Hidden Lakes BESS - CATL Ener C+ (306 Ah)

HAZARD MITIGATION ANALYSIS

July 15th, 2024 | Ver. 0

SUMMARY

This document serves as the Hazard Mitigation Analysis performed for the CATL EnerC+ (306Ah) battery energy storage system for use within the Hidden Lakes BESS Facility in Dickinson, TX.

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PROJECT DESCRIPTION

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1 INTRODUCTION

1.1 Background

Energy Safety Response Group (ESRG) has been retained by Stella Energy Solutions to conduct a site- specific Hazard Mitigation Analysis (HMA) in accordance with *NFPA 855 Standard for the Installation of Stationary Energy Storage Systems §4.4.1 Hazard Mitigation Analysis* and the *2021 International Fire Code (IFC) §1207.1.4.1*. for the Hidden Lakes BESS project. This HMA can be utilized to assess the anticipated overall effectiveness of protective barriers in place to mitigate the consequences of a battery-related failure.

This document is provided as a product-level and site-specific review of the CATL Ener-C+ BESS solution to be utilized for the Hidden Lakes BESS.

1.2 Applicable Codes and Standards

The 2023 edition of *NFPA 855 Standard for the Installation of Energy Storage Systems §4.4.1 Hazard Mitigation Analysis* requires an evaluation on the consequences of the following failure modes:

1) *Thermal runaway or mechanical failure condition in a single ESS unit*
2) *Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA)*
3) *Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, fire suppression, or gas detection*

Additionally, for the completeness, this report also includes two additional failure modes required per *2021 International Fire Code (IFC) §1207.1.4.1:*

4) *Voltage surges on the primary electric supply*

5) *Short circuits on the load side of the ESS*

For the purposes of this report, only single failures modes shall be considered for each mode given above.

Per *NFPA 855 §4.4.3,* the AHJ shall be permitted to approve the hazard mitigation analysis as documentation of the safety of the ESS installation provided the consequences of the analysis demonstrate the following:

1) *Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 §9.6.4.*
2) *Fires and products of combustion will not prevent occupants from evacuating to a safe location.*
3) *Deflagration hazards will be addressed by an explosion control or other system.*

The following key codes, standards, and local requirements are referenced throughout the report:

- *NFPA 855 Standard for the Installation of Stationary Energy Storage Systems*, 2023 Edition
- *International Fire Code §1207 Electrical Energy Storage Systems*, 2021 Edition
- *UL 9540A Standard for Test Method for Evaluation Thermal Runaway Fire Propagation in Battery Energy Storage Systems,* 4th Edition
- *UL 9540 Standard for Energy Storage Systems and Equipment,* 2nd Edition

1.3 Summary of Findings

Based on review of documentation provided by Stella Energy Solutions, ESRG finds that adequate protections are provided for the fault conditions listed per *NFPA 855 §4.4.1* and *IFC §1207.1.4.1,* as well as for analysis approval requirements per *NFPA 855 §4.4.3*. Key findings include:

- The CATL EnerC+ (306Ah) is equipped with a number of protection systems (e.g., deflagration vent panels, exhaust ventilation system, BMS control, an active liquid-cooling system for thermal management, electrical shutdowns and disconnects, etc.) that are anticipated to effectively manage all applicable fault conditions required per NFPA 855 §4.1.4 and IFC §1207.1.4.1.
- The CATL EnerC+ is compliant with all applicable Analysis Approval requirements per NFPA 855 §4.1.4.2.
- UL 9540A Unit level testing indicates that no flaming occurred and that no heat propagation from initiating unit to adjacent units / modules reached levels capable of initiating cell venting or thermal runaway.
- The proposed BESS facility and location poses minimal risk to the public, life safety, and property by way of being on a secured site with no public access to the site. The CATL EnerC+ enclosures within the facility meet or exceed manufacturer's recommendations

for separation distances and the installation exceeds minimum required separation distances from all exposures.

- It is recommended that training is provided to the local fire departments to familiarize personnel with the site and hazards associated with lithium-ion ESS. First responders are instructed to stay at a safe distance in the unlikely event of a system failure.

- This HMA focuses on the DC side of the BESS installation (CATL EnerC+ enclosure only). The BESS enclosures will be coupled to a UL 1741 and IEEE 1547 compliant SC4000UD-MV-US Power Conversion System (PCS) with electrical protections that add an additional layer of safety.

2 SITE DESCRIPTION

2.1 Site Overview

The proposed Hidden Lakes BESS facility will be located within 1431 Caroline Street, Dickinson, TX 77539 (Figure 2-1). The BESS boundary area is proposed to be re-zoned to ## type use. The project will consist of nine (9) CATL EnerC+ Battery Energy Storage Systems (BESS), for a total system capacity of approximately 10 MW/## MWh (Figure 2-2).

Figure 2-1 – Site Location

Fire department access to the facility is provided via Caroline Street, as a fire apparatus accessible entrance. The site will be bounded along all exposures by seven-foot-high chain-link fencing. The fenced facility boundary is approximately 720 feet from the roadway. Access to the fenced BESS facility is provided via a 20-ft wide concrete paved road from Caroline Street that is designed to support Fire Department Apparatus vehicle weight. The facility will be located within the Floodplain zone AE with a base flood elevation of 14 feet and 500-year floodplain of 15.9 feet. The battery equipment will be installed on elevated piling foundations above the floodplain elevation.

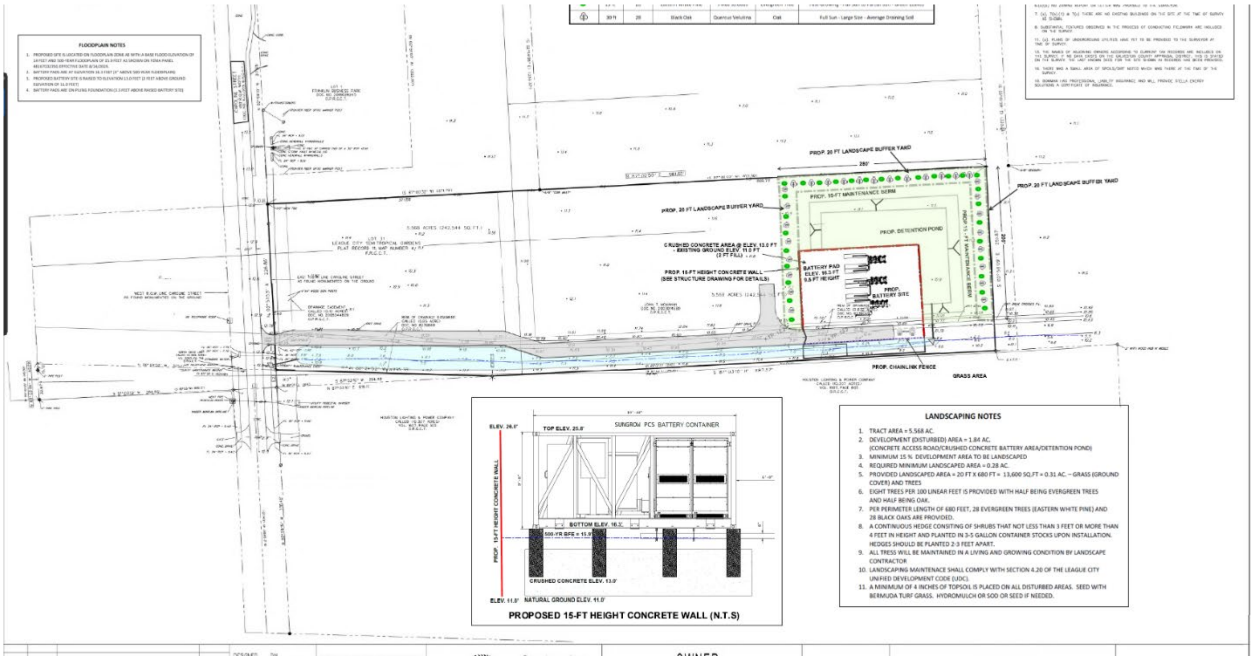


Figure 2-2 – Site Layout and Access

2.2 Nearby Exposures

The CATL EnerC+ units will be sited outdoors at grade level. The separation distances between the CATL enclosures within the facility meet or exceed the manufacturer's recommended separation distances. The proposed BESS facility is classified as an installation near exposures, per *IFC §1207.8.1*. The nearest exposures to the BESS enclosures include a lot line and utility transmission lines to the south (approximately 50 ft.), an existing single-story building and Gas Station to the northwest (approximately 600 ft), and FM 646 Road to the north (approximately 450 ft.).

2.3 Fire Department Access and Water Supply

The proposed Hidden Lakes BESS project is within the response area of the League City Fire and Emergency Services department. The closest fire station to the proposed facility is League City Fire Station 6, approximately 1.1 miles from the facility. The League City Fire Department is comprised of three divisions: Fire, EMS, and Fire Marshal's Office and operates out of six stations comprising of around 150 volunteer Firefighters and several full-time and part-time EMT's/Medics. Responders from the League City Fire Department are anticipated to arrive on scene expeditiously after receiving an emergency alert from the remote monitoring facility communicating with the fire department.

The proposed site will be provided with a nearby private fire hydrant, providing a robust water supply to first responders. The primary hydrant is located within the facility, within 300 ft from the most remote portion of the facility to the East.

3 ENERGY STORAGE SYSTEM DESCRIPTION

3.1 Energy Storage System Overview

The CATL EnerC+ is a modular stationary storage battery system. Each 20’ x 8’ x 9.5’ enclosure utilizes a cabinet-style design and is fully populated by battery modules and associated electrical components, and therefore cannot physically be entered at any time.

The system utilizes lithium iron phosphate (LFP) battery modules and has undergone required UL 9540A Cell, Module, and Unit level testing. Two (2) heat, two (2) smoke, and two (2) combustible gas detectors are provided within each enclosure. An additional (1) smoke detector is provided within the electrical support cabinet at the narrow end of the enclosure. The automatic detectors are interconnected to an internal UL 864 listed (Potter) Fire Alarm Panel and are designed as an addressable system. A thermal management system ensures the battery cells are kept at a uniform temperature to improve performance. The EnerC+ is provided with a glycol based Thermal Management System (TMS) to maintain the optimum temperatures of battery cells within safe operating conditions for each module/rack.

The CATL ENERC+ is equipped with explosion protection in the form of active ventilation system designed in accordance with *NFPA 69: Standard on Explosion Prevention Systems*.

While each enclosure comes with an internal dry-pipe sprinkler which can be charged manually by the fire department to provide water directly to the affected battery modules for cooling, it is recommended by ESRG that this system is not sought out by first responders during a fire event.

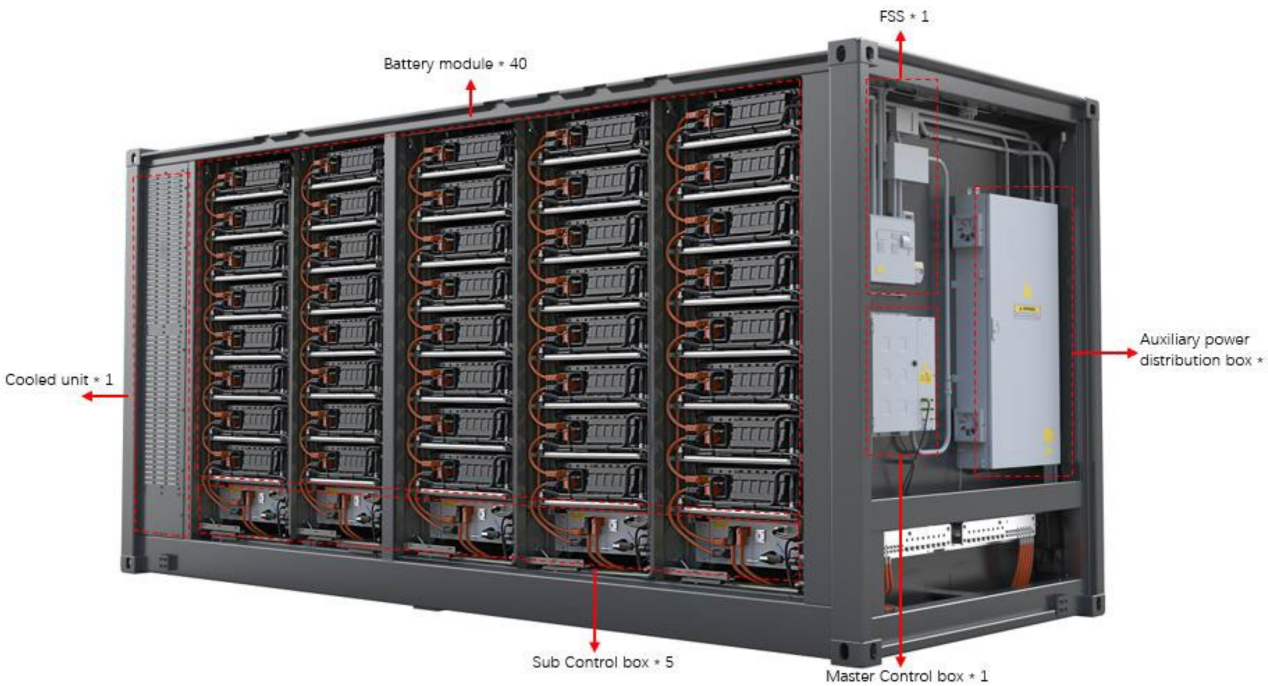
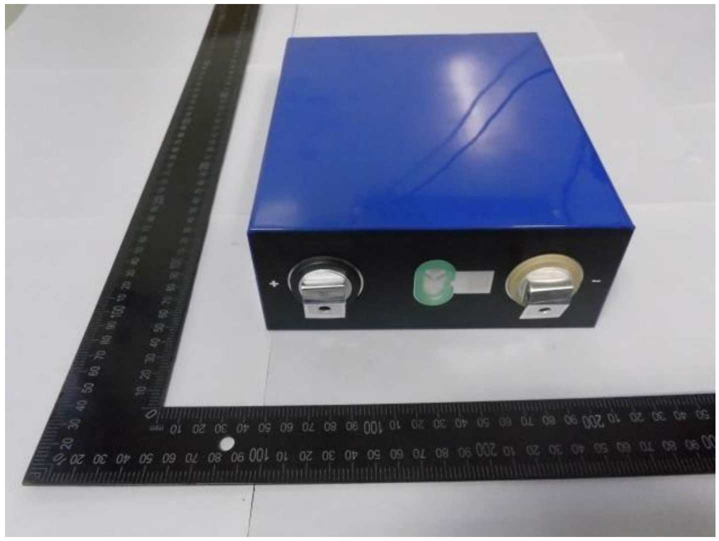


Figure 3 - CATL EnerC+ Enclosure

3.1.1 Battery Cell

The CATL EnerC+ utilizes CATL 3.2 V, 306 Ah lithium iron phosphate (LFP) battery cells.

