Risk mitigation for the safe ocean and short sea carriage of electric vehicles (EVs)

3 September 2025

In response to the call to decarbonize all modes of transport, the number of new energy vehicles has increased significantly. Preparing for and dealing with the specific characteristics of fires in battery electric vehicles must therefore be addressed and adequately trained for. This paper focusses on risks and risk mitigation options associated with the carriage of electric vehicles (EVs) on two different ship types: Pure Car and Truck Carriers (PCTCs) and RoRo/RoPax vessels. Hybrid cars and other alternative fuel vehicles are not considered since the largest share of new energy vehicles are currently EVs. A summary of key points can be found at the end of this paper.

1. Technical information on EVs

Battery technology

Battery electric vehicles are usually fitted with a lithium-ion traction battery which is encapsulated and shielded by the vehicle's body. The safety performance of different cathode types[1] varies since different chemical compositions are associated with different risks. Depending on the tests conducted, safety levels differ. Battery technologies are however evolving rapidly which may lead to the development of new cathode types.

The battery pack consists of various battery modules which in turn are comprised of several battery cells. The chemical process which produces electricity that can be used for propulsion of the EV takes place within the battery packs. The battery system is usually placed in the vehicle floor or undercarriage where it is protected from damage by an anti-crash frame.

Electric vehicles have safety systems such as in-built battery management systems (BMS) that will automatically shut down the power and isolate the battery pack in case of hazards. It monitors the battery by ensuring that the cell operates within its safe operating parameters such as:

- Voltage
- Temperature
- State of charge
- Cell's state of health
- Cell's state of safety

[1] The cathode is the electrode where electricity flows out. The anode is usually the positive side. A cathode is a negative side.

The BMS communicates with the car's general warning system in case an unsafe situation occurs.

Thermal runaway

Thermal runaway may occur if a cell is abused, e.g. by heat, mechanical damage or overcharge. Thermal runaway can also occur as a consequence of a cell or battery manufacturing error.

When thermal runaway occurs, the cell is undergoing an unstable chemical reaction that is difficult to bring under control. At some point, the separator structure collapses and the electrodes touch, causing an internal short circuit and masses of heat, bringing the cell to ever higher temperatures and generating toxic and flammable gases. Cell heating will continue until the rise in temperature exceeds the heat that can be dissipated to the cell's construction. This released heat will then increase and start to affect other nearby battery cells. When the generation of heat becomes self-sustaining - the heat releases energy and the energy in turn releases more heat - the overheating propagates from cell to cell and the battery is in thermal runaway. Once thermal runaway occurs, at present no fire suppression agent has been proven to completely stop the chemical chain reaction. While flames may be suppressed by an extinguishing medium, this may not be sufficient to interrupt thermal runaway.

The safety standards integrated into EV traction batteries, including solid casings and the BMS, make the likelihood of damage to an EV battery pack and thermal runaway extremely low. However, as there is a possibility for thermal runaway, the significance of the BMS as incorporated into EVs is particularly relevant. These safety systems are intended to prevent the battery cells from over and under-charging and thus prevent thermal runaway.

State of charge

State of charge (SoC) is an electrical cell's or battery's charge level compared to the total capacity of the cell or battery. Batteries at high SoCs have been shown to experience more violent reactions during thermal runaway. Testing has indicated that high SoC cells produce higher heat release rates, maximum temperatures, and concentrations of flammable and toxic gases during thermal runaway events. However, while the SoC does affect the growth and peak heat release, it does not affect the total heat release. At the same time, parameters such as heat release rate, maximum temperature and concentration of gases display different attributes depending on the SoC. Hence, risks can vary depending on the battery's charge level. This complexity must be accounted for when considering the impact of SoC on a battery's chemical reactions[2].

In view of the long transport stability of the cells on the one hand and the safety of thermal runaway on the other, the SoC for transport onboard car carriers should be kept as low as practically and technically possible. Currently, no international requirements for SoC in maritime transport have been agreed. A particularity of RoPax vessels is the growing interest among passengers in having the possibility to charge their EVs on board.

