

Prüfbericht-Nr.: <i>Test report no.:</i>	CN25P9GU 001	Auftrags-Nr.: <i>Order no.:</i>	326096316	Seite 1 von 22 Page 1 of 22	
Kunden-Referenz-Nr.: <i>Client reference no.:</i>	2371109	Auftragsdatum: <i>Order date:</i>	2025-02-21		
Auftraggeber: <i>Client:</i>	CSI Energy Storage Co., Ltd. No.348 Lushan Road, SND, Suzhou, 215129 Jiangsu, P.R. China				
Prüfgegenstand: <i>Test item:</i>	Battery Energy Storage System				
Bezeichnung / Typ-Nr.: <i>Identification / Type no.:</i>	CSI-SolBank-S-5016-2h-NA, CSI-SolBank-S-5016-4h-NA, CSI-SolBank-S-5016-2h-EU, CSI-SolBank-S-5016-4h-EU				
Auftrags-Inhalt: <i>Order content:</i>	Test report				
Prüfgrundlage: <i>Test specification:</i>	This report provides evaluation and CFD analysis of the ventilation system in energy storage system referring to Chapter 8 in NFPA69:2024.				
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Prüfmuster-Nr.: <i>Test sample no.:</i>	Engineering sample				
Prüfzeitraum: <i>Testing period:</i>	2025-03-08 - 2025-03-18				
Ort der Prüfung: <i>Place of testing:</i>	TÜV Rheinland (Shanghai) Co., Ltd.				
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Prüfergebnis*: <i>Test result*:</i>	See main report				
geprüft von: <i>tested by:</i>	 Shiheng Zhang		genehmigt von: <i>authorized by:</i>	 Simon Wang	
Datum: <i>Date:</i>	2025.03.28		Ausstellungsdatum: <i>Issue date:</i>	2025.03.28	
Stellung / Position:	Project Engineer		Stellung / Position:	Authorizer	
Sonstiges / <i>Other:</i>					
Zustand des Prüfgegenstandes bei Anlieferung: <i>Condition of the test item at delivery:</i>	Prüfmuster vollständig und unbeschädigt Test item complete and undamaged				
* Legende:	P(ass) = entspricht o.g. Prüfgrundlage(n)	F(ail) = entspricht nicht o.g. Prüfgrundlage(n)	N/A = nicht anwendbar	N/T = nicht getestet	
* Legend:	P(ass) = passed a.m. test specification(s)	F(ail) = failed a.m. test specification(s)	N/A = not applicable	N/T = not tested	
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1. General Production Information:

1.1. Cell

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

Manufacturer	CSI Energy Storage Co., Ltd.	
Model number	CSI314	
Chemistry	LiFePO ₄	
Physical configuration	Prismatic	
Electrical rating	Rated capacity:	314 Ah
	Nominal voltage:	3.2 V
Standard charge method.....	Charge current:	157 A
	End of charge voltage:	3.8 V
Standard discharge method	Discharge current:	157 A
	End of discharge voltage:	2.0 V

1.2. Module

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

Manufacturer name :		CSI Energy Storage Co., Ltd.	
Model number :		CSI-SolBank-P-104.5-2h-A	CSI-SolBank-P-104.5-4h-A
Physical configuration :		Metal enclosure with metal cover	
		Weight: 670±15kg	
		Cells in series/parallel: 1P104S	
Cooling method :		Liquid cooling	
Separation between cells :		Aerogel	
Electrical rating :		Rated capacity: 314 Ah	
		Nominal voltage: 332.8V	
Standard charge method :	Charge current :	157 A	78.5A
	End of charge voltage :	374.4 V	
	Charge temperature range:	0~55 °C	
Standard discharge method	Discharge current :	157 A	78.5A
	End of discharge voltage :	265.2 V	
	Discharge temperature range:	0~55 °C	
External dimensions (mm) :		2180±5mm(L)×790±3mm(W)×248±5mm(H)	

1.3. Energy Storage System

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

	Battery rack	Battery rack
Product	LFP Lithium Ion Energy Storage System	LFP Lithium Ion Energy Storage System
Type/model	CSI-SolBank-R-418-2h-A	CSI-SolBank-R-418-4h-A
Cell Capacity [Ah]	314	314
Cell Quantity	416	416
Battery structure	(104)4S	(104)4S
Nominal voltage [V]	1331.2	1331.2
Rated capacity [kWh]	418	418
Upper limit charging voltage [V]	1497.6	1497.6
Maximum charging power[kW]	208	104
Maximum discharging power[kW]	208	104
Over charge protective voltage [V]	1518.4	1518.4
Cut-off voltage [V]	1060.8	1060.8
Temperature range for charging [°C]	0°C to 55°C (Environment)	0°C to 55°C (Environment)
Temperature range for discharging [°C]	0°C to 55°C (Environment)	0°C to 55°C (Environment)
Temperature threshold for protection	Low temperature of battery:5°C High temperature of battery:45°C Battery temperature difference: 15°C	Low temperature of battery:5°C High temperature of battery:45°C Battery temperature difference: 15°C
Recommend charging method by manufacturer	208 kW CP 2h	104 kW CP 4h
Dimension [mm]	2180(L)×790(W)×248(H)×4	2180(L)×790(W)×248(H)×4
Weight [kg]	2640	2640
Cooling type	Liquid cooling and liquid heating for cell	Liquid cooling and liquid heating for cell
Altitude	3000m	3000m

2. Product Description:

2.1. General Description

This product is used for Energy Storage System.

This EUT covered by this report is DC system for energy storage, which mainly consists of 12 Lithium ion battery racks, 1 liquid chiller, fire protection, some auxiliary power supply components integrated in 1 cabinet.

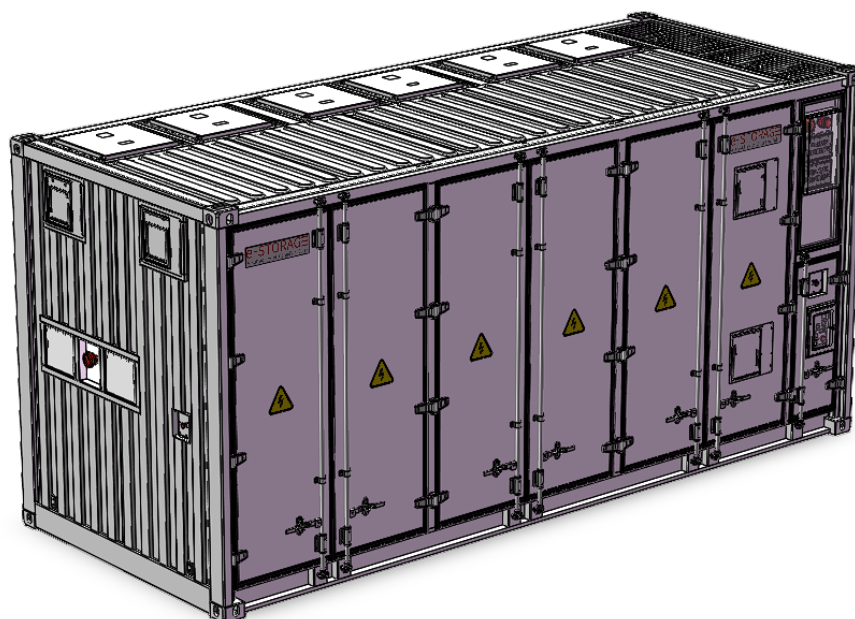
Each battery rack includes 1 master control box and 4 battery packs in series connection. Total 12 racks parallel connection for the completed system.

