Marine Loss Control

Safe Ocean Transportation of New Electric Vehicles

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Introduction

Global sales of electric vehicles (EVs) have been steadily increasing, a trend which is expected to continue for the foreseeable future. This has resulted in a growing number of EVs being shipped aboard roll-on/roll-off (RoRo) vessels, which handle the overwhelming majority of vehicle shipments.

The growing volume of EVs being shipped and the challenges of fighting an EV-involved fire at sea have raised industry concerns, with EVs being linked to several recent high-profile fires aboard RoRos. While the circumstances of these losses vary, and the potential involvement of EVs and the Lithium-ion (Li-ion) battery packs is not established, it is clear that Li-ion battery-powered EVs present unique risks that were not commonly encountered aboard vessels until recently. This document briefly reviews how Li-ion batteries function, their primary failure mode, and current risk mitigation best practices for shipment of EVs aboard RoRos.

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What are Lithium-Ion Batteries?

Li-ion batteries are manufactured in a wide variety of configurations and chemistries. However, at their most basic, each battery is made up of cells consisting of a cathode and an anode separated by a membrane. Between these is a liquid electrolyte solution containing a small quantity of lithium. The cells are assembled into modules, which are combined with other modules to form a battery pack. The electricity contained by the battery is generated within the cells as lithium ions move from the anode to the cathode; when charging this process is reversed.

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What is Thermal Runaway?

A significant advantage of Li-ion batteries over previous technologies is the higher density of energy within the battery. While this greater energy density provides an increased capacity and longer run time, there is a potential disadvantage. If one of the cells is damaged it can result in thermal runaway, a self-sustaining exothermic chemical reaction.

The heat generated by thermal runaway increases the rate of reaction, which results in additional heat generation. This further increases the rate of reaction as the self-sustaining chemical reaction begins to run away. The intensity of thermal runaway can vary, but is largely dependent on the battery's state of charge, with higher charges resulting in more intense reactions and lower charges less intense reactions.

In addition to the large amounts of heat generated, toxic and flammable gasses are also created. As flammable gasses are released, they can result in jets of flame being emitted from the battery. If the flammable gasses are not ignited and burned off, they can accumulate, creating a potentially explosive atmosphere. Any toxic gasses released can also accumulate and create a potentially toxic atmosphere.

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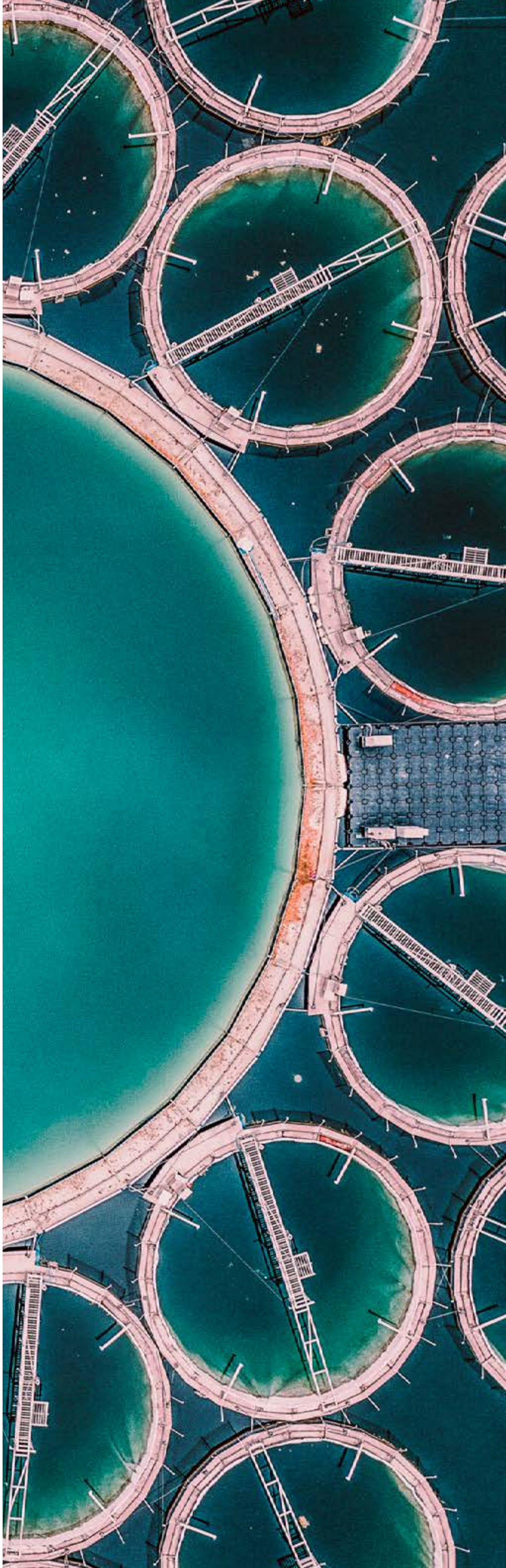
What Causes Thermal Runaway?

