



HAZARD GUIDE

Lithium-ion batteries

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Overview

While lithium ion-batteries are safely used every day, they have gained widespread attention for their unique fire risks. Their rapid rise in popularity stems from key advantages over other batteries, such as faster charging, longer lifespan, and higher energy density. As a result, they are widely used across various industries, from small cells powering personal electronics to large battery packs driving electric vehicles.

The challenge with their rapid growth was many safety codes and standards lagged behind in addressing their hazards. This gap left limited understanding of how to manage associated hazards, including fire protection designs and fire department response. Today, the standards are catching up and providing guidance for specific situations.

How lithium-ion batteries work

Lithium-ion batteries consist of four main components:

- Anode (negative end)
- Cathode (positive end)
- Separator that keeps the anode and cathode apart
- Electrolyte solution that allows transport of lithium-ions between the anode and cathode

The lithium ions travel across the separator from one side of the battery to the other, while the electrons flow through the circuit. The direction of flow depends on whether the battery is charging or discharging (in use). It is important to note that the electrolyte solution is an ignitable liquid.

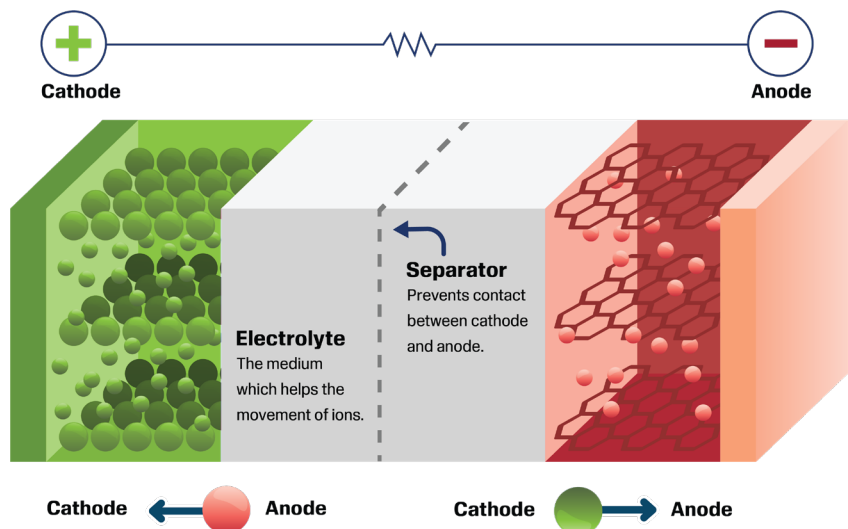


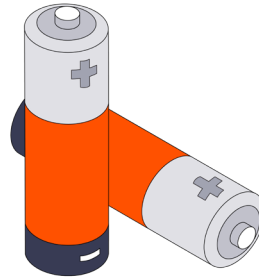


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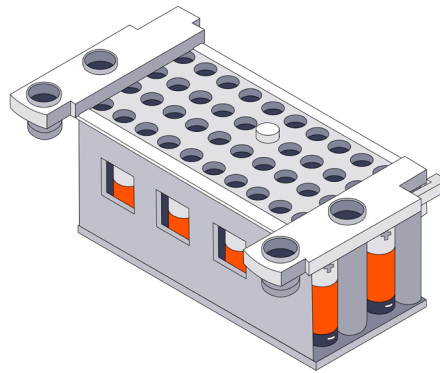
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Battery overview

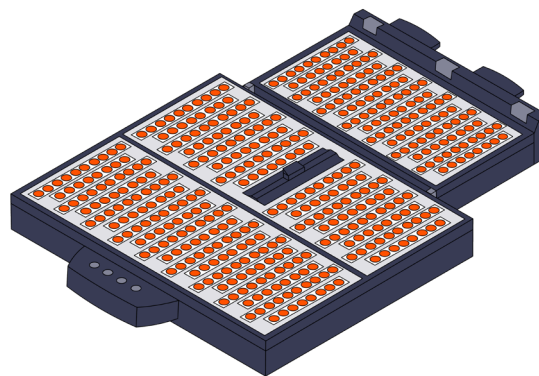
Lithium-ion batteries come in the form of an individual cell. Multiple cells are connected to form a module, and multiple modules can be connected to form a pack. The number of cells, modules, and arrangement will vary based off the specific battery or application.