Figure 4 - CATL 306Ah LFP Cell



3.1.1 Battery Module

Each battery module consists of up to 104 CATL battery cells in a 52S2P arrangement with a dedicated high speed DC fuse on the negative side of the string. Each module is also equipped with a dedicated Battery Management Unit (BMU) for sensing and control of cell balancing functions.

Figure 5 – Battery Module

3.1.2 Battery Rack

Each CATL EnerC+ enclosure consists of five battery bays (which shall also be referred to as racks) connected in parallel. Each rack is comprised of 8 battery modules, with each module comprising of 104 cells for a total of 4160 battery cells (306Ah) per EnerC+ enclosure. Each rack is equipped with a Sub control box comprising of the SBMU, fuse, and DC isolation switch.

Figure 6 - Battery Rack and Electrical Enclosure

3.2 Fire Protection Features

The CATL EnerC+ is equipped with numerous fire safety features designed to mitigate the propagation of a battery failure or prevent the failure from occurring altogether.

3.2.1 Detection Systems

3.2.1.1 Fire Detection

Each CATL EnerC+ enclosure is equipped with two automatic (2) smoke detectors and two (2) heat detectors, with an additional smoke detector installed within the electrical compartment. Automatic detectors and associated equipment shall be installed in accordance with *the International Fire Code and NFPA 855*. System activation will initiate the following notifications and other respective safety actions.

Figure 6 - Fire Protection I/O Matrix

EnerC+(Plan USA02)

CAUSE AND EFFECT MATRIX
FIRE PROTECTION SYSTEM

No.	Name	Position	Function	1	2	3	4	5	6	7	8	9	10	11	12
				Fire suppression control panel status display (indicator light on and displays alarm information)	The fire suppression control panel beeps	The fire suppression control panel 1st-stage fire alarm signal to BMS	The fire suppression control panel 2nd-stage fire alarm signal to BMS	Fan stop	Trouble output	Horn & strobe alarm	The fire suppression control panel outputs aerosol after a delay of 30S	The fire suppression control panel outputs aerosol after a delay of 10S	Fan trouble to BMS	Fan start signal output to BMS	Fan start
INITIATING DEVICE				FACP	FACP	JB01 31-32	JB01 39-40	Fan	JB01 41-42	TRTI	NAC	NAC	Fan	Fan	Fan
1	Smoke detector 1	Battery compartment	Only battery compartment smoke detector 1 fire alarm.	X	X	X				X					
2	Smoke detector 1	Battery compartment	Smoke detector 1 circuit is short.	X	X				X						
3	Smoke detector 1	Battery compartment	The circuit of smoke detector 1 is open, or terminal resistance is off, or probe is off.	X	X				X						
4	Smoke detector 2	Battery compartment	only battery compartment smoke detector 2 fire alarm.	X	X	X				X					
5	Smoke detector 2	Battery compartment	The circuit of smoke detector 2 is short.	X	X				X						
6	Smoke detector 2	Battery compartment	The circuit of smoke detector 2 is open, or probe is off.	X	X				X						
7	Smoke detector 3	Electrical compartment	Only electrical compartment smoke detector 3 fire alarm.	X	X	X				X					
8	Smoke detector 3	Electrical compartment	The circuit of smoke detector 3 is short.	X	X				X						
9	Smoke detector 3	Electrical compartment	The circuit of smoke detector 3 is open, or probe is off.	X	X				X						
10	Heat detector 1	Battery compartment	Only battery compartment heat detector 1 fire alarm.(85℃)	X	X	X				X					
11	Heat detector 1	Battery compartment	The circuit of heat detector 1 is short.	X	X				X						
12	Heat detector 1	Battery compartment	The circuit of heat detector 1 is open, or probe is off.	X	X				X						
13	Heat detector 2	Battery compartment	Only battery compartment heat detector 2 fire alarm.(85℃)	X	X	X				X					
14	Heat detector 2	Battery compartment	The circuit of heat detector 2 is short.	X	X				X						
15	Heat detector 2	Battery compartment	The circuit of heat detector 2 detector is open, or probe is off.	X	X				X						
16	Gas detector 1(H2)	Battery compartment	Only gas detector 1 alarm(10%LEL) , the fan stop button is not pressed.	X	X	X				X				X	X
17	Gas detector 1(H2)	Battery compartment	Gas detector 1 alarm(10%LEL) , the fan stop button is pressed.	X	X	X		X		X					
18	Gas detector 1(H2)	Battery compartment	Gas detector 1 alarm circuit is open.	X	X				X						
19	Gas detector 1(H2)	Battery compartment	Gas detector 1 alarm circuit is short.	X	X	X				X				X	X
20	Gas detector 1(H2)	Battery compartment	Gas detector 1 body is trouble.	X	X				X						
21	Gas detector 2(CO)	Battery compartment	Only gas detector 2 alarm(500ppm) , the fan stop button is not pressed.	X	X	X				X				X	X
22	Gas detector 2(CO)	Battery compartment	Gas detector 2 alarm(500ppm) , the fan stop button is pressed.	X	X	X		X		X					
23	Gas detector 2(CO)	Battery compartment	Gas detector 2 alarm circuit is open.	X	X				X						
24	Gas detector 2(CO)	Battery compartment	Gas detector 2 alarm circuit is short.	X	X	X				X				X	X
25	Gas detector 2(CO)	Battery compartment	Gas detector 2 body is trouble.	X	X				X						
26	Fan emergency start switch	/	Press the fan emergency start switch, the pull station button is not pressed	X	X					X				X	X
27	Fan emergency start switch	/	Press the fan emergency start switch, the pull station button is pressed	X	X			X		X					
28	Smoke detector 1 & Heat detector 1	/	Smoke detector 1 fire alarm and heat detector 1 fire alarm, the abort switch button is not pressed, the disablement switch is in the allowed state.	X	X	X	X			X	X				
29	Smoke detector 1 & Heat detector 2	/	Smoke detector 1 fire alarm and heat detector 2 fire alarm, the abort switch button is not pressed, the disablement switch is in the allowed state.	X	X	X	X			X	X				
30	Smoke detector 2 & Heat detector 1	/	Smoke detector 2 fire alarm and heat detector 1 fire alarm, the abort switch button is not pressed, the disablement switch is in the allowed state.	X	X	X	X			X	X				
31	Smoke detector 2 & Heat detector 2	/	Smoke detector 2 fire alarm and heat detector 2 fire alarm, the abort switch button is not pressed, the disablement switch is in the allowed state.	X	X	X	X			X	X				
32	Smoke detector 1 & Heat detector 1	/	Smoke detector 1 fire alarm and heat detector 1 fire alarm, the abort switch button is pressed, the disablement switch is in the allowed state.	X	X	X	X			X					
33	Smoke detector 1 & Heat detector 2	/	Smoke detector 1 fire alarm and heat detector 2 fire alarm, the abort switch button is pressed, the disablement switch is in the allowed state.	X	X	X	X			X					
34	Smoke detector 2 & Heat detector 1	/	Smoke detector 2 fire alarm and heat detector 1 fire alarm, the abort switch button is pressed, the disablement switch is in the allowed state.	X	X	X	X			X					
35	Smoke detector 2 & Heat detector 2	/	Smoke detector 2 fire alarm and heat detector 2 fire alarm, the abort switch button is pressed, the disablement switch is in the allowed state.	X	X	X	X			X					
36	Smoke detector 1 & Heat detector 1	/	Smoke detector 1 fire alarm and heat detector 1 fire alarm, the abort switch button is not pressed, the disablement switch is in the disable state.	X	X	X	X		X	X					
37	Smoke detector 1 & Heat detector 2	/	Smoke detector 1 fire alarm and heat detector 2 fire alarm, the abort switch button is not pressed, the disablement switch is in the disable state.	X	X	X	X		X	X					
38	Smoke detector 2 & Heat detector 1	/	Smoke detector 2 fire alarm and heat detector 1 fire alarm, the abort switch button is not pressed, the disablement switch is in the disable state.	X	X	X	X		X	X					
39	Smoke detector 2 & Heat detector 2	/	Smoke detector 2 fire alarm and heat detector 2 fire alarm, the abort switch button is not pressed, the disablement switch is in the disable state.	X	X	X	X		X	X					
40	Heat detector 1 & Heat detector 2	/	Heat detector 1 fire alarm and heat detector 2 fire alarm, the abort switch button is not pressed, the disablement switch is in the disable state.	X	X	X	X		X	X					
41	Pull station	Man Release	The pull station button is pressed ,the abort switch button is not pressed, and the disblement switch is in the allowed state.	X	X		X			X		X			
42	Pull station	Man Release	The pull station button is pressed ,the abort switch button is pressed, and the disblement switch is in the allowed state.	X	X		X			X					
43	Pull station	Man Release	The pull station button is pressed ,the abort switch button is not pressed, and the disblement switch is in the disable state.	X	X		X		X	X					
44	Pull station	Man Release	The pull station switch circuit is short.	X	X		X			X		X			
45	Pull station	Man Release	The pull station switch circuit is open, or the terminal resistance is off.	X	X				X						
46	Fan trouble signal	/	Fan body trouble (the fan or louvers cannot operate when the fan is opened)	X	X				X				X		
47	Fan condition signal	/	After the fan starts, feedback the start signal to the fire suppression control panel.	X	X					X				X	
48	Disablement switch	/	The disablement switch is in disable stage.	X	X				X						
49	Disablement switch	/	The circuit is short or open.	X	X				X						
50	Abort switch	ABORT	The abort switch circuit is short.	X	X				X						
51	Abort switch	ABORT	The abort switch circuit is open, or the terminal resistance is off.	X	X				X						
52	Horn & strobe alarm	NAC1	The horn & strobe alarm circuit is short.	X	X				X						
53	Horn & strobe alarm	NAC1	The horn & strobe alarm circuit is open, or the terminal resistance is off.	X	X				X						
54	Aerosol	Exting	Aerosol circuit is short.	X	X				X						
55	Aerosol	Exting	Aerosol circuit short is open.	X	X				X						

Description

1 If any heat detectors， smoke detectors or gas detectors have a fire alarm, the horn & strobe alarm acts and outputs 1st-stage fire alarm signal.

2 Any one of gas detectors alarms (10%LEL or 500ppm), the horn & strobe alarm acts and starts the fan， When the gas sensing concentration is lower than the alarm value, the fan does not stop.

3 Any one of the smoke and heat detector channels alarms at the same time in battery compartment, the 2nd-stage alarm signal is triggered. The fan stops, and the aerosol is triggered after a delay of 30 seconds.

4 Press the pull station switch to trigger the 2nd-stage alarm signal. The fan stops, then the horn & strobe alarm act, and the aerosol is triggered after a delay of 10 seconds.

5 Press the emergency start button to start the fan.The horn & strobe alarm acts and outputs fan start signal.

6 Press the abort switch button to stop the fan.

7 The disablement switch is in the disable state, and The fire suppression control panel outputs trouble signal. At this time, if the fire extinguishing conditions are met, the aerosol will not be released.

8 Any line break, terminal resistance fall off, probe fall off, gas trouble, control panel main power failure or backup battery trouble, the fire suppression control panel outputs trouble signal.

Notes

When container A(control panel locate in container A) output first-stage alarm to BMS,container B,C,D will also output first-stage alarm to their BMS simultaneously.And horn/strobe will be triggered for all containers.

When container A(control panel locate in container A) output second-stage alarm to BMS,container B,C,D will output second-stage alarm to their BMS simultaneously.And horn/strobe will be triggered for all containers.

If there is fault for any container,container A,B,C,D will output fault signal to BMS simultaneously.

Each CATL EnerC+ enclosure is equipped with two (2) combustible gas detectors (calibrated to H2) which are programmed to trigger the exhaust ventilation system at 10% LFL (lower flammability limit). Activation of the combustible gas detectors will trigger the exhaust ventilation system to reduce the concentration of flammable gases released during thermal run away from the enclosure and maintain limits below flammable concentrations.

