Transportation Study: Impacts Associated with New and Emerging Natural Gas Liquefaction Facilities

Phase 1 Whitepaper

January 2016

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I. Background

This whitepaper has been developed by the Volpe Center for PHMSA's Research and Development Office (PHH-23) of the OHMS Engineering and Research Division (PHH-20) under existing interagency agreement IAA #DTPH5615V00001 to assist OHMS in completing a transportation study on the impacts associated with new and emerging small scale liquefied natural gas (LNG) facilities and the LNG powered vehicles they support.

Total dry natural gas production in the United States increased by 35% from 2005 to 2013, with the natural gas share of total U.S. energy consumption rising from 23% to 28%. Production growth resulted largely from the development of shale gas resources in the lower 48 states (including natural gas from tight oil formations).[1] The abundant supply of domestic natural gas is driving the rapid development of liquefaction plants, new industrial uses for LNG, and new vehicles that use LNG as fuel. These developments are driving industry and regulators to develop transportation packagings and systems to support this growth.

In general, LNG facilities that either receive or deliver natural gas from or to a pipeline are regulated by 49 CFR Part 192 (*Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards*) and by 49 CFR Part 193 (*Liquefied Natural Gas Facilities: Federal Safety Standards*). This whitepaper focuses on the following categories of new and emerging LNG facilities/operations identified by PHMSA's Pipeline Safety Office in a May 2014 draft report that are not regulated under 49 CFR Part 193:

A. LNG marine export/import terminals not supplied by/connected to pipelines regulated by 49 CFR Part 192;
B. Marine cargo transfer system components between the vessel and the last valve on the storage tank;
C. LNG tanker and carrier ships, LNG tank trucks, and other vehicles (e.g., heavy-duty trucks, buses, ships, locomotives, and mining vehicles) that consume LNG fuel or transport LNG;
D. LNG ISO tank containers that are not used as storage vessels at LNG plants connected to pipelines regulated by 49 CFR Part 192;
E. Natural gas processing plants that do not store the LNG at the plant;
F. Distributed production facilities that use LNG in gas treatment or hydrocarbon extraction processes but do not store LNG;
G. LNG facilities that store and vaporize LNG produced on-site (such as agriculture and industry on-site storage and regasification facilities) or LNG supplied by another transportation mode, as long as the LNG is consumed solely by the LNG facility owner;
H. LNG refueling stations for vehicles that use LNG for fuel;

[1] U.S. Department of Energy/U.S. Energy Information Administration (DOE/EIA-0383); *Annual Energy Outlook 2015, with Projections to 2040*; April 2015.

I. LNG marine and land depots, where LNG is loaded onto transport vehicles such as bunker barges, trucks, and ISO containers;
J. Floating LNG liquefaction and gasification facilities not supplied by pipelines regulated by 49 CFR Part 192, and such facilities supplied by pipelines regulated by 49 CFR Part 192 if the facility is located in navigable waters (as defined in Section 3(8) of the Federal Power Act (16 U.S.C. 796(8));
K. LNG at satellite plants that is consumed by power drill rig equipment, even if the LNG source is a pipeline regulated by 49 CFR Part 192 ("ultimate consumer exemption"); and
L. LNG-based distributed power plants supplied by pipelines regulated by 49 CFR Part 192 serving only the pipeline operator, and LNG plants where LNG is supplied by means other than a pipeline regulated by 49 CFR Part 192.

II. Project Objectives

Based on the increased production and transport of LNG in the U.S., PHH-20 seeks to identify, prioritize, and recommend solutions for potential transportation impacts associated with new and emerging LNG facilities/operations that involve non-pipeline transport (i.e., LNG facilities not covered under 49 CFR Part 193). This whitepaper is the initial document the Volpe Center has developed to begin identifying transportation impacts associated with these new and emerging LNG facilities/operations.

III. Overall Summary of Phase 1 Activities

The Volpe Center did not find any additional categories of LNG facilities and operations not regulated under 49 CFR Part 193 than those previously identified in Section I by PHMSA's Pipeline Safety Office in its May 2014 draft report. The Volpe Center conducted multiple Internet searches on the categories of new and emerging LNG facilities/operations identified in PHMSA's May 2014 draft report, specifically:

- The activities, processes, and equipment used at each type of facility/operation;
- U.S. locations where these new and emerging facilities/operations are located;
- How LNG is transported to and from these new and emerging facilities/operations; and
- General safety, security, and/or risk parameters specific to each type of new and emerging facility/operation.

The information found on these new and emerging LNG facilities/operations categories is summarized in Section V.

IV. Basic LNG Information

A. LNG Properties

LNG is classified as "methane, refrigerated liquid (cryogenic liquid) or natural gas refrigerated liquid (cryogenic liquid), with high methane content" in 49 CFR 172.101, Identification Number UN1972, Hazard Class/Division 2.1 (flammable gas). It is in liquid form (i.e., LNG) at temperatures of -259°F (-161°C) or below. LNG is forbidden to be transported by air (on both passenger and cargo planes) and on passenger rail; non-bulk transport on roadways and waterways is authorized only in UN T75 portable tanks, and non-bulk LNG can only be stored on the deck of cargo and passenger ships carrying passengers limited to not more than 25 passengers or one passenger per three meters of overall vessel length, whichever is larger[2]; bulk packaging of LNG in container-on-flatcar or trailer-on-flatcar via rail requires approval from the Federal Railroad Administration's Associate Administrator of Rail Safety[3]; and bulk packaging of LNG on vessels must comply with all requirements set forth in 49 CFR 173.318[4].

When regasified, LNG behaves and burns just like natural gas (50% lower emissions than coal; negligible sulfur oxides, nitrogen oxides, and particulates; can be used by most energy sectors cost effectively). When liquefied, natural gas is 1/600th its volume at standard pressures, making it more economical and safer to ship.[5]

B. U.S. LNG Facilities

More than 110 LNG facilities operate in the U.S. and perform a variety of services. Some facilities export natural gas from the U.S., some provide natural gas supply to the interstate pipeline system or local distribution companies, while others are used to store natural gas for periods of peak demand. There are also facilities which produce LNG for vehicle fuel or for industrial use. Depending on location and use, an LNG facility may be regulated by several federal agencies and by state utility regulatory agencies.[6]

Most natural gas is imported and exported by pipeline as a gas and by ship as LNG. Small amounts of natural gas are also exported on trucks as LNG and as compressed natural gas. In 2014, 96% of U.S. net imports of natural gas came by pipeline, and 4% came in LNG ships.[7]

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[2] 49 CFR 172.101, 49 CFR 172.102.

[3] 49 CFR 174.63(a).

[4] Bulk Packaging of Cryogenic Liquids in Cargo Tanks.

[5] http://www.narucmeetings.org/Presentations/Sandia%20NARUC%20LNG%20Cascading%20Damage%20Summary%20Overview%202-2013.pdf, "Marine LNG Transport—Cascading Damage Study Summary and Risk Management Considerations." DOE/Sandia National Laboratories. M. Hightower. Updated February 2013. Accessed October 20, 2015.

[6] http://www.ferc.gov/industries/gas/indus-act/lng.asp Updated October, 1, 2015. Accessed October 14, 2015.

[7] http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_imports Updated July 16, 2015. Accessed September 24, 2015.

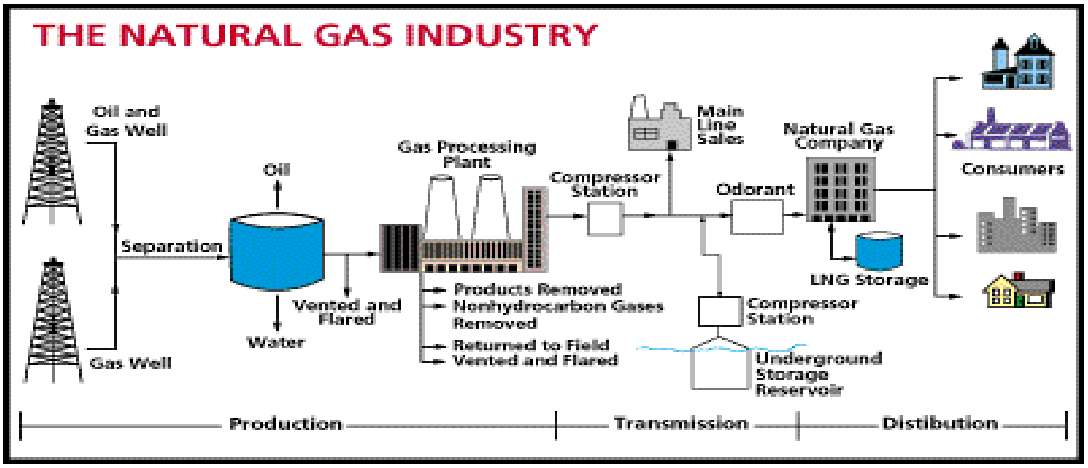

Figure 1. The Natural Gas Industry
Source: http://www.dteenergy.com/images/naturalGasIndustry.gif

C. Safety in the LNG Industry8

The following four elements provide for multiple layers of safety in the LNG industry for the safety of both LNG industry workers and the surrounding communities:

- Primary containment is the first and most important layer of protection. It involves the use of appropriate materials for LNG facilities as well as proper engineering design of storage tanks onshore and on LNG ships and other LNG transport and storage containers.
- Secondary containment ensures that, if leaks or spills occur at an onshore LNG facility, the LNG can be fully contained and isolated from the public.
- Safeguard systems offers a third layer of protection, by minimizing the frequency and size of LNG releases both onshore and offshore and preventing harm from potential associated hazards, such as fire. LNG operations use technologies such as high-level alarms and multiple back-up safety systems, which can identify problems and shut off operations in the event of certain specified fault conditions or equipment failures; these systems are supplemented with the establishment of operating procedures, training, emergency response systems, and regular maintenance to protect people, property, and the environment from any release.
- The fourth level of protection includes the regulatory-mandated separation distances of land-based LNG facilities from communities and other public areas, and the required safety zones around LNG ships.