The main output circuit for the system is optional for a set of ports (for 12 racks), or two sets of ports (each for 6 racks), depends on the main output busbar. Suitable disconnect device(s) should be provided for main circuit(s) in end-installation.

The insulation between the DC circuit and the metal enclosure is basic insulation. And the insulation between the DC circuit and communication ports is reinforced insulation or double insulation.

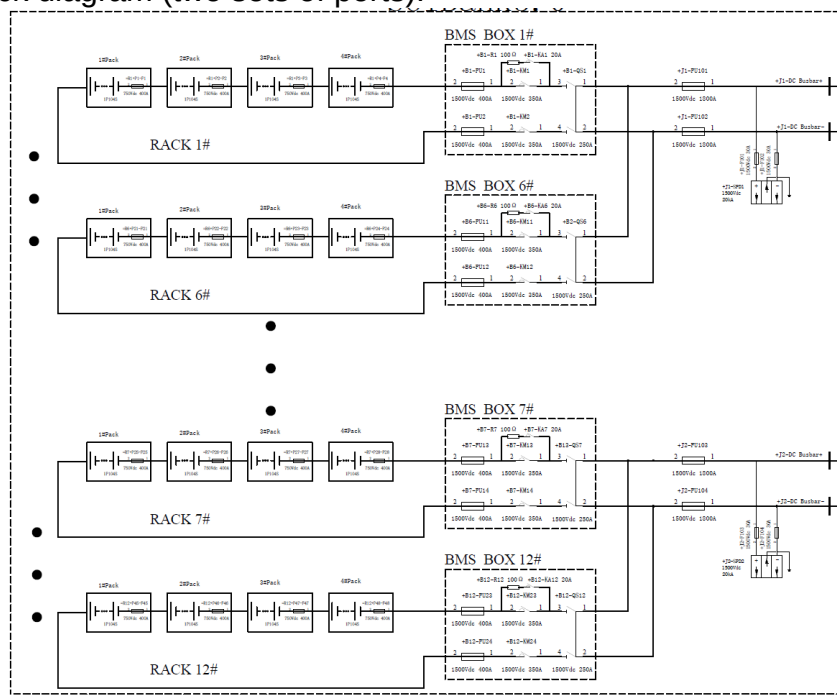
The battery system has overcharge, over-discharge, over current and short-circuits proof circuit. The electronic circuits and software controls for the battery system relied upon protective functions of the battery management system have been evaluated in accordance with UL 60730-1 Annex H.

The EUT is outdoor type with IP55 degree, PD2 was evaluated for inside and PD3 for outside.

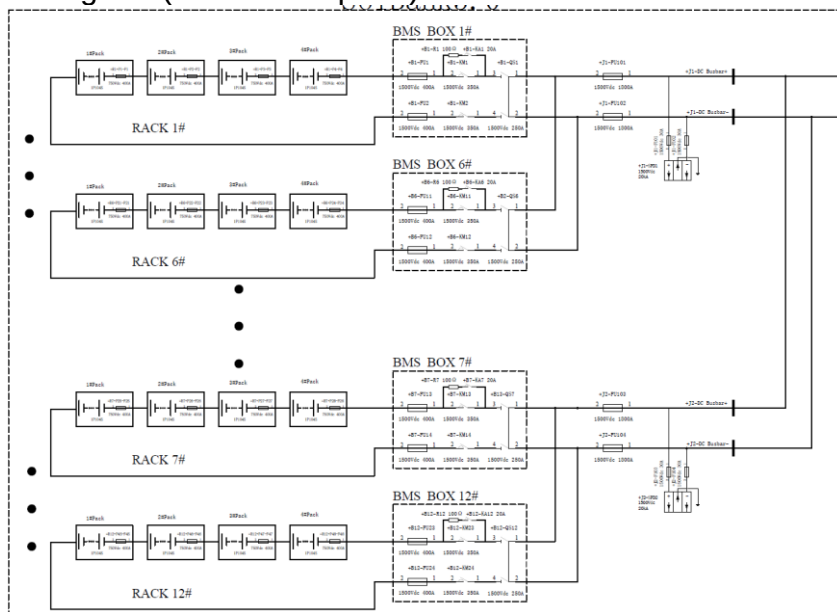


2.2. Energy Storage System Block Diagram

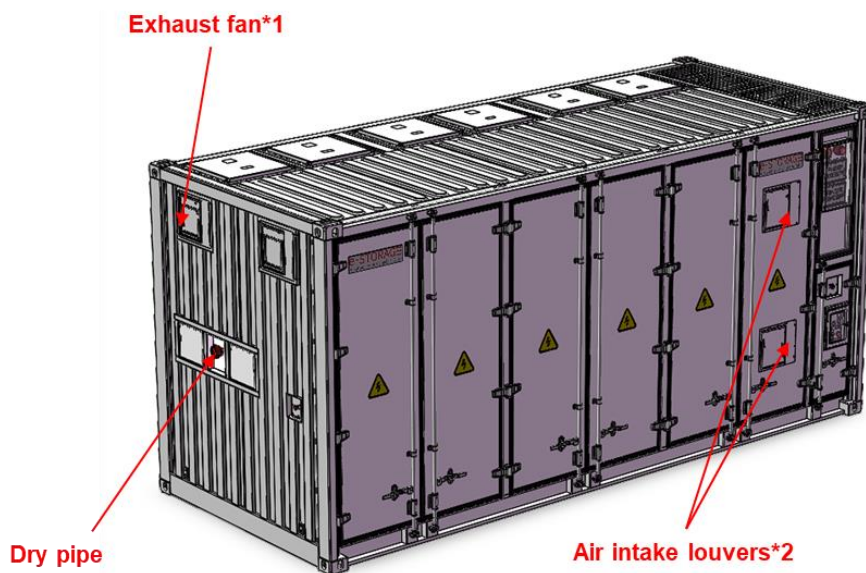
Main circuit block diagram (two sets of ports):



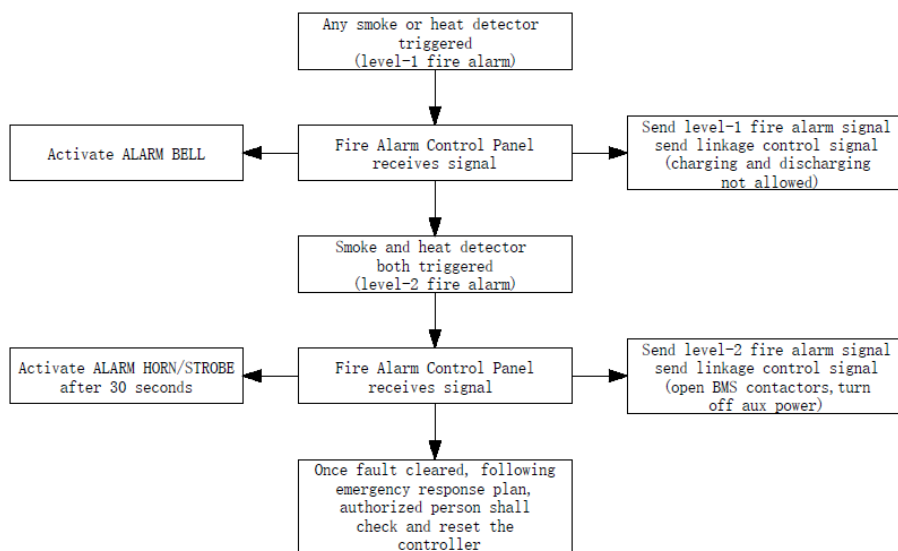
Main circuit block diagram (one sets of ports):

