First Responders Guide to Lithium-Ion Battery Energy Storage System Incidents

1 Introduction

This document provides guidance to first responders for incidents involving energy storage systems (ESS). The guidance is specific to ESS with lithium-ion (Li-ion) batteries, but some elements may apply to other technologies also. Hazards addressed include fire, explosion, arc flash, shock, and toxic chemicals. For the purposes of this guide, a facility is assumed to be subject to the 2023 revision of NFPA 855 [B8][1] and to have a battery housed in a number of outdoor enclosures with total energy exceeding 600 kWh, thus triggering requirements for a hazard mitigation analysis (HMA), fire and explosion testing in accordance with UL 9540A [B14], emergency planning, and annual training. (The 2021 International Fire Code (IFC) [B2] has language that has been largely harmonized with NFPA 855, so the requirements are similar.)

This guide provides recommendations for pre-incident planning and incident response. Additional tutorial content is provided for each of the hazard categories. The Bibliography provides references to applicable codes and standards, and other documents of interest.

2 Abbreviations and acronyms

AHJ	authority having jurisdiction
BMS	battery management system
ERP	emergency response plan (designated in NFPA 855 as ‘emergency operations plan’)
ESS	energy storage system
HMA	hazard mitigation analysis
IDLH	immediately dangerous to life and health
LEL	lower explosive limit
LFL	lower flammable limit
LFP	lithium iron phosphate battery
Li-ion	lithium-ion
NCA	lithium nickel-cobalt-aluminum oxide
NFPA	National Fire Protection Association
NMC	lithium nickel-manganese-cobalt oxide
PPE	personal protective equipment
SCBA	self-contained breathing apparatus
SDS	safety data sheet
SME	subject-matter expert
UFL	upper flammable limit
UL	Underwriters Laboratories

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[1] References in square brackets are to the Bibliography at the end of this guide.

3 Pre-incident planning

3.1 General

The pre-incident plan is used by first responders in effectively managing emergencies. It is required to be available to the incident commander during an event. The plan should be in accordance with the newly released NFPA 1660 [B9]. From the front matter of this new document: “The 2024 edition of NFPA 1660 integrates NFPA 1600, NFPA 1616, and NFPA 1620 into a single standard that establishes a common set of criteria for emergency management and business continuity programs; mass evacuation, sheltering, and re-entry programs; and the development of pre-incident plans for emergency response personnel.” Pre-incident planning, formerly in NFPA 1620, is in Chapters 17 through 23.

Additional ESS-specific guidance is provided in the NFPA Energy Storage Systems Safety Fact Sheet [B10]. NFPA 855 requires several submittals to the authority having jurisdiction (AHJ), all of which should be available to the pre-incident plan developer. These include:

- Results of fire and explosion testing conducted in accordance with UL 9540A
- Hazard mitigation analysis (HMA)
- Emergency response plan (ERP)

While the main document for development of the pre-incident plan is the ERP, the UL 9540A test results and HMA may provide useful additional information for the plan and associated training.

3.2 UL 9540A test results

Testing to UL 9540A provides information at a level of detail that may not be included in the ERP (see 3.4). Cell-level testing provides a breakdown of the composition of vented gas from cells in thermal runaway, including flammable gases and vapors. Potentially significant concentrations of highly toxic hydrogen fluoride may also be produced. Video recordings are made of testing at unit (rack) and installation levels (if the latter is performed). These test results and videos can be used in first-responder training (see 3.6) since they provide insight into system behavior in a thermal runaway event that cannot be gained from outside the enclosure.

3.3 HMA

While testing to UL 9540A is valuable, it involves initiation of thermal runaway in a limited number of cells. This method does not address larger-scale failures that could occur, for example, with a loss of insulation and subsequent arcing, or with mechanical damage potentially caused by vehicle impacts or flying debris. Such failures could result in a fire that consumes the entire enclosure. The HMA should address such an occurrence and should assess, at least by simulation or calculation, the maximum temperature rise of cells in adjacent enclosures. This information is used to justify limited spacing between enclosures and can also be used to determine whether first responders should intervene.

