Midea Industrial Tech.

CLOU Energy Storage

White Paper on Active Ventilation Explosion-Proof System

–A New Fire Safety Barrier for Energy Storage Stations

Being A World-Class Energy Services Provider

Preface

The safety and reliability of energy storage systems (ESS) are pivotal to safeguarding the full lifecycle value of customer assets. At CLOU, we deeply respond to customers' safety needs. Our fire protection framework is built on lean design principles to balance protection performance and deployment efficiency. The core elements include early interruption of thermal runaway, precise fire suppression, and automated ventilation and explosion control. We hope this technical pathway can serve as a replicable safety benchmark for the industry, and drive a paradigm shift toward proactive prevention in energy storage station safety.

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01 Energy Transition: The Safety Imperative

As the global energy landscape rapidly transitions toward cleaner, low-carbon systems, the energy storage industry is undergoing historic growth. According to BloombergNEF, global storage installations are projected to grow at a compound annual rate of 14.7% from 2025 to 2035, with annual additions reaching 220GW / 972GWh by 2035. This surge is driven by falling lithium-ion battery costs and technological advancements like digital twins and artificial intelligence that enhance system efficiency. As a flexible dispatch unit in the grid, energy storage is playing a vital role in integrated energy systems, evolving into a core hub of the future power infrastructure under supportive clean energy policies.

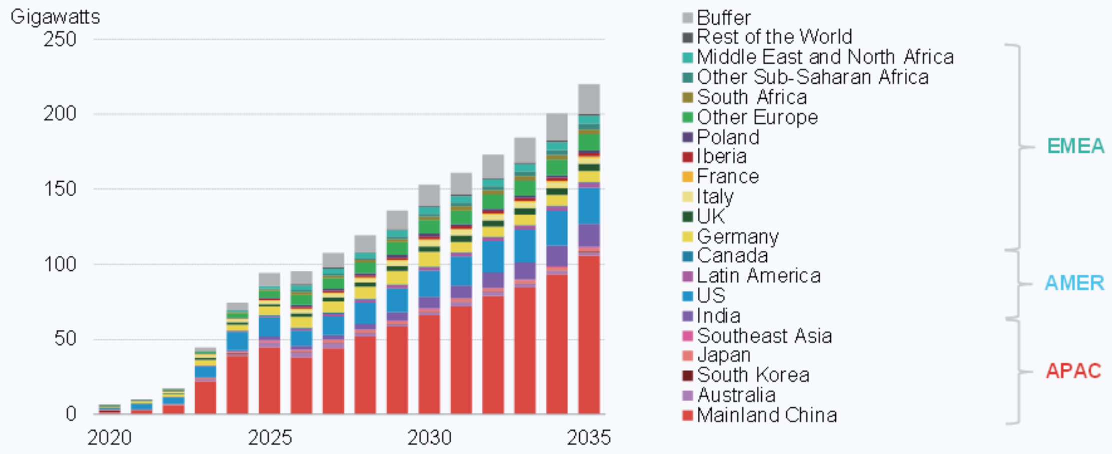

Figure 1: Annual Global Energy Storage Additions (2020–2035), Source: BNEF

However, as the industry scales up, safety risks have become a critical concern. When thermal runaway occurs within a battery container and propagates across units, it can lead to catastrophic chain-reaction disasters at the station level. Over the past nine years (2015–2024), hundreds of fire and explosion incidents have been reported globally. Since early 2025, there have already been seven energy storage safety events involving fires or explosions worldwide. These recurring incidents underscore the urgent need for robust, station-level safety technologies capable of multi-tier protection—from cell clusters to full sites—against cascading failures.

