MARITIME TECHNOLOGIES FORUM

LEADING THE MARITIME WORLD FORWARD

SAFE CARRIAGE OF ELECTRIC VEHICLES

Abbreviations and Definitions

Abbreviation	Definition
AI	Artificial Intelligence
EV	Electric Vehicle
BMS	Battery Management System
CCTV	Closed-Circuit Television
EVB	Electric Vehicle's Battery
FTP	Fire Test Procedures
FSS	Fire Safety Systems
GHG	Greenhouse Gas
HC	Hydrocarbon
HF	Hydrogen Fluoride
HRR	Heat Release Rate
ICEV	Internal Combustion Engine Vehicle
IDLH	Immediately Dangerous to Life or Health
IMO	International Maritime Organization
ISM	International Safety Management
ISO	International Organization for Standardization
LiB	Lithium-ion Battery
LNG	Liquefied Natural Gas
MES	Marine Evacuation System
MSC	IMO's Maritime Safety Committee
MTF	Maritime Technologies Forum
PCTC	Pure Car and Truck Carrier
PPE	Personal Protective Equipment
RO-RO	Roll-on Roll-off
SCBA	Self-Contained Breathing Apparatus
SOC	State of Charge
SSE	MSC Sub-Committee on Ship Systems and Equipment

Executive Summary

The Maritime Technologies Forum (MTF) is a group of flag States and classification societies which aims to bridge the gap between technological progress and regulatory process. With an increasing number of electric vehicles (EV) being transported on vessels and safety concerns regarding onboard EV fires, MTF decided to provide information on safe carriage of EVs in pure car and truck carrier (PCTC) vessels to industry for further development of future mandatory regulations by the International Maritime Organization (IMO).

At the time of writing this report, there are no international regulations dedicated for safe carriage of EVs. Some national and regional governmental organizations have published their own guidelines related to safe carriage of EVs ahead of the IMO, which began working on the development of the mandatory regulations for transportation of new energy vehicles including EVs with the target completion year of 2027. Some delegations have proposed regulations and submitted information papers at the IMO, but the framework for these regulations has not yet been developed or discussed.

The objective of this project is to gather relevant information available among MTF member organizations, provide a framework for the considerations necessary to supplement safe carriage of EVs, and present detailed information on the characteristics of EV fires, including thermal runaway and the necessity of measures such as early detection, prevention of fire spread, firefighting, evacuation, training, and drills.

This report specifies the characteristics and important considerations related to fires involving EVs, as well as the corresponding fire safety measures. Measures were specified with general comments, which may be helpful for the consideration by stakeholders to tackle EV fires in PCTCs. This report provides a starting point for development of safe carriage of EVs in PCTCs, and this work is aimed to provide the information to the IMO and the industry for further development, but to not define nor require prescriptive requirements.

The following main observations are highlighted:

- **Early Detection**

  It is important to detect EV batteries (EVBs) that become heated, as early as possible. A battery management system (BMS) on each vehicle could issue an audible or visual alarm when detecting abnormal conditions, such as a temperature increase, thereby enabling early detection. BMS could also send alerts to the ship if it could be connected wirelessly to the ship's systems.

- **Prevention of Explosion**

  During thermal runaway, flammable gases such as methane, ethane and hydrogen are released from EVBs, creating explosive atmospheres in the vehicle spaces. Since the density of these gases is lower than that of air, it is especially important to consider the risk posed by electrical equipment on the upper part of the deck, such as detectors and lights, that are not explosion-proof.

- **Fire Protection and Prevention of Fire Spread**

  Tight spacing of vehicles may result in fire spreading from a single vehicle to an adjacent vehicle almost immediately. Isolating fires and cooling EVs are crucial to prevent fire spread. It is also noted that the heat release from an EV fire is greater than that from a conventional vehicle fire, which is the fire scenario assumed in FTP Code. Therefore, the current structural fire protection would not be as effective as expected in the case of an EV fire. Structural fire protection of all escape routes and areas around survival crafts also needs to be considered to ensure safe evacuation of the crew.

- **Manual Firefighting**

  Manual firefighting using portable firefighting equipment should be implemented primarily in the early stages of a fire and should be used only when effective response or prevention is possible. It is important to remove excess water at the same time as firefighting operations to prevent water accumulation that could cause adverse effect on vessel stability.

- **Fixed Firefighting**

  SOLAS II-2/Reg.20 requires one of the following fixed fire-extinguishing systems in vehicle spaces: carbon dioxide (CO_2) fire-extinguishing system, high expansion foam fire-extinguishing system or a water-based fire-extinguishing system. MTF conducted an objective comparison of each system's unique advantages and disadvantages.

- **Safety of Crew During Firefighting**

  It is important to understand the characteristic of fire and obstructions such as spacing of vehicles and existence of lashing belts, to proceed the manual firefighting and ensure the safety of crew during the firefighting. Taking into account the amount of time typically required for EVB cooling operations, usage time for self-contained breathing apparatus (SCBA) should be considered.

- **Safety Management System (SMS) — Training and Drills**

  The SMS for PCTCs carrying EVs should be strengthened to address characteristics of EVs and EV fires. Crew training should cover the understanding and familiarization with firefighting measures and tactics. Emergency preparedness should include relevant fire drills.

Introduction

Greenhouse gas (GHG) emissions are an environmental issue experienced globally, affecting countries and industries. As one of the measures to decarbonise road transportation by reducing GHG emissions from automobiles, car manufacturers have been developing EVs that are powered by lithium-ion batteries (LiB) instead of conventional fuels.

Transportation of EVs by PCTC vessels has also begun, and the share of EVs amongst all vehicles being transported has been increasing. Among potential problems, is that if an abnormality occurs in the LiBs used to power an EV, or a fire breaks out from the battery, special response methods must be applied. The characteristics of LiBs include high energy density, high voltage and the ability to be recharged. It is also known that extinguishing a fire from a LiB can take a considerable amount of time.

Moreover, vehicles, whether conventional vehicles or EVs, transported by PCTC vessels are loaded in vehicle spaces (car decks) with minimal distance between each other, which causes a fire rapidly spreading to other adjacent vehicles and difficulty in approaching burning vehicles to conduct firefighting operations. Therefore, special measures must be implemented given the unique environment in the vehicle space, and this further combined with the characteristics of EVs leads to the necessity of implementing firefighting measures specific to EV transportation.

There are no regulations for safe carriage of EVs at the moment, in spite of increasing number of EVs transported by vessels. In April 2022, the Maritime Safety Committee (MSC) of the IMO decided to develop mandatory regulations for transportation of new energy vehicles including EV1), with a target completion year of 2027. In March 2024, a discussion was initiated as an "evaluation of adequacy of fire protection, detection and extinction arrangements in vehicle, special category and roll-on roll-off (RO-RO) spaces in order to reduce the fire risk of ships carrying new energy vehicles" at the 10th session of the Ship Systems and Equipment Sub-committee (SSE 10) under the MSC.

Some national and regional governmental organizations2) and other maritime related organizations3) have undertaken investigations and published their own guidelines for the transportation of EVs, and multiple projects4),5) have also undertaken investigations and reported results at the IMO. Furthermore, front-runner shipowners and management companies are now taking measures for safe carriage of EVs, as it will take a long time to develop mandatory requirements for carriage of EVs at the IMO.

Crews need to become familiar with EVs and be well-trained to ensure safe transportation of these vehicles. In addition, providing effective information on safe carriage of EVs would be beneficial to stakeholders who are now investigating and considering the additional measures.

In the above regard, MTF members brought together relevant information and experience available to them and held discussions to consolidate into this report, which specifies the characteristics and important considerations related to fires involving EVs, as well as the corresponding fire safety measures. Measures are supplemented with general comments by MTF members, which may be helpful for the consideration by stakeholders to tackle EV fire in PCTCs. This report provides a starting point for development of safe carriage of EVs by PCTCs, and this work is aimed to provide the information to the IMO and the industries for further development but does not suggest specific prescriptive requirements.

