LIQUEFIED NATURAL GAS:

An Overview of the LNG Industry for Fire Marshals and Emergency Responders

National Association of State Fire Marshals

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INTRODUCTION

This paper was developed by the National Association of State Fire Marshals (NASFM) under a cooperative agreement with the U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration, Office of Pipeline Safety (OPS).

Its objective is to provide a broad overview of Liquefied Natural Gas (LNG), its hazards and risks, and the issues that fire safety officials may face as LNG infrastructure develops and expands to meet the country's future energy needs. References also indicate several useful sources of information on LNG for additional study. This paper is supported by a companion training video, available from NASFM, which provides more in-depth information on emergency response issues.

PROBLEM STATEMENT

The United States needs more energy to support growing demands for electrical power and other domestic consumption.[1] Natural gas is seen by many as a desirable energy source to meet future electricity demands because of its availability, cost, energy efficiency, and the opportunity it provides to improve air quality.[2] North American gas supplies are limited but can be supplemented by the importation of gas from overseas sources using LNG ships.

If LNG evolves as a primary fuel source in the future to satisfy industrial, commercial and residential usage requirements in the U.S., significant expansion of infrastructure will be required to support its delivery to utilities and consumers. This will include construction of new LNG ships, marine terminals to off load LNG ships, gas plants, storage vessels, and pipelines.

This process of expanding the current LNG infrastructure to support future energy needs will be significant and arduous. LNG import facilities are permitted and regulated by several federal agencies as described in a later section. They require long lead times for permitting, siting, and construction. Some proposed locations in the U.S. have been controversial: several organized opposition groups have been voicing strong concerns based on fire safety and environmental issues as part of the regulatory process.

As new LNG facilities are planned, permitted, and constructed, government, industry and the public will consult fire marshals, fire protection engineers, and fire chiefs on safety and security issues for their communities. The public must be satisfied that current and proposed LNG facilities meet high safety, fire protection, and security standards.

THE NEED FOR LNG

The U.S. Energy Information Administration (EIA) has determined that the total U.S demand for natural gas is expected to rise from 22.9 trillion cubic feet (TCF) in 2002 to 29.95 TCF by 2020 and 30.56 TCF by 2025.[3] EIA estimates also show that natural gas imports into the U.S. will increase from 3.5 trillion cubic feet in 2002 to 8.66 trillion cubic feet by 2025.

Currently, U.S. domestic production supplies most of the natural gas consumed in the U.S.

In recent years, the gap between U.S. demand for natural gas and the amount of domestic production was met with pipeline imports from Canada. However, this gap will widen since current domestic production shows only small increases. Furthermore, pipelines imports from Canada are expected to decrease.

While more LNG terminals will obviously be needed in the U.S. to meet future demand, local opposition has often blocked their construction. Between 2002 and 2004, eight communities in the U.S. have said 'no' to LNG facilities. For example, proposed projects in Harpswell, ME, and Eureka, CA, were cancelled in 2004 because of local residents' concerns about explosions or a terrorist attack. Proponents were subsequently unable to obtain an alternative site. [4]

Nevertheless, according to the Federal Energy Regulatory Commission (FERC), two new offshore terminals and three onshore facilities have been approved as of January 2005. Eleven onshore LNG terminals have been proposed in California, Massachusetts, Mississippi, New Jersey, New York, Rhode Island, and Texas. In addition, six offshore LNG terminals have been proposed and FERC is aware of plans for at least 12 terminals in the United States.

An increased demand for LNG in the U.S. has resulted in a significant increase in shipbuilding. There are currently about 150 LNG ships in operation worldwide. An additional 55 ships are on order for 2006, and another 50 will be added to the U.S. market. [5]

HISTORY OF LNG

Natural gas liquefaction dates back to the 19th century when physicist Michael Faraday conducted experiments. German engineer Karl Von Linde built the first compressor refrigeration machine in Munich in 1873. The first LNG plant began operation 44 years later in West Virginia in 1917, and the first commercial plant was built in West Virginia in 1939, followed by a second in Cleveland, Ohio in 1941. [6]

The first LNG tanker was commissioned in 1959 as The Methane Pioneer. The converted ship contained five, 7,000 Bbl aluminum prismatic tanks with balsa wood supports with plywood and urethane insulation. It carried LNG cargo from Lake Charles, LA, to Canvey Island, United Kingdom. This historic event demonstrated that large quantities of liquefied natural gas could be transported safely across the ocean. [7]

The United States currently has four operational marine import terminals: Elba Island, GA; Cove Point, MD; Everett, MA; and Lake Charles, LA. There is a fifth in Puerto Rico and an export terminal at Kenai, AK, which exports LNG to Japan. The Kenai terminal is the oldest in the U.S. and was constructed in 1969.

LNG imports into the United States began with the construction of the Everett, MA, terminal in 1971. Construction of the Cove Point and Elba Island terminals followed in 1978, while the terminal at Lake Charles was completed in 1982.

In 1979 LNG imports declined because of a gas surplus in North America and LNG price disputes with Algeria, which, at the time, was the sole provider of LNG to the United States. Consequently the Elba Island and Cove Point terminals were mothballed in 1980, as was the Lake Charles terminal after less than two years of initial operations.

However, times changed in the late 1980s. The Lake Charles LNG facility restarted operations in 1989 and witnessed a significant increase in imports. This was due mainly to three factors: 1) the availability of a LNG supply to the U.S., 2) an increased demand for natural gas to support electrical power generation, and 3) an increase in natural gas prices. Elba Island and Cove Point terminals were recommissioned in 2003.[8]

FEDERAL OVERSIGHT

The federal government's oversight of LNG facilities is provided by three federal agencies under a formal Interagency Agreement dated February 1, 2004. The primary agencies include the Federal Energy Regulatory Commission (FERC), the U.S. Coast Guard (USCG) within the U.S. Department of Homeland Security (DHS), and the Office of Pipeline Safety (OPS) within the U.S. Department of Transportation (DOT). Through their cooperative agreement, the agencies have primary responsibility for exercising regulatory authority over the siting, design, construction and operation of liquefied natural gas facilities, and related land and marine safety and security issues. In addition, the Maritimes Administration in the DOT issues the license for all deepwater port LNG facilities.

