July 2024, V2

RISK CONTROL PRACTICE: SPECIAL HAZARD

Stationary Battery Energy Storage Systems Handbook

Didier L. SCHÜTZ
Risk Control Practice Leader,
SCOR

SCOR
The Art & Science of Risk

Important notices and disclaimer

CONTENTS

SCOPE ... 5
1 INTRODUCTION ... 6
1. CATEGORIZATION OF ENERGY STORAGE DEVICES ... 6
2. RECHARGEABLE BATTERIES BASICS ... 6
3. TYPE OF RECHARGEABLE BATTERIES ... 7
3.1 Lead-Acid (PbA) batteries ... 7
3.2 Nickel Batteries ... 9
3.3 Lithium-Ion (Li-Ion) / Lithium polymer batteries ... 10
3.4 Other types of batteries ... 16
3.5 Liquid Electrolyte development ... 17
4. DC BATTERY SYSTEM BASICS ... 17
5. ESS/BESS BASICS ... 18
6. LOSS EXPERIENCE ... 19
2 FOCUS ON DC BATTERY SYSTEMS ... 22
1. LOCATION, ARRANGEMENT & SEGREGATION ... 22
2. ELECTRICAL EQUIPMENT ... 23
3. VENTILATION ... 23
4. FIRE DETECTION AND FIRE PROTECTION ... 24
5. SPILL CONTROL ... 25
3 FOCUS ON ESS/BESS ... 26
1. STANDARDS AND CERTIFICATION ... 26
2. NFPA855 VS FM GLOBAL DATA SHEET 5-33 ... 28
3. PERSISTENT QUALITY & SAFETY ISSUES ... 28
4. LITHIUM-ION BATTERY ENERGY STORAGE SYSTEM (LIB-ESS/BESS) SELECTION ... 29
5. LFP VS NMC LI-ION BATTERY ... 29
6. HAZARDS, FIRE PROPAGATION CHARACTERISTICS AND PROTECTION SCHEMES ... 31
7. LOCATION, ARRANGEMENT & SEGREGATION ... 32
7.1 Location & Separation ... 32
7.2 Storage ... 37
7.3 Vehicle impact protection ... 37
8. ELECTRICAL EQUIPMENT ... 38
9. VENTILATION ... 38
10. FIRE DETECTION AND FIRE PROTECTION ... 38
11. SPILL CONTROL ... 41
12. FIRE DEPARTMENT ... 41
4 TECHNICAL REFERENCES ... 44

1. NATIONAL FIRE PROTECTION ASSOCIATION 44
2. FACTORY MUTUAL GLOBAL DATA SHEET..44
3. OTHER...44
5 ANNEXES.. 45
1. WHY USE SPRINKLER PROTECTION FOR LITHIUM-ION POLYMERE BATTERIES (DRY CELLS)?..45
2. STRANDED ENERGY 45
3. EMERGENCY RESPONSE PLAN OR PRE-FIRE PLAN...46
4. FIRE DEPARTMENT CONNECTION (FDC) 48
5. FIRE RESISTANCE OF BUILDING ASSEMBLIES 50
6. BESS FAILURE EVENT DATABASE...50

SCOPE

Version 1 released in January 2022
Version 2 - Revised and updated July 2024 – section 3 FOCUS ON ESS/BESS

The purpose of this Handbook | Guidance Note is to provide comprehensive technical support to Underwriters and Risk Control Engineers pertaining to Battery & Energy Storage Systems and their related special hazards.

This document provides guidance for Stationary Battery Energy Storage Systems including:

- DC battery systems used for standby operations in stationary applications (including, but not limited to, power-generating stations, substations, telecommunications, data centers, switchgear protection systems, process control systems, emergency power supplies, and uninterruptable power supplies – UPS). All types of batteries (wet/dry cells) except lithium-ion polymer batteries (dry cells) are considered.
- Electrical Energy Storage Systems (ESS) or Battery Energy Storage Systems (BESS) that charge (or collect energy) from the grid or power plant / source and then discharge that energy later to provide electricity or other grid services when needed. ESS/BESS exclusively using polymer lithium-ion batteries (dry cells) are considered.

This handbook is mostly focused on fire explosion hazards. The related special hazards are described. Boiler & machinery hazards are not covered in detail in this document. Examples of losses are also given when relevant.

This handbook was prepared with Franck Orset (FPO), Loss Prevention Engineer for nuclear risks. Many thanks for his invaluable contribution.

Standard recommendations based on recognized international standards and good practices are proposed. Moreover, very good NFPA (National Fire Protection Association) and Factory Mutual Data Sheets (FM Global Data Sheets) upon these subjects exist. As there is no need to reinvent the wheel, readers are redirected to those references when relevant.

- NFPA free viewing at http://www.nfpa.org/
- FM Global Data Sheets free viewing and download when registered at http://www.fmglobal.com/

Note that these materials are periodically revised and updated. Please monitor the above websites for updates and/or revisions.

1 INTRODUCTION

1. CATEGORIZATION OF ENERGY STORAGE DEVICES

Energy storage devices can be categorized as mechanical, electrochemical, chemical, electrical, or thermal devices, depending on the storage technology used:

- Mechanical technology, including pumped hydropower generation and flywheels (kinetic energy storage), is the oldest technology.
- Chemical technologies include energy storage technologies such as fuel cells, and mechanical technologies include electric double-layer capacitors.
- Electrochemical technologies include electrochemical devices called batteries that convert electric energy to chemical energy, and vice versa. Such technologies include lead storage batteries, sodium-sulfur batteries, and lithium batteries. In addition to the recent spread of mobile information technology (IT) devices and electric vehicles, the increased mass production of lithium secondary batteries and their lowered costs have boosted demand for energy storage devices using such batteries.
- Energy storage devices can be used for an Uninterruptible Power Supply (UPS), Transmission and Distribution (T&D) system support, or large-scale generation, depending on the technology applied and on storage capacity.
- Among electrochemical, chemical, and physical energy storage devices, the technologies that have recently received the most attention fall within the scope of UPS and T&D system support.

Electrochemical energy storage devices can be categorized as primary and secondary types:

- Primary battery/cell types are “single use” and cannot be recharged. Dry cells and (most) alkaline batteries are examples of primary batteries.
- Secondary battery/cell types are rechargeable. The chemical reaction that occurs on discharge may be reversed by forcing a current through the battery in the opposite direction. This charging current must be supplied from another source, which can be a generator or a power supply. Examples of secondary batteries include Nickel-Cadmium (NiCd), lead acid, and lithium-ion batteries.

2. RECHARGEABLE BATTERIES BASICS

This handbook focuses on rechargeable batteries (secondary type batteries) using electrochemical technologies. A rechargeable battery, storage battery, or secondary cell, (or archaically “accumulator”) is a type of electric battery which can be charged, discharged into a load, and recharged many times, as opposed to a disposable or primary battery, which is supplied fully charged and discarded after use. It is composed of one or more electrochemical cells.

Rechargeable batteries typically initially cost more than disposable batteries but have a much lower total cost of ownership and environmental impact, as they can be recharged inexpensively many times before they need replacing. Some rechargeable battery types are available in the same sizes and voltages as disposable types and can be used interchangeably with them.

The term "accumulator" is used as it accumulates and stores energy through a reversible electrochemical reaction.

Batteries have already proven to be a commercially viable energy storage technology.

Several applications and uses, including frequency regulation, maintaining voltage levels, renewable integration, peak shaving, microgrids, and black start capability (i.e., restarting a

generator without power from the grid), include battery-based energy storage systems.
Billions of dollars in research are being invested around the world in improving batteries, and industries are also focusing on building better batteries.
Charge and discharge efficiency is a performance scale that can be used to assess battery efficiency. Lithium secondary batteries have the highest charge and discharge efficiency, at 95%, while lead storage batteries are at about 60%-70%, and redox flow batteries at about 70%-75%.
The performance of energy storage devices can be defined by their output and energy density (kW/kg). Higher energy density is currently the main driver of battery technology development.
One important performance element of energy storage devices is their lifespan, and this factor has the biggest impact in reviewing economic efficiency.
Another major consideration is eco-friendliness, or the extent to which the devices are environmentally harmless and recyclable.
A battery system consists of the "battery pack" which connects multiple cells to appropriate voltage and capacity.

3. TYPE OF RECHARGEABLE BATTERIES

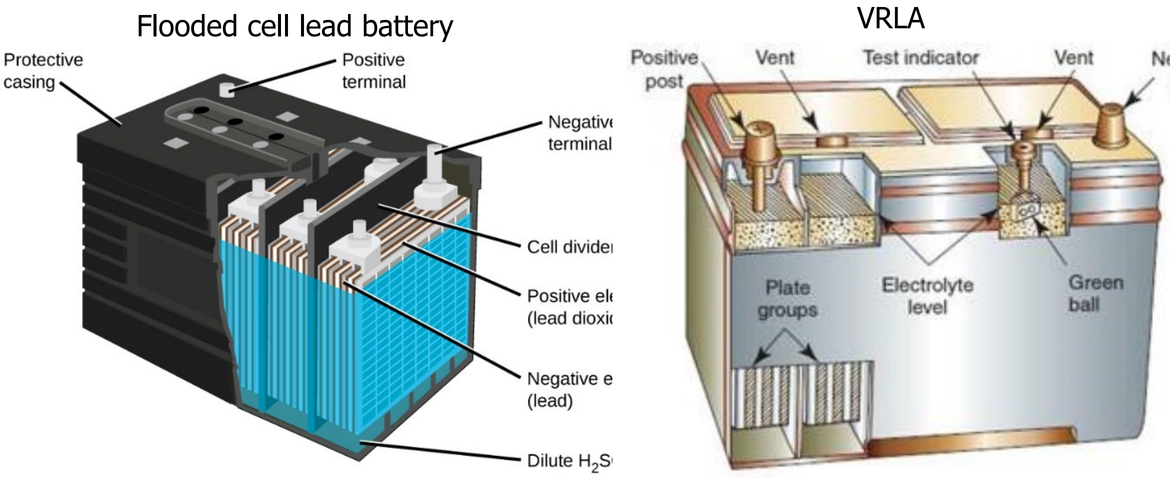
Rechargeable batteries are produced in many different shapes and sizes, ranging from button cells to megawatt systems connected to stabilize an electrical distribution network. Several different combinations of electrode materials and electrolytes are used, including lead–acid, zinc–air, nickel–cadmium (NiCd), nickel–metal hydride (NiMH), lithium-ion (Li-ion), lithium iron phosphate (LiFePO4), and lithium-ion polymer (Li-ion polymer).
The most common stationary standby batteries are Lead-Acid, Nickel-Cadmium, Nickel–Metal Hydride (Ni–MH) and Lithium-Ion (Li-ion) batteries.

3.1 Lead-Acid (PbA) batteries

This type of "secondary cell" is widely used in vehicles and other applications requiring high values of load current. This is the oldest form of rechargeable battery. Its main benefits are low capital costs, maturity of technology, and efficient recycling. Lead acid batteries can be flooded ("wet" = liquid electrolyte) or of a valve-regulated type (VRLA).

3.1.1 Flooded lead acid cells

- These are constructed with the liquid electrolyte completely covering (flooding) the closely spaced plates in a clear container.
- The clear container allows for visual inspection of the plates and internal components.
- Normal charging results in gassing and water consumption.
- While this will necessitate electrolyte maintenance, the ability to replenish lost water makes flooded cells more tolerant of overcharging and operating at an elevated temperature than VRLA cells. Therefore, flooded lead acid batteries can achieve an average service life of 15-20 years when they are well maintained.



Google creative commons. Attribution 4.0 International (CC BY 4.0)
https://upload.wikimedia.org/wikipedia/commons/9/9f/CNX_Chem_17_05_Lead.png

Flooded cell lead battery electrolyte maintenance (replenishing lost water)

3.1.2 Valve-regulated lead-acid (VRLA)

- These batteries are also called “sealed”, “Sealed Lead–Acid” (SLA), or “maintenance free” (because there is no need to top up the water): they first appeared in the mid-1970s. Engineers deemed the term “sealed lead–acid” a misnomer because lead–acid batteries cannot be totally sealed. Sealed batteries are, as their description implies, sealed against spilling or loss of electrolyte, when operated within specifications. Cells are sealed except for a valve that opens, as required, to relieve excess internal pressure. These cells provide a means for recombination of gases to limit water consumption. The valve regulates the internal pressure to optimize recombination efficiency - hence the term “valve- regulated.”
- Non-spillable batteries: batteries termed as non-spillable are the sealed lead-acid (SLA) / VLRA batteries using Gel or Absorbent Glass Matt (AGM) technology.
- Warning: The word non-spillable is a bit misleading, and one can mistake it for sealed batteries. A battery that is sealed cannot automatically be non-spillable. Sealed standard lead-acid batteries with liquid electrolytes are spillable. The International Air Transport Association in the United States defines non-spillable batteries as batteries with no free-flowing liquid. These batteries are mostly used as starter batteries for motorcycles, start–

stop function for micro-hybrid cars, as well as marine vehicles and RVs that need some cycling.

- Construction will allow for operating in any position.
- Generation of gas within the VRLA battery is controlled to allow the recombination of over 99% of the gas generated during normal use. These batteries are equipped with a low-pressure venting system that will release excess gas and automatically reseal in the event that gas pressure rises to a level above the normal rate. While the sealed battery is typically considered safe to operate within enclosed areas, the low-pressure venting capability will still allow some gas to escape under certain conditions.
- Under normal recombination operations, valve-regulated cells periodically vent very small amounts of hydrogen, and some hydrogen may also diffuse through the plastic case.
- When charging above the recommended manufacturer's voltage values or operating at elevated temperatures, VRLA batteries may result in excessive venting of hydrogen and oxygen from the cell and/or can result in premature dry out, potentially leading to thermal runaway.
- Therefore, it is important to observe all the same safety considerations that must be observed when normal wet-cell batteries are used, particularly during charging.
- These batteries are particularly suited to UPS service, where deep discharge and cyclic use are common, because of the use of heavy lead calcium-alloy grids. Sealed lead–acid (SLA) is also used in small UPSs, emergency lighting, and wheelchairs. Because of their low price, dependable service, and low-maintenance requirement, SLAs remain the preferred choice for health care in hospitals and retirement homes.
- The average service life of a VRLA battery is less than 10 years of industrial use when they are well maintained. It is not uncommon to replace VRLA batteries after a service life of less than 5 years. In extreme cases, VRLA batteries must be replaced at 2-year intervals.

3.2 Nickel Batteries

Nickel battery technologies include nickel cadmium (Ni-Cad), nickel metal hydride (Ni-MH), and nickel zinc (Ni-Zn)

3.2.1 Nickel-Cadmium (Ni-Cd) batteries

A nickel-cadmium battery (Ni-Cd) is a rechargeable battery used for portable computers, drills, camcorders, and other small battery-operated devices requiring an even power discharge. Nickel cadmium batteries use an alkaline electrolyte (also called a "dry cell", using paste electrolyte with only enough moisture to allow current to flow, i.e., potassium hydroxide = KOH, solid mineral, fusion temperature 406°C). The active materials are nickel oxyhydroxide in the positive plate, and cadmium metal in the negative plate. This offers a good low-temperature performance. Stationary standby nickel cadmium batteries have an expected life of 20-25 years in a controlled environment, which is equivalent or better than flooded lead-acid designs, and better than VRLAs. Pricing is economical: Ni–Cd has the lowest cost-per-cycle. They are available in a wide range of sizes and performance options.