3.2.2 Exhaust Ventilation System

The CATL EnerC+ is equipped with an active exhaust ventilation system designed in accordance with *NFPA 69: Standard on Explosion Prevention Systems* to remove flammable off-gases during thermal runaway and maintain levels below 25% of the lower flammability limit on average throughout the volume of the enclosure during a simultaneous three-module thermal runaway scenario. The system consists of an explosion proof 820 CFM fan triggered by the included combustible gas detectors (H2) upon detection of 10% LFL of the volume of the enclosure.

A Computational Fluid Dynamics (CFD) analysis of the system has been conducted by TLB Fire Protection engineering (and validated by an independent 3rd party) utilizing UL 9540A data, confirming compliance with NFPA 69. The report indicates that the average LFL concentration throughout the enclosure will be kept below acceptable levels (25% LFL) upon activation. It is also noted that this analysis included a conservative simultaneous 3-module failure scenario which showed that off-gassing can be maintained below flammable limits. Although flammable concentrations may exceed 25% of the LFL in localized areas of the enclosure (at the release points), it is anticipated that the explosion reduction system will mitigate these concentrations to an acceptable level.

3.2.3 Battery Management System

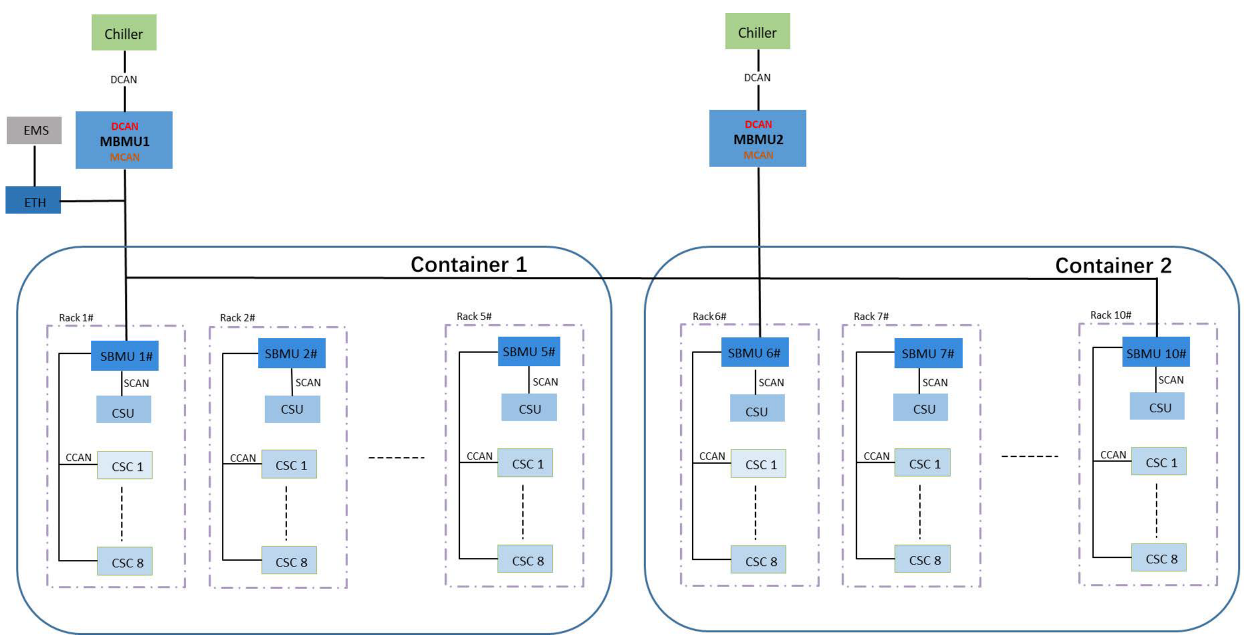
An integrated Battery Management System (BMS) monitors key datapoints such as voltage, current, temperature, state of health (SOH) and state of charge (SOC) of battery cells, in addition to providing control of corrective and protective actions in response to any abnormal conditions. Critical BMS safety functions include prevention of over / under voltages, over-discharge, over-temperature, and overcurrent of the batteries. In the event of any abnormal conditions, the BMS will first raise an information warning, and then trigger a corresponding corrective action should certain levels be reached such as limiting the charging current or power, and automatically disconnecting all HV contactors for isolation.

The CATL Battery Management System (BMS) adopts a three-level management structure design consisting of the following:

- **Cell Supervision Circuit (CSC):** Battery management at the individual module level.
- **Slave Battery Management Unit (SBMU):** The slave battery management unit (rack level) aggregates and analyzes data from the CSC and uploads it to the MBMU.
- **Master Battery Management Unit (MBMU):** The main battery management unit, which receives and controls the information from the SBMU.

For a full list of measurements, fault conditions, and functions of the BMS, please see **CATL ENERC+(306Ah) Documentation.**

Figure 8 – BMS Architecture for two EnerC+ containers in parallel



3.2.4 Fire Suppression System

While the CATL EnerC+ comes with an optional internal dry-pipe water-based suppression system, it has been recommended by ESRG that this system is not utilized.

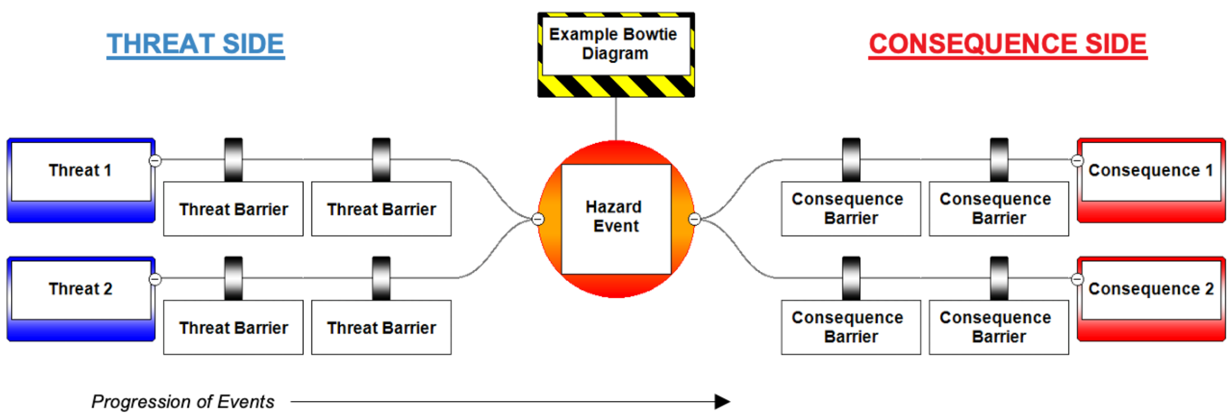
Additionally, the CATL EnerC+ is provided with an optional internal automatically activated aerosol fire suppression generators by FirePro.

4 HAZARD MITIGATION ANALYSIS

4.1 HMA Methodology

ESRG utilizes the bowtie methodology for hazard and risk assessments, as is described in *2023 NFPA 855 Appendix G.3.6* and *ISO.IEC IEC 31010 §B.21*, as it allows for in-depth analysis on individual **mitigative barriers** and serves as a strong tool for visualizing the chronological pathway of **threats** leading to critical hazard events, and ultimately to greater potential **consequences**, as depicted in the figure below. This diagrammatic method of describing and analyzing the pathways of a risk from hazards to outcomes can be considered to be a combination of the logic of a fault tree analyzing the cause of an event and an event tree analyzing the consequences.

Figure 7 - Example Bowtie Diagram



Each fault condition per *NFPA 855* and *IFC* assessed is accompanied by a corresponding bowtie diagram indicating critical threat and consequence pathways and the mitigative barriers between them. As the most critical risk posed by lithium-ion battery cells comes from the propagation of thermal runaway from a failing cell (or multiple cells) to surrounding cells, this serves as the primary critical hazard for the subsequent failure scenarios.

In addition to main barriers for fault conditions on the threat side of the diagram, the consequence barriers on the right side of the diagram (e.g., explosion protection and emergency response plan) **also** contribute added layers of safety on top of the main threat barriers shown. It is important to note that the barriers on the left side, along a threat path, are intended to keep the threat from becoming a thermal runaway, while the barriers on the right side, along the consequence pathway, are intended to keep that single thermal runaway from evolving into one of the more severe consequences such as fire spread beyond containment, off-gassing leading to explosion, or fire spread beyond containment. For more on the methodology and relevant terminology, see Appendix B of this report.

4.2 Relevant Supporting Information

4.2.1 UL 9540A Large-Scale Fire Testing

4.2.1.1 Cell Level Test

UL 9540A (4th Edition) Cell level testing was conducted for the Contemporary Amperex Technology Co., Limited (CATL) CBDD0 306 Ah lithium iron phosphate (LFP) battery cell at UL (Changzhou) Quality Technical Service Co., LTD, issued August 2023.

Thermal runaway was initiated via external heating using thin film with 4°C to 7°C thermal ramp. Cell venting occurred at an average of 154°C over five test samples, with average onset of thermal runaway at 241°C, during which approximately 204 L of gas were released (Figure 14). Gas analysis was conducted to determine Lower Flammability Limit (LFL), burning velocity, and maximum pressure, as noted in the tables below.

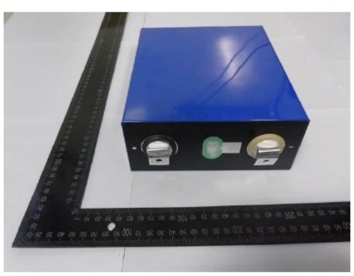
Figure 8 - Cell Thermal Runaway (Left) and Cell Post Test (Right)

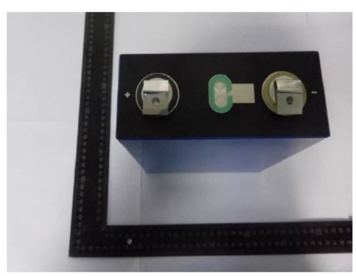
(b) Cell Venting
[34:55]

Table 1 - Cell Level Information

Cell Gas composition		
Gas		Measured %
Carbon Monoxide	CO	14.596
Carbon Dioxide	CO_2	26.925
Hydrogen	H_2	43.066
Methane	CH_4	7.051
Acetylene	C_2H_2	0.119
Ethylene	C_2H_4	3.289
Ethane	C_2H_6	1.060
Propylene	C_3H_6	0.686
Propane	C_3H_8	0.260
-	C4 (Total)	0.865
-	C5 (Total)	0.399
-	C6 (Total)	0.148
1-Heptene	C7H14	0.025
Styrene	C8H8	0.013
Benzene	C_6H_6	0.082
Toluene	C_7H_8	0.012
Dimethyl Carbonate	$C_3H_6O_3$	1.304
Ethyl Methyl Carbonate	$C_4H_8O_3$	0.101
Total	-	100

Cell level information	
Model No ....:	CBDD0
Ratings (Vdc, Ah) ....:	3.2V, 306Ah
Chemistry of test item………………:	Lithium Iron Phosphate
Original Equipment Manufacturer (OEM):	Contemporary Amperex Technology Co., Limited
Branding Manufacturer (if not OEM):	N/A
Was the cell certified? …………………………:	Yes
Standard test item certified to ……………:	UL 1973
Organization that certified test item …….:	MH62898
Average cell surface temperature at gas venting, °C:	154
Average surface temperature at thermal runaway, °C:	241
Gas Volume-:	204L
Lower flammability limit (LFL), % volume in air at the ambient temperature	8.595
Lower flammability limit (LFL), % volume in air at the venting temperature	7.24
Burning velocity (S_u) cm/s:	54.20
Maximum pressure (P_{max}) psig:	102.74





4.2.1.2 Module Level Test

UL 9540A (4th Edition) Module level testing was conducted for the CATL M02306P05L01 battery module consisting of 104 CATL LFP cells (25S2P configuration) by UL (Changzhou) Quality Technical Service Co., LTD labs with report issued 09/13/2023.

Thermal runaway was initiated via external flexible film heaters heated at a rate of 4°C ~ 7°C per minute. Thermal runaway propagation occurred to three adjacent cells during the test. There was no external flaming or flying debris observed during the test. There were no further re-ignitions observed during post-test observations.

Table 2 - Module Level Gas Composition Information

Summary of Module level test Gas Analysis Data:

Gas Analysis:

☒ **Flame ionization detection**

☐ **Fourier-Transform infrared Spectrometer**

☒ **Hydrogen Sensor (palladium-nickel, thin-film solid state sensor)**

☒ **White light source with photo detector (smoke release rate)**

- **Gas Composition & Volume for Each Compound (Pre-flaming and After flame):**

Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate (LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	260.29	No flaming	0.50
Carbon Dioxide	Carbon Containing	217.03	No flaming	1.82
Carbon Monoxide	Carbon Containing	77.57	No flaming	0.61
Hydrogen	Hydrogen	263.37	No flaming	14.29

Table 3 - Module Level Information

Number of initiating cells failed to achieve propagation.	1
Thermal Runaway Propagation:	Initiating cell went into thermal runaway and propagated to three adjacent cells.
Maximum Smoke Release Rate (m^2/s)	0.52
Total Smoke Released: (m^2)	1.41
Total smoke released duration	0:47:08 to 2:00:00
Peak Chemical Heat Release Rate: (kW):	No flaming occurred
External Flaming:	No external flaming occurred
Location(s) of Flame Venting:	No flaming occurred
Flying Debris:	No flying debris occurred
Re-ignitions:	No further re-ignitions were observed during post test observation

 (e) Thermal runaway of adjacent cell 21-1 [00:54:54]	 (f) Thermal runaway of adjacent cell 21-2 [01:07:12]
 (g) Test Termination [02:00:00]	

4.2.1.3 Unit Level Test

UL 9540A (4th Edition) Unit level testing was conducted for the CATL C02306P05L01-R units (and representative models) by UL (Changzhou) Quality Technical Service Co., LTD labs with report issued 10/27/2023.