CELL



MODULE



PACK



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The individual battery cells come in different forms including a cylindrical cell form, prismatic cell form, or pouch cell form as pictured below. Each of these cells have the same basic components—anode, cathode, separator, and electrolyte solution. The selection of a particular cell varies based on intended use. For example, the pouch cell form is often used in personal electronics due to the limited space available for the battery.

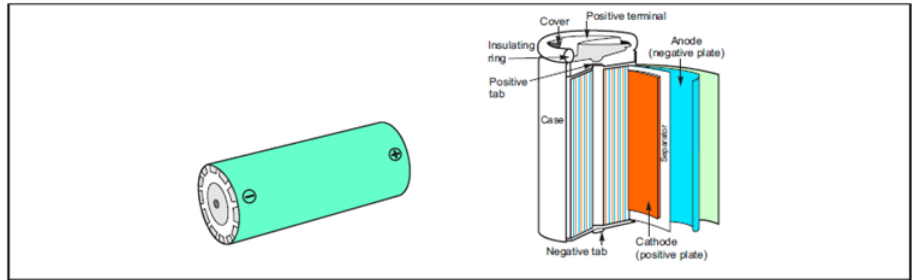


Fig. C.2.1.1. Cylindrical cell form

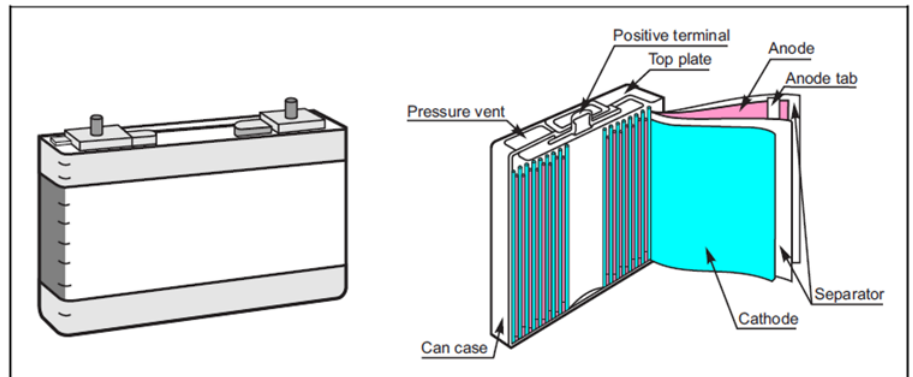


Fig. C.2.1.2. Prismatic cell form

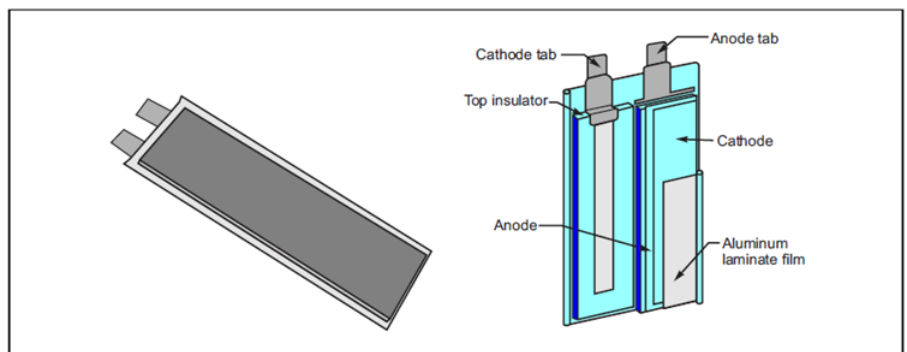


Fig. C.2.1.3. Pouch cell form





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Battery chemistry

Lithium-ion battery is a term that encompasses multiple battery chemistries, resulting in several distinct types. Below are the most common chemistries used in lithium-ion batteries:

- Lithium iron phosphate (LFP)
- Lithium nickel manganese cobalt (NMC)
- Lithium nickel cobalt aluminum oxide (NCA)
- Lithium manganese oxide (LMO)
- Lithium cobalt oxide (LCO)
- Lithium titanate (LTO)

There are advantages and disadvantages to the different cell chemistries, including cost to manufacture, lifespan, thermal stability, energy density, and power density — all dependent on the type of chemistry use. Due to the variation in characteristics, different battery chemistries are used for specific applications.

