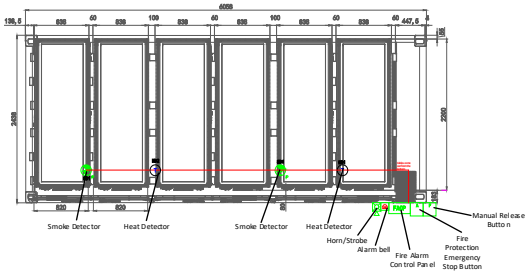


Fig 2-2 Automatic Alarm System

2.2. Ventilation System

The ventilation system mainly consists of combustible gas detector, fan controller, air inlet electric shutter and exhaust fan.

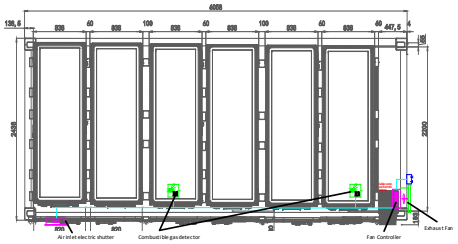


Fig 2-3 Air Inlet and Exhaust System

2.3. Aerosol Fire Extinguishing System

The aerosol fire extinguishing system is mainly composed of 4 aerosols.

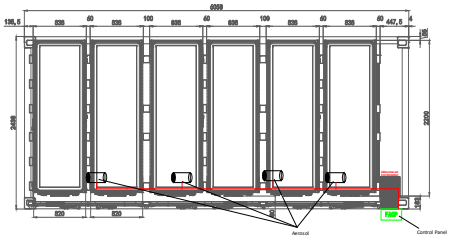


Fig 2-4 Aerosol Fire Extinguishing System

2.4. Water Spray System

The water spray system is mainly composed of sprinklers and pipes.

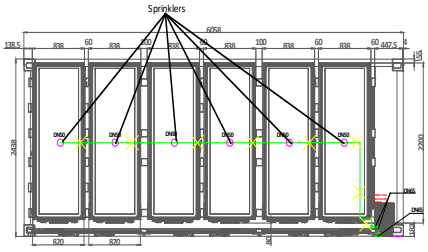


Fig 2-5 Water Spray System

DN65 quick connector shall be reserved for connecting outdoor fire hydrant or fire truck.

2.5. Fire Protection System Diagram

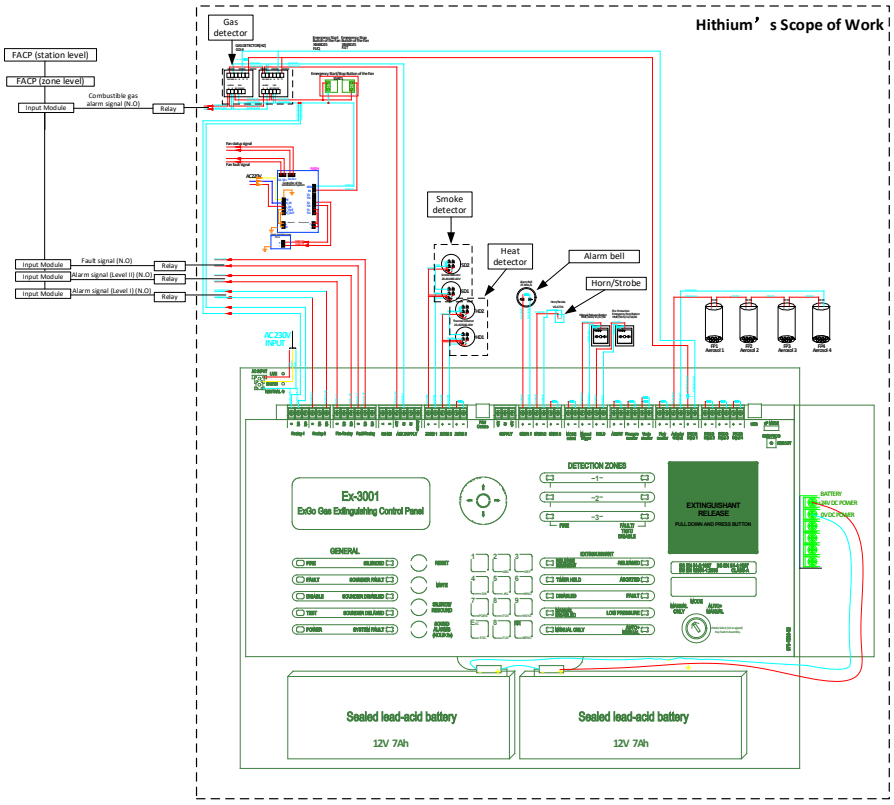
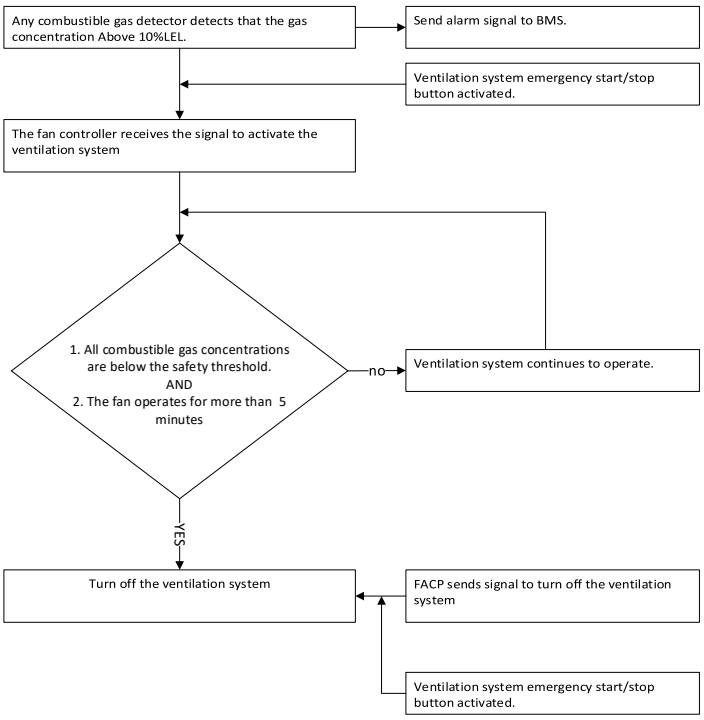


Fig 2-6 Fire Protection System Diagram

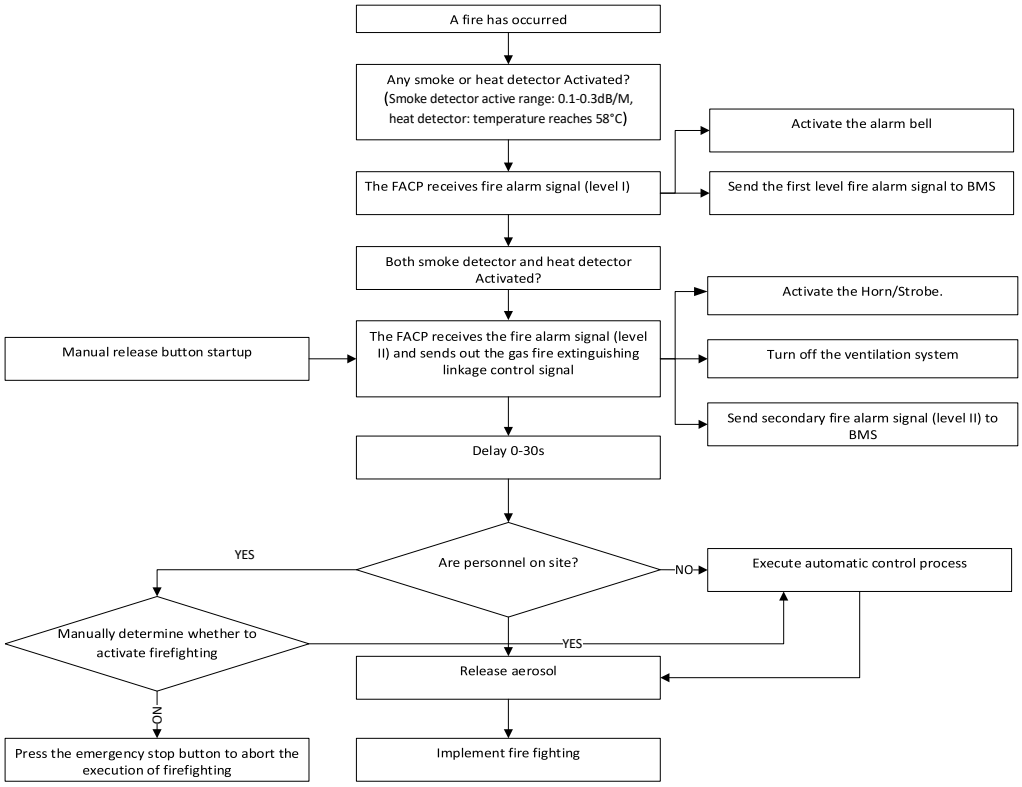
As shown above, four of dry contact output signals will be exported from the ESS fire protection system, which include Alarm signal (level I), Alarm signal (level II), Fault signal and Combustible gas alarm signal. These four signals shall be transmitted to the input modules in the ESS container, and then connects to the station level FACP/zone level FACP (for large projects) for communications.

3. Control Logic of Fire Extinguishing Process

3.1. Control Logic of Air Inlet and Exhaust System



3.2. Control Logic of Automatic Fire Protection System



4. Configuration List

No	Item	Unit	Quantity	Compliance
1	Fire alarm control panel	pcs	1	EN 54-2, EN 54-4, EN 12094-1, EN 12094-3
2	Battery	pcs	2	EN 61056
3	Smoke detector	pcs	2	EN 54-7
4	Heat detector	pcs	2	EN 54-5
5	Detector base	pcs	4	EN 54
6	Fire protection emergency stop button	pcs	1	EN 12094-3
7	Manual Release Button	pcs	1	EN 12094-3
8	Horn/Strobe	pcs	1	EN 54-3
9	Alarm bell	pcs	1	EN 54-3
10	Aerosol	pcs	4	EN 15276
11	Aerosol bracket	set	4	N/A
12	Hydrogen detector (H_2)	pcs	2	EN 50270:2015
13	Electric ventilation louver	set	1	EN 55014-1
14	Exhaust fan	set	1	EN IEC 60079
15	Ventilation system emergency start/stop button	pcs	1	EN 60947-5-1
16	Sprinkler	pcs	6	EN 12259-1
17	Installation accessories	Set	1	N/A

Xiamen Hithium Energy Storage Technology Co., Ltd.
201-2, 5# Comprehensive Building, No.11, Butang Middle Road, Torch High-Tech (Tongxiang) Industrial base, Tong'an District, Xiamen, China
T: +86 0592-6050365
E: hithium@hithium.cn
Web: www.hithium.com

∞ BLOCK

HITHIUM

BESS Container 5.015 MWh

Liquid-cooled battery storage system

Preliminary

Liquid-cooled battery storage system based on HiTHIUM prismatic LFP BESS Cells 314 Ah with highest cyclic lifetime.

Improved safety characteristics and specially optimised for the highest requirements on safety, reliability and performance. Suitable e.g. for industrial, utility, and grid serving applications.

