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INTRODUCTION TO LNG

*An overview on liquefied natural gas (LNG),
its properties, organization of the LNG industry and
safety considerations*



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INTRODUCTION TO LNG¹

Executive Summary

This briefing paper is the first in a series of articles that describe the liquefied natural gas (LNG) industry and the growing role LNG may play in the U.S. energy future. The first edition of this paper was released in January 2003. The second and third papers, *LNG Safety and Security* and *The Role of LNG in North American Natural Gas Supply and Demand*, followed in October 2003 and September 2004 accordingly. All of these reports, along with supplemental information and resource links, are available as part of the online *Guide to LNG in North America* published by the Center for Energy Economics (CEE), Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, www.beg.utexas.edu/energyecon/lng.

LNG is the liquid form of the natural gas people use in their homes for cooking and heating. According to the U.S. Energy Information Administration (U.S.EIA), the U.S. could face a gap in supply of natural gas of about six trillion cubic feet (Tcf) by 2030. Canada, which has been supplying up to 16 percent of natural gas supply to the U.S. "Lower 48" states may not be able to sustain much less grow these exports due to Canada's own increasing demand for natural gas. Consequently, increased imports of LNG will be required to meet future shortfalls. The U.S.EIA expects LNG imports to reach 4.36 Tcf a year by 2030, or about sixteen percent of our total consumption.

To make LNG available for use in the U.S., energy companies must invest in the LNG value chain, which consists of a number of different operations that are highly linked and dependent upon one another. Natural gas can be economically produced and delivered to the U.S. as LNG within a price range of about \$2.60-\$4.20 per million Btu (MMBtu) at Henry Hub in Louisiana, depending largely on economics for exploration and production (E&P; including financial terms offered by producing and

¹ This report was prepared by the Center for Energy Economics (CEE) through a research and public education consortium, *Commercial Frameworks for LNG in North America*. Sponsors of the consortium are BP Energy Company-Global LNG, BG LNG Services, ChevronTexaco Global LNG, ConocoPhillips Worldwide LNG, El Paso Global LNG, ExxonMobil Gas Marketing Company, SUEZ LNG North America/Distrigas of Massachusetts. Shell LNG North America participated in the initial phase of the consortium. The U.S. Department of Energy-Office of Fossil Energy provided critical support and the Ministry of Energy and Industry, Trinidad & Tobago and Nigerian National Petroleum Corporation (NNPC) participate as observers. This report was prepared by Dr. Michelle Michot Foss, Chief Energy Economist and Head of CEE; Mr. Dmitry Volkov, Energy Analyst, CEE; Dr. Mariano Gurfinkel, Project Manager and Assistant Head of CEE; and Engr. Fisoye Delano, Managing Director, Nigerian Petroleum Development Company Ltd., Nigerian National Petroleum Corporation Group (previously a Senior Researcher at CEE-UT). The views expressed in this paper are those of the authors and not necessarily those of the University of Texas at Austin. Peer reviews were provided by a number of outside experts and organizations.

exporting countries) and shipping cost (primarily a function of distance).² This price range incorporates an estimated 30 percent escalation over CEE's 2003 estimate of \$2.00-3.70/MMBtu, a consequence of cost pressure in recent years associated with higher energy and commodity prices.

LNG has been safely handled for many years. The industry is not without incidents but it has maintained an enviable safety record, especially over the last 40 years. Worldwide, there are 23 LNG export (liquefaction) terminals, 58 import (regasification) terminals, and 224 LNG ships altogether handling approximately 142 million metric tons of LNG every year. There are currently over 240³ peakshaving and LNG storage facilities worldwide, some operating since the mid-60s. The U.S. has the largest number of LNG facilities in the world—113 active LNG facilities spread across the country with a higher concentration of the peak shaving and satellite facilities in the northeastern region. As of this update, a number of new LNG import receiving terminals have been approved in the Lower 48. Four onshore terminals are under construction along the U.S. Gulf Coast (with expansions proposed) in Freeport and Port Arthur, Texas and Cameron Parish, Louisiana; one offshore ship-based import/regasification terminal is in operation; one new onshore terminal is in operation on Mexico's upper Gulf Coast (Altamira, near Tampico, Tamaulipas State) and another is under construction in Mexico's Baja California Norte; and one onshore import receiving terminal is under construction in New Brunswick, Canada (with an expansion already announced). Two existing import receiving terminals, Lake Charles, Louisiana and Cove Point, Maryland are undergoing expansion and an expansion for the existing terminal at Elba Island, Georgia has been approved.

The need for additional natural gas supplies and new LNG import receiving capacity, including the reopening of and proposed expansions to existing LNG facilities at Cove Point, Maryland and Elba Island, Georgia has focused public attention on the safety and security of LNG facilities in the U.S. The safe and environmentally sound operation of all LNG facilities and the protection of these facilities from terrorist activities or other forms of accident or injury are a concern and responsibility shared by operators as well as federal, state and local jurisdictions across the U.S. Onshore LNG facilities are industrial sites and, as such, are subject to all rules,

² In this document, the cost term "\$/MMBtu" or dollars per million British thermal unit, is a standard measure of heat content in energy fuels. See Appendix 3. The price range presented here includes both existing and new LNG import terminals. One such basis is \$1.68/MMBtu freight rate from Malaysia (Bintulu) to Lake Charles, Louisiana (round trip 51 days; source, *European Waterborne LNG Report*, May 2005). The cost/price range for new import terminals and locations may vary. Comparisons to CEE's estimate include: California Energy Commission NARG model assumptions (2006) of \$1.67-3.83/MMBtu for transport to Mid-Atlantic U.S. from South America, with East Coast costs at the lower end, and \$2.97-5.59/MMBtu for transport to the Northeast U.S. from Asia/Pacific region (one of the longer shipping routes). CEDIGAZ (www.cedigaz.com) in July 2005 estimated \$2.70-3.30/MMBtu (as compared to their estimate of \$3.50-4.10/MMBtu in the 1990s) for the Middle East-Far East value chain. The July 2005 estimate incorporates the same exploration and production and receiving and regasification cost components, slightly reduces liquefaction and abruptly drops shipping costs by approximately 25-30 percent.

³ See <http://www.shell-usgp.com/lngsashes.asp>.

regulations and environmental standards imposed by the various jurisdictions. These same or similar concerns apply to natural gas storage and pipeline transportation and distribution and our daily use of natural gas, as well as to all energy fuels and infrastructure and critical industrial and public infrastructure throughout the United States, North America and the world.

Introduction

This briefing paper is the first in a series of articles that describe the liquefied natural gas (LNG) industry—technology, markets, safety, security and environmental considerations and the growing role LNG may play in the nation’s energy future. This paper also introduces the reader to LNG and briefly touches on many of the topics relating to the LNG industry. The second paper, ***LNG Safety and Security***, deals with the safety and security aspects of LNG operations in more detail. A third paper, ***The Role of LNG in North American Natural Gas Supply and Demand*** provides an in-depth analysis of why additional LNG will be needed to meet U.S. energy demand in the near future. All three papers, plus supplemental information, are available in a complete online fact book, ***Guide to LNG in North America***.

