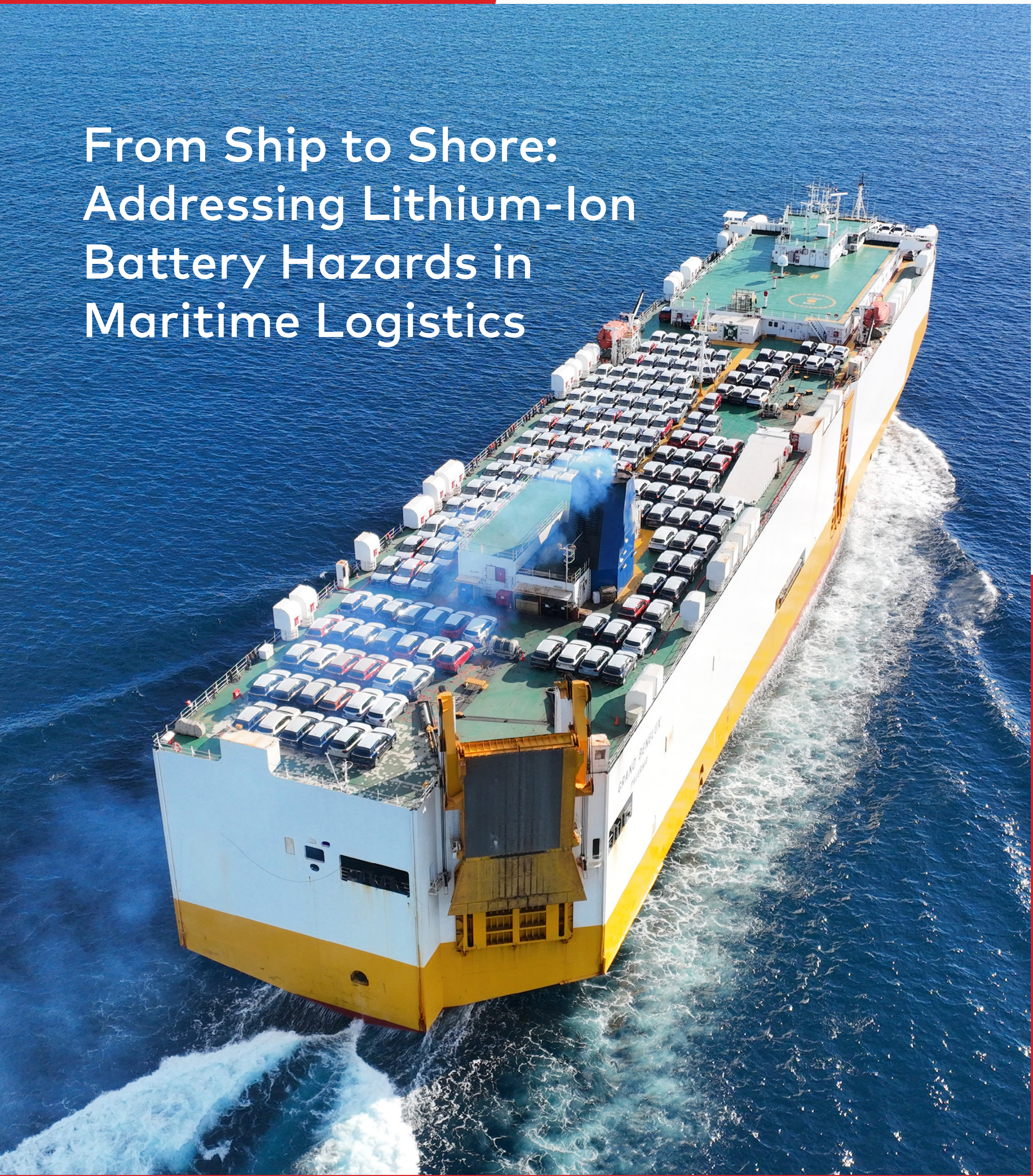
From Ship to Shore: Addressing Lithium-Ion Battery Hazards in Maritime Logistics



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1 Introduction

Catastrophic failures of lithium-ion (Li-ion) batteries will likely increase in frequency as Li-ion technology continues to expand. Lithium-ion batteries are often the main source of energy storage in electric and hybrid powered vehicles. Several recent incidents in the maritime industry have highlighted the need for interim guidance and safety risk assessments for all lifecycle phases of Li-ion batteries being stored, or used, during port operations.