FERC RESPONSIBILITY

Under the Interagency Agreement, FERC is responsible for permitting new LNG onshore import and export terminals and ensuring their safety through inspections and other oversight. This includes authorizing the siting and construction of onshore LNG facilities under Section 3 of the Natural Gas Act (NGA) (15 U.S.C. ß 717 et seq.). FERC is also responsible for the construction and operation of interstate natural gas pipelines that may be associated with the LNG facilities under section 7 of the NGA.

FERC conducts environmental, safety, and security reviews of LNG plants, tanker operations, and related pipeline facilities. As the lead federal agency, it also prepares the overall National Environmental Policy Act (NEPA) documentation (18 CFR Part 380), in conjunction with which it conducts an engineering and safety design review of the proposed facilities. A summary of that review, with conclusions and recommendations, is included in the NEPA document. FERC can impose safety requirements to ensure or enhance operational reliability of the LNG facilities within its jurisdiction.

During construction of the LNG facilities, FERC conducts periodic inspections to ensure compliance with conditions attached to its authorizations. Once the facilities are in operation, it holds biennial inspections of the LNG plant, focusing on equipment, operation, and safety. As part of the design and inspection program, the FERC maintains and updates a Cryogenic Design Inspection Manual for each jurisdictional facility.

DOT RESPONSIBILITY

The U.S. Department of Transportation prescribes safety standards concerning the location, design, installation, construction, initial inspection, and testing of new onshore and offshore LNG facilities.

The DOT's Office of Pipeline Safety (OPS) has the authority to promulgate and enforce safety regulations and standards for the transportation and storage of LNG in or affecting interstate or foreign commerce under the pipeline safety laws (49 U.S.C. Chapter 601). Its authority extends to the siting, design, installation, construction, initial inspection, initial testing, operation, and maintenance of LNG facilities as well as fire prevention and security planning. OPS inspects LNG facilities and enforces regulations based on the National Fire Protection Association's *Standard for the Production, Storage, and Handling of Liquefied Natural Gas* (LNG) NFPA 59A. OPS may enforce NFPA 59A requirements through a broad range of administrative and judicial actions, including annual site reviews.

USCG RESPONSIBILITY

The U.S. Coast Guard exercises regulatory authority over LNG facilities that affect the safety and security of port areas and navigable waterways. This responsibility derives from Executive Order 10173, the Magnuson Act (50 U.S.C. ß 191), the Ports and Waterways Safety Act of 1972, as amended (33 U.S.C. ß 1221, et seq.) and the Maritime Transportation Security Act of 2002 (46 U.S.C. Section 701).

Its concerns are with matters related to navigation safety, vessel engineering and safety standards, and all matters pertaining to the safety of facilities or equipment located in or adjacent to navigable waters up to the last valve immediately before the receiving tanks.

The USCG also has authority for LNG facility security plan review, approval and compliance verification for the entire terminal as provided in Title 33 CFR Part 105, tanker security and siting as it pertains to the management of vessel traffic in and around the LNG facility.

LNG SAFETY

MARINE SAFETY

LNG has been delivered across the world's oceans for about 45 years without major accidents or safety problems either in port or on the high seas. In that time, there have been more than 33,000 LNG carrier trips, covering more than 60 million miles. While over the life of the LNG industry a few minor hull damage incidents worldwide have been reported, they did not result in any LNG spillage overboard. Some additional marine-related LNG spill incidents have occurred during LNG transfer operation with no serious consequences reported. No LNG-related explosions or fatalities have ever occurred on LNG marine vessels in the history of the industry.

Today, ocean tankers safely transport more than 110 million metric tons of LNG annually to ports around the world. This is more than all American homes consume each year. [9]

According to the U.S. Department of Energy, in 2000, one LNG cargo tank ship entered Tokyo Bay every 20 hours, and one entered Boston harbor every week. Japan relies exclusively on imported LNG for its natural gas and has 27 import terminals.

LNG ships vary in size from 20,000 to over 145,000 cubic meters cargo capacity but most modern vessels are between 125,000 and 140,000 cubic meters capacity (58,000 to 65,000 tons). A typical modern LNG ship has a length of about 975 feet (300 m), width of about 140 feet (43 m), draft of about 39 feet (12 m) and is capable of sailing at speeds of up to 21 knots. A new LNG ship will cost about $170 million.[10]

Some shippers are planning 200,000 to 250,000 cubic meter vessels for new import terminals.

All LNG ships have double hulls. The cargo is carried at near atmospheric pressure in specially insulated tanks, referred to as the cargo containment system, inside the inner hull. In a modern membrane tank LNG ship, the cargo containment system consists of a primary liquid barrier, a layer of insulation, a secondary liquid barrier, and a second layer of insulation. If a grounding or collision produced damage to the primary liquid barrier the design of the secondary barrier would enable it to prevent leakage. The insulation spaces are continuously monitored by sensors for any sign of leakage. Another ship design involves storage of LNG in large aluminum spheres, which are insulated on the outside and supported within the outer hull.

Because the insulation cannot prevent all external heat from reaching the LNG some of the liquid boils off during the voyage. The boil-off vapor is removed to keep the tank at a constant pressure and is used as a source of clean fuel for the ship's engines. (See end note #15 for additional background information on auto-refrigeration).