LNG is the liquid form of the natural gas people use in their homes for cooking and heating. Natural gas is also used as fuel for generating electricity. Natural gas and its components are used as raw material to manufacture a wide variety of products, from fibers for clothing, to plastics for healthcare, computing, and furnishings. Natural gas makes up about one-fourth of all energy consumed in the United States each year. The most common use of LNG in the U.S. is for “peakshaving.” Peakshaving is a way local electric power and gas⁴ companies or utilities store gas for peak demand that cannot be met via their typical pipeline sources. Peakshaving can occur during the winter heating season or when more natural gas is needed to generate electric power for air conditioning in the summer months. The utility companies liquefy natural gas when it is abundant and available at off-peak prices, or they purchase LNG from import terminals supplied from overseas liquefaction

⁴ We use the term “gas” as shorthand for “natural gas.” Our use of this shorthand form is not to be confused with “gasoline”, the most heavily used vehicle transportation fuel. Gasoline is manufactured from crude oil which, as noted in the text, also is a fossil fuel and is often found together with natural gas in underground reservoirs.

facilities. When gas demand increases, the stored LNG is converted from its liquefied state back to its gaseous state, to supplement the utilities' pipeline supplies. LNG is also currently being used as an alternative transportation fuel in public transit and in vehicle fleets such as those operated by many local natural gas utilities companies for maintenance and emergencies.

Natural gas comes from reservoirs beneath the earth's surface. Sometimes it occurs naturally and is produced by itself (non-associated gas), sometimes it comes to the surface with crude oil (associated gas), and sometimes it is being produced constantly such as in landfill gas. Natural gas is a fossil fuel, meaning that the natural gas we produce from the subsurface is derived from organic material deposited and buried in the earth millions of years ago. Other fossil fuels are coal and crude oil. Together crude oil and natural gas constitute a type of fossil fuel known as "hydrocarbons" because the molecules in these fuels are combinations of hydrogen and carbon atoms.

The main component of natural gas is methane. Methane is composed of one carbon and four hydrogen atoms (CH₄). When natural gas is produced from the earth, it includes many other molecules, like ethane (used for manufacturing), propane (which we commonly use for backyard grills) and butane (used in lighters). We can find natural gas in the U.S. and around the world by exploring for it in the earth's crust and then drilling wells to produce it. Natural gas can be transported over long distances in pipelines or as LNG in ships across oceans. Natural gas can be stored until needed in underground caverns and reservoirs or as LNG in atmospheric tanks. Transportation of LNG by truck takes place in the United States on a limited basis. Such transportation is more common in countries without a national natural gas pipeline grid. Truck transport of LNG it could grow in the United States if LNG niche markets, such as use of LNG as a vehicular fuel, develop.

Overview: What Is LNG?

Liquefied natural gas (LNG) is natural gas that has been cooled to the point that it condenses to a liquid, which occurs at a temperature of approximately -256°F (-

161°C) at atmospheric pressure. Liquefaction reduces the volume of gas by approximately 600 times⁵ thus making it more economical to store natural gas where other forms of storage do not exist, and to transport gas over long distances for which pipelines are too expensive or for which other constraints exist. Liquefaction makes it possible to move natural gas between continents in specially designed ships. Thus, LNG technology makes natural gas available throughout the world.

To make LNG available for use in a country like the U.S., energy companies must invest in a number of different operations that are highly linked and dependent upon one another. The major stages of the **LNG value chain**, excluding pipeline operations between the stages, consist of the following.

- **Exploration** to find natural gas in the earth's crust and **production** of the gas for delivery to gas users. Most, but not all, of the time natural gas is discovered during the search for oil.
- **Liquefaction** to convert natural gas into a liquid state so that it can be transported in ships.
- **Shipping** the LNG in special purpose vessels.
- **Storage** of LNG in specially made tanks, and **regasification** to convert the LNG from the liquid phase to the gaseous phase, ready to be moved to the final destination through the natural gas pipeline system.

Liquefaction provides the opportunity to store natural gas for use during high demand periods in areas where geologic conditions are not suitable for developing underground storage facilities. In the northeastern part of the U.S., LNG peak shaving is a critical part of the region's supply during cold snaps or heat waves. In regions where pipeline capacity from supply areas can be very expensive and use is

⁵ LNG production, shipping and storage are generally reported in metric tons and cubic meters whereas natural gas is generally presented in standard cubic feet or standard cubic meters. One metric ton of LNG is equivalent to 48.7 thousand cubic feet of gas (Mcf). Note: exact conversion factor depends on gas molecular weight. A conversion table with more units is included in Appendix 2.

highly seasonal, liquefaction and storage of LNG occurs during off-peak periods in order to reduce expensive pipeline capacity commitments during peak periods.⁶

Does the U.S. Need LNG?⁷

The demand for natural gas in the U.S. was boosted in the late 1970s and early 1980s in part by the desire to diversify energy resources in the wake of global oil shocks⁸. Demand for natural gas was sustained due to the clear environmental advantages of natural gas over other fossil fuels and its superior thermal efficiency when used in power generation. Based on U.S. Energy Information Administration (U.S.EIA) data for 2006, the most recent available, the U.S. used just under 22 Tcf of gas. U.S. dry gas production⁹ was about 18.5 Tcf, with the balance comprising mainly exports from Canada (about 16 percent of total consumption) and LNG (just over 2.5 percent of total natural gas consumed). According to the U.S.EIA, dry natural gas production in the U.S. is predicted to grow from 18.8 trillion cubic feet (Tcf) in 2004 to 20.5 Tcf in 2030.¹⁰ The total U.S. demand for natural gas is expected to rise from 22.4 Tcf in 2004 to about 26 Tcf by 2030 (including forecasted gains in energy efficiency and conservation). These projections suggest that the U.S. could face a gap between total supply and total consumption of about six Tcf by 2030.

The bulk of the natural gas used in the U.S. comes from domestic production, in many cases from fields that are several decades old and that are beginning to decline rapidly. New natural gas fields and reserves are constantly being discovered, but with new challenges in production and technology, as reflected

⁶ U.S. EIA, *U.S. LNG Markets and Uses*, June 2004.

http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2002/Ing2002/IngNov6.htm

⁷ A full analysis of the U.S. supply and demand balance is available in the third CEE LNG briefing paper in the online *Guide to LNG in North America*, www.beg.utexas.edu/energyecon.

⁸ Schleede, Glenn R., *Why Would an Electric Utility Want to Increase Dependence on Natural Gas*, contributed paper in *The Case for Natural Gas*, edited by Jacqueline Weaver, The Natural Gas Project, University of Houston, 1991.

⁹ Dry gas production is natural gas that is almost entirely methane, produced from "wet" gas that is stripped of other molecules during processing or that is produced from non-associated gas fields as "dry" gas.

¹⁰ U.S. EIA, *Annual Energy Outlook 2007 with Projections to 2030*, <http://www.eia.doe.gov>.

recently in higher costs and prices. Consequently, increased imports of natural gas may be required to meet future shortfalls.

Most of the imported natural gas used by U.S. customers—indeed, most of the total energy (including also crude oil and petroleum products like gasoline and electric power)—comes from Canada. Canada is the single largest exporter of crude oil, natural gas, and electric power to the U.S. In recent years, pipeline imports of natural gas from Canada have constituted 15-17 percent of total U.S. consumption. Canada may not be able to sustain current or increasing volumes of exports to the U.S. due to Canada's own growing demand for natural gas and the maturation of the Western Canada Sedimentary Basin (WCSB). Recent trends suggest that due to decreasing initial gas well productivities and high production decline rates in the WCSB,¹¹ higher levels of drilling activity are necessary to maintain current production levels. Alternative sources of domestic natural gas supply for both Canada and the U.S. include building pipelines to carry natural gas produced on the North Slope of Alaska and from Arctic gas production in Canada's far north ("mega" projects that entail intensive engineering feasibility and design and that require sound investment and regulatory frameworks for cost recovery); developing onshore natural gas resources in the Rocky Mountain region and other key "unconventional"¹² supply basins in the Lower 48 as well as Canada's WCSB; and developing offshore resources along the North American continental margins in the Pacific, the Atlantic and the Eastern Gulf of Mexico Outer Continental Shelf (OCS). Natural gas from Alaska, an alluring prospect, will require robust natural gas market conditions (demand and pricing) in Canada and the Lower 48 states. Additionally, some projections indicate that a gap in supply could remain even if the delivery of Alaskan gas commences, unless federal and state laws and regulations

