FATE, BEHAVIOUR AND POTENTIAL DAMAGES & LIABILITIES ARISING FROM A SPILL OF LIQUEFIED PETROLEUM GAS INTO THE MARINE ENVIRONMENT

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

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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

ITOPF has also been requested to provide a summary document for lithium-ion batteries as a new technology for vessel propulsion.

A review of Nuclear as a means of vessel propulsion will be described separately, with the summary report provided by ENCO.

This report shall focus on **LPG** as a non-traditional marine fuel.

LPG is by definition any mixture of propane and butane in liquid form and is obtained during the refining process of crude oil. LPG has been shipped globally in bulk within LPG gas carriers for over eighty years, resulting in significant experience in handling and transporting via ship. There are currently 72 LPG carriers that are using LPG for propulsion, while 93 LPG carriers and four ethane carriers are currently on the orderbooks with capacity to use LPG as bunker fuel.[1] However, the experience of handling this substance is currently confined to those within the LPG industry due to the LPG gas carrier fleet dominating bunker use.

LPG is being seen as a viable alternative fuel outside of the LPG carrier fleet, especially in a multi-fuel system. 50.55% of the ordered tonnage in 2023 will be capable of using LPG as well as LNG or methanol in dual-fuel engines.[1] As the number of vessels with the ability to use LPG as fuel increases in the future, an increased likelihood of incidents occurring during handling, transportation, and loading/unloading operations exists. For this reason, it is important that appropriate measures are in place to safeguard the health of the crew and other relevant parties. There are specific requirements already in place for, *inter alia*, storage, distribution, and personal protective equipment (PPE) under the International Code of the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code). This code, adopted by the International Maritime Organisation (IMO), has been mandatory under the International Convention for the Safety of Life at Sea (SOLAS) Chapter VII since 1986. The transportation of LPG is already covered by the IGC Code and if an LPG carrier were to be powered by LPG, this is in principle covered by the IGC Code (for this particular ship type). However, for other vessels proposing to use LPG as bunker fuel, they will be required to follow the International Code of Safety for Ship using Gases or Other Low-flashpoint Fuels (IGF Code).[2] The IGF Code provides an international standard for ships operating with gaseous or low-flashpoint liquids as fuel and provides mandatory criteria to minimise the risk to the ship, its crew and the environment.

The use of dual-fuel engines is increasingly commonplace within the shipping industry and allows for flexibility between alternative fuels such as LPG and more conventional fuel oils (e.g. heavy fuel oil, marine diesel oil or even biofuels). In the future, there may be potential for multiple alternative fuels to be used on the same vessel. This means that, in the event of an incident, there may be potential for multiple alternative fuels to be spilled simultaneously. This could result in a combination of the risks and hazards outlined in ITOPF's alternative fuel summary documents. An incident of this type would require a complex and highly specialised response to be mounted to counteract these risks.

The future possible widespread use of LPG as a shipping fuel creates new challenges related to safe fuel bunkering, storage, supply and consumption for different ship types. Therefore, the fate and behaviour of the

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[1] DNV-GL. 2023. *"Energy Transition Outlook 2023: Maritime Forecast to 2050"*, DNV-GL. Høvik, Norway

[2] DNV-GL. 2017. *"Position paper 2017: LPG as a marine fuel"*, DNV-GL, Høvik, Norway

substance and associated damages and liabilities should be outlined. To date, ITOPF has not been involved in a case involving a spill/release of LPG.

II. Storage and transportation

The specific composition of LPG varies but primarily comprises propane with butane or a mixture of both (> 90% volume). Propylene, isobutane and butylenes may also be present.

At ambient conditions, LPG is a natural gas, which is typically converted into its liquid form for ease of storage and transport because liquid propane takes about 1/300th of the volume of the equivalent quantity of propane gas.[3] In its liquid state, LPG is a colourless, non-toxic liquid. It can be transported and stored using three tank types; refrigerated, typically at -50 °C at ambient pressure; semi-refrigerated, typically at 10 °C and pressurised at 4 – 8 bar; or fully pressurised, typically at 17 bar, which corresponds to the vapour pressure of propane at -45 °C.[2]

The use of fully pressurised Type C tanks is the simplest storage and transportation method with regards to its containment and cargo handling equipment as insulation, re-liquefaction and secondary barriers are not necessary.[4]

III. Fate and behaviour of LPG spilled in the environment

The Standard European Behaviour Classification (SEBC) categorises LPG as a gas (G). During an incident, LPG's hazards will be the drivers for the first actions and emergency response, followed by specific actions linked to its behaviour. Some of LPG's properties that play a role in its hazards, fate and behaviour when spilled are listed in Table 1.