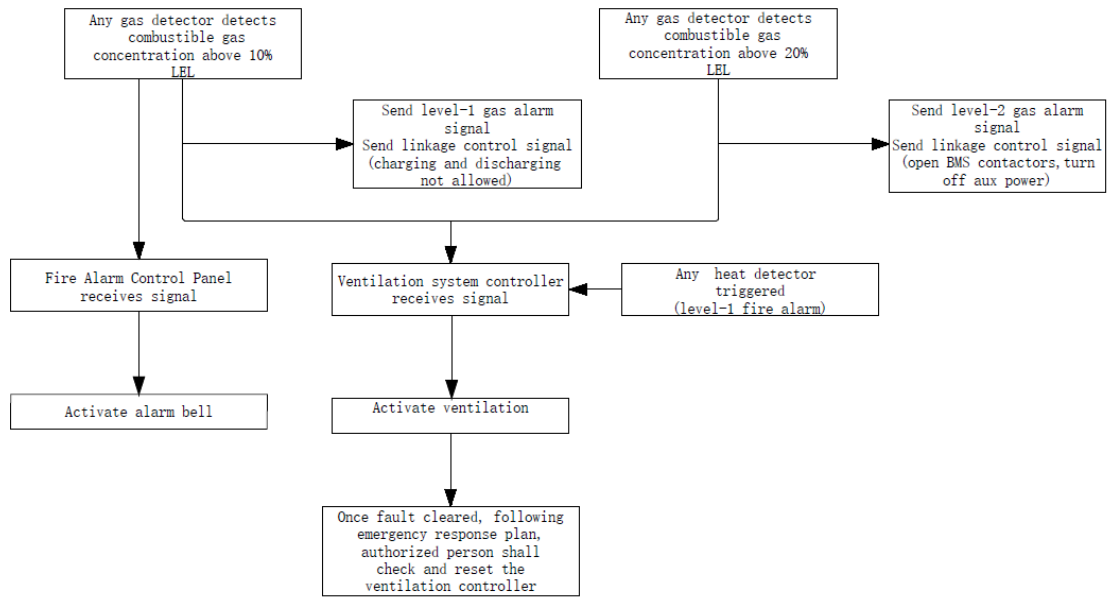


2.3. Venting System Information



Layout





Logic Diagram of the fire safety system and Ventilation System

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3. Ventilation system evaluation referring to Chapter 8 in NFPA69:2024

Clause	Requirement – Test	Result – Remark	Verdict
Chapter 8	Deflagration Prevention by Combustible Concentration Reduction		--
8.1	Application. The technique for combustible concentration reduction shall be permitted to be considered where a mixture of a combustible material and an oxidant is confined to an enclosure and where the concentration of the combustible can be maintained below the lower flammable limit (LFL).	Specified in details in "CFD analysis of the ventilation system"	P
8.2	Basic Design Considerations		P
8.2.1	All of the following factors shall be considered in the design of a system intended to reduce the combustible concentration below the LFL:	Specified in details in "CFD analysis of the ventilation system"	P
	1) Required reduction in combustible concentration		P
	2) Variations in the process, process temperature and pressure, and materials being processed		P
	3) Operating controls		P
	4) Maintenance, inspection, and testing		P
	5) Concentration variation with time and location within the protected enclosure		P
8.2.2	The LFLs of the combustible components shall be determined at all operating conditions, including startup and shutdown.		P
8.2.3	Protection System Design and Operation		P
8.2.3.1	The owner or operator shall be responsible for a thorough analysis of the process to determine the type and degree of deflagration hazards inherent in the process		P
8.2.3.2	Information required for the monitoring and control of the concentration of combustible components shall be compiled and documented. This information shall include, but not be limited to, the following:		P
	(1) Monitoring and control objectives		P
	(2) Monitored and controlled areas of the process		P
	(3) Dimensioned drawings of the process with the following: (a) Equipment make and model if available, including volumes and diameters and design strengths (b) Plan and elevation views with flows indicated		P

3. Ventilation system evaluation referring to Chapter 8 in NFPA69:2024

Clause	Requirement – Test	Result – Remark	Verdict
	(4) Startup, normal, shutdown, temporary operations, and emergency shutdown process conditions and ranges for the following: (a) Flow (b) Temperature (c) Pressure (d) Oxidant concentration (e) Fuel concentration		P
	(5) Process flow diagram and description		P
	(6) Ambient temperature in process area		P
	(7) Process interlocks		P
8.2.3.3	The owner or operator shall disclose any and all process information required for the protection system design.		P
8.2.3.4	The protection system design shall be subject to a documented review by a qualified person.		P
8.2.3.5	The owner or operator shall be responsible for the maintenance of the system after installation and acceptance based on procedures provided by the vendor. Maintenance records shall be retained for inspection by the authority having jurisdiction.		P
8.2.3.6	The owner or operator shall be responsible for periodic inspection of the system by personnel trained by the system manufacturer. The inspection frequency shall be in accordance with Section 15.7.		N/A
8.2.3.7	Management of Change. The effect of any process change shall be addressed as specified in Section 15.11.		N/A
8.2.3.8	All documentation relevant to the protection system shall be retained in accordance with Chapter 15.		P
8.3	Design and Operating Requirements		P
8.3.1	Combustible Concentration Limit. The combustible concentration shall be maintained at or below 25 percent of the LFL for all foreseeable variations in operating conditions and material loadings, unless the following conditions apply:	Specified in details in "CFD analysis of the ventilation system"	P
	(1) Where continuously monitored and controlled with safety interlocks, the combustible concentration shall be permitted to be maintained at or below 60 percent of the LFL.	Not applicable	N/A

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3. Ventilation system evaluation referring to Chapter 8 in NFPA69:2024

