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Moss Landing BESS Fire Report

Operations Analysis

December 2025

ELECTRIC RELIABILITY AND SECURITY FOR THE WEST

Executive Summary

In recent years, multiple battery energy storage system (BESS) fires have been documented across the Western Interconnection and throughout the world as the number of these systems connected to power grids continues to grow. While the size of these fires varies greatly, loss of assets, risk to first responders, and potential environmental impact are concerns of any BESS fire. As BESS deployments accelerate across the grid, ensuring compliance with modern fire safety codes and integrating lessons learned from past incidents is critical.

This report provides insights into the January 16, 2025 fire affecting Phase 1 of the Moss Landing BESS facility in California, along with key findings from other BESS fire events. Moss Landing was one of the earliest large-scale BESS installations, and it was constructed before the release of NFPA 855, the first fire safety standard for energy storage systems. The incident also underscores the importance of evolving design standards.

Key Findings

- **Legacy Design**: Moss Landing predates NFPA 855, highlighting the need for retroactive safety evaluations.
- **Industry Evolution**: Most new BESS facilities now favor outdoor containerized designs to mitigate fire risks and contain thermal runaway conditions, reflecting lessons learned from early failures.
- **High State of Charge (SOC)**: When a battery operates at a high SOC, its cells are storing the maximum amount of energy they can hold. If a fault occurs under these conditions, there is more stored energy that can be released, causing uncontrolled heating and potentially fire. Faults within battery cells commonly result from overheating, mechanical or physical damage, or short circuits.

Recommended Actions

Based on the findings of this work, WECC recommends the following actions for entities to take.

1. **Fire Suppression**: Choose suppression approaches carefully. Lessons from previous events have shown water-based systems can damage energized equipment and potentially exacerbate a chemical fire.
2. **Code Compliance**: Evaluate and retrofit older BESS facilities to the extent it is possible to meet fire safety standards.
3. **Thermal Runaway Prevention**:
    a. Select appropriate cell chemistry for operational needs.
    b. Implement proven thermal management system (TMS) designs.
    c. Establish safe operating parameters, including:
        i. Maximum SOC (many owners/operators choose to limit SOC below capability of the site)
        ii. Controlled operating temperatures
        iii. Limited frequency of capacity tests

iv. Establishing appropriate operating margins for older BESS (especially warehouse style or those systems that have not performed a large-scale fire test as described in UL 9540a).

4. **Determine Maximum SOC**: Charging a BESS to 100% capacity can reduce the battery lifespan and increase safety risks. Many operators sacrifice a small portion of total energy capacity to gain potential years of battery life.
5. **Training for First Responders**: BESS owners and operators should develop emergency response plans for the worst potential outcomes of a BESS fire and regularly conduct training, drills, and rehearsals to deal with BESS fires, ensuring that first responders and public officials are prepared.
6. **Public Education**: Raise awareness on the evolution of the safety of BESS, design improvements from increased installations, adoption of large-scale testing, and ongoing education efforts to minimize misinformation on the risks of BESS.

The Moss Landing BESS fire, as well as other recent BESS fires, serves as a vital learning opportunity for the energy industry, reinforcing the need for proactive safety measures and thoughtful integration of BESS into grid operations.

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Introduction

One of the reliability functions delegated to WECC by NERC as a Regional Entity is Event Analysis. This function offers several benefits, including identifying the conditions that led to an event, discovering strategies to prevent future occurrences, and sharing those insights with the industry.

Following the Moss Landing battery fire on January 16, 2025, WECC staff promptly initiated internal discussions to learn more about the incident, as well as other BESS fires that have occurred within the Western Interconnection. During these conversations, FERC and NERC asked WECC to explore a collaborative effort aimed at analyzing the event and providing valuable information to the industry regarding BESS safety and reliability. Given that this event was in CAISO's footprint, and WECC's extensive work with CAISO on inverter-based resource (IBR) disturbance events, CAISO was invited to join the initiative, completing the team and setting the stage for a coordinated response.

The team reached out to Vistra and received a warm response. Vistra provided thoughtful answers to the team's initial Request for Information (RFI) and graciously extended an invitation for an on-site discussion at the Moss Landing facility. While valuable data was shared and open dialogue pursued, this paper does not constitute a root cause analysis of the Moss Landing battery fire. Dedicated teams are conducting such investigations.