3.2.2 Nickel-Metal Hybrid (Ni-MH) batteries

The Ni–MH battery (dry cell) combines the proven positive electrode chemistry of the sealed Ni–Cd battery with the energy storage features of metal alloys developed for advanced hydrogen-energy storage concepts. Ni–MH batteries outperform other rechargeable batteries and have a higher capacity and less voltage depression. The Ni–MH battery currently finds widespread applications in high-end portable electronic products, where battery performance parameters, notably run time, are major considerations in the purchase decision. It offers greater service advantages over other primary battery types at extreme low-temperature operations (–20°C).

3.3 Lithium-Ion (Li-Ion) / Lithium polymer batteries

This section, and the following on Li-Ion batteries, are exclusively focused on Lithium-Ion (Li-Ion) / Lithium polymer batteries.
Lithium-Ion (Li-Ion) batteries or lithium polymer batteries or lithium polymer cells have evolved from the first lithium-ion and lithium-metal batteries (wet cell). The primary difference is that instead of using a liquid lithium-salt electrolyte (such as $LiPF_6$) held in an organic solvent, the battery uses a “solid” polymer electrolyte (semi-solid / gel-like / paste electrolyte) such as polyethylene oxide (PEO), polyacrylonitrile (PAN), polymethyl methacrylate (PMMA) or polyvinylidene fluoride (PVdF).
Lithium-Ion (Li-Ion) / Lithium polymer batteries chemistries have the highest energy density. No memory or scheduled cycling is required to prolong battery life. Li-Ion batteries are used in electronic devices such as cameras, calculators, laptop computers, and mobile phones, and are increasingly being used for electric mobility.

- The term “lithium-ion battery” covers a broad category of chemistries. The product should be considered as a system of integrated components and not just a set of separate cells. The components in a conventional lithium-ion battery system are the lithium-ion cells, integral parts, and the auxiliary systems, including the Battery Management System (BMS). Manufacturers package these components in configurations known as packs, modules, or units. The charger may be integrated into the battery system, or it may be a separate component.
- Due to their higher specific energy density and a greater sensitivity to electrical and environmental abuse, lithium-ion batteries need to be effectively managed with a BMS. The level of management depends on the specific chemistry chosen. When improperly managed, a lithium-ion battery will easily reach a “thermal runaway” state because it has a low cell resistance and high energy storage capacity. Therefore, a key determination in evaluating lithium-based battery reliability is the ability of its BMS to monitor and control the operational parameters reliably and safely.
- Lithium-ion batteries have an average service life of up to 15 years when they operate in a controlled environment.
- There is a high specific energy and high-load capability with power cells. They degrade at high temperatures and when stored at high voltage. They are impossible to charge rapidly at freezing temperatures (<0°C, <32°F).
- There are different types of lithium-Ion Batteries, e.g., lithium cobalt oxide ($LiCoO_2$), lithium manganese oxide ($LiMn_2O_4$), lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$, or NMC), lithium iron phosphate ($LiFePO_4$), and lithium titanate ($Li_4Ti_5O_{12}$).
- Solid-state or lithium-metal batteries (said to be “next generation”) uses a solid electrolyte for ionic conductions between the electrodes, instead of the liquid or gel. (i.e. solid lithium metal anode and a solid ceramic electrolyte).

3.3.1 Unique Hazards

Lithium-ion battery technology, while highly beneficial, also comes with some unique hazards when considering fire protection, including a tendency to generate a lot of heat and emit toxic / flammable gasses when damaged. This can have a cascading effect throughout the battery cells, a process referred to as “thermal runaway”, potentially causing a fire or explosion.

It is very difficult to control events once an ESS/BESS is fully involved in a fire. ESS/BESS can also store large amounts of energy and burn for long periods of time, often many hours, and can reignite after being extinguished.

3.3.2 Why do lithium-ion (Li-ion) batteries fail?

Cells with ultra-thin separators of 24µm or less (24-thousandths of a mm) are more susceptible to impurities than the older designs with lower Ah ratings.
Whereas the 1,350mAh cell in the 18650 package can tolerate a nail penetration test (*), the high-density 3,400mAh can ignite when performing the same test.
(*) Lithium battery abuse testing (Nail Penetration Test): Nail penetration testing is a type of safety testing done to simulate internal short-circuiting. The sample battery is penetrated with a nail to simulate an internal short-circuit and verify that the battery does not catch fire or burst.
Note that the UL1642 Underwriters' Laboratories (UL) test no longer mandates nail penetration for safety acceptance of lithium-based batteries.
Issues start when an electrical short develops inside the cell. The external protection peripherals are ineffective in stopping a thermal runaway once in progress.
There are two basic types of battery failures:

- One occurs at a predictable interval-per-million and is connected with a design flaw involving the electrode, separator, electrolyte, or processes.
- The more difficult failures are random events that do not point to a design flaw. They could be a stress event such as charging at sub-freezing temperature, vibration, or a fluke incident that is comparable to being hit by a meteor.

Incorrect uses of all batteries are: excessive vibration, elevated heat and charging Li-ion below freezing.

The fact that their components have been designed to be lightweight, means there are thin partitions between the battery cells and only a thin outer covering. Both the partitions and coating are fairly fragile and, if punctured when the battery is damaged, a short occurs and this spark can ignite the highly reactive lithium.

Alternatively, the battery may overheat and the heat of the contents exerts pressure on the battery, potentially causing an explosion.

There are reportedly five types of causes for this phenomenon, which are:

1. Uncontrollable internal heat generation, which causes oxygen release from the cathode material, triggering numerous side reactions.
2. Separator defects (due to thermally induced shrinkage or mechanical damage) create short circuits in the battery and rapid discharge of the energy stored in it, accompanied by undesirable chemical chain reactions and release of massive amounts of heat.
3. Electrolyte decomposition, especially in a high state of charge (SOC), occurs at the cathode interface. This leads to heat accumulation, consequent release of oxygen from the cathode, and damage to the separator.
4. Electrochemical side reactions caused by local thermal abuse. If the heat generated during normal operations cannot be dissipated quickly enough, the separator in that specific place will shrink or rupture.
5. Mechanical battery damage, which causes short circuits and/or air to penetrate the battery.

The main causes of battery safety accidents among these five categories above are short-circuiting due to: 2. separator damage; 3. electrolyte decomposition; and 5. mechanical battery damage.

When a lithium-ion cell goes into thermal runaway (increase in temperature), there are multiple sources of heat. For example:

- Combustion – burning of electrolyte, packaging…
- Ohmic – resistive heating caused by a high-current flow through short circuits
- Thermodynamic – if the electrodes are no longer isolated, then the system will revert to its lowest energy state for that temperature if the activation energy is met
- Chemical – reaction of the electrode material with other components of the battery (electrolyte), thermal decomposition of the metal oxide electrode, especially cobalt oxide.

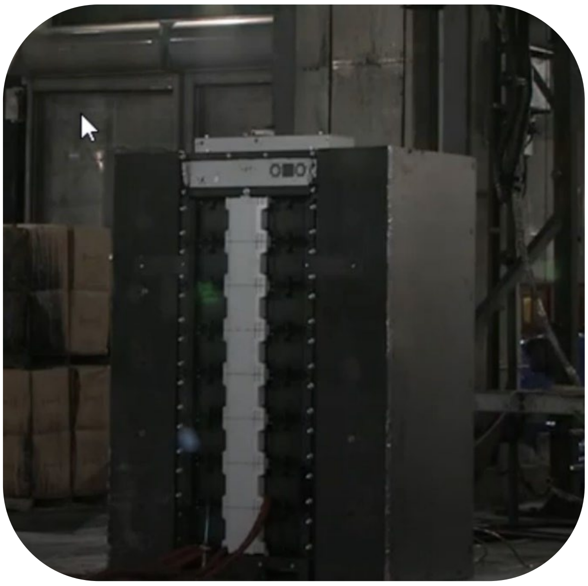
In addition to this multitude of mechanisms, the design of the cell often prevents direct access of the extinguishing agent to the source of the fire.

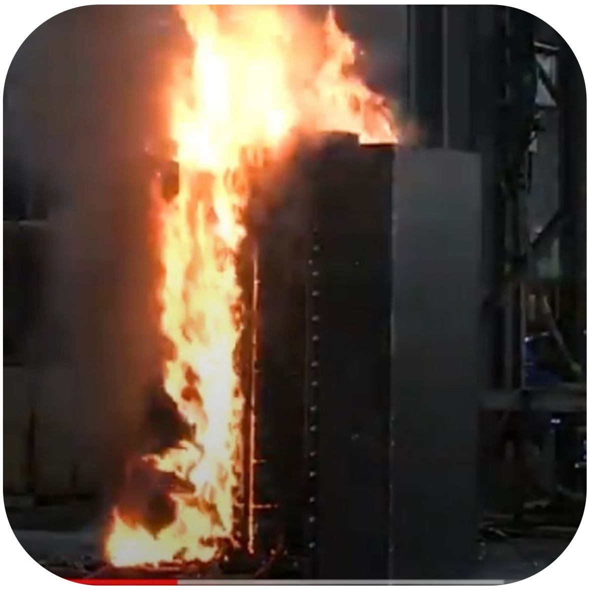
Thermal runaways lead to high temperatures and gas buildup, with the potential for an explosive rupture of the battery cell that can lead to fire and/or explosion.

During a thermal runaway, the high heat of the failing cell inside a battery pack may propagate to the next cells, causing them to become thermally unstable also. A chain reaction can occur in which each cell disintegrates following its own timetable. A pack can thus be destroyed in a few seconds or over several hours as each cell is consumed.

Images captured by a screen shot from the FM Global Fire Hazard of an 83 kWh Energy Storage System comprised of Lithium Iron Phosphate Batteries video that was posted on YouTube on September 13, 2019.

https://www.youtube.com/watch?v=uLzPSN8iagk





3.3.3 What to do in case of fire?

To date there is no publicly available test data that confirms the effectiveness of any active fire protection for energy storage systems.

Automatic sprinkler protection is recommended to limit fire spread to the surrounding structures, equipment, and building contents. (See Section: Battery Room / Battery Energy Storage for more details. See also Annexes 1. and 2.).

If a Li-ion battery overheats, hisses or bulges, the device should immediately be moved away from flammable materials and placed on a noncombustible surface.

If at all possible, the battery should be removed and put outdoors to burn out. Simply disconnecting the battery from its charge may not stop its destructive path.

For the most part, a lithium-ion battery fire can at best be cooled, contained, and suppressed. Extinguishing a lithium-ion battery fire with 100% certainty is not always possible due to the unpleasant issue of a potential thermal runaway.

Lithium-ion battery fires do not require oxygen to burn and can be considered as a chemical fire in nature.

A small module that is on fire can be immersed in water. Water-based products are most readily available and are appropriate, as lithium-ion contains very little lithium metal that reacts with water. Water also cools the adjacent area and prevents the fire from spreading. Research laboratories and factories also use water to extinguish Li-ion battery fires. (See Annexes for details).

A small Lithium-ion fire can be handled like any other combustible fire.
For best results, use a foam extinguisher, CO_2, ABC dry chemical, powdered graphite, copper powder or soda (sodium carbonate).
For small fires, specific extinguishers approved for lithium-ion battery fires, such as Lith-Ex extinguishers, could be used.
The portable fire extinguishers can be used for batteries installed inside equipment (mobile phones, tablets…) and where batteries are stored and/or are under charge.
Note that general Class D extinguishers can normally only be applied to a flat surface as the extinguishant cannot adhere to vertical or other angular surfaces.

Copper-based Class D units, which are designed to cling to vertical surfaces, are also ineffective on lithium battery fires.
In the case of lithium-ion battery fires, these extinguishing agents are unable to cool cells in order to prevent the propagation of the fire throughout a module.
A large Li-ion fire, such as in an Electric Vehicle, may need to burn out. Water with copper material can be used. Using water, even with large Li-ion fires, is advisable, as water lowers the combustion temperature. However, it is not recommended for battery fires containing lithium metal. (See Annexes for details).

3.3.4 Safety precautions

A safe separation distance should be maintained between battery charging stations and any combustible materials.

The minimum separation distance should be 0.9 m (3 ft) for large-format battery charging stations and 0.3 m (1 ft) for small format batteries (such as the ones used in tools).
Battery docking/charging stations should be positioned on a flat noncombustible surface.

In storage areas, battery chargers for relatively small lithium-ion batteries should be surrounded with a barrier preventing any storage less than 1.5 m (5 ft) away.

For large lithium-ion batteries such as those used in lift trucks or automated guided vehicles, all chargers should preferably be relocated in a detached structure 15 m (50ft) from any facilities, or in a cutoff room with 2-hour fire rated walls, ceiling and door(s). The room should preferably be protected by automatic sprinklers (EH1 - Extra Hazard group 1) designed to deliver a minimum density of 12.2 mm/min (0.3 gpm/ft^2) over the entire area of the room or 232 m^2 – 2500ft^2, - whichever is smaller. Hose allowance for EH1 : 1900 L/min (500 gal/min). Fire water supply duration for EH1: 90-120min. Drainage for fire water and potential contaminants should be provided leading to an underground tank with sufficient capacity.

Any lithium-ion batteries with external visible damage should be replaced and the waste batteries disposed of in a dedicated waste bin. The internal integrity of a battery (components and mechanisms) is susceptible to severe damage when subjected to external forces or dropped on a hard surface/ground.

3.3.5 Used/damaged battery disposal

- Battery terminals should be isolated (covered by insulation material) before disposal. This would prevent any accidental contact with metal or other battery contact that would close the battery circuit and result in energy discharge.
- Batteries with physical or mechanical damages should be stored separately from other batteries.

- A safe separation distance of at least 3 m (10 ft) should be provided between disposal of damaged/waste/discarded batteries and bins filled with other combustible material, or any combustible material.
- Waste disposal bins for lithium-ion batteries should be made of metal (no plastic) and equipped with a metal lid.

