Allianz Global Corporate & Specialty

Lithium-ion batteries: Fire risks and loss prevention measures in shipping

Allianz Risk Consulting bulletin

Firefighting efforts around the *Hoegh Xiamen* after it caught fire in Jacksonville, Florida, in June 2020. The fire was linked to a car battery. Photo: Jacksonville Fire and Rescue Department, Wikimedia Commons

Lithium-ion (Li-ion) batteries are increasingly impacting shipping safety with a number of fires. Allianz Global Corporate & Specialty (AGCS) marine risk consultants have long warned about the potential dangers that Li-ion batteries can pose if they are not handled correctly. In this risk bulletin, the AGCS team takes a deeper dive into the hazards and storage concerns associated with newly manufactured Li-ion batteries being shipped on vessels as cargo or already installed in new electric vehicles.

All of the recommendations in this bulletin are technical advisory in nature from a risk management perspective and may not apply to your specific operations. Please review the recommendations carefully and determine how they can be applied to your specific needs prior to implementation. Any queries relating to insurance cover should be made with your local contact in underwriting and/or broker.

Introduction

AGCS marine risk experts continue to see incidents involving fires on board container ships and ro-ro (roll-on roll-off) vessels, with investigators looking into the involvement of Li-ion batteries as a possible cause or contributing factor.

However, the overwhelming challenge investigators face in determining the cause and origin of such incidents is the fact that shipboard fires burn at such extreme temperatures, and for such extended periods of time (usually days), that little, if any, traces of evidence remain for them to examine.

In most shipboard incidents, a thermal runaway event *(see page 2)* is almost inevitable unless immediate action can be taken by the vessel's crew to mitigate the fire. Unfortunately, this is rarely possible due to a lack of early detection, a shortage of manpower, and a lack of adequate firefighting capabilities on board.

So what can be done? The primary focus must be on prevention and Allianz marine risk consultants offer the following recommendations to manufacturers, shippers, carriers (transporters), as well as insurance underwriters, based on the information and testing currently available. This information is provided to assist in determining the risks associated with shipments of Li-ion batteries as standalone cargo and when installed within vehicles.

What we know

Cargo hazards and causes

There are four main hazards associated with Li-ion batteries:

- **Fire**: Li-ion batteries contain electrolyte, an ignitable liquid, and auto reignitions are common
- **Explosion**: this can result from the release of ignitable vapor/gases in a confined space
- **Thermal runaway**: a rapid self-heating fire that can cause an explosion
- **Toxic gases**: the first three hazards can produce irritating, corrosive or poisonous gases.

The most common causes of the above hazards are:

1. Substandard manufacturing of battery cells/devices
2. Over-charging of the battery cells
3. Over-temperature by short circuiting
4. Damaged battery cells or devices.

Loss prevention guidance

Guard against the four most common causes of loss with the following preventative steps:

1. **Choose a reputable manufacturer** – In this growing competitive market, manufacturers of Li-ion batteries can range from excellent to substandard. Manufacturing the batteries is a complex process and packaging specifications are very detailed. Both are key to keeping Li-ion batteries safe during transportation. Industry standards and testing requirements have been developing over the past few years to provide guidance on how to test and validate the batteries, as well as how to provide proof these requirements are being met.

   a. **Guidance**: The UN Manual of Tests and Criteria sets out a series of design tests (see subsection 38.3) that must be completed by manufacturers of Li-ion batteries.

   b. **Proof**: Test Summaries (TS) are now required and must be made available by manufacturers. The TS should attest to the fact that the standards specified in the UN Manual of Tests and Criteria (part III, subsection 38.3, paragraph 38.3.5) have been met. Since January 1, 2020, these TS have been a requirement for international air cargo, as instructed by the International Civil Aviation Organization (ICAO), and vessel shipments, according to the International Maritime Dangerous Goods (IMDG) Code. For US domestic shipments, a TS report has only been required since January 1, 2022, and is to be made available to downstream shippers and consumers in the distribution chain. See Lithium Battery Test Summaries (TS) (dot.gov).