- Product certifications:
  IEC 62619, IEC 62477, IEC 63056, IEC 61000, UL 1973, UL 9540A, UN 38.3
- Company certifications:
  ISO 9001, ISO 14001, ISO 45001
- Environmental Compliance:
  ROHS, REACH

High safety

- High thermal stability thanks to liquid cooling
- Multi-stage, active fire protection system, compliance to NFPA 855
- Use of highly safe prismatic HiTHIUM LFP cells
- Dedicated cell monitoring and protection system

Low LCOS (Levelised Cost of Storage)

- Excellent thermal management improves energy throughput by ensuring optimal operating temperature
- Highly integrated: including thermal management system, fire protection system, BMS, etc.
- Very high energy density using dual channel compact module technology (DCCM)
- Supports back to back and side by side installations

BESS **Container**
5.015 MWh

Liquid-cooled battery storage system based on prismatic LFP cells with very high cyclic lifetime

GENERAL	
Battery Type	HiTHIUM LFP314-2P52S
No. of Battery Modules	48 (6 x 8) with DCCM Technology
Configuration	12P416S
Cooling Method	Liquid Cooling
BMS Communication	CAN, RS485, Ethernet
Gravimetric	> 111 Wh/kg
Volumetric	> 117 Wh/l
Application Altitude	≤ 4,000 m

ELECTRICAL	
Nominal Voltage Container	1,331.2 V
Operating Voltage Container	1,040 … 1,497.6 V
Nominal Energy Container	5,015.96 kWh [1, 2]
Nominal SOC at delivery	27 % [2]
Nominal Charge/Discharge Rate	0.5 P / 0.5 P
Round Trip Efficiency	> 94 %

[1] 0.5 P / 0.5 P
[2] 25°C +/- 2.0
[3] ambient temperature

MECHANICAL	
Dimensions (L x W x H)	6,058 x 2,438 x 2,896 mm
Weight Container (20 ft.)	< 45,000 kg
Protection Level	IP 55

TEMPERATURE RANGE	
Operating	-30 °C … 55 °C [3]
Storing (recommended)	-20 °C … 35 °C [3]

PRODUCT CERTIFICATIONS	
Certificates and Reports	IEC 62619, IEC 62477, IEC 63056, IEC 61000, UL 1973, UL 9540A, NFPA 855, UN 38.3

ENVIRONMENTAL	
Compliance	ROHS, REACH
	Cobalt free

COMPANY CERTIFICATIONS
ISO 9001, ISO 14001, ISO 45001

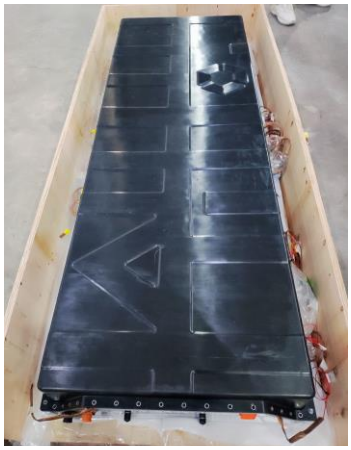
HiTHIUM Energy Storage Technology USA Inc.
Address: 4046 Clipper Ct, Fremont, CA 94538, United States
Email: hithium@hithium.com

Xiamen HiTHIUM Energy Storage Technology Co., Ltd.
Address: HiTHIUM Industrial Park, Tongxiang High-Tech Zone, Xiamen, Fujian, China | Email: hithium@hithium.com

LinkedIn Website

Prüfbericht-Nr.: *Test report no.*:	**CN23XXY9 003**	**Auftrags-Nr.:** *Order no.*:	168449171	Seite 1 von 37 *Page 1 of 37*
Kunden-Referenz-Nr.: *Client reference no.:*	2347845	**Auftragsdatum:** *Order date:*	2023-12-16	
Auftraggeber: *Client:*	**Xiamen Hithium Energy Storage Technology Co., Ltd.** No.1 Benyuan Road, Tongxiang High - Tech Zone, Xiamen, Fujian, China			
Prüfgegenstand: *Test item:*	Lithium iron phosphate battery module			
Bezeichnung / Typ-Nr.: *Identification / Type no.:*	LM010401-A			
Auftrags-Inhalt: *Order content*:	Test Report			
Prüfgrundlage: *Test specification:*	UL 9540A: 2019 (Fourth Edition)			

Wareneingangsdatum: *Date of sample receipt:*	2023-12-16
Prüfmuster-Nr.: *Test sample no:*	A003672973-001
Prüfzeitraum: *Testing period:*	2024-01-08 - 2024-01-10
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



erstellt von: *created by:*		**genehmigt von:** *authorized by*:	
Datum: *Date:* 2024-05-11	Jason Zhu	**Ausstellungsdatum:** *Issue date:* 2024-05-11	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: **Prüfmuster vollständig und unbeschädigt**
Condition of the test item at delivery: ***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

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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: 2024.01.09 to 2024.01.10

Refer to Clause 3 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

Description of changes:

1. Updated the Figures 12 to 16, detail see page 23 to 31.

Change	Testing	Comment
1	N/A	No additional test necessary.

History of amendments and modifications:

Ref. No. CN23XXY9 001, dated 2024-03-11(original test report)

Ref. No. CN23XXY9 002, dated 2024-04-24(1st amendment)

Ref. No. CN23XXY9 003, dated 2024-05-11(2st amendment)

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 675.0kg (before test) and 674.5kg (after test).

Measured peak chemical heat release rate HRR was 22.70kW.

Measured total heat release through the test THR was 97.90MJ.

Measured peak smoke release rate SRR was 0.821m^2/s.

Total smoke release TSR was 118.0m^2

Total hydrocarbons gas was 101.04L.

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

2.2.1 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):	5.60±0.20
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):	2.5(T>0°C) 2.0(T≤0°C)
Maximum continuous charge current (A):	314(25°C±2°C)	
Maximum continuous discharge current (A):	314(25°C±2°C)	
Compliance with UL 1973:	☒ Yes TUV Report No.: CN23RGEH 001 ☐ No	

2.2.2 Cell level test information

Cell level thermal runaway test information is copy from TUV Rheinland UL 9540A cell level test report No.: CN23F118 001

Thermal Runaway Methodology:	External heater applied on one side of the cell with surface heating rate at about of 5°C per minute until thermal runaway triggered.
Average Cell Surface Temperature at Gas Venting:	203.7°C
Average Cell Surface Temperature Start Thermal Runaway:	295.7°C

2.2 Module

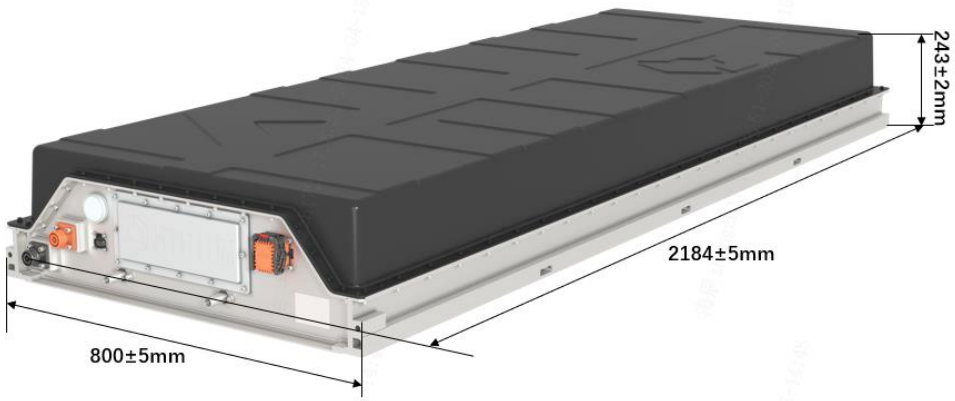
2.2.1 Product information and parameters

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:	LM010401-A	
Physical configuration:	Metal base, the other sides are non-metallic material. A mica plate is installed under the top enclosure.	
	Weight:	667 ±10 kg
	Cells in series/parallel:	2P52S
Cooling method:	Liquid cooling	
Separation between cells:	Thermal insulation sheet: Aerogel Heat insulation pad and Polyurethane foam, see Figure 4 for install location details.	
Electrical rating:	Rated capacity:	628 Ah
	Nominal voltage:	166.4Vdc
Standard charge method:	Charge power:	52.25KW
	End of charge:	The highest cell voltage reaches 3.65 V
Standard discharge method:	Discharge power:	52.25KW
	End of discharge:	The lowest cell voltage reaches 2.5 V
Compliance with UL 1973:	☐ Yes	☒ No

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.

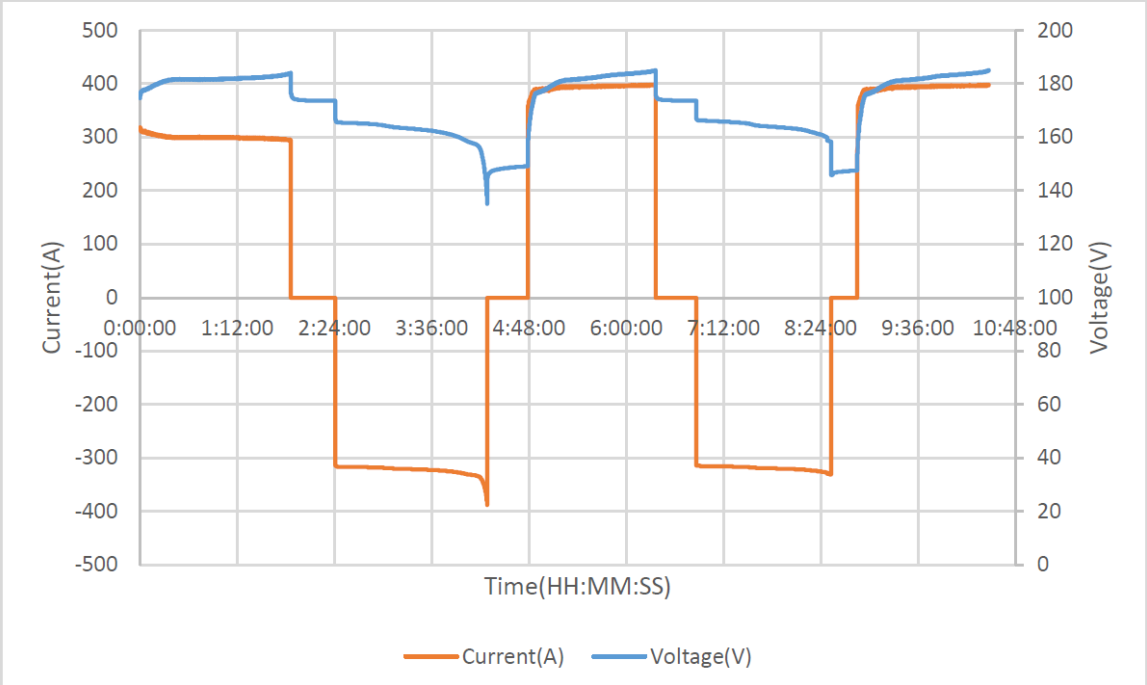
3.2 Sample preparation

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 104 cells 2P52S. All cells in the pack were numbered from #1-1 to #1-26, #2-1 to #2-26, #3-1 to #3-26, #4-1 to #4-26 as below.

External heating method was used to initiate thermal runaway in the module. One metal heater was fitted on cell (rated 220V ac/1000 W, size 190*160).

Total 11 thermocouples (type K, 24AWG) were attached at the center of the wider side surface of cell and below the hater film in the module. See Figure 3 and Figure 4 for the detail locations.

Voltage of the module was monitored during test.

Figure 3 Internal view of module

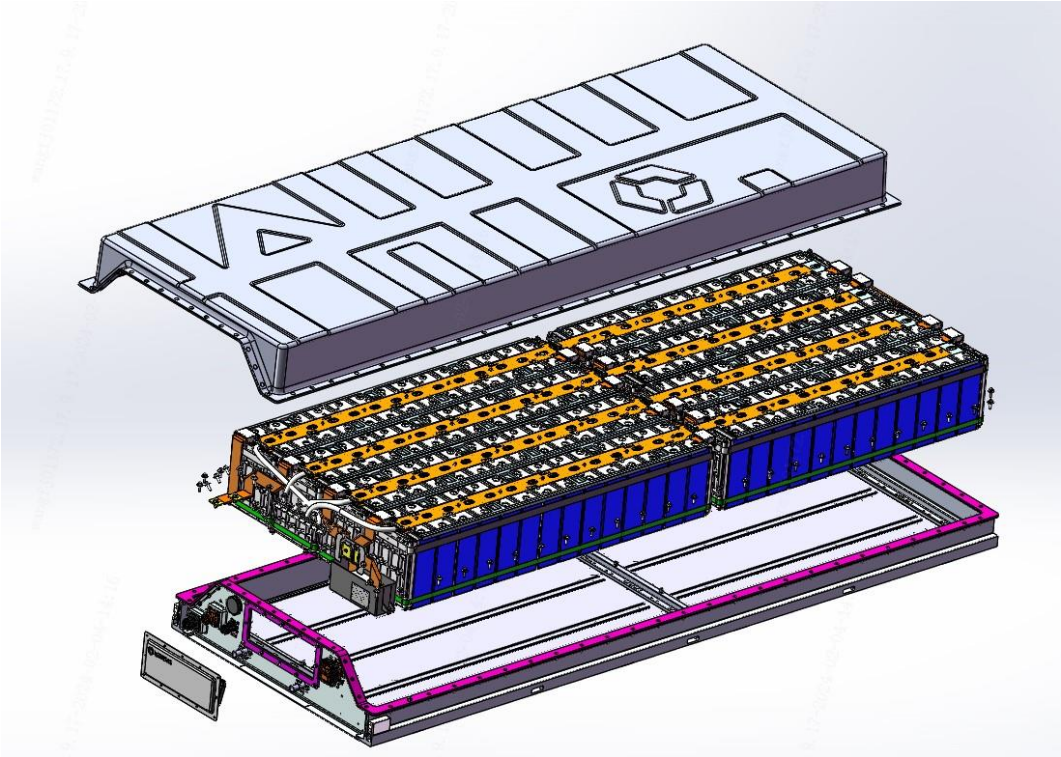


Figure 4 Cell number, location of heater, thermal insulation sheet (Aerogel Heat insulation pad and Polyurethane foam) and thermocouple

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.