Region	Incident	Cause
China	Fengtai District, Beijing: Fire and explosion in an integrated PV-storage-charging station resulted in the deaths of two firefighters and one operator, with losses exceeding RMB 16.6 million.	Short circuit within LFP cells led to thermal runaway propagation. Fire escalated when unsealed cable trenches allowed flammable gases to accumulate and ignite upon contacting electrical sparks, resulting in an explosion.
South Korea	Gyeongsangbuk-do, South Korea: A frequency regulation ESS explosion destroyed over 100 battery racks, causing KRW 2.3 billion in damages.	BMS design flaw, compounded by the system being under maintenance inspection, resulted in the fire suppression system's failure to contain the fire.
South Korea	Gimhae City, Gyeongsangnam-do, South Korea:A co-located PV-ESS facility resulted in combustion of 297 lithium battery modules, with reaching KRW 700 million.	Overcharged beyond limits; protective systems failed to detect it.
South Korea	SK Group 50MW Peak Shaving ESS facility: A major fire destroyed a three-story building and 2,000 lithium battery cells, requiring 8 hours for full containment by emergency responders.	Substandard O&M environment management, non-compliant installation practices, and inadequate integration/protection system management.
USA	Moss Landing, California (Phase I – 300MW/1200MWh): Fire resulted in 84MWh (7%) of battery modules damage.	Faulty HVAC thermal sensors triggered deluge system discharge onto live battery racks, inducing short circuits and cascading thermal runaway.
USA	Moss Landing, California (Phase II – 100MW/400MWh): A subsequent fire at the facility resulted in 10 battery racks meltdown.	Post-incident fixes from the Phase I fire were not fully implemented, with persistent flaws in cooling systems and container sealing integrity.
USA	Jefferson County, New York – Solar + Storage Hybrid Project: Fire forced shelter-in-place orders within a 1.6 km radius for 4 hours and caused multi-million-dollar losses.	Mechanical failure triggered the fire, which lasted 4 days.

Region	Incident	Cause
Japan	Kagoshima, Japan – Solar Plant: Fire burned for over 20 hours at a storage facility caused an explosion during suppression efforts, injuring four firefighters.	A short circuit inside the battery triggered thermal runaway fire propagation across battery modules.
Germany	Thuringia, Germany – Suncycle Storage Project: Three fires occurred within 9 months at the Suncycle BESS facility. Toxic gases from the fires forced local residents to stay indoors for 2 days. Losses exceeded €700,000.	The fires originated from decommissioned lithium-ion batteries that were improperly stored in non-compliant environmental conditions, compounded by critical failures in the integrated control and protection systems.
UK	Essex County, UK – Fire incident at 300MW/600MWh BESS construction site: A fire has been reported.	Fire caused by a single faulty battery cell.
USA	Moss Landing, California – Two Fires in One Month (Total of Four Since 2021): One fire reignited after being extinguished. Around 1,500 residents were evacuated.	Internal suppression system failure led to the uncontrolled fire ignition.

Source: Public News Reports

The development of global energy storage safety standards remains fundamentally rooted in post-incident forensics and systemic learning. As the market with the most rigorous fire safety regulations currently in force, the United States has established critical industry benchmarks through its safety framework. The National Fire Protection Association (NFPA) developed a data-driven safety thresholds—with parameters spanning flammable gas concentration and thermal runaway propagation rates, and explosion overpressure limits—providing both measurable risk control baselines for engineering design and standardized reference systems for integrated safety solutions.

02 Decoding Energy Storage Safety Standards

As the regional market with the most comprehensive energy storage safety standards globally, North America has a rigorous regulatory framework that spans full lifecycle risk management from cell-level failure to station-wide protection systems. The core standards include:

NFPA 69 – Standards for Explosion Prevention Systems

Issuing Authority

National Fire Protection Association (NFPA)

Scope of Application

High-risk sites such as chemical plants, ESS, and dust processing facilities.

Summary

- Mandates design, installation, and maintenance requirements for explosion protection systems—including pressure venting, chemical suppression, mechanical isolation, and inert gas blanketing—to prevent or mitigate combustible gas or vapor or dust explosions through engineered controls.
- Requires third-party validated effectiveness though computational modeling and testing.
- Enforces synchronized implementation with NFPA 68 and NFPA 855 for flame propagation containment during incipient explosions, and ensures personnel, equipment, and building structure safety through rapid blast isolation.