Cell-to-cell propagation was observed in the initiating module, with propagation confirmed to at least two adjacent cells within the module, and module-to-module propagation was not observed. There was no external flaming observed during the test, and no further re-ignitions observed during the post-test observation period. As Unit level performance criteria were met, Installation level testing was not required.

Table 4 - Unit Level Information

Number of initiating cell(s)	1
Thermal Runaway Propagation:	Initiating cell went into thermal runaway and propagated to at least two adjacent cells.
External Flaming from BESS:	No external flaming occurred
Location(s) of Flame Venting:	No flaming occurred
Maximum Target BESS Temperature, °C	30.5
Maximum Wall Surface Temperature[1], °C	28.3
Peak Chemical Heat Release Rate, kW	No flaming occurred
Peak Convective Heat Release Rate, kW	No flaming occurred
Maximum Smoke Heat Release Rate, m^2/s	0.12
Maximum Heat Flux on Target Modules, kW/m^2	0.01
Maximum Heat Flux of Egress Path, kW/m^2	0
Flying Debris:	No flaming occurred
Re-ignitions:	No further re-ignitions were observed during post test observation

Table 5 - Unit Level Gas Measurements

Summary of Unit level test Gas Analysis Data:

Unit level Gas Composition & Volume for Each Compound (Pre-flaming and After flame):

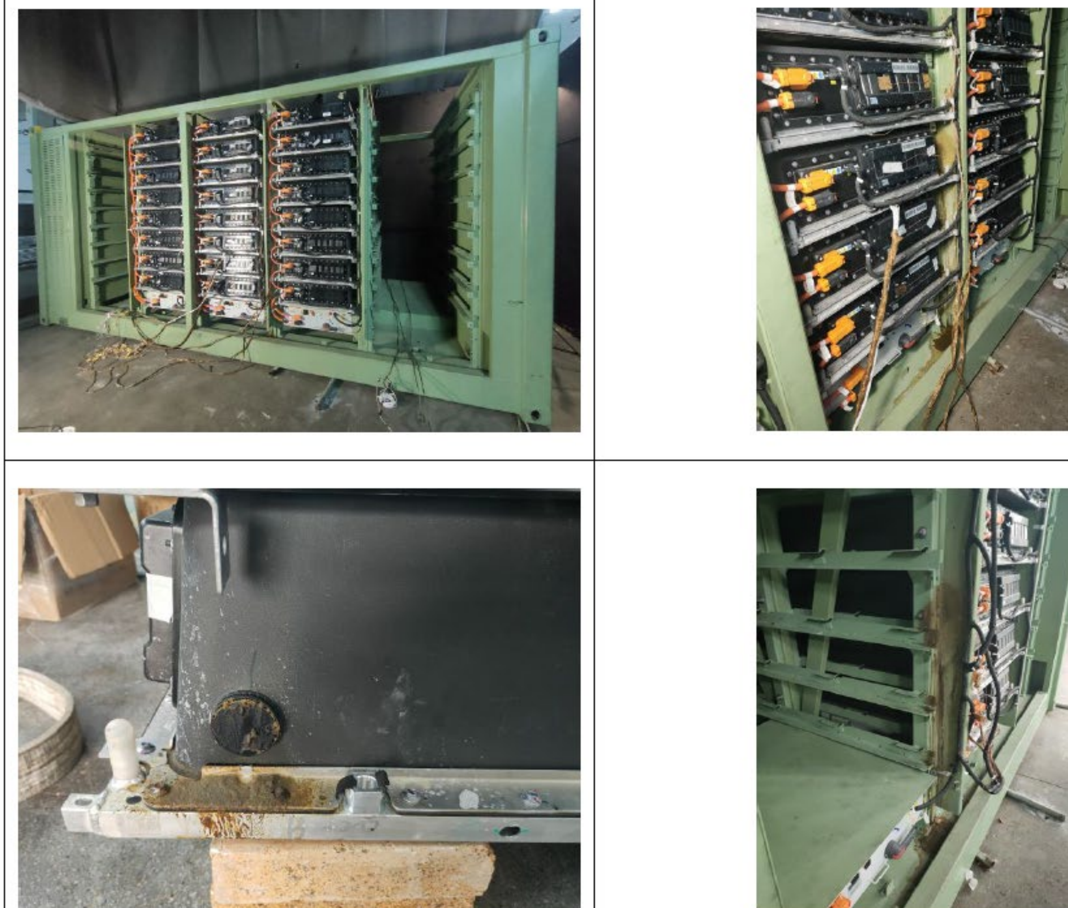
Gas Compound	Gas Type	Pre-Flaming (L)	Flaming (L)	Minimum detectable flow rate(LPM)
Total Hydrocarbons (Propane Equivalent)	Hydrocarbons	111.98	No flaming	4.13
Carbon Monoxide	Carbon Containing	59.54	No flaming	3.08
Carbon Dioxide	Carbon Containing	138.34	No flaming	3.97
Hydrogen	Hydrogen	3.54	No flaming	104.03

Summary of BESS Unit Test Results

Figure 12 - Unit Test Setup

BESS unit and module Construction Photos

Figure 13 – Post Test Photos



[X] Flaming outside the initiating BESS unit was not observed;
[X] Surface temperatures of modules within the target BESS units adjacent to the initiating BESS unit did not exceed the temperature at which thermally initiated cell venting occurs, as determined in 7.3.1.8;
[X] For BESS units intended for installation in locations with combustible constructions, surface temperature measurements on wall surfaces did not exceed 97°C (175°F) of temperature rise above ambient per 9.2.15;
[X] Explosion hazards were not observed, including deflagration, detonation; and
[X] Heat flux in the center of the accessible means of egress did not exceed 1.3 kW/m^2.

Necessity for an Installation level test

[ ] The performance criteria of the unit level test as indicated in Table 9.1 of UL 9540A 4th edition has not been met, therefore an installation level testing in accordance with UL 9540A will need to be conducted on the representative the installation with this unit installed.

[X] The performance criteria of the unit level tests as indicated in Table 9.1 of UL 9540A 4th edition has been met, therefore an installation level testing in accordance with UL 9540A need not be conducted.

4.3 Primary Consequences of ESS Failure and Mitigative Barriers

The dynamics of lithium-ion ESS failures are extremely complex, and the pathway of failure events may vary widely based on system design, mitigative approaches utilized, and even small changes in environmental or situational conditions. However, the primary consequences stemming from a propagating lithium-ion battery failure largely fall into a number of specific hazard scenarios, as depicted in the diagram and associated table below (though other scenarios not listed may certainly also occur). These primary consequences serve as the basis for the consequence side of the majority of the fault condition diagrams in the following sections of this report.

While not explicitly detailed in the simplified diagram below, the criticality and effectiveness of the barriers may vary based on associated threat or consequence pathway. For example, a water-based suppression system may be more critical for mitigation of cell or module combustion from spreading, ultimately leading to fire spread beyond containment, than it is for preventing off-gassing within the enclosure, potentially leading to explosion. Similarly, the same water-based suppression system may be more effective for mitigating spread of fire throughout the system than it is for reducing risk of explosion).

Figure 9 - Primary Consequence Diagram

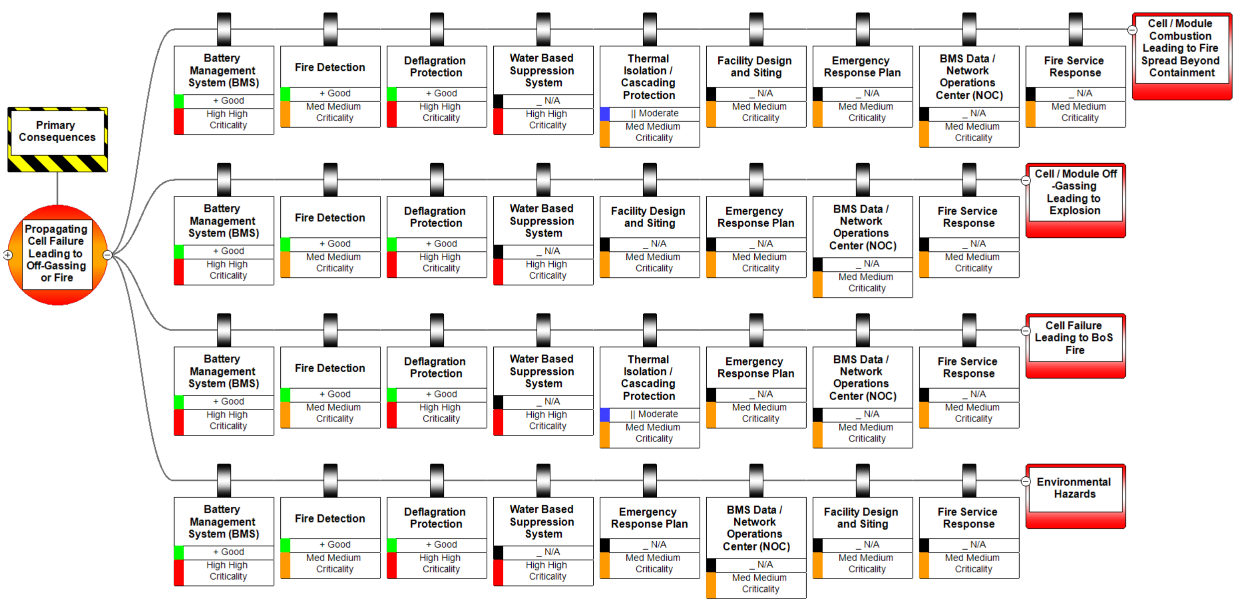


Table 6 - Primary Consequence Barriers

Barrier	Barrier Description	Criticality	Effectiveness
PRIMARY CONSEQUENCE BARRIERS			
Battery Management System (BMS)	The CATL ENERC+ utilizes BMS consisting of three layers (CSC, SBMU,MBMU). Critical BMS sensing parameters include, but are not limited to, over / under voltage, over temperature, temperature signal loss, and over current. In the event of abnormal conditions, the BMS will first raise an information warning, and then trigger a corresponding corrective action in the event that certain levels are reached.	**High**	**Good**
Fire Detection	The CATL ENERC+ is equipped with two (2) smoke detectors, two (2) heat detectors, and two (2) combustible gas detectors for early detection of abnormal conditions in the event of a thermal runaway or fire event within the enclosure and triggering of relevant alarming and fire protection systems.	**Med**	**Good**
Water-Based Suppression System*	The CATL EnerC+ Energy Storage System does not rely on any external or internal water-based suppression system to prevent or mitigate hazards resulting from large-scale failure.	**Med**	**N/A**
Deflagration Protection	The CATL ENERC+ is equipped with an explosion prevention system designed in accordance with NFPA 69 to automatically exhaust flammable gases before they are allowed to accumulate and create an explosive atmosphere within the enclosure. The exhaust system is triggered at 10% LFL detected by the gas detectors such that concentrations are maintained below 25% LFL of the volume of the enclosure.	**High**	**Good**
Facility Design and Siting*	The proposed BESS facility and location poses minimal risk to the public, life safety, and property by way of being on a secured site with no public access to the site. The CATL EnerC+ enclosures within the facility meet or exceed manufacturer's recommendations for separation distances and the installation exceeds minimum required separation distances from all exposures.	**Med**	**Good**
Emergency Response Plan / First Responders*	A site-specific Emergency Response Plan (ERP) is to be provided by ESRG and may greatly improve the strength of this barrier. Additionally, familiarization with the site and applicable equipment by the designated Subject Matter Experts (SMEs), and corporate responders may also provide an increased level of safety.	**Med**	**Good**
BMS Data Availability / Network Operations Center (NOC)*	24/7 remote monitoring of the BMS is to be provided by project developers on a site-specific basis and thus is outside the scope of this product-level	**Med**	**N/A**

	assessment. Further review should be provided on a site-specific basis.		
Fire Service Response*	The proposed site will be provided with a nearby private fire hydrant, providing a robust water supply to first responders. The primary hydrant is located within the facility, within 300 ft from the most remote portion of the facility to the East.	**Med**	**Good**

4.4 Fault Condition Analysis

Per *NFPA 855 §4.4.1*, the analysis shall evaluate the consequences of the following failure modes and others deemed necessary by the AHJ:

1) *Thermal runaway or mechanical failure condition in a single ESS unit*
2) *Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA)*
3) *Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, fire suppression, or gas detection*

Additionally, for the completeness, this report also includes two additional failure modes required per *2021 International Fire Code (IFC) §1207.1.4.1:*

4) *Voltage surges on the primary electric supply*
5) *Short circuits on the load side of the ESS*

For the purposes of this report, it shall be assumed that all construction, equipment, and systems that are required for the ESS shall be installed, tested, and maintained in accordance with local codes and the manufacturer's instructions. The assessment is based on the most recent information provided by Stella Energy Solutions at the time of this writing.