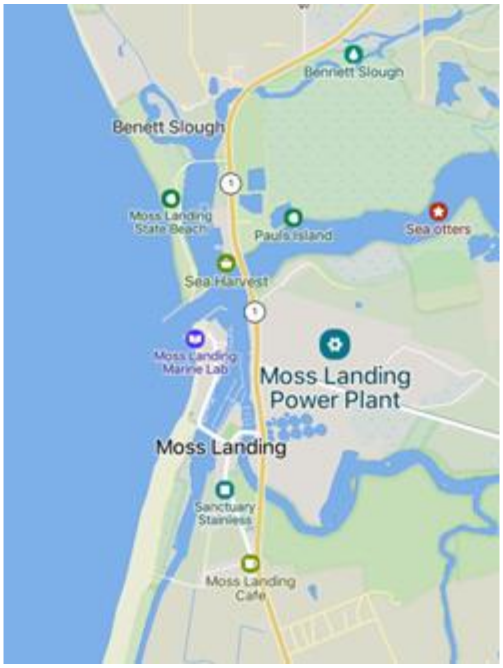
Some of the information shared with the team was provided in confidence, and we have agreed to withhold those details while formal investigations are ongoing.

Following the engagement with Vistra, the team met with several BESS Original Equipment Manufacturers (OEM) to broaden its understanding. RFIs were also sent to other BESS sites that have experienced fires, with the goal of learning from their experiences as well. As several of these incidents are still under investigation, these entities have requested anonymity.

BESS are invaluable assets to the electric grid. They play a crucial role in meeting system demand, particularly during evening hours when solar generation is ramping down and the demand on the system is still high. In addition, BESS contribute to a range of ancillary services that enhance grid stability and reliability.

At the time that this report was published, there were approximately 27 GW of BESS installations in the Western Interconnection. BESS projects are appearing increasingly in other interconnection queues across North America, signaling widespread adoption. Because many entities are integrating these systems into their infrastructure for the first time, this paper outlines key considerations and best practices for successful BESS deployment.

Moss Landing — A History of Energy Supply in the Western Interconnection



Located in Monterey County, California, the Moss Landing Power Plant has played a pivotal role in the state's energy landscape for decades. Construction began in 1949 under Pacific Gas & Electric (PG&E). By 1950, the plant was commercially operational with five natural gas and oil-fired steam units, delivering a combined capacity of 613 MW. Over the next 40 years, continued improvements and additions allowed Moss Landing to become California's largest power plant by capacity, reaching 2,560 MW.

Over the decades, the Moss Landing Power Plant has undergone several ownership transitions. The most recent change occurred on April 9, 2018, when Vistra Corp merged with Dynegy, thereby assuming control of Moss Landing.

Addition of BESS:

In response to California's 2013 mandate requiring utilities to deploy substantial battery storage by 2024, Vistra Energy announced plans on June 29, 2018, to construct a 300 MW / 1,200 MWh energy storage system at Moss Landing. The project leveraged existing infrastructure, including the turbine hall and interconnection from retired generating units, linking directly to the 500 kV transmission grid.

Construction began in December 2019, and Phase 1 became operational by the end of 2020. This phase features LG JH4 cells using nickel manganese cobalt (NMC) chemistry, housed in TR1300 racks stacked two high across both stories within the repurposed turbine building. At the time of commissioning, it was recognized as the largest battery energy storage system in the world.

Following the successful launch of Phase 1, Vistra Energy continued to expand the Moss Landing BESS capacity to meet California's growing demand for flexible, clean energy.

Phase 2, completed in August 2021, added 100 MW / 400 MWh of capacity. Phase 2 was housed in a newly constructed warehouse designed specifically to accommodate the additional infrastructure.

Phase 3, completed in 2023, consists of 122 engineered containers, installed in open-air configurations. The expansion contributed 350 MW / 1,400 MWh, bringing Moss Landing's total storage capacity to 750 MW / 3,000 MWh.

January 16, 2025, Fire

The Moss Landing Phase 1 BESS (aka Moss Landing 300, ML300) consists of three arrays: Dallas 1, 2 and 3. On Thursday, January 16, at 1100 hours, Vistra began conducting a capacity test on Dallas 1 and 2. The test was part of routine performance validation for the Phase 1 system.

At 1448 hours on Thursday, January 16, 2025, a fire alarm was triggered in the Phase 1 building on Dallas 1. This was the first sign of a potential thermal runaway event. The fire was confirmed by the plant's system operators and emergency services were notified.

At 1506, the fire department arrived and initiated the incident command system.

At 1648 hours, due to worsening conditions inside the Phase 1 building, the fire department ordered the activation of exhaust fans to ventilate the structure and clear the smoke from the building. The decision to deactivate the overhead sprinklers was also made since they were proving ineffective in suppressing the fire.

From 1752 to 1830 hours, the situation rapidly deteriorated. Flames broke through the roof of the Phase 1 building, prompting a full evacuation of the Moss Landing site. The blaze generated a massive plume of smoke. In response to potential airborne hazards, authorities issued the following emergency measures:

- **Mandatory evacuations** in surrounding areas
- **Closure of nearby roads**, including a segment of California Highway 1
- **Temporary shutdown of local schools**
- **Shelter-in-place advisory** for residents outside the evacuation zone, urging them to keep doors and windows closed and turn off HVAC systems

Subsequent air quality monitoring revealed no significant public health risks. However, the evacuation and shelter-in-place orders were deemed necessary due to the unpredictable and potentially hazardous nature of lithium-ion battery fires.