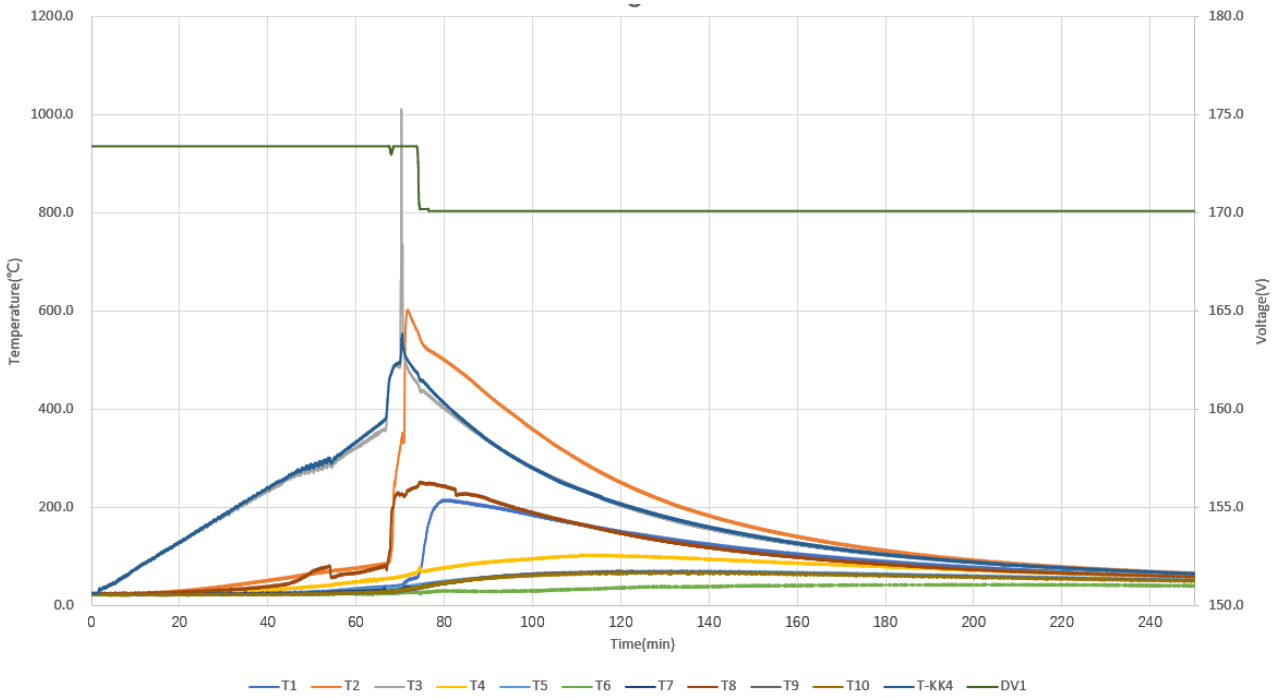
The initiating cells were heated at a rate of 4°C to 7°C per minute until the cell thermal runaway. Once the measured temperature exceed the set heating rate, the heaters were immediately de-energized.

3.3.2 Observations and records

Ambient conditions at the initiation of the test	:	21.2°C, 62% R.H.
Sample number	:	A003672973-001
Open circuit voltage before test (V)	:	173.4
Weight before test (kg)	:	675.0
Time initiating the test	:	2024.01.09 11:30:56
Observations during test	:	The first thermal runaway cell (#1-10) and smoke release at 12:38. The second thermal runaway cell (#1-9) at 12:41. 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 (#1-9 to #1-10) went into thermal runaway during test. one cell (#1-9) went into thermal runaway by cell to cell propagation.
Open circuit voltage after test (V)	:	170.1
Weight after test (kg)	:	674.5
Weight loss (kg)	:	0.5

3.3.3 Temperature measurements

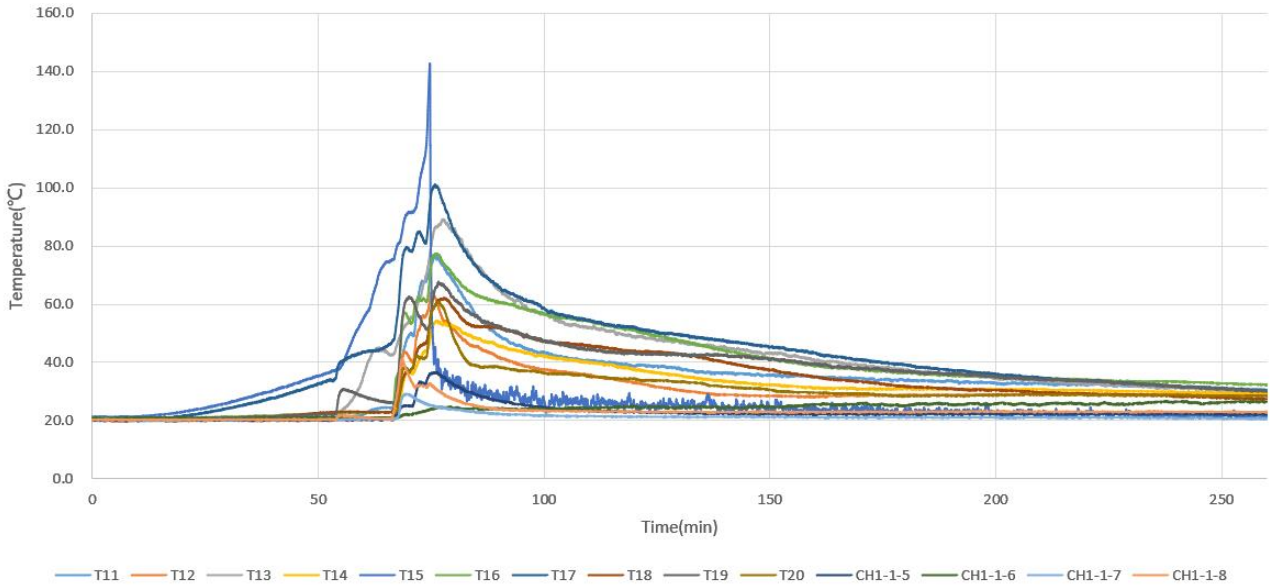
Figure 5 The cells temperature and module voltage VS time curve



Thermocouple no.	Location	Maximum temp. °C
T1	Surface of cell #1-8	214.0
T2	Surface of cell #1-9	601.7
T3	Surface of cell #1-10	1010.4
T4	Surface of cell #1-11	102.3
T5	Surface of cell #1-12	70.4
T6	Surface of cell #1-13	42.3
T7	Surface of cell #2-9	67.4
T8	Surface of cell #2-10	251.3
T9	Surface of cell #3-9	69.1
T10	Surface of cell #3-10	65.5
T-KK4	Heater	553.3

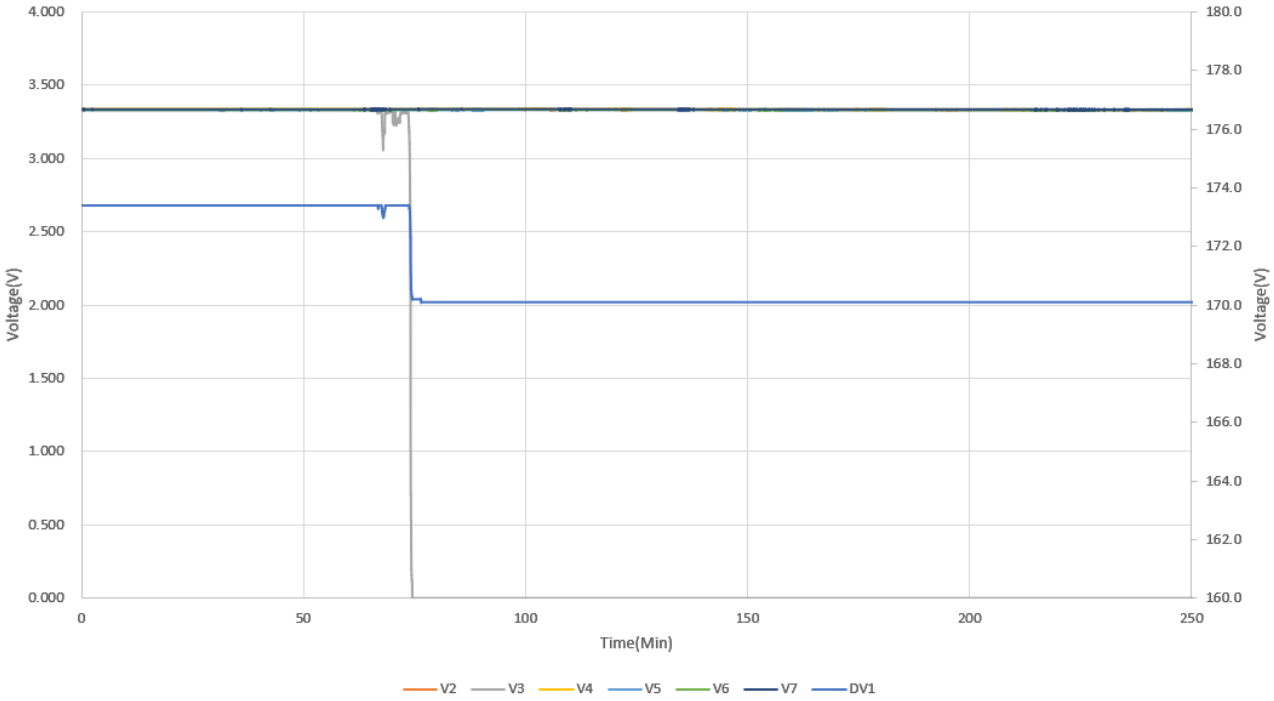
Voltage no.	Name	Voltage(V)
V-Module	Voltage of Module	173.4 V to 170.1 V

Figure 6 The enclosure temperature VS time curve



Thermocouple no.	Location	Maximum temp. °C
T11	Top surface of the Enclosure	76.6
T12	Top surface of the Enclosure	64.4
T13	Top surface of the Enclosure	89.2
T14	Top surface of the Enclosure	54.3
T15	Top surface of the Enclosure	142.7
T16	Top surface of the Enclosure	77.3
T17	Top surface of the Enclosure	101.1
T18	Top surface of the Enclosure	62.1
T19	Top surface of the Enclosure	67.7
T20	Top surface of the Enclosure	60.8
CH1-1	Right surface of the Enclosure	36.6
CH1-2	Left surface of the Enclosure	26.9
CH1-3	Back surface of the Enclosure	29.2
CH1-4	Front surface of the Enclosure	41.1

Figure 7 The cells and module voltage VS time curve



Name	V2 #1-7 & #1-8	V3 #1-9& #1-10	V4 #1-11& #1-12	V5 #1-13& #1-14	V6 #2-9& #2-10	V7 #3-9& #3-10	DV1
Begin of the test	3.334	3.335	3.338	3.331	3.332	3.336	173.4
End of the test	3.330	0.000	3.334	3.331	3.331	3.335	170.1

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)

