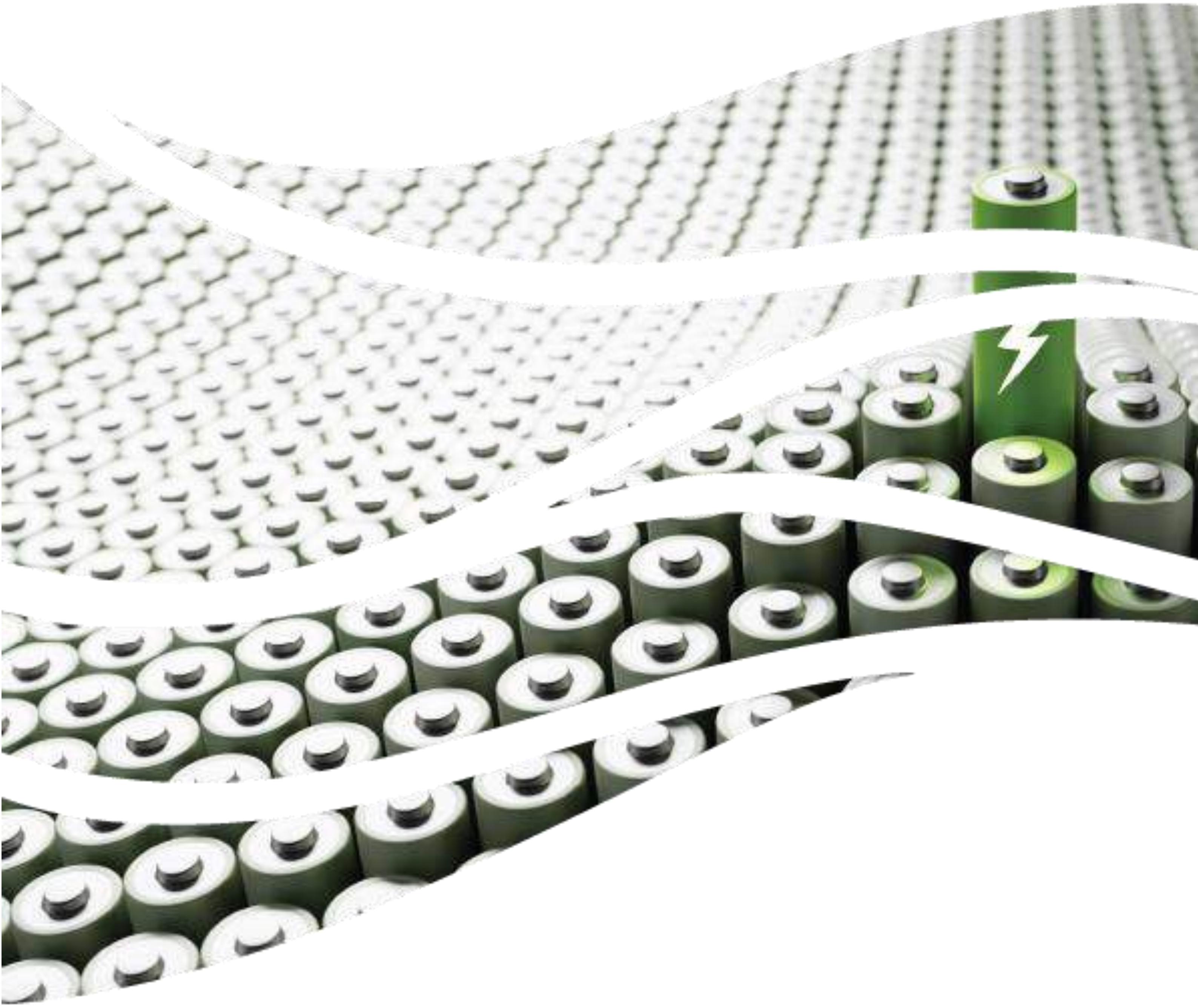
POTENTIAL DAMAGES & LIABILITIES ARISING FROM A SHIPPING INCIDENT INVOLVING A LI-ION BATTERY POWERED VESSEL

Report for the International Group of P&I Clubs Alternative Fuels Working Group

July 2024



I. Introduction

ITOPF, as part of the International Group of P&I Clubs Alternative Fuels Working Group, has been requested to provide a series of brief summary documents to describe the expected fate and behaviours of the following alternative fuels and to outline the possible damage and liabilities that may arise from incidents involving vessels carrying these fuels as bunkers.

The alternative fuels covered are:

- Biofuels
- Liquefied Natural Gas (LNG)
- Liquefied Petroleum Gas (LPG)
- Hydrogen
- Ammonia
- Methanol

Other marine propulsion technologies covered by the IGP&I Alternative Fuels Working Group include:

- Lithium-ion (Li-ion) Batteries
- Nuclear

This summary report prepared by ITOPF shall focus on **Li-ion Batteries** as a non-traditional method of marine propulsion.

A review of Nuclear as a means of vessel propulsion will be described separately in a report authored by ENCO.