3.4 ERP

The ERP forms the basis for pre-incident planning. Among other information, the ERP should include details on the following:

- Site overview and ESS nameplate information
- Potential hazards
- Fire protection and safety systems
- Emergency response recommendations

- Emergency contacts, including subject-matter expert (SME)
- Safety data sheets (SDS)
- PPE

The firefighting philosophy should be outlined, whether that be to suppress the fire using built-in systems or to let it burn out safely (and in some cases, to make it burn. See 5.1.)

3.5 Availability of battery management system data

Access to battery management system (BMS) data is critical for informed incident response. Depending on the severity of the incident, it may be possible to observe the current conditions within the enclosure where the incident began, such as module temperatures and readings for any gas sensing systems that may be installed. If a fire is in progress, it is important to monitor module temperatures in adjacent enclosures, to determine whether additional actions should be taken.

BMS access may be direct, such as using a first responder's computer to access the local human-machine interface or a remote digital twin, or it may be indirect, such as through a voice connection to a network operations center or SME. Data may also be available on a screen local to each enclosure, but this should not be accessed if there is any danger of fire, explosion, or toxic emissions.

3.6 Training

NFPA 855 mandates initial and annual refresher training for facility staff (see section 4.3.2.2). First responders should be included in such training, either in person or via video recordings of the training sessions. Trainees should be familiar with the site layout, installed equipment, SDS contents, and emergency response recommendations of the ERP.

4 Incident response

4.1 General

An incident command system should be established immediately on arrival, and an appropriate incident command individual should have access to BMS data (see 3.5). Working with facility personnel, the scene should be assessed, and potential hazards should be communicated to all responders.

4.2 Personal protective equipment (PPE)

Full firefighter protective gear should be worn where there is any possibility of fire or explosion, including proper use of self-contained breathing apparatus (SCBA). If there is no risk of fire or explosion per the project incident command, protective clothing for arc-flash and shock hazards should be worn by anyone operating within the arc-flash boundary (see 4.5). Jewelry and other metallic items should be removed.

4.3 Fire

If a fire is in progress, flammable gases will be consumed as they are released, and an explosion is unlikely. The safest approach is to allow the enclosure to burn in a controlled manner, so that all fuel is consumed and the possibility of reignition is minimized. BMS data from adjacent enclosures should be monitored to verify that module temperatures remain at safe levels (typically up to around 80 °C/180 °F). Application of water should be limited to cooling and protecting nearby exposures (and adjacent enclosures if module temperatures are above thresholds identified in the ERP).

Once the fire has self-extinguished, there may be ongoing releases of flammable or toxic gases. Full protective gear and SCBA should continue to be used until releases (such as carbon monoxide) are measured to be at a safe level.

If an earlier fire has been extinguished by the enclosure's fire suppression system, there is a potential for ongoing release of flammable gases, with a corresponding explosion risk (see 4.4). See 5.1 for additional discussion of fire hazards.

4.4 Explosion

If system sensors (temperature, smoke, heat, and/or flammable gas) indicate that a thermal runaway event occurred, but there is no sign of fire, it should be assumed that an explosion risk is present. Personnel should be stationed outside the potential blast radius, at an angle to the doors, and upwind of the enclosure. The enclosure should be inspected from a distance using BMS data to determine the status of the system, including module temperatures, gas sensing, and ventilation systems for gas exhaust. If the BMS is not functioning because of system damage, thermal scanning may provide an indication of ongoing thermal issues. However, responders should be aware that enclosure insulation may make it difficult to make an accurate assessment of internal temperature.

If the enclosure has been vented by automatic door or panel opening and there is no indication of high temperatures, the enclosure may be approached by responders using continuous gas monitoring to warn of any residual atmospheric risk.

If the enclosure appears to be sealed – for example, if gas venting is accomplished through a magnetic flap or if there is no provision for gas venting – BMS data and external visual assessment should be reviewed with the SME before attempting to open the enclosure.