Some noteworthy examples are listed below:

- In June 2025, the Morning Midas caught fire. The 600-foot ship was carrying 70 electric vehicles (EVs), 681 hybrids, and more than 2,000 internal combustion engine vehicles. The fire burned for multiple weeks before the ship eventually sank in the Pacific Ocean. The incident resulted in a complete loss of the ship and all cargo onboard.
- In July 2023, the Fremantle Highway, a 650-foot ship carrying 3,783 cars including approximately 500 electric vehicles was traveling in the North Sea. A fire broke out which resulted in crew members jumping overboard. One crew member died as a result of injuries sustained from the jump, while 16 others received non-life-threatening injuries.
- In February 2022, the Felicity Ace, was a 656 ft shipping vessel, carrying 3,965 vehicles including many EVs. It caught fire, requiring the entire crew to evacuate. The ship burned for more than two weeks before sinking along with all its contents.
- The United States Coast Guard issued Marine Safety Alert 14-25 on July 14, 2025, regarding Li-ion Battery System Installations. According to this release, an integrated Li-ion battery bank caught fire onboard an inspected passenger vessel when loosely crimped lugs overheated.

In response to the increase in Li-ion battery incidents, in July and August 2025, respectively, the shipping container companies Matson, and Alaska Marine Lines suspended shipment of EVs specifically citing fire concerns. They joined a growing number of shipping lines, including Havila Kystruten, which have recently banned the transport of EVs.

Legislation and published codes often lag behind innovation. Very few regulations or standardized guidance documents exist for the proper handling of Li-ion vehicles and consumer electronics. While Li-ion batteries are often manufactured to meet minimum safety standards, recurring hazards due to handling, transport and charging increase the likelihood of catastrophic failures. End-of-life hazards associated with Li-ion batteries are also increasing and require guidance and regulation. E-waste transport faces the same scrutiny as EV transport and many shipping providers are refusing to carry e-waste.

Conducting a thorough risk assessment and applying lessons learned from past failures can help reduce risks until the gap in oversight is resolved. For accuracy and proper allocation of resources to implement mitigation strategies, it is imperative that knowledgeable safety engineers lead the risk assessment process.

2 Background

2.1 Lithium-ion Battery Fundamentals

Lithium-ion batteries are similar to traditional alkaline batteries. Each battery is made up of an anode (-) and cathode (+), along with an electrolyte solution to move the lithium ions. The anode and cathode are separated to prevent the flow of ions within the battery. Individual battery cells can be combined to form a battery pack and increase the amount of energy stored.

Battery cells and battery packs generally contain one or more safety mechanisms to reduce the likelihood of catastrophic failure.

Safety mechanisms include the following:

- Venting on the cells to relieve pressure buildup
- Overcurrent protection to limit the amount of energy that can be readily absorbed or released in the event of a failure
- Fuses, or temperature monitoring devices to activate additional cooling (i.e., liquid cooling, forced air, etc.) if a battery begins to overheat

External hazards can lead to a phenomenon called "thermal runaway". Thermal runaway is a compounding condition in which heat generated by the battery increases the battery temperature. The increased temperature increases the rate of heat release which, in turn, further increases the battery temperature. Batteries in thermal runaway can start fires and generate explosive atmospheres if left unmitigated. The thermal runaway condition also makes these fires very difficult to suppress.