During the event, the thermal cameras at the adjacent PG&E Elkhorn BESS detected the Moss Landing 300 fire and tripped the Elkhorn BESS.

Active flames were visible through January 17, while smoldering and residual heat persisted until January 22, requiring ongoing monitoring and containment efforts.

Re-ignition in February

At 1838 on February 18, 2025, smoke was detected at the ruins of the Moss Landing 300 structure. This flare-up lasted about 10 hours. There were no evacuations issued; however, there was continuous air monitoring in place due to lingering concerns about hazardous materials released from the initial January fire. During this time, residents were advised to limit outdoor activities and close windows and doors to avoid smoky air.

Given the fire damage to the BESS, partial building collapse, and the inclement weather that the damaged section of the Moss Landing 300 BESS was exposed to, this reignition event is understandable.

The Phase 1 BESS at Moss Landing was a complete loss of both building and grid assets. Vistra has committed to a safe, environmentally conscious and thorough clean-up of the site. The clean-up plan included insights from several agencies, including the Environmental Protection Agency, and could take up to two years. Current progress of the clean-up can be found at the Moss Landing Response — Recovery Process website[1].

BESS Safety Systems

Thermal Runaway

Thermal runaway is a dangerous and uncontrolled process in which a battery cell rapidly overheats. It begins when the heat generated inside the cell surpasses the rate at which it can be dissipated into the surrounding environment. As the temperature rises, the affected cell releases flammable and toxic gases, which can ignite if the heat reaches critical levels. This ignition can trigger a chain reaction, spreading to neighboring cells and escalating throughout the container or facility.

Thermal runaway is one of the most serious safety risks in BESS and is the leading cause of BESS-related fires. To mitigate this threat, modern designs incorporate advanced safety mechanisms capable of detecting early signs of overheating at the individual cell level. These systems enable automatic intervention to prevent escalation and protect infrastructure and personnel.

Battery Management System (BMS)

A BESS installation incorporates multiple layers of monitoring and protection to ensure each cell operates within designed parameters and helps guard against thermal runaway. The BMS serves as the first line of defense and is a sophisticated control system included in all BESS installations. The BMS continuously monitors critical parameters (voltage, current, temperature, state of charge, etc.) helping to ensure the safety, performance, and longevity of the BESS.

Some key functions of a BMS include:

- Monitoring the health of the batteries by tracking cell performance and identifying anomalies or cells exhibiting undesired behavior
- Thermal management down to the cell level, preventing overheating as well as controlling of the cooling systems
- Controls the charge and discharge of the batteries ensuring safe and efficient energy flows

[1] Moss Landing Response — Recovery Process

- Fault detection and isolation at the cell level, designed to prevent cascading failures
- Communicates real-time data through SCADA systems to assist with monitoring and control of the resource

If temperature or voltage approach dangerous thresholds, the BMS can automatically override commands from the plant controller, halting charging or discharging to prevent damage. These systems are critical to the safe and optimized operation of a BESS resource.

Thermal Runaway Mitigation System (TRM)

In rare cases in which the BMS fails to isolate an overheating cell, some BESS designs incorporate a Thermal Runaway Mitigation (TRM) system — also known as a heat suppression system. These systems serve as a critical secondary safeguard to contain and minimize the impact of thermal events.

The team has engaged in discussions with many BESS OEMs, with a particular focus on their TRM strategies and implementation approaches. Designing an effective TRM system involves several key considerations:

- Detection speed and accuracy: Rapid identification of thermal anomalies before escalating to a runaway situation.
- Suppression method: Choice of active (e.g., inert gas, aerosol, water deluge) vs. passive (e.g., thermal barriers, spacing) systems.
- Integration with BMS and control systems: Ensuring seamless communication and coordinated response.
- Material compatibility: Avoiding adverse reactions with battery components or enclosures.
- Maintenance and serviceability: Designing for ease of inspection, testing, and replacement.
- Regulatory compliance: Meeting Underwriters Laboratory (UL), the National Fire Protection Association (NFPA), and regional fire safety standards.

ML300 TRM System

ML300 was constructed using 4,539 LG TR 1300 racks, a UL9540 tested design. Each rack comes with 22 battery modules, cabling, and nozzle assembly and weighs a little over 5,000 lbs. Also mounted within the rack are the Battery Protection Unit and BMS.

Each rack contains approximately 327 kWh of battery capacity, and racks can be double-stacked to further boost the energy density at a facility, a feature used in the construction of ML300.

