Bulk Transportation by Road and Rail: Relative Risk of LNG Versus LPG

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Summary

To examine risks of transportation of bulk LNG, Exponent has investigated the potential risk profiles for LNG versus LPG shipping via road tanker truck and via rail tank car. A generalized accident model was developed from comparison of accident rates in all pressure tankers (as an LNG vessel analog) to specifically LPG pressure tanker accident rates. The resulting risk profiles for a range of transportation cases and population densities were used to benchmark the risk of bulk LNG transportation compared to the historically (implicitly) accepted transportation risk of LPG.

We describe here our findings that the risk profiles for LNG and LPG transportation are similar. In general, the safety risk for rail transportation is slightly higher than for road transport; likely due to the larger volumes of tank cars relative to highway tankers.

Introduction

Booming natural gas production in North America has spurred many opportunities to utilize the increasingly abundant domestic commodity. To capitalize on the environmental and cost benefits of natural gas for power (both stationary and motive), recent efforts have focused on storing and transporting natural gas as liquefied natural gas (LNG). The demand for small-scale, regional LNG sourcing is expected to be driven by power generation and the use of LNG as a transportation fuel for rail, truck fleet, and marine applications.[i] Regional hub-and-spoke models are anticipated to create extensive growth in shipping of LNG via road and rail tankers [ii]to supply fueling stations and power plants isolated from the gas pipeline networks in the Americas and Caribbean.

The public perception of LNG risks is inexplicably misaligned with the risks compared to other common flammable commodities. This article addresses and compares the transportation risks of LNG to those posed by a material whose distribution hazards are well known and readily accepted by the public, namely liquefied petroleum gas (LPG). Many areas of the country rely exclusively on small pressurized tanks, (e.g., 500 gallons) of LPG to provide fuel gas for industry, commercial, and residential uses. Thus, it is informative to compare the potential hazards and safety aspects of LNG bulk transport to those of bulk LPG transportation, for which the risks are known and acceptable to society.

LNG and LPG Hazards

The primary hazards associated with storage, handling, and transportation of LNG and LPG include fires and explosions that may be caused by a loss of containment. The fire and explosion hazards include radiant heat exposure from pool fires, vapor-cloud flash fires, jet fires, overpressure from vapor-cloud explosions and boiling liquid expanding vapor explosion (BLEVE).[iii]

LPG is normally stored at ambient temperature, but it must be pressurized to keep it in liquid form. If a pressurized container of LPG leaks or is opened, the LPG will flow rapidly through the opening and will flash, creating a cold, dense vapor cloud. In contrast, LNG is typically stored at low pressure at its boiling point of –260°F. LNG containers must be insulated to keep the LNG in liquid form. As a consequence of the low storage pressures of LNG containers, a breach typically causes liquid to flow out at lesser velocities than LPG. The resulting cryogenic LNG liquid spill will boil to create a cold, dense vapor cloud.

LNG and LPG Transportation Analysis

Bulk commodity transportation of LNG and LPG typically occurs in the U.S. via truck for both materials, but only LPG has a history of large-scale transport by rail. The U.S. Department of Transportation (DOT) regulates these shipments directly for road trucking and through the Federal Rail Administration (FRA) for rail shipping. LPG has a long history of transport as a commodity in the U.S., and the transportation risk is broadly accepted by society. The transportation risk of LNG in the U.S. is currently unknown.

A Quantitative Risk Analysis QRA was performed for the two commodities, via two transportation modes, and with varying population density. Detailed discussion of the assumptions and analytical methods is provided in the full manuscript.[iv] An abbreviated explanation of the most significant analytical assumptions and model inputs is provided in this article.

Tanker trucks for LPG are single-walled pressure vessels, whereas LNG trucks use double-walled cryogenic tankers. Cryogenic tanker trucks[v] compose a small percentage of the pressurized tanker truck fleet. Mileage data were not available for the subset of cryogenic pressure tankers but were available for the larger set of all pressurized tanker trucks.

The annual vehicular accident rate for all pressure tankers was found to be identical to that for the smaller subset[vi] of LPG pressure tankers; thus, we reasonably assumed a common accident rate of 9×10^{-8} accidents per mile per year for both LNG and LPG tanker trucks.

Rail cargo tankers for LPG are nominally 30,000-gallon single-walled pressure tank cars, typically DOT015 or DOT112 classification. Currently, LNG is not permitted to be transported by rail without a waiver from the FRA. Cryogenic liquefied gases (e.g., ethylene, argon, oxygen, etc.) are shipped in double-walled vacuum insulated DOT113 cars with a capacity of 30,000 gallons. These cars are relatively rare in the U.S. rail pressure tanker fleet compared to other pressure cars. Available cryogenic rail accident data are sparse and not statistically significant. Similar to road tankers, the annual accident rate for all rail pressure tankers was found to be identical to that for the smaller subset[vii] of LPG pressure tankers; thus, we reasonably assumed a common accident rate of 6×10^{-7} accidents per mile per year for both LNG and LPG tanker trucks.

The QRA model also requires a probability of leak size[viii] (outflow probability). Given the double-walled construction of cryogenic tankers, the probability of puncture of the inner vessel is anticipated to be lower than a comparable single-walled pressure tanker. However, piping connections that may be severed or damaged in an accident may differ in size, location, and protection between single wall pressure tankers and double wall cryogenic tankers.[ix] Thus, the probability of a specific hole size will depend on the type of tanker and the type of accident. As a foundational basis, we found that the probability of no release was approximately 95% in a rail accident and 77% in a road accident for pressure tankers. LPG hole size probabilities were based on historical LPG incident data; whereas the LNG probabilities were assumed to be represented by all HAZMAT pressurized containers. This assumption likely overestimates the probabilities of leaks for double-walled cryogenic tankers due to the anticipated diminished contribution of shell punctures compared to single-walled pressure tankers.