The following table provides a summary of findings from the hazard mitigation analysis performed in fulfillment of *NFPA 855 §4.4.1,* with each fault condition described in greater detail, accompanied by simplified bowtie diagrams for visualization of mitigative barriers. Additionally, full bowtie diagrams with barrier descriptions are provided in Appendix A.

Table 7 - Summary of Fault Condition Analysis

Compliance Requirement	Comments
1. Thermal runaway or mechanical failure condition in a single ESS unit	A number of passive and active measures are implemented to reduce the potential of a thermal runaway event from occurring including BMS control and active cooling to internal components. Battery components have been listed to UL 1973 and UL 9540. Should a thermal runaway event occur, additional mitigative measures are provided to prevent further propagation of failure throughout the system (see Section 3.3 above for list of all consequence barriers).
2. Failure of an energy storage management system or protection system that is not covered by the product listing failure modes and effects analysis (FMEA)	The CATL BMS adopts a three-level management structure for monitoring and control of the systems at the battery module, battery cluster, and battery cabinet level for redundancy in the event that one level of control should fail, as described in Section 2.2.4 of this report.

	To further isolate any failure stemming from a failure of the energy storage management system, passive and active electrical fault protections are provided at multiple levels.
3. Failure of a required protection system including, but not limited to, ventilation (HVAC), exhaust ventilation, smoke detection, fire detection, fire suppression, or gas detection	In the event of failure of the exhaust ventilation system, the potential for accumulation of flammable gases leading to a potential for explosion within the enclosure may be present. Proper Facility Siting, Emergency Response Planning, and Fire Department response shall be critical to mitigate the potential consequences stemming from failure of the exhaust ventilation system. Failure of the provided heat or smoke detectors may result in failure to properly activate respective safety systems as well and provide notification signals to the fire alarm control panel and central station to be relayed to the fire department. However, it is anticipated that the BMS shall still be capable of triggering the respective safety actions in the event of heat or smoke detectors, depending on the nature of the battery failure. Failure of the provided gas detectors may directly affect proper activation of the exhaust ventilation system; therefore, it is imperative that proper emergency response procedures be developed and documented in site-specific Emergency Response Plans for all sites utilizing the CATL EnerC+. It is also noted that UL 9540A Unit level testing indicates that no flaming occurred and that no propagation of heat from the initiating unit to adjacent units / modules reached levels capable of initiating cell venting or thermal runaway.
4. Voltage surges on the primary electric supply *(IFC §1207.1.4.1(4))*	Voltage surges on the primary electric side are anticipated to be mitigated by the provided BMS, voltage monitoring and automatic disconnect provided by the BMS, in addition to a number of passive circuit protections briefly noted in Section 3.2.5 of this report.
5. Short circuits on the load side of the ESS *(IFC §1207.1.4.1(5))*	Short circuits on the load side of the ESS are anticipated to be mitigated by BMS control and subsequent safety actions, in addition to a number of passive circuit protections briefly noted in Section 3.2.5 of this report.

4.4.1 Thermal Runaway Condition

Thermal runaway, as defined per *NFPA 855 §3.3.20*, is defined as the condition when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing, fire, or explosion. The cause of a thermal runaway event can range from a manufacturer defect in the cell, external impact, exposure to dangerously high temperatures, or a multitude of controls and electrical failures. Furthermore, a thermal runaway event in a single cell can propagate to nearby cells, thus creating a cascading runaway event across battery modules and racks, leading to more heat generation, fire, off-gassing, and increased potential for a deflagration event.

The CATL EnerC+ is equipped with a number of passive and active mitigations such as BMS Control and active thermal management system for cooling of internal components to reduce the potential of a thermal runaway event from occurring, as is depicted on the threat side of the diagram below. Threat scenarios accounted for include single-cell thermal runaway, multi-cell thermal runaway, and internal defect or failure not resulting in thermal runaway, leading to the primary hazard event (propagating cell failure leading to off-gassing or fire).

Should thermal runaway occur within a battery module, a number of key barriers are provided to mitigate against propagation of failure throughout the system leading to more severe consequences, which are described in detail in Section 3.3 of this report above.

Figure 10 - Thermal Runaway Condition Diagram

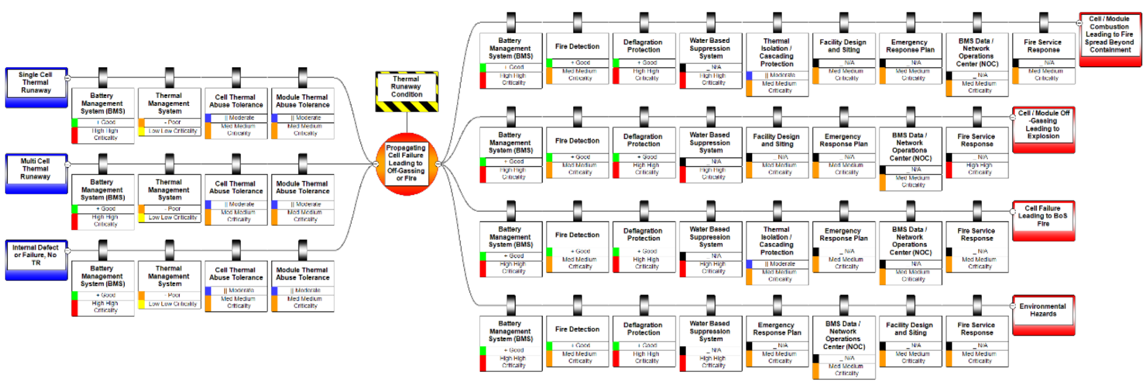


Table 8 - Thermal Runaway Condition Barriers

Barrier	Barrier Description	Criticality	Effectiveness
THREAT BARRIERS			
Battery Management System (BMS)	BMS provides sensing and control of critical parameters and triggers protective or corrective actions if system is operating out of normal parameters. The BMS consists of three layers (CSC, SBMU, MBMU). Critical BMS sensing parameters include, but are not limited to, over / under voltage, over temperature, temperature signal loss, and over current. In the event of abnormal conditions, the BMS will first raise an information warning, and then trigger a	**High**	**Good**

	corresponding corrective action in the event that certain levels are reached.		
Thermal Management System	Active thermal management system provides liquid cooling to internal components within the CATL EnerC+ to limit heat diffusion to adjacent battery cells / modules.	**Low**	**Poor**
Cell Thermal Abuse Tolerance	Cell has been tested and listed to UL 1973 in which thermal abuse tolerance was tested.	**Med**	**Moderate**
Module Thermal Abuse Tolerance	Module has been tested and listed to UL 1973 in which thermal abuse tolerance was tested.	**Med**	**Moderate**
CONSEQUENCE BARRIERS			
See Section 3.3 above for list of primary consequence barriers.			

4.4.2 Failure of an Energy Storage Management System

The loss, failure, or abnormal operation of an energy storage control system (controllers, sensors, logic / software, actuators, and communications networks) may directly impact the proper function of the system. The CATL EnerC+ utilizes a tiered hierarchy of controls, as noted in Section 2.2.4 above, providing multiple levels of redundancy in the event that one level of controls fails.

To further isolate any failure stemming from a failure of the energy storage management system, passive and active electrical fault protections are provided at multiple levels, as described in previous sections.

Finally, should a propagating thermal runaway occur, a number of key barriers are provided to mitigate against propagation of failure throughout the system leading to more severe consequences, which are described in detail in Section 3.3 of this report above.

Figure 11 - Failure of an Energy Storage Management System Diagram

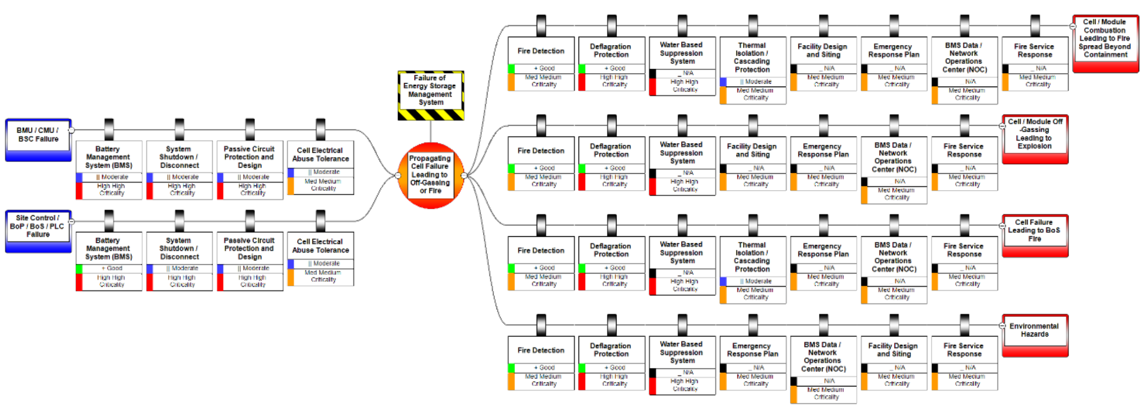


Table 9 - Failure of an Energy Storage Management System Barriers

Barrier	Barrier Description	Criticality	Effectiveness
THREAT BARRIERS			
Battery Management System (BMS) Levels	The CATL EnerC+ utilizes three levels of BMS control (CSC, MBMU, SBMU) for redundancy in the event that one level fails.	**High**	**Moderate**
BMS in Event of Site Control / BOP / BOS / PLC Failure	BMS provides sensing and control of critical parameters and triggers protective or corrective actions if system is operating out of normal parameters. The BMS consists of three layers (CSC, SBMU, MBMU). Critical BMS sensing parameters include, but are not limited to, over / under voltage, over temperature, temperature signal loss, and over current. In the event of abnormal conditions, the BMS will first raise an information warning, and then trigger a corresponding corrective action in the event that certain levels are reached.	**High**	**Good**
System Shutdown / Disconnect	Multiple levels of electrical protection are provided including module level fuses, manual maintenance switch (MSD), sub control box fuse, sub control box relay and isolating switch, etc. Additional site-specific electrical protections should also be reviewed on a site-specific basis for completeness.	**High**	**Moderate**
Passive Circuit Protection and Design	Fused disconnects and isolation switches, in addition to ground fault detection / interruption and over voltage (surge) protection provided.	**Med**	**Good**
Cell Electrical Abuse Tolerance	Cell tested and certified to UL 1973/UL 9540 in which electrical abuse tolerance was tested	**Med**	**Moderate**
Module Electrical Abuse Tolerance	Module tested and certified to UL 1973/UL 9540 in which electrical abuse tolerance was tested	**Med**	**Moderate**
CONSEQUENCE BARRIERS			
See Section 3.3 above for list of primary consequence barriers.			

4.4.3 Failure of a Required Ventilation or Exhaust System

As noted in previous sections, there are a number of mitigative barriers in place to prevent a thermal runaway event from occurring at all. For the purposes of this fault condition, it shall be assumed that a thermal runaway condition has already occurred and that the exhaust ventilation system has failed. Failure of this exhaust ventilation system may result in the accumulation of large quantities of flammable off-gases released during thermal runaway within the enclosure, potentially leading to a deflagration or explosion event. This worst-case scenario presents a severe hazard to emergency responders and the mitigative barriers will shift from fire safety systems intrinsic to the system to facility siting and human factors including emergency response planning and fire department response.

The availability of BMS data transmitted to a 24/7 remote Network Operations Center (NOC) may be helpful for providing useful information to guide fire operations. It is recommended that additional information on BMS data availability / Network Operations Center (if available) be provided for evaluation.