3.3.6 Fire protection for storage of large quantities of lithium-ion batteries

- In the case of storage of large quantities of lithium-ion batteries, the commodity classification should be considered as "unexpanded plastic" and should be sprinkler protected in accordance with NFPA/FM.
- When stored in cardboard boxes, the classification is "unexposed unexpanded plastic", and when no packaging material is present, it should be considered as "exposed unexpanded plastic".
- Lithium-ion batteries kept in storage areas should not be charged at more than 50% of their full capacity. Fully-charged lithium-ion batteries have a higher energy density and are at greater risk of generating significant heat from short circuiting due to internal defects.
- The storage area should be kept at a temperature between 4 and 27°C (40-80°F) to limit the risk of thermal runaway from manufacturing defects or internal failures.
- An interesting video for battery storage and sprinkler protection, made by FM Global, can be seen at: https://www.youtube.com/watch?v=NeaK9V69Xks

3.4 Other types of batteries

The following types of batteries are not usually used for DC Battery Systems and ESS/BESS:

- **Molten-Salt battery**: a class of battery that uses molten salts as an electrolyte. Traditional non-rechargeable thermal batteries can be stored in their solid state at room temperature for long periods of time before being activated by heating. Rechargeable liquid-metal batteries (e.g., sodium-nickel batteries with welding-sealed cells and heat insulation) are used for industrial power backup, special electric vehicles and for grid energy storage, to balance out intermittent renewal power sources such as solar panels and wind turbines.
- **Sodium–Sulfur (Na–S) battery**: the Na–S battery or liquid-metal battery is a type of molten metal battery constructed from sodium and sulfur. It exhibits a high-energy density, high efficiency of charge and discharge (89%–92%), and a long-life cycle, and is fabricated from inexpensive materials. However, because of its high operating temperatures of 300°C–350°C and the highly corrosive nature of sodium polysulfides, such cells are primarily used for large-scale nonmobile applications such as electricity grid energy storage.

- **The Sodium Nickel Chloride "Zebra" Battery**: The "ZEBRA" Battery (Zero Emission Batteries Research Activity) is a Sodium Nickel Chloride battery, manufactured in limited volume in Switzerland for EV applications. It is the only dedicated EV battery in production in the world today. The technology was first developed in South Africa during the 1970s and 1980s. The major perceived drawback of the Sodium Nickel Chloride battery is that it is a high-temperature technology. The battery has to be maintained at an internal operating temperature of between 270°C and 350°C for efficient operation.

- **Redox Flow Battery (RFB)**: The Na–S battery or liquid-metal battery is a type of molten-metal battery constructed from sodium and sulfur. It exhibits a high-energy density, and high efficiency of charge. RFBs are charged and discharged by means of the oxidation–

reduction reaction of ions of vanadium or the like. RFBs have a system endurance period of 20 years, with an unlimited number of charge and discharge cycles available without degradation. In addition, the electrolytes can be used semi-permanently. The energy densities of RFBs are usually low compared with those of other types of batteries. Other types of Redox Batteries include the Vanadium Redox battery (VRB), Polysulfide–Bromine battery (PSB), and zinc–bromine (Zn–Br) battery.

- **Fuel cell**: An electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen into electricity through a pair of Redox reactions. Fuel cells are different from most batteries in that they require a continuous source of fuel and oxygen to sustain the chemical reaction, whereas in a battery, the chemical energy usually comes from metals and their irons or oxides that are commonly already present in the battery. The first fuel cell was invented in 1838. The alkaline fuel cell has been used in NASA space programs since the mid-1960s to generate power for satellites and space capsules. Fuel cells have also been used as back-up power for facilities in remote areas.

3.5 Liquid Electrolyte development

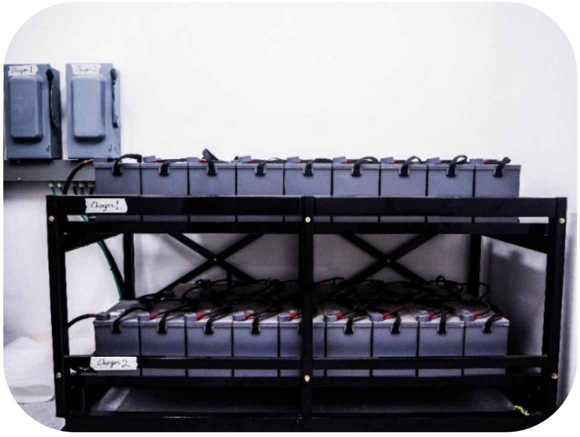
- Potassium secondary batteries are contenders for the next generation energy-storage device, owing to the much higher abundance of potassium than lithium. However, safety issues have been raised by the occurrence of bottlenecks (e.g., highly reactive potassium metal and flammable organic electrolyte or ionic liquid electrolyte comprised of 1-ethyl-3methylimidazolium chloride/AlCl3/KCL/potassium bis fluorosulfonyl imide).

4. DC BATTERY SYSTEM BASICS

- Batteries are operating most of the time on a float charge with infrequent discharge (i.e., float service). DC Battery Systems can be located in the electrical room, or in cut-off rooms in dedicated detached buildings.

- The most frequent application of batteries is for an uninterruptible power supply (UPS):
  - An uninterruptible power supply, or uninterruptible power source (UPS), is an electrical apparatus that provides emergency power to a load when the input power source or mains power fails.
  - A UPS is typically used to protect hardware such as computers, data centers, telecommunications equipment, or other electrical equipment where an unexpected power disruption could cause injuries, fatalities, serious business disruption or data loss. In such cases, a UPS is a device that allows a computer to keep running, at least for a short time, when the primary power source is lost.
  - For a computer, a UPS contains a battery that "kicks in" when the device senses a loss of power from the primary source. If an end user is working on the computer when the UPS notifies the power loss, they have time to save any data they are working on and exit before the secondary power source (the battery) runs out. UPS devices also provide protection from power surges.
  - UPS in the data center: while UPS systems are commonly called double-conversion, line-interactive and standby designs, these terms have been used inconsistently and manufacturers implement them differently.
  - UPS for Industrial Control Systems: commonly used in the industry, this is an immediate back-up power for the Distributed Control System, preventing electric power disruption of the process control prior to starting the standby power source, thus allowing for a safe shutdown of equipment in case of blackout.

- A UPS differs from an auxiliary or emergency power system or standby generator in that it will provide near-instantaneous protection from input power interruptions, by supplying energy stored in batteries (but also from supercapacitors, or flywheels).
- Every UPS converts incoming AC to DC through a rectifier and converts it back with an inverter. Batteries or flywheels store energy to be used in a utility failure. A bypass circuit routes power around the rectifier and inverter, running the IT load on an incoming utility or generator power.
- The on-battery run-time of most uninterruptible power sources is relatively short (from only a few minutes to 2 hours for the largest ones) but sufficient to start a standby power source (i.e., a Diesel- Engine Driven Generator) or to properly shut down the protected equipment (i.e., process equipment). It is a type of continual power system.



Lead-Acid batteries

Nickel Batteries

Battery room for back-up emergency cases

5. ESS/BESS BASICS

- Energy Storage Systems (ESS) are also called Battery Energy Storage Systems (BESS).
- An ESS/BESS is an electrochemical system that charges (or collects energy) from the grid or a power plant / source and then discharges that energy at a later time to provide electricity or other grid services when needed.
- Today there is an increased interest in energy storage and in particular having an ESS/BESS integrated into renewable developments, and/or even existing thermal plants connected to a grid, and in off-grid developments.
- The large-scale grid integration of renewables into traditional electric power systems and emerging smart grid technologies is challenging because renewable power generation does not often coincide with electricity demand. Surplus power should either be curtailed or exported. The key to overcoming such challenges is to increase power system flexibility. Storage offers one possible source of flexibility.
- ESS / BESS can be located in outside enclosures, dedicated buildings or in cut-off rooms within buildings. ESS and BESS are modular systems that can be deployed in standard shipping containers.

6. LOSS EXPERIENCE

Latin America - Magnitude 8.8 Richter scale Earthquake (2011) – DC Battery System

- Pulp Mill Electrical Room: a rack of 30 acid-filled UPS batteries collapsed during the EQ. The plastic bodies of the broken batteries released acid which reacted with both epoxy resin paint on the ground and the plastic components. This resulted in highly corrosive and toxic fumes contaminating the entire room housing several rows of cabinets. The ventilation was automatically shut down during the EQ due to a power failure preventing the extraction of fumes from the room. It took about 2 weeks to clean the entire room and equipment. This involved 50 people and 3 contractor companies.

In South Korea – ESS/BESS

- 23 fires occurred in the period between 2017-2019. The Government then ordered the shutdown of about 35% of installed ESS. Despite this preventive shutdown, 5 more fire events occurred in 2019. As a result, the charge rate in ESS is now limited by law to 80-90%.

In the US, some major events involving ESS/BESS were reported, such as:

- **Arizona (2012)**
  A 1.5-megawatt system caught fire.
  The ESS consisted of a container housing 16 cabinets, in turn containing 24 lithium-ion cells.
  An investigation into the accident determined that a severely discharged cell degraded and affected a neighboring cell, setting off a fire.
  The root cause of the 2012 accident was found to be faulty logics used to control the system.

- **Hawaii Wind Farm (2012)**
  A 15-megawatt plant burnt down.
  The plant was supplied by a manufacturer who used advanced lead-acid batteries, rather than lithium-ion technology. The manufacturer went bankrupt two years later.

Firefighters did not enter the building until seven hours after the flames started because of doubts as to the toxicity of the "12,000 batteries."
After 18 hours, the FD stopped fighting the fire and let the building burn itself out.
Portions of the building collapsed. No one was injured.
The Fire Department said a fire at the same building in April 2011 burned itself out. There was another fire in May of this year, and both fires were attributed to ECI capacitors in inverters.

- **Solar Program Arizona (2019)**
  The facility in question was installed in 2017 as part of the Solar Program.
  4 firefighters were injured by the explosion (involving lithium-ion batteries) when the responders tried to check on the battery enclosure.
  At around 5:41 p.m., dispatchers had received a call alerting them to smoke and a "bad smell" in the area around the Battery Energy Storage System (BESS) site in a suburban area of a big city.
  Three fire engines arrived at the scene within 10 minutes. Shortly after their arrival, first responders realized that energized batteries were involved and elevated the call to a hazmat response. After consulting with utility personnel and deciding on a plan of action, a fire captain and three firefighters approached the container door shortly before 8:00 p.m., preparing to open it.
  With the door to the BESS container open, combustible gases (that had been building up inside since the incident began several hours earlier) received a flow of oxygen which instantly created an ignition source.
  The gases erupted in what was described as a "deflagration event."

  What was first thought to be a fire was in fact an extensive cascading-thermal runaway event inside the BESS. That event was initiated by an internal cell failure in one battery cell. The failure was caused by "abnormal lithium-metal deposition and dendritic growth" within the cell.
  Once the failure occurred, the thermal runaway cascaded from the cell through every other cell and module in one rack via heat transfer. The runaway was aided by the "absence of adequate thermal barrier protections" between battery cells, which otherwise might have stopped or slowed the thermal runaway.

  The enclosure was protected by NOVEC 1230, but the gas protection system was ineffective during this event.

  As the event progressed, a large amount of flammable gas was produced within the BESS. Lacking ventilation to the outside, the gases created a flammable atmosphere in the container. Around 3 hours after thermal runaway began, when firefighters opened the BESS door, flammable gases made contact with a heat source (or spark) and exploded.

USA California (2001) – UPS/Battery room.

- A hydrogen explosion occurred in a UPS/Battery room.
  The explosion blew out a large part of the roof, collapsed numerous walls and ceilings throughout the building, and significantly damaged a large portion of the remainder of the building housing the battery room.
  The facility was formerly a large computer/data center, with battery rooms and emergency generators, which had been vacated some time ago.
  The ventilation for the battery room was interlocked to a hydrogen monitoring system. The

hydrogen alarm activated, but it was only a local alarm (not remotely reported).
After the explosion, it was not possible to determine whether the ventilation failed to operate or if it had been disconnected when the building was vacated.

UK (2020) – ESS/BESS.

- The ESS of a solar farm caught fire in 2020.
  This solar farm had been completed at the beginning of 2019.
  The fire occurred at the 20 MW ESS station on September 15, 2020.
  The fire started shortly before 1 a.m., and the fire brigade had to use main jets and ground monitors to fight the fire for several hours. At 11:45 a.m., one fire engine was still at the scene, with firefighting still continuing, although by that stage only one hand-held pump was in use.

Australia – ESS/BESS:

- A BESS (700-megawatt battery) was under construction in a coal-fired power station.
  The battery project was expected to be ready by the end of 2021 before the peak summer demand period. It was known as the "biggest battery" in the southern hemisphere.
  Fire broke out during testing performed in mid-2021. A 13-tonne lithium battery was engulfed in flames, which then spread to an adjacent battery bank.
  More than 150 people from Fire Rescue Victoria and the Country Fire Authority, as well as more than 30 fire trucks and support vehicles, responded to the blaze, which was contained and closely monitored until it burnt itself out.
  The blaze was extinguished after taking more than three days to bring it under control.
  Emergency services remained at the site with staff and contractors to monitor the temperature decline of the two affected battery packs.
  Authorities said that, because of the nature of the fire – a 13-tonne battery, firefighters could not put water on it nor employ ordinary suppression methods. Instead, they had to let it "burn out" and wait for the container to cool down enough to open its doors.

2 FOCUS ON DC BATTERY SYSTEMS

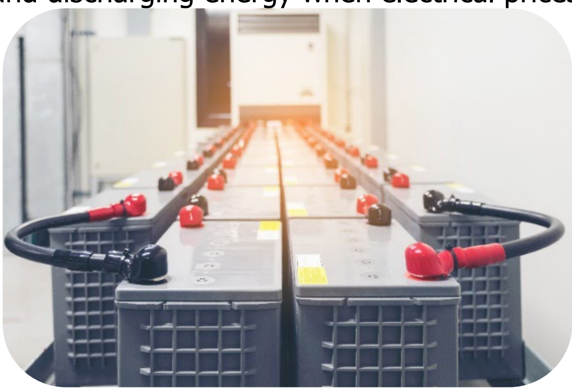
This section covers DC Battery Systems:

- Used for standby operations in stationary applications (including, but not limited to, power-generating stations, substations, telecommunications, data centers, switchgear protection systems, process control systems, emergency power supplies, and uninterruptable power supplies – UPS).
- All types of batteries (wet/dry cells), except for lithium-ion polymer batteries (dry cells), are considered. (Please refer to Section 3: "Focus on ESS/BESS").

The specific case of battery storage areas, where the batteries are stored but not in use, is not covered. (See NFPA standard: "Commodity Fire Protection").

1. LOCATION, ARRANGEMENT & SEGREGATION

Battery rooms range from small rooms housing a limited number of batteries, to very large rooms that store electrical energy for use at a later time, for applications that include supplementing renewable energy sources such as solar panels and wind turbines, or for storing and discharging energy when electrical prices fluctuate.



Location

- Batteries should be installed in a separate 2-h fire compartment.
- In Nuclear Power Plants, battery rooms associated with redundant separation trains should be separated from each other and from other areas of the plant by fire barriers with a minimum 3-h fire rating.

The battery room or area should be maintained as close to 25°C (77°F) as possible to limit the production of hydrogen.
No combustible storage, unrelated to the battery room, should be allowed inside the room.
A 2.7 m (9 ft) minimum separation should be provided from combustibles and combustible construction elements.
Noncombustible material related to the battery room and noncombustible construction elements should be located at a minimum distance of 90 cm (3 ft) from the equipment.
The maximum-rated energy in one single area within a non-dedicated-use building housing DC batteries, should be 600 kWh for sodium nickel chloride batteries (no limitation for lead-acid and nickel batteries).

2. ELECTRICAL EQUIPMENT

- For all AC Battery Systems that can generate flammable and explosive gases such as flooded lead-acid, flooded (wet) nickel-cadmium (Ni-Cd), flooded (wet) nickel–metal hydride (Ni–MH) and Valve- Regulated Lead Acid (VRLA) batteries / "Sealed lead–acid" (SLA) batteries), all electrical equipment installed or used in battery rooms should be intrinsically safe (explosion proof).
- Direct current switchgear and inverters should not be located in the battery rooms.