Li-ion batteries are becoming increasingly prevalent in many industries, with applications ranging from small electronic devices to electric scooters, electric vehicles (EVs) and to larger energy storage units. Li-ion batteries have been shipped in packaged form and/or as part of electric vehicles for many years. They are now a viable option for energy storage systems in the shipping industry, particularly for smaller vessels. Use of battery propulsion reduces or removes the need for traditional bunkering of traditional oils or alternate fuels i.e. ammonia, hydrogen, LNG, methanol etc.

As of 2019, 169 ships were operating with Li-ion batteries as part of their propulsion mechanism, with a further 104 under construction. The number of vessels under construction is expected to increase[1]. The majority of these vessels are car/passenger ferries (95 operating and 75 under construction in 2019), with a smaller proportion made up of offshore supply vessels (27 in operation and 19 more under construction in 2019). With the rise in commercial viability and therefore uptake of Li-ion battery powered vessels, a better understanding of the risks associated with this propulsion technology is required. The understanding of these risks will then assist in the formulation of effective preparedness strategies that will play a vital role in the event of an incident.

At least half of existing vessels with Li-ion batteries utilise the technology as part of a hybrid system paired with a traditional combustion engine using conventional fuels (or possibly biofuels). These hybrid systems typically have smaller battery packs and are primarily charged via the onboard combustion engine or through regenerative braking. Approximately a quarter of Li-ion battery vessels use a plug-in hybrid system, which typically have larger battery packs capable of storing more energy and are charged from external 'plug-in' sources onshore in addition to onboard charging. Approximately 20% of vessels using Li-ion batteries use a pure-electric system, where the vessel runs entirely on electric power without any combustion engine backup[1]. Li-ion batteries within the hybrid systems may be incorporated as part of an automated power management system that optimises fuel oil consumption and reduces emissions, or as a back-up power system which can provide an emission-free alternative for complying with increasingly strict port requirements[2].

Although they currently constitute a relatively small proportion of all Li-ion battery fuelled vessels, fully electric systems are increasing in popularity. They are limited presently to small coastal vessels due to the restricted power density and battery life span of current Li-ion battery technology. Whether a vessel is fully-electric or a

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[1] SAFETY4SEA. 2019 *"352 confirmed ships are using battery installations"*. [online] Available at: https://safety4sea.com/352-confirmed-ships-are-using-battery-installations/. [Accessed 19th February 2024]

[2] Chi Tan, Woei. 2023. "*Battery-powered ships: Moving from the drawing board to the seas*" [online] Available at https://axaxl.com/fast-fast-forward/articles/battery-powered-ships-moving-from-the-drawing-board-to-the-seas#:~:text=Integrating%20lithium%2Dion%20batteries%20into,that%20ships%20can%20sail%20safely. [Accessed 5th April 2024]

plug-in hybrid, infrastructure must be in place to enable these vessels to recharge while in port, ideally using renewably generated electricity to maximise emission reduction.

II. Li-ion Battery Properties

Li-ion batteries are electrochemical devices that are integrated into the larger electric infrastructure within the vessel. The Li-ion battery stores and delivers electrical energy through a reversible reaction in which Li+ ions are shuttled between two electrochemically dissimilar electrode materials (an anode and a cathode) separated by an electrolyte solution and physical "separator" (Figure 1).

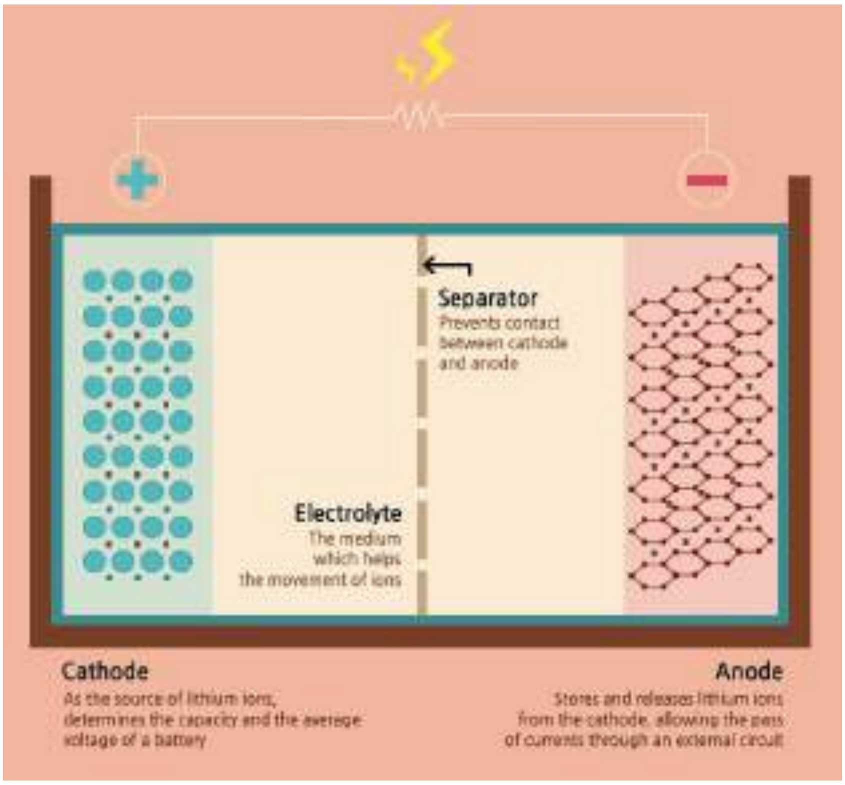

Figure 1: The four components of Li-ion battery[3].