The main structure of this report is as follows:

1. Characteristics of Transportation of EVs in PCTCs
2. Early Detection
3. Prevention of Explosion
4. Fire Protection and Prevention of Fire Spread
5. Manual Firefighting
6. Fixed Fire-extinguishing System
7. Safety of Crew during Firefighting
8. Safety mangement system — training and drills

1. Characteristics of Transportation of EVs in PCTCs

This chapter provides the characteristics of EVs and thermal runaway for consideration of measures. This information would be helpful for stakeholders to consider measures on EV fires in PCTCs.

Electric Vehicles (EVs)

Electric vehicles (EVs)s are vehicles powered by electricity. The types of vehicles that use electricity as a power source include pure EVs, plug-in hybrids and hybrid vehicles. In spite of differences in the types of batteries used in the respective vehicles and their systems and capacities, they can all be considered as types of EV. However, it should be noted that the fire characteristics of different types of battery cells may vary significantly. EVs have the largest battery capacity and use many LiBs. Many EVs contain the battery cells in a battery pack that extends under the entire floor of the vehicle. From tens to several thousands of individual LiB cells may be installed in the battery pack, although the number differs depending on the type of vehicle and battery. EVs have a BMS that monitors and controls the current, voltage and when in use, or when charging, adjusts performance to maintain a safe temperature of batteries.

At present, the LiB is considered to be the only type of battery that has an energy density which makes it possible to install the power capacity necessary for vehicle travel at a practical level. Lithium-ion batteries achieve a high rated voltage and high energy density because electrolysis is less likely to be caused until a high potential (high voltage) due to the use of an organic solvent in the electrolyte.

However, if electrolysis occurs and gasification takes place, the battery does not return to its original state. As mentioned previously in EVs, a robust case which houses the LiB cells, called a battery pack, is installed, and the total capacity of the battery ranges from 20 kWh to more than 100 kWh. The voltage ranges between 300 V to 400 V.

Thermal Runaway

Transportation of EVs has introduced a new fire characteristic, known as thermal runaway, which is a common phenomenon of LiB. Thermal runaway, which may be the result of internal defects, external heat or thermal, mechanical, or electrical abuse, is an exothermic chemical reaction. Thermal runaway, which although very unlikely, is an unstoppable chemical reaction once it is initiated and the EVB cell temperature rapidly reaches a high temperature. Test results show that the temperature may exceed 1,000° C within about 30 minutes referred from cylindrical type cell data6). It is difficult to stop the chemical reaction, which may cause severe impacts such as quick and uncontrollable fire spread. Thermal runaway is classified in three stages as shown in Figure 1: temperature rise stage, combustible gas generation stage and fire outbreak stage.

- Temperature rise stage — The temperature of the battery cell in which the internal short-circuit occurred rises.
- Combustible gas generation stage — It is known that EVB may emit combustible gases such as hydrogen and hydrocarbon (HC) gases7) and toxic gases8),9) such as hydrogen fluoride (HF) from battery pack until the chemical reaction stops.
- Fire outbreak stage — EVB catches fire when the temperature of the white gas reaches its ignition point or contacts an ignition source.

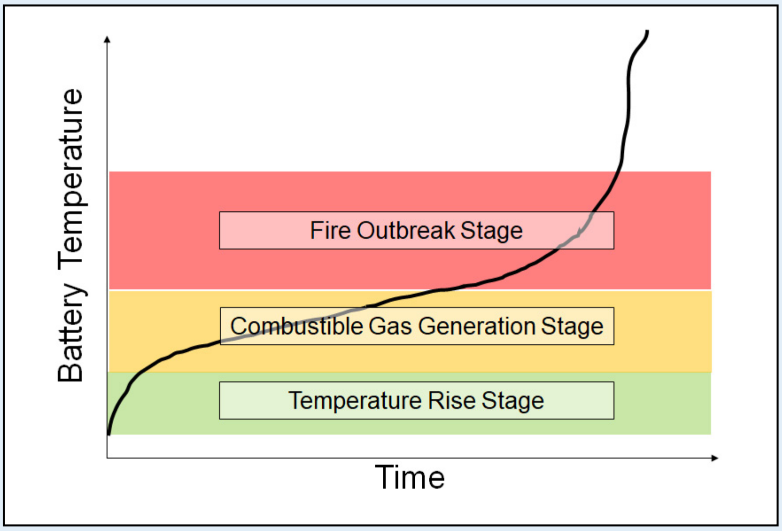

Figure 1: Arrangement of events leading to thermal runaway of LiB cell

Even if an EV fire appears to be extinguished, there is a risk of reignition, since the chemical reaction and emission of flammable gases continue, and the battery cell and pack remain heated. It is important to note the currently available research results, where typically both peak and total heat release rate (HRR) of EVs is comparable to traditional internal combustion engine vehicles (ICEVs).10)

Vehicle Spaces

In general, vehicles, including EVs, are transported by PCTCs and RO-RO passenger and cargo ships. Unlike RO-RO passenger ships, PCTCs do not transport passengers. Furthermore, PCTCs are different from RO-RO passenger ships in the layout of vehicle spaces and the loading condition of the vehicles. Furthermore, a typical PCTC has more decks of vehicles than RO-RO passenger ships. Vehicles carried by PCTCs tend to be more tightly packed than vehicles carried by RO-RO passenger ships. Figures 2 and 3 show the severest loading condition of vehicles in vehicle spaces on PCTC vessels. Operationally, front-back (rear-to-bumper) distance between vehicles is 300 mm or less, side-to-side (door-to-door) distance between vehicles is 100 mm and distance between vehicle roof and structural members of above decks is 100 mm. This loading condition may lead to rapid fire spread. In addition, due to the lashing belts used to secure vehicles, these will restrict the access to vehicles during manual firefighting. Therefore, fire safety measures are different from those for RO-RO passenger ships.

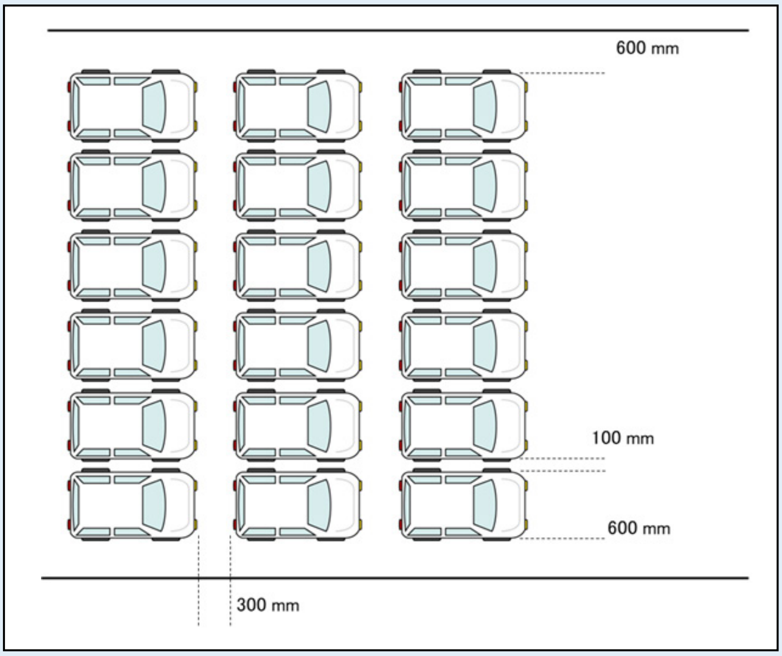

Figure 2: Loading condition of vehicles (Deck view)

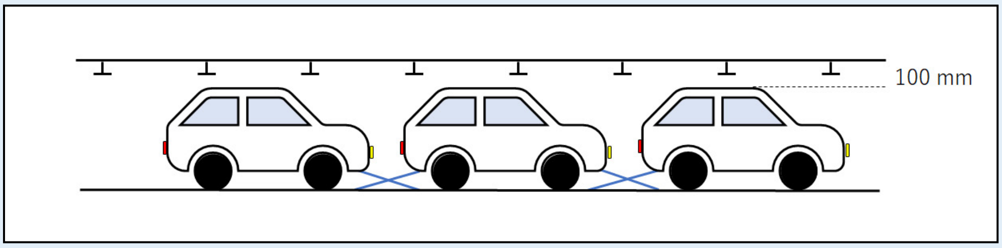

Figure 3: Loading condition of vehicles (Side view)

Measures

Considering the characteristics of transportation of EVs in PCTCs, the following measures were identified.