[2] Impact of different Li-ion cell test conditions on thermal runaway characteristics and gas release measurements, Ola Willstrand (2023)

Probability of fire in EVs

There is no experience yet with large numbers of older EVs and the share of EVs in the global vehicle fleet is still comparatively low. The volume of cars being shipped by maritime transport globally is around 20 million units per annum. EVs have been transported at a large scale since 2020 (figures 1a and 1b).

As statistics continue to be gathered, it is currently estimated that, in general, the frequency of EV fires compared to fires in conventional vehicles is lower when driven over the same distance[3]. At the same time, it is important to bear in mind that a fire may not be caused by an EV. If a fire spreads to an EV battery, the higher reignition risk and thermal runaway must be accounted for.

Fig. 1a: Global Seaborne Car Trade[4]

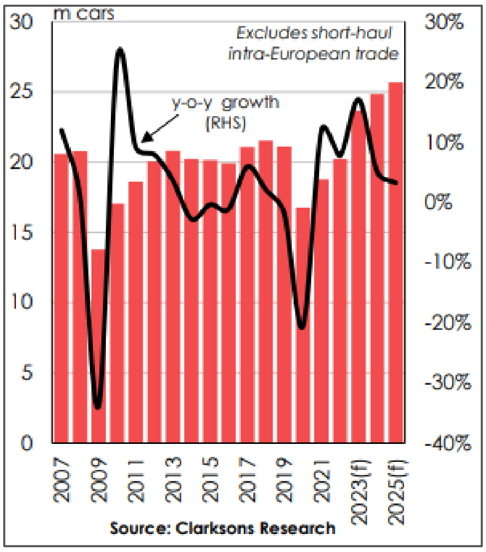
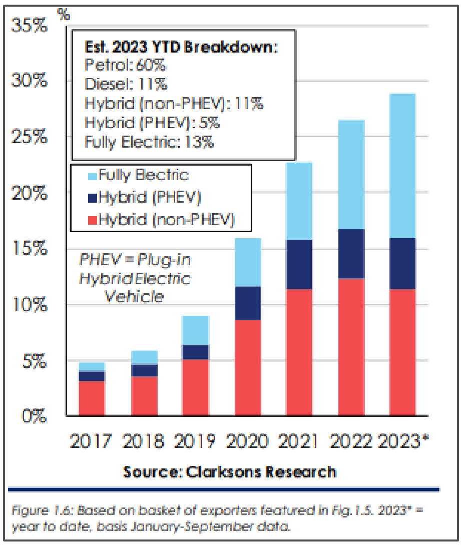


Fig. 1b: Seaborne Car Trade:[2]
Share of Alternative Fuel Vehicles



Characteristics of EV fires

Potential for thermal runaway: Unlike ICEV fires, EV fires can be self-sustaining when thermal runaway occurs. They do not require external oxygen to fuel the fire because the cathode material generates its own oxygen, enabling the fire to continue. Currently no extinguishing media can interrupt the chemical chain reaction occurring in a battery in thermal runaway.

Re-ignition: A particularity of EVs is the risk of re-ignition which is higher for a longer period than for ICEVs. Precautionary measures to avoid re-ignition of the traction battery must therefore be taken for an extended period after a fire has been extinguished.

[3] Electric Vehicle Fire Primer for Fleet Managers, U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, February 2024
[4] Clarksons Research

Toxic gases: Hydrofluoric and other highly poisonous gases are emitted from Lithium-Ion battery (LIB) fires. In this context it is important to consider that combustion gases from all types of vehicle fires are highly toxic and can cause incapacitation. Carbon monoxide and hydrogen cyanide are common causes of death when smoke has been inhaled in a fire accident. Staying out of the smoke plume and wearing adequate personal protective equipment when dealing with burning or burnt vehicles is crucially important for all fires regardless of the energy source of the vehicle.

Flammable and explosive gases: Flammable gases may be emitted during thermal runaway. If the gases do not ignite immediately upon release, they can form explosive atmospheres above the lower explosion limit when mixed with the ambient atmosphere. If these gases cannot burn and thus concentrate, this risk shifts from fire to a potential explosion. Such an explosion can occur if the concentration in a closed and unventilated space reaches values exceeding the explosion limits. The venting gases usually contain around 30% hydrogen by volume as well as a varying yet significant amount of carbon monoxide (sometimes up to 60% by volume), methane and other gases. Research into the nature and chemical composition of gases produced during an EV fire is ongoing and still in its early stages.

