EFFECTS ON PASSENGERS, SHIP AND CREW IN THE EVENT OF AN ACCIDENT CAUSED BY AN ALTERNATIVELY POWERED VEHICLE
Work Packages 2.3 and 2.4

ALBERO Project

Institut für Sicherheitstechnik/Schiffssicherheit e.V.

Evaluation of the potential impact on passengers, ship and personnel in the event of an accident caused by an alternatively powered vehicle (WP 2.3 and WP 2.4)

Institut für Sicherheitstechnik/Schiffssicherheit e.V.

1. Ship accidents as a cause for the damage of an alternatively powered vehicle onboard

As a result of the work carried out in WP 2.2 of the ALBERO Project accidents, vehicles can mainly be damaged during

- collisions
- fires on car deck
- slipping of cargo in heavy weather conditions.

As a result of the work carried out in WP 1.4 of the ALBERO Project external influences can cause damage to batteries of electric cars by

- mechanical damage
- overheating.

Combining these two analyses, it can be seen that in each of the aforementioned marine accidents, the battery of an electric vehicle can be damaged in such a way that a thermal runaway with a subsequent fire can occur. For gas-powered vehicles, these types of accidents would also be a starting point for further hazardous situations. Conventional vehicles could also be damaged in such a way that consequential hazards could occur.

	collision	**fire on car deck**	**slipping of cargo**
mechanical damage	yes	-	yes
overheating	-	yes	-
expected consequence - accident of an electric vehicle	fire very likely	fire very likely	fire very likely
expected consequence - accident of an gas-powered vehicle	release of gases, fire possible	release of gases, fire possible	release of gases, fire possible
expected consequence - accident of a conventional vehicle	release of fuel, fire cannot be excluded	fire or explosion probable	release of fuel, fire cannot be excluded

table 1: possible consequences in the event of damage to an alternatively powered vehicle as a result of a an accident of the vessel

2. Vehicle-specific causes for an accident on board

Possible causes originating from the vehicle itself are primarily:

- mechanical damage due to an accident prior to boarding the ship.
- technical defects (e.g. in electronics), subsequently short circuits or local overheating of parts
- improper charging of electric vehicles (use of unsuitable cables or unsuitable connectors)
- incorrect behavior of the driver (smoking in the vehicle, unsecured transport of hazardous materials)

	mechanical damage due to previous accident	technical defects, internal short circuit	incorrect charging	incorrect behavior of the driver
expected accident for an electric vehicle	release of gases possible, fire possible	release of gases possible, fire possible	release of gases possible, fire possible	fire possible
expected accident for a gas-powered vehicle	release of gases or a fire cannot be excluded	release of gases or a fire cannot be excluded	-	fire possible
expected accident for a conventional vehicle	release of fuel, a fire cannot be excluded	release of fuel, a fire cannot be excluded	-	fire possible

table 2: possible consequences in the event of damage to an alternatively powered vehicle as a result of internal malfunctions of the vehicle

3. Evaluation of accidents concerning alternatively powered vehicles

The statistical studies in WP 2.2 have shown that electric cars do not burn more frequently than conventional cars, and a large amount of the accidents are self-inflicted by humans. What makes fires of electric cars or alternatively powered vehicles to be a special risk yet?

a. course of fire

In almost two third (42) of all 65 cases listed in WP 2.2. the sources clearly pointed out that extinguishing a fire on the electric car took a very long time because the fire was difficult to extinguish, in 6 cases of these it was clearly noted that backfires occurred again and again, in one case even 2 months after an accident! In 7 cases, the vehicle could only be extinguished by completely immersing in a container filled with water, there is only one case with an overlap to the "backfire cases":

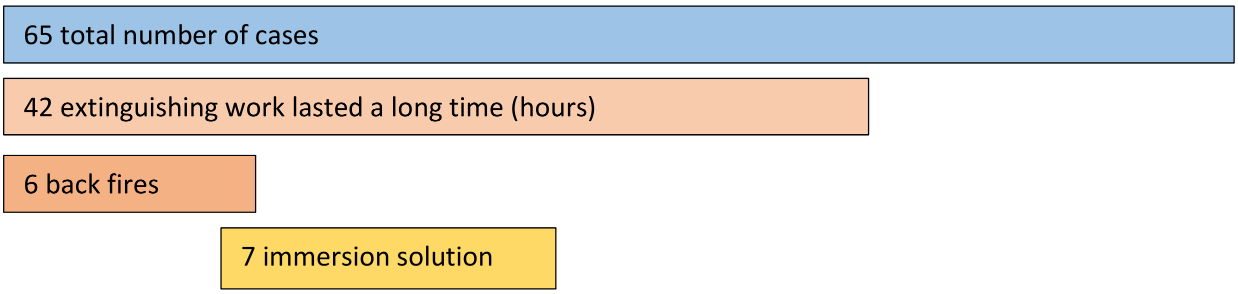

Figure 1: Proportion of prolonged extinguishing operations in firefighting of electric cars