3.4.2 Test result

Peak chemical heat release rate HRR: 22.70kW

Total heat release through the test THR: 97.90MJ

Figure 8 HRR curve

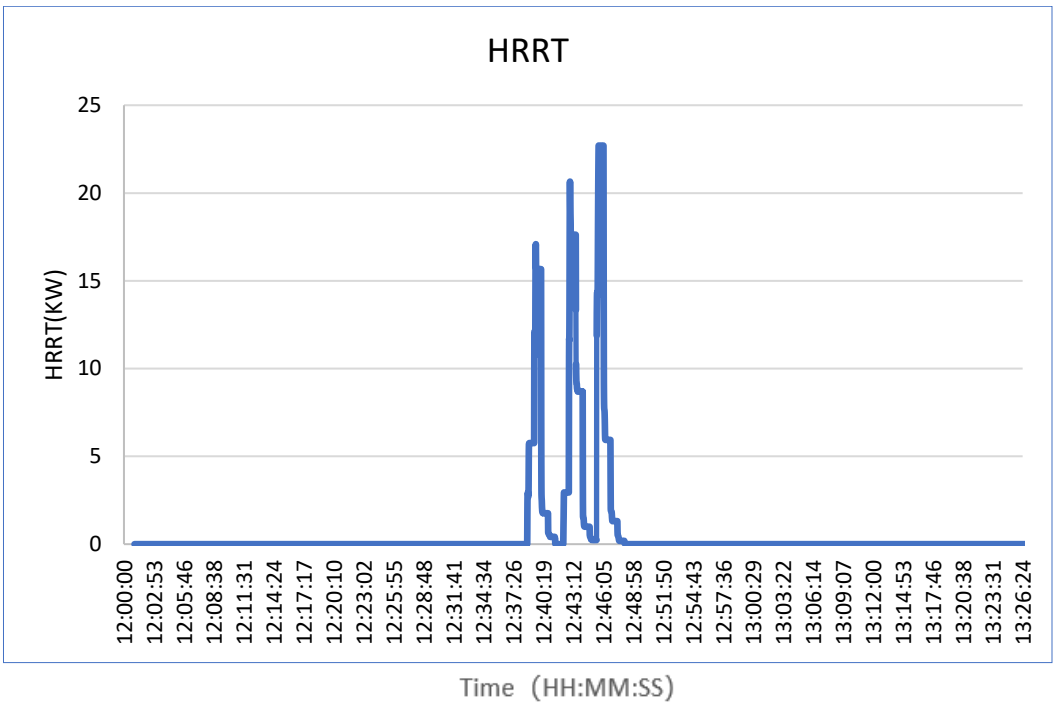
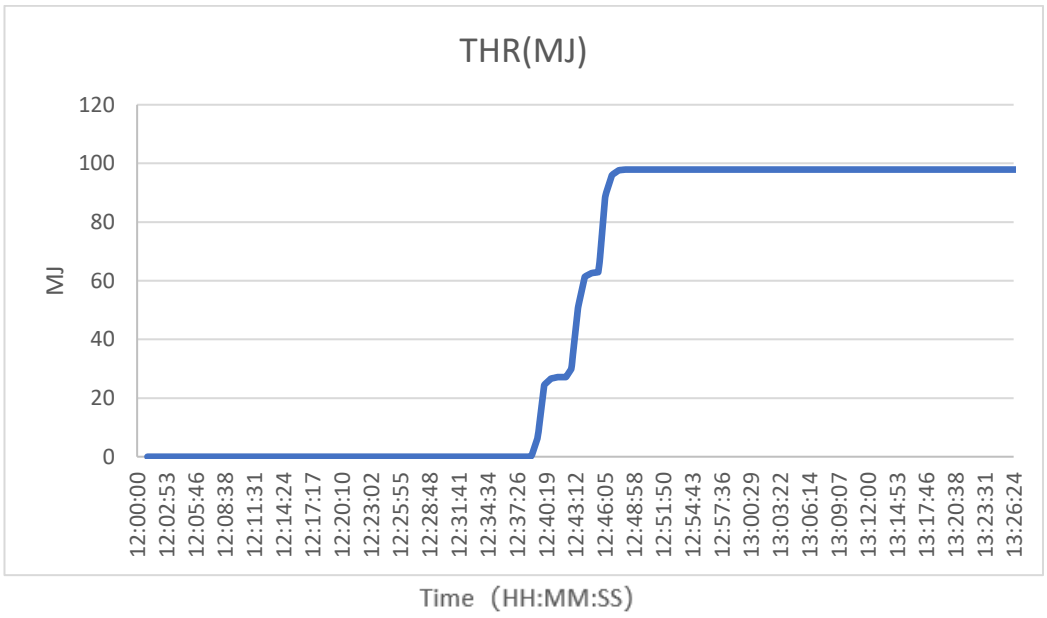


Figure 9 THR curve



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: 0.821m²/s

Total smoke release TSR: 118.0m²

Figure 10 SRR curve

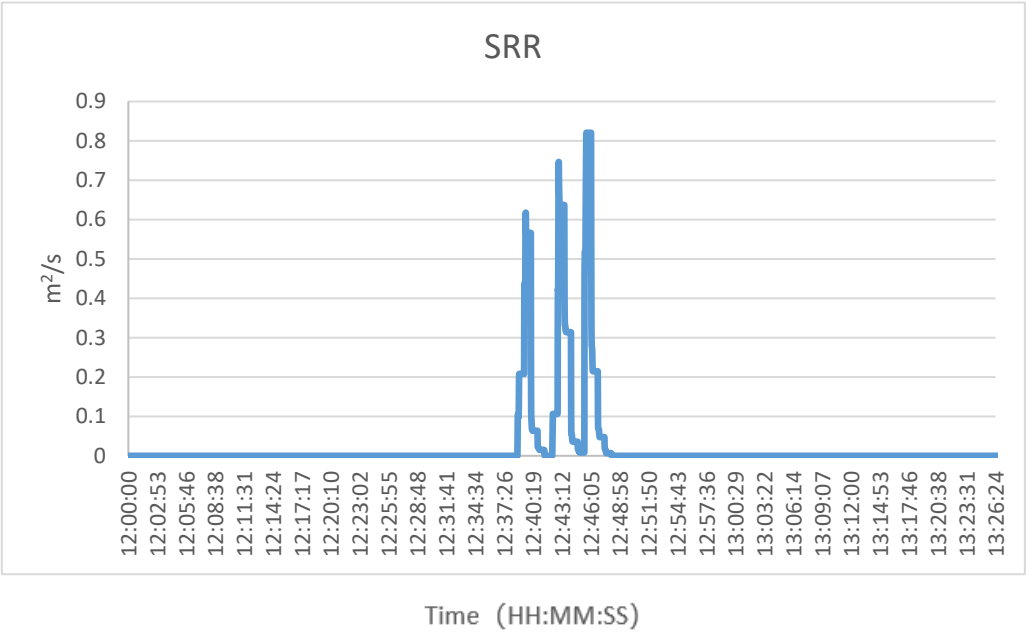
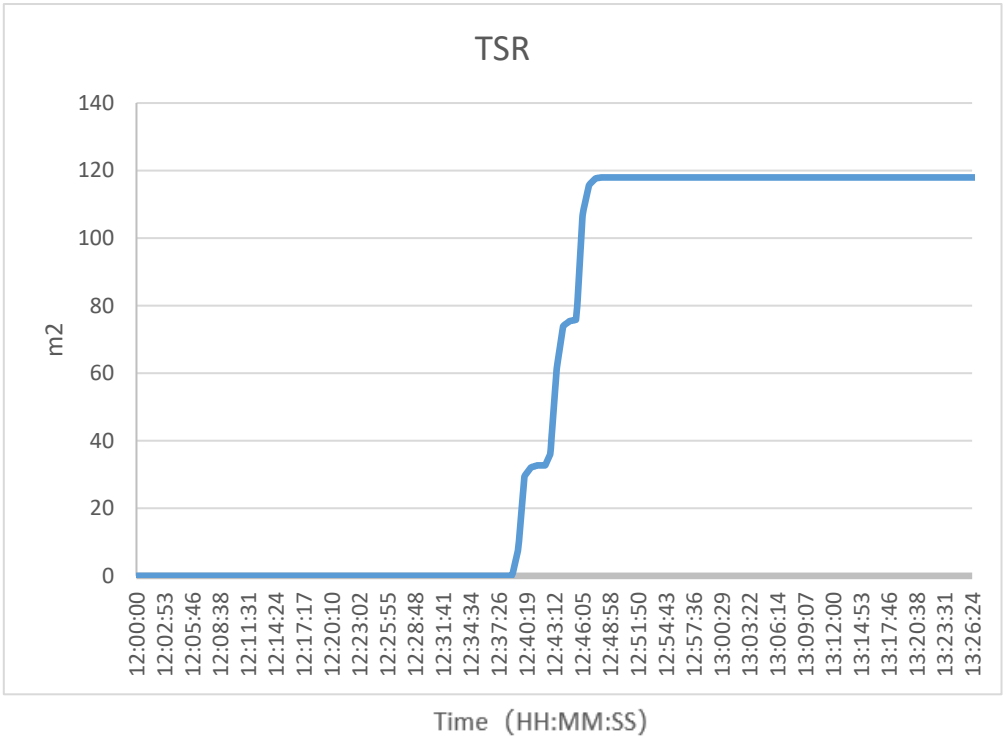


Figure 11 TSR curve



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 0.5 cm^{-1} and a path length of 5.1 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	20.570
	Ethylene	C_2H_4	13.594
	Ethane	C_2H_6	1.787
	Propylene	C_3H_6	2.581
	Propane	C_3H_8	0.824
Hydrogen halide species	Hydrogen Fluoride	HF	0.872
Others	Carbon Monoxide	CO	33.852
	Carbon Dioxide	CO_2	77.634
	Hydrogen (Electrochemical) For reference only	H_2	160.97**
	Hydrogen (Palladium nickel thin film solid state sensor)	H_2	Below detectable limit*

	Carbonyl Sulfide	COS	0.464
	Oil as octane	/	1.362
	Dimethyl carbonate	$C_3H_6O_3$	36.830
	Ethyl methyl carbonate	$C_4H_8O_3$	16.244
	Methanol	CH_3OH	/
Total Hydrocarbons (equivalent to C_3H_8, measured by FID)			101.04

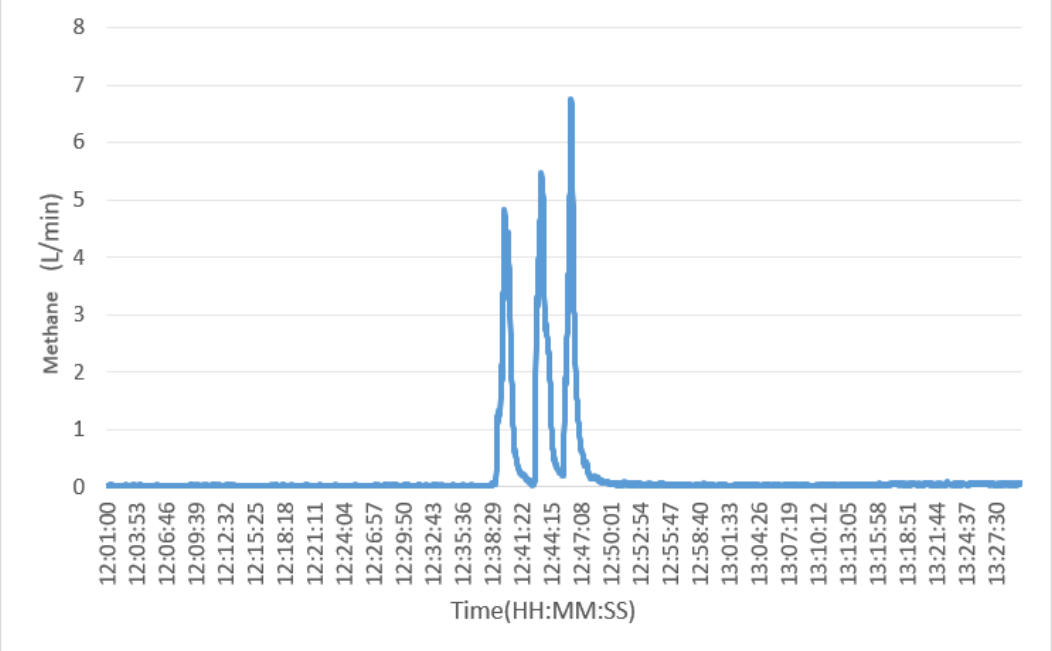
* = The volume of hydrogen released by a single cell after thermal runaway referred to the cell UL 9540A report is about 64.8L. However, it should be noted that the gas production of a single cell in the current test environment is not exactly equivalent to the gas production of the cell level test, because the test environment is not the same.

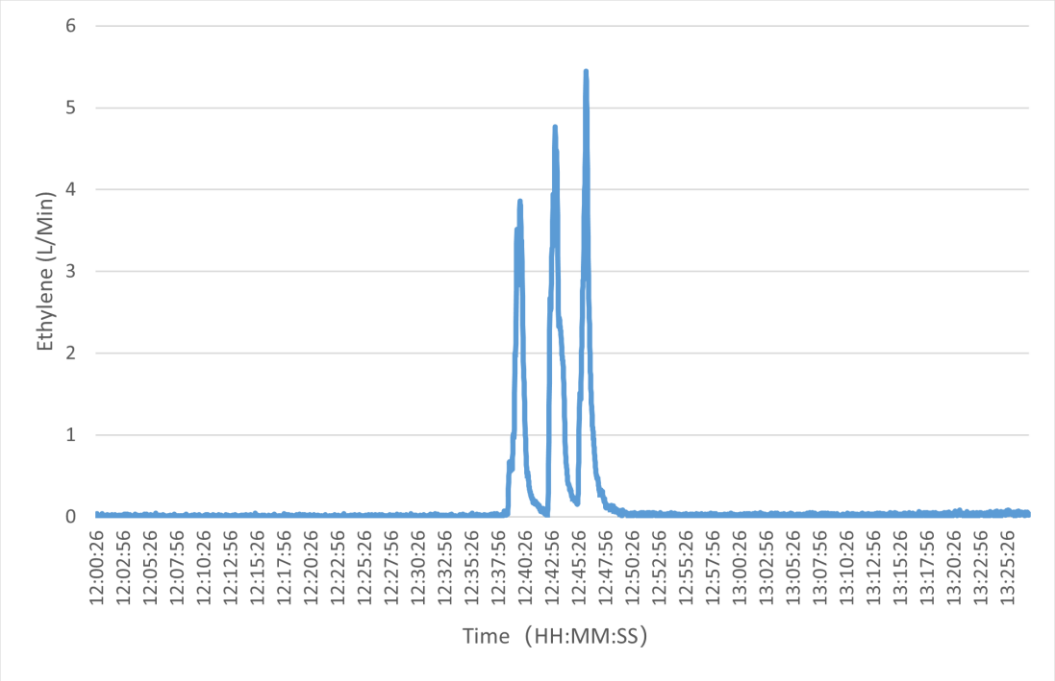
** = As there are some factor sensors which can affect the accuracy of hydrogen gas measurements, such as the accuracy for gas voltage signal, airflow rates, and environmental variables, the 160.97L in only for reference.