The electrolyte solution is typically comprised of lithium salt dissolved in an organic solvent such as ethylene carbonate/diethyl carbonate. A number of additives can be included depending on the desired properties of the battery. The separator provides a physical barrier between anode and cathode, preventing short circuit during normal operation of the battery and is typically made of polyethylene or polypropylene[3].

Most cathodes are constructed from graphite, but the composition of the anode can vary, typically giving the batteries their name. Examples include lithium cobalt oxide (LCO), lithium nickel manganese cobalt oxide (NMC), lithium iron/ferrous phosphate (LFP), and lithium cobalt aluminium oxide (LCA) batteries. The composition of the Li-ion battery determines its power density, lifespan, safety and cost[4,5]. For example, LCO batteries have high energy density but have short life cycles so are rarely used in the maritime industry. LFP batteries are more

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3 Samsung SDI. 2018. *"The four components of a Li-ion Battery"*. [online] Available at: https://www.samsungsdi.com/column/technology/detail/55272.html?pageIndex=1&idx=55272&brdCode=001&listType=list&searchKeyword= [Accessed 12th April 2024]

4 Marine & Offshore BUREAU VERITAS. 2021. *"Entering a new era for battery-powered ships"* [online] Available at: https://marine-offshore.bureauveritas.com/insight/entering-new-era-battery-powered-ships#_ftn1 [Accessed 21st February 2024]

5 MAN Energy Solutions. 2019. *"Batteries on board ocean-ocean going vessels"*. [online] Available at: https://www.man-es.com/docs/default-source/marine/tools/batteries-on-board-ocean-going-vessels.pdf?sfvrsn=deaa76b8_14 [Accessed 12th April 2024]

stable therefore reducing the risk of thermal runaway, and have a longer life span, but a lower energy density. NMC batteries are often utilised in electric vehicles and in the maritime industry as they have a long life cycle and a satisfactory energy density[5].

The smallest unit of a Li-ion battery (i.e. where the reaction takes place) is the cell. Many cells together make a string or module, many strings or modules together constitute a battery or battery pack. In cases where batteries are used as the sole propulsion mechanism for a vessel, a large energy storage system (ESS) will be constructed, made up of several batteries. For example, one of the largest battery powered ferries built to date has an ESS of 40 MWh that is used to power eight electric motors and subsequently eight waterjets (Figure 2)[6]. In comparison, 1 MWh of energy is the equivalent of burning approx. 300 L of petroleum liquids[7], or the average energy consumption of a US household for over a month[8].

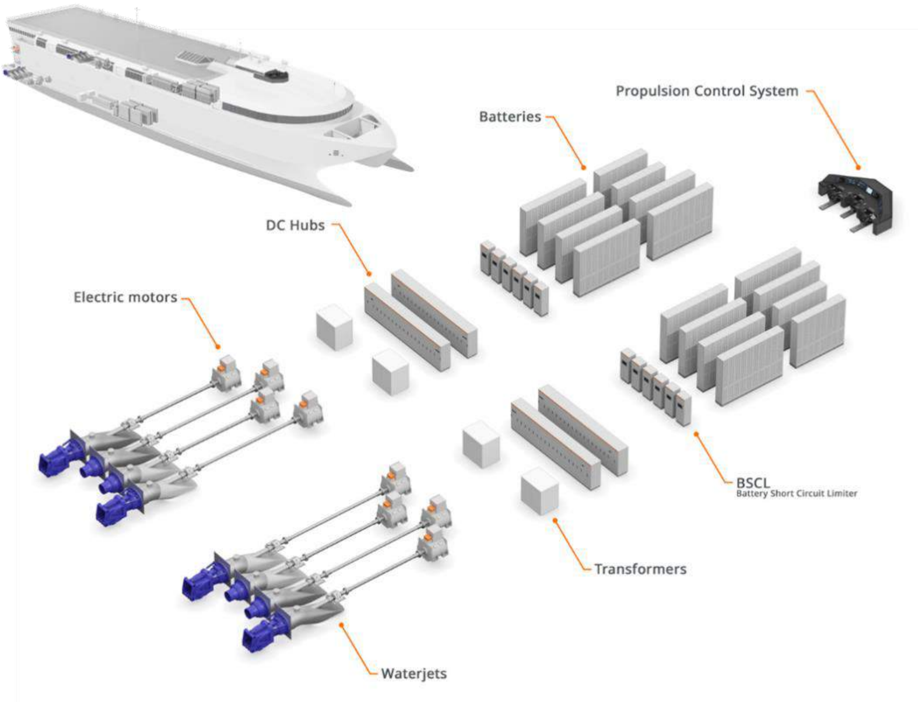

Figure 2: Wärtsilä battery powered ferry[6].