- Early Detection
- Prevention of explosion
- Fire protection and Prevention of fire spread
- Manual firefighting (portable equipment and their location)
- Fixed firefighting (Carbon dioxide, Hi-expansion foam, water (drencher/water mist)
- Safety of Crew during Firefighting
- Training and drills

Figure 4 shows the scope of identified measures at each stage. The thermal runaway of a LiB is initiated by internal or external causes, such as an internal short circuit, or external fire source. In some cases, fixed fire-extinguishing systems may be activated without manual firefighting.

For example, fire detection can be effective in identifying fires originating from external fire sources within the vehicle space or thermal runaway of an EVB during the early stages by detecting smoke, heat and flame.

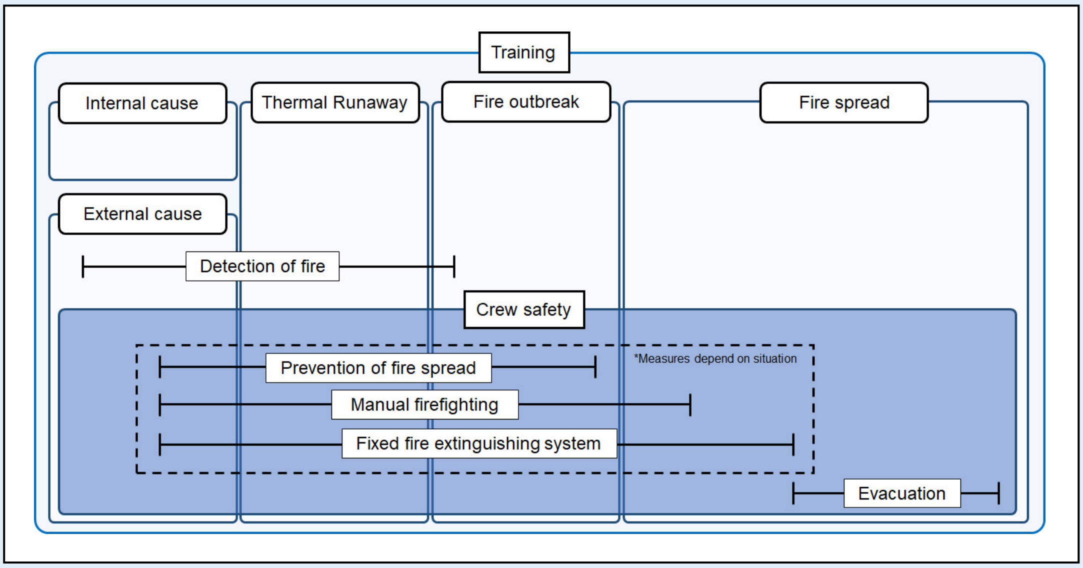

Figure 4: Phase of measures

Next chapter provides measures with descriptions in italics and general comments on those measures.

2. Detection

Vehicles, whether conventional vehicles or EVs, are carried tightly in vehicle spaces of PCTCs, which could lead to fast fire spread to adjacent vehicles. Such a fire would be uncontrollable and existing fixed fire-extinguishing systems would probably not be effective, putting the lives of the crew at severe risk, and risking both the cargo and the vessel. Therefore, early detection is a key to ensure that fires do not develop to an extent where the fixed firefighting systems are no longer effective and to initiate any firefighting such as isolation, cooling, and fire suppression, before thermal runaway of EVBs occurs and a major fire develops. If thermal runaway occurs, the key objective should be the prevention of fire spread to adjacent vehicles.

In a typical PCTC configuration, the smoke detection system is installed within vehicle spaces as required by SOLAS II-2/Reg.20. However, smoke may accumulate in pockets within the space formed by the beam and the girder where smoke detectors are not installed, which may cause late detection. Furthermore, smoke may pass through lashing holes, which may then make it difficult to detect smoke immediately at the deck where fires occur. It is noted that these are general concerns for PCTCs loading both EVs and ICEVs.

Through the discussion about early detection, the following measures with general comments were identified.

Closed-Circuit Television (CCTV) with Artificial Intelligence (AI) or Video Analytics Function

This system would detect fire in an EV, and smoke would automatically and trigger the alarm. This can also be used for monitoring the fire condition or firefighting situation in vehicle spaces.

- The system can possibly detect smoke or fire before conventional detectors detect them.
- Numerous cameras might be needed to monitor all vehicles because the distance between car top and beam (10 cm) restricts the view angle of the CCTV.
- Since a large amount of image data cannot be checked by a crew, it is necessary to use a video analytics software or AI.
- CCTV is recommended being of explosion-proof type as flammable gases are emitted during thermal runaway.
- Cameras need to be infrared (IR) or night-vision capable, as usually, car decks will be dark and lights off during a long voyage.

Infrared (IR) Cameras

This system would confirm abnormal temperatures detected in the vehicle deck and trigger the alarm. This system can also be used for monitoring fire development. Such systems are not affected by poor lighting, but visibility is limited due to the layout of the vehicle decks.

- Crew could confirm and identify the location of a fire without entering the vehicle spaces. This would minimize the reaction time of any firefighting actions, thereby increasing the likelihood of suppressing the fire.
- Numerous IR cameras might be needed to monitor all vehicles because the distance between car top and beam (10 cm) restricts the view angle of the camera.
- An IR camera is recommended being of explosion proof type as flammable gases are emitted during thermal runaway.
- It may be difficult to find IR cameras with suitable explosion proof and fire-proof type.

Gas Detection System

The system detects hydrocarbon gases emitted prior to smoke from an EVB in thermal runaway.

- The system can detect hydrocarbon (HC) or hydrogen gases before conventional detectors detect smoke or heat.
- The system cannot identify a location of vehicle in thermal runaway. The absolute amount of HC or hydrogen gases during thermal runaway cannot be estimated, and the total amount of HC or hydrogen gases are highly dependent on the EVB state of charge (SOC) and battery capacity.
- Location of sampling point and gas detectors for effective detection should be considered.
- Sampling type gas detection system may also be easily affected by ventilation drafts and may not detect any gases promptly.
- Such a system must be verified to ensure that the gas detection system can detect flammable gases earlier than conventional smoke detectors.

Additional Detectors

Providing heat or flame detectors within vehicle spaces, which includes combined heat and smoke detectors, in addition to smoke detectors. Smoke detectors are installed appropriately with consideration of smoke behaviour.

- Flame detectors, which detect ultraviolet waves, can identify the location of vehicles on fire, and heat detectors can identify a deck where EVs are on fire.
- Increasing installation number of smoke detectors or installing additional heat or flame detectors will contribute the early detection of smoke or fire. Furthermore, smoke, flame and heat detectors can be supplied anywhere and anytime.
- A combination detector of smoke and heat ensures detection of fire and the location, reducing false alarms.
- The SOLAS amendments implementing the measure was adopted for RO-RO passenger ships.
- The arrangement of additional fire detectors should be considered and verified to ensure the earlier detection of smoke, heat, and flame compared to the conventional arrangement of smoke detectors.