A comprehensive firefighting strategy must not only consider the firefighting itself but also the management of potentially explosive gases that may accumulate during such incidents. The aim must be to integrate both aspects, firefighting and ventilation operation, without limiting the effectiveness of the overall firefighting system. It should be recognised that where EVs are involved in fires, disparate gasses may accumulate. Considering the explanations in the previous paragraph, careful consideration should be given by shipowners to appropriate ventilation procedures for the extinguishing system installed and the vessel concerned.

Fire intensity: Heat release rates (HRR) from full-scale fire tests performed in recent years with both, ICEVs and EVs, have been reviewed. The data compiled showed a minor difference in the total energy released during the fire (total heat release) between ICEVs and EVs, i.e. EV fires are not more intense than ICEV fires, though the peak heat release may be higher for EVs depending on the battery type. In this context it is important to emphasize that the SoC affects the growth and peak heat release. The total heat release for both EVs and ICEVs are similar, however the fire dynamics and fighting methodologies differ. These are discussed further in section 3 (“Risks and mitigation methods”).

While there is general agreement that the total energy released by EVs and ICEVs during a fire is broadly comparable, opinions diverge when it comes to peak temperatures. Some studies, such as the EU LASH FIRE Project, do not identify significant differences in peak temperatures between EV and ICEV fires (fig. 2). However, other sources suggest that EV fires may release energy more rapidly, potentially reaching temperatures exceeding 1,000°C which is substantially higher than the typical peak of around 600°C observed in ICEV fires (fig. 3).

As can be seen, there are nuances in the details of fire intensity. For underwriters, the focus should be on the overall risk profile, particularly in scenarios where fires are not contained swiftly. Regardless of whether the source is an EV or ICEV, an uncontrolled fire at sea can lead to severe consequences.

Fig. 2: Heat release rate for three vehicles[5]

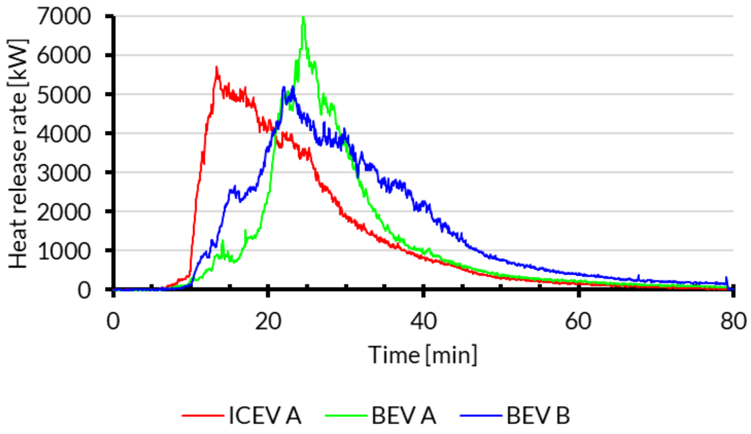
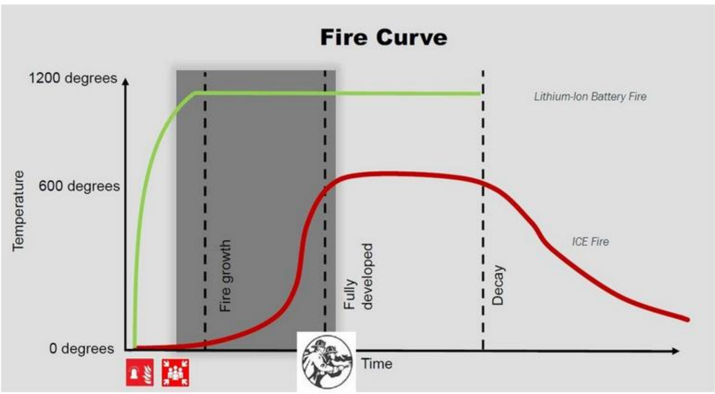


Fig. 3: Time taken to reach maximum fire potential[6]



Time taken to reach maximum fire potential. Graph courtesy of Brookes Bell.