Thermal runaway is primarily caused by three factors:

Mechanical abuse — Physical damage to the battery itself such as an impact, puncture or denting.

Electrical abuse — Damage to the battery caused by overcharging, over-discharge, excessive current, or other factors which results in the decomposition of the electrolyte solution within the battery. Electrical abuse can also be the result of a malfunction or defect within a charger, the battery itself or battery management system.

Thermal abuse — Overheating of the battery either internally or externally, i.e., a fire in close proximity. Overheating can also result from electrical abuse or if a battery is unable to adequately dissipate heat.



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How Are Fires Involving Li-Ion Batteries in Thermal Runaway Fought?

Fires involving a Li-ion battery in thermal runaway are difficult to extinguish and are prone to reflash, which can occur hours or even days after extinguishment, especially the larger batteries used in EVs.

The most effective method for fighting these fires requires the application of water directly to the battery. This provides cooling which will slow and then stop the thermal runaway. However, applying water directly to an EV battery is difficult as they are mounted underneath the vehicle, which significantly complicates access.

While any water applied to an EV, but not directly to the battery, may help contain the fire and limit damage to the surroundings, it will not stop thermal runaway. Additionally, the comparative quantity of water required to stop an EV battery in thermal runaway is much greater than that needed to extinguish an internal combustion engine (ICE) vehicle fire, which can be a significantly complicating factor aboard a ship.

These difficulties have led to the development of some specialized firefighting equipment, two of the most common being:

- Lances[1] that can penetrate the vehicle to apply water to the battery exterior or pierce the battery and apply water directly to the interior of the battery.
- Fireproof blankets[2] that will contain the flames and help prevent the spread of the fire to the surroundings. However, these do not act to stop thermal runway; they can only help contain it.

While this specialized equipment for fighting thermal runaway may be effective for shoreside firefighters, there are significant challenges aboard a vessel which complicate their deployment and use.

> From Tesla's Model X Emergency Guide, "It can take between approximately 3,000 - 8,000 gallons of water, applied directly to the battery, to fully extinguish and cool down a battery fire..." This equates to between 12 and 33 tons of water, which could introduce stability issues, especially if firefighting efforts are prolonged.

[1]Two examples of firefighting lances; Rosenbauer Battery Extinguishing System Technology and Murer E-Extinguishing Lance
[2]Two examples of firefighting blankets; Bridgehill Fire Blankets and Fire Isolator

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Difficulties Fighting EV Fires Aboard Ship

The same challenges that professional shoreside firefighters face with EV fires are also present for any shipboard fire, but with the following additional challenges:

- Small crews of non-professional firefighters lack the experience, resources and personnel available to shoreside firefighters.
- Fixed CO_2 systems may be temporarily effective at extinguishing any flames present, but will not stop thermal runaway.
- The quantity of water required to extinguish an EV fire is significantly greater than a conventional ICE vehicle fire and may introduce stability issues.
- The ability to access any RoRo cargo deck during a fire is difficult. This is due to the tight stowage of the cargo, smoke-impaired visibility, cargo lashing trip hazards, and any generated heat, smoke or gasses being trapped within the space. These can combine to create a challenging and dangerous scenario for a direct attack on the fire.[3]
- Being able to directly apply water to the battery is unlikely due to the location of the battery within the EV and surrounding tightly stowed cargo. Even the deployment of specialized equipment, such as a lance or fireproof blanket, may not be feasible. The best the crew may be able to accomplish is to cool the surroundings to contain and try to prevent any spread of the fire.
- Any fire within the cargo space may also result in the failure of web lashings used to secure cargo. This would introduce the potential for the cargo to shift if the fire occurs in anything other than calm seas. This would likely exacerbate any stability issues, potentially damage critical systems and impact the ability of the crew to safely enter the cargo space to attack the fire.