In addition to considering the consequent effects of jet fires, pool fires, and flash fires, BLEVEs were also considered for both materials. BLEVEs were considered for LNG tankers, because in a transportation accident, the outer vessel/insulation and/or pressure relief system may be compromised. For example, in train derailments, rail car shells can be punctured and cars tipped over to bury or block pressure relief lines. We recognize that, due to differences in vessel design and construction, the likelihood of an LNG vessel being involved in a BLEVE is less than an LPG vessel (none have ever been recorded in the U.S.). However, statistically significant data regarding LNG vessel BLEVEs relative to single-wall pressure vessels is not available. Thus, the QRA conservatively assumed that BLEVEs were possible for both single-walled LPG pressure tankers and double-walled cryogenic pressure tankers for LNG.

LNG and LPG rail tank car and road tanker transport releases were evaluated along 1-mile-long stretches of rail/road, and the population densities were varied within ranges representing rural to urban regions[x] (i.e., 100 people/mi^2 to 10,000 people/mi^2). For a transportation route analysis, this mile-by-mile approach best reflects the risk posed by the operation. The risk levels were quantified for a range of distances from the transportation route.

Conclusions

This conservative analysis demonstrated that the individual risk (IR) and societal risk (SR) for bulk LNG transportation are expected to be similar to or less than that for LPG, a commodity that is commonly shipped in the Americas. The analysis revealed that, within each mode of transportation (truck and rail) of bulk transportation for pressure tankers, the accident rates and hole size probabilities in an accident were independent of the HAZMAT commodity being shipped. Thus, a single value of accident rate could reasonably be applied to both LNG and LPG. This significant result supports side-by-side comparison of the risk posed by the two commodities. Also, the rail incident rate per mile was approximately five times higher than the rate for road tankers, which was an intriguing result because annual HAZMAT pressure tanker rail mileage was one-seventh of the road mileage. This finding warrants further analysis but is likely a direct result of the underlying causes of accidents; whereas, in trucking the dominant causes may be due to the driver, while they are due to equipment or track in rail transportation.

Given the uncertainty in leak probability distributions between single-walled (LPG) and double-walled (LNG) tankers, we believe that using the all pressure tanker leak probability profile to represent LNG leads to a conservative overestimate of the risk profile.

The QRA results indicated that the individual risk for road LPG transport was similar to road LNG transport. For example, the distance from the route to the individual risk contour of 3×10^{-7} fatalities/year[xi] for road transport was 100 m to 200 m for rural to urban population densities, for both LPG and LNG. The individual risk (IR) contour of 3×10^{-7} fatalities/year for LPG and LNG showed a slight difference between commodities. The distance was approximately 100 m to 200 m from the route for rail transport of LNG as population density increased from rural to urban. The LPG rail transport scenarios were found to be independent of population density, with an IR contour at 300 m. This result was due to the dominant risk contribution of immediate ignition of the cloud and/or BLEVE scenarios.

The societal risk (SR) profiles for LNG and LPG transportation are similar. In general, the SR for rail transportation is slightly higher than for road transport; likely due to the larger volumes of tank cars relative to highway tankers.

The analysis was based on a conservative set of assumptions regarding the consequences of LNG tank failures. This analysis did not represent any specific real case from industry or incident. By changing the conditions to reflect a specific situation or transport route, the results may change.

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[i] Ibarreta A, Kytömaa HK, Morrison DR. "LNG Small Scale and Transportation: Navigating the Risk." Exponent Oil & Gas Newsletter, Vol. 1 (2015).
[ii]
[iii] It should be noted that there is much discussion surrounding the applicability of BLEVEs to LNG marine tankers. We acknowledge that the probability of double-walled LNG storage vessel undergoing a BLEVE is likely to be less than an LPG storage vessel. Consistent with its reduced likelihood, no data exist that are suitable for quantifying the probability of an LNG storage vessel BLEVE relative to a typical single wall, uninsulated pressure vessel. Thus, LNG BLEVEs were treated similarly to LPG vessel BLEVEs in the analysis presented here as a conservative assumption.
[iv] Hart RJ, Morrison DR. The hazard we know: Comparing transportation risk of LPG and LNG. American Institute of Chemical Engineers, 2015 Spring National Meeting and 11th Global Congress on Process Safety, Austin, TX, April 26–30, 2015.
[v] For example, liquefied argon, ethylene, helium, methane, nitrogen, and oxygen.
[vi] LPG road tankers represent 3% of the mileage and 3% of the total annual incidents of all pressure tankers.
[vii] LPG rail tankers represent 5% of the mileage and 5% of the total annual incidents of all pressure tankers.
[viii] The terms "hole size" and "leak size" here are used to represent the theoretical hole size in the QRA model to release a certain quantity of material in an accident given basic assumptions of pressure and temperature of the HAZMAT commodity.
[ix] For example, DOT112 tankers have all piping connections located in a top dome whereas DOT113 tankers have piping connections located in side cabinets below the tanker shell. Both types are designed with specific crash protection structures to mitigate the likelihood of a release.
[x] Guidelines for Chemical Transportation Risk Analysis, Center for Chemical Process Safety, American Institute of Chemical Engineers, Wiley: New York (1996).
[xi] The value of 3×10^{-7} fatalities/year corresponds to the lowest considered risk level in NFPA 59A 2013. Risk below that level is de minimus.