Certain battery chemistries are less likely to experience thermal runaway; however, it is important to note that any of the lithium-ion battery chemistries are subject to thermal runaway. The guidance provided in FM Data Sheets does not differ based on battery chemistry.





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Science of the hazard

Thermal runaway

Fire and/or explosion due to thermal runaway is the main hazard associated with lithium-ion batteries. Physical, electrical, or thermal abuse to a battery cell along with manufacturing defects can lead to a short circuit that causes the cell to generate heat faster than it can dissipate. As the damaged cell generates heat, the electrolyte solution (ignitable liquid) converts to a flammable gas that builds pressure within the cell. Lithium-ion battery cells typically have a relief valve that relieves the pressure of the flammable gas, allowing flammable gas to vent from the cell. Once the flammable gas is vented outside the cell, it may be ignited by the damaged battery cell or an external ignition source.

Thermal runaway starts in one cell and moves to adjacent cells, modules, and packs. As one cell is heated, the adjacent cells begin to heat to the point of failure and this effect can continue throughout the modules and racks.

The damaged cells that experience thermal runaway are a result of physical, electrical, or thermal abuse along with manufacturing defects.

- Electrical abuse: Improper charging or discharging of lithium-ion batteries can lead to thermal runaway. This can include the use of an incompatible charger.
- Thermal abuse: Lithium-ion batteries have an operating range that define the temperature limits of the batteries. Operating outside this range, exposure to an external fire, or exposure to other battery cells experiencing thermal runaway are forms of thermal abuse.
- Physical abuse: Physical impact can damage the separator or other components within the battery and lead to an internal short circuit.
- Manufacturing defect: Specific errors during the manufacturing process could lead to conditions causing the thermal runaway of a battery cell.

State of charge

The state of charge (SOC) of the battery can impact the fire hazard. The SOC is identified as a percentage of the battery charge. The higher the SOC, the more reactive the battery. Lithium-ion batteries with a higher SOC can generate more flammable gases, produce more heat during a fire, and propagate to other cells easier than batteries with a lower SOC. Additionally, thermal runaway is more likely at higher SOC. Since lithium-ion batteries with a higher SOC are a higher hazard, *FM Data Sheet 7-112 Lithium-Ion Battery Manufacturing and Storage* does identify specific controls at various SOC.





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Fire challenges

Thermal runaway can lead to fire or explosion; however, once a fire occurs, additional challenges exist. Lithium-ion battery fires require a large amount of water to control the fire. In addition to needing a lot of water to control a fire, lithium-ion batteries are often shielded, making it more difficult for water to access the fire. For example, electric vehicle batteries are difficult to access due to their location on the vehicles.

Since lithium-ion battery fires require a lot of water to control, specific sprinkler designs are often needed to protect lithium-ion batteries. Many of the sprinkler designs for protecting lithium-ion batteries are relatively new, meaning the fire protection systems may not be adequate to protect a lithium-ion battery fire unless the system was upgraded. Failure to have a properly designed sprinkler system may allow a fire to overcome the current fire protection system.

Once a fire is extinguished, fires involving lithium-ion batteries—or lithium-ion batteries exposed to a nearby fire—have a higher likelihood of reignition. Heat from the fire can damage battery cells leading to thermal runaway after the initial fire is extinguished. Even a battery cell that did not experience direct flame impingement may have been exposed to heat that increases the likelihood of thermal runaway.

Explosion hazard

During a thermal runaway event, the electrolyte solution is converted to a flammable gas that builds pressure within the cell. As the pressure builds, the pressurized flammable gases vent out a relief valve on lithium-ion battery cells. If the flammable gas immediately ignites, a fire occurs. If the flammable gas mixture does not immediately ignite, flammable gases may build up in a confined area or container. Once an ignition source meets the built-up gas mixture, a resulting explosion can occur.





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Loss prevention

General control measures and protection

While individual situations may warrant specific controls against lithium-ion battery fires, there are general control measures that should be considered in all scenarios.