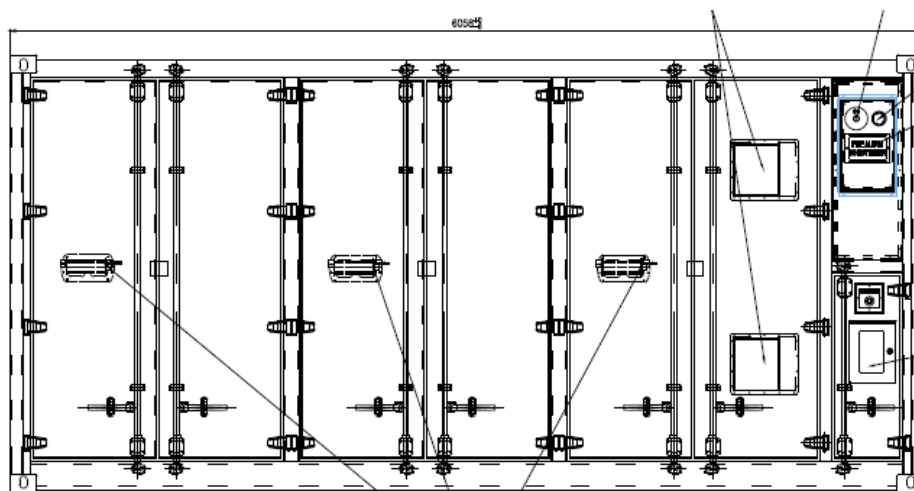
Clause	Requirement – Test	Result – Remark	Verdict
	(2) Aluminum powder production systems designed and operated in accordance with NFPA 484 shall be permitted to be maintained at or below 50 percent of the LFL.	Not applicable	N/A
8.3.2	Catalytic Oxidation. Where catalytic oxidation is used for combustible concentration reduction, the following shall apply:		N/A
	(1) Isolation systems shall be provided in all inlets to the catalytic oxidation unit.		N/A
	(2) Unless the combustible concentration is monitored continuously, the effectiveness of the catalytic oxidation system shall be verified periodically in accordance with the manufacturer's recommendations.		N/A
8.3.3	Ventilation or Air Dilution		P
8.3.3.1	If ventilation is used, the outlets from the protected enclosures shall be located so that hazardous concentrations of the exhausted air cannot enter or be drawn into the fresh air intakes of environmental air – handling systems.		P
8.3.3.2	Air intakes shall meet one of the following requirements:		P
	(1) They shall be located so that combustible material cannot enter the air-handling system, even in the event of spills or leaks.		P
	(2) They shall be provided with gas detectors that automatically interlock to stop air intake.		P
8.3.3.3	Filters, dryers, or precipitators in the air intakes shall be located such that they are accessible for cleaning and maintenance.		P
8.4	Instrumentation		P
8.4.1	Instrumentation shall be provided to monitor and control the process flows.		P
8.4.2	Instrumentation shall be calibrated according to the requirements of Chapter 15.		P
8.4.3	Where the enclosure being protected presents a personnel hazard, alarms shall be provided to indicate abnormal operation of the system.		P

4. CFD analysis of the ventilation system

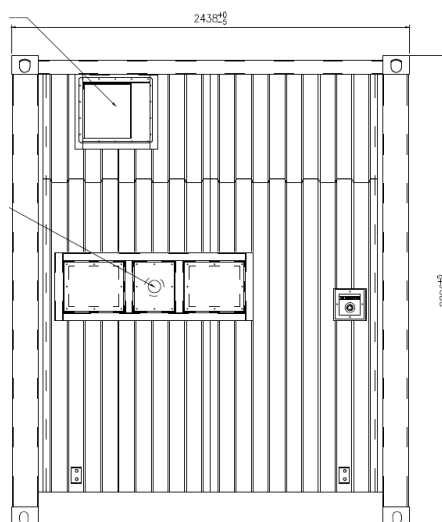
4.1. Basic Information of the system

The interior and exterior drawings provided by CSI were verified between TÜV and CSI before running any calculation.

Figure 4-1 shows an external view of the container and the dimensions from a front and left view. The cube measures 6.058*2.438*2.896 m including one battery cabinets, liquid coolant unit and Auxiliary power supply unit. The cabinet contains 48 modules in rack and 104 cells in each module. The overall internal volume of battery cabinet is approximately 31.38 m³. Subtracting the space filled by racks, modules, and the support structure, the actual open internal volume (efficient volume) is 8.74 m³.



Front view



Left view

Figure 4-1: Geometry of CSI energy storage system

4.2. Principles and Assumptions

The following safety systems and CFD analysis have been acknowledged for the basis of the study's assumptions. Note that the scenarios and assumptions are run according to cell level, module level and unit level UL9540A test to show progressively worse-case scenarios based on the information available and are considered to be conservative.

4.2.1. Thermal runaway and propagation

(1) Propagation between cells:

The UL 9540A test report of module level and unit level indicate that cell to cell propagation could happen within a submodule which contains 26 cells. According to the test report, a total of 5 cells failed both the module level test and the unit level test. Therefore, 5 cells failure is considered in this study.

Assumption 1: There are 5 cells failure within submodule is considered in this study.

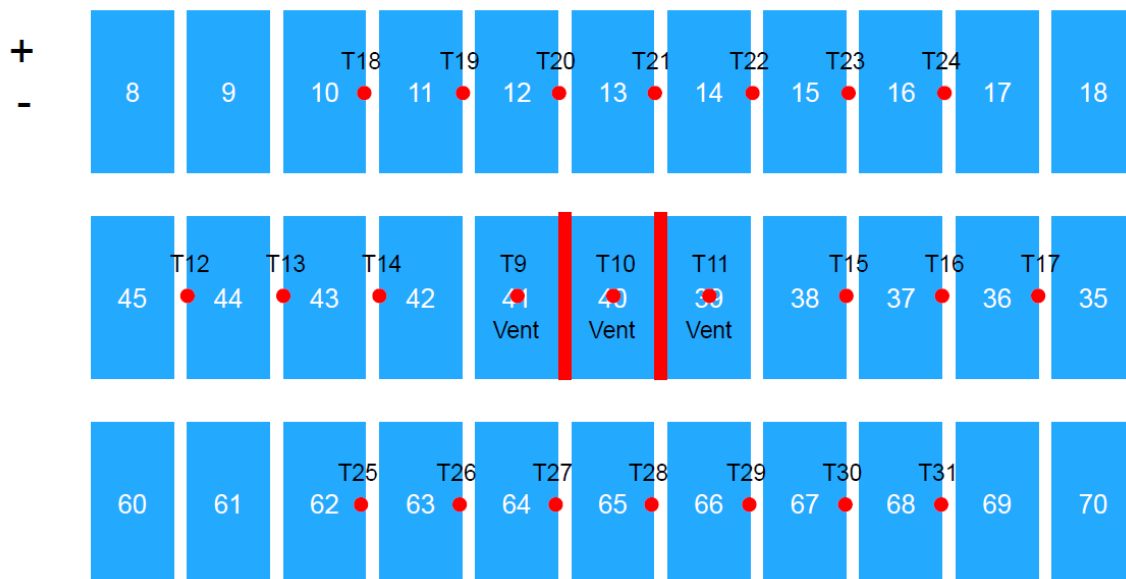


Figure 4-2: Initiating module set up in unit level UL9540A test report.

(2) Propagation between modules:

The UL 9540A test report of unit level does not indicate that it is possible to have propagation between modules.

Assumption 2: There is no module-to-module propagation.

4.2.2. Leakage profile and gas composition

(1) Leakage profile:

The data and test phenomenon in cell level, module level and unit level UL 9540A test report provide gas release rate and total amount. The gas release rate profile in this study is the worst scenario that considered the raw data from module level UL 9540A test. (See Figure 4-3).