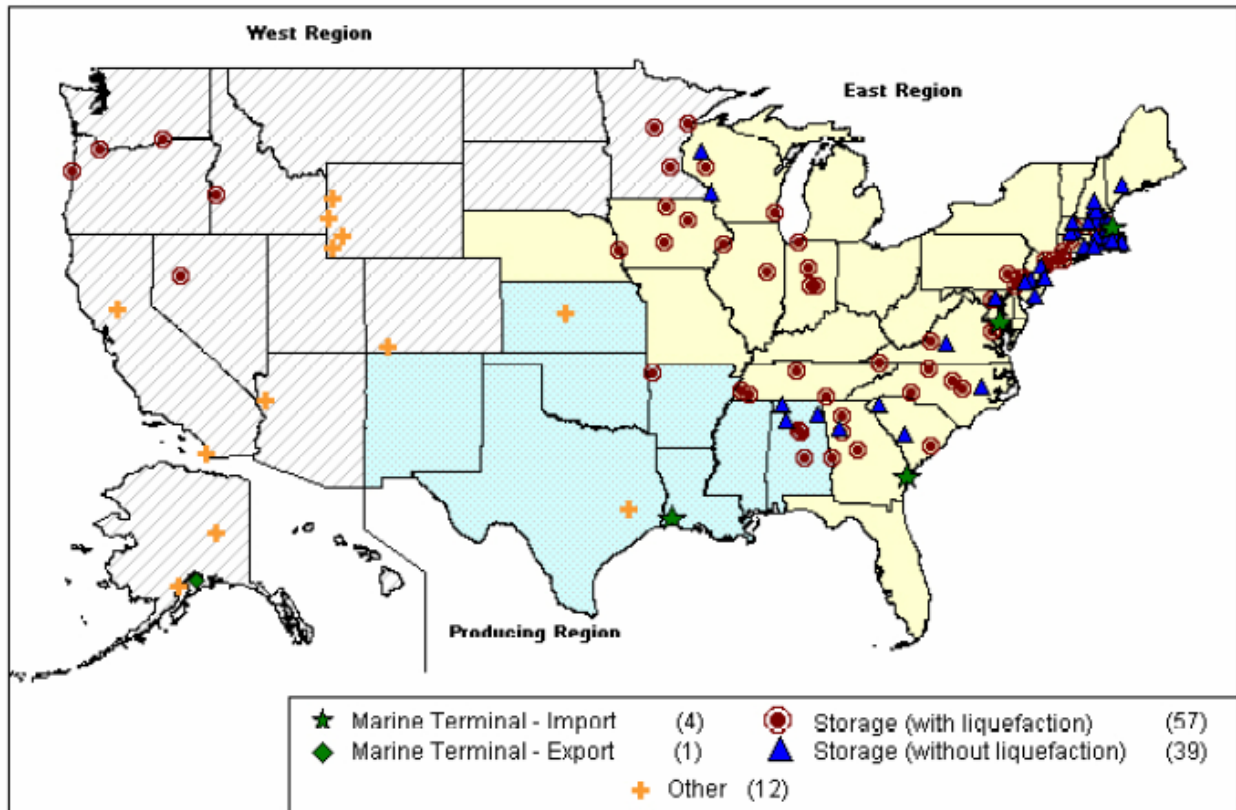
¹¹ Jim Delay, Alberta Energy & Utilities Board, *Alberta Natural Gas Outlook*, Calgary, October 2002.

¹² We use the term "unconventional" to refer to those natural gas producing reservoirs that must be treated for natural gas to flow in sufficient volumes to ensure that a field is commercially viable at a given natural gas price.

that constrain access to much of the offshore resources in the eastern Gulf of Mexico and the onshore Rocky Mountain region are altered.¹³

Currently, LNG imports account for slightly less than three percent of the total U.S. consumption of natural gas. The U.S. EIA expects LNG imports to reach 4.5 Tcf a year by 2030, or about 17 percent of our total consumption. Although many factors can alter this outlook, the demand for LNG is expected to grow.

Figure 1. U.S. LNG Facilities¹⁴



Notes: Map excludes the import facility in Puerto Rico. Other includes: stranded utilities, vehicular fuel facilities, nitrogen rejection units and other special processing plants.
Sources: Energy Information Administration, Office of Oil and Gas, and industry sources.

¹³ U.S. EIA, *Mid-Term Natural Gas Supply: Analysis of Federal Access Restrictions*, <http://www.eia.doe.gov/oiaf/servicerpt/natgas/chapter2.html>, December 2001.

¹⁴ U.S.EIA, *U.S. LNG Markets and Users*, June 2004 update. See http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2004/lng/lng2004.pdf

There are 113 active LNG facilities in the United States, including four existing onshore marine import terminals, peak shaving and satellite storage facilities, and operations involved in niche markets such as vehicular fuel as shown in the figure above. Most of these facilities were constructed between 1965 and 1975 and were dedicated to meeting the supply and storage needs of local utilities. Approximately 55 local utilities own and operate domestic natural gas liquefaction and storage facilities as part of their distribution networks.¹⁵

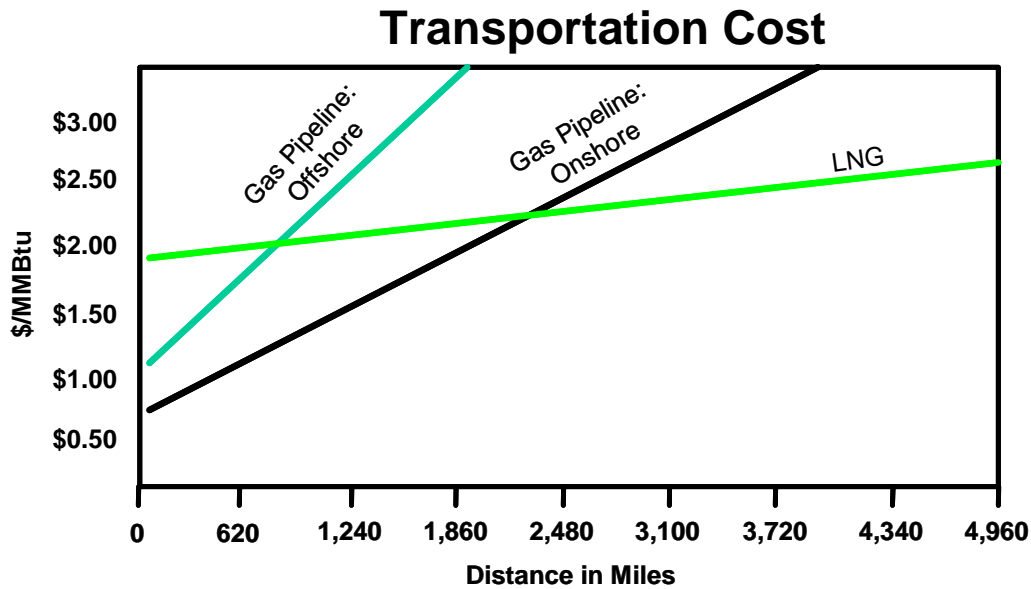
Is LNG a Competitive Source of Natural Gas?