The U.S. Coast Guard (USCG) is responsible for assuring the safety and security of marine operations at LNG terminals and of tankers in U.S. coastal waters. It regulates the design, construction, manning, and operation of LNG vessels and the duties of LNG ship officers and crews. This branch is also responsible for:

- Inspecting LNG ships, including foreign flag vessels, to ensure their compliance with U.S. safety regulations.
- Working with terminal and ship operators and host port authorities to ensure that policies and procedures conform to required standards.
- Working with operators to conduct emergency response drills and joint exercises to test response plans.
- Ensuring that operators have adequate safety and environmental protection equipment and procedures to respond to an incident.
- Determining the suitability of a waterway to transport LNG safely and securely.

ONSHORE SAFETY

The LNG industry has substantial experience in safely operating LNG marine terminals, liquefaction plants, and storage facilities. For example, there are approximately 133 LNG peak-shaving facilities operating in the U. S. These consist of small liquefaction plants that make LNG from pipeline gas during periods of low gas demand, store it as LNG, and then regasify it to supplement pipeline supplies during periods of high demand. Approximately 55 local utilities own and operate LNG plants as part of their natural gas distribution networks.

Considering the number of facilities handling LNG, the industry's fire safety record over the last 40 years has been excellent. This is due to the close oversight by federal and state regulatory agencies and the regular review, improvement, and enforcement of the National Fire Protection Association's *Standard for the Production, Storage, and Handling of Liquefied Natural Gas* (LNG) NFPA 59A.

All LNG storage facilities must comply with Department of Transportation (DOT) Title 49 CFR Part 193—Liquefied Natural Gas Facilities. As noted previously, the Office of Pipeline Safety relies heavily on the use of the National Fire Protection Association's *Standard for the Production, Storage, and Handling of Liquefied Natural Gas* (LNG) NFPA 59A as the primary document for compliance with LNG fire safety requirements. The Federal Energy Regulatory Commission regulations also apply to fixed facilities.

Placement and Construction of Onshore Storage Tanks

DOT regulations require exclusion zones around LNG facilities. Setback distances must be great enough so that fire hazards from major accidents will be within acceptable limits at facility property lines.

LNG tanks have double walls, basically a container within a container. The outside wall is designed to hold LNG vapors and the insulation system around the inner container which holds the liquid. Due to LNG's cryogenic characteristics, tanks are required to meet very high metallurgical standards and are constructed of aluminum or nine-percent nickel steel.

In addition the tanks are surrounded by embankments or "dikes" to contain any leakage in the unlikely event of tank failure. Newer LNG facilities are required to have a dike or impounding wall capable of containing 110% of the maximum LNG storage capacity (some older facilities were designed to contain 100%). Some LNG tank designs have a reinforced prestressed concrete outer tank which is capable of holding the tank contents should the inner tank leak. This outer tank design replaces the need for a separate 110% capacity dike.

LNG is stored slightly above atmospheric pressure so that no air can leak into the tank. Since the tank contains no air, the LNG inside is neither flammable nor explosive, but if spilled into an impoundment area or on water, it will mix with air and either ignite forming a pool fire or will rapidly vaporize. In the flammable range (5-15% by volume of gas in air), the vapor can be ignited. An explosion can result if a flammable mixture is confined in the presence of an ignition source. Again, LNG itself is not explosive within its own storage tank since no air is present. [11]

National Fire Protection Association Standard 59A, much of which has been adopted by DOT as the federal standard, addresses the protection of LNG facilities and tanks from earthquakes. No LNG storage tank failures have ever occurred due to seismic activity. This is true even in Japan, which is one of the most seismically active areas in the world.

Industry Safety Programs

The LNG industry follows additional codes, rules, regulations and standards established by organizations such as the Society of International Gas Tanker and Terminal Operators, the Gas Processors Association, and the National Fire Protection Association.

LNG facility safety programs are based on four primary elements: 1) well-designed engineering controls, 2) frequently reviewed and updated standard operating procedures, 3) trained and qualified operating personnel, and 4) fire protection and security requirements that provide for a timely and effective response to threats and emergencies.

1. **Engineering Controls—**LNG facilities are equipped with alarms that warn of operating conditions outside of normal ranges and also with multiple back-up safety procedures including emergency shutdown (ESD) systems. These can identify major problems and can shut down operations, limiting the amount of LNG that could be released in an emergency. ESDs are normally linked to automated gas, liquid, and fire detection equipment. There are also detectors for monitoring LNG levels and vapor pressures within storage tanks and closed-circuit television equipment for monitoring all critical locations of LNG facilities.

2. **Standard Operating Procedures—**LNG facilities are operated under strict written Standard Operating Procedures following industry process safety guidelines. SOPs cover issues ranging from safe operation to receiving and shipping procedures, maintenance, and emergency response.

3. **Training—**Operators play a critical role in reducing the risk of accidents and fires at LNG facilities. The level of training they receive is one of the primary reasons why the LNG industry has an excellent safety record. Operators and maintenance personnel must meet training requirements established by FERC, DOT, USCG, and company policies.

4. **Fire Protection and Security—**LNG facilities are required to develop emergency response plans and procedures under FERC and DOT requirements. These must address specific fire scenarios and be exercised and coordinated with local and state emergency response agencies.

LNG INCIDENT HISTORY

FIREFIGHTER SAFETY RECORD

The history of safe response to LNG emergencies in the U.S. has been excellent compared to that of other fossil fuels. For example, from 1945 to 2004 there were 28 American firefighters killed in the line of duty in seven different incidents involving liquid petroleum storage tank fires, and 41 firefighters killed in six incidents involving Liquefied Petroleum Gas (LPG). However, since the first commercial plant became operational in 1941, no firefighters have been killed responding to LNG incidents in the U.S. [12]

MAJOR INCIDENTS

In its 63-year operating history in the U.S. (1941 to 2004), there have been three major incidents at LNG facilities. The first occurred in 1944 in Cleveland and the second involved a construction accident without product release. The only US terminal operating accidents involving a fatality occurred at Cove Point, MD. Of special interest is a more recent incident outside the U.S., which occurred in January 2004 at Skikda, Algeria. These incidents are discussed in more detail below.