The ML300 design features a water-based TRM system engineered to prevent thermal runaway within individual battery modules.[2] The system is a double interlocked nitrogen supervised suppression system. This system was organized into 25 pre-action zones distributed across the facility, each zone covering three to four battery cores.

[2] Moss Landing Phase I Findings and Corrective Actions

Each zone comprises carbon steel header pipes connected via flexible hoses to rack-mounted piping. Integrated into this piping are sprinkler nozzles, strategically positioned within each battery module. Activation of the system requires both smoke detection where water is released into the header pipes of the affected zone and loss of nitrogen pressure when temperature within a specific module rises to the nozzle's activation threshold. Water is injected into that module providing targeted suppression and mitigating the risk of thermal escalation. Parts of the TRM system are owned by Vistra, and other parts are owned by the OEM.

The McMicken Fire

The McMicken Fire was an early, well-documented BESS fire in the Western Interconnection that took place on the Arizona Public Service system[3]. The incident was triggered when a single lithium-ion cell experienced thermal runaway, activating the fire suppression system. Although the Novec 1230 clean agent suppression system functioned as designed, it was unable to halt the cascading thermal runaway, which spread to adjacent cells.

Clean agent systems can be very effective at extinguishing incipient fires involving conventional combustibles. However, this design was ineffective in containing this thermal runaway event. The McMicken Fire underscored this limitation and became a landmark case for the energy storage industry. As one of the earliest BESS deployments in the Western Interconnection, its post-incident analysis has provided invaluable insights, driving significant advancements in safety standards, system design, and emergency response protocols.

Other Designs

The team has reviewed other recent BESS fires. Some of these facilities have implemented a fire suppression system consisting of waterless fire suppressants (Novec 1230, Inert Gas Systems). Fire suppression systems differ from TRMs, as the design is for the entire installation, not the individual battery module. While these systems can help with heat absorption and reduction, they are not designed to stop thermal runaway. This is because by the time the suppression system deploys, the battery cells in the module are already in thermal runaway. Once in thermal runaway, little can be done to stop the spread of the fire. Again, many of these fires have involved older installations where there was limited experience with large-scale deployments and with limited fire and design standards in place.

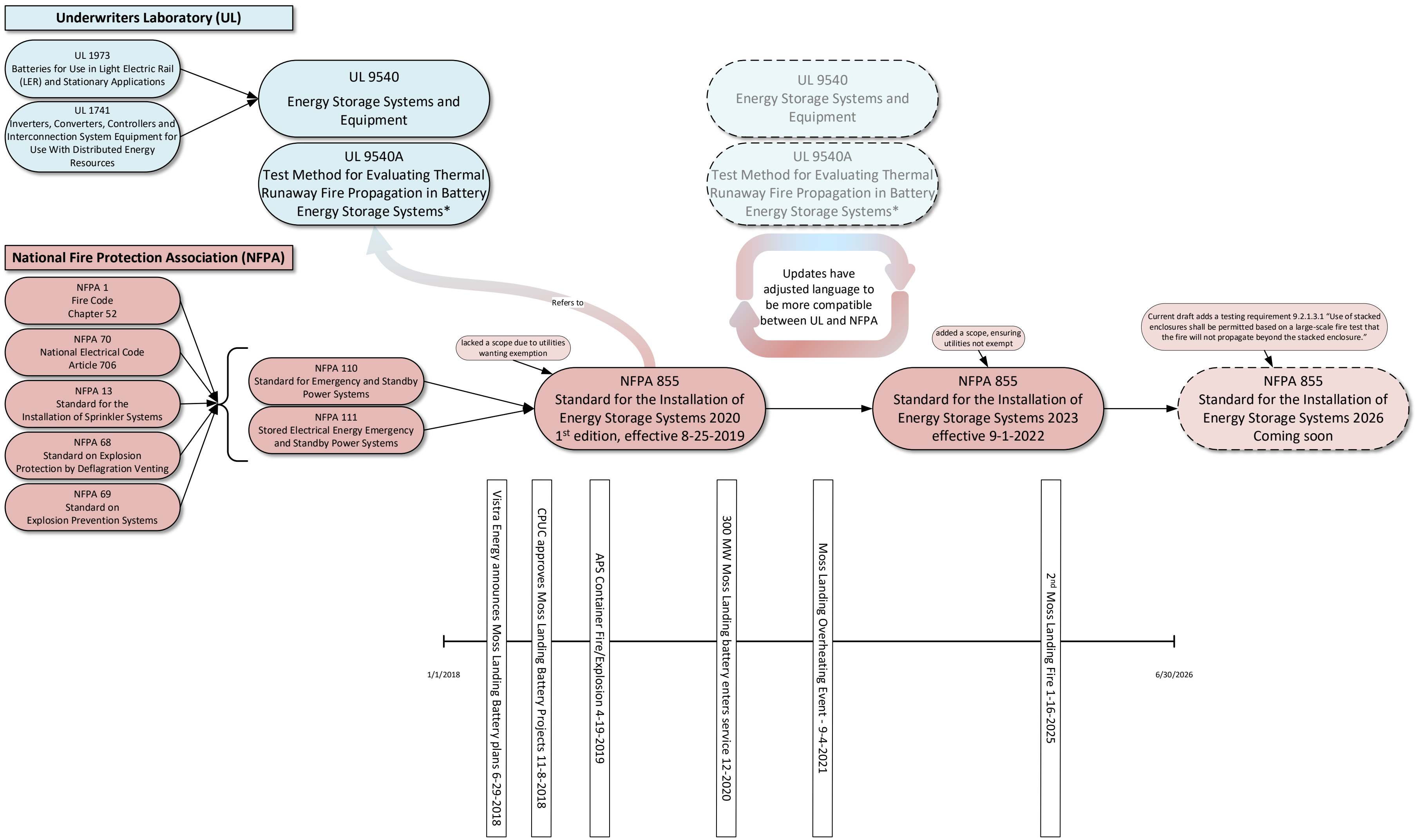
Through conversations with several OEMs, the team has seen various TRM designs. Some manufacturers use a water deluge TRM system similar to the ML300 design, but in containerized installations. The benefit in the design of containerized installations is if the BMS and TRM system fails to prevent a thermal runaway condition, testing has proven that the loss will be limited to a single container.

