LIQUIFIED PETROLEUM GAS (LPG) AND LIQUIFIED NATURAL GAS (LNG) TRANSPORTATION—OVERVIEW OF RISK MITIGATION

Capt. Gareth Marc Hopkins, BP Shipping Limited

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WHAT ARE THESE GASES?
In these days of fluctuating energy costs, natural gas is an attractive fuel source because it is increasingly cost-effective and is environmentally cleaner than oil. Since all fuels require transportation to consumer locations, fuel gases are compressed and transported in a liquefied state by ship to the US. Liquefied petroleum gas (LPG) and liquefied natural gas (LNG) are gases at ambient temperature and atmospheric pressure, but are transported in bulk as liquids to reduce container volume.

THE TRANSPORTATION ISSUE
These gases have been transported in bulk since 1959, with the conversion of a small cargo ship to a 500m³ LNG carrier. This ship carried the first cargoes of LNG between Lake Charles, Louisiana and the United Kingdom. Today’s gas ships have the capacity to transport up to 100,000m³ of refrigerated product. In 1999, the total LPG exported from the Middle East was approximately 24 million tonnes. LNG is comparatively a newer product and the output from the Middle East increased from 2.5 to 5.5 million tonnes per year. The total LNG output from the Gulf States now is in the region of approximately 20 million tonnes per year and expected to double world wide in the next decade. The import of these gases into the United States is likely to increase dramatically, beginning even now. LNG ships, which have been laid up in the US for more than 20 years are being put back into service. There is a strong likelihood that new LNG terminals will be constructed in the US, beyond those which have been in use in Boston, MA, Lake Charles, LA and Savannah, GA.

Many regulators are concerned with about the potential risks associated with the transportation of these compressed gases near or in their communities, since the accidental release of compressed gases presents obvious safety risks. This paper highlights the potential hazards and risk mitigation techniques associated with the marine transportation of LNG and LPG.

LNG AND LPG PROPERTIES
Both LPG and LNG are petroleum hydrocarbons and originate in a manner similar to the way crude oil is formed; they can be found either with crude oil or by themselves. They are both composed of low molecular weight hydrocarbons; LNG is composed mainly of methane (approximately 65% to 99%) and LPG generally is either propane or butane. Like crude oil, their actual composition varies from place to place with geologic conditions.
To transport LNG, the volume is reduced by a factor of approximately 600; for LPG the volume is reduced by a factor of roughly 250. These gases can be liquefied either by low temperature, by high pressure or a combination of the two. In the case of LNG, the critical temperature is below ambient so that pressurization alone is insufficient for liquefaction and therefore cooling is necessary. This is not the case for LPG, which liquefies readily under pressure and is common in many households in this form. LNG is carried at very low temperatures near atmospheric pressure in the marine mode; LPG is usually carried in bulk either at low temperatures at atmospheric pressure or higher temperatures and under pressure in large ships and fully pressurised in smaller ships or barges.

LPG and LNG are not toxic and do not burn in the liquid state. The principle hazard during any release is from the heavy vapor cloud, which forms quickly and can burn or explode. The LPG vapor cloud is always heavier than air, suppressing the dispersion of the cloud; consequently the cloud remains hazardous for a greater distance downwind than if the cloud were neutrally or positively buoyant. The result is that LPG vapors tend to hug the ground, depending upon ambient wind conditions. In these conditions it is more likely that an ignition source, from passing traffic, land or sea based, or from a stationary plant, may be encountered, and the possibilities of a conflagration are much higher.

For LNG, the vapor warms by mixing with the diluting air, cooling the surrounding air in the process. With a large release, the air-gas mixture is, initially, denser than the warm air in the immediate vicinity of the release and it may be some distance from the release before the cloud is diluted below the low flammable limit. This, though, depends on local conditions such as topography and meteorological conditions. In the case of an accidental release into a diked area, the rate of vaporization of liquefied gases will be initially rapid but can decline as the impoundment floor freezes. A typical impoundment area filled with LNG, for example, might take hours to evaporate, especially if its rate of evaporation is reduced by the application of a “foam blanket”.

Tests show that if LNG spills into water in significant quantities a flameless vapor “explosion” can also occur as the LNG rapidly changes from a liquid to a vapor. This has to be taken into account when fighting LNG fires, as water directed on to an LNG fire can create these “explosions”, which feed the fire with more vapor. Such “explosions” from liquid to vapor phase do not occur with LPG.