Cleveland, Ohio 1944

The first commercial LNG peak-shaving plant was built in West Virginia in 1939. Two years later, the East Ohio Gas Company built a second facility in Cleveland, which operated without incident until 1944 when the facility was expanded to include a larger tank. A shortage of stainless steel alloys during World War II led to compromises in the design of the new tank. It failed by brittle fracture shortly after it was placed in service, allowing LNG to overflow a dike designed to hold small spills only. The liquid flowed into the surrounding utility plant area and into the storm sewer system, forming a vapor cloud that filled the surrounding streets and ignited. The resulting vapor and pool fire caused the deaths of 128 people in an adjacent utility company building and in the adjoining residential area. The U.S. Bureau of Mines investigating the accident concluded that the concept of liquefying and storing LNG was valid if "proper precautions were observed." Had the Cleveland tank been built to current codes, this accident would not have happened. In fact, LNG tanks properly constructed of 9 percent nickel steel have never had a brittle crack failure in their 35-year history.

Staten Island, New York February 1973

In February 1973, an industrial accident occurred at the Texas Eastern Transmission Company peak-shaving plant on Staten Island. Operators suspected a possible leak in the tank and placed the facility out of service. Once the LNG tank was emptied, tears were found in the mylar lining. During the repairs, the mylar liner and the polyurethane tank insulation were ignited, thus raising the temperature in the tank. Enough pressure was generated to dislodge a 6-inch thick concrete roof, which then fell on the workers in the tank and killed 40 people. The New York City Fire Department report of July 1973 determined that the accident was clearly a construction accident and not a "LNG accident."

Cove Point, Maryland October 1979

In October 1979, an explosion occurred within an electrical substation at the Cove Point, MD receiving terminal. LNG had leaked through an inadequately tightened LNG pump electrical conduit seal, and had passed through 200 feet of underground electrical conduit to enter the substation. Since natural gas was never expected in this building, there were no gas detectors installed.

The natural gas-air mixture was ignited by the normal arcing during the opening of normally energized contacts of a motor control circuit. The resulting explosion killed one operator in the building, seriously injured a second, and caused about $3 million in damage.

The National Transportation Safety Board found that the Cove Point Terminal was designed and constructed conforming to all appropriate regulations and codes. As a result of this accident three major design code changes were made both at the Cove Point facility prior to its reopening and also industry-wide.

Skikda, Algeria January 2004

At 6:40 pm on January 19, 2004 a steam boiler exploded at a LNG production plant in Skikda, Algeria on the Mediterranean Sea, after it probably drew flammable vapors from a hydrocarbon refrigerant leak into its air intake. This triggered a secondary, more massive vapor cloud explosion destroying a large portion of the plant. The incident killed 27 people, injured 74, and created an $800 million loss. The fire and explosion caused material damage outside the plant's boundaries. None of the LNG storage tanks were damaged. Prior to this tragedy the plant had a good safety record and had operated for over 30 years without a significant incident. [13]

The situation began when a control room operator noticed rapidly rising pressure within a steam boiler. The operator attempted to correct the problem by reducing the flow of fuel to the boiler. Before this was possible, however, the boiler's pressure relief valve activated.

Another operator near an adjacent LNG unit observed a vapor cloud forming near the boiler. According to Sonatrach (the company that operated the plant), the leaking gas was drawn into the boiler by its air inlet fan. The gas then mixed with the right amount of air within the boiler's fire box and exploded. The boiler was located close enough to the gas leak area to ignite the vapor cloud and produce an explosion and fireball. It is believed that a pipe failed, releasing hydrocarbon gas that formed the vapor cloud. Contributing factors included the absence of wind to disperse the gas and ignition in a confined area. [14]

LNG HAZARDS

In this section hazards are defined as the physical and chemical characteristics exhibited by a material that may cause harm.

LNG presents three main hazards: 1) flammability, 2) dispersion, and 3) cryogenic temperatures. When LNG is spilled and its vapors come into contact with an ignition source, the spill will develop into a pool fire and present a thermal radiation hazard. If there is no ignition source, the LNG will vaporize rapidly forming a cold gas cloud that initially is heavier than air, spreads and is carried downwind until it reaches neutral buoyancy when enough air mixes with it. The vapor is ignitable in the 5 to 15% range. The flammable region of the vapor cloud is closely approximated by the visible white cloud that is actually water vapor condensed due to the cold LNG vapor. Once ignited it will burn back to the LNG source.

FLAMMABILITY HAZARDS

LNG is primarily composed of 85% to 96% methane, with other light hydrocarbons such as propane, ethane, and butane making up most of the balance. LNG also contains about 1% nitrogen.

LNG is flammable in its vapor state between 5% and 15% concentration of gas in air. By comparison with other common fuels, propane's flammable range is 2.1% to 9.5%, and gasoline is 1.3% to 7.1%. The ignition temperature of LNG vapor at 1004ºF degrees is higher than that of other common fuels. For example, LPG = 850ºF, ethanol = 793ºF, diesel = 600ºF, and gasoline = 495ºF.

DISPERSION HAZARDS

Methane is a flammable and odorless gas. While it is non-toxic, it can be an asphyxiant when it displaces oxygen in a confined space.