[3] NERC Lessons Learned on McMicken Fire; APS Report on McMicken Fire

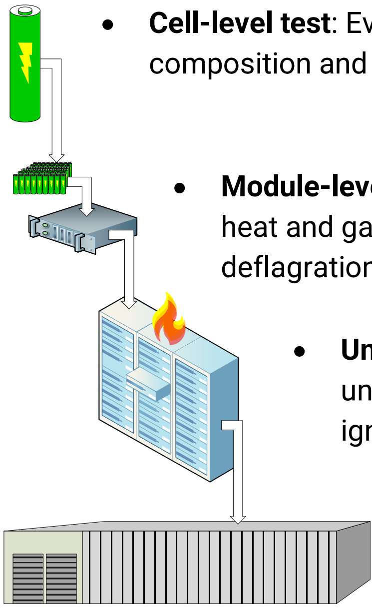
Another OEM adopted a similar strategy; however, instead of using a water deluge system, they employed a clean agent that would flood the overheating module to prevent thermal runaway. The manufacturer expressed confidence in its solution, having conducted large-scale testing that demonstrated the system's effectiveness in mitigating runaway scenarios. While the McMicken BESS was equipped with a clean agent suppression system, its design varied significantly from other installations, and no large-scale fire propagation testing was performed, as such testing was not standard practice at the time it was installed. Other manufacturers who only build containerized BESS do not include any kind of TRM system in their design. Through installed fleet performance, they have confidence that the risk of a thermal runaway event is minimal. Large-scale fire testing also provides confidence that, if a unit were to enter thermal runaway, the fire would not propagate to adjacent units.

Fire Code Evolution

The main fire codes discussed here are from UL and the NFPA. The diagram below describes the establishment of codes and standards related to BESS, along with a timeline of key dates for ML300.



UL 9540A contains four testing levels for thermal runaway propagation in energy storage systems (ESS):



- **Cell-level test**: Evaluates the thermal runaway characteristics of the cell as well as the composition and flammability of the gases
- **Module-level test**: Evaluates the tendency of cell thermal runaway propagation, the heat and gas release rate of the module, and the potential danger of ignition or deflagration
- **Unit-level test**: Evaluates the likelihood of fire spread between modules, the unit's heat and gas release rates, and the potential for deflagration or re-ignition
- **Installation-level test**: Evaluates the effectiveness of the fire protection system, as well as the heat and gas release rate of the system, and the danger of deflagration or re-ignition

The first edition of NFPA 855, released in 2020, established comprehensive safety requirements for the deployment of stationary ESS. It also applied to mobile and portable ESS when installed in a stationary configuration. NFPA 855 governs the design, construction, installation, commissioning, operation, maintenance, and decommissioning of an ESS. The standard defines minimum requirements to mitigate hazards associated with ESS, including:

- Emergency planning and training
- Hazard mitigation analysis (references UL 9540A test results)
- Combustible storage
- Equipment
- Installation
- Smoke and fire detection
- Explosion control
- Fire control and suppression
- Size and separation

The design of ML 300 was complete and accepted before NFPA 855 2020 being issued. UL 9540 pre-existed (initially released in 2016) the design of Moss Landing and was applicable, and the racks used for ML 300 were UL 9540a tested and certified.