   Recommendation
   Request a TS report from the manufacturer.

2. **Check the battery's state of charge** – The ideal state of charge (SOC) for transporting purposes is between 30% and 50% depending on your battery manufacturer's recommendation, the battery size/type, the time anticipated in storage before being used, and its ultimate usage.

   Recommendation
   Request information from your supplier/manufacturer on the battery's SOC.

3. **Beware of short circuits** – Short circuiting is a problem if the protection provided by the manufacturer and shipper between the terminals or cells (cathode/anode) is compromised. Once a short circuit develops, if the heat being generated by the short circuit is unable to dissipate (as in a closed package, or an intermodal freight container) the internal temperature will rise quickly to a point of ignition, which may be quickly followed by a thermal runaway event, or an explosion caused by the rapidly expanding dangerous gases being given off.

   Recommendation
   Request a TS report from your supplier/manufacturer as proof that compliance has been met.

4. **Follow packing instructions and train your staff** – Cargo damage is one of the most common claims handled by the AGCS marine team. Battery shipments, whether large standalone storage units or palletized container loads that have been packaged according to Dangerous Goods Regulations, have to withstand the rigors of transit. This includes numerous touch points and handling of cargo, which can lead to damaged cells, batteries, and packaging. Cartons can get dropped, hit by forklifts, or crushed by superimposed cargoes, any of which can compromise the battery/cell itself and introduce one of the previously listed hazards.

Recommendation

Ensure the manufacturer provides handling instructions that require all transporters to conduct a visual inspection for damages of cargo packagings, at all handling opportunities. Train employees who are responsible for the physical stuffing of intermodal freight containers and provide instructions that state transporting any damaged packages is strictly forbidden, and that any damages should immediately be reported and/or escalated to a supervisor until resolved. Under no circumstances should any damaged package be moved or transported onwards for it to become someone else's problem.

What we know

Electric vehicles on car carriers and within freight containers

The maritime industry continues to be concerned by fires on board vessels that are associated with Li-ion batteries in electric vehicles (EVs). Studies show that some of the common causes of fires in EVs with Li-ion batteries may be related to internal manufacturing defects, physical damage or substandard quality, internal electrical failure (over-charge, over-discharge, short circuit), and thermal runaway issues. Li-ion batteries are a relatively new technology and there is not yet a consensus on the best design and construction methods for their use in EVs.

These fires have caused considerable physical damage, financial losses, environmental pollution, and loss of life in a manner never seen before. Fires in EVs with Li-ion batteries burn more ferociously, are very difficult to extinguish, and are capable of spontaneously reigniting hours or even days after they have been put out. Most ships lack the suitable fire protection, firefighting capabilities, and detection systems to tackle fires at sea, which has been made more difficult by the dramatic increase in ship size. Even a full-time, professional firefighting team would struggle to control these complex fires quickly enough.

Evidence shows that time is of the essence when it comes to successfully extinguishing fires of this type: early detection and a quick response by suppressing it with copious amounts of water over a long period of time.

One potential idea being explored by some car carrier operators, as part of fire-preventative measures, is the use of fire-proof blankets manufactured specifically for EVs.

Loss prevention guidance

These fire risks will likely ease over time as manufacturers, carriers, and regulators address the current challenges. Meanwhile, all eyes are on preemptive measures from all stakeholders in their operating procedures to help mitigate this peril.

Regardless of the cause, the fire conditions encountered on board a vessel at sea can be extreme.