Large reserves of natural gas exist around the world in areas for which there is no significant market, or where natural gas resources far exceed local or regional demand, or where pipeline options are limited. Such hydrocarbon reserves are “stranded” in North Africa, West Africa, South America, Caribbean, the Middle East, Indonesia, Malaysia, Northwestern Australia and Alaska. Some of the natural gas produced from these resources is liquefied for shipping to areas where usage of natural gas exceeds indigenous supply. Such markets include Japan, Taiwan, Korea, Western Europe and the U.S. LNG offers greater trade flexibility than pipeline transport, allowing cargoes of natural gas to be delivered where the need is greatest and the commercial terms are most competitive. The figure below shows that as the distance over which natural gas must be transported increases, usage of LNG has economic advantages over usage of pipelines. In general, liquefying natural gas and shipping it via ocean transport becomes cheaper than transporting natural gas in offshore pipelines for distances of more than 700 miles or in onshore pipelines for distances greater than 2,200 miles.¹⁶

¹⁵ U.S.EIA, *U.S. LNG Markets and Uses*, November 2002.

¹⁶ Figure 2 reflects the competition between natural gas transported in pipelines and natural gas transported as LNG. The relationships depicted may vary depending upon size and economics of liquefaction trains and dedicated shipping routes. Figure 2 reflects relationships as of roughly 2000-2002.

Figure 2. Natural Gas Transportation Technology and Cost Relative to Distance



Source: Institute of Gas Technology.

In countries like Nigeria and Angola, much of the natural gas that is produced with crude oil has been or is flared because of lack of alternatives for usage or disposal of the excess gas. In the case of Nigeria, flaring has been reduced through that country's anti-flaring initiative which has spurred growth in both domestic demand (through use of natural gas for electric power generation) as well as new investments in liquefaction for export and gas-to-liquids (GTL) projects for export. For both countries, LNG projects offer additional options for export earnings.

Brief History of LNG

Natural gas liquefaction dates back to the 19th century when British chemist and physicist Michael Faraday experimented with liquefying different types of gases, including natural gas. German engineer Karl Von Linde built the first practical compressor refrigeration machine in Munich in 1873. The first LNG plant was built in West Virginia in 1912 and began operation in 1917. The first commercial

liquefaction plant was built in Cleveland, Ohio, in 1941.¹⁷ The LNG was stored in tanks at atmospheric pressure. The liquefaction of natural gas raised the possibility of its transportation to distant destinations. In January 1959, the world's first LNG tanker, *The Methane Pioneer*, a converted World War II liberty freighter containing five, 7,000 barrel equivalent aluminum prismatic tanks with balsa wood supports and insulation of plywood and urethane, carried an LNG cargo from Lake Charles, Louisiana to Canvey Island, United Kingdom. This event demonstrated that large quantities of liquefied natural gas could be transported safely across the ocean.

Figure 3. British Gas Canvey Island LNG Terminal, A World First



Source: BG

Over the next 14 months, seven additional cargoes were delivered with only minor problems. Following the successful performance of *The Methane Pioneer*, the British Gas Council proceeded with plans to implement a commercial project to import LNG from Venezuela to Canvey Island. However, before the commercial agreements could be finalized, large quantities of natural gas were discovered in Libya and in the gigantic Hassi R' Mel field in Algeria, which are only half the distance to England as Venezuela. With the start-up of the 260 million cubic feet per day (MMcfd) Arzew GL4Z or Camel plant in 1964, the United Kingdom became

¹⁷ See Platts, <http://www.platts.com/features/lng/trading.shtml>.

the world's first LNG importer and Algeria the first LNG exporter. Algeria has since become a major world supplier of natural gas as LNG.

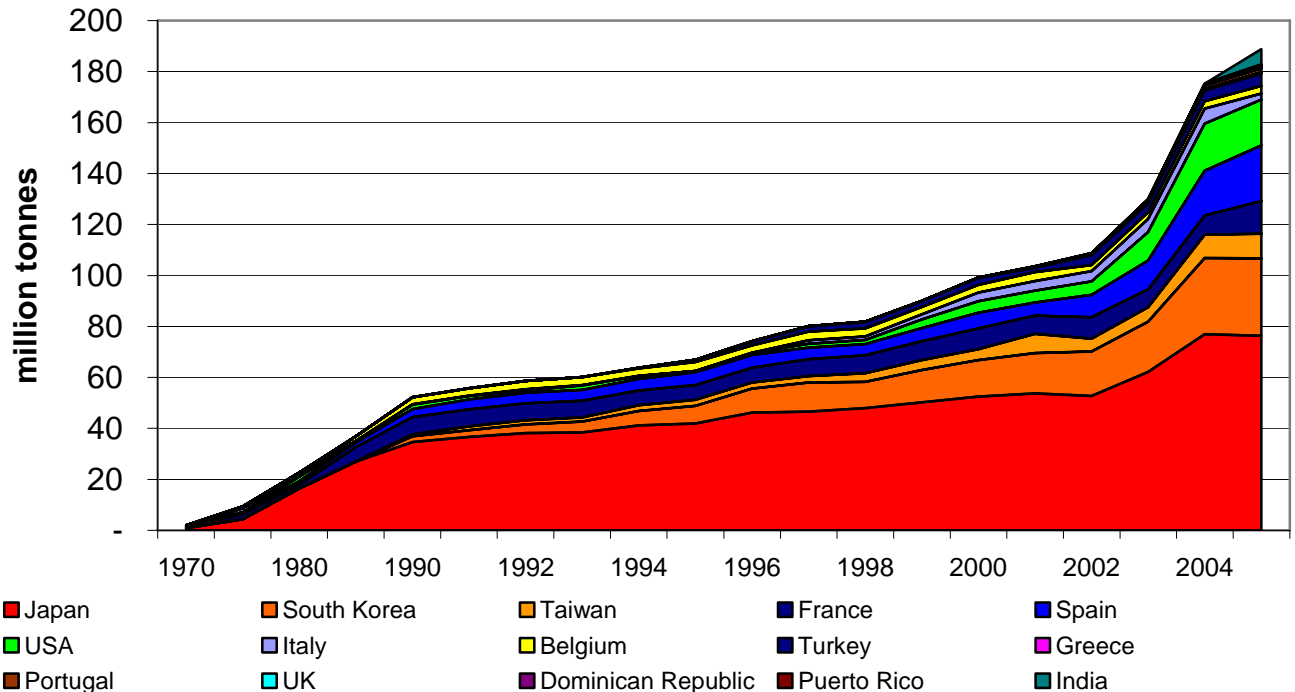
After the concept was shown to work in the United Kingdom, additional liquefaction plants and import terminals were constructed in both the Atlantic and Pacific regions. Four marine terminals were built in the United States between 1971 and 1980. They are in Lake Charles (operated by CMS Energy), Everett, Massachusetts (operated by SUEZ through their Distrigas subsidiary), Elba Island, Georgia (operated by El Paso Energy), and Cove Point, Maryland (operated by Dominion Energy). After reaching a peak receipt volume of 253 BCF (billion cubic feet) in 1979, which represented 1.3 percent of U.S. gas demand, LNG imports declined because a gas surplus developed in North America and price disputes occurred with Algeria, the sole LNG provider to the U.S. at that time. The Elba Island and Cove Point receiving terminals were subsequently mothballed in 1980 and the Lake Charles and the Everett terminals suffered from very low utilization.

The first exports of LNG from the U.S. to Asia occurred in 1969 when Alaskan LNG was sent to Japan. Alaskan LNG is derived from natural gas that is produced by ConocoPhillips and Marathon from fields in Cook Inlet in the southern portion of the state of Alaska, liquefied at the Kenai Peninsula LNG plant (one of the oldest, continuously operated LNG plants in the world) and shipped to Japan. The LNG market in both Europe and Asia continued to grow rapidly from that point on. The figure below shows worldwide growth in LNG since 1970.