2.2 Lithium-ion Battery Hazards

Li-ion batteries can catastrophically fail at any point in their life cycle when exposed to hazardous conditions. These hazards, which may lead to failure, can be categorized three ways: (1) mechanical, (2) electrical, and (3) thermal.

1.

Mechanical damage is any physical damage to the battery. Incidents like crushing, bending, impacts and penetrations can cause the battery's internal components to short circuit. The internal damage to the cell results in the rapid discharge of stored energy, generating heat and sparks.

2.

Electrical damage results from overcharging, internal short circuits, or high current draw while discharging. These types of failures are often the result of abnormal operations of internal battery electronic components. These electronic components manage the operation of the battery, and the components vary depending upon application.

3.

Thermal damage results from the battery overheating. Simply, the batteries getting too hot can lead to thermal runaway and catastrophic failure. In these instances, heat buildup in battery cells cannot be dispersed faster than the heat is generated. This, in turn, forms a feedback loop generating more heat and leading to a runaway failure.

3 Regulations

Existing regulations and standards which govern the use and safety of Li-ion batteries are limited. Regulations do not yet extend to EVs and consumer electronics, however codes are being developed to bridge the gap.

3.1 Existing Regulations

UN DOT 38.3

The UN Manual of Tests and Criteria contains requirements and test methods for Li-ion batteries. The legislation includes requirements for Li-ion batteries to be transported safely.

They include the following eight tests:

1. Altitude simulation test
2. Thermal test
3. Vibration test
4. Shock test
5. External short circuit test
6. Impact crush test
7. Overcharge test (for rechargeable cells)
8. Forced discharge test

IMO International Maritime Dangerous Goods (IMDG) Code

The IMO IMDG Code calls for Li-ion batteries to meet the criteria outlined in UN 38.3. This includes the following:

- Transport of wastes and wastes which may contain Li-ion batteries
- Documents other requirements for the types of Li-ion batteries being shipped
- The condition of the batteries themselves
- How batteries are packaged (i.e., loose or electronic equipment)

For example, batteries to be treated as waste, or to be recycled must be labeled with the appropriate UN label with additional markings to designate the battery as end of life. These packing instructions are found in P908 and P909.

NFPA 505 - Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations

NFPA 505 applies to fork trucks, tractors, platform lift trucks, motorized hand trucks, and other specialized industrial trucks powered by electric motors or internal combustion engines.

Among other requirements, NFPA 505 specifically calls out that:

- Battery charging installations shall be located in areas designated for such purposes. The areas shall be kept free of extraneous combustible material.
- Facilities shall be provided for the following:
    1. Flushing spilled electrolyte
    2. Fire protection
    3. Protection of charging apparatus against damage by trucks
    4. Adequate ventilation for dispersal of fumes from gassing batteries

3.2 Proposed Regulations

A new standard is being developed by the National Fire Protection Association (NFPA) called the NFPA 800 Battery Safety Code. When/if published, this is intended to be a comprehensive code which will address all phases of the battery lifecycle, including the following:

1. Battery manufacturing and storage
2. Battery transportation
3. Manufacturing of products containing batteries
4. Battery installation/use/maintenance
5. Worker safety
6. Emergency incident response
7. Reuse/recycling/disposal

Currently, the NFPA has issued **NFPA 855 Standard for the Installation of Stationary Energy Storage Systems**. The scope of this document covers the design, construction, installation, commissioning, operation, maintenance and decommissioning of stationary energy storage systems (ESS). The standard defines ESS as "one or more devises, assembled together, capable of storing energy to supply electrical energy at a future time". This document provides guidance for handling these systems; however, the scope does not cover details specifically related to electric vehicles or maritime safety. It does not provide guidance on what minimum/maximum level of charge will be required for storage/shipment.