Electric cars and systems with (large) Li-Ion batteries in general burn for a particularly long time. One of the reasons for this is that the individual cells built into the battery - often hundreds or even thousands - only gradually burst in the event of a fire, and the electrolyte and gases released in each case feed the fire. The risk of the fire spreading to neighboring materials must therefore be regarded as higher than with conventional cars. This applies in particular to the transport situation on a ferry.

Although various statements can be read that Li-Ion batteries burn hotter than gasoline or diesel, no publication could be found to scientifically prove this statement. The adiabatic combustion temperature in the air of petroleum fuels is given as approx. 2100 °C, for pure lithium as 2438°C but in pure oxygen [1]. No value was found for Li-Ion batteries. In fire tests with Li-Ion batteries a maximum flame temperatures of 900 °C were measured [2]. In other fire tests [3] the heat release rate for Li-Ion battery fires was determined and the value of 112Wh was found for the combustion of 5 single cells. This publication contains the following statement in the discussion:

The nominal energy content of the five-cell pack is 112 Wh. Electrified vehicles typically have 10 to 30 kWh batteries, and extrapolating our values to the energy released for this size of battery pack gives a total heat rate of 700 to 2100 MJ, which is equivalent to a fire of about 20 to 50 l of gasoline.

The energy released depends on the state of charge. In another publication [4], the heat release rate of a 100 kWh battery was determined to be between 17 and 75 kJ/Wh, depending on the state of charge - according to the publication, comparable to the fire of 70 - 300 l of gasoline.

Comparability of the values is difficult, also due to different units used. Some refer to the area of distributed material, some to the mass of burned material. In [5], for example, a calorimeter is used to determine a released heat of 800 kWh for 58 l of gasoline. However, a work that clearly proves experimentally and scientifically that Li-ion batteries burn hotter than gasoline or diesel could not be found.

The maximum temperatures to be expected for propane and methane (in the event of a fire in an LPG or LNG vehicle) are somewhat lower than for diesel fuel (2140°C) at approx. 1970°C according to [1].

b. (still) insufficient extinguishing agents

Currently, water is considered the best extinguishing agent for electric vehicles - the better term in this case would probably be coolant. Other extinguishing agents are currently being investigated. On board ships, however, the extinguishing agent water must be evaluated differently than ashore: too massive or incorrect entry of extinguishing water may have a negative impact on the ship's stability. Additionally, seawater is usually used as extinguishing water on board. Depending on the salinity, a high conductivity can be expected here, which may additionally accelerate the dangerous processes in a damaged car battery. However, for the area considered in the ALBERO Project (Baltic Sea), this effect should be negligible compared to the cooling effect to be achieved. The water spray extinguishing systems currently installed on car decks of ro-ro ferries, even for conventional vehicles, are designed only to contain a fire in a way that it cannot spread to other vehicles, but not to extinguish the fire. Based on everything known so far about electric vehicle fires, it can be assumed that this design is not sufficient to contain the spread of fire from an electric vehicle.

Ashore, gas-powered vehicles are usually allowed to burn out unless it is possible to stop the escaping gas. The possibility of containing a gas fire with a water spray flooding system currently installed on board is to be estimated lower than for conventional vehicles. In principle, it must be assumed that the vehicle will burn at least as long as gas is still being released. Once a gas vehicle starts burning, the risk of fire spreading must therefore be assessed as high. However, if a gas is already burning, there does not exist any risk of explosion.

c. release of gases

Numerous studies have already been carried out on the release of gases from Li-Ion batteries. A summary is already available in the document "Gas development during thermal runaway" from WP 1.4. The gases to be expected here can be very corrosive or highly toxic even in low concentrations. In the event of a fire, further highly toxic gases (hydrogen fluoride HF) can be expected, which can react with extinguishing water to form corrosive compounds. Otherwise these are gases do not occur in common gas fires. Accordingly, respirators or normal firefighting clothing may be affected. Crew members assigned to firefighting brigades may need to be equipped with special protective gear for such a fire. The type of protective clothing that would actually be practicable in this case has not been conclusively researched and determined yet.