*Use of gas detectors to monitor flammable gas concentration. Once the gas concentration exceeds 10% LEL, the exhaust systems are activated to reduce and maintain the gas concentration below 25% LEL.

Standard Update

2024 Edition.

NFPA 855 – Standard for the Installation of Stationary Energy Storage Systems

Issuing Authority

National Fire Protection Association (NFPA)

Scope of Application

Specifically addresses safety installation requirements for battery energy storage systems (BESS) and other energy storage technologies (e.g., flywheels, supercapacitors).

Summary

- Mandates critical safety criteria for system siting, spacing, fire compartmentalization, ventilation design, thermal management, fire suppression systems, and emergency response.
- Establishes tiered safety classifications based on battery chemistry (e.g., lithium-ion), energy capacity (kWh), and deployment environment (indoor or outdoor).
- Integrates standards of NFPA 68, NFPA 69, and UL 9540.
- Prioritizes risk mitigation through thermal runaway propagation containment, fire scale limitation, and mandatory large-scale testing (e.g., UL 9540A).
- Aims at risk reduction for fires, explosions, and toxic gas releases and assurance of personnel and infrastructure safety.

Standard Update

The current version is the 2023 edition. The next scheduled version (2026 edition) is expected to be released in the second half of 2025. The most significant change in the new edition is that the Large-Scale Fire Test (LSFT) will become a mandatory test item. Final technical requirements subject to codified language upon publication.

NFPA 68 – Standard on Explosion Protection by Deflagration Venting

Issuing Authority National Fire Protection Association (NFPA)

Scope of Application High-risk facilities include chemical processing plants, ESS, and dust processing/handling facilities.

Summary NFPA 68 mandates selection, installation, and computational design requirements for explosion venting devices (e.g., vent panels/doors) to ensure rapid pressure/flame release during deflagration, preventing structural damage from overpressure. The standard covers vent area calculations, safe discharge pathways, and shockwave control, while requiring integration with NFPA 69. Its primary objective—mitigating blast forces through controlled venting to protect personnel and infrastructure—is validated via third-party simulations.

Standard Update 2023 Edition.

UL 9540A – Test Methods for Safety of Energy Storage Systems

Issuing Authority Underwriters Laboratories (UL)

Scope of Application Large-scale safety assessment specifications for thermal runaway and fire risks in the BESS.

Summary Conducts tiered fire risk assessments at the cell level, module level, cluster level, and installation level. Core testing characteristics include:

1) Cell level: Trigger single-cell thermal runaway to analyze ejecta, temperatures profiles, and gas composition.

Module level: Validate thermal runaway propagation within modules and suppression effectiveness.

2) Cluster (Unit) level: Assess flame spread and system protection across modules.

3) Installation level: Simulate real-world deployments scenarios (such as the container), evaluate integrated fire protection designs (ventilation and suppression) for runaway containment.

The above rigorous tiered tests provide critical safety data for standards compliance (e.g., NFPA 855), ensuring controlled risk in large-scale deployments.

Standard Update 2025 Edition.

CSA/ANSI C800 – Testing Protocol for Energy Storage System Reliability and Quality Assurance Program

Issuing Authority	Canadian Standards Association (CSA)
Scope of Application	Full-scale energy storage units (e.g., containerized systems).
Summary	Validates safety performance of energy storage containers under real fire conditions by simulating: extreme thermal runaway propagation, explosion risks, and fire suppression system effectiveness. Assessment criteria include flame spread control, limitation of toxic gas release, and fire suppression capability.
Significance	It fills the gap in system-level risk assessment that traditional cell or module-level tests cannot cover. It also provides large-scale fire data support for installation standards like NFPA 855, promoting industry improvements in system design, fire safety strategies, and emergency response protocols.
Standard Update	CSA/ANSI C800:25 expands on the work of CSA TS-800:24. TS-800 is a technical specification specifically focused on large-scale fire testing, while CSA C800 is a fully developed, consensus-based national standard jointly recognized by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC). As an independent standard, CSA/ANSI C800:25 focuses on the reliability and quality assurance of energy storage systems, aiming to help manufacturers demonstrate the long-term reliability of their systems under extreme conditions. Key improvements in CSA/ANSI C800:25 include: 1) Integrating LSFT into a broader energy storage system test framework; 2) Robust durability testing under various environmental and mechanical conditions; 3) A structured methodology for supporting investment and insurance assessments.