IMO Sub-Committee on Ship Systems and Equipment (SSE)

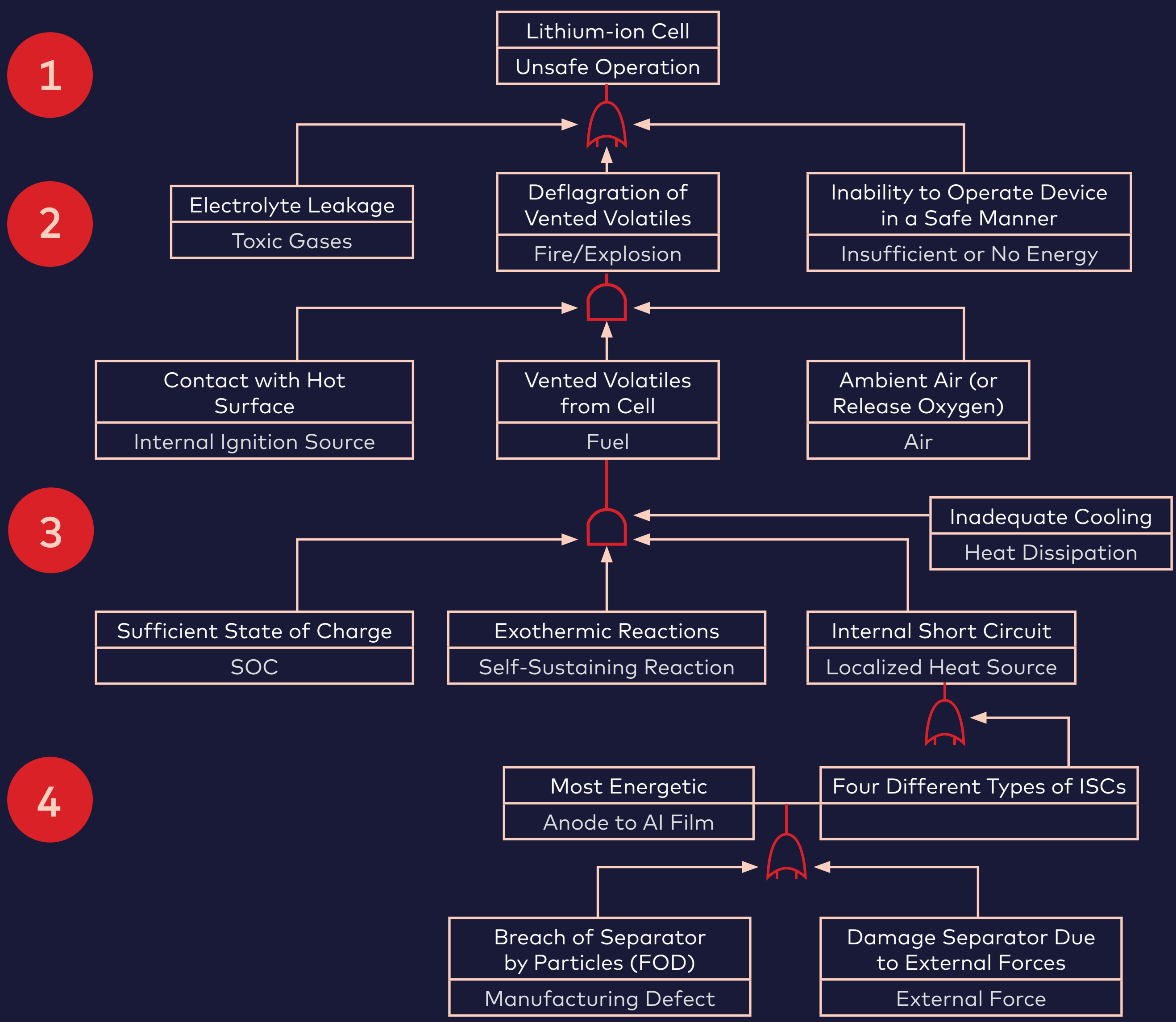
In February 2025, the IMO SSE included an agenda item "Evaluation of adequacy of fire protection, detection and extinction arrangements in vehicle, special category and ro[ll-on,] -ro[ll-off] spaces, in order to reduce the fire risk of ships carrying new energy vehicles". These additional regulations were proposed to ensure the International Code for Fire Safety Systems (FSS Code) specifically addressed reducing the risk, improving detection and controlling fires in cargo holds and on the cargo deck of shipping vessels.