Alert from EV Itself

EVs produce audible and visual alarms such as the sound of a horn and headlights flashing, when BMS detects some abnormal conditions such as voltage and temperature rise in batteries.

- The system would contribute to detect an early abnormal condition of the battery (e.g., temperature rise of battery cell), and to take early action to suppress fire.
- Only EVs release audible and visual alarms so the crew can distinguish between EVs and ICEVs.
- As well as audible and visual alarms, the EV could also send alerts to the ship if it could be connected wirelessly to the ship’s systems.
- This measure could not be achieved by the maritime industry alone, it would need the cooperation of the automobile industry.

3. Prevention of Explosion

SOLAS II-2/Reg.20.3.2 stipulates that electrical equipment and wiring shall be of a type suitable for use in an explosive petrol and air mixture. In addition, above a height of 450 mm from the deck, electrical equipment is of a type so enclosed and protected as to prevent the escape of sparks is to be permitted as an alternative on condition that the ventilation system is so designed and operated as to provide continuous ventilation of the cargo spaces at the rate of at least 10 air changes per hour, whenever vehicles are on board. However, during thermal runaway, flammable gases such as methane, ethane and hydrogen gases are released from EVBs and create explosive atmospheres in the vehicle spaces. The density of these gases is lower than air. Therefore, these gases might accumulate on the upper part of deck where electrical equipment is not of an explosion-proof type such as detectors and lights. Furthermore, required explosion proof grade of these gases is different from gasoline.

Through the discussion, the following measures with general comments were identified.

Use of Explosion Proof Type Electric Device

Suitable explosion-proof type electric devices with consideration of the gases emitted from the battery during thermal runaway.

- Equipment is not a fire risk and can be used safely even when combustible gases generated by batteries form an explosive atmosphere.
- Since the type and amount of gas generated differs depending on the type of EVB electrolyte, the materials of the positive and negative electrodes, and the SOC, it is necessary to carefully examine the appropriate explosion-proof class.

Ventilation Control

Activating mechanical ventilation continuously to avoid an explosive atmosphere during voyage to mitigate the risk of EV fires.

- Ventilation control prevents the formation of explosive atmospheres and dilutes the explosive gas concentration.
- Continuous supply ventilation supplies fresh air, which increases the probability of fire and creates a greater fire, if fire is already present, before detection, whilst continuous exhaust ventilation removing combustible gas outside the space will reduce and lower the probability of fire.
- There may be places where air is stagnant and cannot be ventilated because the cargo hold is large, and structural members have a complicated arrangement.
- The overall ventilation strategy should be carefully considered by the companies and the crew needs to be appropriately trained to be able to evaluate if EVs are involved in the fire, venting out gases may be an appropriate strategy to deal with this issue but also to be able to better monitor the fire and intervene as appropriate.

4. Fire Protection and Prevention of Fire Spread

SOLAS II-2/Reg.9 requires fire integrity of boundaries and decks between vehicle spaces and the other spaces. In the case where the fire is not suppressed early enough, the fire load on ships carrying numerous vehicles can easily overwhelm any available fixed systems and subsequently the structural fire protection. There is a case that fires initiated in higher decks of vehicle spaces were eventually suppressed while several fires initiated in lower decks of vehicle spaces ended up as total losses because the fire could not be contained in one deck. A single continuous fire zone of the vehicle spaces makes fire spread difficult to contain. SOLAS II-2/Reg.9 requires A-30 boundaries between vehicle spaces, however such boundaries, while capable to contain a conventional fire, are unlikely to be able to contain an EV fire.

4.1 Adjacent Vehicles

Tight spacing of vehicles may result to the fire spreading from a single vehicle to an adjacent vehicle almost immediately, and the spread of the fire may be quick. Not only short circuit, but external heat can induce thermal runaway. Therefore, prevention of fire spread to adjacent vehicles is important.

Through the discussion, the following measures with general comments were identified.

Fire Blanket

A Fire blanket is used to cover vehicles on fire or surrounding vehicles, to prevent fire spread10).

- A fire blanket blocks the entry of air, and fire can be extinguished due to suffocation, which is effective as an initial firefighting measure and makes shifting focus to other firefighting operations possible after a fire blanket has been put in place.
- Fire blankets covering vehicles and surrounding vehicles can be efficient in "controlled" environments or non-fire environment, but it will be hard to deploy once a fire has developed.
- Tight vehicle stowage in vehicle spaces restrict crew's ability to deploy fire blankets.
- Lashing equipment such as lashing belts and lashing holes on car decks causes obstruction and therefore the fire blanket is unable to be fully closed.
- Fire blankets can be used as a precautionary measure if there is suspicion that an EV might have an increased risk of ignition.

Fixed boundary Cooling System

The system consists of fixed piping and nozzles for discharging water spray that can form water curtain between vehicles or in separated zone within one vehicle deck to shut off radiated heat to adjacent vehicles. (Figure 5)

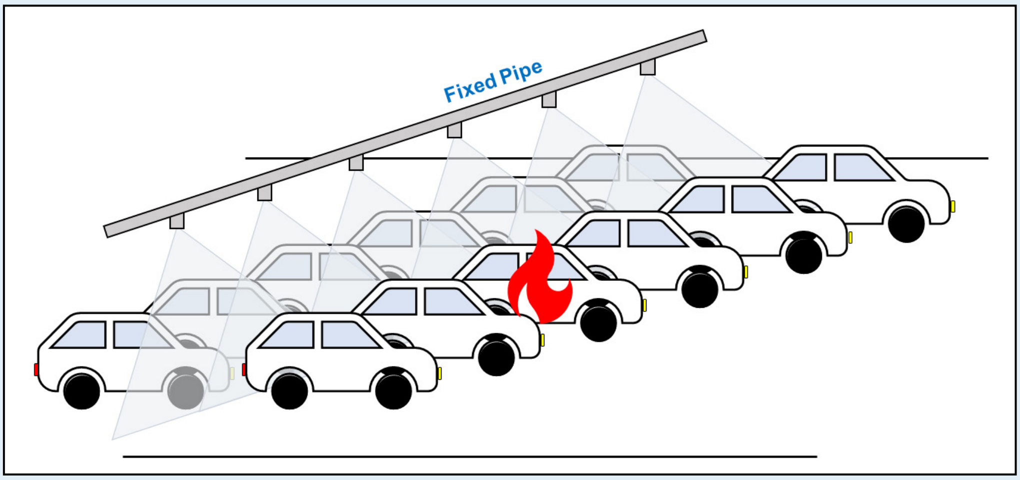

Figure 5: Image of fixed boundary cooling system

- The activation of a water curtain between vehicles will reduce to probability of fire spreading and indirectly cool and act as shield to those unaffected areas.