- Prevent electrical, thermal, and mechanical abuse of lithium-ion batteries.
 - Proper charging: The batteries and charging equipment should be listed/ approved by a reputable third-party testing agency and intended for use with the equipment it powers. All charging should be done in accordance with the manufacturers' instructions.
 - Operating temperature: Store and use batteries within the temperature range specified by the manufacturer.
 - Avoid damaged batteries: Avoid physical impact to batteries and never use batteries that have been subject to physical damage. Damaged batteries should be stored in a manner that limits fire damage potential until they can be properly discarded.
- Control ignition sources: Lithium-ion batteries can add to the intensity of a fire, even when the fire did not originate with the battery. By controlling surrounding ignition sources, the probability of a lithium-ion battery being exposed to fire is reduced.
- Adequate sprinkler protection: Depending on the use, quantity, or storage arrangement, specific fire protection designs may be needed to protect lithium-ion batteries. Sprinkler protection is intended to cool the structure, nearby combustibles, and in some cases prevent the spread of fire to adjacent modules. Sprinkler protection is not designed to extinguish the fire or stop active thermal runaway. Proper sprinkler protection can also prevent a fire from spreading to a lithium-ion battery when the fire originates elsewhere in the building.
- In-house policies and training: Occupancies using or storing lithium-ion batteries should develop a written fire prevention plan and train all team members on the plan. The plan should include the following topics.
 - Hazard description: Outline the hazards associated with lithium-ion batteries and where they are present in the facility.
 - Proper use: Address proper charging practices, protecting batteries from physical damage, proper disposal of batteries, etc.
 - Proper storage: Identify where and how to properly store lithium-ion batteries. Storing the batteries outside, away from the building is the preferred, where applicable (i.e. electric vehicles, e-bikes, etc.). Note that it may not be practical to remove all lithium-ion batteries from the building as most personal electronics, such as cell phones and laptop computers, utilize lithium-ion batteries.
 - Emergency response procedures: Determine the plan of action if a fire does occur. The plan should include early notification of the fire department and identify any important safety features such as emergency shutoffs. Pre-incident and emergency response planning should be done in accordance with *FM Data Sheet 10-1 Pre-Incident and Emergency Response Planning*.

Fire department preplanning: The responding fire department should be brought in for preplanning. Preplanning allows the local fire department to know where the batteries are located, the location of emergency shutoffs, and allows them to develop a plan for how to





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Occupancy specific hazards

Habitational

Lithium-ion batteries are likely present in habitational occupancies whether it is a single-family home or a high-rise residential complex. The level of risk and controls can vary depending on the use, quantities, etc. of the batteries. Examples of common uses in residential occupancies are below.

- Electric vehicles
- E-bikes or scooters
- Lawn equipment
- Maintenance tools
- Personal electronics

Electric Vehicles

The frequency of electric vehicle fires is lower than fires involving vehicles with internal combustion engines; however, electric vehicle fires have gained attention because once they ignite they are difficult to extinguish. The combination of ignitable liquids in compartmentalized lithium-ion batteries and the amount of plastic in vehicles make electric vehicles a challenging fire hazard. Additionally, due to thermal runaway from heat exposure, reignition has increased potential. Depending on the specific property, vehicles may be parked outside, in a detached garage, or a garage attached to a primary structure. An electric vehicle fire in or near a property may create significant property damage due to the intensity and duration of the fire. Parking electric vehicles outside, away from structures, is the best practice. See Parking Garages section for additional information.





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E-bikes and scooters

Fires involving e-bikes and scooters brought early attention to the lithium-ion battery fire hazard. E-bikes and scooters are susceptible to physical damage. In addition low-quality replacement chargers and batteries may be unknowingly used if the original components were misplaced. These factors increase the risk of fire. The compact nature of e-bikes and scooters allows residents to bring the equipment inside, leading to potential property damage. Habitational facilities should have a plan for e-bikes, that includes educating residents about the associated hazards. Methods for controlling potential e-bike fires include the following (additional controls may be applicable based on-site specific conditions).