3.3 Guidance and Recommended Practices

The following list includes published documents offering guidance and recommended practices. These are not required by code or regulation; however, they are recognized as strategies which can effectively mitigate risk when combined with general Fire Protection Engineering best practices.

UL 2580 – Batteries for Use in Electric Vehicles was published in 2020 and revised in 2022. It is an optional standard to be applied during the manufacturing process. Batteries held to this standard meet UL's requirements for use in specific applications. This standard outlines requirements for batteries in EVs with respect to typical failure modes identified by UL. They have published a fault tree analysis in the Sustainable Energy Journal (see Figure 1).

Figure 1: Fault Tree Analysis results conducted by UL.



UL 1642 - Lithium Batteries is a UL standard that covers requirements for individual rechargeable and nonrechargeable Li-ion batteries. The standard addresses various types of abuse and failure modes and the conditions that must be met for such batteries to be UL listed. It also indicates that appropriate safety measures have been implemented.

4 Managing Risk

Maritime and port facilities have an inherent level of risk during typical operations. Elimination of all risk is not possible given the hazards present when fueling, loading/unloading cargo, moving machinery and storing potentially hazardous materials. The goal of this analysis is not to eliminate all risks but to provide insight into what levels of risk are acceptable and practical. Quantifying risk allows for more effective use of resources allocated to reduce risks.

Quantitative risk management considers all phases of the Li-ion battery life cycle. Hazards for each Li-ion battery state are considered and ranked for evaluation.

For the maritime industry, this includes consideration of items such as:

- Use of Li-ion batteries as energy for propulsion
- Charging and discharging of related energy storage system(s)
- Shipping of Li-ion containing products (including e-waste)
- Electric vehicles
- Electric powered machinery and vehicles used to handle cargo at a port
    - » i.e., forklifts, container handlers, etc.

4.1 Risk assessment

Hazards should be identified through a rigorous, formal, systematic approach. This systematic approach evaluates consequences and provides necessary mitigation measures prior to implementation, which then facilitates the effective prioritization of resources. This approach is outlined by MIL-STD-882E and is shown in Figure 2. This process identifies both the consequences when new Li-ion hazards are introduced and the likelihood of them occurring. An initial risk level for the condition, prior to any mitigation, is documented. Mitigation measures are suggested, and the risk is reassessed after the implementation of the mitigation strategies (residual risk).

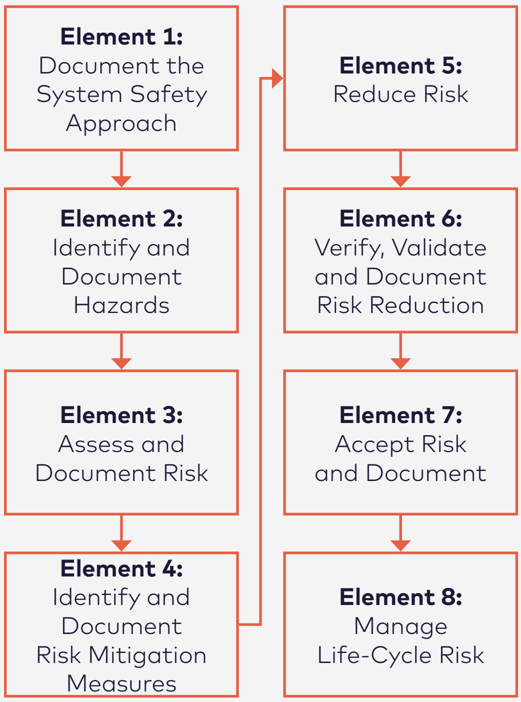


Figure 2: MIL-STD-882E Eight Elements of the system safety process

4.1.1 Mitigation measures

Mitigation measures for Li-ion related hazards are constantly evolving. Employing best practice measures is the common strategy while more prescriptive standards and regulations are still being developed. Lithium-ion hazards for maritime operations can be generally classified into four main categories that require mitigation:

1. Energy Storage Systems for Propulsion
2. Li-ion Containing Products (including e-waste)
3. Electric Vehicle Transport
4. Powered Industrial Equipment

Many of the mitigations for each of these categories are similar, however specific mitigation strategies are applied to individual categories and are listed below.

Lithium-ion energy storage systems for propulsion

Large power requirements for ship propulsion depend on large energy storage solutions. Mitigation measures for catastrophic failures of these bulk energy storage systems will require significant capital investment and specialized equipment. NFPA 855, while not directly applicable, requires limited volume individual energy storage system cabinets for indoor storage. This strategy is an effective way to limit the energy stored in a confined space in the maritime environment. Energy limitations would result in multiple smaller battery storage locations spread throughout the available area, as opposed to one large battery bank. This will allow for a reduced fire load and focused fire suppression efforts.

By comparison, other energy storage system standards call for the use of "safety gaps". Safety gaps indicate minimum spacing required between battery packs both to prevent the buildup of heat and to prevent thermal runaway escalation from a single battery pack failure.

Specialized Li-ion fire suppression equipment, such as foam or water mist, will control the rate of fire growth and off-gassing of hazardous vapors. These systems should be rigorously designed and tested to assure they are appropriate for this application and have sufficient capacity to mitigate a thermal runaway. They must also address the risks associated with conductive extinguishing media and high voltage hazards.

Lithium-ion containing products and e-waste

New Li-ion batteries have a relatively low frequency of failure, however the broad range of products available which contain Li-ion batteries make hazards associated with them more challenging to mitigate. The challenge is two-fold:

1. Appropriately identifying products which contain Li-ion batteries
2. Tracking them through the shipping/storage process

UN and DOT standards require labeling of Li-ion batteries and products containing batteries however these products may not always be labeled and easy to identify as containing Li-ion batteries. Some items such as cell phone batteries or electric scooters/bikes are easy to identify. Other products often contain secondary equipment which may use unlabeled Li-ion batteries. Examples include merchandise such as backpacks with integrated charging for lights and speakers. For end-of-life Li-ion batteries that become e-waste or are recycled, the same provisions apply. The waste batteries must add an indication that the batteries are waste or "with defects" which will indicate the increased likelihood of catastrophic failure.

Strategies to reduce the frequency of failures include auditing and tracking Li-ion containing products throughout the shipment process. Products which are mislabeled or have Li-ion battery details omitted from a bill of landing may result in products being mishandled.

Strategies to reduce the consequences of failure include limiting the allowable amount of charge in a device. There is conflicting data as to what level of charge presents the lowest risk, this needs to be resolved. Additionally, small scale mitigation measures, such as Li-ion specific fire extinguishers can be effective if applied early enough. Localized storage for Li-ion battery products allows for additional automatic fire suppression systems during shipment. Passive mitigation measures including compartmentalization, designating fire-resistant storage containers and their isolation (i.e., storing Li-ion batteries away from combustibles) are also effective.

Lithium-ion electric vehicle transport

When transporting Li-ion containing EVs follow the manufacturers recommended best practices. There is conflicting information regarding long-term storage of Li-ion EVs and their battery health and safety. For example, the Tesla Model Y owner's manual recommends leaving the vehicle plugged in, if it is not to be used for several weeks. The manual suggests that background systems may use up to 1% charge per day when not plugged in. Ford recommends maintaining their batteries at 50% charge for the duration of storage. BMW recommends parking the vehicle with a battery charge level between 30% and 50% and not to leave the charging cable connected. It is not possible to leave a charging cable connected during vehicle transport, however some level of charge is required. Guidance is needed to resolve these inconsistencies.