In 1999, the first Atlantic Basin LNG liquefaction plant in the western hemisphere came on production in Trinidad. This event, coupled with an increase in demand for natural gas in the U.S. particularly for power generation and an increase in U.S. natural gas prices, resulted in a renewed interest in the U.S. market for LNG. As a result, the two mothballed LNG receiving terminals have been reactivated. Elba Island was reactivated in 2001. In October 2002, the Federal Energy Regulatory Commission (FERC) gave approval to Dominion Resources for its plans to re-open Cove Point LNG facility in 2003; first shipments to the reactivated terminal were

Figure 4. Worldwide Growth in LNG Demand

Growth in LNG Demand



Source: Cedigaz, BP Statistical Review of World Energy 2006

received in fall 2006. In April 2005 the world's first offshore, ship-based regasification facility was set in operation in the Gulf of Mexico by Exceleerate Energy. Additionally, a number of approved, planned, and proposed import receiving projects are under development (see www.ferc.gov for updates).

Composition of Natural Gas and LNG

Natural gas is composed primarily of methane, but may also contain ethane, propane and heavier hydrocarbons. Small quantities of nitrogen, oxygen, carbon dioxide, sulfur compounds, and water may also be found in natural gas. The Figure 5 provides a typical natural gas composition.¹⁸ The liquefaction process requires the

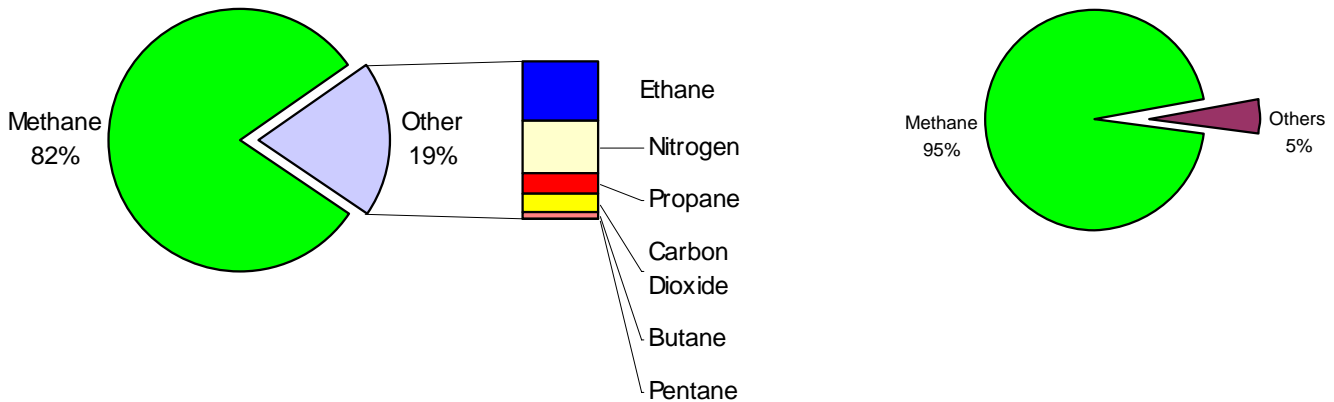
¹⁸ Danesh, Ali: *PVT and Phase Behavior of Petroleum Reservoir Fluids*, Elsevier, 1998.

removal of some of the non-methane components such as water and carbon dioxide from the produced natural gas to prevent them from forming solids when the gas is cooled to about LNG temperature (-256°F). As a result, LNG is typically made up mostly of methane as shown in Figure 5.

Figure 5. Typical Natural Gas and LNG Composition

Typical Natural Gas Composition

Typical LNG Composition



Examples of LNG composition are shown in Table 1.

Table 1. LNG Composition with Geographic Variation

LNG COMPOSITION (Mole Percent)					
Source	Methane	Ethane	Propane	Butane	Nitrogen
Alaska	99.72	0.06	0.0005	0.0005	0.20
Algeria	86.98	9.35	2.33	0.63	0.71
Baltimore Gas & Electric	93.32	4.65	0.84	0.18	1.01
New York City	98.00	1.40	0.40	0.10	0.10
San Diego Gas & Electric	92.00	6.00	1.00	-	1.00

Source: *Liquid Methane Fuel Characterization and Safety Assessment Report*. Cryogenic Fuels, Inc. Report No. CFI-1600, Dec. 1991

LNG is odorless, colorless, non-corrosive, and non-toxic. However, as with any gaseous material besides air and oxygen, the natural gas vaporized from LNG can cause asphyxiation in an unventilated confinement.

Appendix 1 explains the differences between LNG and other products used in the industry such as Natural Gas Liquids (NGLs), Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG) and Gas-to-Liquids (GTL).

The LNG Value Chain

The LNG “value” or “supply” chain consists of four highly linked, interdependent segments—exploration and production (or E&P); liquefaction; shipping—from the point of liquefaction to the final destination; and receiving, storage and regasification at the final destination. We use the term “value” because at each stage investments are made to take natural gas from an unusable state to one in which optimal use of natural gas as a critical energy fuel and feedstock for materials can be achieved.

Figure 6. The Global LNG Supply (Value) Chain

LNG Value Chain



Sources: BG; ALNG; CMS.

Exploration and Production



The first segment in the LNG value chain is exploration and production. E&P activity ranges from the development of ideas about where natural gas resources might occur (prospect generation), to the mobilization of financial capital to support drilling and field development, to ultimate production. The E&P segment incorporates geologic risk—the chance that natural gas resources in a “play” (an area of interest) either do not exist or exist in quantities or subsurface conditions that do not favor commercially successful exploitation. U.S. natural gas reserves increased by more than 11 percent, from 183.5 to 204.4 Tcf, between 2001 and 2005.¹⁹ To a large extent, this increase in reserves reflects the impact of higher natural gas prices since 1999; higher natural gas prices both spur drilling and increase the amount of natural gas resource that can be recovered (higher prices facilitate production from higher cost fields that might otherwise not be economic). The U.S., and North America, remains rich in natural gas resources. Natural gas trade—via pipelines and LNG—helps to provide a diverse portfolio of supply options that can offset tight domestic supplies and soften impacts of higher prices during periods when the U.S. demand for natural gas exceeds deliverable supply.

For the year 2005, worldwide proved reserves of natural gas were 6,348 Tcf, an increase of 25 percent over the year 1995, and more reserves of natural gas continue to be discovered.²⁰ Much of this natural gas is stranded a long way from market, in countries that do not need large quantities of additional energy. The leading countries producing natural gas and selling it to world markets in the form of LNG are Indonesia, Malaysia, Qatar and Algeria. Trinidad & Tobago is an

¹⁹ U.S.EIA: *2006 Annual Report, U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves*. Advance Summary, February 2006.

²⁰ BP: *Statistical Review of World Energy 2006*, July 2006.
<http://www.bp.com/genericsection.do?categoryId=92&contentId=7005893>

example of a small country that has benefited hugely from its LNG export strategy. Several countries are growing rapidly as natural gas producers and LNG exporters, such as Nigeria and Australia. Countries like Angola and Venezuela are striving to reach their full potential in the global LNG marketplace, and countries like Saudi Arabia and Iran, that have vast reserves of natural gas, could also participate as LNG exporters.

LNG Liquefaction



Currently, liquefaction capacity to serve the Atlantic and Pacific basins is about the same; all together, including Middle East facilities, about 170 million tons per year (MTPA) of capacity is in place (as of March 2007). Another 91 MTPA is under construction and 285 MTPA are planned.²¹ Egypt joined the club of LNG exporters in

May 2005 by shipping a first cargo from newly constructed Idku terminal on the Mediterranean Sea. In 2006 two liquefaction projects came into operation: Australia started its second LNG project in Timor Sea, and Qalhat terminal in Oman shipped first cargoes to Japan and Spain. Feed gas to the liquefaction plant comes from the production field.