03 CLOU Energy Storage Fire Safety Technology Architecture

Guided by North American safety standard framework, CLOU has engineered a multi-barrier protection system encompassing thermal runaway warning, fire suppression, and explosion prevention, with systematic elaboration per core defense tier below.

3.1 Early Warning and Detection of Thermal Runaway

During lithium battery thermal runaway, significant abnormalities occur in cell temperature and voltage. Real-time monitoring of these core parameters enables early warnings. At the battery module level, the BMS continuously tracks cell status, triggering immediate alarms and disconnecting charge/discharge circuits when temperature or voltage exceeds safety thresholds to prevent propagation.

At the container level, sensors track combustible gases (H_2,CO), smoke, and temperature. When flammable gases generated by thermal runaway inside a module spread to the container-level space, gas detectors trigger a first-level alarm and simultaneously activate the active ventilation explosion-proof system. Forced ventilation reduces the concentration of flammable gases inside the container, effectively suppressing explosion risks. If a smoke-temperature composite detector senses smoke and abnormal temperature rise (second-level alarm), the fire signal is immediately transmitted to the fire command center, providing real-time data for emergency response.

3.2 Fire Suppression System Design

In energy storage system fire prevention, traditional total flooding gaseous fire suppression systems—such as aerosol, perfluorohexanone (Novec 1230) and heptafluoropropane (FM-200)—are widely used. These systems operate on the principle of extinguishing fires by reducing the oxygen concentration within the protected area, thereby breaking the "fire triangle" needed for combustion. However, such systems have a critical limitation: they require a highly sealed environment. When applied to containerized energy storage units, where the enclosure is not fully airtight, the concentration of extinguishing agents drops rapidly over time. Once the concentration falls below a critical threshold, high temperatures at short-circuit points may reignite accumulated flammable gases, resulting in the common "reignition phenomenon" seen in lithium battery fires. Additionally, total flooding systems are unable to timely expel flammable gases during agent deployment. As these gases continue to accumulate, if the extinguishing agent concentration drops below the critical level, there is a risk that the gas mixture reaches its explosive limit—triggering deflagration or explosion.

To address these limitations, CLOU adopts a water spray fire suppression system as a safer and more effective solution. In the event of a thermal runaway, the water spray rapidly cools the flames through physical heat absorption, while continuously reducing the temperature of overheated cells—fundamentally preventing reignition. More importantly, the water spray system is designed to operate in coordination with the ventilation system: during fire suppression, ventilation remains active, continuously reducing the concentration of flammable gases inside the container and preventing explosion hazards caused by gas accumulation. This establishes a comprehensive "extinguishment–cooling–explosion containment" safety mechanism.

3.3 Explosion Prevention and Venting System Design

During thermal runaway, lithium batteries release large volumes of flammable gases (e.g., H_2, CO, VOCs). Accumulating within containers and mixing with air, these gases form explosive combustible clouds. Should gas concentrations reach explosive limits and encounter ignition sources (e.g., open flames or electrical sparks), violent explosions may occur. Resulting fireballs and shockwaves not only compromise container structural integrity but also trigger chain-reaction thermal runaway in adjacent energy storage units—posing far greater hazards than standalone fires.

Explosion protection and relief strategies fall into two categories:

1) Preventing explosions - reducing occurrence probability;

2) Containing explosion hazards – mitigating post-explosion and damage.

1) Explosion Hazard Preemptive Control

Gas explosions require simultaneous fulfillment of three conditions: flammable gas within explosive limits, presence of oxidizer (oxygen), and an ignition source. Since oxygen cannot be fully eliminated from air, and potential sparks may arise from system faults, lower the concentration of flammable gases constitutes the most viable mitigation approach. Per NFPA 69 standard, combustible gas detectors must trigger alarms when the concentration reaches no more than 10% of the Lower Explosive Limit (LEL). Once triggered, the ventilation system activates, continuously exchanging air to keep gas concentrations below 25% LEL, effectively preventing explosive conditions at their source.