LNG has an expansion ratio of 1 to 600 when vaporized at 1 atmosphere and warmed to room temperature. It is usually stored and transported at very low pressures, typically less than 5 psig, in well-insulated containers. Heat leaking in causes the liquid to boil, and removal of the boil-off gas helps maintain the LNG in its liquid state—a phenomenon known as "auto-refrigeration". [15]

The density of LNG is 3.9 pounds per gallon—about half that of water. If it is spilled on the ground, it will boil rapidly at first and then boil slowly as the ground cools. If it is spilled on water it will float on top and vaporize very rapidly since even at water temperatures near freezing, the water is significantly warmer than the spilled LNG. The resulting vapor cloud is very cold and quite visible because it condenses water out of the air. Initially, the vapor cloud is dense, and made visible by ice crystals from water vapor in the air. If ignition is delayed, the mixture hugs the ground and spreads laterally. As the cloud becomes warmer than -256ºF (-160ºC) and mixes with air, the expanding vapor cloud may not be visible. As it continues to disperse, the cloud will eventually become neutrally buoyant (-160ºF).

A natural gas cloud may ignite, but has not been shown to explode if it is not confined. LNG itself will not burn or explode: it must be vaporized and mixed with air in the right concentrations (5% LFL to 15% UFL) to make combustion possible.

CRYOGENIC HAZARDS

LNG is a cryogenic liquid and is stored and transported at minus 260 degrees Fahrenheit. When cooled to this temperature (-160ºC) at atmospheric pressure, natural gas turns into a liquid which provides a practical and economical method for transportation and storage.

Contact with a cryogenic can cause severe damage to the skin and eyes. It can also make ordinary metals subject to embrittlement and fracture; therefore, cryogenic operations require specialized containers and piping. LNG is stored in containers made of metals such as 9% nickel steel or aluminum, and moved through stainless steel pipes that are capable of handling these low temperatures. Insulation on cryogenic transfer lines protects workers from the potential for contact freeze burns.

LNG RISK-RELATED SCENARIOS

Planners and responders prepare for emergencies by considering the probability that something may go wrong, and if it does, what the appropriate response and outcome should be. This thought process considers various risk-related but credible scenarios as the basis for developing mitigation strategies and for emergency planning. For the purpose of this section, the term “risk” is defined as the likelihood that something serious may go wrong.

Research conducted for development of this paper identified four possible general risk-related scenarios.[16] 1) fire, 2) vapor cloud explosion, 3) cryogenic effects, and 4) rapid phase transition.

FIRE SCENARIOS

LNG vaporizes quickly as it absorbs heat from the surface on which it spills. When LNG vapor concentrations in air are between 5% and 15%, and an ignition source is present, it will burn.

At its normal boiling point of -260ºF (-160 ºC), LNG vapor is 1.5 times denser than air at 77ºF (25ºC). When LNG vapor is released into the atmosphere it remains negatively buoyant until it warms to approximately -180ºF (-117ºC); it then rises and disperses below the lower flammable limit.

LNG presents three potential fire risk scenarios: pool fire, jet fire, vapor cloud fire.

- **Pool Fire**—LNG released from a storage tank or transfer pipeline can form a liquid pool. As the spill forms, some of the liquid evaporates. If an ignition source is encountered, the vapors will ignite and travel back to the origin of the spill resulting in a pool fire. If the spill occurs inside a properly designed and maintained diked area, the pool fire will remain contained inside and will continue to burn until the fuel is consumed.

If the spill occurs outside a confined area, the burning pool fire is free to flow based on topography and the geometry of the spill. Spraying water on an LNG pool only increases the vaporization rate and intensifies any fire; spraying a gallon of water will vaporize about two gallons of LNG.

The preferred extinguishing agent for small LNG fires is dry chemical such as potassium bicarbonate. High expansion foams are not considered to be effective LNG fire extinguishing agents, but they are effective in controlling LNG pool fires in dikes and impoundment areas because the foam blanket reduces the radiant heat generated by the fire. They can also prove valuable in vapor control of unignited LNG. When high expansion foam is first applied to the spill, there is some initial warming and an increase in vaporization, but the rate of vaporization eventually stabilizes and slows down the escaping LNG vapor so the flammable region of the spill at ground level is much smaller.

- **Jet Fire—**If there is a release of compressed natural gas or liquefied gases from storage tanks or pipelines, the vapor discharging through the hole in the container will form a gas jet that entrains and mixes with air. If the mixture finds an ignition source while in the flammable range, a jet fire may occur. This type of fire is unlikely for an LNG storage tank since the product is not stored under pressure. However, jet fires could occur in pressurized LNG vaporizers or during unloading or transfer operations when pressures are increased by pumping. A fire occurring under this scenario could cause severe damage but would be confined to a local area, and would be limited by safety systems that stop the LNG flow. At base load import terminals, there is little storage of any pressurized liquids, so there is no possibility of a BLEVE (boiling liquid expanding vapor explosion).

- **Vapor Cloud Fire—**When LNG is released to the atmosphere a vapor cloud forms and disperses by mixing with air. If the vapor cloud ignites before the vapor cloud is diluted below the lower flammable limit, a flash fire may occur. Under this scenario, ignition can only occur within the portion of the vapor cloud that has concentrations in the flammable range; i.e., 5% to 15%. The entire cloud does not ignite at once. A flash fire may burn back to the release point producing either a pool fire or a jet fire, but it will not generate damaging overpressures if it is unconfined.

Vapor Cloud Explosion

If a LNG vapor cloud with concentrations in the flammable range is confined inside a structure and ignited, damaging overpressures may occur. Areas congested with equipment and structures can also help confine LNG vapor and may facilitate an overpressure upon ignition. As indicated earlier, pure methane has not been known to generate damaging overpressures if ignited in an unconfined area. Other vaporized hydrocarbons including propane and butane are more susceptible to vapor cloud explosions.