During liquefaction, contaminants found in produced natural gas are removed to avoid freezing up and damaging equipment when the gas is cooled to LNG temperature (-256°F) and to meet pipeline specifications at the delivery point. The liquefaction process can be designed to purify the LNG to almost 100 percent methane.

The liquefaction process entails cooling the clean feed gas by using refrigerants. The liquefaction plant may consist of several parallel units ("trains"). By liquefying the gas, its volume is reduced by a factor of 600, which means that LNG at -256°F

²¹ From various industry sources and trade publications.

uses 1/600th of the space required for a comparable amount of gas at room temperature and atmospheric pressure.

LNG is a cryogenic liquid. The term “cryogenic” means low temperature, generally below -100°F. LNG is clear liquid, with a density of about 45 percent the density of water.

At both liquefaction and receiving and regasification facilities, the LNG is stored in double-walled tanks at atmospheric pressure. The storage tank is really a tank within a tank. The annular space between the two tank walls is filled with insulation. The inner tank, in contact with the LNG, is made of materials suitable for cryogenic service and structural loading of LNG. These materials include 9 percent nickel steel, aluminum and pre-stressed concrete. The outer tank is generally made of carbon steel or pre-stressed concrete.²²

LNG Shipping



LNG tankers are double-hulled ships specially designed and insulated to prevent leakage or rupture in an accident. The LNG is stored in a special containment system within the inner hull where it is kept at atmospheric pressure and cryogenic temperature (-256°F).

Three types of cargo containment systems have evolved as modern standards. These are:

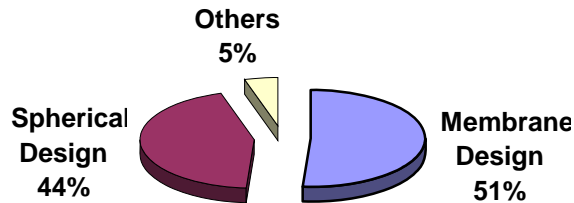
- The spherical (Moss) design (as shown in the photo above);
- The membrane design; and
- The structural prismatic design.

²² Details on LNG tank designs, construction, and materials can be found in CEE’s report, LNG Safety and Security, at www.beg.utexas.edu/energyecon/lng.

Historically most of the LNG ships used spherical (Moss) tanks. Moss-type ships are easily identifiable as LNG ships because the top half of the tanks are visible above deck. However, the trend is toward membrane design. The figure below shows that 44 percent of LNG ships were spherical design in 2006; this compares to 52 percent of LNG ships in 2002.

Figure 7. LNG Fleet Containment

**LNG Fleet Containment System - September 2006
(Number of ships)**

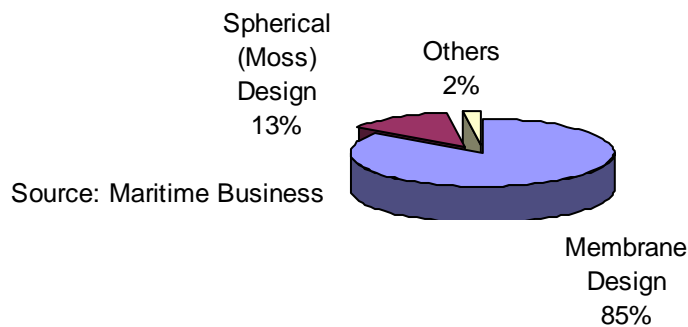


Source: Maritime Business Strategies, LLC

The shift toward membrane design is even more obvious by analyzing the structure of orders for LNG carriers (see below).

Figure 8. LNG Fleet Containment – Ship Orders

**LNG Fleet Containment System - Order Book 2005 - 2010
(Number of ships)**

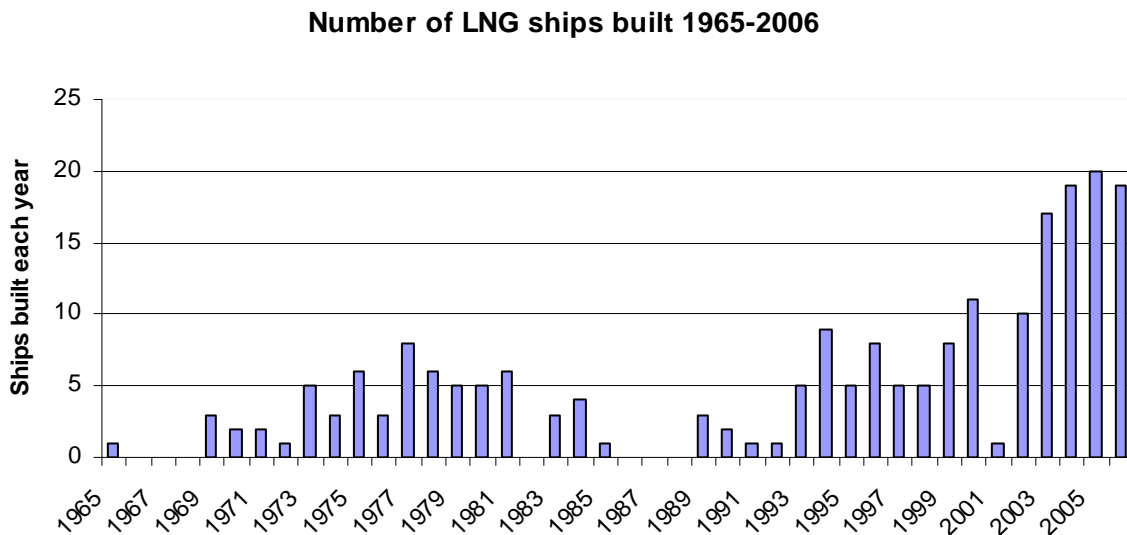


Source: Maritime Business

The typical LNG carrier can transport about 125,000-138,000 cubic meters of LNG,²³ which will provide about 2.6-2.8 billion standard cubic feet of natural gas. The typical carrier measures some 900 feet in length, about 140 feet in width and 36 feet in water draft and costs about \$160 million to build. This ship size is similar to that of an aircraft carrier but significantly smaller than that of a Very Large Crude Carrier (VLCC) used to transport crude oil. LNG tankers are generally less polluting than other shipping vessels because they burn natural gas in addition to fuel oil for propulsion.

The LNG shipping market has been expanding. According to Maritime Business Strategies, as of March 2007, there were 224 LNG tankers in operation with 145 on order.²⁴ By comparison, forty two new LNG tankers were ordered in 2005. About 40 percent of the fleet is less than five years old. The LNG tanker fleet size is estimated to continue to grow to well over 300 tankers by 2010.

Figure 9. Number of LNG Ship Builds



Source: Maritime Business Strategies, LLC

²³ Typically, LNG ship size is designated by cubic meters of liquid capacity.

²⁴ Maritime Business Strategies, LLC: <http://www.coltoncompany.com/>.

Storage and Regasification



At final destinations, LNG may be used in various ways. For instance, LNG may be used as a transportation fuel for truck and bus fleets; in these cases, LNG import receiving terminals will include facilities to dispense LNG into tanker trucks for distribution to central refueling locations. Or, LNG import terminals may be located with electric power generation stations, allowing use of the cryogenic properties of LNG to help cool the power plant

natural gas vapor is burned for power production. In the U.S., LNG is converted back into natural gas for shipment to customers through the U.S. natural gas pipeline system.