3. VENTILATION

For all AC Battery Systems that can generate flammable and explosive gases such as flooded lead-acid, flooded (wet) nickel-cadmium (Ni-Cd), flooded (wet) nickel–metal hydride (Ni–MH) and Valve-Regulated Lead-Acid (VRLA) batteries / "Sealed lead–acid" (SLA) batteries and lithium-ion batteries using liquid electrolyte (wet cells) such as organic solvent:

1. Battery rooms should be provided with natural ventilation to limit the concentration of hydrogen to 1 percent by volume (25% of the LEL – Lower Explosive Limit) and equipped with a hydrogen detection system.

   The hydrogen concentrations should be monitored.

   OR

2. Mechanical exhaust ventilation should be provided at a rate of not less than 1 cubic foot per minute per square foot (0.0051 m^3/s / m^2) [1 $ft^3/min/ft^2$] of the floor area of the room and should be activated by a hydrogen detection system set to operate the ventilation at 25% of the LEL (1% of H_2 inside the room).

   The hydrogen concentrations should be monitored and the gas detection system should be provided with a minimum of 2 hours standby power.

   The mechanical ventilation should remain on until the flammable gas detected is less than 25% of the LEL.

   OR

3. Continuous ventilation should be provided at a rate of not less than 1 cubic foot per minute per square foot (0.0051 m^3/s / m^2) [1 $ft^3/min/ft^2$] of the floor area of the room.

   Excessive concentrations (>1 % vol.) and/or loss of ventilation and/or failure of the gas detection system should sound an alarm signal at a constantly attended location (Main Control Room).

   The exhaust ventilation lines should be located at the highest level of the fire compartment.

In addition to the above for critical battery systems such as data centers, UPS battery rooms, or telecommunication battery rooms, the following should be provided:

- HVAC systems, separate from the equipment areas, for thermal management.
- Room temperature monitors that will alarm remotely to a constantly attended location.

4. FIRE DETECTION AND FIRE PROTECTION

Detection:

- Fire detection should be provided inside the room.

Room protection:

- This section applies to battery rooms where batteries are in use.

- Note that the following configurations do not require a fixed fire-protection system:
  - Lead-acid and nickel-cadmium battery systems of less than 50 V ac, 60 V dc that are in telecommunications facilities for installations of communications equipment, under the exclusive control of communications utilities, and located outdoors or in building spaces used exclusively for such installations.
  - Lead-acid battery systems in uninterruptable power supplies, utilized for standby power applications, which are limited to not more than 10 percent of the floor area on the floor on which the DC Battery System is located.
  - Lead-acid and nickel-cadmium battery systems, used for dc power for control of substations and control or safe shutdown of generating stations, under the exclusive control of the electric utility, and located outdoors or in building spaces used exclusively for such installations

- For all other cases, the fire protection design focuses on battery installations, which are typically an arrangement of tightly packed cells with plastic casing placed in modules that are stacked vertically in racks.

- Since these systems often consist of multiple racks, a main objective of the protection is to make sure, if a fire occurs, that it is contained to a single rack.

- If the fire is able to propagate from one rack to the next, it could last for a considerable length of time, potentially overwhelming the sprinkler system or taxing the water supply.

- To mitigate this risk, one of the objectives of any fire protection system should be to contain the fire to the rack of the originating fire through the installation of a sprinkler system and the spacing of battery groups.

- Water is an effective extinguishing agent for most battery fires. This is why sprinkler systems are the preferred fixed fire-protection method (if designed properly).

- Battery rooms should preferably be protected by automatic sprinklers designed to deliver a minimum density of 12.2 mm/min (0.3 gpm/ft^2) over the entire area of the room or 232 m^2 – 2500 ft^2, - whichever is smaller.

- Clean agent fire extinguishing systems can be provided as supplementary protection when there is a need to limit equipment and nonthermal damage.

- Gaseous protection systems are not recommended for battery applications for the following reasons:
  - Efficacy relative to the hazard: as of 2019, there is no evidence that gaseous protection is effective in extinguishing or controlling a fire involving batteries.
  - Gaseous protection systems may inert or interrupt the chemical reaction of the fire, but only for the duration of the hold time. The hold time is generally 10 minutes, not long enough to fully extinguish a battery fire.

- If provided anyway, total flooding gas protection systems should be designed to maintain the design concentration within the enclosure for a time sufficient to ensure that the fire is extinguished and that the battery temperatures have cooled to below the autoignition temperature of the combustible material present and the temperature that could cause thermal runaway (with a minimum of 10 minutes).

- The design of the system should be based on:
  - The agent concentrations required for the specific combustible materials involved.
  - The specific configuration of the equipment and enclosure.

- Protections by water mist or dry chemical systems are not advised/recommended.

5. SPILL CONTROL

Rooms containing free-flowing liquid electrolyte in individual vessels with a capacity of more than 208 L (55 gal.) or multiple vessels with an aggregate capacity exceeding 3785 L (1000 gal.) should be provided with spill control to prevent the flow of liquids to adjoining areas.
Spill control is not required for sealed valve-regulated lead-acid (VRLA) batteries and other equipment with immobilized electrolyte and immobilized hazardous liquids.
When battery acid spill control is provided:

- Use only approved (Class 4955) battery acid absorbent pillows.
- Remove or replace pillows (where required) whenever indications of acid exposure are exhibited (e.g., pillow fabric shows distinct color change).
- Promptly replace leaking batteries to eliminate the need for battery acid absorbent pillow protection.

3 FOCUS ON ESS/BESS

This section covers electrical Energy Storage Systems (ESS) or Battery Energy Storage Systems (BESS):

- that charge (or collect energy) from the grid or a power plant / source and then discharge that energy at a later time to provide electricity or other grid services when needed.
- that exclusively use lithium-ion polymer batteries (dry cells). (Refer to Section 2: "Focus on DC Battery systems for Li-Ion wet cells using liquid electrolyte).

The specific case of battery storage areas, where the batteries are stored but not in use, is not covered. (See NFPA standard: "Commodity Fire Protection").
Lithium-ion battery ESS are becoming increasingly popular and include specific additional hazards.

1. STANDARDS AND CERTIFICATION

Safety Codes and Standards for ESS/BESS:
The purpose of codes and standards in any industry is, respectively, to provide minimum criteria for ensuring the safety of life and property, and to establish industry best practices. Codes are written into regional laws and are therefore required, while standards are written by reputable industry organizations, such as Underwriters Laboratories (UL) and International Electrotechnical Commission (IEC); and are only required if referenced in a code.

In North America, the "standards" that basically govern energy storage systems are:

- UL 9540 "Standard for Safety of Energy Storage Systems and Equipment"
- UL 9540A "Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems Standard"
- NFPA 855 "Standard for the Installation of Stationary Energy Storage Systems"

In Europe the conformity assessment procedure may be **self-certification** or **third-party certification**, depending on the risk level of the product. CE marking is not an indication of product quality, but rather an assurance that the product meets the minimum requirements for health and safety as defined by EU regulations. This may include the requirement that batteries be designed and manufactured in compliance with current European regulatory requirements relating to batteries and industrial products. The basic requirements are those required for the CE marking provided by the following European provisions:

- Directive 2014/30/EU Electromagnetic Compatibility (EMC)
- Directive 2014/35/EU Low Voltage (LVD)
- Directive 2011/65/EU Restriction of the use of certain hazardous substances (RoHS)
- Regulation (EC) n. 1907/2006 Chemical substances (REACH)
- Regulation (EC) n. 1542/2023 New regulation on batteries

In addition to lithium batteries being classified as dangerous goods for transport, the requirements specified in the UN Manual of Tests and Criteria, often referred to as UN38.3, must also be verified.
Note that in a relatively unregulated market for such products (lithium-ion batteries) the lack of a mark (other than CE) or a testing report is an area of concern.

UL safety standard & limitations:
UL stands for Underwriters Laboratories. Recently, however, the company rebranded and is now known only as UL. UL is a global standards company that develops safety standards for

a variety of consumer goods, especially those with electrical parts.
A product that is UL Listed is one that has been tested and found to have met strict standards for safety and sustainability. These standards might include fire and flame resistance, functionality, and potential electrical hazards. After the products are tested and found to function well and comply with standards, they are then certified as UL Listed.
UL Certified is a broader term that includes UL Listed, UL Recognized([1]),and UL Classified (which simply means that the product has been tested for one specific standard, such as sustainability).

UL9540 is a safety standard for energy storage systems developed by UL. The standard provides a roadmap for ensuring that ESS works safely and reliably. It covers how these systems are designed, built, tested, and used. UL9540 has strict requirements for electrical safety, thermal safety, mechanical safety, fire safety, system performance, system reliability, and system documentation. Most people agree that the standard is a benchmark for the safety and performance of ESS.

UL9540 is a set of standards that an energy storage system (ESS) must meet. UL9540 doesn't cover the components of an energy storage system on its own. Instead, it looks at the system as a whole after all the components have been integrated into it.

UL9540A is a method of evaluating thermal runaway in an ESS; it provides additional requirements for battery management systems (BMS) used in ESS. It covers the BMS functions and performance, including battery safety, performance, and communication protocols. Ultimately, UL9540A verifies the effectiveness of the ESS protection levels against critical thermal runaway and fire hazards.

UL 9540 certification means that a nationally recognized testing laboratory (NRTL) has independently evaluated and verified that a product meets the requirements set forth in UL 9540. **However, unless specified, it does not necessarily mean that UL 9540A testing has been conducted**.
While UL 9540A is a critical starting point for battery storage system testing, and provides very useful information, it is still limited in scope since the parameters of the test setup may not create the conditions for a fire to ignite.

UL9540A is not a test certificate. It provides standard test data for thermal runaway behavior. Results require interpretation and are subjective.

NFPA855 & limitations:
NFPA 855 "Standard for the Installation of Stationary Energy Storage Systems" provides guidance for the equipment, arrangement, emergency planning, and passive and active fire protection of ESS/BESS.
The maximum rated energy in one single area within a non-dedicated-use building housing ESS/BESS, should be 600 kWh for lithium-ion.
Recommended arrangement is based on 50kWh ESS groups spaced 0.9 m (3 ft) from other groups & walls.
Other arrangements should be based on large-scale fire testing.

Need for Large-Scale Fire Testing:
The details of how a large-scale fire test should be performed are not yet clearly defined in

[1] Achieving UL certification for component parts will add credibility to products. Additionally, the standards set forth by UL help ensure the safety of those installing UL Recognized components.

the industry.
The definition of a large-scale fire test per NFPA 855 is the testing of a representative energy storage system that induces a significant fire in the device under test and evaluates whether the fire will spread to adjacent energy storage system units, surrounding equipment, or through an adjacent fire-resistance-rated barrier.

2. NFPA855 VS FM GLOBAL DATA SHEET 5-33

Facts:
NFPA (National Fire Protection Association) is a self-funded nonprofit organization. NFPA855 "Standard for the Installation of Stationary Energy Storage Systems" becomes binding by a building or fire code.
FM Global is an "insurance company" that has fire suppression standards for its clients. It is generally more restrictive than NFPA. The Data Sheet (DS) 5-33 is dedicated to "Electrical Energy Storage Systems".
Authorities Having Jurisdiction (AHJ) are governmental or non-governmental entities responsible for enforcing building codes, fire codes, and other regulations.
The AHJ will review the design for compliance with NFPA, not FM.

From a Risk Control Standpoint (SCOR):

- NFPA855 "Standard for the Installation of Stationary Energy Storage Systems" is currently providing the current most practical answer to the growing installation of ESS/BESS.
- FMDS5-33 "Electrical Energy Storage Systems" currently provides the most conservative answer to the unknown regarding ESS/BESS development.

From a risk Control perspective (SCOR):

- We will consider NFPA855 as the current minimum requirement for SCOR and FM Global DS5-33 as the current most stringent requirement we should target.
- Consequently, both NFPA855 and DS5-33 are considered in the following sections.

3. PERSISTENT QUALITY & SAFETY ISSUES

Highly flammable liquid electrolytes:
Developers of electrical devices are desperate for ways to package more energy in the same amount of space.
A key innovation is an advanced non-volatile and mechanically tunable polymer electrolyte replacing the highly flammable liquid electrolyte in conventional lithium-ion batteries

ESS/BESS cells require high precision manufacturing:
Clean Energy Associates – CEA[2] has conducted factory-quality audits on over 30 GWh of lithium-ion energy storage projects over the past six years:

- 320+ inspections in 52+ battery energy storage system (BESS) factories
- 64% of tier 1* BESS cell manufacturers audited worldwide
- 1300+ total manufacturing issues identified

[2] Clean Energy Associates (CEA) is a clean energy advisory company founded in 2008 with offices in Denver, USA and Shanghai, China. As a North American-owned solar PV, green hydrogen, and battery storage service provider. CEA provides the following services: Supplier ranking and Market Intelligence, Engineering and Design Services, Supply Chain Management and Traceability, Quality Control and Testing, Manufacturing Strategy, ESG.

The recent report (2024) by Clean Energy Associates found that:

- 26% of inspected energy storage systems had quality issues related to the fire detection and suppression system (e.g. faulty actuator, non-responding sensor).
- 18% of inspected systems had quality issues related to the thermal management system (i.e., dysfunctional liquid cooling system due to circulation system component failure, compressor mainboard short circuiting).

System-level findings accounted for nearly half of all defects found in battery energy storage systems (BESS):

- 58% of system-level findings are due to component defects and improper system integration procedures.
- 34% of system-level findings are enclosure-related: defects from enclosure manufacturing process and mishandling during transportation.
- 8% of system-level findings are related to performance tests: a wide variety of manufacturing defects and/or improper system integration.

There are two reasons for a higher level of system-related issues. The first is the BESS integration process being mostly manual and labor-intensive, while the second is problems originating from defects in upstream components that might not have been caught in earlier quality checks.

Despite a higher automation process, cell issues represent 30% of the issues found by CEA, with a third of the incidents occurring during electrode manufacturing, 38% during cell assembly, and 30% during cell finishing.

Finally, 23% of the total findings by the CEA concerned production lines, and more specifically their manual nature. Half of these issues related to interconnection wielding and arose due to the manual aspect of this and a lack of efficient quality control procedures.

Strict precision and safety requirements need to be ensured by highly automated cell manufacturing processes.

System-level issues account for nearly half of BESS defects (energy-storage.news)

4. LITHIUM-ION BATTERY ENERGY STORAGE SYSTEM (LIB-ESS/BESS) SELECTION

The use of refurbished or previously used LIB-ESS/BESS components, including cells or modules, **should be prohibited** (including LIB batteries recycled from EVs: the repurposing of EV LIBs in stationary applications is expected to provide cost-effective solutions for utility-scale energy storage applications).

The LIB-ESS design, including cell type, battery management system (BMS), etc., should be appropriate for the application.

A management of change (MOC) procedure should be established to ensure that batteries or BMS components are compatible with modified system requirements, or that replacements are suitable for the existing system requirements.