III. Thermal Runaway of Li-ion Batteries

What is a thermal runaway?

Li-ion batteries can be considered as inert when functioning normally and do not pose the same risk of pollution as the fuel oils in traditional combustion engine propelled vessels. However, if damaged, Li-ion batteries have the potential to undergo thermal runaway, to generate large vapour clouds and to result in vapour cloud explosions.

Thermal runaway is an internal exothermic reaction resulting in the release of explosive and toxic gases. Within a battery cell, the chemical reactions that store and release electrical energy produce small amounts of heat. This is usually regulated by natural heat dissipation, or by active thermal management systems. The point at

[6] Wärtsilä *"Case Incat Tasmania"*. [online] Available at: https://www.wartsila.com/marine/products/ship-electrification-solutions/case-incat-tasmania. [Accessed 23rd April 2024]

[7] US EIA *"How much coal, natural gas, or petroleum is used to generate a kilowatthour of electricity?"*. [online] Available at: https://www.eia.gov/tools/faqs/faq.php?id=667&t=6. [Accessed 10th July 2024]

[8] Freeing Energy *"What can you do with a megawatt-hour?"*. [online] Available at: https://www.freeingenergy.com/what-is-a-megawatt-hour-of-electricity-and-what-can-you-do-with-it/. [Accessed 9th July 2024]

which a battery will go into thermal runaway cannot be predicted with certainty but is more likely to occur after excessive heat exposure, if the battery is physically damaged or is overcharged as described in Figure 3.

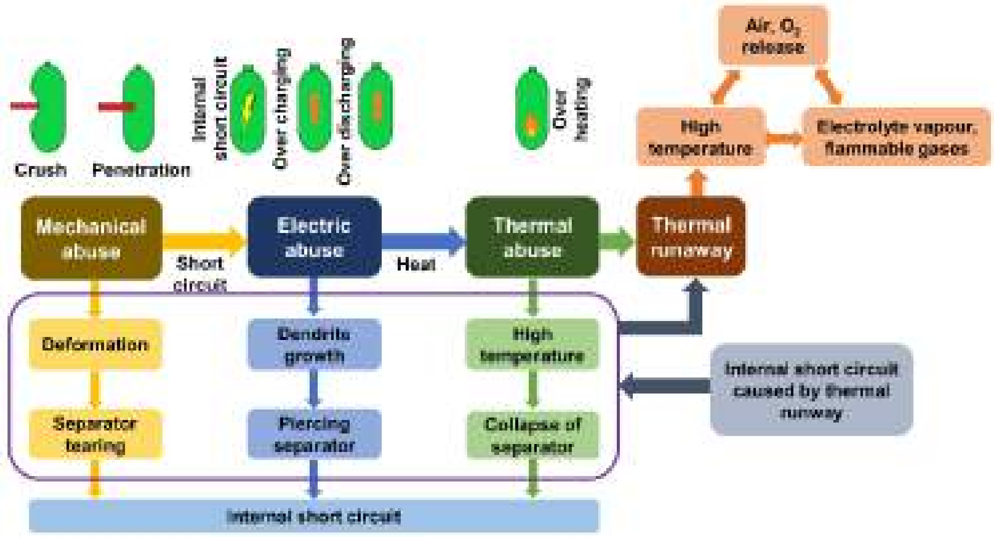

Figure 3: Scenarios that can lead to Li-ion battery failure[9].

Increased heat production increases the reaction rate, in turn producing more heat, which then leads to uncontrolled positive feedback: the thermal runaway. The sharp rise in internal battery temperature causes the inner structures of the battery to destabilise and degrade, which leads to failure of the battery[10]. This will result in extremely high temperatures and may lead to jet-like flames emanating from the battery on very short timescales (seconds to minutes). This is a self-sustaining heat source that is challenging to extinguish, with the potential to reignite hours to days after the initial flames have been extinguished. If a battery undergoes thermal runaway, the resulting flames and/or explosion are likely to result in propagation of thermal runaway to neighbouring battery units.

When a Li-ion battery enters thermal runaway, prior to ignition, a large white vapour cloud will be produced. The greater the power density of the battery, the greater the amount of gas likely to be produced.

Vapour cloud composition

The composition of this vapour cloud will vary depending on many factors, including the state of charge (SOC), the electrode material, the electrolyte and battery age[11]. Vapour is likely to be primarily made up of hydrogen and carbon monoxide, but may also contain carbon dioxide, sulphur and nitrogen oxides, ethane, methane, ethylene, propane, hydrochloric acid, hydrogen fluoride, hydrogen cyanide, and small droplets of organic solvents[12].