[3] A challenge also faced by shoreside firefighters but exacerbated for shipboard firefighting due to the enclosed space, is caused by the toxic gasses released during thermal runaway. Current studies indicate that turnout gear with an SCBA provides adequate protection from the toxic gasses. However, the firefighting gear would be considered HAZMAT at the conclusion of firefighting and need to be properly disposed of.

Data on EV Fires on RoRos

To date we are only aware of one fire aboard a RoRo (specifically a RoPax[4]) that was confirmed to have originated within an EV. In 2010 an ICE vehicle that had been converted to an EV by the owner caught fire aboard the Pearl of Scandinavia. Per investigators, the vehicle's owner had plugged the EV into the ship's power without the crew's knowledge. It then suffered an unknown issue causing it to enter thermal runaway, although the crew was able to control the fire and the vessel was able to safely reach port.

Aside from this one instance, we are not aware of any other shipboard fires that have been confirmed to have originated from an EV. However, there have been multiple instances where used ICE vehicles are known or suspected of being the source of ignition of a fire aboard a RoRo. This is best explained by the below excerpt from the NTSB[5] report for the fire aboard the Hoegh Xiamen in Jacksonville, Florida in 2020.

> "
>
> Factory-new, clean, unworn, and undamaged parts and electrical components are much less likely to produce electrical faults. However, it is not uncommon for used vehicles to have problems, including deterioration of internal electrical connections (which may result in electrical faults) while awaiting shipment in a port area (The North of England P&I Association 2017). The circumstances of this accident and others suggest that used vehicles, particularly those that are older with unknown maintenance history and/or crash-damaged, require extra protections to mitigate the risk of vehicle fires on board RoRo vehicle carrier vessels.

While EVs may not have been the source of ignition in recent high-profile RoRo fires, it is important to recognize that any fire spreading to an EV can cause the battery to enter thermal runaway, which would make the fire significantly more challenging to contain and extinguish.

For this reason, it is of particular importance that any used vehicles, ICE and/or EVs are inspected to ensure they meet regulatory requirements, are in safe condition, and that the inspections are subject to oversight to ensure they are being properly completed. This is especially true if used vehicles are being shipped jointly with new EVs.[6]

[4] RoPax — A Roll on Roll off vessel with passenger carrying capacity
[5] NTSB. Fire aboard Roll-on/Roll-off Vehicle Carrier Höegh Xiamen. Washington, DC: NTSB, 2021
[6] Ocean transportation of ICE vehicles deserves separate and more complete commentary which is beyond the scope of this document

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Regulatory Perspective

The seaborne shipment of new and used vehicles, including EVs, is subject to a variety of regulations that are not within the scope or intent of this review.[7] While these shipments are considered to be dangerous goods (DG), vehicle shipments aboard RoRos are exempted from the majority of the regulations, as the cargo spaces are specifically designed for vehicle carriage.

Of the exemptions afforded to these shipments, the most notable is that EVs are not required to be declared as DG when being booked. This hinders the ability to plan the stow in a manner that minimizes the potential of a fire spreading to or from an EV and in the event of a fire, this information would be critical to the crew's response.

There is concern that regulations have not kept pace with the increasing volume of EV shipments and the exposures they introduce. Despite the apparent slow pace of regulatory update, multiple studies and research have been commissioned to develop best practice guidance and to support development of potential future regulatory proposals.

Some of the more commonly cited best practices based on this research are provided in the following section. However, with new regulations not appearing imminent and the volume of EV shipments increasing, this creates the present need for a collaborative effort from all stakeholders to develop industry-accepted best practices to prevent, prepare for and effectively respond to an EV-involved fire.

[7] Shipments via vessels are regulated by the International Maritime Dangerous Goods Code (IMDG). Domestic U.S. shipments (Jones Act) are regulated within 49 CFR.