D. Risks Associated with LNG Applicable to all Categories of New and Emerging Facilities and Operations

Natural gas is the cleanest burning fossil fuel and is being used throughout the world to reduce carbon dioxide emissions. Compared to coal, natural gas produces far fewer carbon dioxide emissions and sulfur emissions. LNG is simply natural gas in a liquid state. As a fuel, LNG

[8] Energy Economics Research, Bureau of Economic Geology, The University of Texas at Austin, Professor Michelle Michot Foss, "LNG Safety and Security." http://www.beg.utexas.edu/energyecon/LNG_Safety_and_Security_Update_2012.pdf Updated June 2012. Accessed November 9, 2015.

produces relatively low emissions when burned to heat and cool homes, generate electricity, and power vehicles.[9]

LNG is odorless, non-toxic and non-corrosive. When exposed to the environment, LNG rapidly evaporates, leaving no residue on water or soil.[10] Thus, if spilled, LNG is not a persistent cargo, the Oil Pollution Act of 1990 and other similar acts are not applicable, and liability focus is on fire and damage vs. pollution.[11] In addition, as LNG is cryogenic, contact with some non-cryogenic materials will cause such materials to become brittle and fail, and exposure to skin will cause cryogenic burns.[12]

V. Phase 1 Initial Research Results

This section provides high-level, general information obtained primarily via Internet searches on the categories of new and emerging LNG facilities and operations identified in PHMSA's May 2014 draft report.

A. LNG marine export/import terminals not supplied by/connected to pipelines regulated by 49 CFR Part 192

Marine export terminals supply LNG (natural gas that has undergone liquefaction[13]) to ships that transport the LNG to locations that store and/or convert the LNG to natural gas. The increase in shale gas production and lower price in the U.S. has renewed interest in the U.S.'s exporting of LNG. Marine import terminals receive LNG from ships and store and/or convert the LNG to natural gas in a process called regasification[14]. The U.S. imports small amounts of LNG.[15]

The Federal Energy Regulatory Commission (FERC) is responsible for authorizing the siting and construction of onshore and near-shore LNG import or export facilities under Section 3 of the Natural Gas Act. As required by the National Environmental Policy Act, the FERC prepares environmental assessments or impact statements for proposed LNG facilities under its jurisdiction. Projects which are approved and built are subject to FERC oversight for as long as the facility is in operation. FERC currently regulates 24 operational LNG facilities.[16]

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[9] http://www.lngfacts.org/about-lng/environment/ Updated 2015. Accessed September 23, 2015.

[10] Ibid.

[11] "Marine Transport of LNG" PowerPoint Presentation by B. Curt, Qatargas II, to Intertanko Conference on March 29, 2004, http://www.marad.dot.gov/wp-content/uploads/pdf/DWP -- Marine Transportation of LNG.pdf Accessed September 24, 2015.

[12] Ibid.

[13] Liquefaction terminals convert natural gas into LNG. Liquefaction terminals are on the export side of LNG transactions. Liquefaction terminals generally receive natural gas by pipeline from a well field. Before the natural gas is liquefied by cooling it to -259°F (-161°C), natural gas must be cleaned of water, carbon dioxide, hydrogen sulfide, and other impurities that might freeze, become corrosive, or interfere with the liquefaction process. Once liquefied, the LNG is sent by pipeline to a LNG carrier ship or into storage to await transport. (http://geology.com/articles/lng-liquefied-natural-gas/)

[14] Regasification terminals convert LNG back into natural gas. Regasification terminals are on the import side of transactions. These terminals receive natural gas—usually by ship—from other areas. At a regasification terminal, the LNG might be temporarily stored or sent directly to a regasification plant. Once regasified, the LNG is sent by pipeline for distribution or placed in temporary storage until it is needed. (http://geology.com/articles/lng-liquefied-natural-gas/)

[15] http://www.energy.ca.gov/lng/faq.html Updated 2015. Accessed September 23, 2015.

[16] http://www.ferc.gov/industries/gas/indus-act/lng.asp Updated October, 1, 2015. Accessed October 14, 2015.

FERC regulations require safety zones around LNG facilities. Setback distances must be great enough so that flammable vapors will not reach the facilities' property lines and heat radiation from a potential fire will not impact those beyond the facilities' property line. Sophisticated safety systems add an additional layer of protection. Sophisticated alarms and multiple back-up safety systems, which include emergency shutdown (ESD) systems, are core components of LNG facilities. ESD systems can identify problems and shut down operations, limiting the amount of LNG that could be released. These systems are normally linked to automated gas, liquid, and fire-detection equipment. Detectors for monitoring LNG levels and vapor pressures within storage tanks and closed-circuit television equipment for monitoring all critical locations of LNG facilities are present at these facilities. Facility safety systems combined with special operating procedures, training, and equipment maintenance minimize the risk of an accident.[17]

A minimum water depth of approximately 50 to 60 feet is needed to berth LNG carriers.[18]

Based on the facility descriptions, the following U.S. location may fall under this category of new and emerging LNG facilities/operations[19]:

- Everett, MA (1.035 Bcfd[20]): As New England lacks underground gas storage, the region relies on LNG to meet heating demand on very cold days and, more recently, for industrial customers without access to pipeline gas. This terminal furnishes LNG in liquid form to customers with their own LNG storage tanks through four truck-loading bays, for a total liquid send-out of more than 100 million cubic feet, or 1.2 million gallons daily. Everett Terminal's truck-loading bays are able to fill more than 25,000 truckloads a year and has a new LNG fueling station specifically built to serve heavy-duty trucks.[21]

Other U.S. LNG marine export/import terminal locations regulated by FERC or MARAD/USCG include the following (***Note:*** Some/all of these facilities may be connected to pipelines regulated by 49 CFR Part 192, and thus would not be considered a "new and emerging facility/operation" under this category.):

- Existing LNG import/export terminals[22]:
  - Cove Point, MD (1.8 Bcfd)
  - Elba Island, GA (1.6 Bcfd)
  - Lake Charles, LA (2.1 Bcfd)
  - Offshore Boston, MA (two terminals—0.8 and 0.4 Bcfd)
  - Freeport, TX (1.5 Bcfd)
  - Sabine, LA (4.0 Bcfd)
  - Hackberry, LA (1.8 Bcfd)
  - Sabine Pass, TX (2.0 Bcfd)
  - Pascagoula, MS (1.5 Bcfd)
  - Kenai, AK (0.2 Bcfd)
  - Peñuelas, Puerto Rico (0.2 Bcfd)

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[17] https://www.dom.com/corporate/what-we-do/natural-gas/dominion-cove-point/safety-at-dominion-cove-point Updated 2015. Accessed October 14, 2015.

[18] D. Blakemore. "Regional LNG Update: Energy Demand Fuels LNG Import Site Development in the Gulf of Mexico." Fall 2005. http://www.uscg.mil/proceedings/archive/2005/Vol62_No3_Fall2005.pdf Updated Fall 2005. Accessed October 6, 2015.

[19] http://www.ferc.gov/industries/gas/indus-act/lng/lng-existing.pdf Updated and Accessed September 29, 2015.

[20] Bcfd stands for billion cubic feet per day.

[21] http://www.gdfsuezna.com/media/files/files/dcb795dc/Fueling-Growth-of-LNG-in-NA-Brochure.pdf Updated 2015. Accessed October 14, 2015.

[22] http://www.ferc.gov/industries/gas/indus-act/lng/lng-existing.pdf Updated and Accessed September 29, 2015.

- LNG export terminals approved and under construction[23]:
  - Sabine, LA (2.76 Bcfd)
  - Hackberry, LA (1.7 Bcfd)
  - Freeport, TX (1.8 Bcfd)
  - Cove Point, MD (0.82 Bcfd)
  - Corpus Christi, TX (2.14 Bcfd)
- LNG export terminal approved, but not under construction[24]: Sabine Pass, LA (1.4 Bcfd)
- LNG import terminal approved and under construction[25]: Corpus Christi, TX (0.4 Bcfd)
- LNG import terminals approved, but not under construction[26]:
  - Salinas, Puerto Rico (0.6 Bcfd)
  - Gulf of Mexico (two terminals—1.0 and 1.4 Bcfd)
  - Offshore Florida (1.2 Bcfd)

Additional U.S. LNG export and import terminals are in the proposed stage with FERC and MARAD/USCG.

Ships that transport bulk LNG to and from import and export facilities are generally double-hulled and insulated; can be up to 1,000 feet long requiring a minimum water depth of 40 feet when fully loaded; and are designed to handle LNG's low temperature and to limit the amount of LNG that boils off or evaporates.[27]

1. *Safety at LNG Import and Export Terminals*[28]

LNG import and export terminals are designed with multiple layers of protection and must meet rigorous safety regulations. They are equipped with spill containment systems, fire protection systems, multiple gas, flame, smoke and low- and high-temperature detectors and alarms, automatic and manual shut-down systems, video surveillance systems, and highly trained personnel.