Portable Boundary Cooling Device[6,12])

Portable boundary cooling device such as water curtain hoses or similar device can connect to hydrants in vehicle spaces. Portable boundary cooling device is laid down between vehicles to create water curtain to shut off radiated heat to adjacent vehicles. (Figure 6)

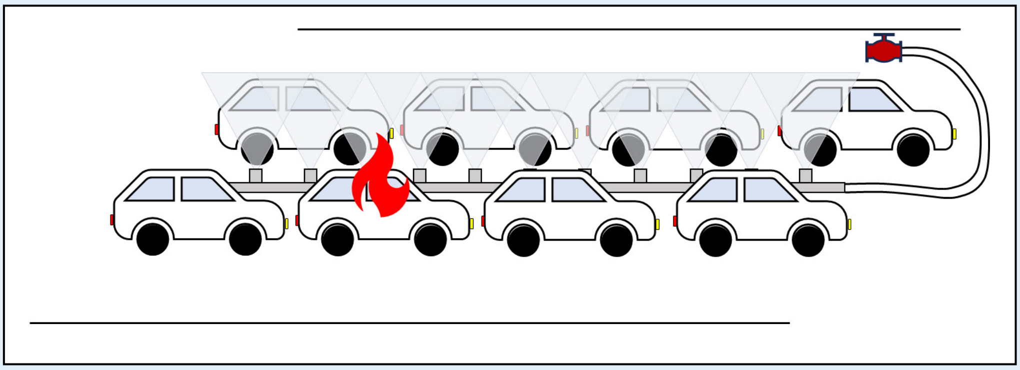

Figure 6: Image of portable boundary cooling device

- The device can be activated without any additional fixed system such as piping to connect fire hydrants directly.
- The activation of water curtain between vehicles will reduce to probability of fire spreading and indirectly cooling and acting as a shield to those unaffected areas.
- It is difficult to place on decks with lashing belts.
- This equipment would be effective provided that crew are knowledgeable to fight and come into close proximity to the fire. A boundary cooling device will require crew to risk themselves to get close to the seat of the fire and deploy the equipment.
- This equipment should also be easy to use, and connection compatible with all fire hoses on board and portable firefighting equipment.

4.2 Adjacent Spaces

Typically, vehicle spaces are located under the accommodation area. Therefore, heat from vehicle spaces propagates to the adjacent spaces such as accommodation spaces. SOLAS II-2/Reg.9 requires A-30 boundaries on decks between vehicles spaces and accommodation spaces to ensure the time for evacuation. Such boundaries shall be approved by the Administration and tested in accordance with the IMO's Fire Test Procedure (FTP) Code referring International Organization for Standardisation (ISO) standards for testing, which require the use of the ISO Curve. However, experimental data shows that the heat release from an EV fire is greater than that from a conventional vehicle fire, which is the fire scenario assumed in the FTP Code. Therefore, the current structural fire protection would not be as effective as expected in the case of a real EV fire.

Through the discussion, the following measures with general comments were identified.

Application of Higher Rate of Fire Integrity

SOLAS II-2/Reg.9 requires A-30 boundaries on deck between vehicles spaces and accommodation spaces. Applying more than A-60 boundaries on the deck would be one of measures to prevent from fire spread to adjacent spaces.

- This may contribute to protecting crew from fire underside the accommodation space
- Application or upgrading to existing ships might be unrealistic

Application of the Hydrocarbon (HC) Curve for Test Required in FTP Code

Present fire insulation is tested in accordance with FTP Code, referring ISO curve. However, it could be further investigated if HC curves are better suited for such spaces. (Figure 7)

- This may contribute to protect crew from fire underside the accommodation space
- Application or upgrading to existing ships might be unrealistic
- This measure should be considered together with application of higher rate of fire integrity

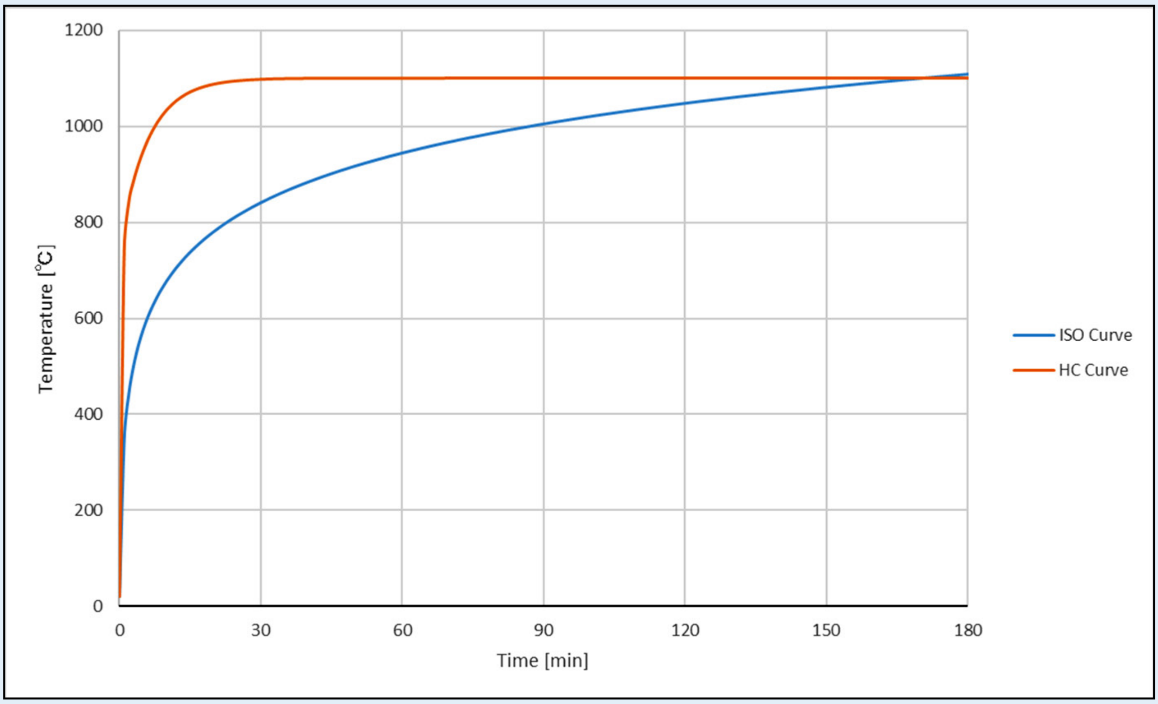

Figure 7: ISO Curve vs HC Curve

4.3 Evacuation

Upper deck above vehicle spaces is not protected by any insulation. Heat from vehicle spaces quickly propagates to the upper deck where escape routes, lifeboats and liferafts are located, and this may prevent crew from safe evacuating. The smoke from the fire in the vehicle loading space is discharged from the ventilator on the upper deck through the ventilation duct, and the smoke may also prevent the crew from escaping.

Furthermore, the current design of lifeboats is on the PCTC's uppermost deck. In view of the height and distance of lowering the lifeboat to the waterline, this would require additional time to deploy lifeboats compared to tankers, and general cargo vessels due to high freeboard. There would also be difficulties in lowering the lifeboat if the vessel is listing. To reduce the crew evacuation time, this could be solved by increasing the lifeboat's lowering speed or redesign the location of survival crafts nearer to the waterline. Having a reduced lowering height (distance) of lifeboat would reduce the lowering time. This will greatly help in fast evacuation, fast deployment of survival crafts and reduce the chance of injury, assuming crew would otherwise jump directly overboard from the uppermost deck. After the liferafts are launched, the crew would have to climb down the embarkation ladder (from uppermost deck to waterline).

Through the discussion, the following measures with general comments in addition to 4.2 were identified.

Fire Protection of all Escape Routes and Area Around Lifeboats and Liferafts on Upper Deck

Current escape routes on the upper deck and area around lifeboats and liferafts are not protected by any insulation. Applying A-60 or A-30 class on deck-heads underside the escape route or area around lifeboat and liferafts could protect the crew during evacuation. Otherwise, installing elevated walkways for escape.

- This may contribute to protecting crew from fire underside the accommodation space
- Application or upgrading to existing ships might be unrealistic

Water Spray System for Lifeboats and Liferafts

The system consists of piping and nozzle to cover the lifeboat and liferafts directly to ensure safe evacuation.

- This may contribute to protect lifeboats and liferafts from fire underside
- Application or upgrading to existing ships might be unrealistic

Water Spray Curtain System for Escape Route and Lifeboat and Liferafts

The system consists of piping and nozzle to create water curtain on all escape route (vehicle spaces and upper deck) or lifeboat and liferafts to ensure safe evacuation.