To return LNG to a gaseous state, it is fed into a regasification facility. On arrival at the receiving terminal in its liquid state, LNG is pumped at atmospheric pressure first to a double-walled storage tank, similar to those used in the liquefaction plant where LNG is stored at atmospheric pressure until needed. At that time, LNG is then pumped at higher pressure through various receiving terminal components where it is warmed in a controlled environment. The LNG can be warmed by passage through pipes heated by direct-fired heaters, or pipes warmed by seawater, or through pipes that are in heated water. The revaporized natural gas is then regulated for pressure and enters the U.S. pipeline system as the methane used in homes and businesses. Residential and commercial consumers receive natural gas for daily use from local gas utilities or in the form of electricity.

Of great interest is the development of new LNG receiving terminals in the U.S. and North America as well as worldwide. Of all world regions, the U.S. and North America as a whole have been the most active with respect to receiving terminal development. Seven terminals are in operation (four existing, with expansions, and three new facilities, including an offshore LNG ship-based design), six are under

construction, 11 have been approved by regulatory bodies (including both onshore and offshore terminal designs), and more than 50 terminal projects are planned or have been proposed. This last figure compares with about 49 planned or proposed receiving terminal projects in the entire remainder of the world. Several factors account for the interest in developing terminals in North America, particularly the U.S. Most important of these is the size and competitiveness of the U.S. natural gas market and expectations that LNG will be an important part of the U.S. supply portfolio in the future. But LNG is also viewed to be an important, strategic part of the supply portfolios for Canada and Mexico as well, even though these countries have large and prolific domestic natural gas resources.

How Much Does LNG Cost?

Current estimates are that natural gas can be economically produced and delivered to the U.S. as LNG in a price range of about \$2.60-\$4.80 per million Btu (MMBtu) depending largely on terms established by producing countries for E&P investment and shipping distance and cost.²⁵ The current estimate is about 30 percent higher than the full value chain cost we estimated in 2002. The increase in LNG value chain cost is a reflection of general cost escalation in the global energy sector and the LNG industry, a response to strong demand for energy and higher energy prices and a consequence of competition for key inputs like materials and skilled labor. Within this overall picture, a number of gains continue to be made.

Exploration and production costs have been declining due to improved technologies such as 3-D (three-dimensional) seismic; drilling and completion of complex well architectures; and improved subsea facilities. 3-D seismic allows detailed complex imaging of rocks below the earth's surface, enabling exploration earth scientists to predict better where accumulations of natural gas might exist and contributing to higher success rates for new drilling. Drilling and completion of complex well architectures allow petroleum engineers to target more precisely natural gas accumulations and to optimize oil and gas reservoir recovery using multi-branched

²⁵ Estimates developed by CEE based on LNG industry and trade data.

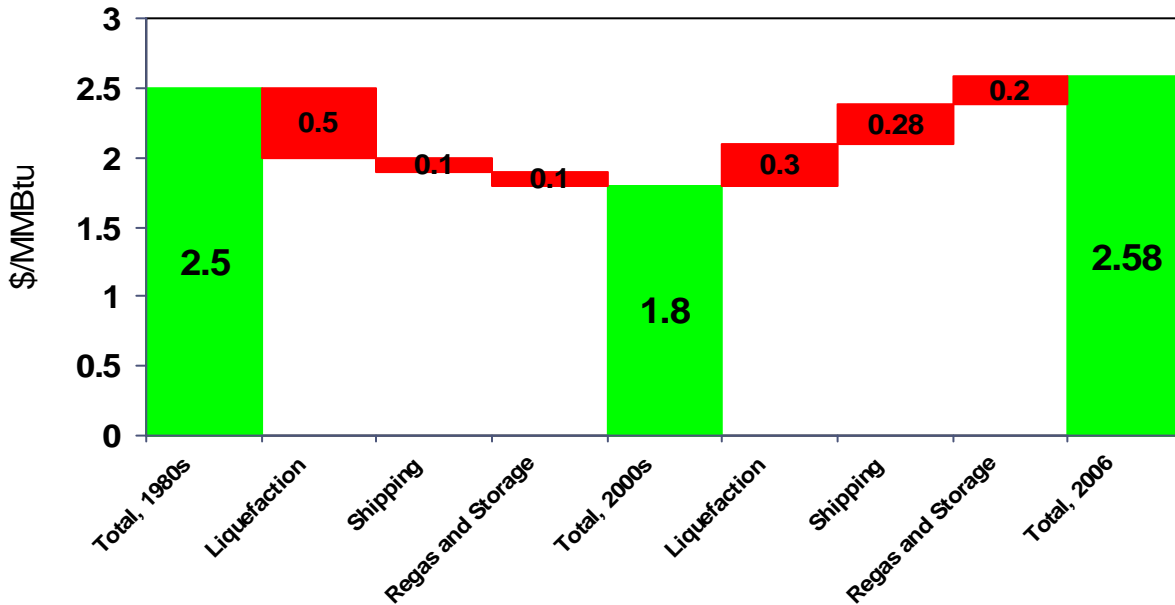
well architecture and “intelligent” completion systems. Improved sub-sea facilities allow companies to produce natural gas from deep below the surface of the ocean.

Further along the LNG value chain, technical innovations in LNG liquefaction and shipping are allowing more LNG projects to achieve commercial viability. Design efficiencies and technology improvements are contributing to improved project economics.

With respect to ship design, costs for ships that typically have been used—those capable of carrying about 120,000 cubic meters of LNG—have remained relatively stable. Most new ship orders are for larger, more expensive tankers that also can deliver larger volumes of LNG, thus improving “economies of scale”. New technologies are helping to reduce costs for ship operations. Propulsion systems that replace traditional steam turbine engines with smaller units that are more efficient will not only reduce fuel costs but also increase cargo carrying capacity. Enhanced tanker efficiencies—longer operating lives, improved safety technology and improved fuel efficiency—have lowered shipping costs substantially.

The introduction of new technologies and general growth in LNG trade should allow natural gas to play a larger role in meeting U.S. energy demand at a competitive price even though the fast-growing industry currently faces a stiffer cost structure. Today, natural gas from imported LNG competes vigorously with pipeline gas in the North American and European markets as well as with other fuels like oil derivatives and coal (for power generation). LNG also competes against other forms of energy like oil derivatives in Asian markets. This inter-fuel competition creates benefits of competitive pricing and cost savings for consumers while also ensuring access to cleaner burning natural gas. These competitive forces ultimately work against periodic cost escalation in a capital intensive industry like LNG and result in new capacity and new diversity of natural gas supplies.

Figure 10. LNG Value Chain Cost Structure



Is LNG a Safe Fuel?²⁶

LNG has been safely handled for many years. The industry is not without incidents, but it has maintained an enviable safety record, especially over the last 40 years. There are currently about 240 peakshaving and LNG storage facilities worldwide,²⁷ some operating since the mid-60s. The U.S. has the largest number of LNG facilities in the world. There are 113 active LNG facilities spread across the U.S. with a higher concentration of the facilities in the northeastern region (see map on page 9).

The need for additional natural gas supplies, including the reopening of existing LNG facilities at Cove Point, Maryland and Elba Island, Georgia, has focused public attention on the safety and security of LNG facilities. The safe and environmentally sound operation of these facilities, both ships and terminals, and the protection of

²⁶ A second CEE briefing paper, *LNG Safety and the Environment*, addresses comprehensively the worldwide safety and security record of the industry as well as the U.S. policy and regulatory safeguards. www.beg.utexas.edu/energyecon/lng.

²⁷ <http://www.shell-usgp.com/lngsashes.asp>.

these facilities from terrorist activities or other forms of accident or injury is a concern and responsibility shared by operators as well as federal, state and local jurisdictions across the U.S. Onshore LNG facilities are industrial sites and, as such, are subject to all rules, regulations and environmental standards imposed by the various jurisdictions. These same or similar concerns apply to natural gas storage and pipeline transportation and distribution and our daily use of natural gas.