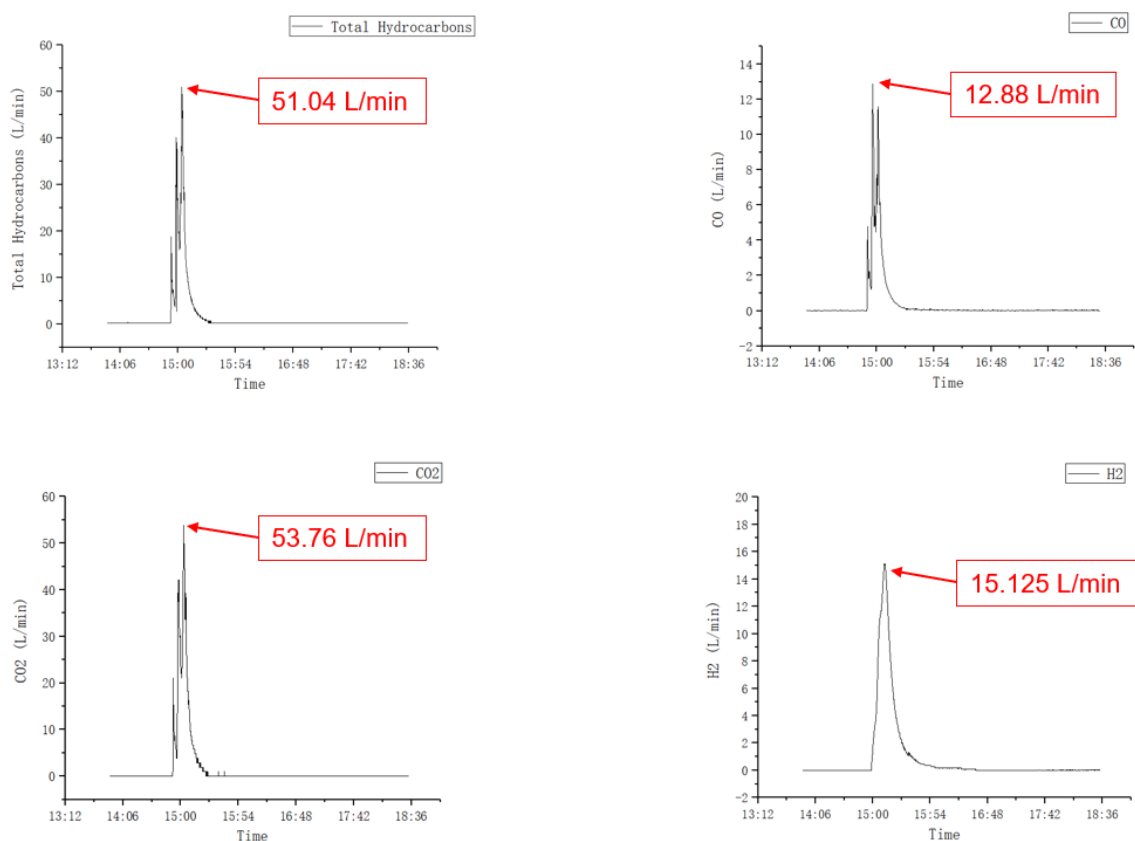


Figure 4-3: Module level gas generation and composition data

For conservative consideration, it is assumed that gas release rate is set to be a constant value which is the maximum release rate throughout the test. Based on module level and unit level test, the gas release is 132.805 LPM according to the test raw data of THC, CO, CO₂ and hydrogen release rate in module level test (See Figure 4-4).

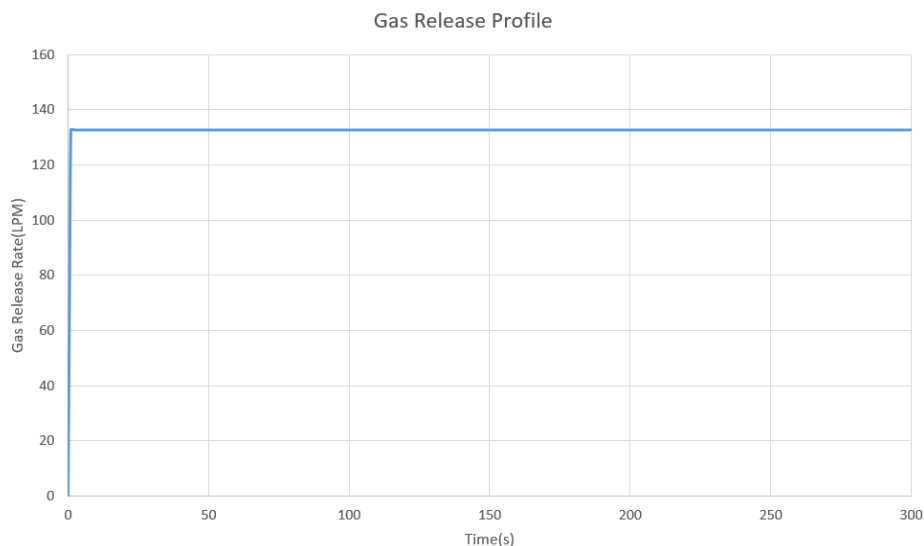


Figure 4-4: Gas release rate profile

Assumption 3: The offgas release profile is set as above for each scenario.

(2) Position of the leak:

According to unit level UL 9540A test, module 1-2 was chosen to be the initial module to form a maximum thermal effect (See Figure 4-5), and the test photo shows the offgas will release from the gas release valve located at the back of module. However, the gas release from the bottom module of the rack (M1-1) takes more time to reach the detector which located at the top of the container. For conservative consideration, the bottom module of the rack (M1-1) is set to be the initiating module.

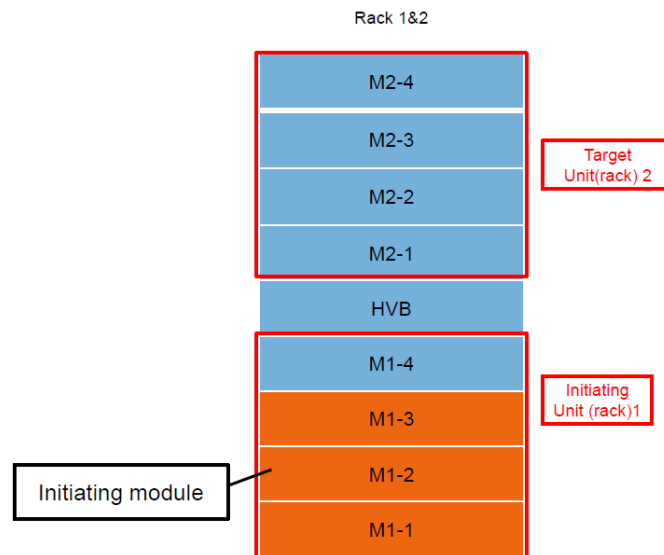


Figure 4-5: Unit level UL 9540A test setup

In order to investigate the influence of the gas release position relative to the sensor and the position of the air inlet and outlet on the exhaust effect, three gas release positions which located on the bottom module of left rack, middle rack and right rack are calculated and simulated separately to see the effect. (See Figure 4-6)