Given the variety of gases included in the vapour cloud, the cloud may stratify depending on the gas' individual relative vapour densities. However, these gases tend to mix quickly, particularly in small, confined spaces. During early stages of thermal runaway, the gases produced will be cooler and therefore heavier than air and likely to

[9] Kaliaperumal, M. et al. 2021. "*Cause and Mitigation of Lithium-Ion Battery Failure—A Review*". Materials, 14 (19), 5676; DOI: https://doi.org/10.3390/ma14195676

[10] Shahid, S., Angelin-Chaab, M. 2022. *"A review of thermal runaway prevention and mitigation strategies for lithium-ion batteries"*. Energy Conversion and Management: X. Vol.16, 100310. DOI: https://doi.org/10.1016/j.ecmx.2022.100310

[11] Qiu, M., Liu, J.,Cong, B., Cui., Y. 2023. *"Research Progress in Thermal Runaway Vent Gas Characteristics of Li-Ion Battery"*. Batteries, 9(8), 411. DOI: https://doi.org/10.3390/batteries9080411

[12] DNV-GL. 2019. *"Technical Reference for Li-ion Battery Explosion Risk and Fire Suppression."* DNV-GL. Høvik, Norway

form a plume at ground level. Gases produced later in the thermal runaway process are likely to be warmer and therefore lighter than air and will rise upwards. Gas production is approximately halved if there is visible combustion outside the battery[12].

Some examples of the relative vapour specific gravities of gases that are likely to be released are given in Table 1, alongside the relative volume of gas that is expected.

Table 1 - Volumes of primary gases of concern with regard to toxicity[12].

Toxic gas	Maximum observed % of vapour cloud composition	Immediately dangerous to life or health (IDLH) limit (ppm)	Vapour specific gravity at (20 °C)	Behaviour (at 20 °C)
Carbon monoxide (CO)	38 %	1200	0.97	When released, the gas will be lighter than air (buoyant) and will easily disperse in open or well-ventilated areas.
Benzene (C_6H_6)	14 %	500	2.7	When released, the gas will be denser than air and will sit above the ground/sea surface.
Nitrogen dioxide (NO_2)	10 %	20	2.62	When released, the gas will be denser than air and will sit above the ground/sea surface.
Hydrogen chloride (HCl)	10 %	50	1.3	When released, the gas will be denser than air and will sit above the ground/sea surface.
Hydrogen fluoride (HF)	4 %	30	0.92	When released, the gas will be lighter than air (buoyant) and will easily disperse in open or well-ventilated areas
Hydrogen cyanide (HCN)	< 1 %	50	0.94	When released, the gas will be lighter than air (buoyant) and will easily disperse in open or well-ventilated areas
Toluene (C_7H_8)	4 %	500	3.1	When released, the gas will be denser than air and will sit above the ground/sea surface.

Vapour cloud explosions

- If these gases remain trapped within the battery casing, rapid overpressure will result, causing the battery (and surrounding infrastructure) to explode. This is known as a confined vapour cloud explosion (VCE). In many instances no warning is given prior to a confined VCE, and the result can be long jet-like flames (tens of metres for an electric vehicle battery) and the abrupt ejection of shrapnel. There is typically a very short time frame between the vapour cloud being produced and the explosion, often only a few seconds.
- If the vapour cloud vents from the battery unit, this can result in an unconfined VCE if the gases saturate the surroundings, are within their flammability range and an ignition source is present. The vapour cloud will be opaque white and is likely to be accompanied by hissing or popping noises as the gases escape from the plastic casing of the battery. Black vapours (similar in appearance to smoke) may be visible also when heavy metal nanoparticles from within the cathode of the battery are ejected, or when the plastic casing from the battery pack burns. An unconfined VCE may have a delayed ignition, and therefore a longer warning period for those on-board, compared to a confined VCE, however it still poses a significant fire risk.

- An important additional component of Li-ion battery fires is self-generation of oxygen. When the metal oxides in a battery's cathode, the positively charged electrode, are heated sufficiently, they decompose to release oxygen gas. This release of oxygen can be a factor in the ignition of flammable electrolyte and/or combustible gases. As a consequence, battery fires, once started can be self-sustaining despite efforts to isolate external oxygen sources[13].

Li-ion battery fires & maritime incidents

Li-ion batteries within a propulsion mechanism are not necessarily more prone to fire compared to traditional combustion engines, however the consequences can be more significant because they are far more difficult to extinguish and are capable of spontaneously reigniting hours or days after the initial fire has been extinguished.

From recent industry experience of incidents involving Li-ion battery-powered electric vehicles (EVs) being transported at-sea, the speed at which thermal runaway initiates and the ability of the Li-ion batteries to sustain fire may lead to the vessel sinking or being declared a constructive total loss (CTL). Primary concerns of these EV fires have been the difficulties in locating the source vehicle from which the fire originated (amongst the large numbers of vehicles being transported), and the difficulties in accessing this source fire on decks loaded with many closely-parked vehicles. Example incidents include FREEMANTLE HIGHWAY, a car carrier which caught fire off the coast of the Netherlands in 2023 with over 3,000 vehicles on board, FELICITY ACE which sunk in 2022 along with its cargo of 4,000 vehicles, and HÖEGH XIAMEN which caught fire and was declared a CTL, along with its cargo of 2,420 used vehicles off Florida in 2020[5]. In these three incidents, an additional concern of the responding authorities was the potential for a release of the bunker fuel oil on-board. For example, the FELICITY ACE released oil over an extended period following sinking. If Li-ion batteries are being used to propel a vessel as part of a hybrid system in tandem with more traditional hydrocarbon fuels, this same concern may exist i.e. a damaged or sunken vessel could still pose a pollution risk from a significant oil release.