Best Practice Guidance for Safe Ocean Transportation of New EVs

While the pace of regulatory change is likely to be slow, best practices are being developed and implemented. The following are drawn from a variety of sources[8] and provide a summary of current best practice "do" and "do not" guidance regarding the prevention of, preparation for and response to an EV fire at sea.

Due to the difficulties in controlling and extinguishing thermal runaway, measures aimed at prevention of an EV fire should be the highest priority:

Battery Charge

- **Do** limit the state of charge for EVs being loaded to the vessel. The most commonly recommended range is 20 to 50 percent, but this varies depending on the source. Some EV manufacturers require that their vehicles be shipped with a fully charged battery due to concerns regarding the gradual loss of charge during transportation, but generally this is contrary to current best practices.
- **Do** ensure that any EVs equipped with a transportation mode, which reduces battery consumption during transportation have that transportation mode enabled.
- **Do not** charge EVs onboard vessels. EVs are more likely to enter thermal runaway while charging, because it introduces the potential for electrical damage to the battery and/or the charging system.
- **Do** have a plan for safely handling an EV with a dead battery at the port of discharge. A totally discharged battery at the conclusion of a voyage may indicate a damaged or defective battery. Towing the vehicle from the vessel and charging ashore may be the safest option.

Prior to Loading

- **Do** ensure that all vehicles are being inspected and conform to regulatory requirements prior to being loaded. EV inspections should include:
  - Battery state of charge
  - Any warning lights or alarms, especially concerning the vehicle's electrical system
  - Any indication of damage to the vehicle or battery
  - Any indications of leaking fluids
- **Do** require that all EVs be declared when being booked and provide such information to planners, crew and others

During Loading

- **Do** monitor the loading of EVs to ensure that the battery, normally beneath the vehicle, is not impacted and damaged. Particular care should be paid at ramp junctions and ground or deck plate height changes. Any batteries that have been impacted (especially if physical damage is observed) or are leaking fluid should be removed from the vessel.

[8] See Additional Resources

Stowage

- **Do** give consideration to EV stowage:
  - Label all EVs in a prominent and easy to identify manner.
  - Stowage locations of EVs should be documented and readily accessible to crew and emergency responders.
  - Segregate EVs from other cargoes such as ICE vehicles or other DG cargo. This may reduce the potential of a fire spreading to or from an EV to other cargo.
  - Determine stowage locations that may reduce the potential for damage to critical systems, lifesaving equipment and firefighting systems in the event of a fire. This may result in the identification of "no-stow" locations for EVs in addition to acceptable stowage locations.
  - Consider upgrading existing fire detection, CCTV or thermal imaging within cargo spaces. Locations that may be dedicated to EV stowage should be equipped with CCTV.

Crew Training

- **Do** review EV manufacturer-specific Emergency Response Guides and maintain copies on board that are easily accessible to crew and emergency responders.
- **Do** update any policies or procedures to include EVs. This could include vehicle inspections, stowage, securing, fire response and more. Crew should be trained on any updates.
- **Do** conduct training and regular drills concerning the risks associated with EV fires, causes of thermal runaway, any specialized equipment aboard that may be used, and effectiveness of the vessel's fixed firefighting system.

Monitoring During Voyage

- **Do** increase the frequency of rounds within spaces loaded with EVs, especially following loading as any vehicles loaded are likely to be temporarily hot.
- **Do** provide crew with thermal imaging equipment to potentially detect the early heat signature of thermal runaway.

Thermal Runaway and Fire Response

- **Do** have a contract with a marine firefighting subject matter expert who can provide advice specifically concerning thermal runaway and potentially offer assistance to the crew.
- **Do** anticipate diverting the vessel to a safe harbor where additional resources and equipment are available.
- **Do** consider the provision of specialized firefighting equipment such as fire blankets and lances.[9]
- **Do** consider supplying additional firefighting gear in excess of regulatory requirements.
- **Do** develop a clear strategy with respect to the deployment of fixed firefighting systems. CO_2 systems are ineffective in stopping thermal runaway; however, water-based systems can help contain the fire and provide some cooling.[10]
- **Do** be prepared for reflash. Extinguished EV fires can reflash even several days after extinguishment.
- **Do** anticipate significantly greater volumes of water to be used fighting an EV fire versus an ICE vehicle. This is likely to introduce stability issues more rapidly than, or in excess of, those anticipated for non-EV firefighting.