- Use the optimal SOC for transportation, which ranges from 30% to 50%, depending on the manufacturer's recommendations and the length of the voyage
- Review the safety data sheet or data information card describing a process, and preventive actions to be taken in case of an accident
- All EVs should display clear and precise identification on the windshield detailing the battery type (e.g. BEV, PHEV, HEV)
- EVs with low ground clearance should be clearly labeled as this can present loading and discharging challenges arising from the vessel's ramps, inner slopes, or deck appendages
- All EVs with a Li-ion battery must have successfully passed pressure, temperature, crush, and impact tests as described in the UN Manual of Tests of Criteria – subsection 38.3 for transport of Li-ion batteries
- All EVs must be fully functional, self-propelled, safe to drive and contain an undamaged battery system
- There should be no charging of EVs during the passage
- All EVs must be properly secured to prevent any shifting during transport
- Seafarers should have enhanced training and awareness protocols on Li-ion firefighting techniques
- Early detection systems are critical, including watch-keeping and fire rounds, thermal scanners, gas detectors, heat and smoke detectors, and CCTV cameras.

What we know

Li-ion batteries in storage

Generally very stable, Li-ion batteries can store up to four times more energy per unit of mass than other batteries. As Li-ion battery technology improves, battery energy density has continued to increase, which heightens the risk and severity of battery failures. Large-format Li-ion batteries, such as those used in EVs, tend to ignite more quickly in a warehouse fire and present a higher hazard than small-format batteries used in smartphones, laptops, and power tools. As previously mentioned, the main hazards associated with Li-ion batteries are fire, explosion, and thermal runaway. Since the batteries contain an ignitable (flammable) electrolyte, the fire hazard is very high. If the ignitable vapor is released in a confined space or in an area with limited ventilation, there is an explosion hazard. Loss history involving Li-ion batteries shows that large property losses can occur, and the presence of plastics and other flammable liquids increases this hazard.

When comparing heat release during thermal failures, Li-ion batteries have twice as much energy as internal combustion engines powered by gasoline fuels per mile range. Thermal runaway can be caused by manufacturing defects or improper handling, such as mechanical damage, overheating or overcharging. Thermal runaway is a rapid exothermic reaction whereby heat (up to approx. 1472°F (800°C) is generated faster than it can be dissipated. This results in the electrolyte evaporating, over-pressuring the cell, and finally gassing off through safety vents. If the temperature inside the cell is high enough, the electrolyte can ignite into a severe torch-like flame. Because of this, thermal runaway can easily cascade or spread from one cell to adjacent cells.

Li-ion batteries should not be stored for long periods, either uncharged or fully charged. The best storage method, as determined by extensive experimentation, is to store them at a low temperature, not below 32°F (0°C) at 30% to 50% capacity. Temperature is vital for understanding how to store lithium batteries. The recommended storage temperature for most is 59°F (15°C) — but that's not the case across the board. Always consult instructions on proper storage for each specific battery type.

The storage of Li-ion batteries poses a dilemma for many companies because there is no unified legislation. To avoid and limit damage, safety measures can be taken depending on the individual case. Generally, the potential risk associated with Li-ion increases as the amount of energy stored by the batteries increases, and as the number stored increases.

Fire testing for Li-ion batteries has been limited, mostly due to the continuously evolving battery chemistries and the very high cost for full-scale testing. Unfortunately, the fire protection and property insurance industries have not been able to keep up with the hazards associated with Li-ion batteries. FM Global and testing institute VdS have performed limited fire testing for Li-ion battery storage. In the US, the National Fire Protection Association (NFPA) has no guidance, except for the recently developed NFPA 855, Standard for the Installation of [Stationary Energy Storage Systems.]

There is no unified legislation for storage of Li-ion batteries.

Currently, there are limited fire protection options for Li-ion batteries. Contrary to the belief that Li-ion batteries contain lithium metal, which is highly combustible and reactive with water, this is not true. Water is the best medium to cool and control Li-ion battery fires and has been proven to be the best agent to fight a fire involving Li-ion batteries. Other extinguishing agents, such as aerosols or gaseous extinguishing systems, may temporarily extinguish the fire, but they do not provide cooling like water. Insufficient cooling allows a hot and deep-seated core to remain as the chemical reaction continues, even after the fire appears extinguished. The heat generated by the ongoing chemical reaction will rapidly spread back through the battery and can reignite any remaining active sections.