IV. Hazards of Li-ion Battery incidents

Flammability

A Li-ion battery in thermal runaway provides a self-sustaining ignition source. The vapour cloud produced during thermal runaway is made up of a number of flammable gases, therefore a sustained fire is likely. If gases are vented at high pressure, jet-like flames may be produced. Given that thermal runaway produces a self-sustaining heat-source and generation of oxygen, Li-ion fires can be difficult to extinguish. Extinguishing external flames will not remove the risk of fire, the internal battery temperature must be reduced, and thermal runaway stopped to prevent further fire. Batteries undergoing thermal runaway are also prone to reignition hours to days after the initial flames are extinguished.

Explosion

If the Li-ion battery undergoes thermal runaway but the gases do not escape the battery unit, a confined VCE is likely to happen with little warning. The explosion is likely to cause ejection of shrapnel. If the gases vent from the battery into the surrounding area during thermal runaway, there may be a delayed explosion or ignition if the gas saturates a confined area.

The lower and upper explosivity limits (LEL & UEL respectively) depend on the composition of the battery and the resulting vapour cloud. Using a mathematical model, one study found the LEL of a typical vapour cloud to be 6.22% and the UEL to be 38.4%, assuming the batteries are fully charged. The LEL and UEL are sensitive to

[13] Sharifi-Asl, S., Lu, J., Amine, K., & Shahbazian-Yassar, R. 2019. "Oxygen *Release Degradation in Li-ion Battery Cathode Materials: Mechanisms and Mitigating Approaches"*. Advanced Energy Materials, 9(22); DOI: https//doi:10.1002/aenm.201900551.

changes in the state of charge, particularly the UEL which tends to increase concurrently with battery state of charge[14]. Oxygen production from decomposing materials will contribute to the ignition potential.

If a Li-ion battery has entered into thermal runaway and is emitting flames, any response measures that extinguish the fire without reducing the battery temperature and halting internal thermal runaway may change the primary hazard from fire to explosion.

Toxicity

Several gases emitted during thermal runaway are considered toxic, but the exact composition of the vapour cloud depends on the type of battery being used. The gases of most concern in terms of toxicity are carbon monoxide (CO), benzene (C_6H_6), nitrogen dioxide (NO_2), hydrogen chloride (HCl), hydrogen fluoride (HF), hydrogen cyanide (HCN), and toluene (C_7H_8). When considering the relative quantity of gas produced and the Immediately Dangerous to Life or Health (IDLH) values (Table 1), laboratory studies have shown that CO, NO_2 and HCl will be the first gases to reach their IDLH values[10]. The IDLH values of many of the toxic gases (Table 1) are lower than the approximate LEL. Therefore, the atmosphere is likely to be toxic to levels damaging to human health before it reaches its ignition level.

Corrosivity

Several of the gases likely to be produced when a battery enters into thermal runaway are corrosive. Of particular note are HCl, HF and HCN. Following exposure to the water vapour naturally present in air, these corrosive gases will form dense white corrosive vapours.

Asphyxiant

Like with any gas in a confined environment, such as a vessel engine room or cargo deck, high concentration of vapours can displace oxygen in the air, decreasing oxygen availability and therefore leading to asphyxiation to those present in these confined environments without suitable breathing apparatus.

Ecotoxicity of firefighting water run-off

Large quantities of water are typically used to manage Li-ion batteries in thermal runaway. However, since Li-ion batteries contain various metals and solvents, and the vapour cloud also contains several harmful gases and heavy metals, the impact of the firefighting water run-off should be considered. One recent study found that run-off waters can contain, *inter alia*, metals such as Ni, Mn, Co, Li and Al, carbonaceous particles (soot, tarballs), undecomposed solvents from the battery electrolyte and/or polycyclic aromatic hydrocarbons (PAHs)[15]. The composition of the run-off varies depending on the type of battery and whether the vapour cloud was ignited.

There is evidence that thermal runaway in Li-ion batteries can continue even when submerged in water. There is little research into the impacts of such an incident, but any gases that are released into the water may dissolve or rise to the surface, and there may be impacts to the environment linked to any dissolved toxic gases. However, these impacts are expected to be limited to the immediate vicinity of the incident.

[14] Guo, C.; Zhang, Q. 2016. *"Determination on explosion limit of pyrolysis gas released by lithium-ion battery and its risk analysis*". J. Saf. Sci. Technol. 12, 4.