Table 1: Summary of key LPG properties dictating its fate and behaviour[5,6]

	Properties*	Behaviour
Chemical Composition	Primarily propane or butane, or a mixture of both. Can contain propylene, of isobutane and butylenes.	LPG properties vary slightly depending on the exact composition.
Boiling Point	-42 °C	At ambient temperatures, LPG is a gas.
Liquid Specific Gravity (@ - 50 °C)	0.51 – 0.58	LPG has half the density of water; therefore, as a liquid, LPG will float if spilled on water.
Vapour Specific Gravity (@ - 13 °C)	2.1	Vapours of LPG at low temperatures are twice the density of air and will spread above the ground/water surface when spilled.
Vapour Specific Gravity (@ ambient temp)	1.5	Vapours of LPG at ambient conditions remain denser than air and will spread above the ground/water surface when spilled.
Solubility	Insoluble	Liquid LPG will not mix with water (run-offs) or seawater.
Flammability Range	2.2 – 9.5 (v/v) %	Outside of this range, the LPG/vapour mixture is not flammable.

*Due to the variable composition of LPG, the primary component, propane, has been used as a proxy.

[3] Cedre. 2009. "Accidents on vessels transporting liquid gases and the responders' concerns: The Galerne Project, Proceedings of the 33rd AMOP Technical Seminar, Environment Canada, Ottawa, ON, pp. 289-300, 2009

[4] Luketa, A. Hightower, M. 2018. "Guidance on hazard and safety analyses of LPG spills on water." April 2018, Sandia National Laboratories, New Mexico, USA.

[5] NOAA. 1999. *"Liquefied petroleum gas – CAMEO chemicals profile"*. June 1999, NOAA. Washington DC, USA

[6] The Engineering ToolBox (2018). *"Propane - Density and Specific Weight vs. Temperature and Pressure."* [online] Available at: https://www.engineeringtoolbox.com/propane-C3H8-density-specific-weight-temperature-pressure-d_2033.html.

In its transported and stored form as a liquid, when the storage tank temperature rises above LPG's boiling point or when liquid LPG is exposed to ambient conditions, it vaporises.

If the liquid LPG spills on or above the waterline, it will first float and, depending on the quantity spilled, may form a shallow pool on the surface of the water before vaporising. If the LPG was refrigerated within the tank, it is also possible for some of the seawater in the immediate vicinity of the release to freeze due to LPG's low temperature, causing localised ice formation. As LPG is insoluble in water, it is not expected to mix into the water column.

If released below the waterline, due to its specific gravity, it will rise to the surface of the water before rapidly boiling and volatilising into the atmosphere.

When vaporising, the LPG vapours are heavier than air and will form a dense cloud that will travel downwind staying close to the ground or sea. Unlike LNG and hydrogen vapours, when the temperature of LPG increases to ambient conditions, it will not become buoyant and disperse into the atmosphere. Over time, the vapours will become diluted by the lateral spread of the cloud and the turbulent mixing with the air.[4] The footprint of the vapour cloud depends on the metocean conditions at the time of the release, with stronger wind conditions resulting in further dilution of the vapour cloud.

IV. Hazards of LPG when spilled in the marine environment

LPG's hazards can lead to direct impacts on health and safety, mainly through its flammability and its explosivity.

Flammability

Liquid LPG is not flammable; however, its vapour has a flammability range of 2.2 – 9.5 (v/v) %, which can be detected with specialised equipment. Outside of this range, the LPG/air mixture is not flammable. This is of similar magnitude to conventional fuels such as diesel, which has a slightly smaller flammability range of 0.6 – 5.5 (v/v) %.