Loss prevention guidance

Steps to raise awareness of Li-ion battery risks in a warehousing operation should include:

- Observe manufacturer's instructions (such as technical product datasheets)
- Protect battery poles from short circuit
- Protect from mechanical deformation
- Do not expose to direct and long-term high temperatures or heat sources (including direct sunlight)
- Ensure structural or spatial separation (min. 10 ft or 3 m) from other combustible materials if there is no automatic extinguishing equipment present
- Floor stacking of Li-ion batteries should be strictly controlled in designated areas with limited stack heights, footprints and separation distances
- Rack storage of Li-ion batteries should not be permitted unless the building and the racks are fully protected with a sprinkler system, with solid metal horizontal and vertical barriers between each storage bay
- Ensure damaged batteries are removed immediately from storage and production areas (store at a safe distance, or in an area that has been rated for fire resistance, until they are disposed of).

Warehouse protection schemes should be based on the following guidance:

- Robust water-based fire protection
- Segregation
- Reduce the footprint/quantity stored
- Manual firefighting strategy (including a cooling strategy or removal)
- On-site structural fire brigade with proper equipment and training is highly recommended
- An electronic battery management system (BMS)
- Prompt removal of damaged or defective Li-ion batteries
- Limited exposure to high temperatures
- Follow manufacturer's guidance for use and storage
- Consideration of installation of a gas detection method targeting CO2 concentration
- Shock/impact and vibration sensors on large-format batteries.

Li-ion batteries should be protected as per recognized industry standards such as [FMDS 8-1, Commodity Classification.](FMDS 8-1, Commodity Classification) Refer to Section 2.4.2 in FMDS 8-1 when:

- State of charge ≤ 60%
- Electrolyte weight ≤ 20%
- Capacity ≤ 41Ah (Amp hours)
- Cartoned, with cellulosic and/or unexpanded plastic internal packaging only
- Limited to three tiers high, maximum 15 ft (4.5 m) in racks or palletized
- Ceiling height limited to 40 ft (12.2 m)
- No storage above the batteries
- Protect using 12 K22.4 or K25.2 (K320 or K360) sprinklers operating at 35 psi (2.4 bar).

Where any one of the variables above are not met, FMDS recommends protecting the rack in accordance with Scheme A in FMDS 7-29. FMDS 7-29, Scheme A is very similar to Scheme 8-9A in FMDS 8-9 and requires in-racks and barriers. These schemes are used to protect commodities that result in very high challenge fires. Refer to Scheme A in FMDS 7-29, Ignitable Liquid Storage in Portable Containers, when:

- State of charge > 60%
- Electrolyte weight > 20%
- Capacity > 41Ah
- Expanded plastic packaging materials in carton
- Exceeds three tiers high, 15 ft (4.5 m) in racks or palletized
- Ceiling height > 40 ft (12.2 m).

For consumer products containing Li-ion batteries within the packaging, protect the rack storage based on the classification of the consumer product, but no less than a cartoned, unexpanded plastic. Confirm the batteries meet the following:

- State of charge ≤ 60%
- Electrolyte weight ≤ 20%
- Capacity ≤ 41Ah.

If batteries do not meet the above, protect as per FMDS 7-29, Scheme A.

Safe warehouse storage is key. Photo: AGCS

Emergency planning

The presence of Li-ion batteries and the subsequent fire risk is something that should be addressed as part of fire protection and emergency response arrangements. Pre-emergency planning with the local fire department and on-site fire brigade, if available, is extremely important due to the fact that this technology may be new to the fire department and there are specific procedures that must be followed to eliminate the hazard.

A pre-defined Emergency Response Plan should be in place to tackle damaged or overheating Li-ion batteries. Key employees should be trained in this before batteries are permitted on site. In addition, a pre-defined Hazard Control Plan to manage receiving, storage, dispatch and supervision of packaged Li-ion batteries should be developed.