<u>Fire load:</u> Many parameters are similar when comparing fires of EVs and ICEVs. The decisive factor in a fire is the actual fire load of the vehicle. For example, much more plastics are built into modern cars than was used previously[7]. Plastics constitute a significant additional fire load. Despite the potential for thermal runaway, studies by the Danish Institute of Fire and Security Technology and U.S. National Fire Protection Association have determined that EV fires, once established, are largely fuelled by the car body and interior parts made from plastic materials and that the fire load is similar to that of ICEVs.[8] Generally, approx. 20% of the fire load, regardless of its propulsion method, is from the energy source and approx. 80% is from plastics and the interior of the vehicle.

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[5] *Toxic Gases from Fire in Electric Vehicles*, Ola Willstrand, Roeland Bisschop, Per Blomqvist, Alastair Temple, Johan Anderson (2020), https://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-52000

[6] *Guidance for the safe carriage of battery powered vehicles on ships*, Australian Maritime Safety Agency, 2023, graph courtesy Brookes Bell

[7] *Plastics in passenger cars, A comparison over types and time*, Erik Emilsson, Lisbeth Dahllöf, Maria Ljunggren Söderman, Chalmers University of Technology (2019), https://www.researchgate.net/publication/339237238_Plastics_in_passenger_cars_A_comparison_over_types_and_time

[8] *Fire safety in garage systems, storage of lithium-ion batteries and batteries for photovoltaic systems in buildings*, DBI (Danish Fire and Safety Institute) and TI (Danish Technological Institute), 2022 and "Modern vehicle hazards in parking structures and vehicle carriers", NFPA Research Foundation, 2020

While the latter is largely comparable for all vehicles, the lower share related to the propulsion technology has limited impact on fighting the fire, i.e. pool fires from petrol vs re-ignition in EVs.

2. Differences between PCTCs and RoRo/RoPax

Pure car and truck carriers (PCTCs)/RoRo and RoPax vessels have significant differences in their design, hence many safety measures, risk control options and incident responses are different on these ship types. This section will look at the key differences.

Roll-on/roll-off (RoRo) and RoPax vessels

The roll-on/roll-off (RoRo) ship was defined in the November 1995 amendments to Chapter II-1 of the International Convention for the Safety of Life at Sea (SOLAS), 1974 as "a passenger ship with ro-ro cargo spaces or special category spaces". These vessels are designed to carry wheeled cargo such as cars, motorcycles, trucks or buses which are driven on and off the ship on their own wheels. RoRo and RoPax vessels have either built-in or shore-based ramps or ferry slips that allow the vehicles to roll on and off the vessel when in port.

RoRo spaces are categorized as either open, closed or weather decks. An open RoRo space is generally a space with more than 10% openings in the hull sides. A RoRo space is defined as a closed space if it is not an open or a weather deck. The large openings in semi-open and open decks on RoRo passenger vessels make firefighting challenging due to the air flow. A fire on an open deck could grow significantly while fires in spaces with smaller openings are restricted by the available oxygen.

A challenge specific to RoRo and RoPax vessels is the cargo they carry. EVs such as cars, buses and excavators are often used vehicles and may have hidden damages. It is difficult to visually check at the terminals which units are safe to carry, and which may not be safe.

A particularity of RoPax vessels is the growing interest by passengers to have the possibility to charge their EVs on board. The permanent electrical fixtures – the interconnection to the vessel's grid – are subject to class approval whereby the installation of the charging station and outlets will require a risk assessment submitted to the flag State or Recognized Organisation. EMSA has published guidelines on the carriage of alternative fuel vehicles in RoRo spaces[9]. These include a section on how charging on board may take place safely. In other geographies, charging on board is prohibited, e.g. on Chinese domestic ferries.

Pure car and truck carriers (PCTCs)

Pure car and truck carriers (PCTCs) are purpose-built vessels for the transportation of different types of rolling cargo, e.g. new and used passenger cars and trucks, heavy

[9] Guidance on the carriage of AFVs in RO-RO spaces, EMSA, May 2022: https://emsa.europa.eu/publications/reports/item/4729-guidance-on-the-carriage-of-afvs-in-ro-ro-spaces.html

construction equipment, and other heavy loads. They present some inherent safety challenges stemming from their unique design characteristics.