Figure 12 - Failure of a Required Ventilation or Exhaust System Diagram

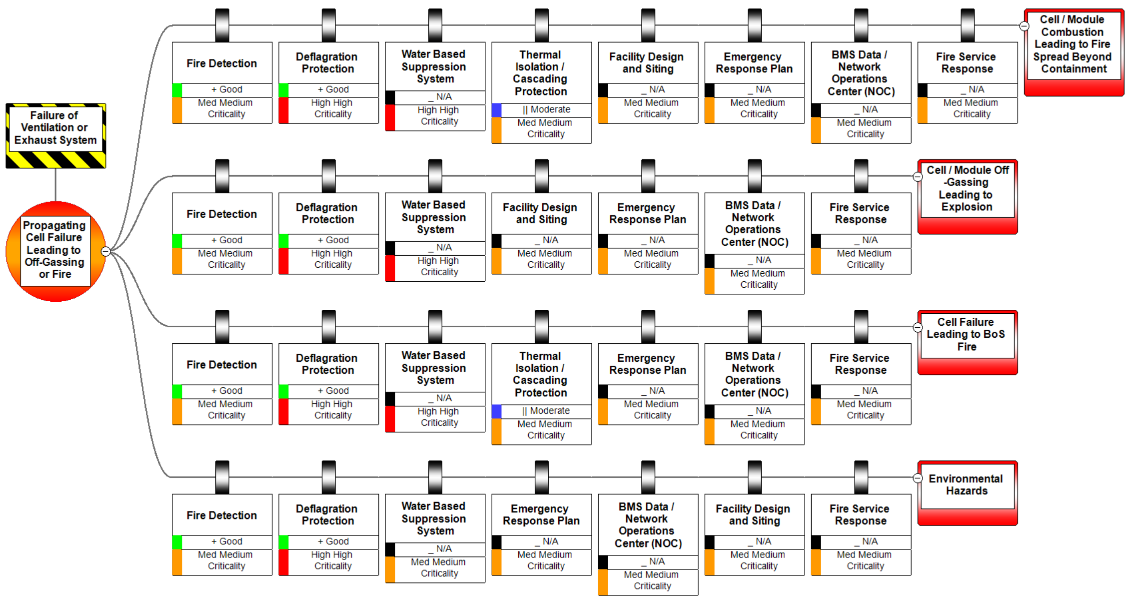


Table 10 - Failure of a Required Ventilation or Exhaust System Barriers

Barrier	Barrier Description	Criticality	Effectiveness
CONSEQUENCE BARRIERS			
Battery Management System (BMS)	In the event of failure of the exhaust ventilation system, BMS monitoring and safety actions may be useful in preventing further propagation of failure to nearby battery cells or modules, though will not be able to control the affected exhaust ventilation system.	**Low**	**Low**
Fire Detection	While useful for detection of excessive heat, smoke, or gases released during thermal runaway, triggering respective safety actions, in the event of an exhaust system, provided detection systems may only provide a limited amount of information in the event of a critical battery failure.	**Low**	**Low**

Thermal Isolation / Cascading Protection	UL 9540A (4th Ed.) Unit level testing indicated no observation of module-to-module propagation, flying debris or explosive discharge of gases, sparks, electrical arcs or other electrical events, or external flaming observed during test.	**Med**	**Moderate**
Facility Design and Siting*	The proposed BESS facility and location poses minimal risk to the public, life safety, and property by way of being on a secured site with no public access to the site. The CATL EnerC+ enclosures within the facility meet or exceed manufacturer's recommendations for separation distances and the installation exceeds minimum required separation distances from all exposures.	**Med**	**Good**
Emergency Response Plan / First Responders*	A site-specific Emergency Response Plan (ERP) is to be provided by ESRG and may greatly improve the strength of this barrier. Additionally, familiarization with the site and applicable equipment by the designated Subject Matter Experts (SMEs), and corporate responders may also provide an increased level of safety.	**Med**	**Good**
BMS Data / Network Operations Center (NOC)	24/7 remote monitoring of the BMS is to be provided by project developers on a site-specific basis and thus is outside the scope of this product-level assessment. Further review should be provided on a site-specific basis.	**Med**	**N/A**
Fire Service Response*	The proposed site will be provided with a nearby private fire hydrant, providing a robust water supply to first responders. The primary hydrant is located within the facility, within 300 ft from the most remote portion of the facility to the East.	**Med**	**Good**

4.4.4 Failure of a Required Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System

The failure of the provided heat, smoke, or gas detection systems may result in failure to activate respective safety systems and provide notification signals to the fire alarm control panel and central station to be relayed to the fire department.

While it is anticipated that the BMS shall still be capable of triggering the respective safety actions should the provided smoke or heat detectors fail, depending on the nature of the battery failure event, notification signals to the fire alarm control panel and central station may be directly impacted. Heat and smoke detector fault notifications are provided by the integral fire alarm panel and will be relayed off-site if received.

The failure of the provided gas detectors may directly affect activation of the exhaust ventilation system, potentially allowing flammable concentrations of off-gases to accumulate within the enclosure, posing a serious deflagration risk should a source of ignition be provided. Similar to above, combustible gas detectors are monitored for integrity by the integral Fire Alarm Control Panel.

In the event of a failure of any one of these systems, proper response procedures should be established and provided in a site-specific emergency response plan (which is provided by ESRG). If BMS data is available via Network Operations Center, a more detailed understanding of the failure event and required emergency response procedures may be put together. Additionally, as noted in previous sections, strong facility siting may reduce direct impact to the surrounding areas.

It is also noted that UL 9540A Unit level testing indicates that no flaming occurred and that no heat propagation from the initiating unit to adjacent units / modules reached levels capable of initiating cell venting or thermal runaway, which is favorable. However, preparation for a worst-case scenario should be planned for and procedures documented in the aforementioned Emergency Response Plan and site-specific training.

Figure 18 - Failure of Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System Diagrams

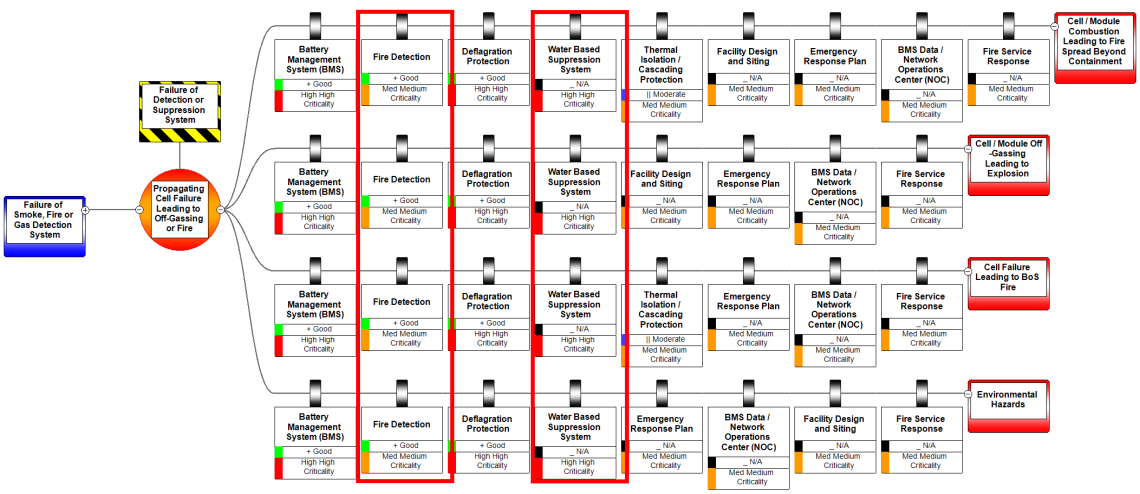


Table 11 - Failure of Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System Barriers

Barrier	Barrier Description	Criticality	Effectiveness
CONSEQUENCE BARRIERS			
Battery Management System (BMS)	In the event of failure of the exhaust ventilation system, BMS monitoring, and safety actions may be useful in preventing	**Low**	**Low**

	further propagation of failure to nearby battery cells or modules, though will not be able to control the affected exhaust ventilation system.		
Fire Detection	The CATL EnerC+ is equipped with two (2) smoke detectors, two (2) heat detectors, and two (2) gas detectors for early detection of abnormal conditions in the event of a thermal runaway or fire event within the enclosure and triggering of relevant alarming and fire protection systems.	**N/A**	**N/A**
Water-Based Suppression System	The CATL EnerC+ is equipped with an optional internal water-based suppression system. It is recommended by ESRG that this system is not sought out by First Responders during an event.	**N/A**	**N/A**
Thermal Isolation / Cascading Protection	UL 9540A (4th Ed.) Unit level testing indicated no observation of module-to-module propagation, flying debris or explosive discharge of gases, sparks, electrical arcs or other electrical events, or external flaming observed during test.	**Med**	**Moderate**
Facility Design and Siting	The proposed BESS facility and location poses minimal risk to the public, life safety, and property by way of being on a secured site with no public access to the site. The CATL EnerC+ enclosures within the facility meet or exceed manufacturer's recommendations for separation distances and the installation exceeds minimum required separation distances from all exposures.	**Med**	**Good**
Emergency Response Plan / First Responders	A site-specific Emergency Response Plan (ERP) is to be provided by ESRG and may greatly improve the strength of this barrier. Additionally, familiarization with the site and applicable equipment by the designated Subject Matter Experts (SMEs), and corporate responders may also provide an increased level of safety.	**Med**	**Good**
BMS Data / Network Operations Center (NOC)	The CATL EnerC+ has the capability of being remotely monitored by a Network Operations Center (NOC), though further evaluation of these capabilities should be performed on a site-specific basis for projects utilizing the CATL EnerC+.	**Med**	**N/A**
Fire Service Response*	The proposed site will be provided with a nearby private fire hydrant, providing a robust water supply to first responders. The primary hydrant is located within the facility, within 300 ft from the most remote portion of the facility to the East.	**Med**	**Good**

4.4.5 Voltage Surges on the Primary Electric Supply

Voltage surges on the primary electric supply are expected to be largely mitigated by voltage monitoring and corrective actions taken by the BMS. Should corrective actions triggered by the BMS fail to prevent further propagation of failure, a number of electrical fault protections (e.g., fused disconnects for modules and racks, DC isolation switch, and surge protection devices) are provided. E-stops are also to be located at a safe distance from ESS units, though assessment of site-specific electrical protections is outside the scope of this report.

Figure 19 - Voltage Surges on the Primary Electric Supply Diagram

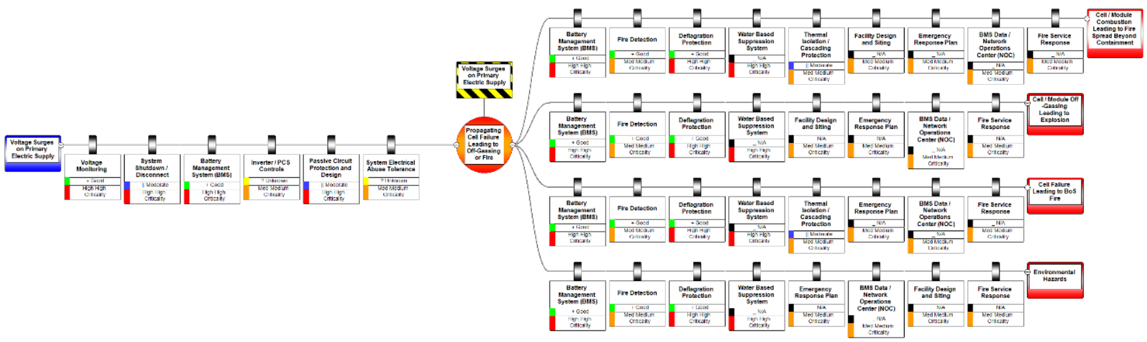


Table 12 - Voltage Surges on the Primary Electric Supply Barriers

Barrier	Barrier Description	Criticality	Effectiveness
THREAT BARRIERS			
Voltage Monitoring	Voltage is measured by BMS, triggering fault and alarm monitor indicators, and potential system disconnect or other corrective actions if operating out of normal parameters.	**High**	**Good**
System Shutdown / Disconnect	Multiple levels of electrical protections provided including fused disconnects for module (pack) and rack, DC isolation switch, etc. Additional site-specific electrical protections should also be reviewed on a site-specific basis for completeness.	**High**	**Moderate**
Battery Management System (BMS)	BMS provides sensing and control of critical parameters and triggers protective or corrective actions if system is operating out of normal parameters. The BMS consists of three layers (CSC, SBMU, MBMU). Critical BMS sensing parameters include, but are not limited to, over / under voltage, over temperature, temperature signal loss, and over current. In the event of abnormal conditions, the BMS will first raise an information warning, and then trigger a	**High**	**Good**

	corresponding corrective action in the event that certain levels are reached		
Inverter / PCS Controls	The BESS enclosures will be coupled to a UL 1741 and IEEE 1547 compliant SC4000UD-MV-US Power Conversion System (PCS) with electrical protections that add an additional layer of safety.	**Med**	**Moderate**
Passive Circuit Protection / Design	Fused disconnects provided for battery module and rack.	**High**	**Moderate**
System Electrical Abuse Tolerance	CATL EnerC+ has been tested and certified to UL 9540.	**Med**	**Moderate**
CONSEQUENCE BARRIERS			
See Section 3.3 above for list of primary consequence barriers.			

4.4.6 Short Circuits on the Load Side of the ESS

Short circuits on the load side of the ESS are anticipated to be largely mitigated by BMS control and passive circuit protection and design (e.g., fused disconnects, ground fault detection / interruption, and overvoltage (surge) protection), as described in previous sections of this report. The CATL EnerC+ has been tested and listed to UL 9540, demonstrating adequate system electrical abuse tolerance and compatibility of constituent components.

Finally, as is consistent across all previous fault conditions covered above, should propagating thermal runaway occur, a number of key barriers are provided to mitigate against propagation of failure throughout the system leading to more severe consequences, which are described in detail in Section 3.3 of this report above.