Extra vigilance is required for product returns as devices sent back from customers might arrive damaged and are often unpackaged so can suffer more physical impact in transit.

Infrared thermography inspections using a hand-held IR gun should be made on each Li-ion battery package on arrival and before dispatch. Visual damage inspections and further inspections with an IR gun should be conducted to cover all Li-ion battery stacks every three to four hours. Any deviation from the normally expected general temperature by 37.4°F (3°C) or more on any individual Li-ion battery package should be reported to management immediately so the pre-defined emergency response plan can be initiated.

As a precautionary measure, a steel bin partially filled with water should be kept outdoors at least 10 ft (3 m) clear of the building, ready for any packaged Li-ion batteries with elevated temperatures to be placed into by forklift truck. Other fire containment materials such as vermiculite or sand can be used to smother the affected battery. These measures might not stop the chemical fire continuing, even under water, but they will assist with fire containment. Packages placed in such a bin should be left untouched by employees of the warehousing company. The supplier of the batteries should be called in to deal with the battery hazard on site and remove it from the site safely for further assessment.

The chemistry in different types of Li-ion battery behaves differently in fire and this may have to be accounted for in the future, as battery technology is changing quickly. Future developments could include a solid electrolyte instead of a liquid electrolyte. With a solid electrolyte, mass and volume energy density will be much higher than that of current Li-ion batteries, with increased storage capacity and a higher temperature range. In addition, the fire hazard will be greatly reduced.

Summary

With quickly evolving technology and a lack of consistent regulation, evaluation of the risks of Li-ion battery usage will need to develop over time. In this bulletin we have not addressed the transporting of used (privately owned) vehicles with Li-ion batteries, for example, or the transporting of used/expired or waste batteries. As we experience the life cycle of this battery type, both will need to be further addressed.

If the maritime industry is to improve its incident record related to the transport of these battery types, all parties involved in the supply chain must understand the hazards involved, the most common causes and problems associated with transporting in commerce.

All parties in the supply chain must understand the hazards.

The regulations, both US domestic (49CFR) as well as the international regulations (IMDG, ICAO), are specific in addressing Li-ion batteries to prevent most incidents but can only be effective if they are communicated and enforced. Only through a concerted effort by stakeholders in the supply chain can we hope to reduce the rate of incidents.

Further information and references

Definitions

Battery electric vehicle (BEV): BEVs are powered entirely by electricity, meaning a BEV has no internal combustion engine (ICE), no fuel tank, and no exhaust pipe. Instead, it has one or more electric motors powered by a larger onboard battery. Users charge the battery via an external outlet.

Battery state of charge (SOC): The battery's state of charge (SOC) refers to how much charge, or energy, is left in the battery. SOC is measured in percent, and it is the same measurement as a gas tank fuel gauge in a fuel-powered vehicle.

Hybrid electric vehicle (HEV): HEVs are the most common type of hybrid, and they have been around the longest, too. HEVs have two power drives: a fuel-based engine and an electric motor with a larger battery.

Plug-in hybrid electric vehicle (PHEV): PHEVs split the difference between BEVs and HEVs. Like BEVs, PHEVs have an electric motor that is recharged via an external plug. And like HEVs, they also have a fuel-based ICE.

Thermal runaway is one of the primary risks related to lithium-ion batteries. It is a phenomenon in which the lithium-ion cell enters an uncontrollable, self-heating state. Thermal runaway can result in the ejection of gas, shrapnel, and/or particulates (violent cell venting) at extremely high temperatures.

Reference Sources

- Lithium Battery Guide for Shippers,
  Lithium Battery Test Summaries (TS) (dot.gov)
  US Department of Transportation Pipeline and Hazardous Materials Safety Administration, September 2021
- USCGSA_0122.pdf
  US Coast Guard, Marine Safety Alert, Lithium Battery Fire, March 2022

Lithium-ion batteries risk bulletin

This is the second marine risk bulletin AGCS has published on the topic of lithium-ion batteries. The first, published in 2017, can be downloaded here

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