Energy Storage

Hazard Mitigation for Battery Energy Storage Systems

Hazard Types

To understand hazards associated with battery energy storage systems (BESS), it helps to start with some basic definitions:

- **Hazard** – a potential source of harm
- **Risk** – the combination of the probability of harm and the severity of that harm
- **Safety** – freedom from unacceptable risk

BESS hazards largely fall into three categories: (1) hazards inherent to the product itself; (2) hazards related to the installation or facility; and (3) hazards to personnel responsible for maintaining the system or responding to emergencies.

Battery System Hazards

Hazards related to the battery system are typically addressed by designers in accordance with IEC 60812, *Failure Modes and Effects Analysis (FMEA and FMECA)*. The IEC offers a rigorous approach to reducing risk associated with each failure mode by assessing three factors: (1) the severity of the failure mode in question (2) its probability of occurrence and (3) the ease of detection prior to actual failure. Each factor is assigned a numerical ranking, and those rankings are multiplied together to give a "risk priority number" (RPN).

Failure modes are associated with the battery itself through its normal operational life cycle and those relating to ancillary systems, such as thermal management. Failure modes with high RPNs are addressed by modifying the design to reduce one or more of the factors until a reduced, satisfactory RPN is achieved. This systematic risk-reduction approach in the FMEA is part of a statistical analysis of functional safety carried out by the manufacturer.

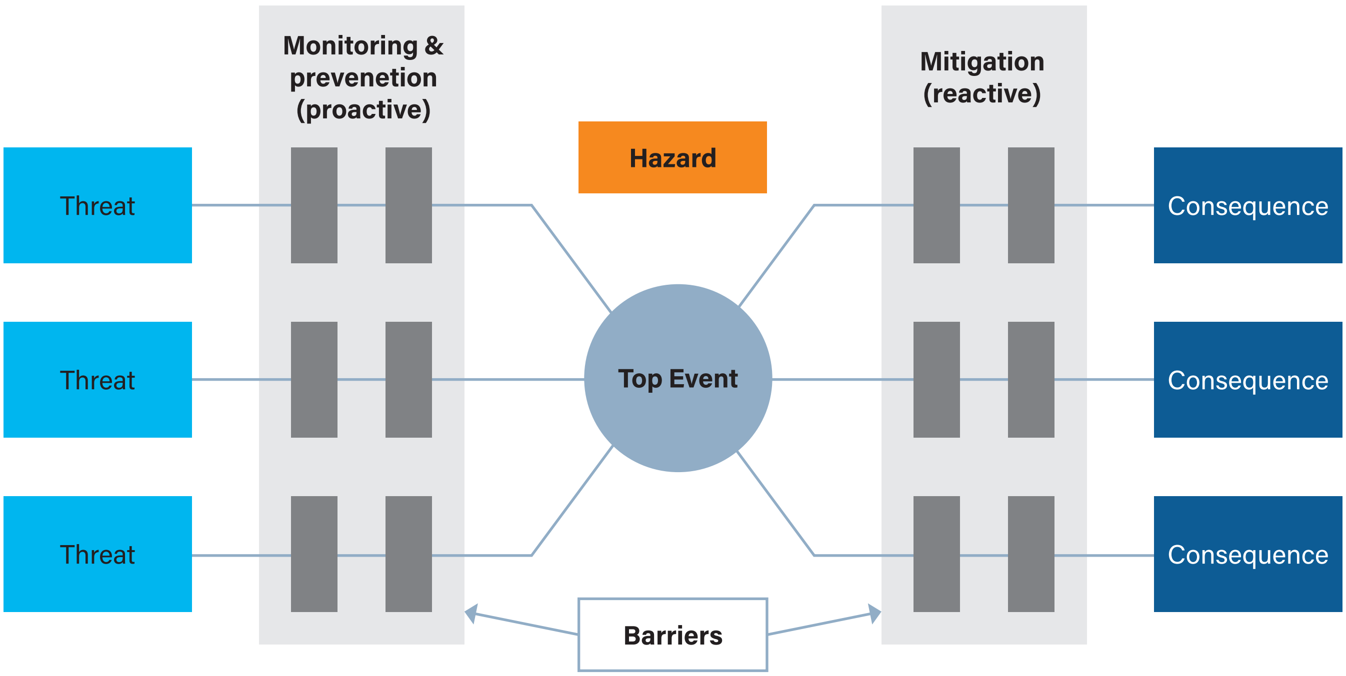
The effectiveness of the FMEA process is validated through system certification and mandatory testing, principally UL 1973, *Batteries for Use in Stationary and Motive Auxiliary Power Applications*, and UL 9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*.

Battery-related hazards are technology-specific. For example, in lithium-ion technology, most risk results from thermal runaway events that can cause fire or explosion, whereas electrolyte spills are a bigger concern for flow batteries.

BESS Installation Hazards

BESS installations or facilities are regulated by NFPA 855, *Standard for the Installation of Stationary Energy Storage Systems*. One of the requirements of NFPA 855 is for a site-specific hazard mitigation analysis (HMA) to be submitted to the authority having jurisdiction (AHJ). This HMA includes the high-level elements of the manufacturer's FMEA, as well as site-specific elements including environmental hazards (flooding, hurricanes, etc.) and actions by first responders. In addition to covering hazards during normal BESS operations, facility operators should also address hazards during the installation and decommissioning phases when active safety systems may be non-operational.