5. LFP VS NMC LI-ION BATTERY

There are different types of lithium-ion batteries, e.g., lithium cobalt oxide ($LiCoO_2$), lithium manganese oxide ($LiMn_2O_4$), lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$, or NMC), lithium iron phosphate ($LiFePO_4$), and lithium titanate ($Li_4Ti_5O_{12}$).

Li-ion batteries (dry cell) or lithium polymer batteries use a solid polymer electrolyte such as:

- polyethylene oxide (PEO),

- polyacrylonitrile (PAN),
- polymethyl methacrylate (PMMA)
- polyvinylidene fluoride (PVdF).

Main type of Li-ion battery in use today:

- NCA = Lithium Nickel Cobalt Aluminum
- NMC = Lithium Nickel Manganese Cobalt
- LFP = Lithium Iron Phosphate (ferro phosphate)

For ESS/BESS:

- NMC = Lithium Nickel Manganese Cobalt
- LFP = Lithium Iron Phosphate (ferro phosphate)

Fire protection experts have told us that lithium-ion batteries release a mixture of flammable gases:

- NCA type: H_2 28%, Hydrocarbon 15% (e.g. Methane, Propane, Benzene), CO 27%, CO_2 29%. LEL similar to Propane – Ethylene mixture
- LFP type: H_2 48%, Hydrocarbon 19% (e.g. Methane, Propane, Benzene), CO 10%, CO_2 20%. LEL similar to Ethylene-Acetylene mixture

HF is mainly toxic and will have an impact on firefighting, but release of HF is a serious indication of lithium salt reaction.

Li-ion battery manufacturing experts have told us that:

- Degradation of hydrocarbons in the solvent produces CO in the early stages.
- It's important to investigate the stage at which gas is released in the thermal runaway, to be able to act.
- What's interesting with LFP is the crystal setup inside the cell. In NCA the structure is built up by Li, but in LFP it's iron and phosphor. This results in a slower collapse of the cell crystal, hence the framework limits the flow of Li+ and releases less heat=> less prone to runaway. There are also new electrolytes based on other solvent mixtures that are less flammable (but they have other performance issues at the moment).
- Temperature and gas monitoring can indicate cell degradation, but this is hard to detect.

Firefighter associations have told us that:

- Thermal runaway without active fire in lithium-ion battery packs may be recognizable by distinctive white/grey smoke leaking from the battery pack.
- A significant explosion hazard can develop before any sign is visible.
- An explosion hazard begins the instant batteries undergo thermal runaway & release gas without burning.
- The gases produced during thermal runaway are always flammable and an ignition source is always present.
- The timing of ignition being random, there is so far no prediction method.
- Conclusion: the timing and severity of a battery explosion is unpredictable.

According to vendors and on a general level, the risks identified in the management of LFP-type lithium batteries compared to batteries with other chemistries are as follows:

- Thermal Risk: in the event of a short circuit or cell problems there are overheating phenomena of some battery components

- Chemical Risk: in the event of damage to or problems with the cells, an emission of gaseous chemical substances may occur, generated by the vaporization of the internal electrolyte from the cells
- Mechanical Risk: during handling or maintenance phases, due to the considerable weight of the batteries and the need for lifting equipment
- Risk of fire: in the event of anomalies, the battery can overheat (maximum temperature 144°C compared to over 550°C for other battery chemistries), but not generate flames (no fire and no propagation[3]); however, if it is involved in a fire it can contribute to the flames through the gases emitted by the cells

6. HAZARDS, FIRE PROPAGATION CHARACTERISTICS AND PROTECTION SCHEMES

Hazards of ESS/BESS include:

- Thermal Runaway: Thermal runaway is a term used to describe the rapid uncontrolled release of heat energy from a battery cell; it is a condition that occurs when a battery creates more heat than it can effectively dissipate. Thermal runaway in a single cell can result in a chain reaction that heats up neighboring cells. As this process continues, it can result in a battery fire or explosion. This can often be the ignition source for larger battery fires.
- Stranded Energy: As with most electrical equipment there is a shock hazard present, but what is unique about ESS is that often, even after being involved in a fire, there is still energy within the ESS. This is difficult to discharge since the terminals are often damaged and presents a hazard to those performing overhaul after a fire. Stranded energy can also cause reignition of the fire hours or even days later.
- Toxic and Flammable Gases Generated: Most batteries create toxic and flammable gases when they undergo thermal runaway. If the gases do not ignite before the lower explosive limit is reached, it can lead to the creation of an explosive atmosphere inside the ESS room or container.
- Deep Seated Fires: ESS are usually comprised of batteries that are housed in a protective metal or plastic casing within larger cabinets. These layers of protection help prevent damage to the system but can also block water from accessing the seat of the fire. This means that it takes large amounts of water to effectively dissipate the heat generated from ESS fires, since cooling the hottest part of the fire is often difficult.

Current state of knowledge:

- Limited research has been performed on LIB-ESS systems to assess fire propagation characteristics and protection schemes.
- The effects of rack design, construction materials, battery specifications and chemistry, and other design features, are not well understood.
- Thermal runaway events create a large amount of heat. The heat, coupled with plastic construction components, can lead to a very large fire.
- Water is the best method of cooling a fire involving Lithium-Ion (LIB) ESS/BSS.
- It does not appear possible to extrapolate the results obtained with the tested lithium iron phosphate (LFP) and lithium nickel oxide/lithium manganese oxide (LNO/LMO) systems to other LIB-ESS.
- NFPAA 855 "Standard for the Installation of Stationary Energy Storage Systems" documents sprinkler operations during large-scale fire testing. The fire size and peak-

[3] (*) Note that the gas (electrolyte) released by the safety valves can build up, leading to fire and or explosion when ignited.

heat release rate varied for the chemistries tested. The worst-case scenario was the LNO/LMO chemistry, which resulted in operation of all sprinklers in the test area. Ceiling gas temperature measurements in the surrounding area indicated that additional sprinklers would have operated outside of the typical 230 m^2 (2500 ft^2) design area.

- Therefore, the FM Global Data Sheet reflects a conservative approach that assumes all sprinklers in the LIB-ESS/BESS room will open.

7. LOCATION, ARRANGEMENT & SEGREGATION

7.1 Location & Separation

Batteries should be installed in a separate 2-hour fire compartment.
In nuclear power plants, battery rooms associated with the redundant separation trains should be separated from each other and other areas of the plant by fire barriers with a minimum 3-hour fire rating.
The battery room or area should be maintained as close to 25°C [77°F] as possible to limit the production of hydrogen.
Energy Storage Systems (ESS) should be grouped into small segments and spaced apart to prevent large and lengthy fire events.
Note that the minimum separating distances given below are not for loss estimate purposes. Maximum Possible Loss (MPL) should be therefore assessed as per our SCOR Handbook Loss Estimate (MPL).

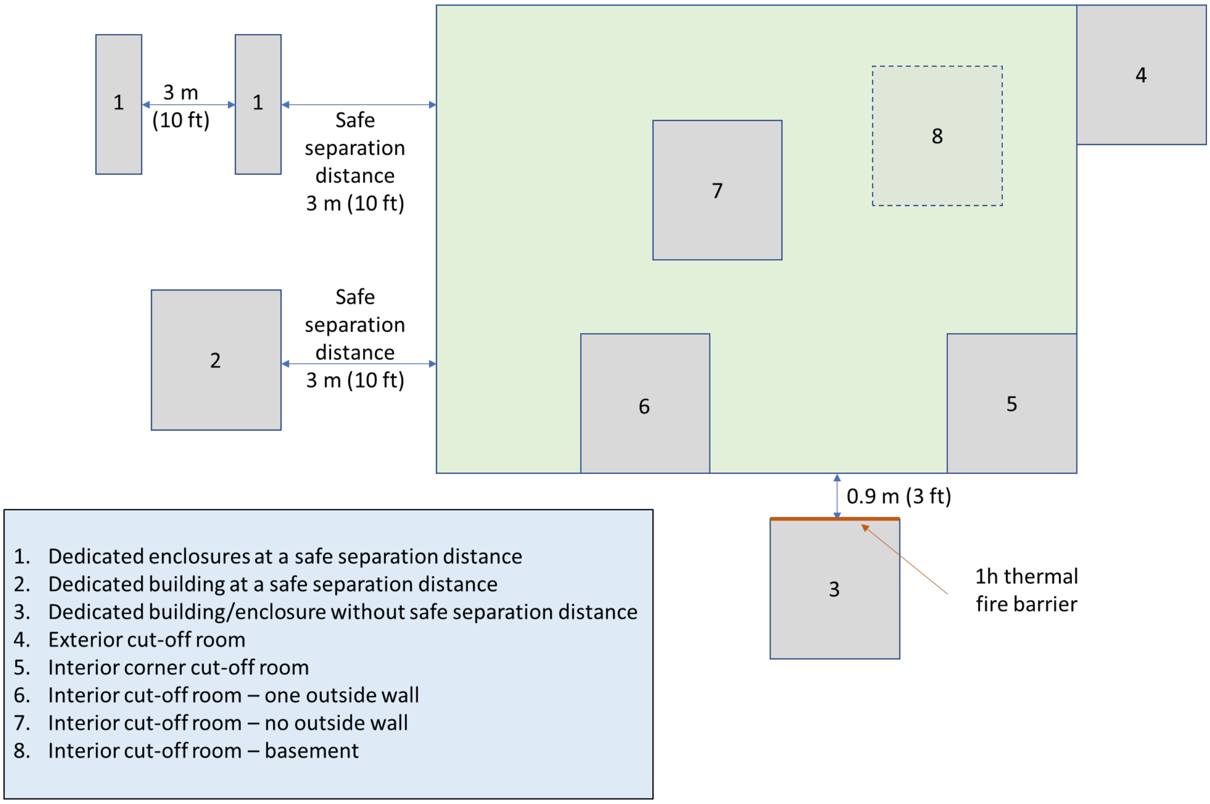
Minimum requirements as per NFPA855 “Standard for the Installation of Stationary Energy Storage Systems”:

The maximum rated energy in one single area within a non-dedicated-use building housing ESS/BESS, should be 600 kWh for lithium-ion. The maximum stored energy by ESS unit (group) should be 50 kWh.
NFPA do NOT differentiate NMC (Lithium Nickel Manganese Cobalt) from LFP (Lithium Iron Phosphate - ferro phosphate) where separations are concerned.
Each group should be spaced at least 0.9 m (3 ft) from other groups and from walls in the storage room or area.
Areas within 3 m (10 ft) on each side of outdoor ESS should be cleared of combustible vegetation and other combustible growth.

For exterior ESS, a minimum space separation should be provided between ESS enclosures and adjacent buildings or critical site utilities or equipment:

- Where enclosure vents or other penetrations are provided, they should be arranged and directed away from surrounding equipment and buildings.
- In a fire, these enclosures may have vents or penetrations that could allow hot gas and products of combustion to escape the enclosure, causing an exposure to adjacent equipment or buildings. Penetrations could include electrical cabling, doors, and HVAC units.
- There should be a minimum space separation of 3 m (10 ft) between adjacent ESS enclosures with noncombustible walls and between ESS enclosures and adjacent buildings/equipment.
- If the space separation between ESS enclosures is less than 3 m (10 ft), a thermal barrier, rated a minimum 1 hour (see annexes), should be provided on the inside or outside of the enclosure.

Energy storage systems should be located with one of the following areas, listed in order of preference (as shown in figure below):



ESS location by preference © Franck Orset (FPO)

1. Detail for detached dedicated enclosure (i.e., prefabricated container) located at a safe distance 3 m (10ft) minimum

Example of Exterior ESS enclosures with fire barrier:

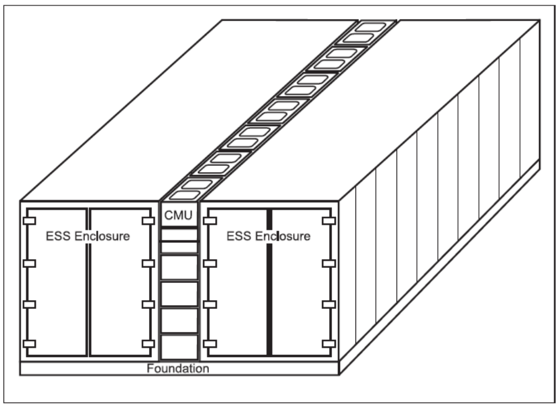


Fig. 2.3.2.2.1. Exterior ESS enclosures with fire barrier

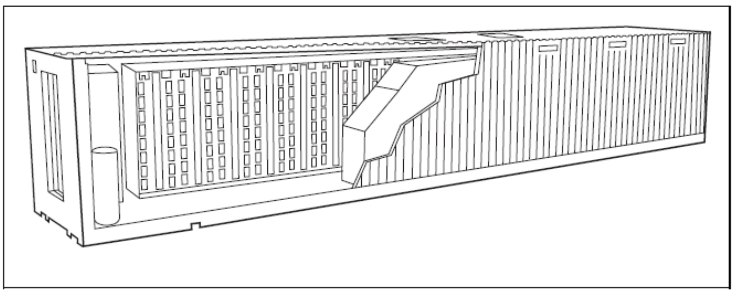


Fig. C.2.4(A). Exterior enclosure with multiple racks

2. Detail for dedicated building containing only ESS and associated support, located at a safe distance of 3 m (10 ft) minimum