- Utilize chargers specifically intended for the e-bike. Plug chargers directly into an outlet—no extension cords.
- Use only approved batteries.
- Storage
 - The preferred method for storage is outside or in a low-cost detached structure, away from the primary property.
 - Where indoors storage is necessary, utilize a rated cut-off room where possible. Limit combustibles surrounding the bike/scooter.
- Disposal
 - Properly dispose of old or unused lithium-ion batteries. Lithium-ion batteries cannot be disposed of in standard household refuse.
 - Do not store damaged batteries or e-bikes inside a building.
- Educate residents on the hazards and site-specific policies relating to lithium-ion batteries. Education should be provided at initial occupancy and continual refreshers provided.
- Schedule recurring self-inspections by building management to ensure adherence to the lithium-ion battery policies.

Maintenance tools, lawn and garden equipment, and personal electronics

A variety of personal electronics and tools powered by lithium-ion batteries are common in habitational facilities. Educating staff and residents on proper charging, handling, battery disposal, and signs of battery damage can help increase awareness on the hazard before it leads to uncontrolled fire.

Manufacturing

For manufacturing facilities where lithium-ion batteries are used, refer to the Storage and Warehousing section below. Where lithium-ion batteries are manufactured, refer to *FM Data Sheet 7-112 Lithium-Ion Battery Manufacturing and Storage* for guidance.



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Parking garages

Vehicle charging stations may be present where vehicles are parked in habitational occupancies and add a potential ignition source. Vehicle charging should be done in accordance with the manufacturers' instructions. The charging unit and all associated equipment/accessories should be independently listed/approved and installed by qualified contractors.

FM Data Sheet 7-15 Garages provides guidance for vehicle charging stations in parking garages. An overview of the guidance is as follows. Review the data sheet for additional details.

Vehicle charging stations in parking garages	
Exterior charging stations (recommended)	Interior charging stations (where interior charging is locally mandated)
<ul style="list-style-type: none"> • Exterior charging stations recommended • Locate charging stations at least 10ft. or 3m away from buildings, structures, and equipment • Locate charging stations at least 50ft. or 15m away from combustible storage, fuel tanks, utilities, and transformers • Locate wall mounted charging units on noncombustible walls 	<ul style="list-style-type: none"> • Locate charging station on a ground level exterior wall or top outdoor level of the parking garage • Do not locate charging stations in underground locations • Where attached to primary building, locate as remote as possible from main building entrance • Located at least 10ft. or 3m from fire pumps, generators, transformers, and utility rooms containing critical equipment • Conduct a structural analysis to evaluate the effects of the added weight of electric vehicles

Repair garages

Repair garages may be servicing electric vehicles with lithium-ion batteries. Due to the difficulty in extinguishing electric vehicle fires, damage to the building can be limited by storing electric vehicles outside, away from the building, when active repairs are not taking place. Electric vehicle charging should follow controls outlined in the "parking garages" section.

While electric vehicles are a potential source of ignition, other ignition sources can start a fire that spreads to an electric vehicle. Controlling ignition sources such as hot work, electrical, and smoking, and controlling the storage and dispensing of ignitable liquids can help prevent a fire that spreads to electric vehicles.

Fire protection systems in repair garages also help limit the spread of fire. Fire protections systems should be designed in accordance with *FM Data Sheet 3-26 Fire Protection for Nonstorage Occupancies*.



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Retail

Retail occupancies regularly sell products with lithium-ion batteries such as personal electronics, tools, etc. No special fire protection design is needed for retail of general products containing lithium-ion batteries unless bulk storage is present, such as back of store storage or big box retail stores.

Some retail occupancies may recycle used electronics or batteries. Employees should be aware of the hazard and a plan should be in place on proper handling and storage of the batteries. See “returned, defective, or damaged cells/modules/batteries” section in this document under the “storage and warehousing” for additional details.

Storage and warehousing

Loss control measures and fire protection guidance associated with the bulk storage of lithium-ion batteries can vary based on several factors.

- Amount of lithium-ion battery storage
- New or used batteries
- Whether the batteries are part of a finished product or a standalone battery
- State of charge—The state of charge (SOC) for transportation and storage is typically between 30-60% SOC—charges higher than 60% are typically intended for immediate use

Bulk storage can include warehousing, wholesale/big-box stores, or even bulk storage of lithium-ion batteries in back of house storage at retail facilities. When bulk storage of batteries is taking place, reference [FM Data Sheet 7-112 Lithium-Ion Battery Manufacturing and Storage](#) for specific guidance.