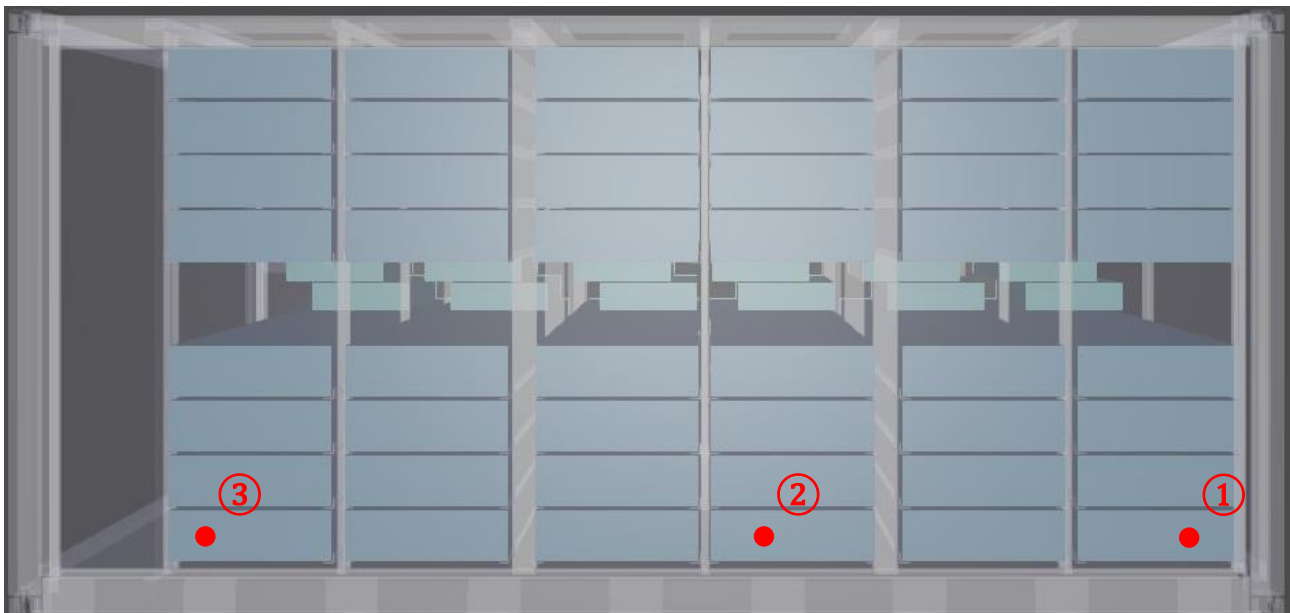


Figure 4-6: Location of gas leakage position (back view).

Assumption 4: Three offgas release positions on M1-1 of the three racks are considered in this study. (See Figure 4-6)

(3) Gas detector:

Regarding the construction of the container, there is two gas detectors equipped on the edge of roof, the location is shown in figure 4-7.

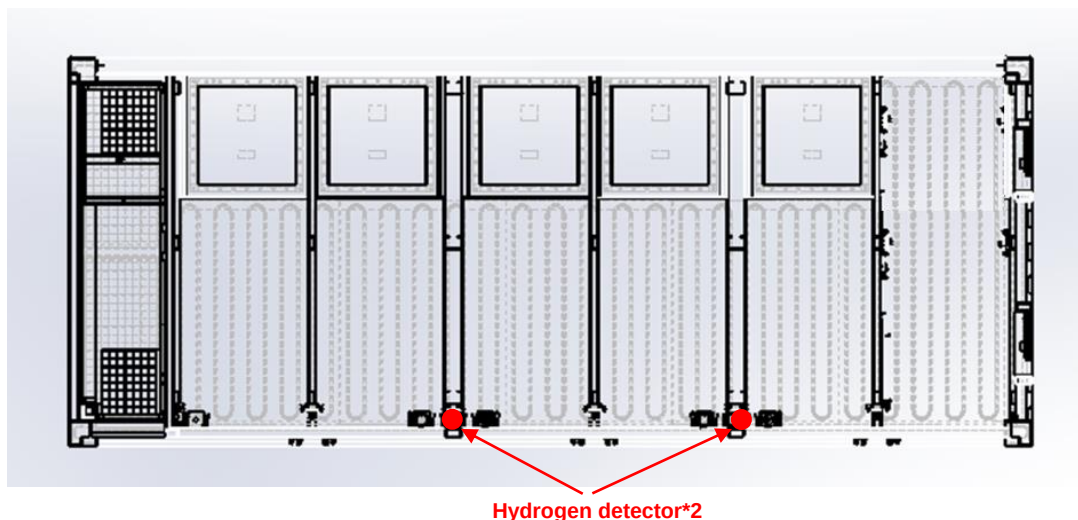


Figure 4-7: Location of gas detectors (top view).

Assumption 5: The positions of gas detectors are set as above to monitor the concentration of hydrogen and trigger ventilation fans.

(4) Gas composition and LFL:

Gas composition was provided in the test data of cell level UL 9540A report. Table 4-1 lists the release gas composition by volume.

Table 4-1: Gas composition by volume

Gas component		Concentration % (v/v)
Methane	CH ₄	4.495
Acetylene	C ₂ H ₂	0.157
Ethylene	C ₂ H ₄	2.299
Ethane	C ₂ H ₆	0.729
Propyne	C ₃ H ₄	0.012
Propylene	C ₃ H ₆	0.952
Propane	C ₃ H ₈	0.211
Butylene	C ₄ H ₈	0.616
Butane	C ₄ H ₁₀	0.080

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Hydrogen	H ₂	49.725
Carbon Monoxide	CO	13.898
Carbon Dioxide	CO ₂	26.826
Total	-	100

The LFL of offgas is provided as 7.3%vol by cell level UL 9540A test report.

Assumption 6: Gas composition is as above, LFL of gas is set to be 7.3%vol in this study.

4.2.3. System safety

(1) Ventilation system:

The container is fitted with one exhaust fan and two inlet motorized blinds which activate immediately when 10% LFL H₂ is detected. The rated flow rate of exhaust fan is 1393.34 m³/h (820 CFM), consider flow rate attenuation in actual container, the exhaust fan operates at a flow rate of 1019.52 m³/h (600 CFM) for a conservative consideration. (See 2.3).

Manufacturer name	Type number	Dimension	Flow Rate (Max)
NANJING HEBEN M&E EQUIPMENT TECHNOLOGY CO., LTD	TPF13, TPF14	410×360mm	820 CFM

Assumption 7: The dispersion simulations are run with exhaust fan which operates at a flow rate of 1019.52 m³/h (600 CFM). The activation time will be calculated from the CFD simulations.

(2) Thermal runaway control:

No thermal runaway prevention system is installed.

Assumption 8: Thermal runaway occurs in the module.

(3) Deflagration panels:

No deflagration panel installed on the container.

Assumption 9: No deflagration panel acts in this report.

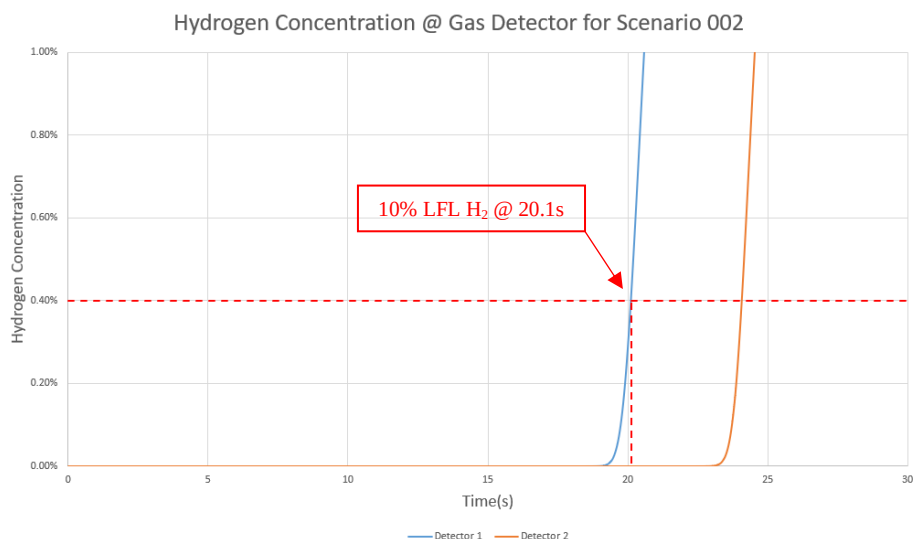
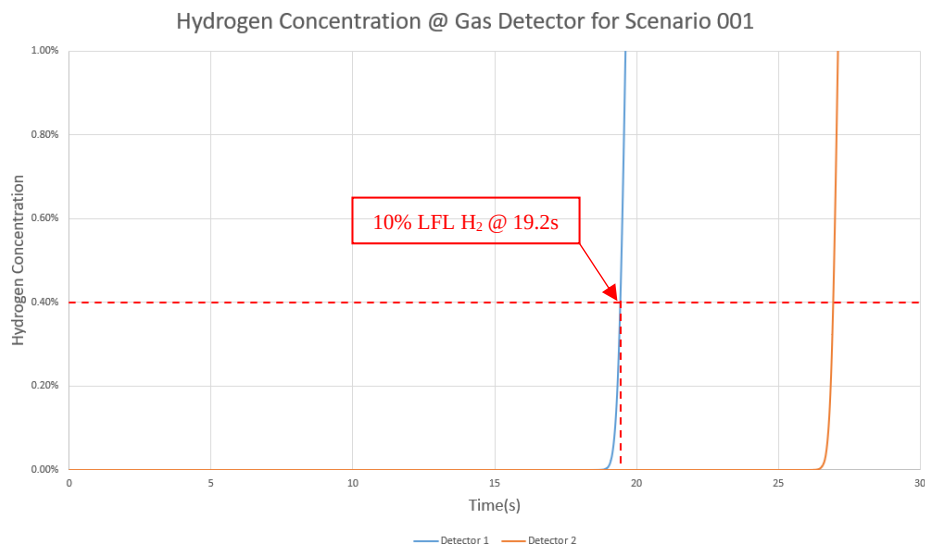
4.3. Simulation Results