The USCG determines the suitability of a waterway to transport LNG safely and creates safety and security rules for each specific port. The USCG works with terminal and ship operators and host port authorities to ensure that policies and procedures conform to required standards and works with operators to conduct emergency response drills. The USCG has the authority to require and receive background checks of crews and to conduct ship searches and may require the use of Sea Marshals, who are specially trained and armed USCG personnel.

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[23] http://www.ferc.gov/industries/gas/indus-act/lng/LNG-approved.pdf Updated and Accessed September 29, 2015.
[24] Ibid.
[25] Ibid.
[26] Ibid.
[27] http://www.energy.ca.gov/lng/faq.html Updated 2015. Accessed September 23, 2015.
[28] http://www.lngfacts.org/about-lng/safetysecurity/ Updated 2015. Accessed October 1, 2015.

2. *Safety at LNG Liquefaction Facilities*[29]

Liquefaction of natural gas to LNG requires cooling the natural gas until it becomes a liquid. These processes include gas conditioning before liquefaction, processing and managing the impurities and liquid hydrocarbons, and storing and handling of the refrigerants that are used to cool the natural gas to a liquid state.

Refrigerants used in natural gas liquefaction plants (typically some combination of light hydrocarbons such as methane, ethane, ethylene, propane, butane, and isopentane; nitrogen is also a common refrigerant component) are safely produced and handled routinely in hundreds of U.S. refineries, petrochemical plants, and natural gas processing facilities.

Natural gas liquefaction facilities must comply with rigorous government regulations and industry codes and standards for their engineering, operations, maintenance, and personnel training.

The liquefaction process requires significant compression systems for refrigeration that include large centrifugal compressors typically driven by gas turbines, steam turbines, or large electric motors. This type of rotating equipment is larger than typically found in LNG import terminals and is similar to what is found in refineries, power plants, and large chemical plants. Rigorous measures are utilized at liquefaction facilities to ensure the safe design and operation of this equipment.

3. *Activities at Regasification Facilities*[30]

The Department of Energy (DOE) is studying a novel method of unloading and regasifying LNG directly from ocean tankers for storage in underground salt caverns. Under this process, called the "Bishop Process," LNG would be received directly from an offshore tanker, regasified, pressurized, and warmed to 40°F, then injected into underground salt caverns. A DOE study identified more than two dozen potential sites that had suitable salt formations, sufficiently close proximity to existing pipelines and navigable water.[31] This process would eliminate the need to build expensive aboveground cryogenic storage tanks. A combination of the Bishop Process with the construction or conversion of existing offshore depleted gas fields, platforms, and lines could also be a means to import, store, and transport LNG. There are many offshore depleted gas fields that could be used for this purpose. Environmental concerns such as brine disposal used in the development of salt caverns and land use have been raised.

4. *Risks Associated with **LNG Marine Export/Import Terminals***

"Public support for LNG projects is generally mixed - especially on the import side where large numbers of people may be located near the regasification facility. Although some people hope that LNG will bring them a reliable source of economical natural gas, others have concerns that the regasification plant or the transport vehicles might explode or catch

[29] Ibid.

[30] http://www.ferc.gov/EventCalendar/Files/20041020081349-final-gs-report.pdf, Federal Energy Regulatory Commission, Staff Report, September 30, 2004, page 15. Accessed October 2, 2015.

[31] http://www.fe.doe.gov/programs/oilgas/storage/index.html Updated September 2015. Accessed October 2, 2015.

fire. Some people are also concerned that LNG facilities are terrorist targets. Although LNG has an excellent history of safety, these concerns cannot be assigned a probability of zero."[32]

B. Marine cargo transfer system components between the vessel and the last valve on the storage tank[33]

LNG contained in the ship's tanks is transferred from the tanks via pipes located in the bottom of each tank compartment; these pipes run from the tanks' bottoms to pipe manifolds on the ship's deck, where connection between the ship and the onshore facilities is made. Tankers are typically equipped with manifolds on both their starboard and port sides to allow the ship to berth at either side of the terminal.

To discharge the tanks to the shore facilities, the liquid cargo is pumped from the bottom of the tanks up to the pipe manifolds on the ship's deck. Typically, a tanker is equipped with three or four cargo pumps located in a pump room immediately forward of the engine room near the ship's stern and at the end of the tank section. The ship's pumps have the power to move the LNG from the tanks to the deck manifold and on to the shore side distribution system. An important part of the tankers cargo system is the inert gas system (IGS), which is used to inert the atmosphere within the cargo tanks as the cargo is pumped to the terminal.

Tankers will have a boiler to manufacture power for the steam turbines, which in turn provide power to the cargo pumps. Alternately, a tanker may have electric motor-driven cargo pumps which are powered by diesel generators. Typically a tanker is equipped with three service generators which supply the electric power for all tanker operations and act in redundant capacity in case of a single generator breakdown .Electrical power can also be generated using steam driven turbo-alternators if the ship is so equipped.

The system used to control cargo operations is typically a combination of mechanical, hydraulic, and electronic automated systems that provides cargo personnel with the ability to fully monitor operations, and gives adequate warnings when tanks are full or pumps are not operating correctly. The topside equipment and systems provide all the pipelines, valves, fire protection, vessel access, and control systems required to safely transfer the cargo and crew between the land facility and the tanker. All topside equipment is controlled by the central control room located onshore near the water.

The onshore cargo transfer system includes marine loading arms, manifolds, pipelines, booster pumps, and valves. Connection between the ship and the marine terminal is made with the use of marine loading arms, which feed into an adjacent onshore manifold that controls the flow of product being transferred through the system. The onshore manifold in turn is connected to pipelines running on the platform deck and along the access trestle to the onshore tank facilities.

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[32] http://geology.com/articles/lng-liquefied-natural-gas/ Updated 2015. Accessed September 24, 2015.

[33] http://www.southportland.org/files/5213/9533/7249/Northern_Gateway_Pipelines_TERMPOL_Surveys_and_Studies_-_Cargo_Transfer_and_Transhipment_Systems.pdf Updated January 20, 2010. Accessed September 29, 2015.

Marine loading arms consist of articulated pipe assemblies able to swivel in all directions and are designed to be directly connected to the ship's manifold. The loading arms can accommodate the movements of a moored ship while maintaining a secure seal for leak-free cargo transfer. Marine loading arms are standard equipment for most marine oil terminals around the world, and their operating range is established based on the required ship movement envelope at the point of loading/unloading. The marine arms are equipped with a variety of visual and audible alarms and systems designed to monitor the arm's position and provide warnings when the maximum operation envelope is reached. They are supplied with hydraulic or powered emergency release couplings, which allow for rapid connection between the loading arm and various diameters of ship manifolds without the need for special adaptors, and also stop the flow of LNG and provide rapid disconnection during emergencies.

Alternately, an LNG hose transfer system is used by some companies, which describe these systems as "more cost effective, more flexible, and a portable alternative to conventional loading arm systems."[34]

An area in the U.S. where marine LNG transfer operations occur is the Freeport LNG Terminal in Quintana, Texas.[35]

Most LNG carrier ships and shore facilities have coordinated and detailed arrival, loading, unloading, and departure procedures for personnel to follow during normal and emergency events.[36] Transfer of LNG from ship to terminal usually occurs in well-defined and secured marine areas.

1. Risks Associated with Marine Cargo Transfer System Components

Emergencies can occur on the vessel or at the berthing location, and can include situations such as but not limited to, the following[37] [38]:

- Problems with the LNG tank's pressure release valves, which could result in LNG compromising the tank's and/or the vessel's structural integrity, and natural gas releases that, if contacting an ignition source, have the potential to ignite;
- Extreme weather conditions that can compromise LNG transfer operations;

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[34] KLAW LNG, United Kingdom, http://www.klawlng.com/lng-applications/lng-ship-to-shore-transfer-systems/ Updated 2015. Accessed September 29, 2015.

[35] http://www.freeportlng.com/PDFs/FMOManual.pdf Updated December 1, 2011. Accessed October 5, 2015.

[36] http://www.liquefiedgascarrier.com/cargo-loading.html Last update date not listed on website. Accessed on various days in September and October 2015; http://www.freeportlng.com/PDFs/FMOManual.pdf , December 1, 2011. Accessed September 30, 2015.

[37] http://www.narucmeetings.org/Presentations/Sandia%20NARUC%20LNG%20Cascading%20Damage%20Summary%20Overview%202-2013.pdf, "Marine LNG Transport—Cascading Damage Study Summary and Risk Management Considerations." DOE/Sandia National Laboratories. M. Hightower. Updated February 2013. Accessed October 20, 2015.

[38] J. de Baan/Bluewater Energy Services B.V.; M.H. Krekel, R. Leeuwenburgh/Bluewater Offshore Production Systems (USA), Inc.; M.M. McCall/Conversion Gas Imports, LLC. "Offshore Transfer, Re-Gasification and Salt Dome Storage of LNG." Paper copyrighted and presented at the 2003 Offshore Technology Conference in Houston, TX, May 5-8, 2003. http://www.marad.dot.gov/wp-content/uploads/pdf/DWP_--_Offshore_Transfer,_Re-Gasification_and_Salt_Dome_Storage_of_LNG.pdf Accessed various days in September and October 2015.