See 5.2 for additional discussion of explosion hazards.

4.5 Arc flash and electric shock

Even when disconnected from external circuits, batteries retain their stored energy and should be considered to be energized. A battery may be partially destroyed by fire yet retain stranded energy at hazardous levels. All batteries, whatever their visual condition, should be treated as fully charged with respect to arc flash and electric shock hazards.

Appropriate PPE should be worn by properly trained individuals when working within the arc flash boundary. See 5.3 for additional discussion of arc flash and shock hazards.

4.6 Toxic chemicals

Toxic chemicals, including hydrogen fluoride, hydrogen chloride, hydrogen cyanide, and carbon monoxide, may be released during an incident. Spraying water on smoke or vapor released from the battery, whether burning or not, may cause skin or lung irritation and contaminated run-off similar to plastic fires [B1]. This is one additional reason for allowing the battery to burn in a controlled manner. The site perimeter should be entered only by trained firefighters wearing full protective gear and using SCBA. See 5.4 for additional discussion of toxic chemical hazards.

5 Discussion of Li-ion hazards

5.1 Fire

There is ongoing debate in the energy storage industry over the merits of fire suppression in outdoor battery enclosures. On one hand, successful deployment of clean-agent fire suppression in response to a limited event (for example, an electrical fire or single-cell thermal runaway with no propagation) can limit damage to the system, which can then be expeditiously returned to service. On the other hand, actuation of the same system in response to a large event, such as a multicell arcing fault, may knock out or prevent a fire but allow ongoing release of flammable gases, thus creating an explosion hazard.

Some ESS designs employ a ‘make it burn’ strategy, in which a sparker ignites flammable gas when the lower flammable limit (LFL) is exceeded but before the lower explosive limit (LEL) is reached. Such designs do not include fire suppression, on the basis that the loss of an enclosure through controlled burning is preferable to increasing the risk of an explosion. This strategy can be effective for Li-ion technologies based on transition metal oxides, such as lithium nickel-cobalt-aluminum oxide (NCA) and lithium nickel-manganese-cobalt oxide (NMC) materials, which release oxygen during thermal runaway, thus maintaining a flammable gas mixture. The same arrangement would potentially be less effective for batteries using lithium iron phosphate (LFP) material, as discussed in 5.2.

There are pros and cons to each of the common fire-suppression media in use today, including clean agents, inert gases, aerosols, and water.

- Clean agents, such as Novec 1230®, and inert gases, such as nitrogen, will extinguish small fires without causing extensive damage within the enclosure; they also have a cooling effect, which can assist in limiting thermal runaway propagation. In a larger-scale event, such as a multi-cell arcing fault, their effect may be temporary and may result in ongoing propagation with the risk of reignition or explosion. Also, inert gases are oxygen-depleting and cannot be used in structures where personnel may be present.
- Aerosol devices, such as Stat-X®, can be self-actuating, releasing based on elevated temperature without the need for control systems. They are effective on small fires and can help to limit initiation of thermal runaway. The aerosol itself is typically alkaline and may damage BMS and other electronic components in the enclosure. These devices are unlikely to be effective in larger-scale events or when thermal runaway is freely propagating between cells or modules.
- Water is the most efficient medium for cooling cells below the level at which thermal runaway can occur. However, to be effective, the water must be able to reach cells that may be otherwise shielded within closely spaced modules. This means that directed spray across the top of each module is more likely to achieve full extinguishing and arresting of propagation than can be realized with ceiling-mounted sprinklers, and this precise coverage may not always be feasible to achieve. Liberal use of water may also serve as the initiator for electrical arcing that may cause thermal runaway in otherwise unaffected modules. Additionally, the combination of water and highly energized battery systems could electrolytically generate more explosive hydrogen gas. Finally, similar to plastics fires [B1] use of water for directly targeting a fire will also create contaminated run-off [B11], which must be contained and removed for treatment.