Key international governmental and industry organizations, which have responsibility for the safe operations of LNG and LPG vessels and terminals, include:

- The International Maritime Organization (IMO)
- The Society of International Gas Tanker and Terminal Operators Ltd. (SIGTTO)
- Permanent International Association of Navigation Congresses (PIANC)
- Oil Companies International Marine Forum (OCIMF)
RISK MITIGATION FOR VESSELS

The gas transportation industry is relatively new in comparison to the shipping industry in general. The developing legislation with regard to gas carriers has served the industry well and has generally been proactive. Not a single operating LNG or LPG ship with a capacity above 5,000 m³ has been lost nor has there been any substantial loss of product ashore or at sea. There have been losses of small, fully pressurised, LPG carriers at sea, but the cargo in these incidents has been released in a controlled manner, despite, in some cases, the containment breaking free of the vessel. Nonetheless, should there ever be an uncontrolled release of gas following an accident to a gas carrier, especially in the case of LNG carriers, the consequences are not fully known. Thus it has been necessary to regulate to prevent such an occurrence.

The principal areas of vessel-related risk include gas ship construction, equipment, operation, and human factors. The “Gas Codes”, promulgated by the International Maritime Organization (IMO), are specific international regulations for vessel risk areas. There are three Gas Codes:

- The Code for Existing Ships Carrying Liquefied Gases in Bulk (Existing Ship Code).

The International Maritime Organization (IMO) also requires that ships be regularly surveyed to comply with their Gas Codes. Ships that comply with the IMO Codes carry a Certificate of Fitness for the Carriage of Liquefied Gases in Bulk. Other risk areas pertain to the mistakes people make. Industry has been proactive in protecting against the risk of human error by “designing out” human input as far as possible with the use of automated control and emergency systems. Another related area concerns the training of gas carrier seafarers and this is addressed in the IMO convention known as the Standards of Training and Watchkeeping 1995 (STCW95).

The most critical period of the transportation phase is when the ship approaches the port and berths at the jetty to load or discharge cargo. The frequency of marine accidents is always greater in the port area and the approaches than in the open sea. From the time the ship approaches the port area until the time she leaves, the gas carrier is at its most vulnerable. Vessel Traffic Systems (VTS) has been implemented in some ports in the United States to assure a high level of traffic control and reduce the potential for traffic related incidents in busy port areas. The United States also has undertaken extra operational precautions, beyond those recommended in the SIGTTO publications, primarily because some terminals are located in congested ports and urban areas with additional risks. The Coast Guard now requires various operational constraints to enhance safety in these ports, e.g., escorts in congested areas.
RISK MITIGATION FOR TERMINALS

The design of a port receiving liquefied gas carriers must address the complete passage from the port approaches to the jetty, suitably sized access channels and turning circles to provide the ship with safe transit through the port. This safe transit may be further improved by establishing strict rules of port operation while a gas vessel is in transit. Suitably located ship speed of approach indicators may also assist in preventing damage to ship or berth, especially in the case of large vessels.

There are no international regulations for terminals, although they usually are located, designed, constructed, and operated against internationally accepted recommendations, which give advice on operational safety and design practices. Key site selection factors for a marine terminal include:

- The availability of sheltered water, especially with regard to prevailing wind direction, swell and strength of currents,
- Sufficient depth of water in the vicinity of the terminal near to the site and in the approaches, at all states of tide.

Once the basic requirements for sighting the terminal have been satisfied, there are critical requirements for sighting and design of the jetty, including:

- Protection from prevailing wind and swell, and adequate 24-hour water depth,
- Location in minimum current, both river and tidal,
- Location immediately adjacent to the gas terminal,
- Minimal movement by the jetty from sea and local traffic,
- The means to establish good and effective moorings, and
- The suitability of fenders and their position.

Yet, even when these guidelines are used, there is always a risk of a spill when a ship is moving in the vicinity of, or berthed at, a terminal. When considering the distant possibility of a major accident, existing standards, though relevant, are seldom sufficient to obtain the assurance required for liquefied gas. Accordingly, at liquefied gas jetties, risk related methods that address the incident probability should also be adopted. There are plume distribution models that are helpful tools in identifying areas at risk from accidents around a terminal.

The design of liquefied gas terminals must provide the gas carriers with safe transfer conditions 24-hours a day at the terminal. The design of the terminal must take into account the risk of ignition and ensure that fire protection equipment appropriate to the type and volume of cargo is provided.

RISK MITIGATION THROUGH CONTINGENCY PLANNING

No matter how much care is taken in design and planning, mistakes sometimes happen. This section of the paper addresses how to use contingency planning to minimize the risks from an accident, if one occurs. Effective contingency planning is an ongoing process that actively involves response personnel. The basic process includes the following steps:
1. **Develop contingency plans** for responding to incidents, using likely and worst case scenarios identified during a risk assessment.
2. **Train responding personnel** on the response procedures and management process in the contingency plan.
3. **Exercise the plan** Practice responding to simulated events with all personnel.
4. **Identify lessons learned** from the exercises.
5. To improve contingency plans, **incorporate lessons learned into the plans.**

Ann Hayward Walker  
Scientific and Environmental Associates, Inc.  
325 Mason Avenue  
Cape Charles, VA 23310  
Phone: 757-331-1788  
Email: seahq@erols.com