- Congested berthing/mooring areas where vessels have an increased chance of making unintended contact with other vessels/berthing structures, which could damage LNG tanks on a vessel or equipment at the berthing location; and
- Shallow water areas where vessels cannot access the berthing location or become unintentionally grounded.

Onshore facilities in the Gulf of Mexico have drawn the skepticism of home and landowners who are wary of the safety and security of both LNG tankers and facilities. Deepwater ports have drawn strong interest from many interest groups, especially the LNG industry's desired use of open rack vaporizers (ORVs) to regasify LNG. Environmentalists claim that ORVs will significantly harm fisheries, while LNG project companies assert that ORVs will have minimal impact on oceanic environment.[39]

C. LNG tanker and carrier ships, LNG tank trucks, and other vehicles (e.g., heavy-duty trucks, buses, ships, locomotives, and mining vehicles) that consume LNG fuel or transport LNG

1. LNG Tankers and Carrier Ships

LNG tank ships are different from regular tank ships carrying oil and chemicals. Each LNG tank ship has two hulls so that, if a collision or grounding punctures the outer hull, the ship will still float and the LNG will not spill out. The ships tend to ride high in the water, even when loaded. A typical LNG ship is 950 feet long and 150 feet wide, and many new ships being built are even bigger.[40]

Figure 2. Moss Ship and Tank Schematic

Source: http://www.narucmeetings.org/Presentations/Sandia%20NARUC%20LNG%20Cascading%20Damage%20Summary%20Overview%202-2013.pdf

LNG tanks are either spherical ("Moss" model, aluminum alloy spheres with the upper half of the sphere sticking out above the deck, which are structurally independent from the ship), or box-shaped ("Membrane" model, thin, stainless steel tanks supported by the ship's hull structure).[41]

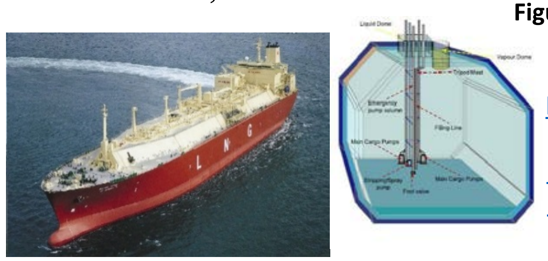

Figure 3. Membrane Ship and Tank Schematic

Source: http://www.narucmeetings.org/Presentations/Sandia%20NARUC%20LNG%20Cascading%20Damage%20Summary%20Overview%202-2013.pdf

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[39] D. Blakemore. "Regional LNG Update: Energy Demand Fuels LNG Import Site Development in the Gulf of Mexico." Fall 2005. http://www.uscg.mil/proceedings/archive/2005/Vol62_No3_Fall2005.pdf Updated Fall 2005. Accessed October 6, 2015.

[40] Dr. A. Schneider. "LNG: Liquefied Natural Gas—What is it? Is it Safe? What is the Coast Guard Doing about it?" Fall 2005. http://www.uscg.mil/proceedings/archive/2005/Vol62_No3_Fall2005.pdf Updated Fall 2005. Accessed October 7, 2015.

[41] http://www.narucmeetings.org/Presentations/Sandia%20NARUC%20LNG%20Cascading%20Damage%20Summary%20Overview%202-2013.pdf, "Marine LNG Transport—Cascading Damage Study Summary and Risk Management Considerations." DOE/Sandia National Laboratories. M. Hightower. Updated February 2013. Accessed October 20, 2015.

Key design issues that need to be considered include[42]:

- LNG fuel tank capacity and type.
- LNG fuel tank location—consider the following risks:
- Sustaining mechanical damages;
- Fire in adjacent space, causing tank over pressure;
- Leaked flammable product, causing fire and explosion; and
- Leaked cryogenic fluid, leading to loss of tank's structural integrity.
- Leak mitigation in tank hold space—safe distances and access areas.
- Fuel gas pipe arrangements.
- Bunker station requirements: sufficient natural ventilation, physical separation and structural protection, stainless steel drip trays, Class A-60 protection, remote control and monitoring, manual and remote emergency shutdown valves, provisions for draining/purging/inerting, and ventilation and gas detection of bunkering lines.
- Standardization of the interface between the ship and the fuel supply facilities, to ensure that a LNG fueled ship can refuel in any port with LNG fuel supply facilities.
- Burn off gas management—a means of pressure and temperature control must be available at all times even when in port or maneuvering.
- Continuity of power – fault tolerant design.

On 1 August 2012, the North American Emission Control Area was established with the goal of reducing air pollution by imposing enforceable vessel air emission limits. To comply with these stricter emissions standards, the maritime industry has begun looking into ways to convert and/or construct vessels to use LNG as fuel, as LNG produces substantially lower air pollutants. The maritime industry is considering a variety of methods for supplying LNG to vessels for use as fuel, including, but not limited to, supplies delivered from vessels (e.g. barges, small tankers) or via shore-based structures (e.g. storage tanks, mobile tank trucks, railcars).[43]

To meet the growing demand for LNG marine fueling operations, international organizations [e.g., International Maritime Organization (IMO) and the International Standards Organization (ISO)] are working to develop guidelines that countries can use to establish standardized infrastructure and operational procedures to help ensure LNG marine fuel transfer operations are conducted safely and uniformly in the global maritime community.[44]

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[42] ABS PowerPoint Presentation, "LNG Fuel Systems: Certification & Approval," S. Gumpel, February 24, 2012. http://www.glmri.org/downloads/focusAreas/presentations/gumpel2-2012.pdf Updated February 24, 2012. Accessed October 15, 2015.

[43] U.S. DHS, USCG, CG-OES Policy Letter No. 02-14, "Guidance Related to Vessels and Waterfront Facilities Conducting LNG Marine Fuel Transfer (Bunkering) Operations—Draft for Public Comment, Background Section." http://www.uscg.mil/TVNCOE/Documents/default/LNGBunkering.pdf Updated 2014. Accessed October 15, 2015.

[44] Ibid.

2. *Safety of LNG Tankers and Carrier Ships*

The USCG determines the suitability of every LNG ship that delivers cargoes into and out of the U.S. through a rigorous annual inspection. If a ship fails the inspection, all deficiencies must be fixed before it can unload its cargo or leave the country. LNG ships are issued a Certificate of Compliance by the USCG to state that they are in complete compliance with U.S. regulations.[45]

More than 135,000 LNG carrier voyages have taken place without major accidents or safety or security problems, either in port or at sea. As LNG ships are double-hulled, with more than six feet of void space or water ballast between the outer and inner hulls and the cargo tanks, the double hulls help to prevent leakage or rupture in the event of an accident. LNG ships are also equipped with sophisticated leak detection technology, ESD systems, advanced radar and positioning systems, and numerous other technologies designed to ensure the safe and secure transport of LNG. Studies undertaken by various technical authorities and Sandia National Laboratories on LNG shipping safety and security confirm that risks from accidental LNG spills, including as a result of collisions and groundings, are highly unlikely due to the rigorous safety policies and practices put in place by the LNG industry. Risks resulting from intentional events, such as terrorist acts, can be greatly reduced with appropriate security, planning, mitigation, and prevention, and the LNG carrier industry has these precautions in place.[46]

The ESD system is a requirement of the IMO Code for the carriage of liquefied gases in bulk and is a recommendation of the Society of International Gas Tanker and Terminal Operators. All members of the ship's company must be aware of locations and the methods of activating and testing the ESD system specific to their vessel. The ESD system is a quick closing system, which may be activated automatically or manually; it will close all deck valves and shut down all cargo machinery. The ESD system will stop cargo liquid and vapor flow in the event of an emergency and bring the cargo handling system to a safe, static condition. The ESD system minimizes potential risks during the transfer of liquefied gases between ship and shore loading and unloading installations. It provides a quick and safe means of stopping the transfer of cargo and isolating ship and shore cargo systems in a controlled manner, either manually or automatically, in the event of fault conditions that affect the ability of the operator to control safely the transfer of cargo. Most export terminals, and an increasing number of import terminals, now have a second level of protection providing for the rapid disconnection of the loading arms from the ship. These two levels of cover are known as "ESD-1" and "ESD-2." Manual emergency shutdown push buttons are situated strategically around the ship, at locations that include the wheelhouse, cargo control room, fire control station, manifold platforms and tank liquid domes. In addition, manual activation of the shore ESD system will, through the ship/shore link, set off the ship's ESD-1. ESD-2 is normally initiated by the terminal and will result in all the actions as for ESD-1, plus the initiation of a dry break of the shore arm from the ship. ESD-2 may be initiated manually or automatically.[47]

[45] http://www.lngfacts.org/about-lng/safetysecurity/ Updated 2015. Accessed October 9, 2015.
[46] Ibid.
[47] http://www.liquefiedgascarrier.com/cargo-emergency-shutdown.html Last update date not listed. Accessed on various days in September and October 2015.

LNG vessels must always conduct pre-arrival ESD system tests 48 hours before arrival at any load or discharge port. Additionally, in the event of an extended voyage, the ESD system should again be tested at intervals of not more than 30 days from the previous test. Successful completion of these tests must be recorded in the deck log book. Prior to loading/discharge operations in port, additional ESD testing in both the warm and cold conditions shall be carried out as part of the pre-transfer ship-shore checklist.[48]

3. *Security of LNG Carrier Ships*[49]

The LNG industry carefully follows requirements set forth by the IMO, FERC, U.S. DOT, and USCG, and works closely with the U.S. Department of Homeland Security (DHS) to ensure that its operations are safe and secure.