PCTCs are usually configured with 10-13 decks for the loading of different vehicle types. The height between the decks can be adjusted depending on the types of vehicles being transported. The height of the vehicle decks is extremely low to reduce the loss of cargo space. Adjustable decks further optimize the cargo space. The vehicles are loaded with very little space between them (lateral distance can be as little as 10 cm, the longitudinal space is 30-80 cm). This impedes quick access to individual units.

A specific fire risk onboard PCTCs arises from their large, undivided horizontal fire zones. Unlike the vessel designs of the 1970s, which incorporated subdivided decks to limit fire spread, modern PCTCs lack such compartments. This shift has resulted in expansive open decks where a fire, once ignited, can rapidly escalate and spread across large areas. The absence of smaller, subdivided fire zones severely hampers the ability to contain incidents effectively.

The stability of PCTCs is sensitive to cargo movements due to their large, open vehicle decks and high centre of gravity. Even minor shifts in stowed vehicles – whether resulting from rough seas or emergency response efforts – can cause the vessel to list, or in extreme cases, capsize.

Currently, PCTCs are not equipped with water-based fixed fire extinguishing systems. Existing CO_2 and foam-based systems have limitations in open-deck environments, particularly in containing fires involving thermal runaway. Water-based systems, while not without challenges, could offer improved cooling capacity and fire containment potential. However, if such systems are to be considered in future vessel designs, the effects of water accumulation on deck, especially its influence on vehicle friction and cargo movement, must be carefully evaluated, as this could exacerbate the risk of stability loss. The use of anti-slip deck coatings may help mitigate this risk by enhancing surface friction and reducing the likelihood of cargo shifting under wet conditions.

A particular challenge associated with PCTCs equipped with CO_2 systems are alongside fires during the cargo loading and unloading process in port, because the operation of the CO_2 system can be significantly limited and, in some circumstances, the system cannot be operated at all. When both the internal doors and the stern/side ramps are open during the loading and/or discharging process, the CO_2 cannot be contained within the vessel. Foam based extinguishing systems are less effective due to the uneven airflow which hinders an even spread of the foam. Due to their construction the ramps cannot be closed quickly. External firefighting teams are not familiar with the design of vessels and are not trained to fight fires in such environments.

3. Risks and mitigation methods

Loading process and loading condition of cars

As noted in figure 1a, the volume of cars being shipped by maritime transport globally is around 20 million units per annum. A growing share are EVs (fully electric and hybrid). Considering the safety systems incorporated into EVs, new cars of this type present a lower risk of igniting as compared to used vehicles. Used EVs may have had accidents causing mechanical damages or may have suffered from electrical abuse which could negatively impact the integrity of the battery pack.

- ➔ A clear policy on the cargo which is accepted/rejected for RoRo spaces should be in place. Vehicles should be screened and used/second-hand vehicles in particular should be carefully checked before being allowed on board. If there is suspicion that the battery of an EV is damaged or defective, they should only be allowed if their battery is removed and if they are free from leakages. IMDG Special Provisions 961 and 962 address requirements for vehicles which are being carried on board a transport vessel.

- ➔ Prior to the loading, the Vehicle Carrier Safety Forum's (VCSF) "Presentation of Vehicle Guidelines" recommend that all vehicles should be marked on the front and rear windscreen with details of the propulsion type fitted.[10] Markings that include basic information about the drive train of the vehicles could be useful, e.g. colour-coded stickers for EVs, ICEVs, or hydrogen powered cars. To address new and existing safety hazards associated with vehicle fires and accidents, the ISO 17840 standard has created uniform symbols. It provides useful guidance for markings.

- ➔ Carriage of EVs in containers: While the bulk of maritime vehicle transports is onboard PCTCs and RoRo/RoPax, a small share of cars, including EVs, is also shipped in containers onboard container ships. To ensure the safe carriage of EVs in containers, the risks associated with LIBs as outlined in section 1 of this paper must be considered carefully. The IMDG Code classifies an EV under battery powered vehicles or battery powered equipment (UN no. 3171). The onboard stowage location and proximity of other cargo (including IMDG cargo) or equipment on board require particular attention. Since the share of EVs transported in containers compared to their carriage on PCTCs, RoRos and RoPax ships is comparatively low, this is not a focus of this paper.