Figure 20 - Short Circuits on the Load Side of the ESS Diagram

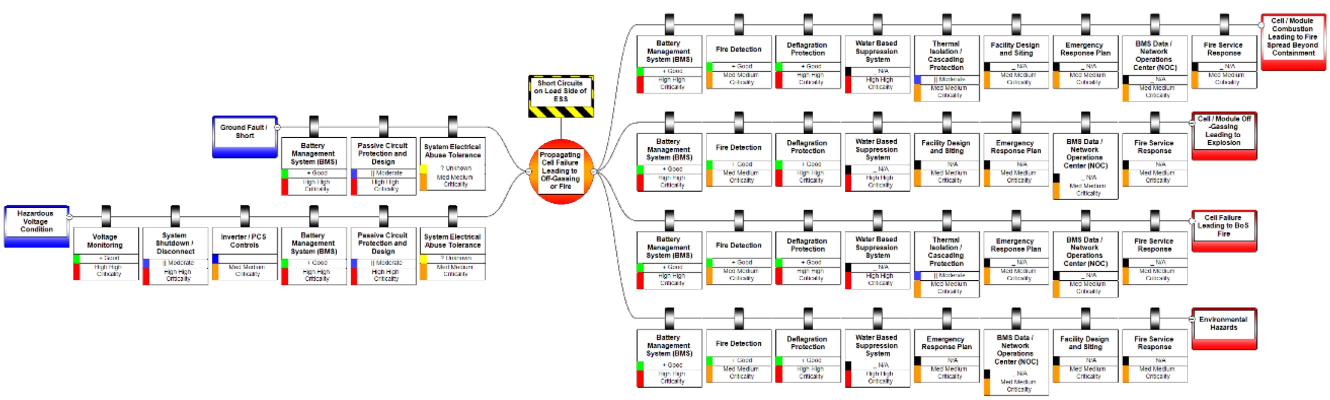


Table 13 - Short Circuits on the Load Side of the ESS Barriers

Barrier	Barrier Description	Criticality	Effectiveness
THREAT BARRIERS			
Battery Management System (BMS)	BMS provides sensing and control of critical parameters and triggers protective or corrective actions if system is operating out of normal parameters. The BMS consists of three layers (CSC, SBMU, MBMU). Critical BMS sensing parameters include, but are not limited to, over / under voltage, over temperature, temperature signal loss, and over current. In the event of abnormal conditions, the BMS will first raise an information warning, and then trigger a corresponding corrective action in the event that certain levels are reached	**High**	**Good**
Voltage Monitoring	Voltage is measured by BMS, triggering fault and alarm monitor indicators, and potential system disconnect or other corrective actions if operating out of normal parameters.	**High**	**Good**
System Shutdown / Disconnect	Multiple levels of electrical protections provided including fused disconnects for module (pack) and rack, DC isolation switch, etc. Additional site-specific electrical protections should also be reviewed on a site-specific basis for completeness.	**High**	**Moderate**
Passive Circuit Protection / Design	Fused disconnects provided for battery module (pack) and rack.	**High**	**Moderate**
System Electrical Abuse Tolerance	CATL EnerC+ has been tested and certified to UL 9540.	**Med**	**Moderate**
CONSEQUENCE BARRIERS			
See Section 3.3 above for list of primary consequence barriers.			

4.5 Analysis Approval

As per NFPA 855 §4.4.3, the AHJ shall be permitted to approve the hazard mitigation analysis as documentation of the safety of the ESS installation provided the consequences of the analysis demonstrate the following:

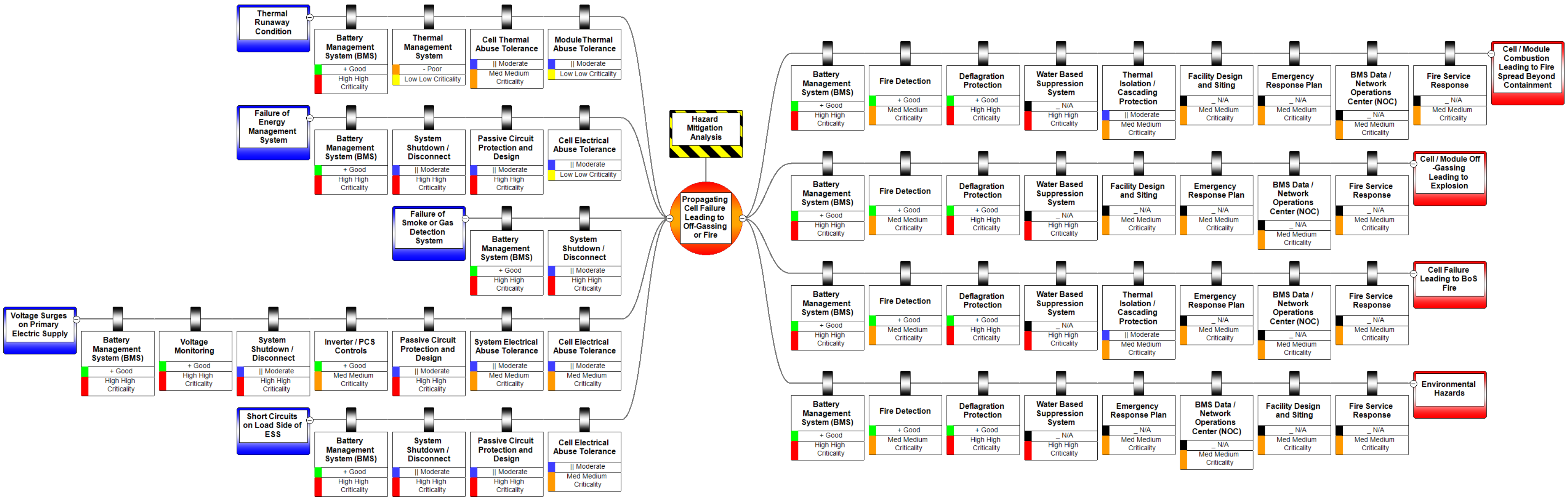
1) *Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 §9.6.4.*
2) *Fires and products of combustion will not prevent occupants from evacuating to a safe location.*
3) *Deflagration hazards will be addressed by an explosion control or other system.*

Table 3-14 - Summary of Analysis Approval

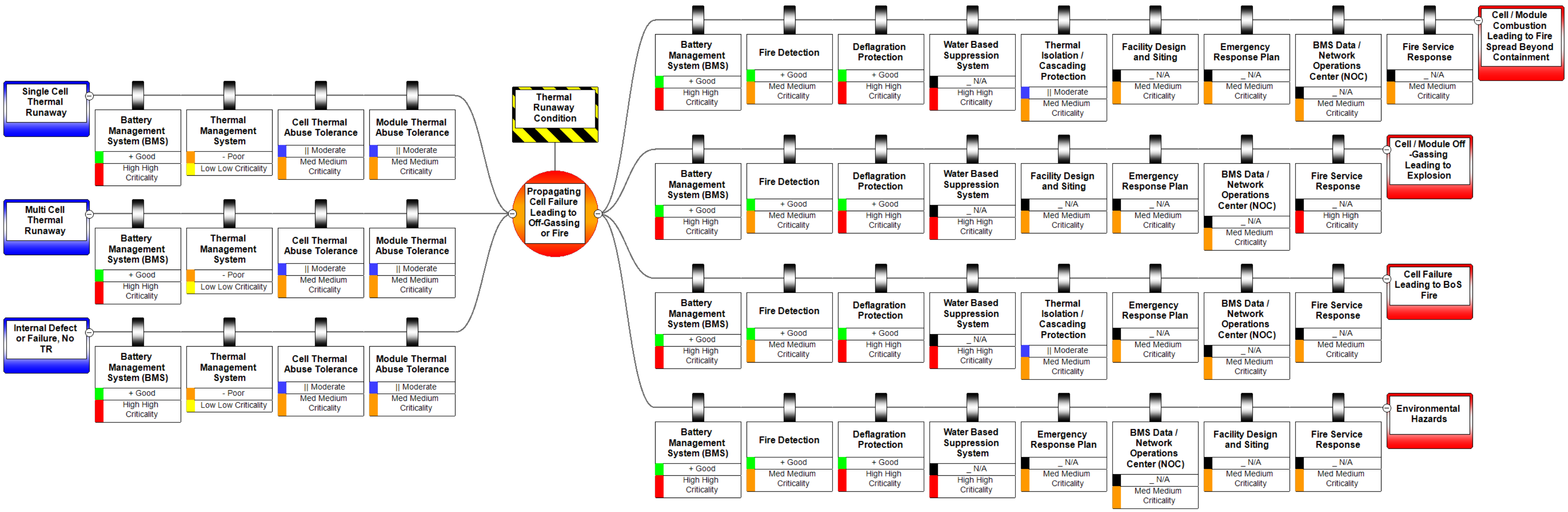
Compliance Requirement	Comments
1. Fires will be contained within unoccupied ESS rooms for the minimum duration of the fire resistance rating specified in NFPA 855 9.6.4.	**Not applicable.** The CATL EnerC+ is intended for outdoor ground-mounted installations only and shall not be installed within any ESS rooms or structures.
2. Fires and products of combustion will not prevent occupants from evacuating to a safe location.	**Compliant.** While UL 9540A 4th Ed. does not require measurement of many toxic gases (only flammable gases), limited information on toxic gases released for the specific battery system is available. In ESRG's extensive experience performing large-scale fire testing of li-ion batteries, proprietary gas data measured indicate that toxicity levels are much in line with that of typical structural fires. Additionally, concentrations of any potentially toxic gases are expected to be highly diluted by natural ventilation of the open space area. The proposed BESS facility and location poses minimal risk to the public, life safety, and property by way of being on a secured site with no public access to the site. The CATL EnerC+ enclosures within the facility meet or exceed manufacturer's recommendations for separation distances and the installation exceeds minimum required separation distances from all exposures.
3. Deflagration hazards will be addressed by an explosion control or other system.	**Compliant.** The CATL Ener-C+ is equipped with an explosion prevention system (automatic exhaust ventilation) designed to exhaust flammable gases before they are allowed to accumulate and create an explosive atmosphere within the enclosure.