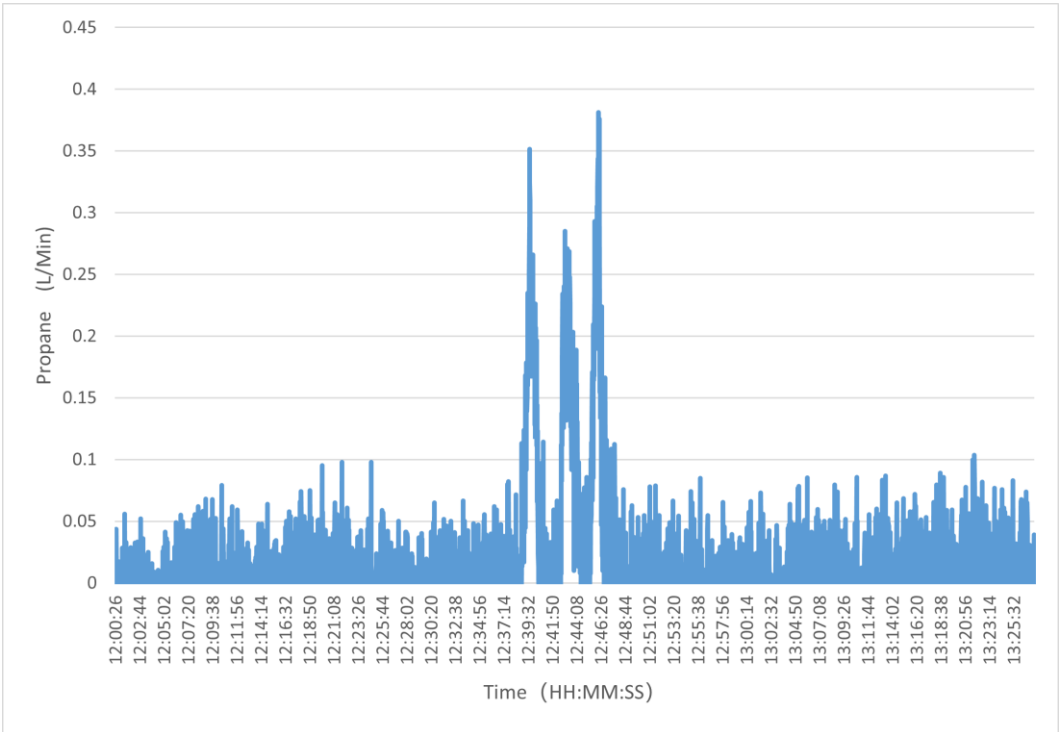
3.6.3 Gas components

Concentration of different gas components were present according to gas species classification in Figures 12 to 16. Average flow rate was 2.09 m^3/s during test.

Figure 12 Hydrocarbon species:




Ethylene (L/Min)
0
1
2
3
4
5
6
12:00:26
12:02:56
12:05:26
12:07:56
12:10:26
12:12:56
12:15:26
12:17:56
12:20:26
12:22:56
12:25:26
12:27:56
12:30:26
12:32:56
12:35:26
12:37:56
12:40:26
12:42:56
12:45:26
12:47:56
12:50:26
12:52:56
12:55:26
12:57:56
13:00:26
13:02:56
13:05:26
13:07:56
13:10:26
13:12:56
13:15:26
13:17:56
13:20:26
13:22:56
13:25:26
Time (HH:MM:SS)


Propane (L/Min)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
12:00:26
12:02:44
12:05:02
12:07:20
12:09:38
12:11:56
12:14:14
12:16:32
12:18:50
12:21:08
12:23:26
12:25:44
12:28:02
12:30:20
12:32:38
12:34:56
12:37:14
12:39:32
12:41:50
12:44:08
12:46:26
12:48:44
12:51:02
12:53:20
12:55:38
12:57:56
13:00:14
13:02:32
13:04:50
13:07:08
13:09:26
13:11:44
13:14:02
13:16:20
13:18:38
13:20:56
13:23:14
13:25:32
Time (HH:MM:SS)

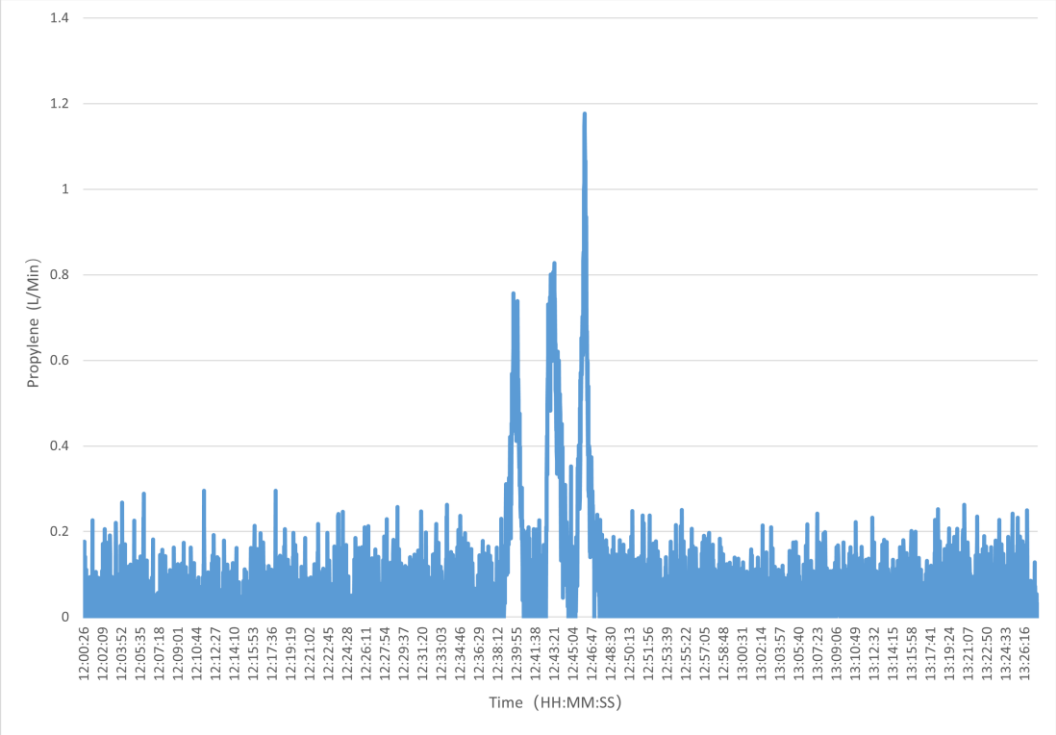


Figure 13 Hydrogen halide species:

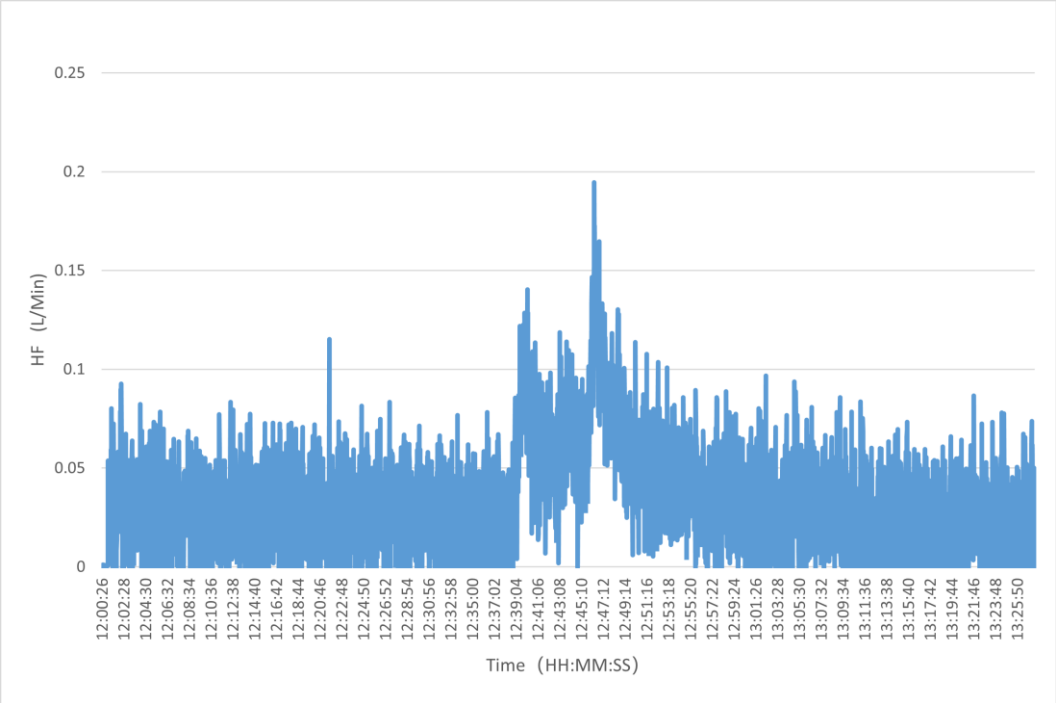
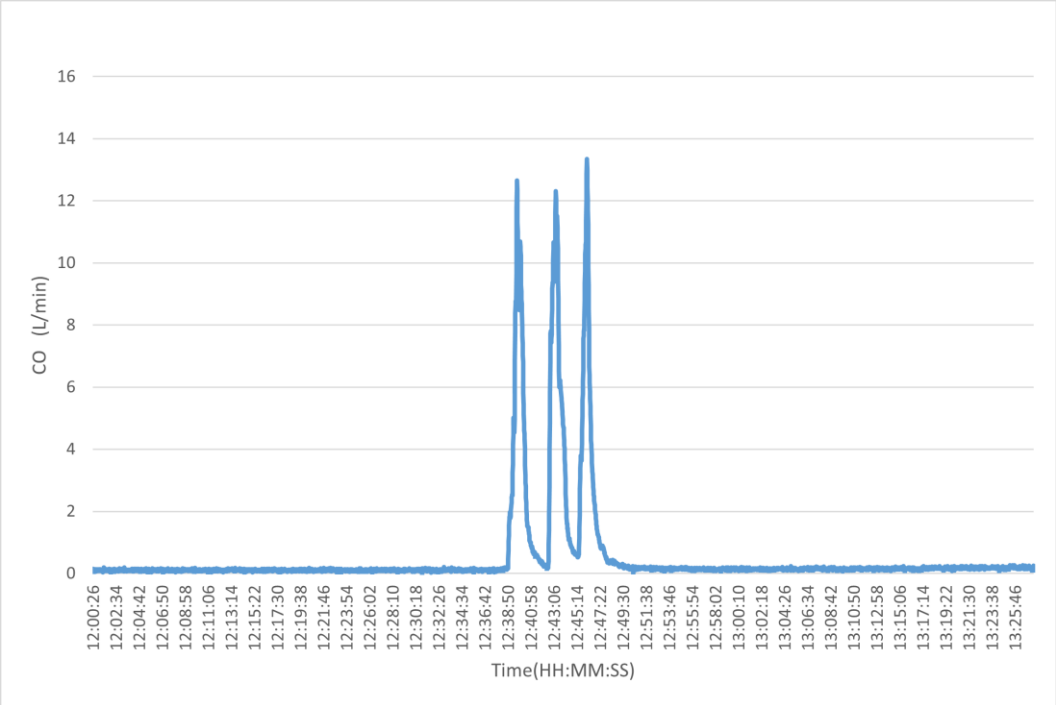


Figure 14 CO, CO2 concentration:



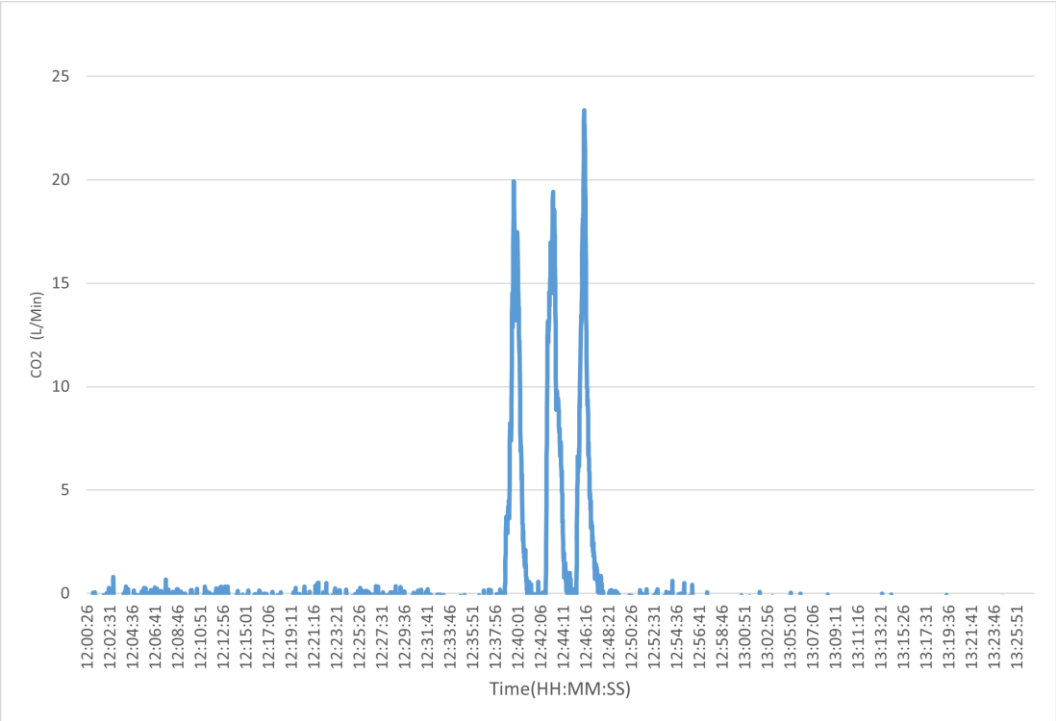


Figure 15 Total Hydrocarbons (equivalent to C3H8, measured by FID):