LNG ships are fast for their size and less prone to pirate attacks since they sit high in the water relative to crude oil carriers and conventional cargo ships. The industry takes piracy seriously and follows international best practices. There are additional security measures, procedures, and equipment on board LNG tankers to deter and repel such attacks, but they are not disclosed in order to increase their effectiveness.

Before a ship enters a U.S. port, the captain is required to inspect each and every compartment and report this inspection as part of the 96-hour notice. This written inspection is given to the USCG upon arrival in U.S. waters. The USCG may then perform its own inspection. There are other security procedures in place when the vessel is at sea, which are also not disclosed to ensure their effectiveness.

Every crew member must either have a visa that has been approved by the U.S. State Department, or the ship has to have an armed guard to prevent crew members without visas from disembarking. The crew list is provided to the USCG 96 hours prior to arrival. A background check is run on all crew members by the USCG and U.S. Immigration and Security Authorities.

4. *Risks Associated with LNG Tankers and Carrier Ships*

Transferring LNG [reducing natural gas to LNG by cooling it to -259°F (-161°C)] comes with a host of risks due to the cryogenic characteristics when the gas is in its liquid form; for example, a leak can crack a ship's deck and hull.[50]

In February 2013, DOE/Sandia National Laboratories produced an LNG carrier bulk transport cascading damage study and risk management summary report.[51] The report provided the following information:

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[48] Ibid.

[49] Ibid.

[50] http://www.marinelink.com/news/rise-the-lng380156.aspx, "LNG on the Rise." Posted by E. Haun. Updated November 3, 2014. Accessed September 30, 2015.

[51] http://www.narucmeetings.org/Presentations/Sandia%20NARUC%20LNG%20Cascading%20Damage%20Summary%20Overview%202-2013.pdf, "Marine LNG Transport—Cascading Damage Study Summary and Risk Management Considerations." DOE/Sandia National Laboratories. M. Hightower. Updated February 2013. Accessed October 20, 2015.

- LNG hazards depend on the size, location, and approach of marine LNG shipping and distribution operations.
- In near-term, small LNG ships, barges, and isotainers are more likely to be present in ports, while larger LNG ships are more likely to be present in deep harbors or offshore areas.
- Moss and Membrane model ships have four to six million elements that can fail.
- Fire testing and analysis results:
    - LNG dispersion distance is limited by the closest ignition source:
        - Hazard distance for a small LNG spill (300 gallons/minute) is approximately 10 meters in diameter.
            - Maximum lower flammability limit (LFL[52]) dispersion distance of natural gas is approximately 75 meters.
        - Hazard distance for possible isotainer or LNG trailer spill (7,000 gallons/minute) is approximately 43 meters in diameter.
            - Maximum LFL dispersion distance of natural gas is approximately 300 meters.
    - LNG fires produce temperatures of 700-1,200°C.
        - Material testing show these temperatures will significantly reduce LNG ship steel structural strength.
    - Fire tests show flames anchor to ship structure (no detached floating pools).
    - Typical crosswinds can make an LNG fire and associated thermal radiation impact large portion of an LNG ship structure.
    - Using measured heat flux values, analyses suggest LNG cargo tank pressure increases only 1-2 psi during nominal spill and fire:
        - Likely no over pressurization of tank or relief valves.
        - Simultaneous cascading damage of LNG cargo tanks from a large fire deemed unlikely.
- Cryogenic damage testing and analysis results:
    - LNG is known to cause brittle fracture of ship deck plates; testing shows all ship steel is vulnerable to fracture.
    - About 40% of LNG spilled from a large cargo tank breach can stay within the ship.
    - LNG can flow into many areas between individual cargo tank cofferdams.
    - Fractures are likely to occur in all structural elements that come in contact with LNG for extended time.
    - Major cryogenic fractures and damage will begin to occur to the ship within 3-5 minutes of a spill; fire damage within 5-15 minutes of a fire starting.
    - Cryogenic fracture and damage will occur as flow progresses and the structural elements cool.
    - Fire weakening of the ship structure begins following a spill once a fire stabilizes.
    - Damage to an LNG ship from a large spill could be significant.
    - Damage identified from large spills would force a ship safety assessment.
    - Pool diameter is less than spill diameter.

[52] LFL is the lowest value where LNG can be ignited.

- Cascading damage testing and analysis results:
  - About 40% of LNG spilled can stay within the LNG vessel, causing cryogenic and fire thermal damage to the vessel's structure, which for large spills would make the ship unable to be moved and require a safety evaluation.
  - The cargo tank insulation and relief valve systems appear to be adequately designed to prevent over pressurization of the cargo tanks or over capacity of relief valves from an LNG fire.
  - Simultaneous, multiple cargo tank spills (cascading failure) from an initial event seem unlikely, though sequential ruptures could occur from ship damage and extend the duration of a fire.
  - Ship damage from small spills will provide less severe damage and allow for up to 24 hours to assess and implement response measures.

5. *Risk Management Information*[53]

Suggested risk management approaches for reducing the possibility of a large LNG spill:

- Eliminate other vessel transit and movement during marine LNG import or export operations;
- Modify LNG tanker escorts to improve protection from potential large breach events through enhanced standoff or active interdiction;
- Modify offshore LNG operations to improve protection from potential large breach events through active interdiction or enhanced standoff technologies; and
- Provide enhanced standoff systems and protection for LNG ships during transit near populated areas as appropriate and while at LNG terminals during LNG discharge or receiving operations.

Suggested risk management approaches for reducing ship damage and hazards to the public:

- Improve emergency response coordination and procedures for LNG ship maneuvering to safe anchorages to monitor, inspect, and assess ship damage, stability, seaworthiness, and long-term needs;
- Utilize ship ballast tanks to reduce damage through modifications of typical operational use;
- Utilize high performance fire-fighting tugs with 7,000 to 11,000 meters^3/hour (30,000–50,000 gallons/minute) fire monitor capacity to reduce the thermal damage from a fire on LNG ship weather covers and outer hulls;
- Establish lightering[54] procedures and capabilities for marine LNG imports for near-shore terminals and operations, as appropriate; and
- Modify ships by adding lightweight fire insulation, modifying deluge systems, and reducing connectivity of void spaces.

[53] http://www.narucmeetings.org/Presentations/Sandia%20NARUC%20LNG%20Cascading%20Damage%20Summary%20Overview%202-2013.pdf, "Marine LNG Transport—Cascading Damage Study Summary and Risk Management Considerations." DOE/Sandia National Laboratories. M. Hightower. Updated February 2013. Accessed October 20, 2015.

[54] Lightering is the ship-to-ship transfer of cargo from a large to a small tanker ship for transport to destination where access to larger ships is prohibited due to their size and draft (Source: http://www.emm-bahamas.com/lightering.html).

6. LNG Transport Trailers and Tank Trucks

Transgas[55] in Lowell, MA, Cryogenic Vessel Alternatives (CVA)[56] in Mont Belvieu, TX, and Chart Industries[57], a global company with its corporate headquarters in Garfield Heights, OH design, manufacture, and/or maintain cryogenic tankers of various sizes and designs for transporting LNG.

Transgas has MC-338 LNG tankers with capacities from 11,000-13,000 gallons. These tankers are constructed with an outer vessel of carbon steel and an inner pressure vessel made from aluminum or stainless steel, with several inches of insulation and a vacuum between the outer jacked and inner pressure vessel; these double-walled tankers are more durable than similar tanker truck designs used for the transportation of other liquid fuels such as diesel. Transgas' LNG tankers also feature pressure relief valves and safety shut off valves.

CVA's LNG transport trailers are built to carry large payloads; accommodate a variety of pump and drive types; are optimized for maximum payload and durability in difficult terrain; and include pneumatic and mechanical suspension systems to provide for operator comfort and increased safety.

Chart Industries manufactures LNG semi-trailers on various sizes for LNG transport on U.S. highways; 20- and 40-foot LNG ISO intermodal containers for LNG transport by ship, rail, or road; and SR-602 and SR-603[58] tank cars for bulk transport of LNG via rail.

Figure 4. Chart Industries LNG Highway Semi-Trailer, 20-Foot Intermodal LNG ISO Container, and R-602 Bulk LNG Tank Car for Rail Transport

Source: http://lngplants.com/CHART_VEHICLE_FUELING.html#

[55] http://www.transgaslng.com/services/lng-transportation/ Last update date not listed on website. Accessed October 7, 2015.

[56] http://cvatanks.com/products/lng-equipment/lng-transport-trailer/ Updated 2011. Accessed October 7, 2015.

[57] http://www.chartindustries.com/About-Chart Updated 2015. Accessed October 8, 2015.

[58] According to http://lngplants.com/CHART_VEHICLE_FUELING.html#LNG_BULK_TRANSPORT (Updated 2015, Accessed October 8, 2015), Model SR-602 is volume optimized for LNG transport on railroad clearance Plate "C" and FRA's 34,500 gallon limit for flammable products. Model SR-603 LNG tank car is optimized for carrying maximum payloads of LNG. Both models meet DOT/FRA DOT-113C120W tank car design codes.