- ➔ Stowage factor: The stowage and loading of EVs should be guided by a risk-based approach that accounts for their unique fire and thermal runaway hazards. This includes mandatory spacing between units to facilitate early fire detection, effective firefighting access, and heat dissipation. Incorporating passive fire barriers, such as mobile or fixed partitions, can help contain a fire and prevent it from spreading across an entire deck.

  While these measures have clear safety benefits, they present significant challenges for current stowage planning and can reduce overall cargo capacity. Furthermore, the effectiveness of such strategies remains unverified in operational settings, and the limitations of existing vessel designs may hinder their practical implementation.

Charging on board

- ➔ RoPax: Depending on geographies and jurisdictions, charging on board ro-ro passenger ships can be permitted if the ship operator conducts a comprehensive risk assessment and approves and implements appropriate risk control

[10] Common Guidance on the Presentation and Loading of Vehicles: https://www.ics-shipping.org/resource/common-guidance-on-the-presentation-and-loading-of-vehicles/

measures. As mentioned above, information regarding safe charging on board is available in the EMSA Guidance on the carriage of AFVs in RoRo spaces.

- PCTCs: PCTCs are not fitted with charging stations.

Detection & confirmation/verification

- RoRos & PCTCs: Early detection and verification/confirmation of a fire is key to enable successful firefighting operations. These two steps should not be considered as separate but as one single step. Time between detection and confirmation/verification must be reduced to the shortest possible period. The installation of technologies which enhance early detection are therefore supported for these vessel types, in addition to the regular fire rounds currently being conducted onboard. Options include gas detection systems, video monitoring/CCTV, thermal imaging cameras, and AI powered systems, in addition to the usual smoke detectors.

Firefighting

- PCTCs: The fixed firefighting systems should be applied early, correctly, and safely first rather than manual firefighting by the crew because it may be difficult and dangerous to access the burning unit. The timely activation of the fixed extinguishing system is crucial to avoid catastrophic consequences of a fire. Once the fire has grown and affects different fire zones, the existing fire-extinguishing systems may fail. Several incident reports underscore the severe consequences of a delayed activation of the fixed fire-extinguishing system. The safest and most efficient option is to keep the crew out of the cargo holds and release the fixed system. The only situation where manual firefighting should be pursued is to save life and to complement the fixed fire-extinguishing system. The fixed first approach aims at extinguishing the fire of the car before it reaches the traction battery (which typically occurs after 30 min into the fire), thus avoiding the spread of the fire.

- RoRos: Boundary cooling is extremely important to contain the onboard fire because the transfer of heat into the next fire compartment is a worst-case scenario. Boundary cooling should be established in parallel with the activation of the fixed firefighting system. It provides protection against heat spreading to adjacent spaces by cooling decks and bulkheads with water. Boundary cooling can be done using the mobile extinguishing equipment on board (fire hoses, nozzles etc.).

- PCTCs: Boundary cooling plays a significant role in the containment of onboard fires because the heat transfer into the adjacent compartments is rapid, and car fires instantly produce lots of heat. However, there are limited possibilities for boundary cooling on current PCTCs because the outside shell is inaccessible, there are typically no transverse bulkheads, and the fact that introducing water on decks will reduce or completely eliminate friction. This could cause a major cargo shift, thus leading to problems with ship stability. Only in calm weather (without swell and wind waves) locally applied small amounts of water can be recommended. This should be established in parallel with the activation of the fixed firefighting system. It can provide protection against heat transfer to adjacent compartments by cooling decks with water. Boundary cooling can be done using the mobile extinguishing equipment on board (fire hoses, nozzles etc.).

- ➔ RoRos & PCTCs: Fire safety and firefighting equipment such as breathing air compressors, fire suits that are suitable for ICEV/EV firefighting[11], addressable dual detectors, and thermal imaging cameras should be improved and made available in sufficient numbers to put the crew in the best possible position in case of a fire onboard.

- ➔ RoRos & PCTCs: Seeking external help from professional marine firefighters or salvors is recommended whenever possible. Guidance for onshore firefighters is essential before entering a vessel since it is a complex and unfamiliar setting for them. Firefighting methodologies need to be modified to reflect risks associated with EVs. Since the global car park is gradually shifting to fully electric, it is paramount that the firefighting methodologies (use of the fixed firefighting system first and being aware of the re-ignition risk) need to be improved. Crew on PCTC, RoRo and RoPax vessels should receive specific training on car fires (regardless of drive train).