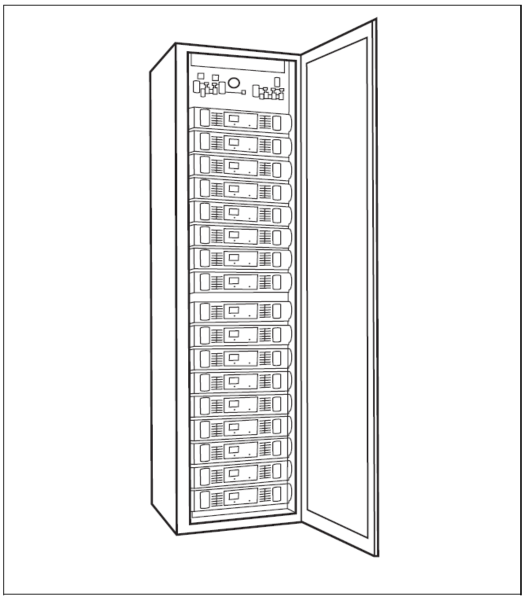
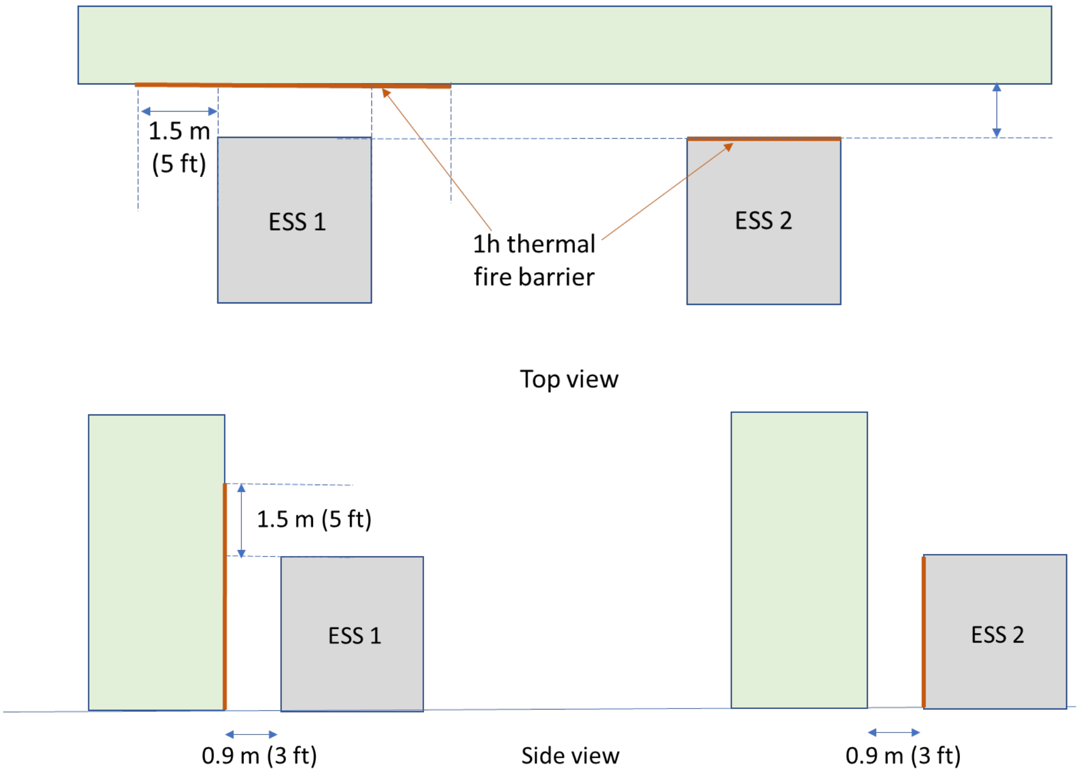


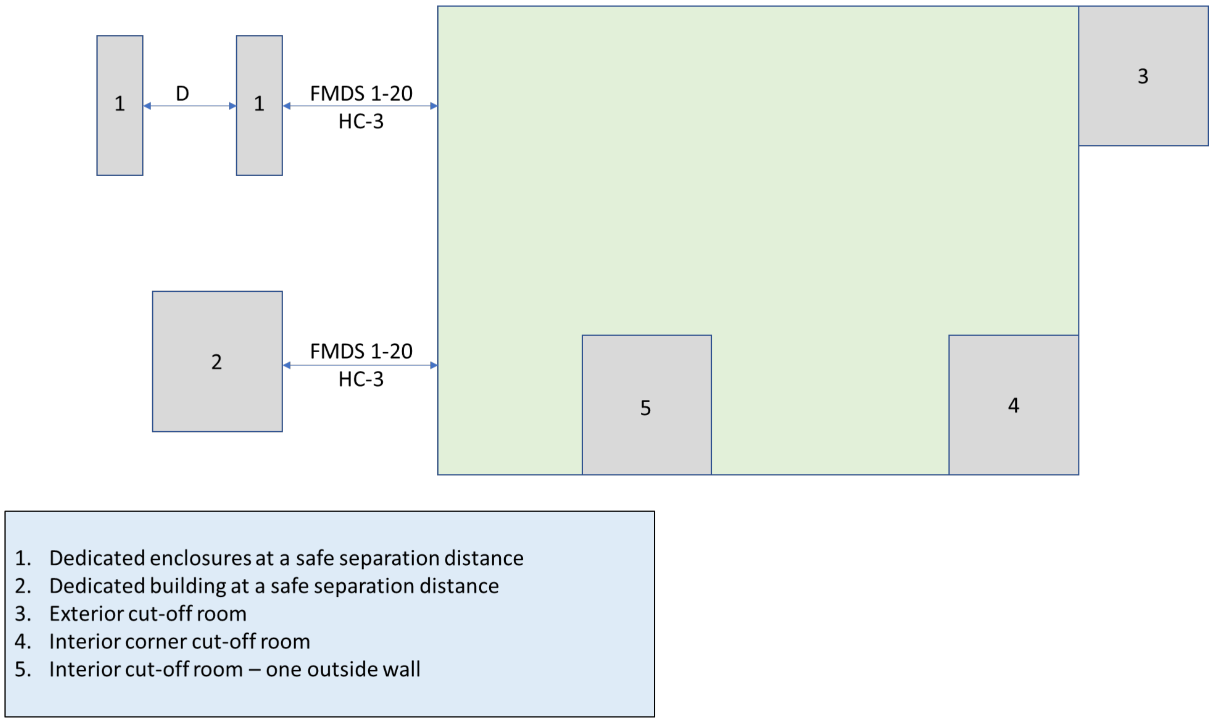
Fig. C.2.3 Typical rack configuration with miltiple modules

3. Detail for dedicated detached building (or enclosure), but not located at a safe separation distance. 1-hour thermal fire barrier necessary and 0.9 m (3 ft) separation. The thermal barrier should extend 1.5m (5 ft) above and 1.5 m (5 ft) beyond the physical boundary of the ESS installation to protect the exposure.



Most stringent requirements as per FM Global Data Sheet (DS)5-33 "Electrical Energy Storage Systems":

Indoor LIB-ESS Racks should be separated by 1.8 m (6 ft) minimum from the accessible face of adjacent LIB-ESS racks and from noncombustible materials, noncombustible construction elements.
FM differentiate NMC (Lithium Nickel Manganese Cobalt) from LFP (Lithium Iron Phosphate - ferro phosphate) where separations are concerned.
Separation distance "D" is based on doors being located on only one side of the enclosure, with no vents or unprotected openings on any other sides. It is also based on active systems (HVAC or liquid cooling) maintaining cell or module temperatures in the target enclosure or container, as follows (issued from section 2.3.2 on FMDS5-33 fig 2.3.1)



© Franck Orset (FPO) modified DLS

For Enclosure (i.e., prefabricated container) up to 46.5 m^2 (500 ft^2) FM recommend[4]:

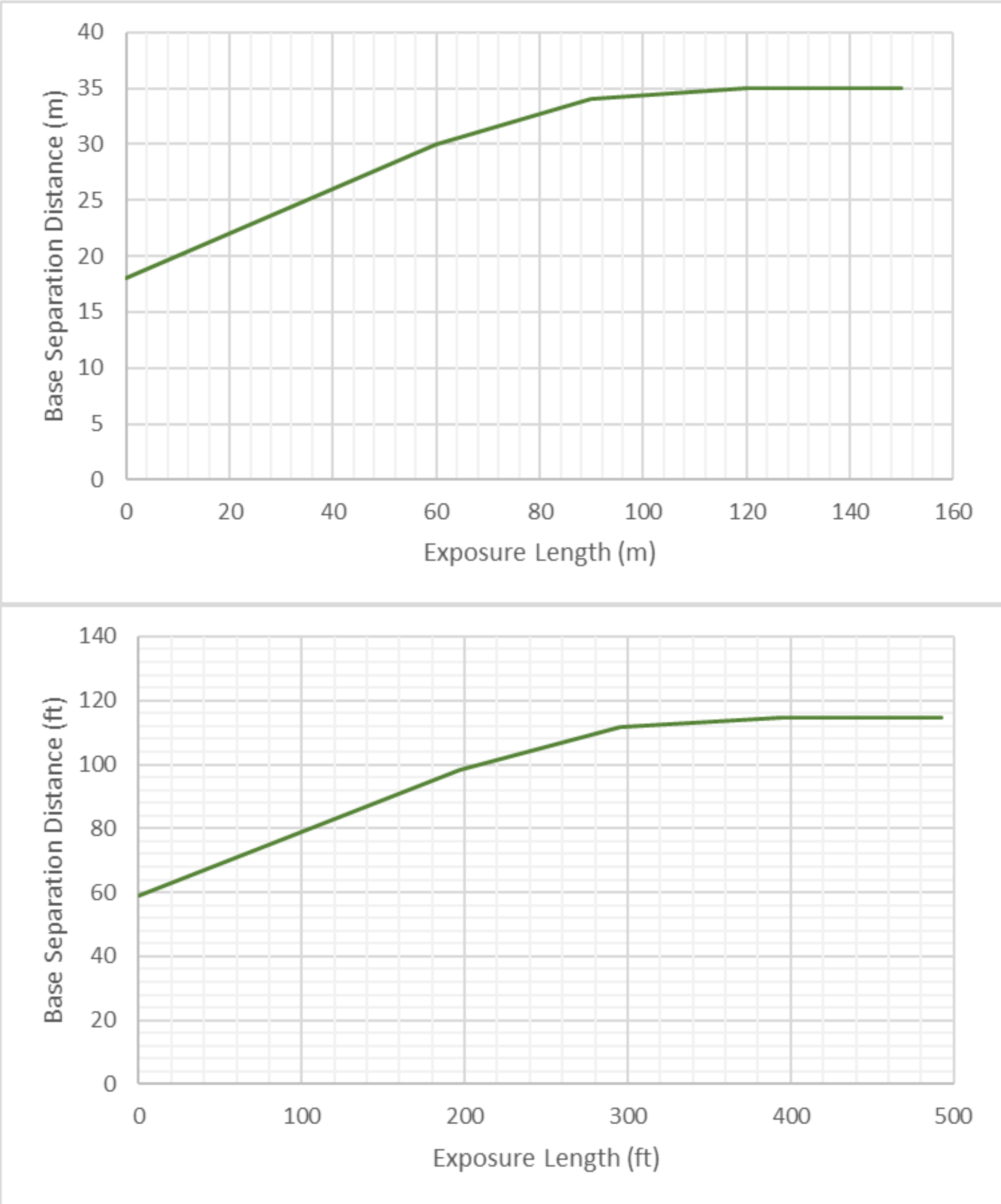
- For containerized LIB-ESS with lithium iron phosphate (LFP) cells, provide aisle separation of at least 1.5 m (5 ft) on sides that contain access panels, doors or deflagration vents.
- **For containerized LIB-ESS comprised of lithium nickel manganese cobalt (NMC) cells where wall construction is unknown or having a rating less than 1 hour, provide aisle separation of at least 4.0 m (13 ft) on sides that contain access panels, doors, or deflagration vents.**
- **For containerized NMC LIB-ESS where wall construction is documented as having at least a 1-hour rating, provide aisle separation of at least 2.4 m (8 ft) is acceptable.**

[4] **Note: as a conservative measure based on current knowledge, research and testing (deemed as non-conclusive) SCOR recommends NOT to differentiate LFP (Lithium Iron Phosphate - ferro phosphate) from NMC (Lithium Nickel Manganese Cobalt) where separations are concerned. Only the separation indicated above for lithium nickel manganese cobalt (NMC) should be considered regardless of the battery chemistry.**

For Dedicated LIB-ESS buildings or enclosures larger than 46.5 m^2 (500 ft^2) or for enclosures up to 46.5 m^2 (500 ft^2) exposing buildings, refer to FMDS 1-20 "Protection against Exterior Fire Exposure" for separations using hazard category 3 – HC-3[5] for the exposing building occupancy as follows:

For combustible constructions based on length of wall exposures:

- From 18 m (60 ft) up to 35 m (110 ft) (see curved below based on FMDS 1-20 Fig. 1b. and Fig. 1a. curve HC-1/HC-2/HC-3)



For non-combustible constructions, regardless of length of wall exposures:

- 12.5 m (40 ft) (based on FMDS 1-20 Fig. 2b. and Fig. 2a. curve HC-1/HC-2/HC-3)

[5] HC-3 Predominant occupancy is defined in FMDS 3-26 "Fire Protection for non-storage occupancies" (as per table 2.2.2) as areas with generally continuous heavier combustible loading with limited quantities of ignitable liquids and/or heavier amounts of plastics (examples include plastic manufacturing, vehicle manufacturing and assembly, and printing plants)

7.2 Storage

- No combustible storage, unrelated to the battery room, should be allowed inside the room.
- A 2.7 m (9 ft) minimum separation should be provided from combustibles and combustible construction elements.
- Noncombustible material related to the battery room and noncombustible construction elements should be located at a minimum distance of 90cm (3ft) from the equipment.

7.3 Vehicle impact protection

Vehicle impact protection, consisting of guard posts or other approved means, should be provided where ESS/BESS are subject to impact by motor vehicles. Guard posts should be designed as follows:

- Posts should be constructed of steel not less than 4 in. (100 mm) in diameter.
- Posts should be filled with concrete.
- Posts should be spaced not more than 1.2 m (4 ft) on center.
- Posts should be set not less than 0.9 m (3 ft) deep in a concrete footing of not less than 380 mm (15 in.) diameter.
- The top of the posts shall be set not less than 0.9 m (3 ft) above ground.
- Posts should be located not less than 0.9 m (3 ft) from the ESS.

BESS on a solar farm

8. ELECTRICAL EQUIPMENT

- Direct current switchgear and inverters should not be located in the battery rooms.

9. VENTILATION

For rooms containing ESS/BESS with flooded lead-acid, flooded Nickel-Cadmium (Ni-Cd) and Valve Regulated Lead Acid (VRLA) batteries, refer to the "ventilation" subsection of DC Battery Systems.

Exception: Lithium-ion and lithium metal polymer batteries should not require additional ventilation beyond that which would normally be required for human occupancy of the space.

- FM recommend ventilation for: LIB-ESS cut-off room at a rate of at least 0.0051 m^3/s / m^2 # 0.3 $m^3/min/m^2$ (1 cfm/ft^2) of floor area.

- Provide ventilation systems arranged to recirculate air into the room, with an FM-approved combustible gas detector arranged to stop recirculation and return to full exhaust when flammable gas is detected in the ductwork. Note: combustible gas detection in the ventilation system is not needed where combustible gas detection arranged for rack shutdown is provided in each ESS rack as part of the Battery Management System.

Exhaust Outlet(s):

- Exhaust outlets from an ESS exhausting anything other than ventilation air should be located at least 4.6 m (15 ft) from heating, ventilating, and air conditioning (HVAC) air intakes, windows, doors, loading docks, ignition sources, and other openings into buildings and facilities.
- Exhaust outlet(s) from an ESS should not be directed onto means of egress, walkways, or pedestrian or vehicular travel paths.

10. FIRE DETECTION AND FIRE PROTECTION

Detection:

- Fire detection should be provided inside the room.
- Gas detection. (See "Ventilation" above).

Protection:

- The fire protection design focuses on battery installations, which are typically an arrangement of tightly packed cells placed in modules that are stacked vertically in racks.
- Since these systems often consist of multiple racks, a main objective of the protection is to make sure, if a fire occurs, that it is contained to a single rack.
- If the fire is able to propagate from one rack to the next, it could last for a considerable length of time, potentially overwhelming the sprinkler system or taxing the water supply.
- For rooms containing ESS/BESS with flooded lead-acid, flooded Nickel-Cadmium (Ni-Cd) and Valve Regulated Lead Acid (VRLA) batteries, refer to the "Fire detection and Fire

protection" subsection of DC Battery Systems.