Companies are beginning to consider transporting natural gas as remote drilling frontiers emerge beyond the reach of pipelines. LNG already powers heavy-duty trucks and boats in the U.S. and Canada via a network of fueling stations. Natural gas by rail is years away and likely to face strong public resistance after a series of explosive crude-by-rail accidents. But the potentially multibillion-dollar development could connect gas-rich regions like North Dakota with urban centers, presenting an opportunity for railroads, drillers, and tank car makers already cashing in from hauling oil on trains. It could also be a cure for environmentally unfriendly flaring, a growing problem in far-flung areas where more than $1 billion of natural gas produced alongside oil is burned off each year for lack of processing plants or pipelines that can take years to build. Small-scale refrigeration plants that can turn gas to LNG are being built in drilling regions to reduce gas flaring. Transporting gas by rail, most likely as cryogenic LNG, faces obstacles, as the technology is in its infancy, tank cars are currently not permitted to carry the fuel on U.S. rails[59], and only a limited number of plants that convert natural gas to LNG exist in the U.S. Many of the major Class 1 railroads that have embraced crude by rail have declined to speak about specific plans for gas by rail, but as railroads team up with companies like General Electric Co., and Caterpillar Inc., to develop technology to run locomotives on LNG, many say that hauling the fuel as cargo is the next step as a drilling revolution transforms North American energy markets. Energy producers have approached Jacksonville, Florida-based CSX Corp. about moving LNG by rail; Westport Innovations has been approached about developing fuel systems for tank cars that would haul LNG as cargo; and BNSF is testing LNG-powered locomotives and million-dollar tank cars that would hold the fuel as a first step to wean trains from using costly diesel as fuel.[60]

The U.S. Energy Information Administration (EIA) projects that LNG will play an increasing role in powering freight locomotives in coming years. Continued growth in domestic natural gas production and substantially lower natural gas prices compared to crude oil prices could result in significant cost savings for locomotives that use LNG as a fuel source, according to EIA's *Annual Energy Outlook 2014*. Some railroads are considering the use of LNG in locomotives because of the potential for significant fuel cost savings and the resulting reductions in fuel operating costs. Given the expected price difference between LNG and diesel fuel, future fuel savings are expected to more than offset the approximately $1 million incremental cost associated with an LNG locomotive and its tender. However, in addition to the risk surrounding future fuel prices, other factors including operational, financial, regulatory, and mechanical challenges also affect fuel choices by railroads.[61]

7. Safety of LNG Transport Trailers and Tank Trucks

DOT requirements for transporting LNG by highway are found in 49 CFR 172.101, Table of Hazardous Materials and Special Provisions; Part 173.318, Cryogenic Liquids in Cargo

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[59] Per 49 CFR 174.63(a), bulk packaging of LNG in container-on-flatcar or trailer-on-flatcar via rail requires approval from the Federal Railroad Administration's Associate Administrator of Rail Safety.

[60] http://www.reuters.com/article/2014/06/16/us-usa-railway-natgas-insight-idUSKBN0ER0D620140616 Updated June 16, 2014. Accessed October 1, 2015.

[61] LNG Shows Potential as a Freight Locomotive Fuel," http://www.eia.gov/todayinenergy/detail.cfm?id=15831 Updated April 14, 2014. Accessed September 23, 2015.

Tanks; and Part 178.338, Insulated Cargo Tank (MC-338). The inner vessel is designed to meet or exceed the requirements for an ASME Code, Section VIII, Division 1 pressure vessel; the internal and external piping is in accordance with the requirements of ASME/ANSI B31.3 Piping Code; and Federal Motor Vehicle Safety Standards FMVSS must be adhered to for all trailer automotive functions—running gear, lights, brakes, etc.[62]

D. LNG ISO tank containers that are not used as storage vessels at LNG plants connected to pipelines regulated by 49 CFR Part 192

Refer to information in Category C (LNG tanker and carrier ships, LNG tank trucks, and other vehicles that consume LNG fuel or transport LNG). If these containers are located at LNG plants connected to pipelines regulated by 49 CFR Part 192, equipment will be used to load/unload LNG into/from these LNG ISO containers from/into the LNG plant storage containers. Additional safety and security measures (safe distances, methods to attach/disconnect loading equipment, personnel requirements for maintaining watch while LNG transfers occur, warning alarms, etc.) may apply.

Some potential U.S. locations/companies that may use/manufacturer these types of ISO tank containers include:

- Applied Cryo Technologies, Houston, TX—Model ACT-LNG-12115-ISO (40' LNG ISO container) is optimized specifically for transporting LNG worldwide by rail, sea, or road and is also ideal for onsite LNG storage. This vacuum super-insulated ISO container is designed for performance, ease of operation and safety. This LNG intermodal container comes standard with penetrations for an Economizer Circuit and Liquid Withdraw Circuit, making it ideal for LNG vaporization applications.[63]
- Lockheed Martin, LA—Lockheed Martin plans to adapt production equipment used to manufacture the external tank for the Space Shuttle for a wide range of LNG supply chain applications as part of its long-range LNG business plan. In addition to applying its external tank manufacturing expertise, the Lockheed Martin LNG tank manufacturing team will draw on its capabilities for spanning propellant handling; assembly, test, and integration; composites manufacturing; and production facility and tooling design. Tanks of varying sizes and capacities for multiple transportation applications by land, rail, or waterway will be manufactured to ASME standards for pressurized storage and transportation of cryogenic materials using the quality and safety standards implemented for the shuttle tank program.[64]
- WesMor Cryogenics, LLC, LaPorte, TX—WesMor Cryogenics manufactures T-75 portable tanks. The marine industry may begin using such portable tanks for both transporting LNG and using the contained LNG to fuel the ships during transport. The LNG stays cold in these double-walled containers for up to 60 days without boiloff.[65]

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[62] http://lngplants.com/CHART_VEHICLE_FUELING.html#LNG_Semi-Trailer_Highway_Delivery_System Updated 2015. Accessed October 8, 2015.
[63] http://www.appliedcryotech.com/products/40-lng-iso-containers/ Updated January 5, 2013. Accessed October 5, 2015.
[64] http://www.lngworldnews.com/lockheed-martin-to-manufacture-lng-tanks-in-louisiana-usa/ "Lockheed Martin to Manufacture LNG Tanks in Louisiana," Updated March 13, 2013. Accessed October 5, 2015.
[65] http://www.lngworldnews.com/zeus-intermodal-lng-tanks-important-for-marine-industry-usa/, Updated May 16, 2013. Accessed October 5, 2015.

E. Natural gas processing plants that do not store the LNG at the plant[66]

Natural gas processing plants extract natural gas liquids (NGL)/liquefied petroleum gas (LPG) from natural gas. Such processes can be integrated into natural gas liquefaction plants to extract these liquids prior to LNG production, and can produce a high quality liquid co-product for sale or export to generate additional project revenues.

Ortloff Engineers, Ltd., in Midland, TX has extended its natural gas liquids recovery process to include LNG processing. The efficiency of its overall liquefaction cycle has improved, allowing more natural gas to be liquefied for a given amount of refrigeration power. Ortloff's NGL/LPG extraction technology can also be used in LNG receiving terminals, to extract the ethane and/or propane and heavier liquids from the LNG as it is being vaporized. Because of the refrigeration inherent in the cold LNG, it is possible to produce a high quality NGL and/or LPG product stream for sale without using any additional refrigeration or external compression power. Using the "free" refrigeration in the LNG to extract the liquids also reduces the amount of external heat needed to vaporize the LNG, reducing the operating cost of the LNG terminal in addition to generating additional project revenue with the NGL/LPG co-product.

For natural gas plants and pipelines located near metropolitan areas where there is a market for vehicular LNG fuel, Ortloff has developed processes for producing high-purity liquid methane to serve this market. Gas plants can be adapted to produce a slipstream of LNG that is almost pure methane using about half the energy a stand-alone plant requires, and without any of the front-end treating and dehydration that small LNG plants require. When there are no gas plants in the area, high-purity liquid methane can instead be produced from the natural gas in high-pressure transmission pipelines at reasonable cost and without the need for CO_2 removal.

Ortloff's LNG production technology, called the Advanced Natural Gas Liquids Extraction (ANGLE), produces LNG with NGL or LPG recovery. By combining hydrocarbon recovery with the liquefaction process, operators remove valuable liquids from the natural gas stream before liquefaction in the most efficient manner, one which integrates refrigeration available in the liquefaction process with refrigeration in the liquids removal step. By integrating Ortloff's liquids removal technology into the liquefaction unit, recompression of the gas stream is not required before the liquefaction step. Additionally, the valuable heavier liquids removed from the natural gas stream as an NGL or LPG product stream can be sold to generate significant revenue. The inclusion of Ortloff's ANGLE liquids removal technology into the process design results in highly efficient recovery of valuable NGL or LPG liquids from the natural gas stream feeding the LNG plant. In addition to the higher value of the liquid NGL/LPG product stream, the overall efficiency of the liquefaction process is improved by 10-20%, resulting in a design that can liquefy additional gas without increasing the power used in the LNG process.

[66] http://www.ortloff.com/lng-processing/ Updated 2009. Accessed October 9, 2015.

F. Distributed production facilities that use LNG in gas treatment or hydrocarbon extraction processes but do not store LNG

No information was found on this specific new and emerging facility/operation category.

G. LNG facilities that store and vaporize LNG produced on-site (such as agriculture and industry on-site storage and regasification facilities) or LNG supplied by another transportation mode, as long as the LNG is consumed solely by the LNG facility owner

No information was found on this specific new and emerging facility/operation category.