Cryogenic Effects

LNG containers are manufactured from high quality metals intended for cryogenic storage. LNG carriers are designed with an inner and outer shell or hull that prevents the LNG from coming into contact with the outer shell/hull. International ship design rules require that areas where cargo tank leakage might be expected must be designed for contact with cryogenic LNG. One study conducted in 2001 by international high risk insurer Lloyds describes 10 LNG spills involving LNG carriers that occurred between 1965 and 1989. Lloyds reported that 7 of these spills led to brittle fracture of the deck or tank covers on the ship. While the report does not specify, the nature, location and damage noted suggest that these were all releases from LNG piping. [17]

Rapid Phase Transition

Also known by the acronym RPT, this term describes a phenomenon that has been observed in some LNG spill experiments on water. It involves a nearly simultaneous transition from the liquid to vapor phase with an associated rapid pressure increase. This is more likely to occur when the LNG contains heavy hydrocarbons, or after a time delay allowing the lighter methane to boil off leaving a heavier liquid. It may result in two types of effects: 1) a localized overpressure resulting from rapid phase change, and 2) dispersion of the "puff" of LNG expelled to the atmosphere. The RPT energy comes from a physical phase change and is much less than the energy available from a chemical combustion reaction. RPT changes have been observed in a few LNG spill experiments on water, but have not resulted in any known incidents involving LNG transport.

LNG SECURITY

Since the attacks on September 11, 2001 security of LNG ships and terminals has been of special interest to the general public. Regulators, owners, and operators have taken numerous steps to address the expressed concern of some citizens about the risk of terrorist attack at LNG terminals in their communities. Heightened security requirements are being addressed for both the operation of existing LNG facilities and for the approval of new or expanded facilities.

FEDERAL SECURITY REQUIREMENTS

As stated previously, federal jurisdiction for LNG facilities is shared by the Federal Energy Regulatory Commission, the Department of Transportation, and the Department of Homeland Security. The following points summarize the federal and requirements for security at LNG facilities in the U.S.

- Title 49 CFR Part 193, Subpart J—Governs the security requirements for land-based facilities and the onshore component of marine terminals. These regulations include requirements for security patrols, protective enclosures, lighting, monitoring, alternative power sources, etc.
- Title 33 CFR Part 127—Includes requirements for maintaining security of the offshore component of marine terminals under Coast Guard regulations. This requires the USCG to prevent other ships from getting near LNG vessels while in transit or docked by enforcing Regulated Navigation Areas and security zones.
- Interstate natural gas companies receive security updates and alerts on a regular basis from federal agencies, including the FBI. The companies carefully evaluate these reports to determine what actions are needed within the company.
- A joint federal Security Task Force has been created and is addressing ways to improve pipeline/facility security practices, strengthen communications within the industry and the interface with government, and extend public outreach efforts.
- Under the Marine Transportation Security Act (MTSA) all facilities are required to develop a Water Security Plan. As of July 1, 2004 the USCG has received all these plans.
- FERC has removed Critical Energy Infrastructure Information (CEII) pertaining to LNG storage facilities from its website.
- FERC is involved with other federal agencies and industry trade groups to coordinate alternate ways to supply natural gas to a region in the event of an outage of its main pipeline.
- FERC coordinates closely with the Coast Guard and other agencies to address marine safety and security at LNG import facilities.
- Depending on the specifics of a project, FERC may convene special technical conferences with other government and law enforcement agencies to address safety and security issues.
- The Coast Guard Captain Of The Port (COPT) sets port safety zones and may require tug escorts. The Coast Guard prevents other ships from getting near LNG tankers while in transit or docked at a terminal by establishing and enforcing security zones. The USCG has a leading role in protecting marine traffic and may use escort boats and/or armed boarding parties to enforce security.

RISK FROM TERRORISM

Recent studies commissioned by the U.S. Government at Sandia National Laboratories have determined that credible breach sizes in a double-hull ship are possible under very specific circumstances. The study provided models for estimating the resulting pool fire and vapor cloud hazards.[18] The December 2004 final report summary conclusion was:

> "In general, the most significant impacts on public safety and property from an intentional spill exist within approximately 500 meters (1,640 feet) of a spill,

with lower impacts at distances beyond approximately 1600 meters (5,249 feet) from a spill, even for very large spills."

OPPOSITION AND SUPPORTING VIEWPOINTS

In recent years there has been considerable public discussion and debate about the advantages and disadvantages of LNG in the United States. Most of these discussions and public testimony (both pro and con) center on the development and operation of large onshore or near-shore LNG terminals. This section provides a brief overview of some of the more widely publicized views.

OPPOSITION VIEWPOINTS

Proposed hazardous materials manufacturing, storage, and waste facilities routinely receive considerable public scrutiny. Concerns for safety, traffic congestion, noise, environmental pollution, and quality of life are typical themes.

LNG has drawn particular attention from citizens in communities where onshore and offshore LNG terminals have been proposed.[19]

Examples of typical opposition views are:

- LNG tanker spills in ports and at marine terminals will result in a fire due to Rapid Phase Transition (RPT) of LNG to vapor in seawater.
- Marine tanker ships are vulnerable to a terrorist attack by boat or aircraft.
- A breach in a ship's hull will allow LNG to escape and drift for miles over populated areas and explode.
- Large pool fires from a ruptured tank and the ensuing thermal radiation flux from a fire will cause burns at distances up to a mile or more.
- Tanker hulls do not have the ability to withstand an explosion from a bomb or impact from a large aircraft.

Opposition to LNG appears regional with respect to primary concerns. The Northeast opposition focuses mainly on safety concerns for densely populated areas where LNG facilities are proposed, while West Coast groups focus primarily on safety and environmental concerns.[20] To these community groups their concerns are real. From a fire safety professional's perspective, however, the actual risks must be evaluated realistically based on a sound knowledge of LNG's hazards balanced with risk control and mitigation measures. The considered expertise of fire safety professionals will be helpful to the regulatory process and may help in fostering better community understanding both of the risks as well as the benefits of LNG importation.