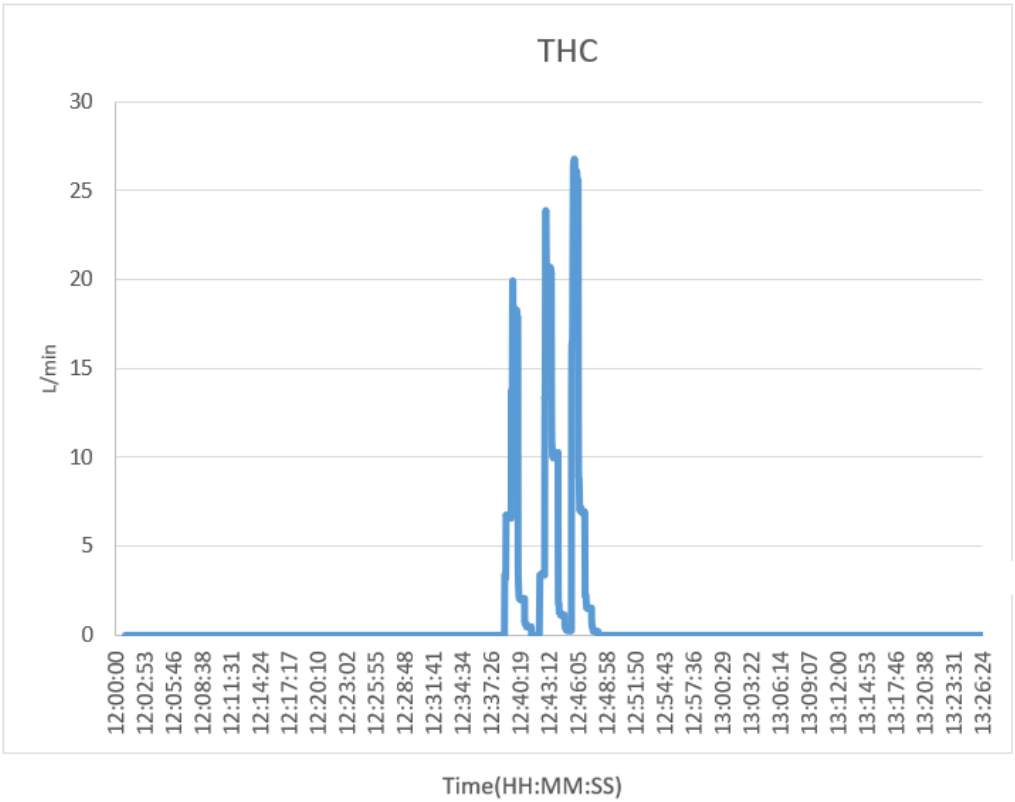
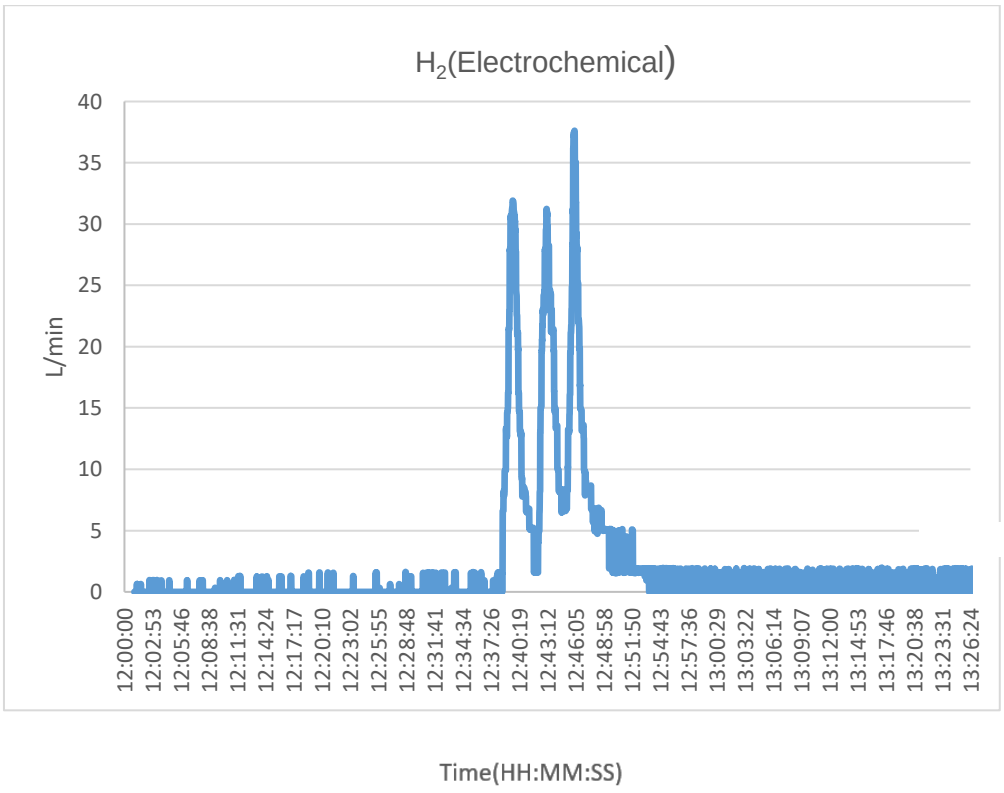
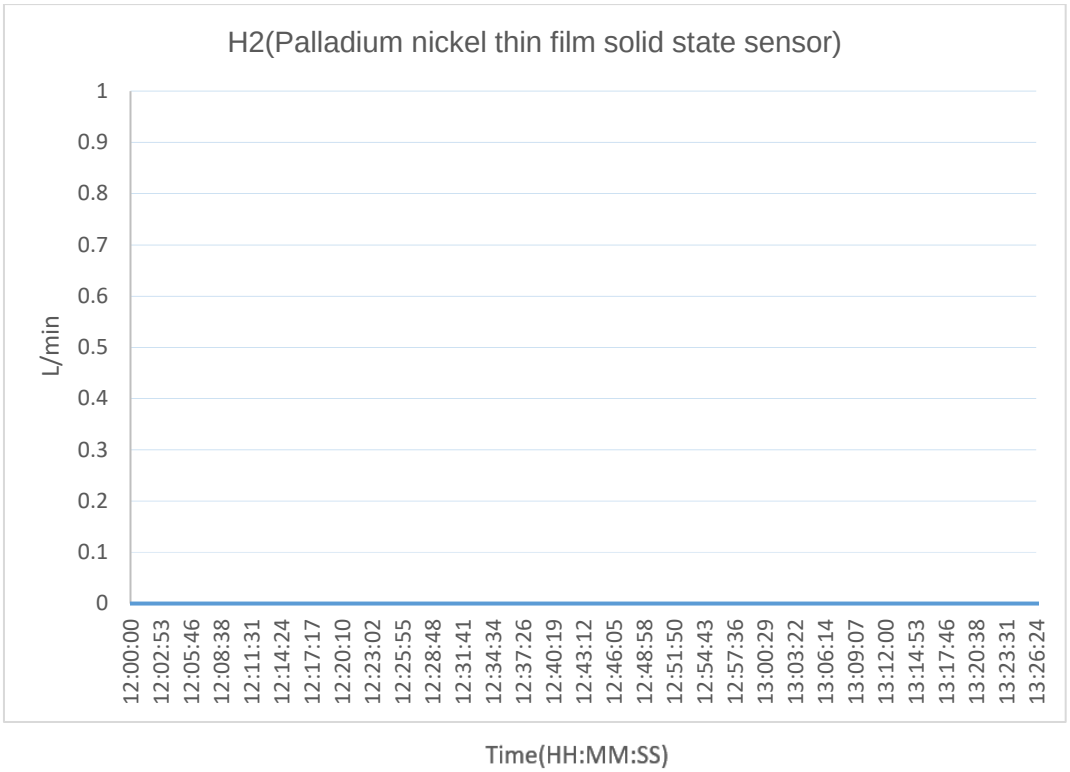
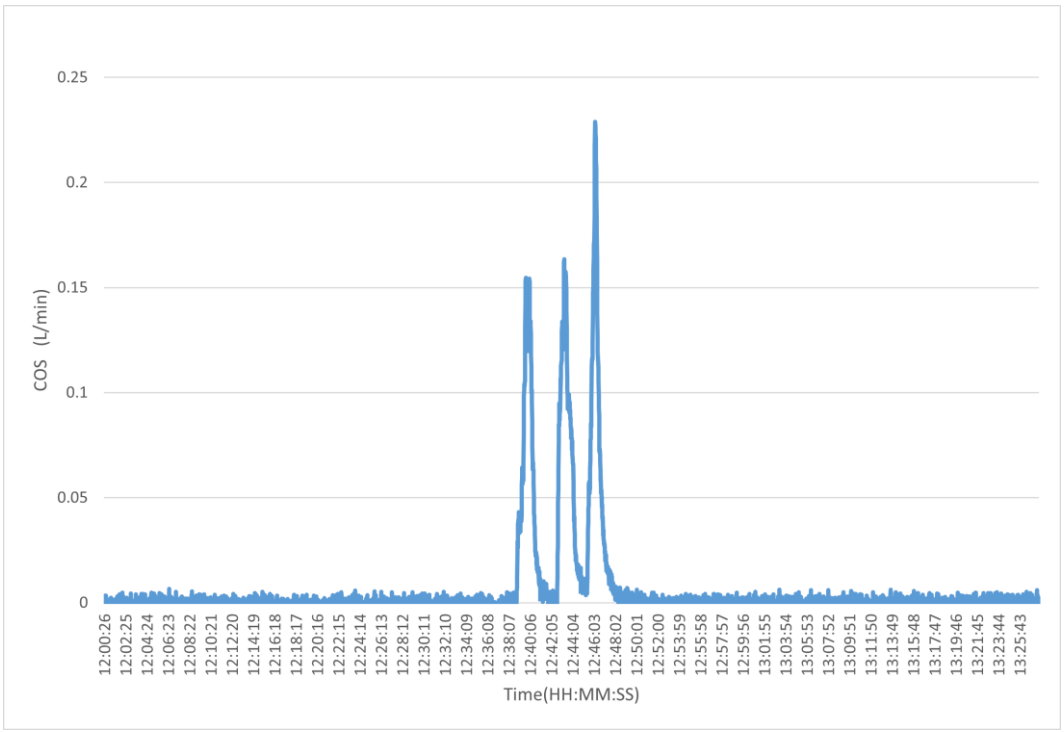
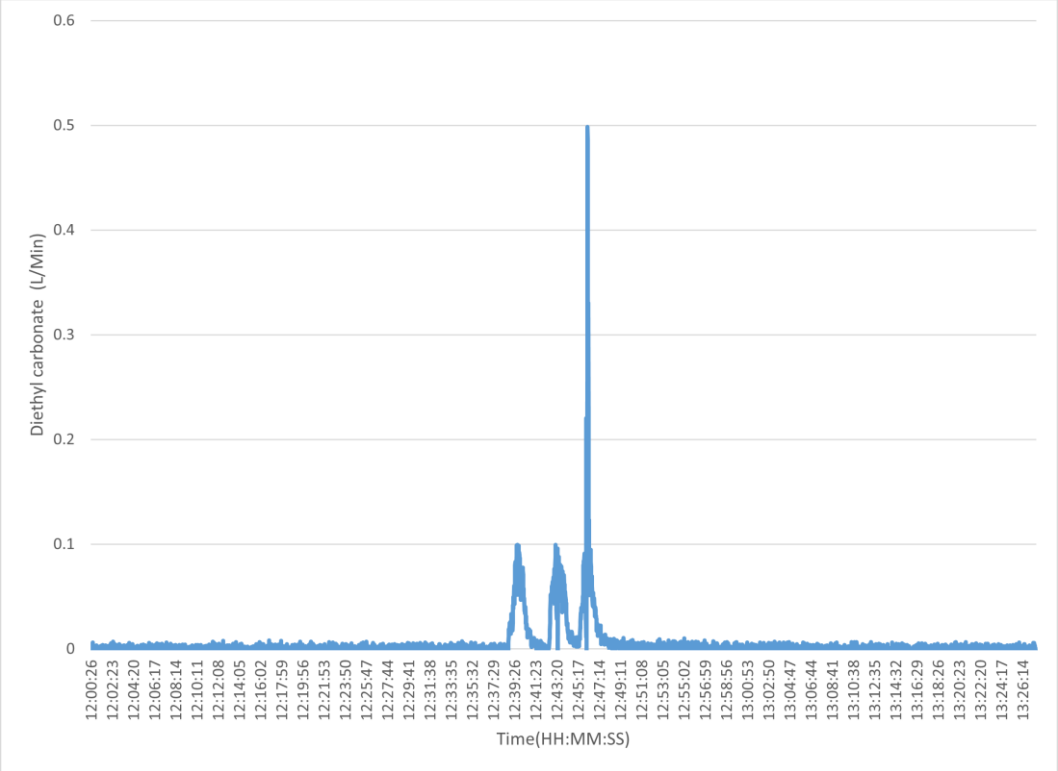