[15] Bordes, A.; Papin, A.; Marlair, G.; Claude, T.; El-Masri, A.; Durussel, T.; Bertrand, J.-P.; Truchot, B.; Lecocq, A. 2024. *"Assessment of Run-Off Waters Resulting from Lithium-Ion Battery Fire-Fighting Operations."* Batteries. 10 (118). DOI: https://doi.org/10.3390/batteries10040118

V. Damage and Liabilities Arising from Incidents involving Li-Ion Batteries

Legal framework

Pollution relating to vessels powered solely by Li-ion batteries is not covered specifically by an International Convention at present, with liabilities relating to a Li-ion battery incident a matter of national legislation. Li-ion batteries transported as cargo are classed as dangerous goods by the IMDG code (classified as 'UN 3090 Lithium metal batteries', 'UN 3091 Lithium metal batteries contained within equipment', 'UN 3171 battery powered vehicle', 'UN3480 Lithium-ion batteries', 'UN 3481 Lithium-ion batteries contained in equipment or lithium-ion batteries packed with equipment', or 'UN 3536 Lithium batteries installed in cargo transport unit'). As cargo they are covered by the International Convention on Liability and Compensation for Damage in Connection with the Carriage of Hazardous and Noxious Substances by Sea, 2010 (2010 HNS Convention). While not in force at the time of writing, this Convention sets out the potential liabilities arising from damage caused by HNS substances. Furthermore, while this Convention does not apply to Li-ion batteries being used as a vessel propulsion mechanism, similar damage can be expected equally from an incident involving Li-ion batteries carried on-board compared to being used to power the ships' engines.

If Li-ion battery fires onboard a vessel cannot be controlled, damage to the vessel may result, in the worst case leading to sinking of the vessel or a CTL. In such cases, the Nairobi International Convention on the Removal of Wrecks, 2007 (2007 Nairobi Convention) may be applicable.

If batteries are used as part of a hybrid propulsion system, damage and liabilities arising from the hybrid fuel (oil, biofuel, ammonia, methanol etc.) should also be considered. In addition, a spill of cargo from a vessel powered in whole or in part by Li-ion batteries may result in additional damage and/or liabilities not considered here.

Clean-up and Preventive Measures

In comparison to the costs associated with clean-up and preventive measures from a traditional spill of persistent hydrocarbon bunker fuel oil, the costs for this claim heading for a Li-ion battery incident would likely be for different measures, primarily limiting/managing thermal runaway, firefighting and monitoring.

Due to the likelihood of fire and the toxicity and flammability of the Li-ion battery vapour cloud, the main focus of this claim heading would be i) prevention and control of fire ii) detection and monitoring:

i) There is no consensus on the best way to manage Li-ion batteries in thermal runaway. Often large quantities of water are applied using water curtains, water spray or water cannons, or if possible, the battery may be submerged in water for extended periods of time. Some bespoke fire blankets (designed for electric vehicle fires) have been tested. In many cases, the battery is left to "burn-out" which could take several days, especially given the high risk of re-ignition. Firefighting measures would also include the deployment of highly trained responders equipped with extensive PPE (breathing apparatus, protective clothing, personal gas monitors and infra-red cameras) if safe to do so.

ii) Monitoring would include the use of infra-red cameras to identify batteries in thermal runaway, multi-gas monitors to evaluate the potential presence of a toxic or flammable vapour/air mixture, which may pose a risk to responders, and to local environmental and economic sensitivities. This can lead to the delimitation of exclusion zones. Monitoring should continue even after the fire has been extinguished because reignition may occur hours or days afterwards.

The rehabilitation of wildlife is another potential cost associated with clean-up and preventive measures. These could come from the impacts of fire and toxic gases clouds in the immediate vicinity of an incident. Both mechanisms could result in mortality for wildlife in the immediate proximity to the incident or other sublethal effects including burns and fire damage. Rehabilitation may be possible by wildlife responders, in addition to the potential recovery of dead wildlife.

Personal Injury and Loss of Life

This claim heading is included within the HNS Convention for Li-ion batteries cargoes. Although incidents involving Li-ion battery propelled vessels are not covered by the HNS Convention, this claim heading is equally relevant to such incidents.

Due to the explosivity, flammability and toxicity hazards of a Li-ion battery in thermal runaway, a clear and acute risk exists to people near an incident. In particular, the majority of Li-ion battery powered vessels on order are car/passenger ferries. Such vessels are likely to be transporting large numbers of people and cars in close proximity, which can lead to rapid propagation of fire between vehicles, and difficulties with evacuation. This may lead to injury and loss of life.

If a Li-ion battery undergoes a confined or unconfined VCE, flames being emitted, and shrapnel being ejected from the battery unit pose a risk to those in the immediate vicinity. Risk of loss of life or injuries may result due to high thermal radiation (heat from the fire), the contact with the flame (burn) and inhalation of hot combustion products. If fire and explosion lead to sustained damage to the vessel or sinking, the crew (and/or responders) may be at risk of becoming trapped and/or drowning.

Due to the presence of toxic gases in the vapour cloud, populations present outdoors within the boundary of the vapour cloud would be at risk of injuries due to inhalation and dermal contact of toxic and corrosive vapours, leading to eye and respiratory irritation/damage, and potentially coma and death. People inside buildings that are sealed (windows shut) are less likely to be directly impacted by the presence of a vapour cloud.

The list of those at high risk include the ship's crew, bunkering operators, stevedores, passengers and other relevant nearby parties (e.g. surveyors, port operators).

The asphyxiant risk due to displacement of oxygen by Li-ion battery vapour clouds would be restricted to those on-board the vessel or first responders where vapours aggregate in confined spaces or in very close proximity of the source of the spill.