SUPPORTING VIEWPOINTS

The importance of expanding the use of LNG has been strongly supported by Federal Reserve Board Chairman Alan Greenspan,[21] who states:

> "Access to world natural gas supplies will require a major expansion of LNG terminal import capacity and development of the newer offshore regasification technologies. Without the flexibility such facilities will impart, imbalances in supply and demand must inevitably engender price volatility."

The state of Louisiana has actively supported the expansion of the LNG industry. According to Governor Kathleen Babineaux Blanco:[22]

"Here in Louisiana, we watch the national and global energy markets. We hear it when Alan Greenspan says over and over that this nation needs energy stability. We feel it when rising prices for natural gas—used as fuel or feedstock—force our petrochemical plants to cut back or even shut down. We see it when plan after plan to build LNG facilities on the East Coast or the West Coast are delayed, stalled or just plain killed. We want you to know that hope is on the way…help is on the way…in Louisiana.

We want you to know that we are at the forefront of a rebirth of the LNG industry in America. It's been more than 25 years since a LNG terminal was built in the United States—we want to see that change. Louisiana already holds the key infrastructure and this industry needs to support new LNG terminals."

The state of Texas has also actively supported the development and expansion of LNG infrastructure. According to Governor Rick Perry:

> "Secure supplies of natural gas are critical to the continued strong economic growth of Texas and the United States. This [Golden Pass LNG project] project will provide jobs and other economic benefits to Sabine Pass and Southeast Texas, and bring long-term supplies of natural gas for our industries, power plants and homes. We support Exxon Mobil's efforts to bring this important project to Texas." [23]

SUMMARY

In the future, the United States will require more electrical and gas energy to support growth and quality of life. Natural gas is a clean, non-toxic, and energy-efficient fuel that has good long-term potential as a major energy source.

Natural gas production in the U.S. is declining, but there are large proven reserves outside the U.S. that could supply and meet the country's energy needs for some time into the future. A significant expansion of infrastructure will be required very soon if LNG is expected to fulfill the projected requirements for natural gas.

The U.S. has considerable experience operating LNG facilities inside the U.S.; moreover, its safety record in transporting and operating LNG has been very good as compared to that of other fossil fuels.

Three federal agencies strictly regulate the U.S. LNG industry: the Federal Energy Regulatory Commission, the Department of Transportation, and the Department of Homeland Security. Federal requirements address safe facility design, siting, and operation. Additional fire safety and emergency planning requirements are enforced by state and local agencies.

While the risk of a LNG incident is low compared to that of other potential hazardous materials transportation and storage, the consequences of a major LNG incident have raised concerns in communities where new LNG facilities have been proposed. One of the key concerns expressed in areas of opposition is the risk and consequence of a terrorist attack on LNG ships and terminals.

In the future, communities will seek the opinions of fire marshals and other public safety officials about the hazards and risks of LNG facilities. Fire officials must prepare now and become well versed on LNG so that they are ready to address emerging issues concerning community safety.

While the federal government has strong oversight of the LNG industry, the final decision to permit new LNG facilities will be heavily influenced by state and local governments and the citizens they represent. It is important that local decisonmakers and stakeholders have an informed and balanced view of the benefits vs. risks of LNG.

REFERENCES

Note: The following sources served as primary references for the development of this paper. Many of these web sites have detailed reports that can be downloaded in PDF format.

PRIMARY INFORMATION SOURCES

LNG Subgroup Report National Petroleum Council
http://www.npc.org/reports/LNG-70704.pdf
This is an excellent resource for LNG imports/future expected use.

FERC: Gas industry
http://www.ferc.gov/industries/gas.asp

FERC: All about LNG
http://www.ferc.gov/industries/gas/indus-act/lng-what.asp

Center for Liquefied Natural Gas
http://www.lngfacts.org/

Liquefied Natural Gas Hazmat fact sheet
http://usfa.fema.gov/downloads/pdf/hazmat/page_307.pdf

Existing and Proposed LNG terminals
http://www.lngfacts.org/multimedia/lng_map.pdf

U.S Fire Administration hazards guide
http://usfa.fema.gov/fire-service/hazmat/hazmatguide/haz_j-k-l.shtm

SECONDARY INFORMATION SOURCES

Department of Energy DOE
http://www.doe.gov/engine/content.do?BT_CODE=ENERGYSOURCES

National Energy Technology Laboratory Strategic Center for Natural Gas
http://www.netl.doe.gov/scng/

Department of Energy Office of Fossil Fuels
http://www.fossil.energy.gov/

DOE PowerPoint May 2002 LNG Safety Myths and Legends
http://www.netl.doe.gov/publications/proceedings/02/ngt/Quillen.pdf

United States Coast Guard
http://www.uscg.mil/uscg.shtm

Department of Transportation
http://www.dot.gov/

Environmental Protection Agency
http://www.epa.gov/

United States Fish and Wildlife Service
http://www.fws.gov/

US Army Corps of Engineers
http://www.usace.army.mil/

Minerals Management Service Department of the Interior
http://www.mms.gov/

NOAA
http://www.noaa.gov/

Coast Guard News: Cove Point terminal
http://www.uscg.mil/news/d5/lng%5Fproposal.htm

END NOTES

[1] The United States produced 19.1 trillion cubic feet in 2000. Annual production is projected to expand to 29 trillion cubic feet by 2020. However, on a per-well-head basis, production in the United States is declining, while demand is projected to increase to 34 trillion cubic feet by 2020 – a shortfall of 5 trillion cubic feet a year. There are huge natural gas reserves in other countries such as Algeria, but the challenge is how to get this gas into the U.S. pipeline system.