5.2 Explosion

Venting of all Li-ion cells results in the release of a gas mixture with high levels of hydrogen, carbon monoxide, and carbon dioxide. Depending on the circumstances, there may also be a fog of unreacted flammable organic compounds, and hydrogen fluoride (normally in trace amounts, but can be higher). The volume of gas released is typically orders of magnitude greater than the cell volume. In the absence of fire, this gas mixture poses an explosion risk.

NFPA 855 requires design provisions for either explosion prevention in compliance with NFPA 69 [B5], or explosion management according to NFPA 68 [B4]. However, systems only complying with NFPA 68 can present explosion hazards to first responders if the following conditions are met: 1) the atmosphere in the enclosure is above the upper flammable limit (UFL), 2) the system has no remote means to ventilate its contents, 3) and a door is opened. Caution and deliberation with the project SME should be taken in situations where gas has accumulated, and automatic ventilation is either not present or not functioning.

The ’**make** it burn’ strategy for explosion prevention is discussed in 5.1. This approach may be less effective for batteries using LFP technology, from which minimal amounts of oxygen are released during thermal runaway. In a multi-cell arcing fault and in the absence of emergency ventilation with outside air, the available oxygen in the enclosure would be quickly consumed. Further cell venting would drive the gas concentration above the UFL, creating the same hazard described in the previous paragraph.

Ventilation for explosion prevention may be accomplished by the automatic opening of doors or other panels. While this measure is unlikely to meet the requirements of NFPA 69, it addresses the intent of the standard and can be important for protecting first responders. It should be noted that this procedure will reduce the effectiveness of airborne fire suppressants and is more compatible with a ‘let it burn’ philosophy.

5.3 Arc flash and shock

Battery strings in an enclosure involved in an incident should have been tripped by the BMS, but as detailed in 4.5, they can continue to present arc-flash and shock hazards. Many ESS designs now operate at dc voltages up to 1500 V, representing a significant risk to untrained personnel. At the time of preparing this guide, there is ongoing work on characterization of dc arc-flash hazards, and it is likely that this work will inform future changes to NFPA 70E [B7].

5.4 Toxic chemicals

Recommendations for first responders are detailed in 4.6. Emissions from battery fires vary by battery chemistry and state of charge. Toxicity issues are discussed at length in [B1], where it is stated that hydrogen chloride is the chemical that reaches its IDLH (immediately dangerous to life and health) value fastest. In terms of 30-minute average release rates as a function of IDLH, the greatest concern is with hydrogen fluoride, followed by hydrogen cyanide, hydrogen chloride, and carbon monoxide.

6 Bibliography

The following documents are discussed in this guide:

[B1] DNV-GL, Considerations for ESS Fire Safety, Report for Consolidated Edison and NYSERDA, 2017

[B2] International Fire Code (IFC), 2021, International Code Council, Inc.

[B3] NFPA 1, Fire Code, 2021

[B4] NFPA 68, Standard on Explosion Protection by Deflagration Venting, 2018

[B5] NFPA 69, Standard on Explosion Prevention Systems, 2019

[B6] NFPA 70, National Electrical Code, 2023

[B7] NFPA 70E, Standard for Electrical Safety in the Workplace, 2021

[B8] NFPA 855, Standard for the Installation of Stationary Energy Storage Systems, 2023

[B9] NFPA 1660, Standard for Emergency, Continuity, and Crisis Management: Preparedness, Response, and Recovery, 2024

[B10] NFPA Energy Storage Systems Safety Fact Sheet, available from the NFPA website

[B11] Quant, M., Willstrand, O., Mallin, T., Hynynen, J., Ecotoxicity Evaluation of Fire-Extinguishing Water from Large-Scale Battery and Battery Electric Vehicle Fire Tests. *Environ. Sci. Technol.* https://doi.org/10.1021/acs.est.2c08581

[B12] UL 1973 Ed. 3, ANSI/CAN/UL Batteries for Use in Stationary and Motive Auxiliary Power Applications, 2022

[B13] UL 9540 Ed. 2, Energy Storage Systems and Equipment, 2020

[B14] UL 9540A Ed. 4, ANSI/CAN/UL Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, 2019