- This may contribute to protect escape route and lifeboats and liferafts from fire underside the escape route and lifeboats and liferafts
- Application or upgrading to existing ships might be unrealistic

Marine Evacuation System (MES)

Marine evacuation system (MES) (slide or chute system) is used together with liferaft. Liferaft onboard PCTC are also installed on the uppermost deck similarly to the lifeboat. The system could be used in place of embarkation ladder for crew to descend from uppermost deck to board the liferaft faster and in a safe manner. (Figure 8)

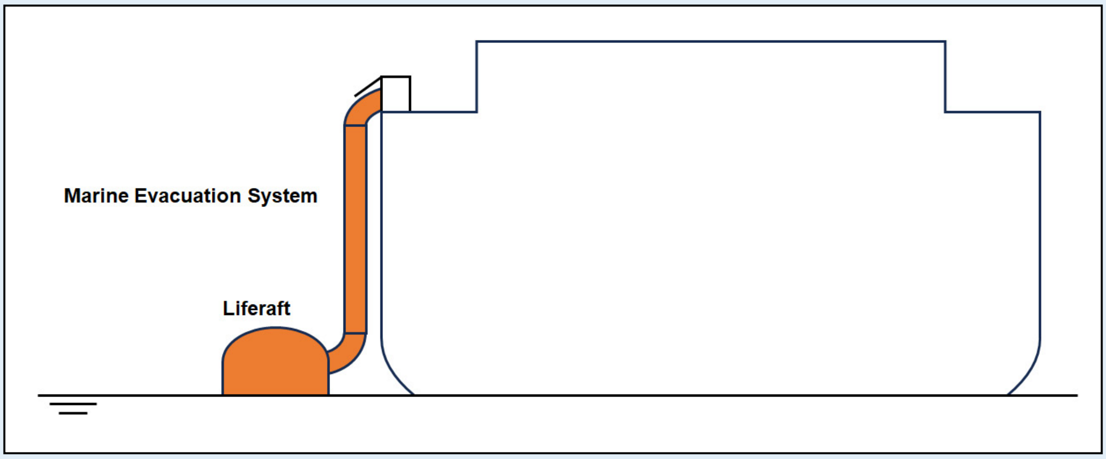

Figure 8: Image of Marine Evacuation System

- Most PCTCs consists of several cargo decks with incredibly high freeboard. Instead of the traditional embarkation ladder, MES can easily be deployed within seconds.
- This also greatly reduces time for crew to evacuate safely without any individual strength to climb any ladders.
- Combination of water spraying system for cooling side shell might be helpful.
- There is concern whether the MES equipment commonly used for passenger ships could be adapted to high freeboard vessels.
- MES may be seriously affected by a fire.

5. Manual Firefighting

Manual firefighting uses portable firefighting equipment such as fire hoses connected to hydrants and any other portable devices. It is extremely important to limit the number of affected vehicles. Therefore, cooling of adjacent EVs and extinguishing any fire not originating in the LiB are important to avoid thermal runaway. Manual firefighting should primarily be used in the early stages of a fire when it can effectively respond to or prevent the fire. It is not a reliable alternative and depends on the situation.

It is important to carry-out excess water removal operations at the same time as firefighting operations to prevent excess water accumulation and to monitor that scuppers discharging water are not clogged or otherwise blocked. The use of water during firefighting operations can in some cases have an adverse effect on vessel stability. It is possible that scuppers may become clogged or blocked by burnt residues or other materials in such cases. It is noted that, SOLAS Ch.II-2/Reg.20.6.1.4 contains requirements related to scuppers, and passenger ships have prescriptive requirements in relation to scuppers.

As a typical PCTC has several vehicle decks, if equipment is located only in the fire station, bringing the equipment from the fire station to the scene of the fire could be very far and require much time. The physical fitness levels of crew members can vary, and they may not always have the strength to carry equipment while wearing full firefighting gear. Therefore, fire equipment should be maintained in a state of readiness at all times to ensure it functions properly during emergencies.

EV fires are generally considered to be a type of electric fire because the voltage of EVBs can typically be quite high, ranging from 300 V to 400 V. Therefore, electric shock during manual firefighting may be considered. On the other hand, LASH FIRE published information sheets7. EVs have extensive safety systems that will automatically break the power and isolate the battery pack when a collision or a short circuit is detected. If the car is submerged in water or if water by other means would get into the battery pack or electrical system and cause a short circuit, then one would need to be physically between the positive and negative poles, or in contact with both conductors at the same time, to experience an electric shock, all of which are very unlikely.

In addition to the risk of electric shock, manual firefighting poses various other risks for crew members. Therefore, it is important to consider the safety of the crew, as discussed in Chapter 7.

Through the discussion, the following measures with general comments were identified.

Water Mist Lance

Water mist lance consist of piercing/penetration nozzle connected with hose or tube. This apparatus can penetrate a vehicle and a battery pack to discharge water inside the vehicle but not the battery pack for firefighting or cooling.

- Piercing the battery pack may induce electric shock and it may cause more harm than benefit.
- In addition, as with the vast majority of manual firefighting items, as access can be extremely difficult, the water mist lance that are portable and should be light and small as possible as the crew is required to carry the equipment to the scene of fire location.

Water Mist Applicator

Water mist applicator can create water shield to protect crew from radiative heat. Water mist applicator can also cool vehicles in fire.

- The crew needs to approach vehicles on fire and exposed by the radiated heat during manual firefighting. Water mist applicator can create water barrier that can block the radiated heat so that the crew operate manual firefighting safely.
- However, access remains an important issue. Therefore, a water mist applicator should be easy to use and its connection should be compatible with all fire hoses onboard.

- When a water-jet is required for an effective firefighting method, the water mist applicator cannot discharge jet water. Therefore, a typical fire hose nozzle which can easily be switched from spray to jet would be ideal. A typical fire hose nozzle in spray mode is more capable of cooling a bigger surface area than the water mist applicator.

Thermal Imager

Thermal imager is used to find hot spots.

- Thermal imager can be used to confirm whether EVs are sufficiently cooled down or not during firefighting.

CCTV with AI Function and IR Camera

See section 2

Fire Blanket

See section 4.1

Portable Boundary Cooling Device

Portable boundary cooling device such as water curtain hoses or similar device can connect to hydrants in vehicle spaces. Portable boundary cooling device is laid down between vehicles to create water curtain to shut off radiated heat to adjacent vehicles.

See section 4.1

Stowage Location of Firefighting Equipment

Fire hoses are located against boundary of vehicle spaces. Water mist lance, boundary cooling devices and some portable firefighting apparatus should be stored in the space easily accessible such as fire station.

- The equipment is provided on several alternative decks rather than fire station only.
- Fire hoses provided in the vehicle space are to be connected to hydrants to be ready to fight the fire manually.

Controlling or Monitoring Excess Water Accumulation During Firefighting

When using water for manual firefighting, accumulated water affects stability of the ships. Removal of excess water by good drainage system and extraction pump and monitoring that scuppers for discharging water are not clogged or otherwise blocked.

- Bilge water level alarms can be applied to bilge wells, which usually are present on board the vessel. Automatic operation of pump to discharge accumulated water directly from bilge wells (vehicle decks only) to sea, can be implemented, only in emergency situations.

6. Fixed Firefighting Systems

SOLAS II-2/Reg.20 requires one of the following fixed fire-extinguishing systems in vehicle spaces: gas fire-extinguishing system, high expansion foam fire-extinguishing system or a water-based fire-extinguishing system. There are ongoing research projects investigating the effectiveness of water-based, CO_2 and high expansion foam fire-extinguishing system for EV fires. The effectiveness of firefighting mediums and systems has not been fully demonstrated for EV fires. Early preparation and activation of the fixed fire-extinguishing system, which is triggered by early detection, is effective for suppress the EV fire as the fire would be more difficult to contain once fire developed. Frequent fire rounds or additional detection systems may be required, while the crew might need to be alert at all times and ready to fight fire.