[2] New power plants burn natural gas in turbines similar to airplane jet engines. In the initial stage, energy in the gas is converted directly to mechanical and then electrical energy, with no need to use steam. However, the exhaust gases are still hot enough to generate the steam necessary to drive a conventional steam turbine downstream. This "combined cycle" process results in an efficiency of 50% to 60%—as much as 60% of the energy in the gas is converted to electricity. Conventional steam generation has an efficiency of about 35%. Natural gas is the cleanest-burning fossil fuel. For a billion Btu of energy input, after pollution reduction measures, natural gas produces about 115,000 pounds of the greenhouse gas carbon dioxide, compared to about 200,000 pounds for a typical coal. And natural gas produces just one pound of the pollutant sulfur dioxide, compared to 1,500 pounds for untreated coal. Because of these advantages, more new power plants are designed to burn natural gas. Many urban transit buses and other motor vehicles now use natural gas in order to reduce emissions in urban areas.

[3] Source: Annual Energy Outlook 2005, Energy Information Administration, December 2004, Table 13.

[4] PROFESSIONAL MARINER, "Tapping Into LNG Jobs for US Mariners", Issue 85 (December/January 2005), page 10.

[5] At least an additional 3,700 merchant mariners will be required to run LNG vessels by 2007. See PROFESSIONAL MARINER, "Tapping Into LNG Jobs for US Mariners", Issue 85 (December/January 2005), page 10.

[6] Source: University of Houston Law Center, Institute of Energy Law Enterprise (www.lngfacts.org).

[7] Source: "Reminiscenes of the Pioneering Days of LNG Transport" by William duBarry Thomas and Alex Pastuhov, The Society of International Gas Tanker and Terminal Operators, Ltd., SITGO Newsletter—Supplement March 2003. Note: The Methane Pioneer began its maiden voyage on January 28, 1959 at the Constock jetty on the Calcasieu River south of Lake Charles, LA. The voyage ended on February 20, 1959 at the Regent Oil jetty at Canvey Island on the River Thames. The trip totaling 5,064 nautical miles, was made at an average of 8.8 knots. The historic trip included the ship's crew and a 10 person technical staff.

[8] Algeria is one of the world's largest suppliers of natural gas. When the Trinidad plant began operation it made LNG a more cost effective fuel due to efficiencies in transportation. See www.lngfacts.org.

[9] Source: University of Houston Law Center, Institute of Energy Law Enterprise. See www.lng-facts.org.

[10] Source: BP LNG Shipping, www.bplng.com.

[11] Source: Federal Energy Regulatory Commission, "What Are the Public Safety Issues Related to LNG? See http://www.ferc.gov/industries/gas/indus-act/lng-safety.asp.

[12] Source: Storage Tank Emergencies, by Hildebrand and Noll, Oklahoma State University, Fire Protection Publications (1997) and Propane Emergencies, 2nd edition, by Hildebrand and Noll, Red Hat Publishing (2001).

[13] Source: California Energy Commission, April 20, 2004 Report, "Algerian LNG Fact Sheet", www.energy.ca.gov.

[14] Source: Presentation given by Bachir Achour and Ali Hached of Sonatrach on March 21, 2004 at the LNG Conference. "The Incident at the Skikda Plant: Description and Preliminary Conclusions," LNG14, Session 1, 21 March 2004, DOHA-Qatar, Sonatrach, 38 pages. The full 7-megabyte report can be downloaded at: www.energy.ca.gov/lng/news.html.

[15] Auto-Refrigeration is a phenomenon that is often misunderstood by emergency responders. LNG is stored as a liquid at near atmospheric pressure in a container at –260ºF. Heat leaking through the insulation warms the liquid that rises in a boundary layer up the walls to the liquid surface. At temperatures above –260ºF the surface liquid will boil off into a vapor until the vapor pressure in the container is equal to its equilibrium vapor pressure. In a closed container this equalization can be achieved by a gradual increase in vapor pressure over the liquid. If vapor is drawn out of the container, the pressure in the container will drop. The result is that the surface pressure of the liquid will exceed the vapor pressure in the container and vaporization (boiling) will resume. The boiling will continue until the container again reaches equalization. When vapor is removed from an LNG tank, the LNG actually cools itself and goes into a state known as auto-refrigeration. When the tank is held at a constant pressure by removing vapor, the energy in the vapor equals the heat energy entering the tank through the insulation. This explains why LNG can be maintained as a cryogenic liquid for prolonged periods in transit and storage. For more information on auto-refrigeration see Propane Emergencies, 2nd edition, by Hildebrand and Noll (2001).

[16] Information in this section is based on work performed by ABS Consulting, Inc. for the Federal Regulatory Energy Commission entitled, "Consequence Assessment Methods for Incidents Involving Releases from Liquefied Natural Gas Carriers", May 12, 2004.

[17] Source: www.lloyds.com

[18] Sandia National Laboratories, "Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water, Sandia Report No. SAND2004-6258, December

2004. This report gives a comprehensive assessment of LNG risks and also explores the possibilities of accidents that result from intentional acts. While the detailed scenarios and calculations for these scenarios are classified, the conclusions are presented in the main unclassified report.

[19] Source: American Public Power Association, Public Power, November/December 2004, and "The LNG Battlefield" by David Chantary. (www.appanet.org). Source: Marsh Special Study.

[20] For more information on the opinions of LNG opposition groups see the following: Coalition for the Responsible Siting of LNG Facilities at (http://www.nolng.org) and Green Futures at (http://www.greenfutures.org), and Tim Riley Law (timrileylaw.com) and LNG Watch (lng-watch.com).

[21] Source: Testimony of Alan Greenspan before the Committee on Energy and Natural Resources, U.S. Senate, July 10, 2003.

[22] Source: Address of Governor Kathleen Babineaux Blanco to the LNG Global Outlook Conference, October 13, 2004.

[23] Source: Governor Rick Perry statement taken from ExxonMobil press release on the Golden Pass LNG project.