Recent revisions to NFPA 855, UL 9540, and UL 9540A have focused on harmonizing terminology and requirements across the standards. This alignment improves clarity for manufacturers, developers, and authorities having jurisdiction (AHJ), streamlining compliance and safety evaluations for ESS.

For legacy BESS installations, several industry bodies and agencies recommend retroactive safety evaluations and upgrades for BESS installed before the current version of NFPA 855 to the extent possible. These recommendations focus on hazard mitigation, emergency planning, and alignment with UL 9540A.

Industry recommendations for legacy BESS installations include:[4]

1. Conduct hazard mitigation analysis
    - Use UL 9540A test results to evaluate thermal runaway risks.
    - Assess fire propagation potential, especially in stacked or densely packed enclosures.
    - Identify failure modes and implement containment strategies.
2. Upgrade fire detection and suppression systems
    - Install smoke and heat detection systems that meet current NFPA 72 and 855 standards.
    - Retrofit with explosion control measures per NFPA 68 and NFPA 69.
    - Consider dry chemical or clean agent suppression systems tailored to lithium-ion fires.
3. Improve emergency response planning
    - Develop or revise site-specific emergency response plans.
    - Coordinate with local fire departments and AHJs.
    - Conduct training and drills for first responders and facility staff.
4. Reassess separation distances and layout
    - Evaluate whether size and separation of battery arrays meet current NFPA 855 guidelines.
    - Modify enclosure spacing or add barriers to reduce fire spread risk.
5. Environmental and community safety
    - Install air monitoring systems to detect toxic emissions during incidents.
    - Establish community notification protocols for fire or smoke events.
    - Review ventilation and exhaust systems to prevent buildup of flammable gases.

Warehouse vs. Containerized Installations

BESS are typically deployed in one of two configurations: housed within a warehouse-style building or packaged in outdoor container units. These containers are generally the size of standard shipping containers and are sealed to prevent water intrusion. In California, both approaches have been widely adopted, with some sites — such as Moss Landing — using warehouse and containerized designs at the same location.

[4] Battery Energy Storage Systems: Main Considerations for Safe Installation and Incident Response | U.S. EPA

Each configuration offers distinct advantages and trade-offs:

Primary Advantages of Warehouse Facilities

1. Warehouses allow for precise management of airflow, temperature, and humidity — critical factors for battery performance and longevity. Certain battery chemistries are especially sensitive to extreme temperatures, with sub-freezing or above-100° F conditions potentially degrading performance and voiding warranties. Controlled indoor environments help maintain optimal operating conditions and support long-term reliability.
2. Warehouse designs allow space efficiency. Indoor facilities can be vertically stacked and tightly configured, maximizing energy capacity within a limited footprint. This is particularly beneficial in space-constrained urban or industrial areas, where auxiliary cooling systems can support dense installations.
3. Warehouse installations allow for efficiencies in maintenance. Maintaining a single warehouse structure is generally more efficient than servicing dozens or hundreds of individual outdoor containers. Roof integrity and HVAC systems can be managed centrally, reducing labor and operational complexity.
4. Warehouses offer controlled access points and a secure perimeter, making it easier to monitor and protect sensitive infrastructure compared to sprawling outdoor setups.

Primary Advantages of Containerized Facilities:

1. Containerized installations allow for flexible site deployment. Containerized systems can be installed on virtually any available land without the need for complex permitting or construction. This flexibility can significantly reduce project timelines and costs.
2. These sites allow for modular scalability. Containers can be easily added, removed, or replaced, allowing for straightforward system augmentation or asset rotation as needs evolve.
3. Containerized installations allow for simplified fire safety. Outdoor installations benefit from passive fire safety design, primarily through strategic spacing between containers. This reduces the risk of fire propagation and simplifies mitigation planning.
4. These installations provide the option to be redeployed to another location, if desired, with minimal disruption. This offers adaptability for changing grid demands or business strategies.

While both configurations have their merits, one of the most critical distinctions lies in fire safety. Warehouse-based systems require more robust fire protection due to the concentration of combustible materials in enclosed spaces. For example, the Moss Landing ML300 facility employed an advanced thermal runaway mitigation system alongside active and passive fire suppression technologies. In contrast, the adjacent Elkhorn outdoor facility relies on simpler, spacing-based fire safety protocols.

TRMs are designed to rapidly remove heat from overheating cells and cool adjacent cells and modules. Heat transfer occurs in different ways depending on the medium involved. When heat moves between solid objects, the process is called conduction. In contrast, heat transfer between a solid surface and a fluid — such as air or liquid — is called convection.

In warehouse environments, especially where metal racks are adjacent to one another, heat can easily propagate from one rack to the next via conduction. This is particularly problematic when the metal components are in direct contact or spaced very closely. By comparison, air gaps are significantly more effective at inhibiting heat transfer, acting as an insulator between structures.