As previously discussed, thermal runaway might be uncontrollable and difficult to stop the chemical reaction, which may cause severe impacts such as quick fire spread and uncontrollable situations. A fire involving a thermal runaway may exceed the expected performance specification of these fixed fire-extinguishing systems. Therefore, it is important to activate the system at early stage with combination of early detection of fire within vehicle spaces.

Table 1 shows comparison between fixed fire-extinguishing system for easy reference.

Table 1: Comparison between fixed fire-extinguishing system

System	Required Quantity of Fire-extinguishing Media	Effect	Characteristics
Gas	Maximum volume of protected spaces	• No cooling effect • Asphyxiation effect	• Vehicle spaces divided into more than two spaces insulated by A-30 insulation have less risk of fire spreading upward • Fire-extinguishing media is limited (Only 1 time discharge) • Broadly known system
High Expansion Foam	5 times of largest volume of protected spaces Or Enough for 30 minutes of full operation for the largest protection space	• Cooling and asphyxiation effect • Prevention of fire spread	• Enough quantity of fire-extinguishing media • Foam has the tendency to break down when exposed to heat and when subject to impact • Fire-extinguishing media is limited to 5 times or 30 minutes discharge
Water	Not limited	• Cooling effect • Prevention of fire spread	• Unlimited extinguishing media • Discharge water may accumulate in vehicle space, which may induce the loss of stability (not in the case of water mist)

6.1 Fixed Gas Fire-extinguishing System

A fixed CO_2 fire-extinguishing system is installed on board as the fixed gas fire-extinguishing system. There are two types of CO_2 fire-extinguishing systems: high-pressure and low-pressure. Low-pressure CO_2 fire-extinguishing systems are generally used for PCTCs because their cargo holds have a larger capacity compared to the cargo holds of other types of ships and require a large quantity of CO_2 gas, which is more efficiently liquefied and held.

As CO_2 systems including discharge piping are not complicated, these are widely used. The system does not require lots of maintenance and crews are familiar with the system for operation so that the system is readily available. However, it is lethal at high concentrations, meaning also that there may be time-delays to its activation. It should be noted there were cases of accidental release.

Generally, for PCTC installing the CO_2 system, vehicle spaces are divided into more than two spaces which are typical number of vehicle space of PCTCs for which the high expansion system is adopted. Therefore, there is less risk of fire spread upward compared to foam system since the boundary (deck) between the spaces are insulated by A-30. On the other hand, CO_2 gas within the vehicle space may leak into the atmosphere due to the tight condition of ramp way, slope way and steel door etc.

The Fire Safety System Code requires a capacity of fire-extinguishing media for maximum volume of protected spaces. This means that the fire-extinguishing media is limited (only 1 time discharge). Generally, there is a risk of reignition once there is fresh air ingress into the protected spaces. Therefore, increasing the amount of fire-extinguishing media, such as allowing two times or more CO_2 discharges, to keep oxygen depleted, would be one of measures. This requires increasing the number of CO_2 cylinders or volume of CO_2 storage tanks. On the other hand, compared with other fixed firefighting systems, CO_2 has asphyxiation and no cooling effect which make the thermal runaway of the EV batteries unstoppable. It should be noted that even if the amount of fire-extinguishing media increases and visible fire is extinguished, the thermal runaway of EVB continues and heat remains, and there is still a risk of reignition with fresh-air ingress into the protected spaces.

Since low-pressure CO_2 liquid for firefighting are often located on the upper deck of PCTCs, it is necessary to pay attention to the effect on vessel stability as the storage tank of CO_2 increases in weight to increase the number of discharging.

6.2 High Expansion Foam Fire-extinguishing System

Some PCTCs install high-expansion foam fire-extinguishing systems in vehicle spaces. High expansion foam extinguishing system extinguish fire through cooling and smothering effects. SSE 9/INF.1413) shows the result of high expansion foam fire-extinguishing system that high expansion foam can extinguish EV fire under a limited space and under ideal conditions. Tests in large spaces should be conducted to ensure foam can extinguish EV fire in vehicle space.

The system consists of more parts such as valve, pump, measurement instrument and so on, than other type of fire-extinguishing systems, which potentially may have more probability of fault. As the failure rate is not investigated during this study, the system's efficiency needs to be proven before it is considered for further use and implementation. SSE 10 noted that further discussion might be necessary on high-expansion foam systems, including revision of the test and approval provisions in Chapter 6 of the FSS Code and the Guidelines for testing and approval of fixed high-expansion foam systems (MSC.1/Circ.1384).

The FSS Code requires to have the capacity of fire-extinguishing media for five times of largest volume of protected spaces or enough for 30 minutes of full operation for the largest protection space. This means that the system has capacity of fire-extinguishing media to discharge several times. Furthermore, the amount of fire-extinguishing media may increase more than five times, which has less impact to increase volume of foam tank. Foam has the tendency to break down when exposed to heat and when subject to impact. Then, air pockets are formed, and EV may re-ignite. Foam system after discharging the foam concentration solution, the water going into the cargo via the nozzles may wash away foam bubbles causing to be ineffective.

6.3 Water-based Fire-extinguishing System

Water-based fire-extinguishing system is typically used for vehicle spaces of RO-RO passenger ships. The system discharge water underside whose piping and nozzles are located under the deck. Water-based fire-extinguishing systems provide continuous cooling and as such can be used for prevention of fire spread. As EV fires need to be cooled to avoid thermal runaway and fire spread, water-based fire-extinguishing system would be a better solution for PCTCs. On the other hands, Discharge water may accumulate in vehicle space, which may induce the loss of stability, apart from water mist systems where water accumulation is very limited. Crew should monitor that scuppers for discharging water are not clogged or otherwise blocked.

EV batteries are typically waterproof (otherwise they would be affected by weather), and water cannot directly reach the batteries when firefighting.

Abundance of supply is available if the fire pump is operational, and the nozzles are not clogged. Large capacity fire pumps for discharging water are required and a drainage system may be required. For water mist tests14),11) performed by ELBAS PROJECT, the cooling properties of water mist show an incredible ability to protect surrounding vehicles very shortly after the activation of the system. As an alternative, a water-based fire-extinguishing system may be complementary to the CO_2 system but not be high expansion foam system.

The system can be installed where the deck can incorporate a water sprinkler system which can project water under the vehicles. However, such equipment interferes with loading/unloading and may block water discharge. The damage to such a system is expected to happen during normal operations (loading/unloading).

7. Safety of Crew During Firefighting

In general, manual firefighting as specified in Chapter 5 is important to extinguish fires at early stage and prevent the fire spread but should only be used in case of a possible effective fire response or prevention. It is important to understand the characteristic of fire and kind of ship to proceed the manual firefighting and ensure the safety of crew during the firefighting. If situation or operational aspect allow the manual firefighting, Crew should be safe during firefighting. There are following characteristic of EV fire and PCTCs to be considered during manual firefighting by crews.

The tight spacing of vehicles during full loading may restrict crew from locating a fire, accessing its seat and preventing access to equipment for firefighting. Lashing belts prevent crew from approaching the vehicle, leading to injuries. Furthermore, the effects of smoke typically create situations where visibility is poor. It is important to ensure firefighter safety and make it as easy as possible for them to identify the source of fire. The nominal air-change rate of the ventilation system is important, but this also brings in high volume of oxygen sustaining the fire.

Lighting may not be available or sufficient. Usage time for the self-contained breathing apparatus (SCBA) provided to firefighters needs to be considered due to amount of time typically required for EVB cooling operations. The onboard usage time of such SCBA generally tends to be limited to between 20 and 30 minutes.