2) Explosion Venting Structure Design

Preset explosion relief structures—such as burst panels or relief valves—are installed in the container. These are engineered to provide directional pressure release using material mechanics principles. During explosions, shockwaves and superheated gases are vented outward through these designed outlets, avoiding total structural failure and localizing explosion damage—thus minimizing impact on adjacent equipment and personnel.

3.4 CLOU Active Ventilation Explosion-Proof System

Based on a multi-tiered protection strategy combining thermal runaway preemptive control, water-based fire suppression, and explosion venting, CLOU's system achieves proactive containment of fire and explosion hazards through mechanically-assisted natural ventilation control.

CLOU's active ventilation explosion-proof system integrates five natural exhaust louvers at the top, two air intakes at the bottom, and gas detectors.

1) High-Reliability Redundant Airflow Design

The system provides five natural exhaust louvers and two intake devices. Verified through simulation testing by Fire & Risk Alliance LLC (USA), it was demonstrated that even if only one intake device remains operational, the system can still maintain flammable gas concentrations within the container below 25% LEL per NFPA 69, ensuring continuous compliance through engineered redundancy.

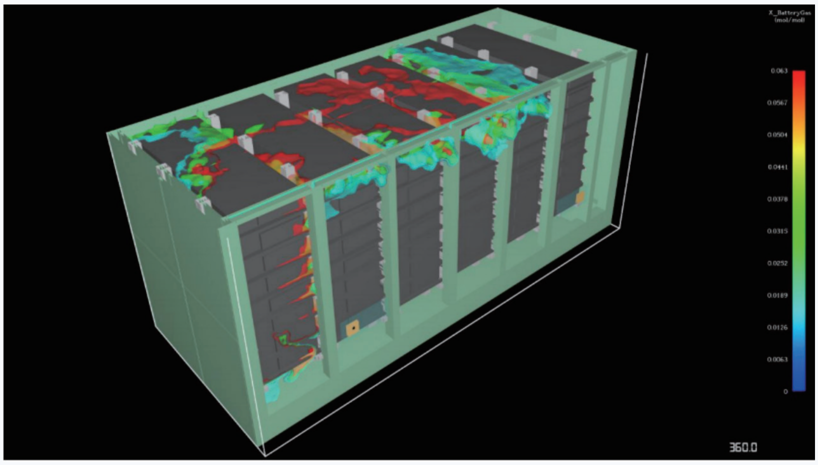

Figure 2: Aqua C2.5 Gas Concentration Isosurface Data

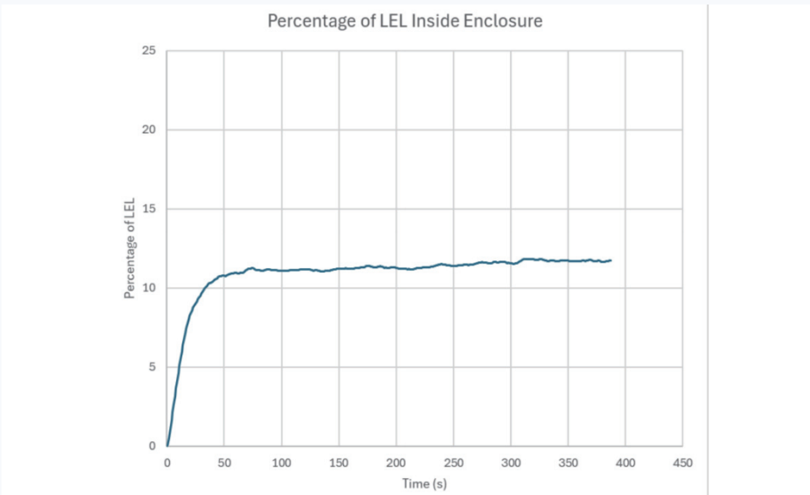

Figure 3: Aqua C2.5 Spatially Averaged Time Dependent Gas Concentration

2) Sustained Natural Ventilation

Per NFPA 855, exhaust systems must ensure continuous operation for at least 2 hours. Upon backup power for the intake fan is depleted, the five top natural exhaust louvers automatically take over, driven by thermal pressure differences, to continuously vent flammable gases. This ensures the system maintains explosion prevention even in a total power outage scenario.