INOXCVA of Baytown, TX manufactures portable LNG vaporizers.[67] Such portable vaporizers may be used at these types of LNG facilities.

Figure 5. INOXCVA (Baytown, TX) Mobile LNG Vaporizer
Source: http://cvatanks.com/products/lng-equipment/lng-vaporizers/

H. LNG refueling stations for vehicles that use LNG for fuel

LNG refueling stations can be situated on land or water, and can be fixed or mobile.

1. Land-Based LNG Refueling Stations

Cryostar, an international company with U.S. locations on the West and East Coasts and in Texas, has developed LNG refueling stations for cars, forklift trucks, buses, trucks, and special vehicles (ferry boats, trains, etc.). LNG is delivered by trailer from a terminal or small-scale LNG production plant, and its composition does not change from the production source downstream to the vehicles. It has a fixed liquefied compressed natural gas (LCNG) station in Los Angeles, CA with six LNG dispensers for super-saturated [-166°F (-110°C)], saturated [-202°F (-128°C)], and cold [-243°F (-150°C)] vehicle refueling. The average fueling time for a 118 gallon (450 liter) tank is three minutes.[68]

Figure 6. Cryostar's Los Angeles LNG and LCNG Fueling Station
Source: http://www.cryostar.com/web/lcng-lng-filling-stations.php

67 http://cvatanks.com/products/lng-equipment/lng-vaporizers/ Updated 2011. Accessed October 13, 2015.
68 http://www.cryostar.com/web/lcng-lng-filling-stations.phpp Updated 2009. Accessed October 1, 2015.

This LCNG station combines LNG and CNG in one station. A typical LCNG station is supplied with LNG and has dispensers for both LNG and CNG vehicles. Like an LNG refueling station, an LCNG station relies on a local LNG supply that can be delivered by tanker truck, similar to diesel and gasoline. The advantage of an LCNG station is that it can offer both LNG and CNG. This type of station can also be set up in areas where there is no local natural gas distribution. At an LCNG station, LNG vehicles are fueled in the same way as at an LNG station with a cryogenic pump moving the LNG from an insulated storage vessel through a dispenser into the vehicle. To produce CNG, the LNG is pumped into a vaporizer that converts it from liquid to gas in a controlled way so that it can be dispensed at the right pressure as CNG.[69]

In 2012, Cryostar partnered with Siemens to automate its LNG/LCNG filling stations. Once programmed by Cryostar, Siemens' automation system handles all of the complex tasks required to operate and monitor the fueling station while presenting a simple operator interface to users. This simple interface allows the LNG/LCNG fueling stations to be successfully operated and maintained by personnel not accustomed to process control. The customer simply inserts payment and fills the vehicle with fuel, as with any other filling station.[70]

Cryostar and INOXCVA in Baytown, TX[71] also manufacturer moveable LNG refueling stations. INOXCVA's mobile LNG refueler has safety features and automated systems that allow for speed and ease of use with minimal demand on the operator, and its design includes an efficient, cooled submerged pump; an engine generator that runs on natural gas vapor from the LNG tank; a 6,000 gallon vacuum-insulated LNG tank; front and rear methane detectors; a flame detector at the rear; explosion-proof night lighting; an optional external on-load pump; a programmable logic controller that automates fueling procedures; and an information screen with operator-friendly instructions, helpful messages, and pump information.

Figure 7. INOXCVA's LNG Mobile Fueling Station
Source: http://cvatanks.com/products/lng-equipment/lng-mobile-fueling-station/

[69] http://www.gowithnaturalgas.ca/operating-with-natural-gas/stations/fuel-station-options/lcng-stations/ Updated 2014. Accessed November 6, 2015.

[70] http://www.industry.usa.siemens.com/verticals/us/en/oil-gas/content/Documents/AMCD-CRYOS-0812_Cryostar_CaseStudy_Midstream.pdf Updated 2012. Accessed October 2015.

[71] http://cvatanks.com/products/lng-equipment/lng-mobile-fueling-station/ Updated 2011. Accessed October 13, 2015.

2. *Safety and Risk Considerations for Land-Based LNG Fueling Stations*

LNG stations are sensitive to heat entries, as the LNG can boil off rapidly.[72] In addition, as LNG is an ultra-cold fuel, people need to wear protective gloves and a face shield when fueling a vehicle, and basic training should be given to people on how to safely dispense LNG into a vehicle.[73]

3. *LNG Refueling from Trucks or Railcars for Marine Vessels*[74]

When trucks or railcars are used as a means for transferring LNG to a marine vessel, the location where the transfer occurs (i.e., any onshore area immediately adjacent to such waters, used or capable of being used to transfer liquefied natural gas, in bulk, to or from a vessel) becomes subject to the existing regulations at 33 CFR Part 127.[75]

USCG jurisdiction of waterfront facilities handling LNG applies primarily over the marine transfer area for LNG as defined in 33 CFR 127.005. Generally, this area will be from the vessel to the last manifold or valve immediately before the tank truck or railcar and would normally include associated piping and transfer hoses. However, due to this unique situation and potential for overlapping Federal jurisdictions between the USCG and the U.S. DOT, special consideration should be given to the Hazardous Material Regulations outlined in 49 CFR Subchapter C. Owners and operators intending to use tank trucks or railcars as part of their LNG transfer operation should provide the Captain of the Port (COTP) a detailed list of requirements in 49 CFR Subchapter C that are applicable to their intended operation.

Typical tank trucks and railcars will carry around 13,000 gallons (49.2 m^3) and 34,500 gallons (130.6 m^3) of LNG, respectively. These quantities are far less than the 265,000 m^3 cargo capacity vessels envisioned by the regulations. Accordingly, it would be appropriate for the COTP to consider alternatives for some of the requirements outlined in 33 CFR Part 127 when considering these types of operations.

4. *LNG Refueling from Vessel to Vessel*[76]

The operator of a vessel transferring LNG for use as fuel must provide transfer procedures that meet the requirements of 33 CFR 155.720 through 155.760 and 33 CFR Part 156. In accordance with 33 CFR 155.740, the transfer procedures must be available for inspection by the COTP whenever the vessel is in operation; legibly printed in a language understood by

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[72] http://www.cryostar.com/web/lcng-lng-filling-stations.phpp Updated 2009. Accessed October 1, 2015.

[73] http://www.gowithnaturalgas.ca/operating-with-natural-gas/stations/fuel-station-options/lcng-stations/ Updated 2014. Accessed November 6, 2015.

[74] U.S. DHS, USCG, CG-OES Policy Letter No. 02-14, "Guidance Related to Vessels and Waterfront Facilities Conducting LNG Marine Fuel Transfer (Bunkering) Operations—Draft for Public Comment, Enclosure 1." http://www.uscg.mil/TVNCOE/Documents/default/LNGBunkering.pdf Updated 2014. Accessed October 15, 2015.

[75] Coast Guard Marine Safety Manual, Volume II, Section B, Chapter 7: Marine Facilities and Structures, p. B7-6.

[76] U.S. DHS, USCG, CG-OES Policy Letter No. 02-14, "Guidance Related to Vessels and Waterfront Facilities Conducting LNG Marine Fuel Transfer (Bunkering) Operations—Draft for Public Comment, Enclosure 2." http://www.uscg.mil/TVNCOE/Documents/default/LNGBunkering.pdf Updated 2014. Accessed October 15, 2015.

personnel involved in the transfer; and permanently posted or available where they can be seen and used by personnel engaged in the transfer.

5. *Safety and Risk Considerations for Vessel-to-Vessel LNG Transfers*

Due to the variation and complexity of LNG fuel transfer systems that can exist aboard vessels using LNG as fuel, operators of vessels supplying LNG should develop LNG transfer procedures that are specific to each vessel they intend to service. Operators of both vessels (supplier and end user) should work together to ensure that the transfer procedures are aligned, equipment is in place, and actions of personnel involved in the transfer are clearly understood.

No person should conduct a transfer operation involving LNG without providing advance notice to the local COTP. The operator of a vessel intending to provide LNG as fuel to a vessel in a vessel-to-vessel transfer operation should notify the COTP as to the time and place of the transfer operation at least 4 hours before it begins.

Vessel compatibility assessments should be conducted to confirm the suitability of vessels participating in LNG fuel transfer operations. Each transfer of LNG, cool-down, warm-up, gas-free, or air-out must be supervised by a person designated as a person-in-charge by name or position as outlined in 33 CFR 155.700.

I. LNG marine and land depots, where LNG is loaded onto transport vehicles such as bunker barges, trucks, and ISO containers

LNG depots act as a type of LNG service station, where LNG is loaded onto transport vehicles for distribution to other locations.

1. *U.S. LNG Land Depot Example*[77]

Valley Green Natural Gas of Hanover, NH, in partnership with a local energy firm and Gulf Oil Limited Partnership, hopes to begin building a 220,000^{+} gallon natural gas depot and supply system in the Route 120 corridor in 2016. The project would involve Gulf Oil trucking LNG extracted from the Marcellus Shale formation in Pennsylvania to a 6- to 12-acre land parcel in Lebanon, NH, where the LNG would be stored in 60,000-gallon tanks before being converted to CNG. The CNG would then be delivered to customers in Lebanon and Hanover for heating purposes via an underground pipe system. The project would also include a fleet refueling station for Gulf Oil's trucks and other vehicles powered by natural gas. Some state representatives have expressed concerns with the project's location, including the proposed site's proximity to wetlands, city-owned conservation land, and a large-mammal wildlife corridor.