In an unconfined space, a release of LPG from a tank or pipeline will rapidly volatilise and its vapours will spread over the ground/water surface. Only a small area near the source of the leak would likely reach the concentration that would allow LPG to ignite. The extent of the vapour cloud spreading will mainly depend on the rate of the spill and the metocean conditions. Even in moderate wind speeds, an ignition of the vapour cloud and subsequent fire may still be able to propagate back to the leak source until all the LPG is consumed below the lower flammability limit (LFL) or is extinguished.

In a confined space, where flammable vapours cannot spread and dissipate, a small leak could lead to a flammable vapour/air mixture. Note that inside a fuel storage tank, the percentage of LPG is almost pure and, as such, the conditions are not within its flammability range. However, following a leak/rupture, a dense vapour cloud will form and once it has mixed with air, when its concentration reaches between the LFL and the upper flammability limit (UFL), the mixture can sustain a flame if ignited. If ignition occurs immediately, a non-pressurised leak will most likely result in a pool fire, which will continue until all the fuel is consumed, whereas a pressurised leak could lead to a torch or jet fire.[4] The flames from these are typically confined to a small localised area, but can result in additional hazards if the jet fire impinges on an adjacent fuel tank.

Explosivity

If LPG vapours concentrate in a confined space, there is a significant risk of combustion, meaning that an invisible spark or hot surface may cause ignition, possibly leading to an explosion.

Compressed LPG

LPG released in sufficient quantities can create a harmful overpressure which may result in direct and indirect hazards from building damage or flying debris. Overpressures can occur as a result of unignited releases of pressurised gas or as a result of ignition of a cloud of flammable gas.

Refrigerated LPG

In particular conditions, there is a possibility that spilled LPG could potentially undergo a boiling liquid expanding vapour explosion (BLEVE), which is an explosion caused by the rupture of a tank containing a pressurised liquid that has reached a temperature above its boiling point of -42 °C. This would be the case if the temperature of the tank were to raise and gas release systems were to fail.

Asphyxiant

Like with any gas in a confined environment, high concentration of LPG vapours displace oxygen in the air, decreasing oxygen availability and therefore leading to asphyxiation to those present in these confined environments.

Temperature

The low temperature of liquid LPG will result in the freezing of any tissue (plant or animal) upon contact and can cause materials to become brittle and lose their strength or functionality.

V. Damage and liabilities arising from incidents involving LPG

LPG carried as bunkers is not covered specifically by an International Convention at present, with liabilities relating to a release, or risk of release, a result of national legislation. LPG, carried as cargo in bulk, is 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 HNS carried as bunker fuel, the same damage can be expected equally from an incident involving LPG carried on-board to power the ships' engines and are set out below.

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 spill of LPG would likely be for different measures, primarily source control.

LPG's non-persistence in the marine environment, means established oil pollution clean-up measures are inappropriate (e.g. collection and recovery using booms and skimmers). Spilled LPG is not recoverable and therefore allowing natural attenuation to occur is the only appropriate option. For this reason, no protracted clean-up operations extending over a large geographic area, as is often seen with traditional persistent hydrocarbon oil spills, are required. Similarly, waste management is expected to be negligible in comparison to persistent hydrocarbon oil spills.

Due to the flammability of the vapours of LPG, the main focus of this claim heading would be i) detection and monitoring, ii) prevention and control of fire and iii) possible bunker fuel removal.

i) Monitoring would include the use of expert atmospheric plume modelling, use of multi-gas monitors, sensors, mounted possibly on drones (UAVs) to evaluate the potential presence of a flammable vapour/air mixture, which may pose a risk to local environmental and economic sensitivities. This can lead to the delimitation of exclusion zones. In addition, due to the spillage of refrigerated substances in the water column, ROVs installed with temperature sensors may be deployed to assess the extent of localised temperature reductions.

ii) Costs associated with stopping the leak (without posing a risk to the lives of responders) could be a technically reasonable and effective way of mitigating against fire, preventing further releases and reducing the risk to sensitivities. In addition, water curtains, water spray, water cannons or fog are techniques that can be used to fight fire or reduce the risk of fire or fight fire. These are typically deployed from specialised firefighting vessels. In comparison to oil spills, responders will need to be specialised and highly trained for HNS incidents.

iii) The removal of LPG bunker fuel from a casualty could come under the 2007 Nairobi Convention if so decided, although note this convention refers only to bunker fuel oil.