APPENDIX A – DETAILED HMA DIAGRAMS

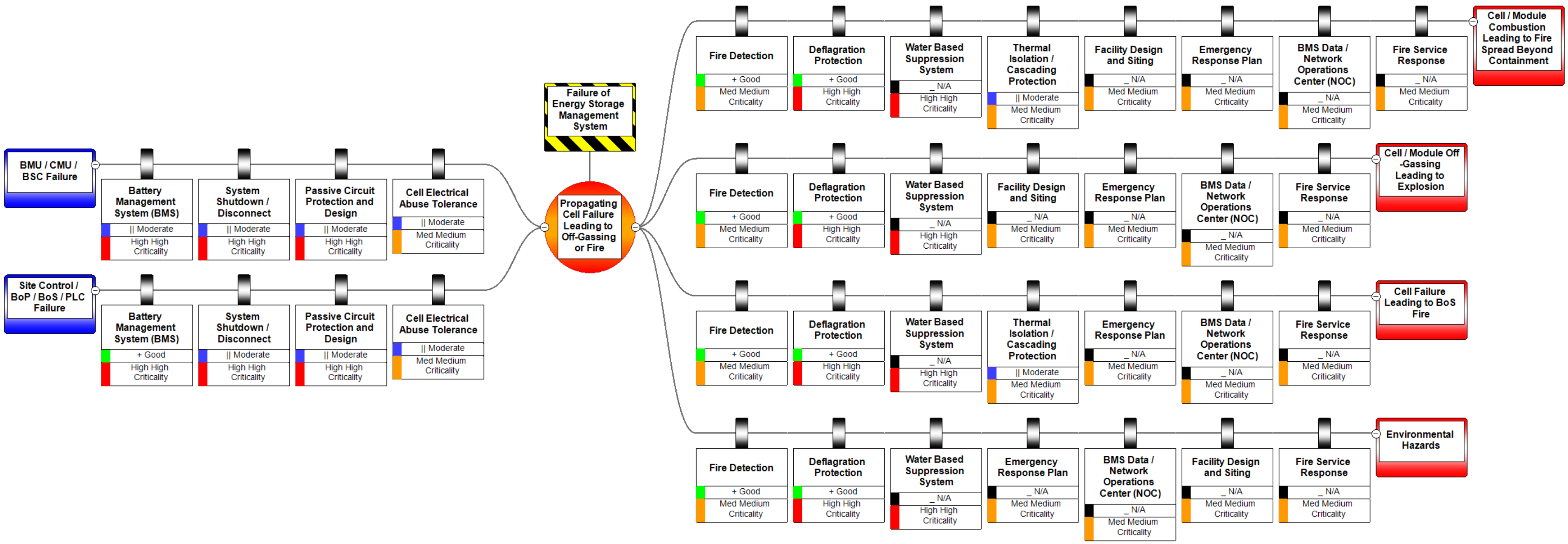
A.1 All Fault Conditions



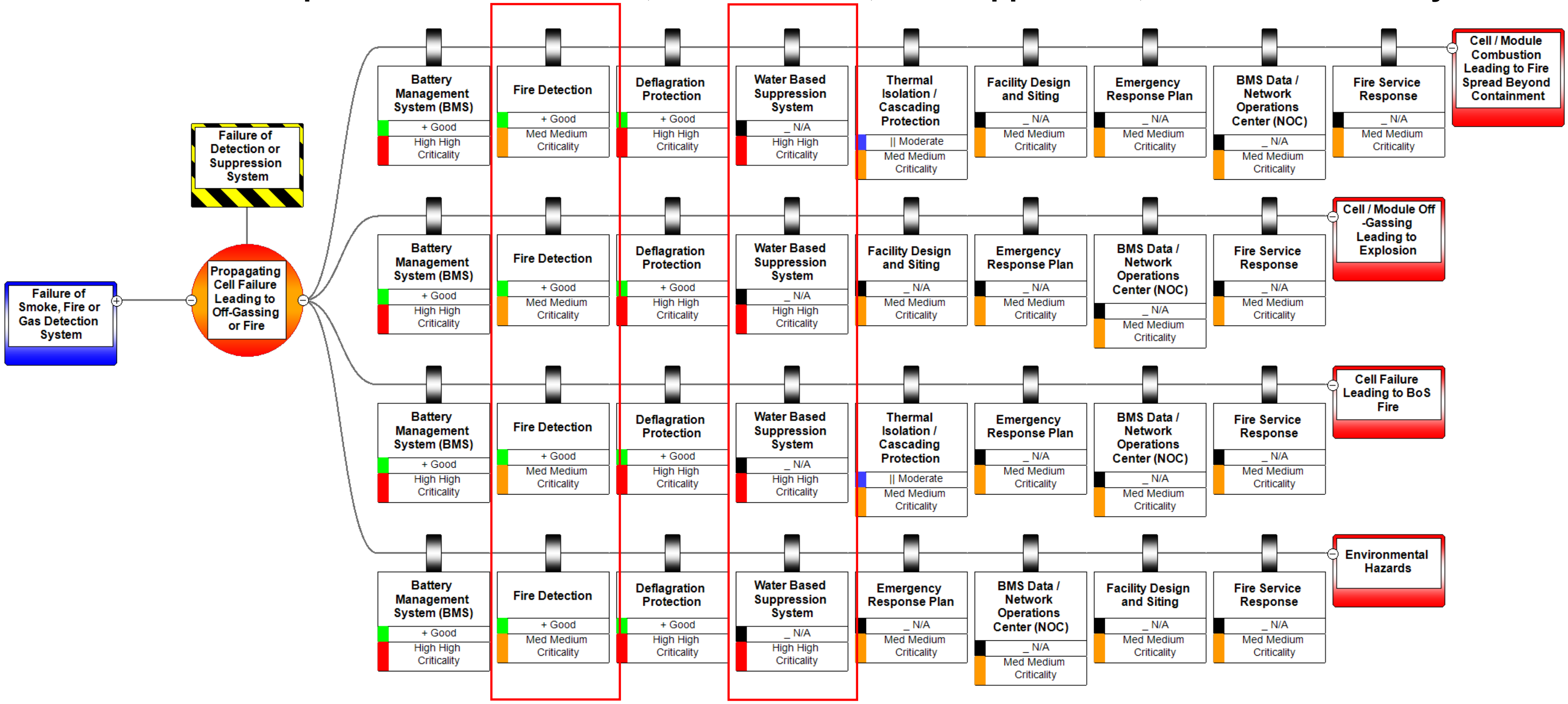
A.2 Thermal Runaway Condition



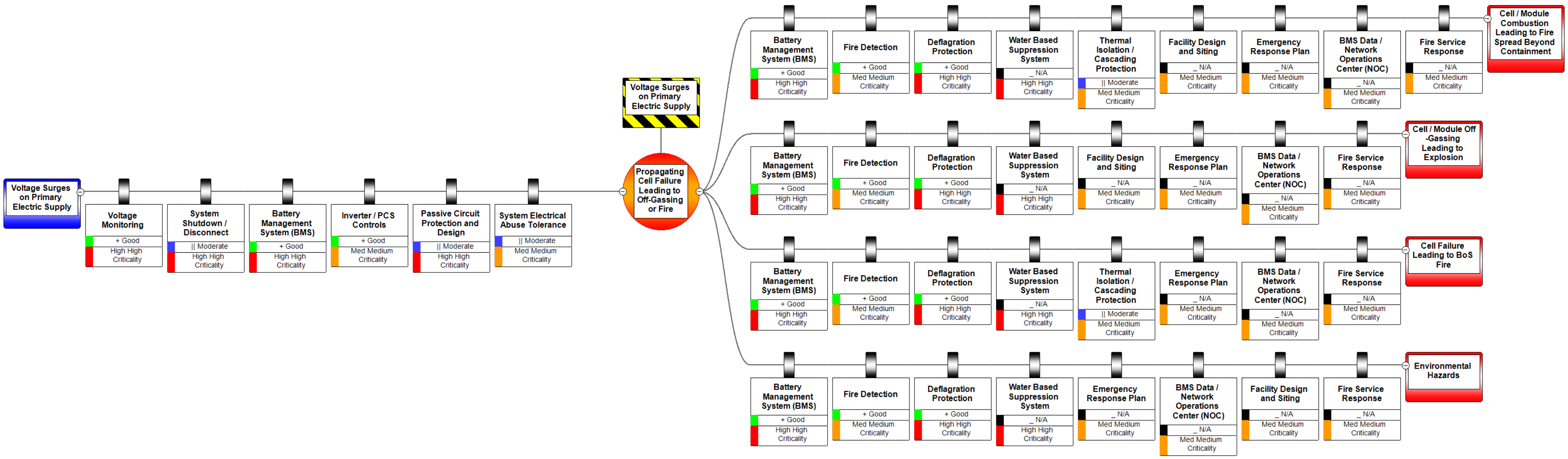
A.3 Failure of an Energy Storage Management System



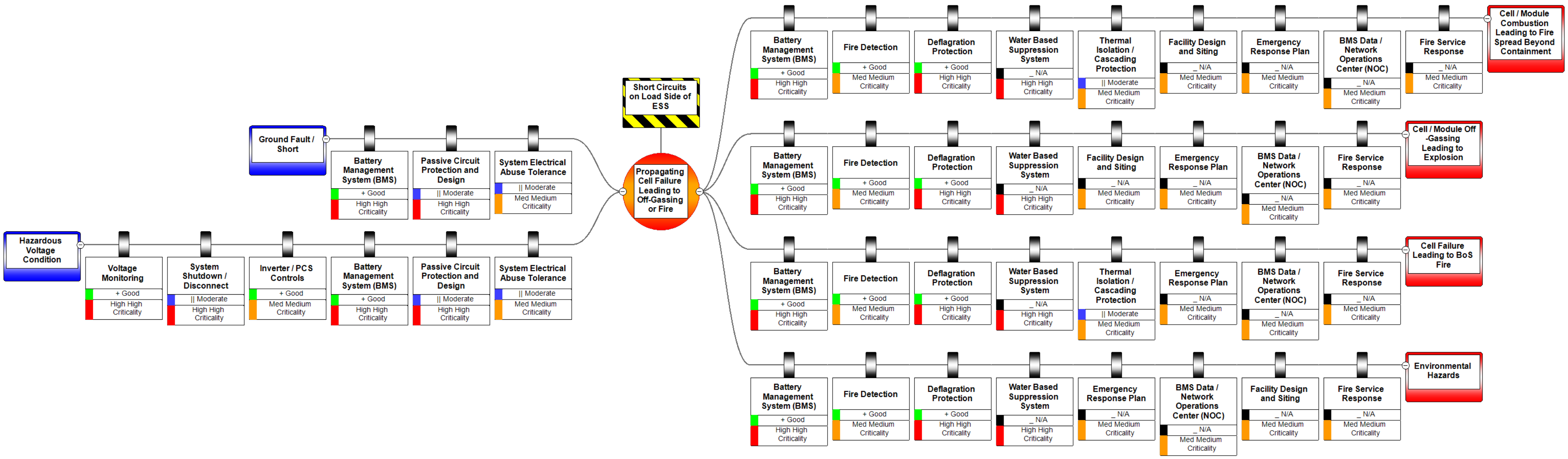
A.4 Failure of a Required Smoke Detection, Fire Detection, Fire Suppression, or Gas Detection System



A.5 Voltage Surges on the Primary Electric Supply



A.6 Short Circuits on the Load Side of the ESS

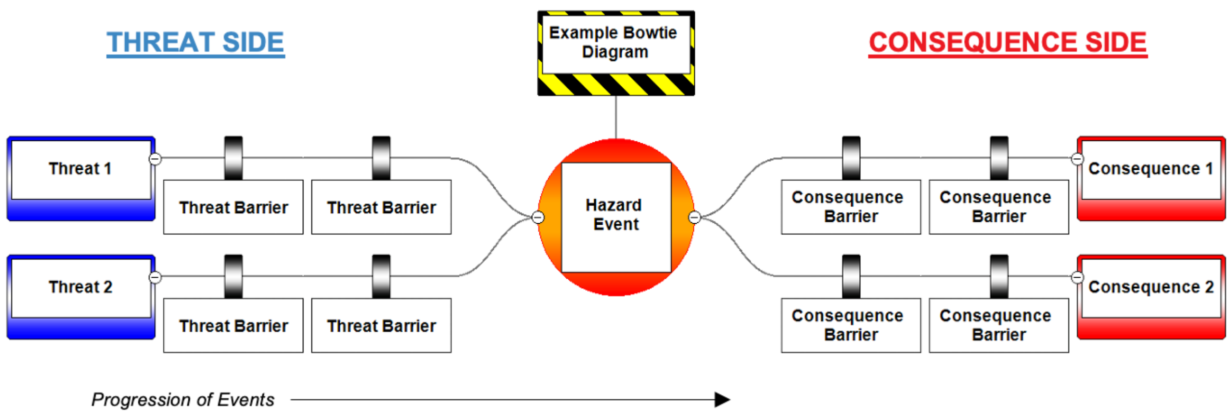


APPENDIX B – HMA METHODOLOGY

This Appendix serves as a supplemental write up for the overall Hazard Mitigation Analysis (HMA) and provides additional context on the Bowtie methodology used, as well as key definitions and concepts.

ESRG utilizes the bowtie methodology for hazard and risk assessments, as is described in *ISO.IEC IEC 31010 §B.21*, as it allows for in-depth analysis on individual mitigative **barriers** and serves as a strong tool for visualizing the chronological pathway of **threats** leading to critical hazard events, and ultimately to greater potential **consequences**, as depicted in the figure below. This simple diagrammatic way of describing and analyzing the pathways of a risk from hazards to outcomes can be considered to be a combination of the logic of a fault tree analyzing the cause of an event and an event tree analyzing the consequences.

The strength of the bowtie approach comes from its visual nature, which forgoes complex, numerical tables for threat pathways which show a single risk or consequence and all the barriers in place to stop it. On the left side are the threats, which are failures, events, or other actions which all result in a single, common hazard event in the center. For our model, many of these threats are the requirements of the fire code such as an unexpected thermal runaway.



- **Hazard Event / Top Event**

  The hazard (or "top") event – depicted as the center point in the middle of the bowtie diagram – represents a deviation from the desired state during normal operations (in this case, a thermal runaway or cell failure event), at which point control is lost over the hazard and more severe consequences ensue. This event happens before major damage has occurred, and it is still possible to prevent further damage.

- **Threats**

  There often may be several factors that cause a "top event". In bowtie methodology, these are called threats. Each threat itself has the ability to cause the center event. Examples of threats are hazardous temperature conditions, BMS failure, and water damage from condensation, each leading to cell failure (the center event for many of the following bowtie diagrams for lithium-ion ESS failures).

Threats may not necessarily address a fully involved system fire or severe explosion, but rather smaller, precursor events which could lead to these catastrophic consequences. Some threats occur without any intervention, such as defect propagation or weather-related events, while others represent operational errors (either human or system-induced). Often threats may also be consequences of even earlier-stage threats, spawning a new bowtie model that includes the threat at the center point or right side of the new bowtie. The diagrams that follow include careful selection and placement of each of the elements to best capture the perspective of system owners and operators responsible for ensuring safe operation.

- **Consequences**

  Consequences are the results of a threat pathway reaching and exceeding its center event. For the models described here, the center events were selected as the event in which proactive protections give way to reactive measures mostly related to fire protection systems and direct response. As the center event then is defined as either "cell failure" or propagating cell failure, the consequences in the models described assume a condition exists in which flammable gas is being released into the system or a fire is burning within the system.

  Consequence pathways include barriers that may help to manage or prevent the consequence event. Threat pathways are often consequence pathways from a separate hazard assessment, as is the case with thermal runaway. In other words, thermal runaway may result from many different threats at the end of a separate hazard pathway (if not properly mitigated) and may also be the threat that could result in several other consequences. The task force identified a set of common consequences representing areas of key concern to utilities, energy storage system operators, and first responders.

- **Barriers**

  In order to control risks, mitigative "barriers" are placed to prevent propagation of failure events across the system. A barrier can be any measure taken that acts against an undesirable force or intention, in order to maintain a desired state, and can be included as proactive threat barriers or reactive consequence barriers.

  Each barrier in these models is more indicative of a concept that may include a single approach or may consist of a complex series of combined measures. Similarly, the analysis may not include barriers required to prevent the threats at the far left of the diagram (which would be placed even further left) to ensure the models do not extend infinitely, though the incorporation of these variables into site-specific safety evaluations may provide additional benefit. This list does not contain all possible solutions and in some designs, these barriers may not exist at all. Many of the same barriers apply to a number of threats.

Barriers may mitigate hazards or consequences in a variety of ways. For example, common barriers to thermal runaway include active electrical monitoring and controls, redundant failure detection, and even passive electrical safeties (such as over-current protection devices and inherent impedances). Should these systems fail to detect the threat, shutdown the system, or otherwise prevent thermal runaway from occurring, the hazard may persist.

APPENDIX D – REFERENCED DOCUMENTATION

APPENDIX E – REFERENCED CODES AND STANDARDS

- *NFPA 855 Standard for the Installation of Stationary Energy Storage Systems*, 2020 Edition
- *International Fire Code §1207 Electrical Energy Storage Systems*, 2021 Edition
- *UL 9540A Standard for Test Method for Evaluation Thermal Runaway Fire Propagation in Battery Energy Storage Systems,* 4th Edition
- *UL 9540 Standard for Energy Storage Systems and Equipment,* 2nd Edition