EVBs during thermal runaway emits toxic HF gas that is harmful to crew. Immediately Dangerous to Life or Health (IDLH) of HF gas is 30ppm, as provided by NIOSH[15]. Then, at the early stage of a fire, ship's crews may fight the fire with portable fire extinguishers without wearing proper firefighting personal protective equipment (PPE)/SCBA. As a result, there are chances for the ship's crew to inhale the toxic gases. On the other hand, it should be noted that HF is highly reactive, and its concentration will reduce very fast.

Crews' physical and mental states should be considered to ensure crew safety during firefighting. It should be noted some crew may panic whilst firefighting.

Ventilation Control

Activating mechanical ventilation continuously to vent smoke for ensuring visibility of firefighters.

In addition to Chapter 3, the following comments were provided:

- Ventilation control, especially one-way ventilation, contributes to clear visibility during manual firefighting and to find the seat of fire
- It should be noted that supplied air will provide sufficient oxygen to vehicles in fire adjacent to the ventilator
- The crew or management company should understand the location of ventilators and prepare the firefighting tactics and strategies for using ventilator for the case if urgent reasons to access. But this should not be prescriptive.
- Vent fans for vehicle decks are usually interchangeable between "exhaust" and "supply". However, if emergency stop switches are activated automatically for these vent fans during a fire alarm, the crew will have to reset and reactivate the fans. Crew members may accidentally switch to "supply" mode, which will then cause the fire to spread even further. Perhaps an interlocking system can be applied to the fans.

Proper or Specific Personal Protection Equipment

Fire Protective clothing to be highest standard available in market, such as EN 469 level 26), 12). Flashlight for clear visibility during firefighting. Communication tools with microphone and speaker integrated or attached with helmet.

- Fire suits are to be inspected regularly for damage or wear, and fire hood, which is worn internationally by all professional firefighters, should also be included as part of the protective clothing to protect from burns around ears and neck area.
- Personnel should be trained in the proper use and maintenance of PPE, including donning and doffing procedures, and how to identify when it needs to be replaced.
- Each firefighter should have their own communication device with microphone and speaker and flashlight integrated in helmet or breathing mask so that the firefighter can work with both hands. The device should also be IP rated and Ex-proof certified.

Sufficient Spare Cylinders of SCBA or Appropriate Devices for Recharging

Spare cylinders of SCBA or recharging device will be provided for the case of amount of time typically required for EVB cooling operations. The onboard usage time of SBCA generally tends to be limited to between 20 and 30 minutes.

- As manual firefighting takes times, such as preparing (connection of hoses), finding vehicles in fire, approaching, etc., such sufficient spare cylinders or recharging device can address prolonged manual firefighting
- Typically, professional firefighters have several teams to take over once the "on scene firefighters" have reached the minimum alarm for SCBA. Therefore, the crew may also need to rotate with rest periods, and the vessel may have four sets of firefighting outfits.

8. Safety Management System Training and Drills

Proper training should be conducted, and procedures/guidance manuals should be available on board to assist the crew in taking appropriate actions in case of a fire. It is also important to establish firefighting plans and implement daily fire drills for effective firefighting operations expected to take long periods of time. Everything on board the vessel is bound by the company safety management system. The training and drills could be linked to ISM code Element 8 (emergency preparedness).

Proper Training and Drill

With consideration of the characteristics of EVs and EV fire, proper training and drills containing the following should be conducted:

- Knowledge of fire and firefighting
- Familiarization of the firefighting equipment and system
- Input the importance of early detection and fire prevention
- Knowledge of potential risk and/or injuries
- Tactics and strategies

- The crew should know the characteristics and behaviour of fire including EV fire and understand what will happen after every few minutes on development of fire. This kind of training and drill can maintain the crews' mental state in emergencies.
- Crew should be familiar with the firefighting equipment for attacking the fire correctly such as manual firefighting using water jet or spray mode, correct places required for boundary cooling device and proper ventilation, and operation of fixed fire-extinguishing system. Additionally, crews should be trained in effective firefighting methods.
- The potential risk element needs to focus on the special characteristics of EVs, including their hazards, battery usual location, the potential to vent gas or reignite.
- Tactics and strategies will be able to make important decisions and give the right precise orders for effective firefighting.

Establishing Firefighting Plan (Procedures/Guidance) for Crew Available on Board

With Consideration of the characteristics of EV and EV fire, establishing firefighting plan containing the following.

- Procedures from detection to evacuation and flow chart
- Tactics such as how to approach the fire and what action to be taken

- Communication for bridge team to seek assistance from vessels in the vicinity and shore is suggested also be included as well.

Summary

The IMO is currently working on the development of the mandatory regulations for transportation of new energy vehicles including EVs with a completion target year of 2027. Some delegations have proposed regulatory text and submitted information papers at IMO, but the framework of the regulation has not yet (as of November 2024) been developed nor discussed.

There are no regulations dedicated for safe carriage of EVs at the moment. Therefore, MTF carried out a study on recent research to supplement the discussion in IMO and provide stakeholders with beneficial information on safe carriage of EVs in PCTCs. With the aim to assist stakeholders' considerations for safe carriage of EVs, this report includes information on the characteristics of an EV fire, including the thermal runaway and vessels' layout, while it discusses the necessity of measures including early detection, prevention of fire spread, firefighting, evacuation, training and drill. The report does not assess the efficacy of the measures and capability of implementation on existing ships; however comments have been included with both the advantages and disadvantages of the measures. Some measures can be implemented for several purposes, such as portable boundary cooling devices for prevention of fire spread and manual firefighting.

Transportation of EVs has introduced new type of fire characteristic, namely thermal runaway, which is a typical phenomenon of LiBs. Thermal runaway, which may be the result of internal defects or thermal, mechanical or electrical abuse, is an exothermic chemical reaction. This reaction is not possible to stop once initiated. During thermal runaway, flammable gases and toxic gases are emitted from the EV's battery.

A thermal runaway may cause quick fire spread and uncontrollable situations if no appropriate measures are implemented. Early response in combination with effective firefighting can consequently reduce the fire damage to the vessel and cargo and avoid further catastrophic consequences. For achieving an early fire response, it is important to detect fires in the vehicle space at the earliest possible stage. An EV BMS releasing audible or visual alarm when detecting some abnormal condition is expected to achieve early detection however vehicle manufacturers have not yet developed such a functionality. Regarding firefighting, research is still ongoing, however it seems that water-based solutions may have the best cooling effect and are not limited in capacity, but stability related issues should also be considered.

It seems that proper training and drill related to EV and EV fire has not been established. To enhance the safe carriage of EV, some measures may be taken by ship owner, and the project also specified the measures. Therefore, proper training and drill including the knowledge of the characteristics of EV and EV fire, the familiarization with the firefighting measures and proper tactics of firefighting is important and should be addressed in the SMS.

To conclude, this report specifies the characteristics and points to note concerning fires involving electric vehicles, and the fire safety measures based thereon. Measures were specified with general comments, which may be helpful for the consideration by stakeholders to tackle EV fire in PCTC. This report wishes to provide a starting point for development of safe carriage of EVs in PCTC, and this work is aimed to provide the information to the IMO and industries for further development. While MTF focused the work on the safe carriage of EVs on PCTCs, it is acknowledged that EVs should also be carried safely on other ship types and that similar considerations might apply.

Disclaimer

While the advice given in this report has been developed using the most up-to-date information currently available, it is intended to be used solely as guidance. No responsibility is accepted by MTF, or its members, for any consequences resulting directly or indirectly from the adoption of any of the information in this report.

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	Tan Yong Meng

For any enquires about this report please send a message to:
contact@maritimetechnologiesforum.com.

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