While heat transfer can be managed through thoughtful system design, warehouses that store combustible materials face heightened risks. In such cases, the effectiveness of the TRM becomes critical. A well-engineered solution is essential to prevent thermal escalation and potential fire hazards.

Battery Chemistry

Our analysis of recent battery fire incidents, combined with conversations with several OEMs, has centered on two dominant lithium-ion chemistries: lithium nickel manganese cobalt (NMC) and lithium iron phosphate (LFP). Each offers distinct advantages and disadvantages that are critical to consider in BESS design.

NMC batteries are more energy dense, providing more capacity in a smaller footprint. These batteries can generally charge faster and have better performance in colder temperatures than LFP. However, the NMC battery cell can become unstable at a lower temperature 160° C (320° F) and, once a cell has entered thermal runaway, the NMC cell burns at a higher temperature — up to 800° C (1,472° F). When an NMC cell enters thermal runaway, there tends to be a 10-to-30-second period in which liquid, gas, and solid materials are violently ejected through the cell vent. These solid materials are typically bits of aluminum, carbon, and burning plastic. During this time, NMC cells bring all three elements of the fire triangle — fuel, oxygen, and an ignition source — creating a highly volatile situation.

LFP batteries are less energy dense, taking additional space for the same capacity. They also take more time to charge. While they perform better than NMC in hotter conditions, they have weaker performance in colder environments. They are a more cost-effective option, because the elements for constructing these batteries are available in abundance. They also offer a longer life cycle.

LFP batteries are also less prone to thermal runaway. LFPs remain stable at higher temperatures than NMCs, 230° C (446° F) and have a lower temperature in thermal runaway — 620° C (1,148° F). LFP cells tend to emit mostly smoke and gas, which, although hot, is typically not actively combusting.

Based on discussions with OEMs, the industry is trending toward LFP batteries for future BESS deployments due to their affordability and superior thermal stability. However, NMC remains a viable option for installations in which space efficiency is a major factor. Ultimately, BESS site developers must carefully evaluate the trade-offs between these chemistries and select the most suitable option based on site-specific requirements, environmental conditions, and safety priorities.

As the global energy landscape shifts toward renewables, researchers are actively exploring new battery chemistries to enhance the safety, performance, sustainability, and scalability of future BESS. While lithium-ion batteries remain dominant due to their high energy density and proven track record, several emerging chemistries are gaining traction for next-generation BESS applications. We anticipate the deployment of these emerging battery chemistries once thorough research confirms their viability for BESS applications.

Maintenance

Regular maintenance is essential to ensure the safe, reliable, and efficient operation of a BESS. A comprehensive maintenance program helps prevent failures, extends system life, and maintains optimal performance. Key activities should include:

- Routine system cleaning: Remove dust, debris, and contaminants from enclosures and components.
- Cooling system inspections: Check fans, liquid cooling loops, and filters for proper function and cleanliness.
- Trend analysis: Use system logs or integrated SCADA platforms to identify performance anomalies or degradation patterns.
- BMS firmware updates and alarm validation: Ensure the Battery Management System is running the latest software and that alarms are functioning correctly.
- Insulation resistance and grounding verification: Confirm electrical safety and system integrity.
- Component replacement: Identify and replace worn or damaged parts to prevent downtime.
- Battery health monitoring: Track metrics such as SOC, state of health (SOH), and temperature.
- Capacity testing: Periodically assess battery capacity to verify continued energy storage efficiency

The warehouse style configuration of the ML300 provided isolation and physical protection of the equipment from external weather conditions and hazards. Vistra collaborated closely with LG, the BESS manufacturer, to develop a tailored maintenance plan for the facility. LG's technical input was incorporated directly into the procedures, resulting in a strategy that is approximately 80% proactive and 20% corrective, according to Vistra. Once finalized, the plan was implemented using the IBM Maximo asset management system, which automates the generation and tracking of work orders. As part of ongoing maintenance, hundreds of individual battery modules have been replaced to maintain operation within design parameters.

Temperature control is a critical factor in BESS performance. With an average high temperature of 82° F at Moss Landing, battery cooling was achieved through a simple air-cooled design, with no additional cooling systems necessary.

Battery cell performance can drift over time, affecting overall system efficiency. To address this, periodic cell balancing or equalization is employed to maintain consistent voltage levels across individual cells. The BMS enables real-time monitoring and automated balancing if needed, helping to extend the operational life of the BESS.

High State of Charge

Operating a BESS at a higher SOC is known to make the system more susceptible to thermal runaway. Worldwide, numerous known BESS fires have occurred while operating in a high SOC, including several of the largest BESS fires in the Western Interconnection.

During the charging and discharging cycles of a lithium-ion battery, oxidation-reduction reactions transfer lithium ions between electrodes. This process releases chemical energy, some of which manifests as heat. The amount of heat generated increases with the battery's SOC. Under normal operating conditions, this heat remains well below critical thresholds and typically does not pose a safety concern.