The above clean-up and preventive measures rely on availability of specialist equipment (e.g. HAZMAT PPE, UAVs and ROVs for monitoring, etc.), modelling capabilities and specialist trained personnel. These resources may not be commonly available across the world and therefore these actions may only be possible in highly prepared areas, where immediate deployment of this equipment would be possible. Due to possible lack of available mitigation measures, the below damages related to these incidents may be increased in these circumstances.

The cleaning and rehabilitation of wildlife is another potential cost associated with clean-up and preventive measures. Wildlife impacts could come from fire hazard and/or low temperatures in the water body in the immediate vicinity of an incident. Both mechanisms could result in mortality for wildlife in proximity to the incident or other sublethal effects including burns and fire damage. Rehabilitation for burns and fire damage may be possible by wildlife responders, in addition to the potential recovery of dead wildlife and any associated costs, would fall under clean-up and preventive measures.

Personal Injury and Loss of Life

This claim heading is included within the HNS Convention for LPG cargoes and has particular relevance to spills involving LPG bunkers.

Due to the flammability hazard of LPG vapours, a clear and acute risk exists to people in the vicinity of an LPG release. Vapours from large unignited LPG spills near developed (residential or industrial) areas would likely quickly encounter an ignition source, ignite and the vapour cloud fire could potentially burn back to the source. Populations present outdoors, within the flammable boundaries of the vapour cloud would be at risk of loss of life or injuries due to high thermal radiation (heat from the fire), the contact with the flame (burn) and inhalation of hot combustion products. People inside buildings are less likely to be directly impacted by direct thermal impact injuries. 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). This is the most likely public safety impact of an LPG spill.

The asphyxiant risk due to displacement of oxygen by LPG vapours, and sub-zero temperature-induced injuries 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. People can sustain cold temperature tissue damage from direct contact with spilled LPG. If directly exposed to sub-zero liquid (or depending on the exposure levels, cold LPG vapours) there may be risk of long-term, life changing injuries, such as blindness from crystallising moisture in the eye, severe cold burns (frostbite), lung damage from inhaling cold vapour, hypothermia and possible brain damage and death.

The costs associated with these may be extensive, dependent in part on applicable international conventions and local legislation and should therefore be considered when dealing with liability and compensation.

Environmental Damage

The environmental impact of LPG 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 characteristics of the constituents of LPG, only a short-term, acute negative impact in the immediate vicinity of the incident location is expected. Water temperatures are expected to return to pre-spill levels quickly, especially with increasing distance from the vessel.

Post spill studies to establish the severity and extent of environmental damage may be technically reasonable. For instance, if the vessel were to ground on a coral reef causing a release of LPG bunkers, there is potential for localised mortality/harm and 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 LPG spill, 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 in a spill of LPG, 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 or explosion and could be significant. Due to the likely short timeframes of an LPG spill, mitigation measures (e.g., placement of water curtains, lift out of vessels) would be more difficult to put in place.

However, with sufficient notice of an LPG-fuelled 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 LPG 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 was in the immediate vicinity of aquaculture facilities, localised reduction in seawater temperatures or a fire/explosion could 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 the very short residence time of LPG in the environment and the non-toxic nature of the substance, there is a possibility that fishing bans may still be imposed, due to the lack of understanding of the impacts of LPG.

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. An interruption of flow to water intakes may also cause pure economic loss claims, however due to the short residence of LPG in the environment, these are likely to be short-lived. 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 to be short-lived and in the order of days rather than weeks to months, unless significant impact from a fire/explosion occurs.

VI. Conclusions

In conclusion, LPG's short residence time in the marine environment and high volatility means that claims arising from incidents involving this alternative fuel would greatly contrast those associated with conventional persistent hydrocarbon oil spills.

Claims from **clean-up and preventive measures** are expected to arise from different measures, such as source control, fire-fighting measures, monitoring via expert modelling or sensors mounted on UAVs/ROVs and possible bunker fuel removal. Traditional clean-up measures will not be possible and therefore, claims from a protracted spill clean-up operation will not arise. However, **personal injury and loss of life** claims may be significant. Risks from fire, explosions, sub-zero temperature exposure and asphyxiating 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, LPG claims are likely to be a result of fire/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, local aquaculture losses from mortality of stock, and local losses resulting from fishing bans. Impacts to commercial water intakes and tourism may also occur.