Extinguishing systems

- ➔ RoRos: The EU's LASHFIRE project has shown that drencher systems are effective to fight fires on board RoRo and RoPax vessels. Full scale tests show that a drencher system has the same impact on the fire regardless of the source of the fire being an ICEV or an EV. Drencher systems are thus effective to manage and control EV fires, but they cannot stop thermal runaway.

  This is reflected in the revised requirements developed by the IMO's Sub-Committee on Ship Systems and Equipment (SSE). The amendments to SOLAS and the Fire Safety Systems (FSS) Code will mainly apply to new passenger ships and include, inter alia, requirements for a fixed fire detection and fire alarm system to be provided for the area on the weather deck intended for the carriage of vehicles; an effective video monitoring system; and a fixed water-based fire extinguishing system based on monitor(s) to be installed in order to cover weather decks intended for the carriage of vehicles.

- ➔ PCTCs: Currently, most PCTCs are either equipped with CO_2 or with foam-based extinguishing systems.

- ➔ PCTCs: CO_2 extinguishing systems if applied quickly after the detection and verification/confirmation of a fire and before thermal runaway has occurred, could work successfully to fight fires on board PCTCs. The challenge of using the CO_2 system is the inherent systematic delay of its release due to the necessity to muster the crew and verify this extinguishing system.[12] Proficiency of the use of the system by the crew in case of an emergency is key for its successful use. To improve the usefulness, the CO_2 capacity on board PCTCs should be at least doubled. Research projects are ongoing to methodically assess and prove the

[11] Findings of the EU Project Lashfire recommend fire suits complying with EN 469 level 2 (X2 Y2 Z2) or similar.
[12] SSE 10/INF.9 "Analysis report on fire risks and fire characteristics of ships carrying lithium battery electric vehicles" submitted by China

effectiveness of the CO_2 extinguishing systems. A particular challenge associated with PCTCs equipped with CO_2 systems are alongside fires, because their operation can be significantly limited and, in some circumstances, cannot be operated at all. As with other extinguishing media, CO_2 cannot stop thermal runaway.

➔ PCTCs: High-expansion foam fire extinguishing systems can hinder the ignition of flammable gas, including gaseous electrolyte from the batteries. The systems have effectively prevented heat transmission from a vehicle on fire as long as it was submerged in the foam.[13] However, while the ignition of gases may be hindered, gases do continue to form during uninterrupted thermal runaway which, in common with any other fixed system, foam-based systems are unable to stop.

There are a number of notable drawbacks to high-expansion foam fire extinguishing systems. They are hindered by their complexity and their reliance on electricity for the simultaneous functioning of pumps and fans. Additionally, new environmentally approved foam compositions mean lower penetration and heat resistance capabilities.

An additional obstacle to consider is the high threshold for the crew to apply the “fixed first” approach for foam-based systems due to the consequences of “unnecessary” release.

➔ PCTCs: An alternative firefighting option would be a total flood high-pressure water mist sprinkler system (fresh water based). It can be activated at any time even with crew present. A major advantage associated with water-based systems is their cooling effect and the potential for effective boundary cooling, though like other extinguishing media it cannot reduce or prevent thermal runaway. Current ship design and construction limitations must be resolved before this option can be applied broadly.

Overarching approach

➔ PCTCs and RoRo/RoPax: Different design, resources, equipment and circumstances have to be considered for each vessel. Individual risk assessments and tactics are essential to ensure an effective response in case of a fire on board.

➔ PCTCs and RoRo/RoPax: Research on the risks and risk mitigation options related to EVs is ongoing and technologies continue to evolve. In light of these developments, all stakeholders involved in the maritime transport of EVs are required to constantly assess new findings and take them into consideration in their risk assessment. A fundamental obligation for the shipping industry is the proactive exploration of improved onboard firefighting capabilities.