A total of 3 dispersion scenarios were run representing progressively worse-case scenarios based on the assumptions made in the previous sections. The modelling covers 3 leakage position.

According to the strategy of ventilation system provided by CSI, the fan will be activated when detection reaches 10% LFL of hydrogen, consider the actual time lag that takes for exhausting fan to reach maximum flow rate, 5s time lag for fan start was added to each scenario after detector activated. Table 4-2 shows the activating time for each scenario. Figure 4-8 shows the hydrogen concentration at the location of gas detector in each scenario.

Table 4-2: Fan activating time.

Scenario	Leakage Point	Activating time (s)
001	1	19.2
002	2	20.1
003	3	20.2



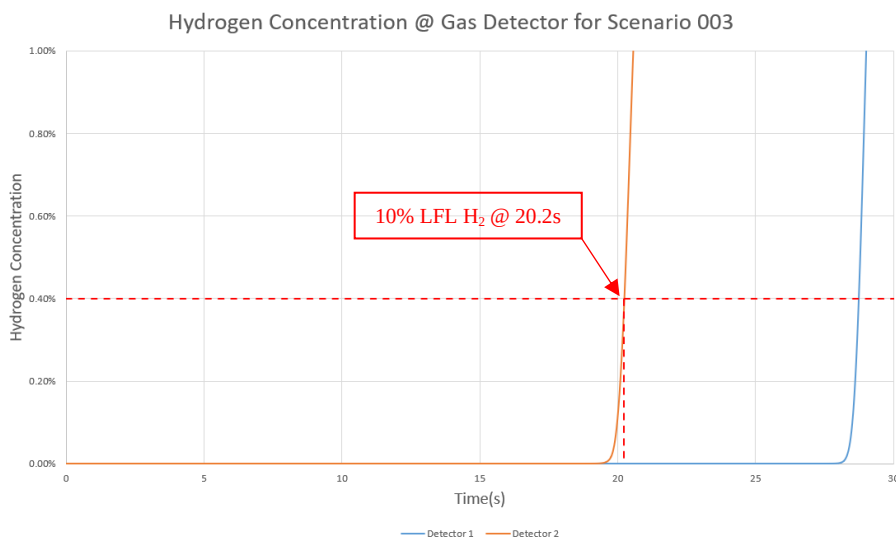


Figure 4-8: Hydrogen concentration at detectors.

Table 4-3 presents a summary of the scenarios and the results from the simulation. The maximum average concentration inside enclosure is presented as the combustible concentration limit according to NFPA 69 Chapter 8.

Table 4-3: Average gas concentration

Scenario	Maximum average gas concentration	
	Vol%	%LFL
001	0.547%	7.49%LFL
002	0.590%	8.08%LFL
003	0.653%	8.95%LFL

Figure 4-9 shows the average gas concentration for each scenario with the extraction fans activated.

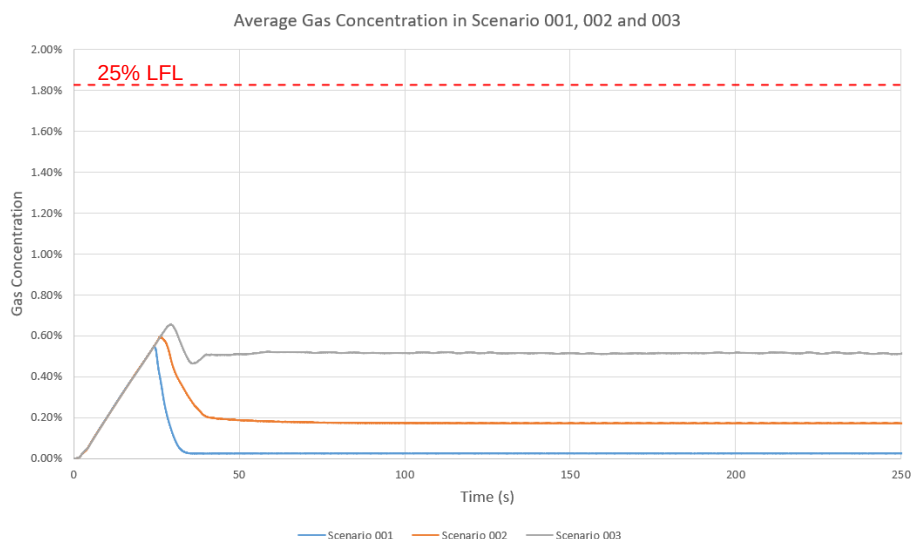
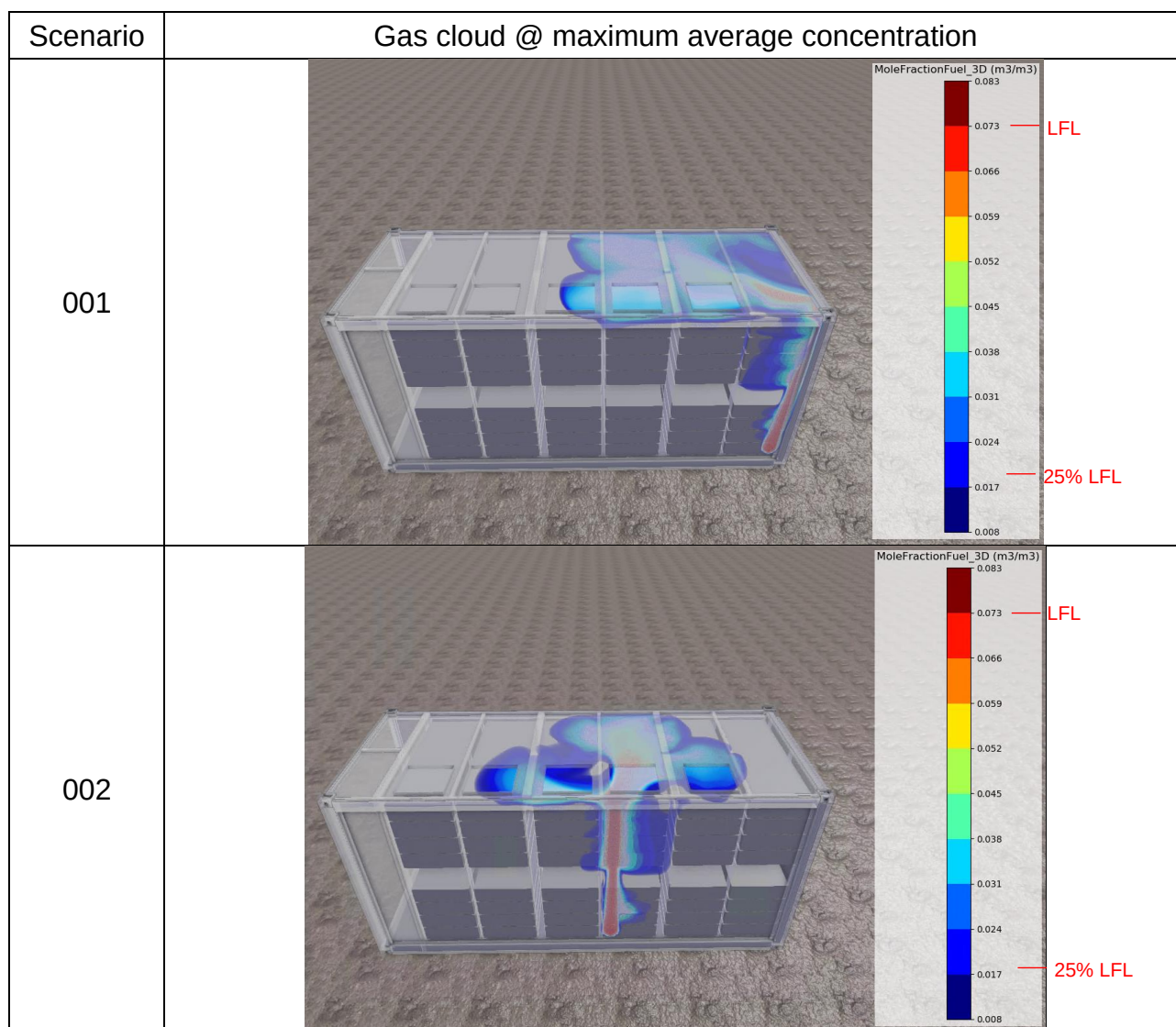