The electrolyte in a lithium-ion battery is generally the most flammable component. These batteries use organic electrolytes, typically composed of linear and cyclic alkyl carbonates. Below are some common triggers for a thermal runaway condition:

1. Overcharging above 3.6 volts or deep discharging below 2.7 volts.
2. Charging or discharging at excessively high current rates.
3. Prolonged high SOC can cause electrolyte decomposition, releasing flammable gases that increase fire hazards.
4. Physical damage to the battery casing that allows oxygen to enter.
5. Internal short circuits, often caused by punctures in the cell separator — a thin membrane that isolates electrodes.

A study analyzing 23 BESS fire incidents in South Korea before 2019 found that 18 of those fires (78%) occurred when the SOC exceeded 95%[5]. This study anecdotally indicates a correlation between a high SOC and the chance of a thermal runaway event. In addition to this study, there are several more recent BESS fires throughout the world that are known to have occurred while at a high SOC.

A high SOC on a BESS can occur through normal operations or when conducting a capacity test. Capacity tests are conducted to validate battery performance against manufacturer specifications as part of the warranty validation. The tests also help predict how long the battery may last under real-world performance parameters. OEMs typically recommend these tests be performed annually.

During a capacity test, the BESS is charged to its maximum SOC to assess cell degradation from the previous test. A critical factor influencing the onset of thermal runaway is the total energy stored within the system. Because capacity tests are designed to push the BESS to its highest SOC, they inherently carry an elevated risk of triggering thermal runaway.

The actual capacity of a BESS site, measured during a capacity test, is often higher than the level an owner/operator typically charges to during normal operations. Although this operating buffer reduces the amount of energy available for injection into the grid, it plays a critical role in extending battery lifespan by minimizing thermal stress. Because many BESS sites only reach their maximum SOC during capacity testing, we recommend implementing several risk mitigation measures when conducting these tests:

Before conducting an annual capacity test:

a. All fire protection systems should be tested and their operational condition validated.
b. The local fire department should be notified.

[5] Unraveling the Characteristics of ESS Fires in South Korea: An In-Depth Analysis of ESS Fire Investigation Outcomes

c. Critical plant staff should rehearse possible failure scenarios and mitigation steps that need to be taken in advance of the capacity test.

The frequency and methodology of capacity testing should be carefully considered. Testing protocols must align with manufacturer recommendations and incorporate robust safety measures to minimize risk.

Conclusions and Recommended Actions

One of the most striking observations the team has experienced through this effort is the extraordinary pace of change in this field. A system designed in 2020 bears little resemblance to those being deployed today, even for projects of similar scale. This rapid evolution reflects the industry's steep learning curve, as manufacturers, operators, and engineers have gained valuable insights through accelerated growth and deployment.

These lessons are now shaping more sophisticated and effective TRM strategies, which are being integrated into modern BESS designs. These designs are no longer theoretical, they are being validated through rigorous UL 9540A testing, ensuring they perform as intended under various conditions. This level of verification was largely absent in earlier installations, making today's systems not only more efficient but demonstrably safer. These advancements have led to a shift away from warehouse-style BESS installations like ML300, which are unlikely to be replicated. The BESS of today is a far more refined and reliable resource than its predecessors of just a few years ago thanks to the collective experience, innovation, and testing rigor that now defines the industry.

OEMs are also re-evaluating battery chemistries, favoring emerging technologies that align with the latest safety standards. Lessons learned from early installations underscore the importance of understanding thermal runaway risks, especially at a higher SOC, and the variability in TRM system designs across manufacturers. Additionally, traditional fire suppression methods, such as overhead sprinklers, may exacerbate warehouse-style fire scenarios, prompting a need for more tailored safety solutions.

Recommended Actions

- **Prioritize standards compliance**: Ensure all new BESS deployments strictly adhere to the latest NFPA and UL standards to mitigate safety risks and future-proof installations.
- **Evaluate battery chemistries carefully**: Select chemistries that balance performance with safety, and are supported by robust TRM systems.
- **Rethink fire suppression strategies**: Avoid defaulting to overhead sprinkler systems; explore alternatives better suited to BESS environments.
- **Conduct capacity tests with caution**: Treat these tests as a higher-risk operation requiring special protocols and heightened awareness, especially if an operational buffer is employed during routine operations.
- **Engage early with stakeholders**:
  - Public education: Build trust and transparency through proactive outreach and education.
  - Fire services collaboration: Involve local fire departments during the planning phase and conduct joint drills to ensure preparedness.

- For those facilities that do not meet the most current NFPA 855 requirements, owners and operators should review operational limits and other parameters with manufacturers to establish appropriate operating margins and limits to minimize the probability of thermal runaway.

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