The International Air Transit Association (IATA) published a document titled, **Guidance Document for Lithium Batteries and Sodium ion Batteries**. Their recommendation is, "that lithium-ion cells and batteries (Section I & II) are offered for transport at a state of charge not exceeding 30% of their rated capacity or an indicated battery capacity not exceeding 25%." Reduced charge limits energy available to incite thermal runaway while also providing enough power for movement about a shipping facility. Unfortunately, this measure is not adopted by all shipping providers. Some providers require a reduced charge, while others require products to be charged 100%.

Fire suppression blankets have been proposed as a useful mitigation measure for EV fires. However, the NFPA recently released guidance that while the blanket was sufficient to extinguish a flaming EV fire, the heat of the battery still produced flammable vapors. These flammable vapors could then be trapped under the blanket resulting in an explosion hazard. It is necessary to evaluate all aspects of the mitigation strategy and emergency responses when dealing with large amounts of stored energy.

Storing EVs in separate locations, free from nearby combustibles and mission critical operations reduces the consequences of a catastrophic failure. Alternatively, having a safety "lay-down" area (an area remote from other objects), where a catastrophically failed EV can be moved will also reduce the risk of escalation.

Lithium-ion powered industrial equipment

Mitigation measures for Li-ion powered industrial equipment are similar to those suggested for EVs. Industrial equipment will require charging and discharging while in use and is more prone to damage than a stationary EV in storage.

Charging operations should also be placed away from other objects and mission critical equipment. Supplemental, dedicated fire suppression in charging areas will reduce the potential consequences of these types of failures.

On board fire suppression systems further reduce the consequences of a catastrophic failure. These systems must be appropriately designed for the application. Simply putting a generic ABC type hand extinguisher on a piece of industrial equipment is likely insufficient. For example, forklifts can be equipped with automatic suppression systems. Large equipment should require onboard fire detection and have active fire suppression equipment installed. Fire suppression media should be specifically designed to mitigate fires resulting from the failure of the energy storage system.

4.1.2 Emergency response and frontline worker training

Implementation of an emergency response plan is an effective, low-cost, way to reduce risk. The plan should consider the new hazards introduced and effective ways to mitigate consequences should an emergency event occur. This plan will include responding to large scale EV and industrial Li-ion equipment fires and to small-scale commodities fires. On-site education for first responders and mandatory on-board drills are strongly recommended. Practicing a simulated emergency response plan has been proven to reduce risk. Training frontline workers to be aware of the hazards associated with Li-ion batteries allows for early identification of developing hazards and quickly reduces the likelihood of escalation.