Figure 4-9: Average gas concentration in scenario 001, 002 and 003.

From the simulations we observe:

- All scenarios with extraction fans activated can reduce flammable volume of gas;
- All scenarios with extraction fans activated can remain gas average concentration below 25% LFL in the container;
- There is small pocket of gas above 25%LFL throughout the process (see Figure 4-10).

Figure 4-10 shows the gas cloud inside container at the time step that the gas average concentration is the maximum for each scenario.



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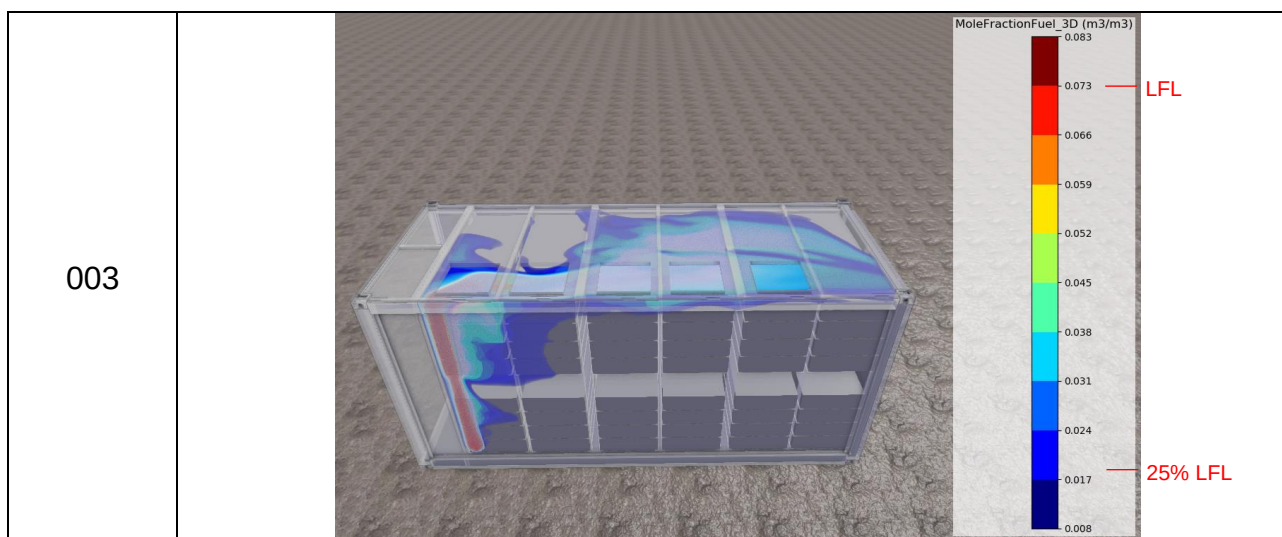


Figure 4-10: Gas cloud at maximum average concentration

4.4. NFPA 69 Analysis

Chapter 8 of NFPA 69 is a section of the standard that discusses deflagration prevention by combustible concentration reduction, which applies to the flammable gas extraction system (via fans and gas detection). Chapter 8 states that the following design and operating requirements must be met to comply with NFPA 69:

The combustible concentration shall be maintained at or below 25 percent of the LFL for all foreseeable variations in operating conditions and material loadings, unless the following conditions apply:

- (1) Where continuously monitored and controlled with safety interlocks, the combustible concentration shall be permitted to be maintained at or below 60 percent of the LFL.
- (2) Aluminum powder production systems designed and operated in accordance with NFPA 484 shall be permitted to be maintained at or below 50 percent of the LFL.

As shown in Figure 4-9, the extraction fans keep the average concentration of gas in the container below 25% LFL in all scenarios. It is noted that small pockets of gas are seen to exceed 25% LFL during the extraction of the gases.

5. Conclusions

Conclusions for CSI Energy Storage System NFPA 69 CFD Analysis are:

- a) All scenarios with extraction fans activated can reduce flammable volume of gas;
- b) All scenarios with extraction fans activated can remain gas average concentration below 25% LFL in the container.
- c) The combustible concentration of all scenarios is within the limit of NFPA 69.

The scenarios in this report follow the situation of cells fail and gas release from test observations outlined in the UL 9540A test report and considered conservative by releasing gas at maximum release rate throughout the test. The exhausting fan activate when gas concentration at detector reaches 10% LFL for hydrogen, consider the actual time lag that takes for exhausting fan to reach maximum flow rate, 5s time lag for fan start was added to each scenario. We could notice from figure 4-9 and 4-10 that the ventilation capability could cover larger scale cell failure condition.

6. References

- (1) NFPA69:2024 Standard on Explosion Prevention Systems
- (2) Cell Level UL9540A Report: CN243TAR 001
- (3) Module Level UL9540A Report: CN25HYJ6 001
- (4) Unit Level UL9540A Report: CN25DK3S 001

End of Report