The release of gases from gas-powered cars on enclosed or semi-enclosed car deck poses a significant fire and explosion hazard; this applies in particular to LPG vehicles, since the lower explosion limit for propane is relatively low at 1.7% by volume, i.e. even the release of small quantities produces an explosive gas mixture. A health hazard due to acute poisoning, on the other hand, is considered to be low, since propane or methane are not very toxic gases. In that cases the main health hazards come from the displacement of oxygen by the released gas.

d. Release of pollutants

Fire tests with vehicle batteries in a tunnel [6] showed that in the event of a fire in batteries, larger quantities of heavy metals are released with fire aerosols and are deposited in the immediate vicinity. Especially for cobalt, lithium, and manganese, values were measured that were significantly above the IDLH value (immediately dangerous to life or health, IDLH). For manganese, the value was 2.2 times higher, for cobalt 55 times higher and for Li even 600 times higher. Other publications also point to the release of heavy metals in the event of a fire in electric cars [7]. This is significantly different compared to conventional fires and gas fires!

4. Effects on passengers, ship and crew

Taking into account the aspects listed above, the effects coming from accidents with alternatively powered vehicles can be summarized as follows:

	effects on the ship compared to fires of conventional vehicles	**effects on passengers/crew**	**effects on crew (task forces)**
electric car on fire	fire hazard not as high at all, but a high risk of fire spreading, since - the fire is more difficult to extinguish - the ejection of individual cells is possible - the spray water systems are not sufficient for containment maximum temperatures reached are not higher, but the total heat release is higher due to longer fire, a massive use of extinguishing water necessary	higher risk for danger to life due to a faster spread of fire, contamination by released heavy metals, toxic inorganic compounds	approach for firefighting operations is more difficult, since - an ejection of individual cells is possible - the release of corrosive, very toxic gases (fluorine and phosphorus compounds) is possible - the release of toxic aerosols (heavy metals) is possible Usual protective clothing may not be sufficient!

	conclusion: **greater damage can be expected, faster fire spread, problems with stability due to extinguishing water are possible, extinguishing water can have a corrosive effect on ship structure**		
gas-powered car on fire	fire hazard not as high at all, but a high risk of fire spreading, since - the fire is more difficult to extinguish - long jet flames are possible - the spray water systems are not sufficient for containment Maximum temperatures reached are not higher **conclusion:** **greater damage can be expected, a faster spread of fire can be expected**	Higher risk for danger to life due to a faster spread of fire	approach for firefighting operations is more difficult, since - long jet flames are possible
release of gases from a defective traction battery	quantities of simultaneously released gases are relatively low, as cells burst one after the other, risk of explosion and fire if ignition sources are nearby	expected gases partly toxic that there may be a health hazard in the immediate vicinity! explosion hazard	
release of gases coming from a LPG car	relatively large quantities are released very quickly, danger of explosion and fire if ignition sources are nearby	propane/butane gas mixture has a narcotic up to asphyxiant effect in very high concentrations, inhalation of such high concentrations is relatively unlikely, even if the tank is blown off main danger to personnel: sudden ignition or explosion	
release of gases coming from a LNG car	quantities of gas are released over a longer period of time, as LNG only gradually vaporizes risk of explosion and fire if ignition sources are nearby	methane has a suffocating effect in very high concentrations, inhalation of such high concentrations is relatively unlikely, even if the tank is blown off. main danger to personnel: sudden ignition or explosion.	

Sources:

[1] https://en.wikipedia.org/wiki/Adiabatic_flame_temperature#cite_note-Physics_p._15-51-3

[2] https://www.researchgate.net/publication/270909577_The_combustion_behavior_of_large_scale_lithium_titanat_battery

[3] https://www.mdpi.com/2313-0105/2/2/9; F. Larsson, P. Andersson, B.-E. Mellander: Lithium-Ion Battery Aspects on Fires in Electrified Vehicles on the Basis of Experimental Abuse Tests, Batteries 2016, 2, 9; doi:10.3390/batteries2020009

[4] https://ec.europa.eu/jrc/sites/jrcsh/files/thermal-propagation-in-lithium-ion-batteries.pdf

[5] https://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/summary_of_output/journal/IJEPBFC/V9/p59-64.pdf

[6] https://hagerbach.ch/fileadmin/user_upload/news/Road_tunnel_safety_Hazards_of_electric_vehicle_fires_Mellert_2018.pdf

[7] https://www.brandskyddsforeningen.se/globalassets/brandforsk/rapporter-2000-2015/matning-av-miljopaverkan-av-brander.-ecotox/bf_700_121_rapport.pdf