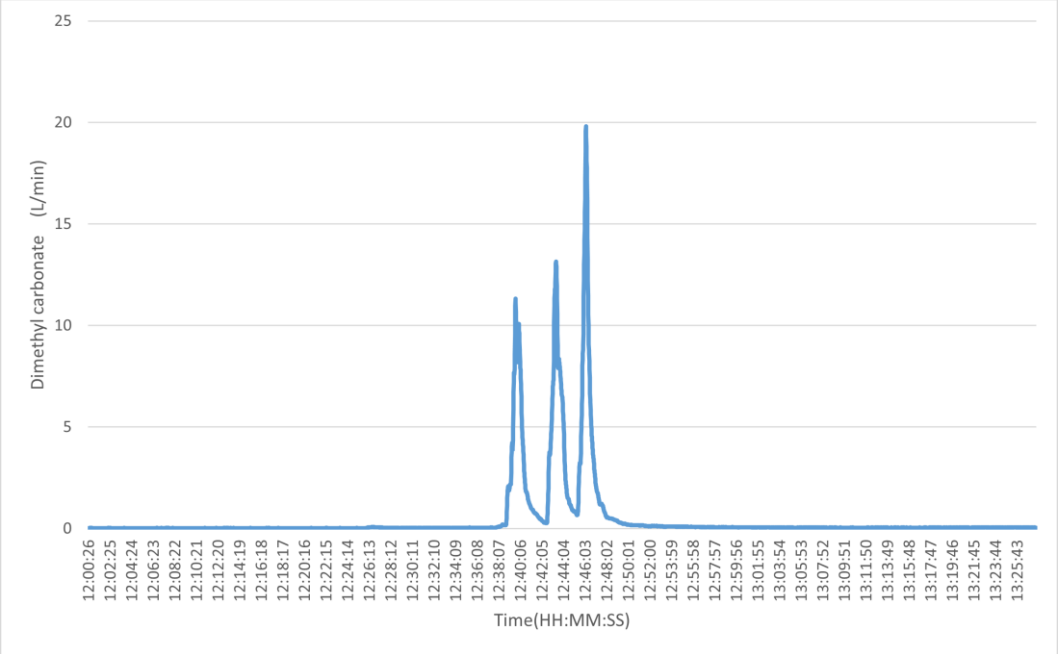
Figure 16 Others:

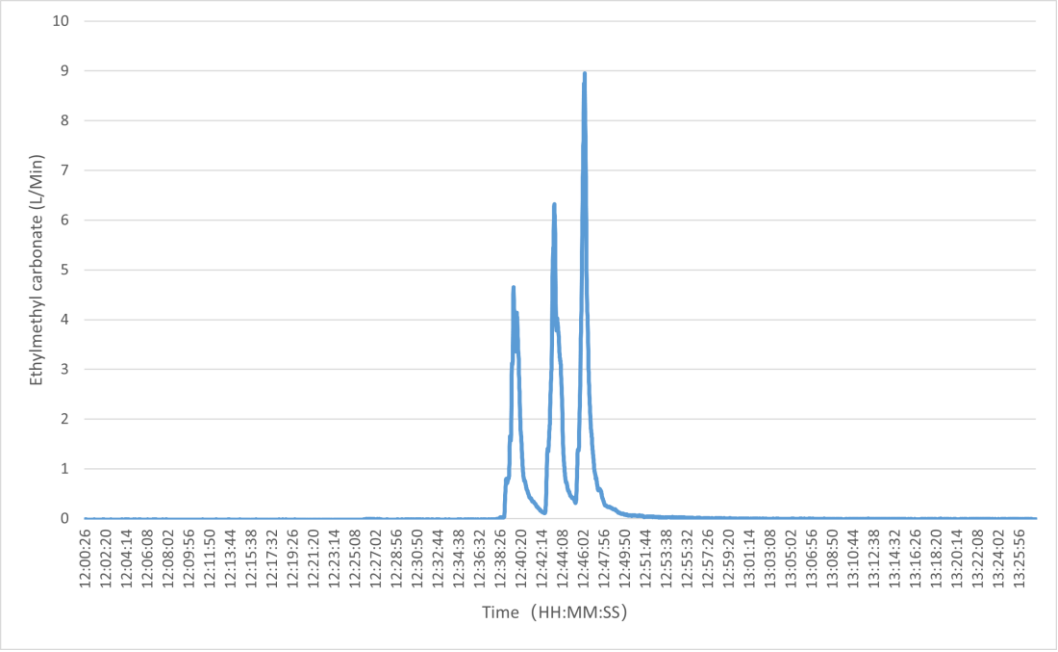


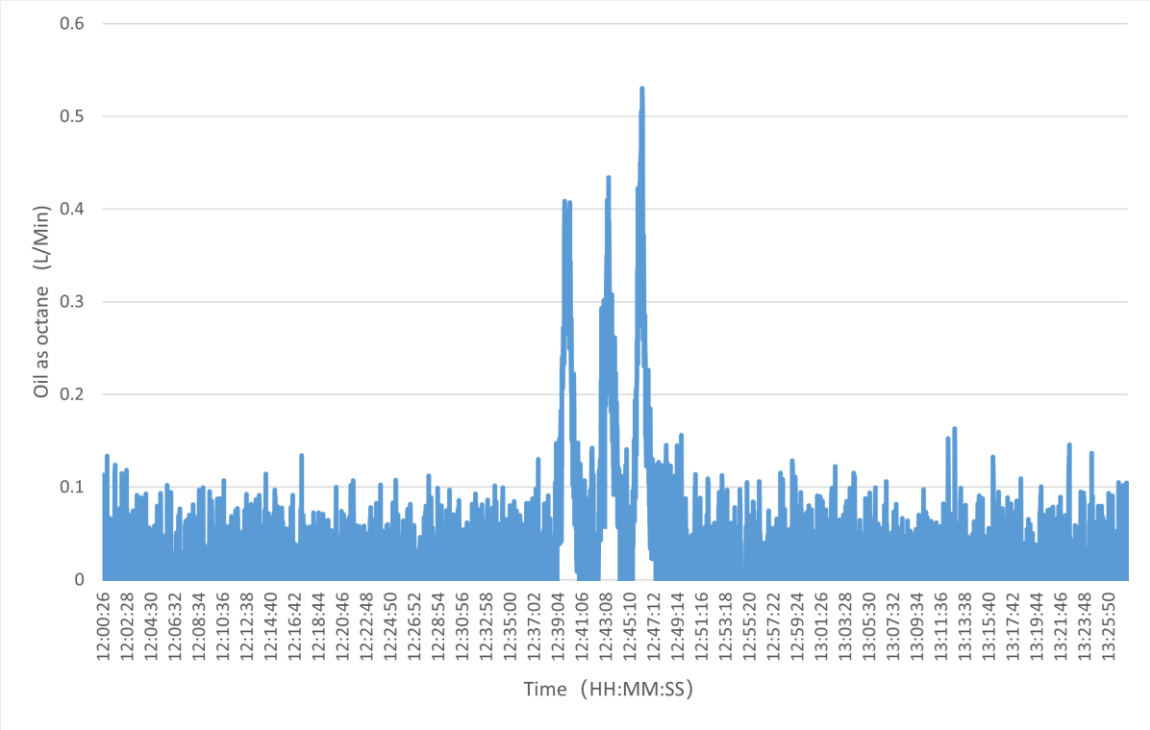

H2(Palladium nickel thin film solid state sensor)
L/min
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12:00:00
12:02:53
12:05:46
12:08:38
12:11:31
12:14:24
12:17:17
12:20:10
12:23:02
12:25:55
12:28:48
12:31:41
12:34:34
12:37:26
12:40:19
12:43:12
12:46:05
12:48:58
12:51:50
12:54:43
12:57:36
13:00:29
13:03:22
13:06:14
13:09:07
13:12:00
13:14:53
13:17:46
13:20:38
13:23:31
13:26:24
Time(HH:MM:SS)


COS (L/min)
0.25
0.2
0.15
0.1
0.05
0
12:00:26
12:02:25
12:04:24
12:06:23
12:08:22
12:10:21
12:12:20
12:14:19
12:16:18
12:18:17
12:20:16
12:22:15
12:24:14
12:26:13
12:28:12
12:30:11
12:32:10
12:34:09
12:36:08
12:38:07
12:40:06
12:42:05
12:44:04
12:46:03
12:48:02
12:50:01
12:52:00
12:53:59
12:55:58
12:57:57
12:59:56
13:01:55
13:03:54
13:05:53
13:07:52
13:09:51
13:11:50
13:13:49
13:15:48
13:17:47
13:19:46
13:21:45
13:23:44
13:25:43
Time(HH:MM:SS)


0.6
0.5
0.4
0.3
0.2
0.1
0
Diethyl carbonate (L/Min)
12:00:26
12:02:23
12:04:20
12:06:17
12:08:14
12:10:11
12:12:08
12:14:05
12:16:02
12:17:59
12:19:56
12:21:53
12:23:50
12:25:47
12:27:44
12:29:41
12:31:38
12:33:35
12:35:32
12:37:29
12:39:26
12:41:23
12:43:20
12:45:17
12:47:14
12:49:11
12:51:08
12:53:05
12:55:02
12:56:59
12:58:56
13:00:53
13:02:50
13:04:47
13:06:44
13:08:41
13:10:38
13:12:35
13:14:32
13:16:29
13:18:26
13:20:23
13:22:20
13:24:17
13:26:14
Time(HH:MM:SS)

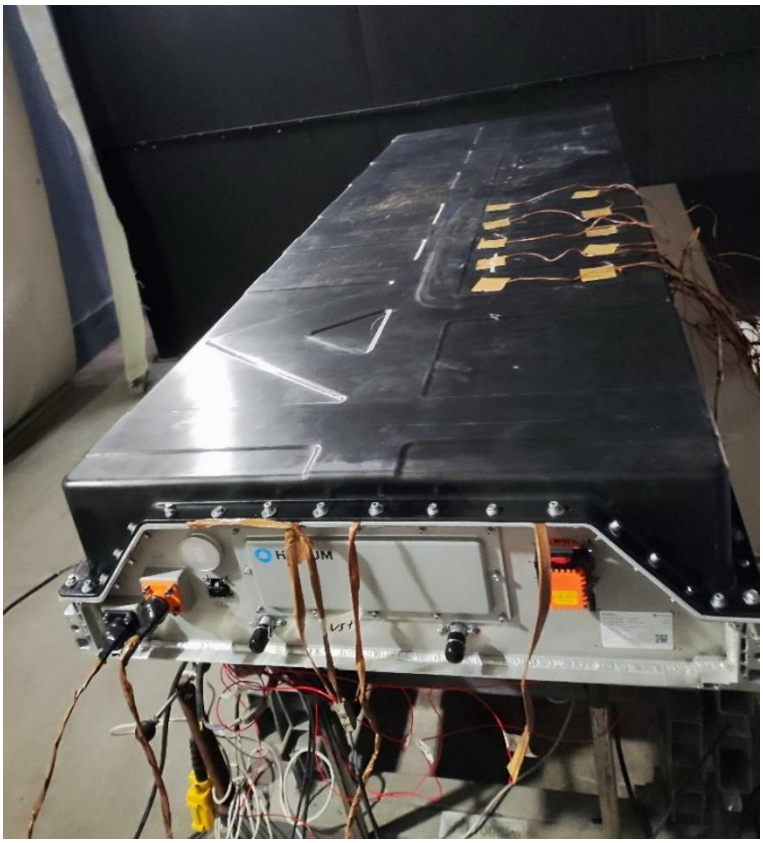

Dimethyl carbonate (L/min)
25
20
15
10
5
0
12:00:26
12:02:25
12:04:24
12:06:23
12:08:22
12:10:21
12:12:20
12:14:19
12:16:18
12:18:17
12:20:16
12:22:15
12:24:14
12:26:13
12:28:12
12:30:11
12:32:10
12:34:09
12:36:08
12:38:07
12:40:06
12:42:05
12:44:04
12:46:03
12:48:02
12:50:01
12:52:00
12:53:59
12:55:58
12:57:57
12:59:56
13:01:55
13:03:54
13:05:53
13:07:52
13:09:51
13:11:50
13:13:49
13:15:48
13:17:47
13:19:46
13:21:45
13:23:44
13:25:43
Time(HH:MM:SS)