- To date there is no publicly available test data that confirms the effectiveness of any active fire protection for energy storage systems with lithium-ion batteries. Automatic sprinkler protection is recommended to limit fire spread to the surrounding structure, equipment, and building contents.
- To mitigate this risk, one of the objectives of an ESS/BESS fire protection system should be to contain the fire to the rack of the originating fire through the installation of a sprinkler system and the spacing of ESS/BESS groups.
- Water is an effective extinguishing agent for most ESS/BESS fires, including lithium-ion battery ESS/BESS. This is why sprinkler systems are the preferred fixed fire protection method (if designed properly). (See Annexes, Section 1, for details).

Minimum requirements as per NFPA855 "Standard for the Installation of Stationary Energy Storage Systems":

- Testing has shown that water is the most effective agent for cooling for a battery ESS. For this reason, a sprinkler system designed in accordance with NFPA 13, "Standard for the Installation of Sprinkler Systems", is required by NFPA 855.
- The maximum stored energy by ESS unit should be 50 kWh.
- ESS/BESS rooms should preferably be protected by automatic sprinklers designed (EH1) to deliver a minimum density of 12.2 mm/min (0.3 gpm/ft²) over the entire area of the room or 232 m^2 – 2500 ft², - whichever is smaller.
- Hose allowance for EH1 (Extra Hazard group 1): 500 gal/min (1900 L/min) for hose streams.
- Fire Water Supply Duration for EH1 (Extra Hazard group 1): 90-120min. However, lithium-ion batteries have shown they can ignite, or reignite, long after they have been damaged or involved in a fire—hours, days, or even weeks later. Consequently, adequate emergency planning including extending the duration of the fire water supply (see Emergency pre-planning and FDC in the annexes) is key.
- Using fire hose: The UL study "Firefighter Safety and Photovoltaic Installations Research Project" (2011) showed that for voltages up to 1000 volts DC, water can be safely applied given the right conditions. This study demonstrated that using an adjustable nozzle at a minimum of a 10-degree fog pattern allowed for the safe application of water at a distance of 1.5 m (5 ft) from the 1000 volts DC electrical source; **however, due to the potential conductivity of pooling water, contact with it may expose people to electric shock**.

Most stringent requirements as per FM Global Data Sheet (DS)5-33 "Electrical Energy Storage Systems":

- As per FM Global DS5-33, testing of a 125 kWh LIB-ESS utilizing lithium nickel oxide/lithium manganese oxide (LNO/LMO) batteries demonstrated that the fire growth ultimately exceeded the 2500 ft^2 design area. Therefore, the sprinkler design should be designed for the room area.
- ESS/BESS rooms should preferably be protected by automatic sprinklers designed (EH1) to deliver a minimum density of 12.2 mm/min (0.3 gpm/ft²) over the entire area of the

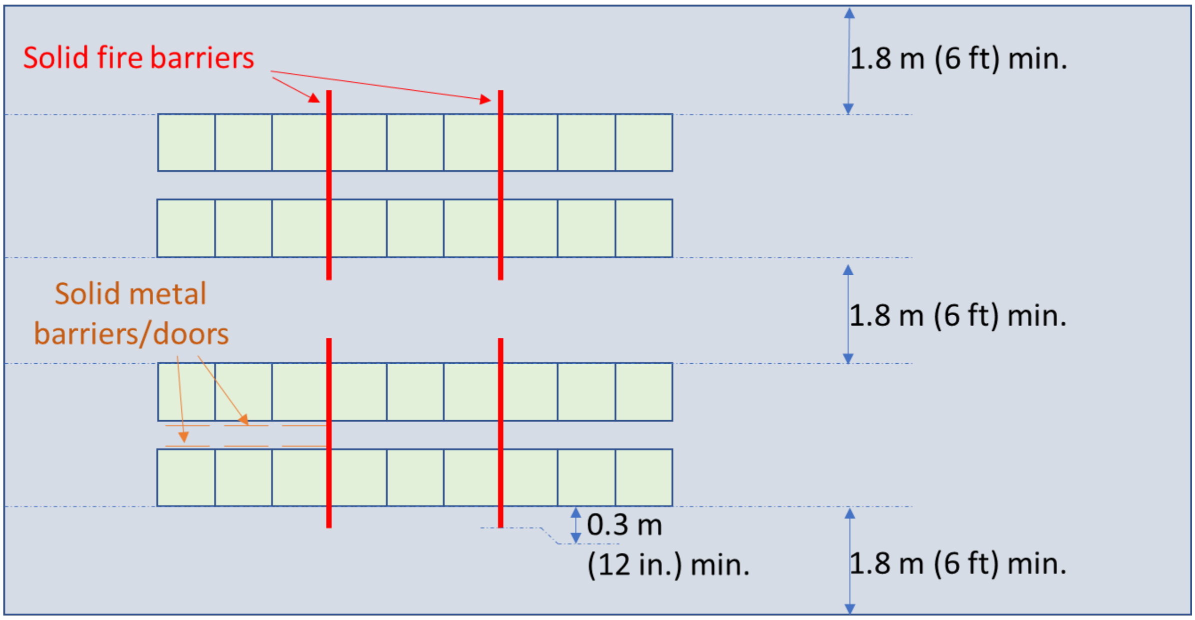
room or 232 m² – 2500 ft², - whichever is larger.

- Hose allowance: 946 L/min (250 gal/min) for hose streams.
- Duration (DS-533/NFPA855): the water supply should be capable of providing sprinkler water and hose stream requirements for the duration of the fire event. The expected duration will depend on the number of racks in a single fire area. The fire area is comprised of a row or rows of racks where minimum separation of 0.9 m (3 ft) is not provided. The duration should be estimated as 45 minutes multiplied by the number of adjacent LIB-ESS racks.
- Drainage: drainage or other mitigation of the water release should be provided.

Where the sprinkler demand area requires a water supply greater than what is available, provide the following:

1. Install noncombustible floor-to-ceiling partitions, with penetrations protected by approved fire stops between adjacent racks perpendicular to the rack door or opening to prevent fire spread. Ensure the partitions extend at least 0.3 m (12 in.) out from the face of the rack. Determine the horizontal distance between thermal barriers based on how many racks can be protected by the available water supply.
2. Install a solid metal partition on the back (non-aisle) of each rack to prevent heat transfer to adjacent racks in the next row. Where the rack design incorporates a solid metal back (no ventilation openings), additional partitions are not needed.

Note that with this configuration, each group should be spaced at least 1.8 m (6 ft) from other groups and from walls in the storage room or area (FM Global design).



Thermal barrier installation to reduce fire risk area
© Franck Orset (FPO)

Other Protection:

- Clean-agent fire extinguishing systems can be provided as supplementary protection when there is a need to limit equipment and nonthermal damage.

- Gaseous protection systems are not recommended for ESS/BESS applications for the following reasons:
  - Efficacy relative to the hazard: as of 2019, there is no evidence that gaseous protection is effective in extinguishing or controlling a fire involving energy storage systems.
  - Gaseous protection systems may inert or interrupt the chemical reaction of the fire, but only for the duration of the hold time. The hold time is generally ten minutes, not long enough to fully extinguish an ESS/BESS fire or to prevent thermal runaway from propagating to adjacent modules or racks.
  - Cooling: FM Global research has shown that cooling the surroundings is a critical factor in protecting the structure or surrounding occupancy because there is currently no way to extinguish an ESS fire with sprinklers. Gaseous protection systems do not provide cooling of the ESS or the surrounding occupancy.
  - Limited Discharge: FM Global research has shown that ESS/BESS fires can reignite hours after the initial event is believed to be extinguished. As gaseous protection systems can only be discharged once, the subsequent reignition would occur in an unprotected occupancy.
- If provided anyway, total flooding gas protection systems should be designed to maintain the design concentration within the enclosure for a time sufficient to ensure that the fire is extinguished and that temperatures of the ESS/BESS have cooled to below the autoignition temperature of the combustible material present and the temperature that can cause thermal runaway (with a minimum of 10 minutes).
- The design of the system should be based on:
  - The agent concentrations required for the specific combustible materials involved.
  - The specific configuration of the equipment and enclosure.
- Protections by water mist or dry chemical systems are not advised/recommended.

11. SPILL CONTROL

For rooms containing ESS/BESS with free-flowing liquid electrolyte (e.g., lithium-ion wet systems) refer to the "Spill Control" subsection of DC Battery Systems.

12. FIRE DEPARTMENT

As mentioned in the previous section on fire protection, FM Global research has shown that cooling the surroundings is a critical factor in protecting the structure or surrounding occupancy, because there is currently no way to extinguish an ESS/BESS fire involving lithium ion batteries with sprinklers.

The purpose of any automatic sprinkler protection is, therefore, to control the fire in order to limit fire spread to the surrounding structures, equipment, and building contents.

The fire can, therefore, last well beyond the duration of the Fire Water Supply of the sprinkler protection.

As a result of the above, fire control and final extinguishment should theoretically be performed by the firefighters feeding the fixed fire protection systems through Fire Department Connections ("FDC" – see Annexes) and using manual firefighting methods.

Significant responsibility is placed on first and second responders to ensure the hazard of stranded energy is properly mitigated and the batteries are safely and properly handled post event. The most effective approach for mitigating the hazard of stranded energy and safely neutralizing the batteries is still unclear.

Firefighters have to face "stranded energy" issues. Stranded energy is any scenario where electrical energy remains in a battery without any effective means of removing it. This typically happens when the battery is damaged—by force, a coolant leakage, heat, or water intrusion—and normal function ceases. This can also lead to thermal runaway.
An emergency response plan or pre-fire plan should be formalized and well documented in coordination with fire fighters, providing a plot plan. Firefighters should be familiar with the installation and firefighting systems. (See Annexes for details: "Stranded Energy").
Fire Department Connections (FDC) should be available, providing a means for firefighters to connect hose lines and supplement the fire sprinkler system's domestic water supply. (See Annexes for details: "Fire Department Connection" (FDC)).

Note on extinguishing agents:

- *For lithium-ion batteries*, water is considered the preferred agent for suppressing lithium-ion battery fires. Water has superior cooling capacity, is plentiful (in many areas), and is easy to transport to the seat of the fire. While water may be the agent of choice, the module/cabinet configuration could make water penetration difficult in terms of cooling the area of origin but may still be effective for containment. Water spray has been deemed safe as an agent for use on high-voltage systems. The possibility of current leakage back to the nozzle, and ultimately the firefighter, is insignificant based on testing data published in the Fire Protection Research Foundation report "Best Practices for Emergency Response to Incidents Involving Electric Vehicles Battery Hazards: A Report on Full-Scale Testing Results." Firefighting foams are not considered to be effective for these chemistries because they lack the ability to cool sufficiently and can conduct electricity. There is also some evidence that foams might actually encourage thermal runaway progression by insulating the burning materials and exacerbating heat rise.
  Firefighting with dry chemical powders can eliminate visible flame. However, such powders lack the ability to cool burning battery components. Quite often, even if visible flame is removed, the thermal runaway inside the battery will continue, resulting in reignition. Carbon dioxide and inert gas suppressing agents will also eliminate visible flame, but will likely not provide sufficient cooling to interrupt the thermal runaway process. ESS with clean agent suppression systems installed have ventilation systems that are tied in with the fire detection and control panel, so that the HVAC shuts down and dampers close to ensure the agents have sufficient hold times at the proper concentration levels to be effective suppressants. In some fire suppression systems, the HVAC recirculates and does not shut down, providing a means of dispersing the clean agents. Responders must ensure adequate hold time has occurred prior to accessing the battery room/container. Manufacturer-recommended times should be made clear. These agents might also reduce flammability by suppressing oxygen levels, but data has identified that flammable gases will continue to be produced due to the continued heating and could create an environment ripe for flashover or backdraft when oxygen is reintroduced into the system.

- *For lead-acid, nickel-cadmium, and other aqueous battery technologies*, water, powders, inert gases, and carbon dioxide are all considered acceptable suppression agents for small fires involving these batteries. However, if the fire is large, water will be the preferred agent because of its superior accessibility, portability, and cooling effectiveness.

Caution:
Battery components are often housed in cabinets or other configurations that can serve to protect the components and thus limit the ability of fire stream penetration. Firefighters should never use piercing nozzles and long penetrating irons. Mechanically damaged cells or puncturing unburned or undamaged cells can result in the immediate ignition of those cells. In addition, internal shorting within the cabinets could create an electrocution risk.
Movement of damaged cells might result in arcing or reignition if active material or cells

remain in the modules. Modules should not be moved without consulting qualified personnel.

Ventilation during suppression is critical. Research has shown that Li-ion batteries might continue to generate flammable gases during and after extinguishing. In addition, testing has shown that during sprinkler suppression, the removal of combustion and flammable gases emitted from the battery significantly improves the effectiveness of the suppression.
Testing has shown that electrical current leakage back through hose streams will not be a shock hazard when appropriate streams are used and distances maintained. In cases where systems are thoroughly destroyed and electric potential is shown to be minimal, close-range engagement with hoses for drowning modules can be performed to provide more direct cooling.

During post-fire operations, SCBA should continue to be worn by all persons near the damaged ESS, especially when systems are in confined or poorly ventilated spaces or have not been sufficiently cooled. Gases, and in particular CO, should be monitored during this period, as dangerous buildups have been observed during post-fire testing. If possible, batteries should be monitored for residual heat and temperature, as reignition is a possibility in cells that are not sufficiently cooled.

Care should be taken to secure the area in which the batteries are located, and to ensure that the heat has been removed and the batteries are not at risk of being electrically shorted or mechanically damaged. This should be done under the guidance of a qualified technician. At this point, the fire scene should be handed over to the owner, operator, or responsible party appointed by the site owner.

In unique cases where a system on fire poses little or no risk to the surrounding uninvolved equipment or the environment, it can be reasonable to assume a defensive posture and allow the system to burn itself out.
This option should only be considered when no risks are posed to the environment and the risk to firefighting operations is otherwise great or unknown.