Incidental storage

When lithium-ion batteries are in metal, wood, or cardboard containers, stored less than 6ft. or 2m high and in piles less than 200 ft² or 18.5m², the storage can be considered incidental. When multiple piles are present, each pile should be separated by 10ft. or 3m aisles. To meet the definition of incidental, the batteries would also need to be charged less than or equal to 60%.

If the batteries are stored in plastic containers, specific sprinkler designs would be needed.





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Finished products with new or refurbished batteries

It's not uncommon to find bulk storage of personal electronics, power tools, electric lawn equipment, etc. in warehouses, retail storage areas, big-box stores and other storage spaces. This raises the question as to whether you need to have a special fire protection design to account for the lithium-ion batteries. If the battery SOC is 60% or lower, no special design is needed for lithium-ion batteries in finished products. The fire protection system can be designed to the commodity classification of the finished product, without factoring the lithium-ion battery. For example, if lithium-ion battery powered lawn equipment made of unexpanded plastics is stored, the fire protection design for unexpanded plastics would be utilized (see [FM Data Sheet 8-9](#)).

For the bulk storage of finished products containing lithium-ion batteries having a charge greater than 60%, in-rack sprinklers are needed. See [FM Data Sheet 7-112 Lithium-Ion Battery Manufacturing and Storage](#) for specific fire protection design.

The guidance above includes replacement batteries to be sold to the customer but not finished electric vehicle modules or packs. Finished electric vehicle modules or packs are not considered finished products.

Standalone lithium-ion batteries (new or refurbished lithium-ion batteries that are not part of a finished product)

When new or refurbished lithium-ion batteries are stored that are not part of a finished product, specific sprinkler designs are called for to properly protect the hazard. These designs can be found in the [FM Data Sheet 7-112 Lithium-Ion Battery Manufacturing and Storage](#). In addition to the sprinkler design:

- Storage is limited to 15ft. or 5m unless adequate in-rack sprinklers are provided
- No storage is provided above the batteries unless adequate in-rack sprinklers are provided
- Keep other combustibles at least 10ft. or 3m away from the battery storage
- In solid-piled arrangements, piles should not exceed a width of 15ft. or 5m and have a minimum aisle space of 10ft. or 3m.

Returned, defective, or damaged cells/modules/batteries

When lithium-ion batteries are returned, it's unknown if the batteries have experienced electrical, thermal, and mechanical abuse. Batteries that have been returned should be assumed a higher risk due to the unknown. Batteries that are known to be defective or damaged also have a higher risk of thermal runaway. For these reasons, precautions should be taken to prevent a battery experiencing thermal runaway.

Storing batteries outside, away from the building is best practice. If lithium-ion batteries are stored inside, they should be stored in a cut-off room with adequate fire protection. [FM Data Sheet 7-112 Lithium-Ion Battery Manufacturing and Storage](#) outlines the specific storage criteria for returned, defective, or damaged batteries. The FM Boiler Re Lithium-Ion Battery Checklist can also be referenced for additional details.





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Lithium-ion battery forklifts

Forklifts powered by lithium-ion batteries may be found in various occupancies. The manufacturers' recommendations should be followed for the use, storage and charging of the forklifts. To reduce the likelihood of ignition and subsequent fire spread from battery charging, forklift charging stations should be located away from combustible materials.

Fire protection should be designed in accordance with the following:

1. Fire protection systems should be designed to protect the surrounding occupancy for unconcentrated, on demand charging (i.e. single panel charging stations).
2. For multi-panel charging stations and dedicated forklift charging areas, provide fire protection in accordance with *FM Data Sheet 7-39 Material Handling Vehicles*.
3. Currently, there is no specified design for lithium-ion battery charging racks.

***The guidance above is for forklifts with lithium-ion batteries smaller than 50kWh.

References

1. FM Data Sheet 3-26, Fire Protection for Nonstorage Occupancies
2. FM Data Sheet 5-33, Lithium-Ion Battery Energy Storage Systems
3. FM Data Sheet 7-15, Garages
4. FM Data Sheet 7-39, Material Handling Vehicles
5. FM Data Sheet 7-112, Lithium-Ion Battery Manufacturing and Storage
6. FM Data Sheet 10-1, Pre-Incident and Emergency Response Planning