➔ PCTCs: Dedicated training schemes should be developed for seafarers sailing on this vessel type. The characteristics of PCTCs and the cargo they carry (ICEVs as well as new energy vehicles) must be fully understood by seafarers who should undergo thorough training for this specific vessel type. Currently, the

[13] SSE 9/INF.4 "Experimental test on lithium-ion-battery-powered vehicle fires with outside air high-expansion foam fire-extinguishing system" submitted by Japan

STCW Convention does not address the carriage of ICEVs nor EVs. Best industry practice must be developed and included in the regulatory requirements.

- ➔ PCTCs and RoRo/RoPax: Since regulatory changes will only come into force in the future, notations issued by individual classification societies may be an additional means of evaluating the risk management and mitigation measures on board.

4. Conclusions

The IMO's SSE Sub-Committee is working on the "Evaluation of adequacy of fire protection, detection and extinction arrangements in vehicle, special category and ro-ro spaces in order to reduce the fire risk of ships carrying new energy vehicles". The regulatory process will be an opportunity to improve safety requirements making them fit for the new reality of large numbers of alternative fuel vehicles being carried on board vessels.

Current limitations in fire detection and protection ought to influence future ship designs and highlight the importance of early detection of deviations in an EV's battery pack, containment measures, crew training and drills. Time between detection and confirmation/verification must be reduced to the shortest possible period. It is a constant task for the shipping industry to advance and implement improved fire safety measures.

It is also important to account for EV technology that is constantly evolving. Fire safety on ships must not be the sole responsibility of the shipping industry. In their role as shippers or charterers, car and battery manufacturers also have a role to play in loss prevention by offering guidance and solutions to enhance safety onboard.

Any regulatory changes must be able to cover technological advancements. At the same time, it is important to recognize that it will take time to fill the current gaps in the regulatory landscape. Therefore, all stakeholders involved in the carriage of EVs onboard ships need to collaborate, share knowledge, learn from each other, and implement and further develop best practices in line with the latest research.

Further developments can be anticipated, hence the safe ocean and short sea carriage of EVs remains an area in which underwriters need to maintain their awareness.

Key points

- The SoC of batteries within EVs being transported by car carriers should be kept as low as practically and technically possible. Currently, no international requirements for SoC in maritime transport have been agreed.
- Currently no extinguishing agent or system can interrupt the chemical chain reaction occurring in a battery in thermal runaway.
- A comprehensive firefighting strategy must not only consider the firefighting itself but also the management of potentially explosive gases that may accumulate during such incidents.
- While there is general agreement that the total energy released by EVs and ICEVs during a fire is broadly comparable, opinions diverge when it comes to peak temperatures.
- A peculiarity of EVs is the risk of re-ignition which is higher for a longer period than for ICEVs. Precautionary measures to avoid re-ignition of the traction battery must therefore be taken for an extended period after a fire has been extinguished.
- A challenge specific to roro and RoPax vessels is the cargo they carry. EVs such as cars, buses and excavators are often used vehicles and so may have hidden damages.
- PCTCs present some inherent safety challenges stemming from their unique design characteristics. A specific fire risk onboard PCTCs arises from their large, undivided horizontal fire zones.
- Markings that include basic information about the drive train of the vehicles could be useful, e.g. colour-coded stickers for EVs, ICEVs, or hydrogen powered cars.
- Early detection and verification/confirmation of a fire is key to enable successful firefighting operations. These two steps should not be considered as separate but as one single step. Time between detection and confirmation/verification must be reduced to the shortest possible period.
- Onboard PCTCs, the fixed firefighting systems should be applied early, correctly, and safely. Manual firefighting by the crew should be a last resort.
- Seeking external help from professional marine firefighters or salvors is recommended whenever possible.
- To improve its usefulness, the CO2 firefighting capacity on board PCTCs should be at least doubled.
- An alternative firefighting option for PCTCs would be a total flood high-pressure water mist sprinkler system. It can be activated even with crew present. A major advantage of water-based systems is their cooling effect and the potential for boundary cooling. Current ship design and construction limitations must be resolved before this option can be applied broadly.
- Foam based extinguishing systems onboard PCTCs have notable draw backs.
- Dedicated training schemes should be developed for seafarers sailing on PCTCs.
- A fundamental obligation for the shipping industry is the proactive exploration of improved onboard firefighting capabilities.

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