4 TECHNICAL REFERENCES

1. NATIONAL FIRE PROTECTION ASSOCIATION

- NFPA 13 - Standard for the Installation of Sprinkler Systems
- NFPA 850 - Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations
- NFPA 855 - Standard for the Installation of Stationary Energy Storage Systems
- NFPA Research Foundation:
- Sprinkler Protection Guidance for Lithium-Ion Based Energy Storage Systems: https://www.nfpa.org//-/media/Files/News-and-Research/Fire-statistics-and-reports/Suppression/RFESSSprinklerProtection.pdf
- Energy Storage System Research and Design Challenge: https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/Proceedings/RFESSResearchDesignChallenge.ashx

2. FACTORY MUTUAL GLOBAL DATA SHEET

- FM Global data sheet 5-28 - DC Battery Systems
- FM Global data sheet 5-33 – Lithium-Ion Battery Energy Storage System
- FM Global data sheet 1-20 - Protection against Exterior Fire Exposure
- FM Global data sheet 1-21 - Fire Resistance of Building Assemblies.
- FM Global data sheet 3-26 - Fire Protection for non-storage occupancies

3. OTHER

- http://www.tc.faa.gov/its/worldpac/techrpt/tc15-59.pdf
- https://www.smart-energy.com/storage/aps-completes-investigation-following-2019-battery-storage-fire-disaster/
- FDNY materials for more information: https://drive.google.com/drive/folders/1zG1se9zzFwlPk-0QS0R8llfftjxY4UdT
- International Association of Fire Chiefs materials for more information: Recommended Fire Department Response to Energy Storage Systems (ESS) Part 1 (iafc.org) or https://www.iafc.org/docs/default-source/1fire-prev/iafcresponseessfires.pdf

5 ANNEXES

1. WHY USE SPRINKLER PROTECTION FOR LITHIUM-ION POLYMERE BATTERIES (DRY CELLS)?

Note that lithium-ion battery ESSs are becoming more and more popular, but there are additional specific hazards involved.
When a lithium-ion cell is exposed to a serious amount of heat from external source or from internal short circuits, it can become unstable and its internal material can react uncontrollably, initiating a process of thermal runaway.
This process often leads to the expulsion of hot gasses and fire in a cell. The situation is made catastrophically worse if cell-to-cell propagation of an individual cell thermal runaway is not controlled in the module and battery system design.
One of the major concerns in extinguishing a lithium-ion battery ESS fire is cooling the energy storage system down below the autoignition temperature of the flammable gases the ESS may discharge in a thermal runaway event.
An interesting video for Energy Storage Systems comprised of Lithium-Ion Battery Sprinkler Protection, made by FM Global, can be seen at: https://www.youtube.com/watch?v=aspF-GFOqHo

To date, there is no publicly available test data that confirms the effectiveness of any active fire protection for Energy Storage Systems (ESS) involving lithium-ion batteries.
However, automatic sprinkler protection is recommended to limit fire spread to the surrounding structures, equipment and building contents.
Sprinkler systems, with a designed density of 12.2 mm/min (0.3 gpm/ft²) over the entire area of the room or 232 m² – 2500 ft², - whichever is smaller, is the recommended protection system for Energy Storage Systems (ESS).
This density has been extrapolated from existing research, testing, and understanding of suppression system performances for this hazard.
Alternate fire suppression methods are permitted if testing shows they are effective, but there is little available information or test data on ESS fire control with such systems.

2. STRANDED ENERGY

If we consider an Electric Vehicle (EV), there are no surefire methods of removing energy from a car's lithium-ion battery when the battery has been damaged in a crash, unlike gasoline, which can be drained from a vehicle's tank. Because of this, energy remains trapped inside the battery and a process known as thermal runaway can occur, in which the battery essentially continues to overheat and over-pressurize, at the risk of eventually causing fires, arc-flashing, off-gassing, and sometimes explosions.
The battery is comprised of more than a dozen separate modules, each made up of hundreds of individual cells. All of these components are neatly packaged in a rectangular metallic case that runs the length of the chassis beneath the passenger cabin.
There are currently no ways for responders to determine how much energy remains in a damaged battery, and no way to drain that energy to reduce the threat. The battery industry is working to improve safeguards so that thermal runaway and stranded energy are no longer issues.
Using water to cool a damaged battery in thermal runaway is currently the dominant strategy for responders and is the tactic taught in the NFPA course on EV and battery response. Based on fire testing conducted at the request of the Fire Protection Research Foundation (FPRF), NFPA recommends that firefighters shoot "copious amounts of water" directly on the area of the battery case and use a thermal imaging camera to periodically look for signs of heat from the ongoing chemical reaction inside the battery. However, because EV batteries are typically

tucked between the vehicle's undercarriage and passenger compartment, firefighters say it can be hard, if not impossible, to access the battery to get water on it.
Another potential option for stopping thermal runaway is to drain the battery of the energy causing the reaction, which is much easier said than done.
The typical de-energization method used by many manufacturers is to submerge the damaged battery for several days in a saltwater bath until the bubbles stop, indicating that the chemical reaction inside the battery has ceased. While this tactic may seem less than ideal for first responders on a freeway who lack the technical expertise to remove a damaged battery, the lack of tried and tested options has forced them to get creative.
In the Netherlands, firefighters use tow trucks to transport large shipping containers to the site of EV accidents where a battery has been compromised. The box is filled with water, and a small crane lifts the vehicle and lowers it into the bath, after which it can be safely taken away to an impound. This strategy is becoming more common across Europe, where many fire departments have already converted their ladder trucks into small cranes to help them deal with train derailments.
See also https://www.nfpa.org/batteredbatteries

3. EMERGENCY RESPONSE PLAN OR PRE-FIRE PLAN

The pre-fire plan should include the following information:

- The buildings and nature of occupancies protected by automatic sprinklers, the extent of this protection and the type of sprinkler systems used (dry, wet, preaction, deluge…).
- The water supply to the sprinklers, including the source and type of supply, the flow and pressure available, and the anticipated duration of the supply.
- The location of all sprinkler control valves and what each valve controls.
- The location of the fire department connections (FDC) to sprinkler systems, the specific area each connection serves, and the water supply, hose, and pump layout that will be used to feed the FDC.
- The specific company assignment having the primary responsibility for charging the FDC.
- The location of water supplies for handlines without jeopardizing the water supply to operating sprinklers (if any).
- An alternate means for supplying water to the system in case of damage to the FDC (using private hydrants on the same supply, for example).

The pre-fire plan for a sprinklered building should detail which responding engine company will supply the FDC. It is common practice for the second responding engine to supply the sprinkler system.

In some cases, such as for large buildings with few doors for access, or buildings where inside hose outlets will be used, it is sound practice for the first engine company to supply the FDC.
The water supply used by the fire department to supply the FDC should be independent of the water supply that normally supplies the automatic sprinkler system, if possible.
Private yard hydrants should never be used to supply the FDC (except if there is no alternative).

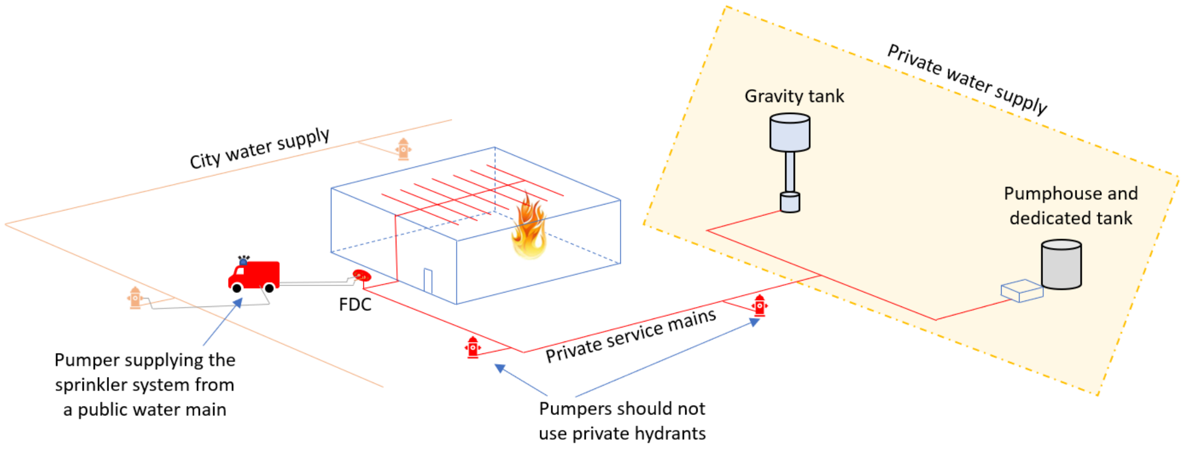
If public water supplies are available, a public hydrant should be located within 15 to 22.5 m (50 to 75 ft) of the FDC.

Water supplies for hose streams should be taken from sources that do not take water away from the sprinkler system (except if there is no alternative AND if the water supply characteristics -flow/pressure/duration – have been designed to supply both demands).

These supplies, if possible, should be:

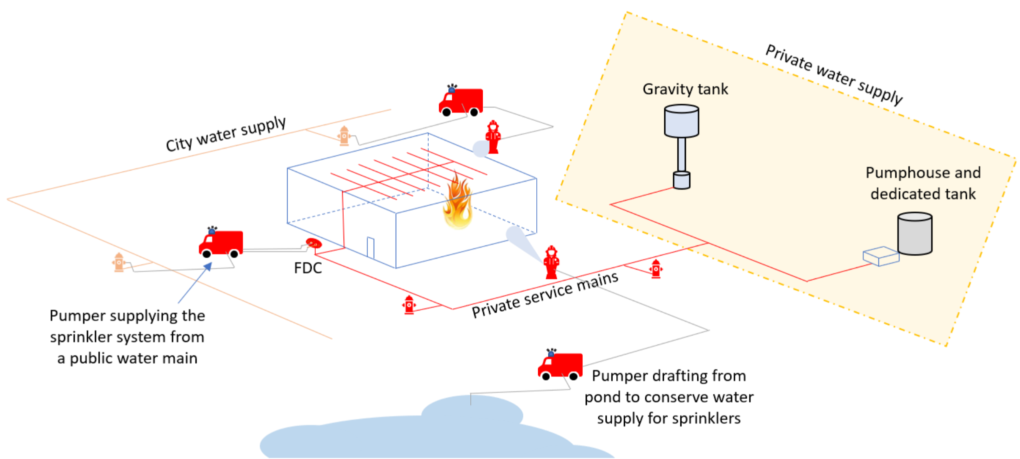
- Large water mains which flow tests have indicated are adequate to supply both sprinklers and the required hose streams
- Water mains not needed for sprinkler supply
- Static sources (ponds, rivers…)

Where hose streams must be used, water should be taken from sources that do not reduce the sprinkler protection.



Single fire engine supplying a sprinkler system – Adapted from NFPA
(There are no control or sectional shut off valves shown in this figure)

© Franck Orset (FPO)



Where hose streams must be used, water should be taken from sources that do not reduce the sprinkler protection
(There are no control or sectional shut off valves shown in this figure)

© Franck Orset (FPO)

4. FIRE DEPARTMENT CONNECTION (FDC)

Fire Department Connections (FDC) Standard

- Fire Department Connections (FDC), or Standpipe Siamese Connections, can be provided at the pumphouse or directly at the sprinkler system risers.

Creative Commons Attribution-ShareAlike 2.0 Generic (CC BY-SA 2.0)

- The FDC provides a means for firefighters to connect hose lines and supplement the fire sprinkler system's domestic water supply.
- Note that the FDC is not intended to deliver a specific volume of water. The purpose of the Fire Department Connection is to supplement the water supply, but not necessarily provide the entire sprinkler system demand.
- It is essential that the FDC be properly maintained so that it is available for use in an emergency situation.
- Note that there should be no shut-off valve on the fire department connection.
- The FDC consists of:
  - 2 hose inlets with female couplings (where the fire department connects hoses to feed the system) – also named "Siamese". Plastic or breakable covers or threaded caps are used to protect the inlets.
  - A check valve (to prevent backflow from the sprinkler system and to avoid taking water from the system – this backflow keeps the pressure downstream and avoids leakage from the FDC).

Creative Commons Attribution Jclemens assumed (based on copyright claims)., CC BY-SA 4.0

Creative Commons Attribution-Share Alike 3.0 Unported license.

Creative Commons Attribution 2.0 Generic (CC BY 2.0)

Regular maintenance should be provided on the FDC:

- Monthly inspections should be performed to check accessibility, good condition (plugs in place, no damaged thread, no leaking check valve, ball drip and drain in working order…).
- Prior to replacing any missing/damaged plug or cap, ensure that the waterway is clear of foreign material.

The most common issues found with FDCs are:

- Obstructions:

  Foreign objects (usually trash) introduced through un-capped inlets.
  In a fire situation, the foreign objects will be pushed through the sprinkler piping by the force of the water from the pumper truck until the object reaches the smaller-diameter sprinkler branch-line piping or sprinkler, obstructing waterflow to the fire area.
  In some cases, the connection should be backflushed to remove foreign materials.

- Access:
  The FDC should be visible and accessible.

  Bushes should be trimmed back.
  No storage should be allowed.
  Vehicles and dumpsters should be moved away. Parking near the FDC should be strictly restricted.
- Freezing:

  If the FDC check valve leaks, the piping between the check valve and the inlets could fill with water and freeze solid. To prevent this, the inlets and the automatic drip should be regularly inspected for leaking water.

- Corrosion:

  The dry section of the FDC can corrode to the point where the piping detaches from the sprinkler system.
  The piping to the sprinkler system should be visually checked.

5. FIRE RESISTANCE OF BUILDING ASSEMBLIES

Refer to Data Sheet 1-21, Fire Resistance of Building Assemblies.
The test procedure is ASTM E 119 (NFPA 251, UL 263).
Example of 1-hour fire rating:

- Masonry wall concrete masonry unit (expanded slag or pumice aggregate) – minimum thickness 53 mm (2.1 inches)
- Autoclaved aerated concrete (AAC is made of Portland cement), commonly referred to as Hollow Concrete Blocks (HCB): not less than 75 mm (2.9 inches) thick where required fire endurance is less than 2 hours for non-load bearing walls.
- Concrete masonry units (CMU): concrete blocks, which can be either hollow (commonly referred as Hollow Concrete Blocks – HCB) or solid, used in masonry construction. The cores or cells of hollow CMU are often filled solid with cement grout (once several courses of CMU are constructed) to obtain an adequate fire resistance rating: minimum thickness 102 mm (4 inches)
- Concrete walls minimum thickness depending on material (*): Siliceous 89 mm (3.5 inches), Calcerous 81 mm (3.2 inches), Lightweight 69 mm (2.7 inches)
- Solid nonbearing partitions minimum thickness depending on material: perlite gypsum 38 mm (11/2 inches), solid gypsum blocks 51 mm (2 inches)

(*) Calcerous (or Carbonate) aggregate: an aggregate from calcium carbonate or magnesium carbonate-based stone such as marble, marl, limestone or dolomite.

Lightweight concrete: Concrete with a weight density of roughly 16 to 18 kN/m^3 (105 to 115 Lbs/ft^3). Lightweight concrete will generally have better fire resistance per unit thickness than normal weight concrete.

Siliceous aggregate: An aggregate from silica-based stone such as granite, basalt, chert or flint. Concrete and concrete masonry made with siliceous aggregate generally has the lowest fire resistive qualities of the common aggregate types. When the aggregate is unknown or cannot be verified, siliceous aggregate is assumed for fire endurance purposes.

6. BESS FAILURE EVENT DATABASE

List of BESS failure events available from public information sources:
https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database

Other publications in this series:

- RISK CONTROL PRACTICE: CONSTRUCTION MATERIAL
- RISK CONTROL PRACTICE: EXPOSURE Falling Aircraft Handbook
- RISK CONTROL PRACTICE: SPECIAL HAZARDS
  - Embankment Dams Handbook
  - Tailings & Tailings Management Facilities Handbook
- RISK CONTROL PRACTICE: OCCUPANCY
  - Renewable Energy Handbook
  - Aluminium Handbook
  - Steel Handbook
  - Wood Processing Pulp & Paper Handbook
- RISK CONTROL PRACTICE: LOSS ESTIMATE
  - Maximum Possible Loss (MPL) Handbook

To learn more about SCOR's strategy, goals, commitments and markets, visit our website.

www.scor.com

Follow us on social media

SCOR
The Art & Science of Risk