[9] Lances and fire blankets will require the crew to be in close proximity to the fire. Given the identified challenges accessing an EV fire within the cargo space during thermal runaway, the ability of the crew to deploy this equipment safely and effectively is likely low.

[10] Few internationally trading RoRos are known to be equipped with such water-based systems, such as water deluge, high pressure water mist and sprinklers. As noted, these systems are more effective at containing and providing cooling during thermal runaway than a CO_2 system. However, they may need to be operated for a long period of time, which could introduce stability issues.

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Conclusions

- Global demand for EVs is anticipated to continue to grow for the foreseeable future, which in turn will result in increasing volumes of these cargoes being handled aboard RoRos.
- New EVs do not appear to present a high risk of ignition during ocean transportation. To date there haven't been any confirmed cases of new EVs initiating a fire onboard a RoRo.
- Due to the potential for thermal runaway of the Li-ion battery, involvement of EVs in a fire would present significant challenges and risk to both crew and vessel.
- While the safety of Li-ion batteries and EVs is likely to improve as the technology advances, the potential for thermal runaway is unlikely to be eliminated altogether.
- While EVs powered by Li-ion batteries have progressed rapidly, the regulations concerning their shipment have not kept pace and any regulatory changes will likely be slow to be enacted.
- As such, vessel operators need to continue to proactively develop policies and procedures to prevent, prepare for and fight an EV-involved fire.
- All stakeholders in the broader EV supply chain should be engaged in supporting vessel operators in this process and in contributing to the establishment of industry-accepted best practices.
- Such best practices need to be based on shared global technology, safety and risk mitigation intelligence, as well as continually evolving research and development.
- Any new regulations need to be effective, realistic and technically feasible for all existing and future generations of RoRos.

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References and Additional Resources

Best Practices for the Transport of Electric Vehicles Onboard Vessels — ABS

Fires on Ro-Ro Decks — DNV GL

Technical Reference for Li-ion Battery Explosion Risk and Fire Suppression — DNV GL

Legislative Assessment for Safety Hazards of Fire And Innovations in Ro-Ro Ship Environment (LASHFIRE)

Methods and Equipment for Fire-Fighting with Alternative Fuel Vehicles in Ro-Ro Spaces — Research Institutes of Sweden (RISE)

BREND 2.0 — Research Institutes of Sweden (RISE)

Firefighting of Alternative Fuel Vehicles in RoRo Spaces — Research Institutes of Sweden (RISE)

Electric Vehicle Carriage — Fires, Safety and Legal Implications — Quadrant Chambers (Webinar)

FIRESAFE Studies and Reports — European Maritime Safety Agency

Guidance for the Safe Carriage of Alternative Fuel Vehicles (AFVs) in Ro-Ro Spaces of Cargo and Passenger Ships — European Maritime Safety Agency

Electric Vehicles Onboard Passenger Ro-Ro Ferries — UK Maritime and Coastguard Agency

Recognizing Fire Hazards & Proper Cargo Stowage on Ro-Ro Vessels — USCG

Lithium Battery Guide for Shippers — US DOT

Loss Prevention Insight: Electric Vehicle Fires an Overview for the Maritime Sector — Britannia P&I

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Lithium-ion Batteries: Fire Risks and Loss Prevention Measures in Shipping — Allianz

Marine Safety Investigation Report on the Auto Banner — Korean Maritime Safety Tribunal

Fire aboard Roll-on/Roll-off Vehicle Carrier Höegh Xiamen — NTSB

Fire aboard Vehicle Carrier Courage — NTSB

Fire on board Vehicle Carrier Honor — NTSB

Enhancing Safety for Emergency Responders at Electric Vehicle Traction Battery Fires — EV FireSafe

Electric Vehicles — NFPA

Emergency Response Guides — NFPA

The Science of Fire and Explosion Hazards from Lithium-ion Batteries — UL Fire Safety Research Institute

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