Ethylmethyl carbonate (L/Min)
10
9
8
7
6
5
4
3
2
1
0
12:00:26
12:02:20
12:04:14
12:06:08
12:08:02
12:09:56
12:11:50
12:13:44
12:15:38
12:17:32
12:19:26
12:21:20
12:23:14
12:25:08
12:27:02
12:28:56
12:30:50
12:32:44
12:34:38
12:36:32
12:38:26
12:40:20
12:42:14
12:44:08
12:46:02
12:47:56
12:49:50
12:51:44
12:53:38
12:55:32
12:57:26
12:59:20
13:01:14
13:03:08
13:05:02
13:06:56
13:08:50
13:10:44
13:12:38
13:14:32
13:16:26
13:18:20
13:20:14
13:22:08
13:24:02
13:25:56
Time (HH:MM:SS)


0.6
0.5
0.4
0.3
0.2
0.1
0
Oil as octane (L/Min)
12:00:26
12:02:28
12:04:30
12:06:32
12:08:34
12:10:36
12:12:38
12:14:40
12:16:42
12:18:44
12:20:46
12:22:48
12:24:50
12:26:52
12:28:54
12:30:56
12:32:58
12:35:00
12:37:02
12:39:04
12:41:06
12:43:08
12:45:10
12:47:12
12:49:14
12:51:16
12:53:18
12:55:20
12:57:22
12:59:24
13:01:26
13:03:28
13:05:30
13:07:32
13:09:34
13:11:36
13:13:38
13:15:40
13:17:42
13:19:44
13:21:46
13:23:48
13:25:50
Time (HH:MM:SS)

3.7 Photos

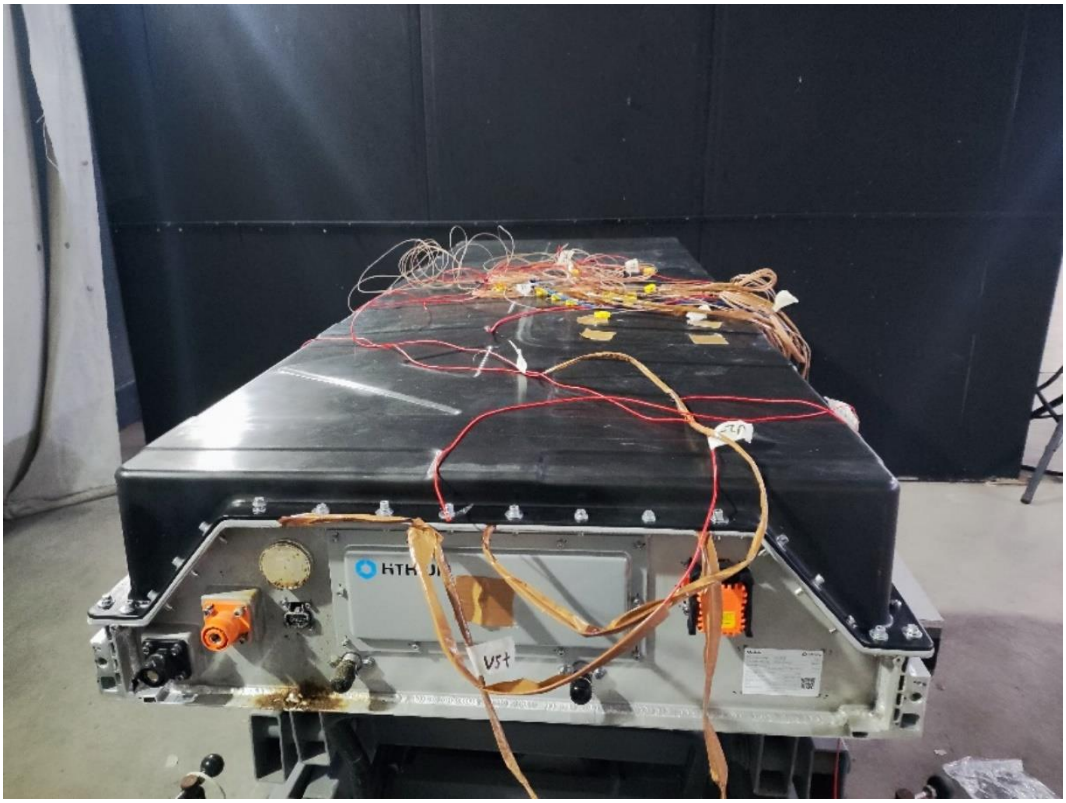
Module before test

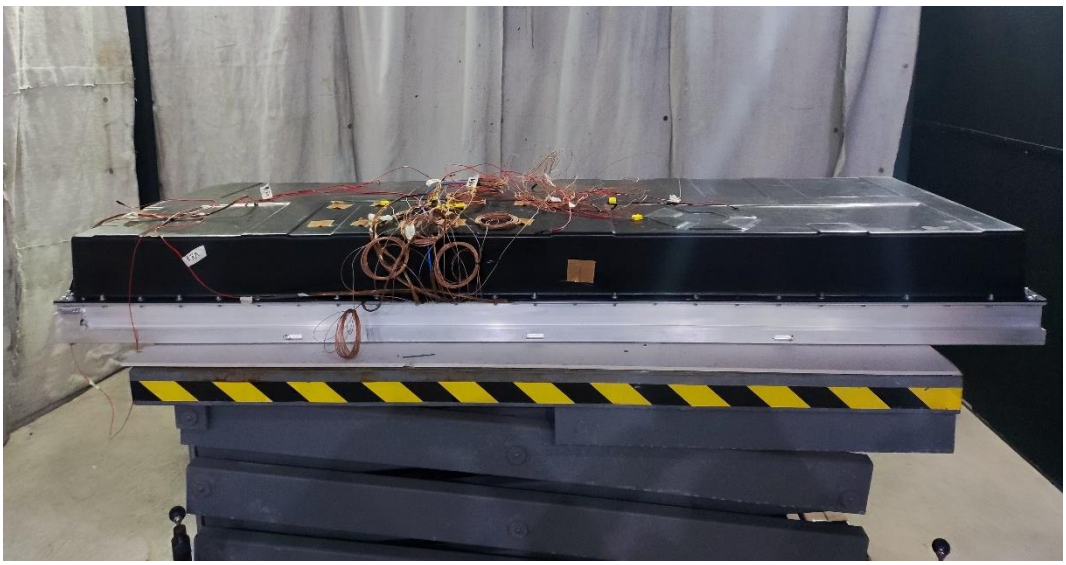


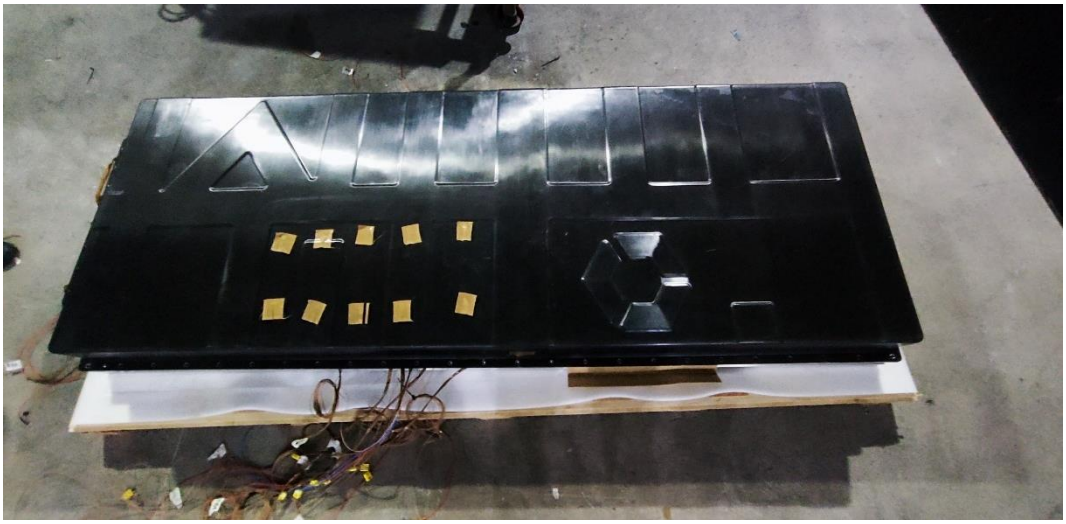

HTHIUM

Smoke release during test

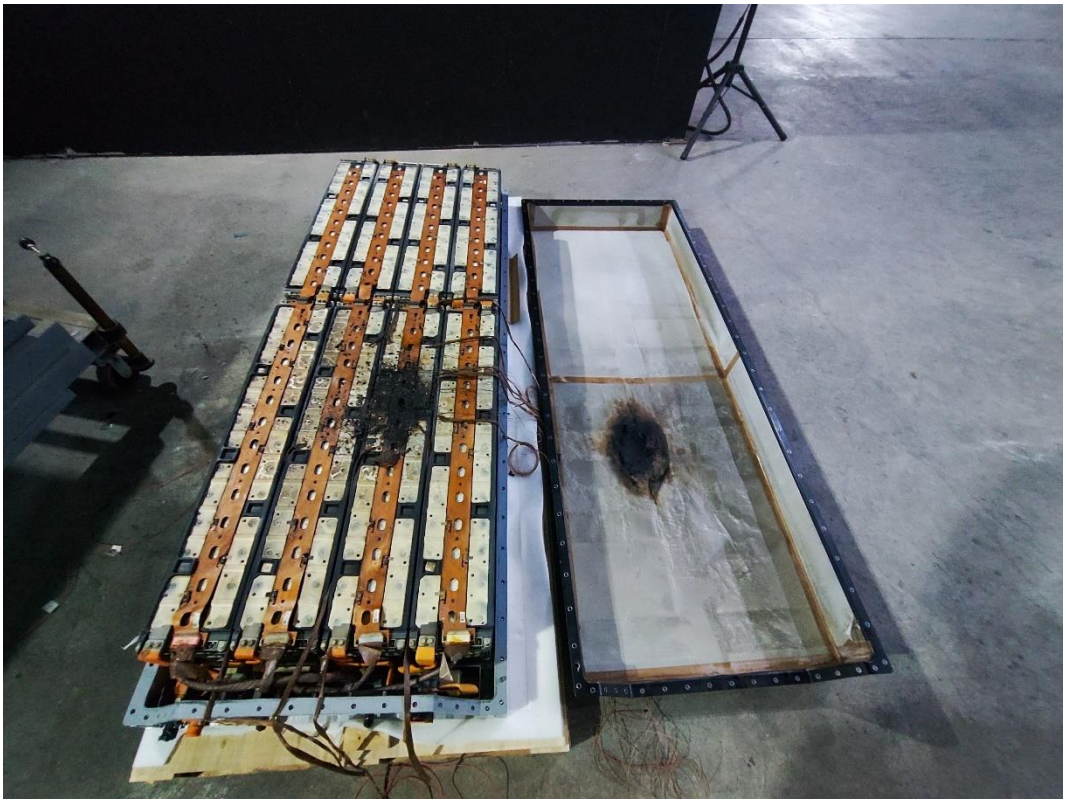
Sample after test







Damage of the internal components



3.8 List of test and measurements instruments:

No.	Equipment	Model	Rating	Inventory no.	Last Cal. date
1	Ambient temperature and humidity	COS-03	0°C ~50°C, 30%RH~95%RH	D-ZNDW23052402	2023.05.24
2	Data acquisition equipment	LR8450-01	0~1100°C	0221-0704-06	2023.10.19
3	Electronic scale	OCS-2t/1kg	1kg~2000kg	0221-0704-10	2023.11.19
4	Paramagnetic oxygen analyser	AO2020	Oxygen measurement: 6.02%vol~24%vol; Hydrogen concentration: 1%~3%; Carbon monoxide: 0.2%~0.8%; Carbon dioxide concentration: 2%~8%	0221-0704-03	2023.03.06
5	Velocity probe	DYM3	800~1060hPa	D-ZNDW23032210	2023.03.10
7	Fourier-Transform Infrared Spectrometer	MULTIGAS 6030	Methane, propane, acetylene concentration: 100μmol/mol~1000μmol/mol; Carbon monoxide concentration: 0.2%~0.8%	0221-0704-08	2023.03.06
9	Palladium-nickel thin-film solid state sensor	HY-OPTIMA-2720	Range: 0.4%~5.0%	0221-0704-01	2023.03.20
10	Flame ionization detector	AO2040	Methane concentration: 100μmol/mol~500μmol/mol	0221-0704-04	2023.03.06
11	Thermopile	TJ120-CAXL-116U-80	0~300°C	0221-0704-31	2023.10.22

Remark: Calibration of equipment is valid for 1 year.

End of Test Report