3) Deflagration Pressure Relief Protection

In the event of container deflagration, the pressure inside the container rises sharply. The five top louvers function as pressure relief outlets, venting the overpressure to maintain the structural safety of the container.

4) Flame Directional Control

Upon activation, the louvers lock into a fixed inclination angle, forcibly channeling combustible gases and flames vertically upward. This prevents high-temperature exposure to adjacent containers, thereby eliminating risks of cross-container thermal runaway propagation.

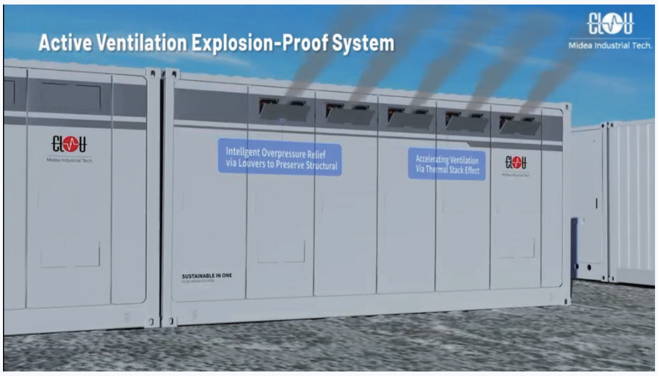

Figure 4: Aqua C2.5 motorized louvers open at a fixed upward angle, directing flame exhaust vertically and preventing lateral fire spread.

Through multi-tiered integrated design of thermal runaway detection, water-based suppression, explosion venting, and active ventilation, CLOU has engineered an end-to-end protection chain spanning the entire disaster lifecycle. This architecture's efficacy was empirically validated under extreme conditions via a station-level fire test per CSA/ANSI C800 standard—simulating worse-case thermal runaway scenario to verify synergistic performance in fire suppression and explosion prevention.

04 Large-Scale Fire Test

At a CSA-accredited independent test facility, four Aqua C2.5 liquid-cooled BESS containers A/B/C/D were deployed in a 20 MWh configuration replicating real-world spacing layouts, back to back, side by side and face to face.

Figure 5: Aqua C2.5 Large-Scale Fire Test Layout

During the test, Container A (ignition unit) sustained combustion for 59 hours and 10 minutes with internal flame temperatures exceeding 1300°C, fully simulating the most extreme thermal runaway scenarios for energy storage systems. Validated by CLOU's refined multi-barrier safety engineering, the test demonstrated the following critical outcomes:

1) Structural Integrity Preservation

The ignition container (A) maintained structural stability, while adjacent containers (B/C/D) exhibited zero deformation or functional compromise. Critical components remained intact.

2) Thermal Radiation Blockade

Even when Container A's external flame temperature reached 695.3°C, the adjacent Container C's battery modules temperature only rose to 80.71°C. Thermal radiation to adjacent containers was limited, and module temperatures remained far below thermal runaway thresholds.

3) Directed Exhaust and Flame Control

During the test, three side-top louvers were opened as outlets for gases and flames. Restricted by fixed angle, high-temperature flames and combustible gases and were vented upward, effectively preventing lateral flame spread.

Figure 6: Aqua C2.5 Large-Scale Fire Test Progression

Figure 7: Flame from Container A Venting Upward at An Inclined Angle

Empirical test data confirms that during extreme single-container combustion of Aqua C2.5, adjacent containers within the station exhibited zero thermal runaway propagation. This outcome validates both the fire containment capability of CLOU's BESS and the safety reliability of the ThermoFlux Active Ventilation Explosion-Proof System in high-density station configurations, thereby establishing critical technical foundations for gigawatt-scale ESS deployments.

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