4.2 Safety certification

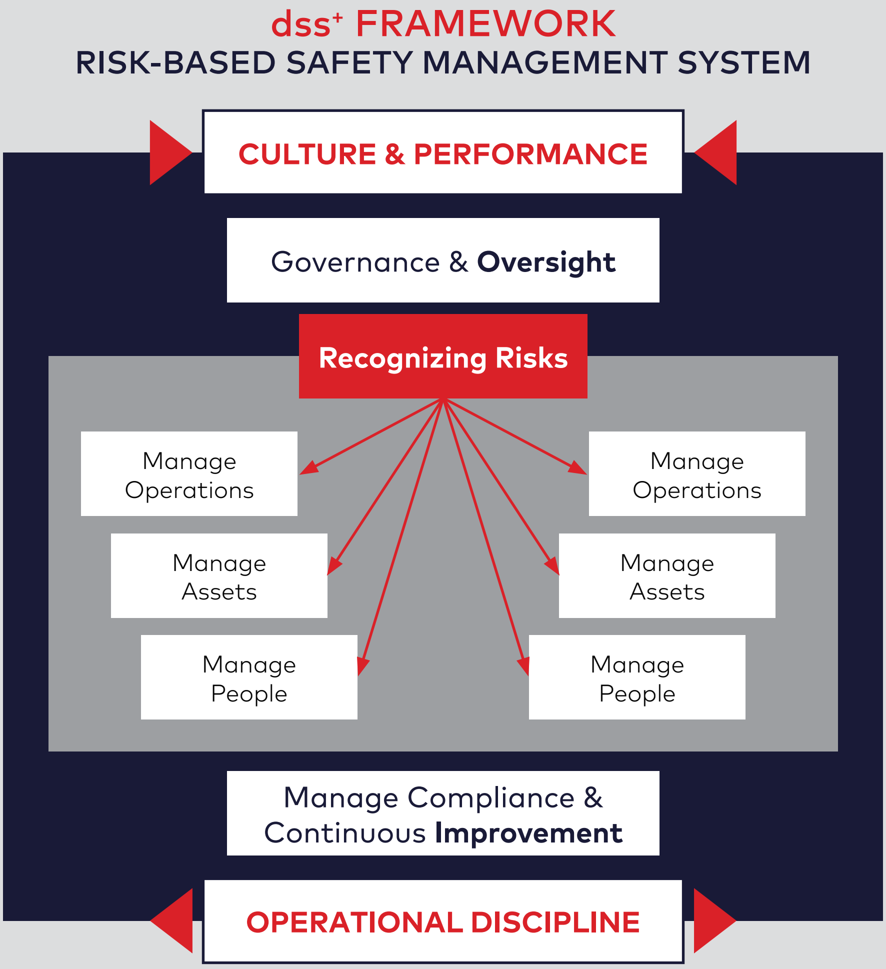
A safety certification (SSC) process is a useful tool for documenting changes and new components being introduced to a facility. This process is commonly used in the U.S. Public Transit industry to actively manage safety risks. It follows a process for identifying, evaluating and mitigating safety risks utilizing Safety Management System (SMS) principles. This process can be used to meet risk management requirements, to manage and mitigate safety risks and hazards to an acceptable level, as defined in a safety plan.

The safety certification process verifies the safety readiness of a project prior to implementation. It involves the verification and validation of mitigation measures for all aspects of the system life cycle, including requirements, design, construction, operations, maintenance, and disposal. The American Public Transportation Association warns that new or altered safety-critical systems have the potential to cause significant harm or damage if subsystems and components do not meet safety and security objectives and requirements. Agencies should adopt a formal top-down approach for managing and mitigating safety and security risk.

Ten steps listed below are recommended in the SSC process:

1. Identify certifiable elements
2. Develop safety and security design criteria
3. Develop and complete design criteria conformance checklist
4. Perform construction specification conformance
5. Identify additional safety and security test requirements
6. Perform testing and validation in support of the SSC program
7. Manage integrated tests for the SSC program
8. Manage "open items" in the SSC program
9. Verify operational readiness
10. Conduct final determination of project readiness and issue safety and security certification

5 Conclusion



Culture & Leadership	Risk Governance & Continuous Improvement	Technical Processes & Capabilities
Value system in the organization and society underpinning prevailing mindsets & behaviors i.e. how organizations and individuals think, act and operate.	Organizational structures, governance mechanisms, assurance and continuous improvement processes that drive and sustain the effective adoption of technical processes to manage risk, including incentives, KPI, etc.	Technical processes (e.g. fire risk profiling, standards, safety & operating procedures, integrity & reliability of critical equipment, etc.) and related capabilities necessary to assess and manage the risk, including tech./digital solutions.

The number of catastrophic failures of lithium-ion (Li-ion) batteries is expected to increase as Li-ion technology continues to expand and global demand for electrified systems grows. Current prescriptive safety requirements for Li-ion batteries in maritime and port operations are lacking or do not exist. Conducting systematic, facility-wide, risk assessment and applying lessons learned from past failures will help reduce risks until the gap in oversight is resolved.

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