[77] Valley News, West Lebanon, NH publication, "Developer Details Liquefied Natural Gas Deport Proposal," http://www.vnews.com/home/17077700-95/developer-details-lng-depot-proposal Updated May 31, 2015. Accessed November 6, 2015.

2. U.S. LNG Marine Depot Example[78]

The Tideflats at the Port of Tacoma, WA may become the site of a new natural gas facility if the Puget Sound community proves receptive to its construction. A San Francisco consulting firm, BSR, has called local civic leaders to test their attitudes about locating an LNG production, storage, and distribution facility in the heart of Tacoma's industrial area. If that plant materializes, it will be the second such LNG depot slated for construction on the Tideflats. Another LNG plant and distribution facility is tentatively scheduled to be built near the Totem Ocean Trailer Express (TOTE) terminal on the Blair Waterway. TOTE plans to convert its two trailerships to burn LNG instead of diesel. The conversion would cut fuel costs for TOTE, while greatly reducing air emissions. The ships transport trailers full of goods between Tacoma and Anchorage. The LNG facility at TOTE could also serve other LNG-powered ships, locomotives, and highway trucks.

J. Floating LNG liquefaction and gasification facilities not supplied by pipelines regulated by 49 CFR Part 192, and such facilities supplied by pipelines regulated by 49 CFR Part 192 if the facility is located in navigable waters (as defined in Section 3(8) of the Federal Power Act (16 U.S.C. 796(8))[79]

Floating regasification is a flexible, cost-effective way to receive and process shipments of LNG. Floating regasification is increasingly being used to meet natural gas demand in smaller markets, or as a temporary solution until onshore regasification facilities are built.

Floating regasification involves the use of a specialized vessel called a floating storage and regasification unit (FSRU), which is capable of transporting, storing, and regasifying LNG onboard. Floating regasification also requires either an offshore terminal, which typically includes a buoy and connecting undersea pipelines to transport regasified LNG to shore, or an onshore dockside receiving terminal. An FSRU can be purpose-built or be converted from a conventional LNG vessel.

Floating regasification offers a flexible, cost-effective solution for smaller or seasonal markets, and can be developed in less time than an onshore facility of comparable size. It can also serve as a temporary solution while permanent onshore facilities are constructed, and an FSRU can be redeployed elsewhere once construction is completed.

The use of floating regasification has grown rapidly in recent years, particularly in emerging markets facing short-term supply shortages. Floating regasification was first deployed in the U.S. Gulf of Mexico in 2005; since its deployment, it has been used in nine other countries: Argentina, Brazil, China, Indonesia, Israel, Italy, Kuwait, Lithuania, and the United Arab Emirates. Floating regasification capacity totaled 7.8 Bcfd at the end of 2014, representing 8% of the global installed regasification capacity, according to data from the International Gas Union.

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[78] Alaska Natural Gas Transportation Projects, "Interest in Building a Second LNG Depot at Port of Tacoma," http://www.arcticgas.gov/2014/interest-building-second-lng-depot-port-tacoma Updated May 5, 2014. Accessed November 9, 2015.

[79] EIA website, "Floating LNG Regasification is used to Meet Rising Natural Gas Demand in Smaller Markets," http://www.eia.gov/todayinenergy/detail.cfm?id=20972 Updated April 25, 2015. Accessed September 22, 2015.

K. LNG at satellite plants that is consumed by power drill rig equipment, even if the LNG source is a pipeline regulated by 49 CFR Part 192 ("ultimate consumer exemption")

Hydraulic fracturing is a process that uses fluid and material to create or restore small fractures in a formation to stimulate production from new and existing oil and gas wells.[80] LNG is being used by the following companies in the U.S. to power drill rig equipment used in this process:

- Energy developer Seneca Resources Corp. and drilling partner Ensign Drilling have installed two of General Electric's Jenbacher gas engines to power the first LNG-fueled drilling rigs of their kind in the Marcellus Shale region of Pennsylvania. Seneca converted the power plants of two existing diesel-powered rigs to use cleaner burning LNG in GE's 1-megawatt Jenbacher J320 turbocharged natural gas engines. The Jenbacher units were combined with Ensign Drilling-designed rig packages to provide all the electricity needed by each drilling rig. The J320 represents GE's first U.S. EPA certified technology for mobile and stationary drilling applications.

  Ensign Drilling operates 15 drilling rigs exclusively on natural gas in the U.S., with 11 of them exclusively using GE's Jenbacher gas engines. Powering a drill rig with natural gas instead of diesel can result in 60% lower fuel costs. LNG also represents a cleaner alternative to diesel for the transportation industry and trucks, reducing overall combustion emissions up to 25%. Truck fleets also can often reduce fuel costs by more than 25% with LNG.[81]
- In early 2013, Apache Corporation in Houston, TX began powering an entire hydraulic fracturing job with engines running on natural gas. The company used drilling rigs manufactured by American Power Group (APG) of Algona, IA. APG supplies drills rigs that use both diesel and natural gas as fuel. Using natural gas allows drilling companies to generate lower emissions while reaping cost savings. Apache estimated use of natural gas would cut fuel costs by about 40% on its fracturing job.[82]

L. LNG-based distributed power plants supplied by pipelines regulated by 49 CFR Part 192 serving only the pipeline operator, and LNG plants where LNG is supplied by means other than a pipeline regulated by 49 CFR Part 192

No information was found on this specific new and emerging facility/operation category.

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[80] https://fracfocus.org/hydraulic-fracturing-how-it-works/hydraulic-fracturing-process Updated 2015. Accessed November 6, 2015.

[81] LNG World News website, "GE's Engines Power LNG Fueled Drilling Rigs, USA," http://www.lngworldnews.com/ges-engines-power-lng-fueled-drilling-rigs-usa/, Updated November 28, 2012. Accessed October 5, 2015.

[82] FuelFix.com, "Natural Gas-Powered Rigs on the Rise in Oil Fields," http://fuelfix.com/blog/2013/01/24/natural-gas-powered-rigs-on-the-rise-in-oil-fields/ Updated January 24, 2013. Accessed October 5, 2015.

VI. Recommendations for Phase 2

A. Obtain Characterization Information for New and Emerging LNG Facilities/Operations Categories F, G, and L

The Volpe Center did not find any specific characterization information via Internet searches on Categories F (distributed production facilities that use LNG in gas treatment of hydrocarbon extraction processes but do not store LNG), G [LNG facilities that store and vaporize LNG produced on-site (such as agriculture and industry on-site storage and regasification facilities) or LNG supplied by another transportation mode, as long as the LNG is consumed solely by the LNG facility owner], and L (LNG-based distributed power plants supplied by pipelines regulated by 49 CFR Part 192 serving only the pipeline operator, and LNG plants where LNG is supplied by means other than a pipeline regulated by 49 CFR Part 192).

Prior to or in conjunction with Phase 2, the Volpe Center proposes participating in a teleconference/meeting with PHMSA staff who authored the May 2014 draft report and/or who have conducted outreach/communication efforts regarding the categories of new and emerging LNG facilities/operations not regulated under 49 CFR Part 193. The goal of the teleconference/meeting is to obtain additional information on these categories and to potentially identify LNG industry points-of-contact (POCs) for these categories. The Volpe Center will then contact the identified LNG new and emerging facilities/operations POCs to obtain categorization, transport, and risk information regarding these categories. This information will be added to the Phase 1 whitepaper.

B. Refinement of Risk Parameters and Site Investigations at Sample LNG Facilities

The general risk information provided in Section IV of this whitepaper applies to all categories of LNG facilities/operations. In addition, specific risk information was found for six of the twelve new and emerging LNG facilities/operations categories.

During Phase 2, the Volpe Center will work with PHH-23 to schedule an on-site meeting, videoconference, or teleconference with representatives from PHMSA divisions who participated in the Section VI.A teleconference/meeting. The purpose of this meeting is to:

- Share results of communications with LNG POCs identified in Section VI.A;
- Determine whether specific risk information may exist for the following new and emerging facilities/operations categories, and how to gather such information (POCs, research avenues, etc.):
    - LNG transport trailers and tank trucks (part of Category C);
    - LNG ISO tank containers that are not used as storage vessels at LNG plants connected to pipelines regulated by 49 CFR Part 192 (Category D);
    - Natural gas processing plants that do not store the LNG at the plant (Category E);
    - LNG marine and land depots, where LNG is loaded onto transport vehicles such as bunker barges, trucks, and ISO containers (Category I);

    - Floating LNG liquefaction and gasification facilities not supplied by pipelines regulated by 49 CFR Part 192, and such facilities supplied by pipelines regulated by 49 CFR Part 192 if the facility is located in navigable waters (Category J); and
    - LNG at satellite plants that is consumed by power drill rig equipment, even if the LNG source is a pipeline regulated by 49 CFR Part 192 (Category K).
- Refine risk parameters identified in the draft Phase 1 whitepaper; and
- Work with PHH-23 to schedule site visits to representative new and emerging LNG facilities/operations for further investigation and characterization of their potential transportation risk parameters.

During Phase 2, the Volpe Center will also determine if the categories of new and emerging LNG facilities/operations described in the Phase 1 whitepaper are covered under the existing hazardous materials regulations, and will identify such regulations, as applicable. The Volpe Center will also identify those categories of new and emerging LNG facilities/operations not currently covered under the existing hazardous materials regulations.