The HMA typically takes the form of a ***bowtie analysis***, a simple and visual tool (depicted in the diagram below) showing threats on the left, a hazard and top event (i.e., the primary, highest-priority disastrous occurrence) in the center, and potential consequences on the right. Between the threats and the top event are multiple preventive barriers, and between the top event and consequences are multiple barriers for mitigation.



For example, one hazard for a lithium-ion battery system is high temperatures not related to the cells. In the bowtie analysis, the top event would be cell failure with venting and thermal runaway. Multiple threats can cause high temperatures, including cooling system failures. One potential consequence of cell venting is an explosion. Typical prevention barriers would include cooling system alarms, battery temperature alarms, and system shutdown. Mitigation barriers against explosion would include emergency ventilation, deflagration venting, and first-responder actions.

While not as rigorous as the FMEA carried out by the manufacturer and lacking assessments of probability, the bowtie analysis is well-suited to a less technical audience.

Personnel Hazards

Hazards faced by maintenance personnel fall into four categories:

- **Electrical** – shock and arc flash
- **Thermal** – burns and thermal runaway
- **Chemical** – electrolyte spills, toxics, etc.
- **Ergonomic/Mechanical** – injuries relating to the weight and handling of battery modules

NFPA 70E, *Standard for Electrical Safety in the Workplace*, requires a battery risk assessment to be completed prior to working on a battery system. Annex F.7 in the 2024 edition of NFPA 70E has a useful flow chart for selection of personnel protective equipment.

Understanding of battery risks has significantly advanced in recent years, especially in the assessment of DC arc flash incident energy. This work is embodied in multiple changes slated for the 2027 edition of NFPA 70E.

Emergency personnel responding to a battery incident are also subject to safety hazards. These are covered by NFPA 855 requirements relating to emergency response, as discussed in the next section.

Emergency Response

The 2026 edition of NFPA 855 expands on prior requirements for training of facility personnel involved in emergency response, including annual refresher training. In addition, it formalizes expectations for coordination with local emergency responders, requiring that first responders receive appropriate training and information to effectively respond to BESS incidents.

Documentation covering emergency response is expanding. The 2026 edition of NFPA 855 introduces a more comprehensive emergency response plan (ERP). This ERP serves as a broader framework addressing mitigation, preparedness, response, and recovery to ensure a more holistic and coordinated approach to emergency management.

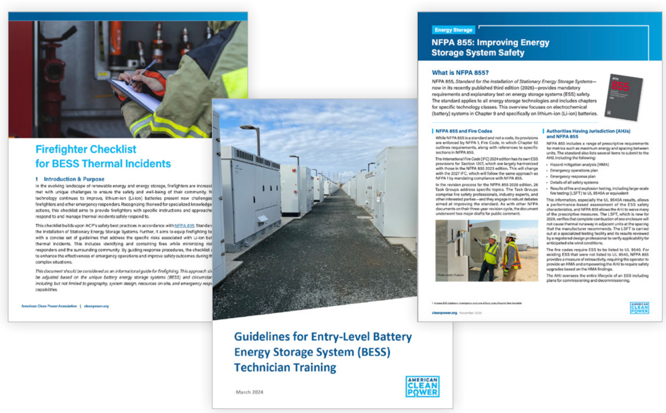
Recommendations

In addition to following the requirements of NFPA 855 and NFPA 70E, ACP recommends that facility operators treat an HMA as a living document addressing all phases of the BESS lifecycle, including installation and decommissioning, with appropriate updates to reflect changes in the installation. Early and regular engagement with the AHJ and emergency personnel promotes improved coordination during the development phase and stronger understanding of the facility. Active engagement empowers personnel to mitigate potential incidents and fosters stronger trust between operators and the community hosting a BESS facility.

ACP Resources

ACP publications on hazard mitigation and emergency response include:

- Firefighter Checklist for BESS Thermal Incidents[1]
- Guidelines for Entry-Level BESS Technician Training[2]
- Qualified Electrical Worker Program for Battery Energy Storage Systems
- NFPA 855: Improving Energy Storage System Safety[3]



Taking a Deeper Dive

The Electric Power Research Institute's (EPRI) Energy Storage Integration Council, published a helpful example of an HMA using the bowtie approach.[4] For those wishing to read the latest draft of NFPA 855 before its final publication, it can be accessed from the NFPA's web page for the standard.[5] Click the "Next Edition" tab and scroll down to the Second Draft Report button. Accessing the document requires an NFPA account, which can be created from the login dialog box. The same procedure can be used to access the First Draft Report of the 2027 edition of NFPA 70E.[6]

1 https://cleanpower.org/resources/firefighter-checklist-for-bess-thermal-incidents/
2 https://cleanpower.org/resources/guidelines-for-entry-level-bess-technician-training/
3 https://cleanpower.org/resources/nfpa-855-improving-energy-storage-system-safety/
4 https://www.epri.com/research/products/000000003002023089
5 https://www.nfpa.org/codes-and-standards/nfpa-855-standard-development/855
6 https://www.nfpa.org/codes-and-standards/nfpa-70e-standard-development/70e