Environmental Damage

The environmental impact of Li-ion battery incidents in the marine environment is not as widely researched as the impact associated with spills of other, more persistent, hydrocarbon oils. However, due to the fate, behaviour and chemical hazards of a Li-ion battery in thermal runaway, only a short-term, acute negative impact in the immediate vicinity of the incident location is expected. However, if water is used to control a Li-ion battery in thermal runaway, water run-off may contain heavy metals, carbonaceous particles (soot, tarballs), undecomposed solvents from the battery electrolyte and/or PAHs (polycyclic aromatic hydrocarbons) which are considered to be hazardous to the environment[15].

Post spill studies to establish the severity and extent of environmental damage may be technically reasonable. For instance, if a vessel's Li-ion battery unit were to undergo thermal runaway, causing the vessel to ground or sink close to an environmentally sensitive resource (e.g., coral reef, mangrove forest), there is potential for localised mortality/harm caused by fire/explosion or toxic gases/water run-off. If environmental damage was observed subsequent studies could be appropriate. Due to the acute and localised nature of any environmental impact, restoration projects would likely be minimal and, if any, confined to a small area.

Property Damage

Costs arising for property damage will be spatially confined to properties in close proximity to the incident. For example, if a catastrophic fire or explosion were to result from an Li-ion battery incident, significant property damage to port structures, vessels (commercial, leisure or fishing), buildings and aquaculture facilities may occur if located near the casualty.

Types of property damage experienced during a persistent hydrocarbon oil spill are not relevant during a Li-ion battery incident, in particular coating by oil of vessel hulls, shoreline infrastructure, surface fishing and aquaculture gear. Instead, replacement of, or structural repair to damaged property may be necessary in the aftermath of a fire and could be significant.

However, with sufficient notice of a Li-ion battery powered vessel in distress, safety zones could be assigned, limiting entry to permitted vessels only. This would mitigate against damage to vessels.

Economic Loss

Economic loss can be split into “consequential loss”, whereby compensation is payable for loss of earnings suffered by the owners of property, which have been impacted and “pure economic loss”, whereby compensation is payable for loss of earnings suffered by persons whose property has not been impacted. In the event of an Li-ion battery incident, both consequential and pure economic loss could be experienced.

In the event of a fire/explosion, loss of earnings/income claims from damaged commercial, leisure or fishing vessels, factories, and other commercial etc. property, could be liable for compensation. If the incident occurred in the immediate vicinity of aquaculture facilities, fire/explosion or the presence of toxic contaminants in the water column may lead to mortality of stock and associated loss of earnings.

Pure economic loss could be experienced from loss of earnings from those impacted by any fishing bans imposed by authorities. Despite there being no release of a substance in bulk expected from a vessel that is solely powered by Li-ion batteries, there is a possibility that fishing bans may still be imposed, due to the lack of understanding of the impacts of such incidents. The effects of firefighting water run-off on fisheries are unknown but expected to be limited to the immediate vicinity of the incident.

In addition, if vessels are delayed due to port closures or impacts to their journey to abide by safety zones, demurrage costs may apply, which could be significant. Losses due to the closure of ports and other areas identified as being at potential risk as a result of safety zones demarcated during an emergency may potentially be claimed also.

Finally, impact to the local tourism industry is expected to be less in comparison to areas impacted by an oil spill. There might be claims arising from organisations impacted in the immediate vicinity of the incident location, however these are expected to be short-lived, in the order of days to weeks, rather than months to years, unless significant impact from a fire/explosion occurs.

VI. Conclusions

In conclusion, given the risks associated with batteries in thermal runaway, claims arising from such incidents would greatly contrast those associated with conventional persistent hydrocarbon oil spills.

Claims from **clean-up and preventive measures** from vessels powered purely by Li-ion batteries are expected to arise from different measures, such as fire-fighting measures and monitoring. Traditional clean-up measures will not be necessary and therefore, claims from a protracted spill clean-up operation will not arise unless pollution resulting from hybrid power systems or spilled cargo occurs also. However, **personal injury and loss of life** claims may be significant. Risks from fire, explosions, and toxic vapours could lead to death or life-altering injuries to crew, passengers, nearby operators and members of the public.

Claims arising from **environmental damage** are likely to be geographically confined in comparison to damage from oil spills. Post spill studies may be undertaken, in certain circumstances, to establish the severity and extent of damage. Restoration measures are likely to be minimal and confined to a small area. Rather than **property damage** claims involving cleaning and cosmetic repair of oiled property, claims are likely to be a result of fire and explosion and therefore, structural repair or replacement may be required, which would likely be more costly and potentially time-consuming. **Economic loss** claims resulting from a fire/explosion could include port closure/disruption and associated demurrage costs, losses from damaged/destroyed property, and local losses resulting from fishing impacts. Impacts to tourism in the immediate vicinity of the incident may also occur.

Finally, given the risk of explosion and sustained fire posed by a Li-ion battery in thermal runaway, there may be significant damage to the vessel itself, which can result in it being declared a CTL or sinking. **Salvage and/or wreck removal** costs may be significant in this instance.