A brief overview of the issues is presented here. The second CEE briefing paper *LNG Safety and the Environment* provides details on the LNG industry safety record and incidents.

What is the safety record of the LNG industry?



The Matthew enters Boston harbor.
Source: SUEZ LNG North America.

Overall, the LNG industry has an excellent safety record compared to refineries and other petrochemical plants. Worldwide, there are 23 LNG export (liquefaction) terminals, 58 import (regasification) terminals, and 224 LNG ships, altogether handling approximately 168 million metric tons of LNG. LNG has been safely delivered across the ocean for over 40 years.

In that time there have been over 45,000 LNG carrier voyages, covering more than 100 million miles, without major accidents or safety problems either in port or on the high seas.²⁸ The LNG industry has had to meet stringent standards set by countries such as the U.S., Japan, Australia, and the European nations.

According to the U.S. Department of Energy, over the life of the industry, eight marine incidents worldwide have resulted in spillage of LNG, with some hulls damaged due to cold fracture, but no cargo fires have occurred. Seven incidents not involving spillage were recorded, two from groundings, but with no significant

²⁸ Based on data from the Society for International Gas Tanker and Terminal Operators (SIGTTO). CEE is a noncontributory member of SIGTTO.

cargo loss; that is, repairs were quickly made and leaks were avoided. There have been no LNG shipboard fatalities.²⁹

Isolated accidents with fatalities occurred at several onshore facilities in the early years of the industry. More stringent operational and safety regulations have since been implemented.

Cleveland, Ohio, 1944

In 1939, the first commercial LNG peakshaving plant was built in West Virginia. In 1941, the East Ohio Gas Company built a second facility in Cleveland. The peakshaving plant 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. The tank failed shortly after it was placed in service allowing LNG to escape, forming a vapor cloud that filled the surrounding streets and storm sewer system. The natural gas in the vaporizing LNG pool ignited resulting in the deaths of 128 people in the adjoining residential area. The conclusion of the investigating body, the U.S. Bureau of Mines, was that the concept of liquefying and storing LNG was valid if "proper precautions were observed."³⁰ A recent report by the engineering consulting firm, PTL,³¹ concluded that had the Cleveland tank been built to current codes this accident would not have happened. In fact, LNG tanks properly constructed of nine percent nickel steel have never had a crack failure in the 35-year history since the Cleveland incident.

Staten Island, New York, February 1973

In February 1973, an industrial accident unrelated to the presence of LNG occurred at the Texas Eastern Transmission Company peakshaving plant on Staten Island.

²⁹ Juckett, Don, U.S. Department of Energy, *Properties of LNG*. LNG Workshop, MD, 2002.

³⁰ U.S. Bureau of Mines, *Report on the Investigation of the Fire at the Liquefaction, Storage, and Regasification Plant of the East Ohio Gas Co., Cleveland, Ohio, October 20, 1944*, February 1946.

³¹ Lewis, James P, Outtrim, Patricia A., Lewis, William W., and Perry, Lui Xin, PTL: *LNG, The Basics*, Report prepared for BP, May 2001.

In February 1972, the operators, suspecting a possible leak in the tank, took the facility out of service. Once the LNG tank was emptied, tears were found in the mylar lining. During the repairs, vapors associated with the cleaning process apparently ignited the mylar liner. The resultant fire caused the temperature in the tank to rise, generating enough pressure to dislodge a 6-inch thick concrete roof, which then fell on the workers in the tank killing 40 people.

The Fire Department of the City of New York report of July 1973³² determined the accident was clearly a construction accident and not an "LNG accident". In 1998, the New York Planning Board, while re-evaluating a moratorium on LNG facilities, concluded the following with respect to the Staten Island accident: "The government regulations and industry operating practices now in place would prevent a replication of this accident. The fire involved combustible construction materials and a tank design that are now prohibited. Although the exact causes may never be known, it is certain that LNG was not involved in the accident and the surrounding areas outside the facility were not exposed to risk."³³

Cove Point, Maryland, October 1979³⁴

Finally, in October 1979, an explosion occurred within an electrical substation at the Cove Point, MD receiving terminal. LNG leaked through an inadequately tightened LNG pump electrical penetration seal, vaporized, passed through 200 feet of underground electrical conduit, and entered the substation. Since natural gas was never expected in this building, there were no gas detectors installed in the building. The natural gas-air mixture was ignited by the normal arcing contacts of a circuit breaker resulting in an explosion. The explosion killed one operator in the building, seriously injured a second and caused about \$3 million in damages.

³² Fire Department of the City of New York, *Report of Texas Eastern LNG Tank Fatal Fire and Roof Collapse, February 10, 1973*, July 1973.

³³ New York Energy Planning Board, *Report on Issues Regarding the Existing New York Liquefied Natural Gas Moratorium*, November 1998.

³⁴ The content in this section is taken from CH-IV International Report *Safety History of International LNG Operations*, June 2002.

This was an isolated accident caused by a very specific set of circumstances. The National Transportation Safety Board³⁵ found that the Cove Point Terminal was designed and constructed in conformance with all appropriate regulations and codes. However, as a result of this accident, three major design code changes were made at the Cove Point facility prior to reopening. Those changes are applicable industry-wide.

How will industry ensure safety and security of critical facilities and shipping activities?

The experience of the LNG industry demonstrates that normal operating hazards are manageable. No death or serious accident involving an LNG facility has occurred in the United States since the Cove Point accident. West and Mannan of Texas A&M University concluded in their paper *LNG Safety Practice & Regulation: From 1944 East Ohio Tragedy to Today's Safety Record* that "The worldwide LNG industry has compiled an enviable safety record based on the diligent industry safety analysis and the development of appropriate industrial safety regulations and standards."³⁶

The over 40 years of experience without significant incidents caused by LNG at liquefaction facilities, on LNG carriers, and at regasification facilities reflects the industry's commitment to safety and safe engineering and operations.

The terrorist attacks on September 11, 2001 raised critical new security risks and exposure for consideration, not just for the LNG industry but for all major industrial activities and infrastructure facilities in the U.S. and worldwide. The LNG industry employs robust containment systems, proven operational procedures and many other safeguards. During the last several decades, technologies have advanced rapidly to ensure safer containment of LNG both during shipping and at onshore facilities. Since 2001, governments and industry have strengthened security

³⁵ National Transportation Safety Board Report, *Columbia LNG Corporation Explosion and Fire; Cove Point, MD; October 6, 1979*, NTSB-PAR-80-2, April 16, 1980.

³⁶ West, H.H. and Mannan, M.S. Texas A&M University: *LNG Safety Practice & Regulation: From 1944 East Ohio Tragedy to Today's Safety Record*, AIChE meeting, April 2001.

measures for all critical infrastructure including LNG receiving terminals, ships, liquefaction facilities and export and import port and harbor operations.

The second CEE briefing paper, *LNG Safety and Security*³⁷, provides details on and evaluates safety and security measures that are currently in use and under consideration, actions by industry and government to ensure safety and security, and technologies under development by industry that will reduce the effect LNG facilities may have on local communities. The major conclusion reached in that briefing paper is that the LNG industry has an excellent safety record. This strong safety record is a result of several factors. First, the industry has technically and operationally evolved to ensure safe and secure operations. Technical and operational advances include everything from the engineering that underlies LNG facilities to operational procedures to technical competency of personnel. Second, the physical and chemical properties of LNG are such that risks and hazards are well understood and incorporated into technology and operations.

Third the standards, codes and regulations that apply to the LNG industry further ensure safety. While we in the U.S. have our own regulatory requirements for LNG operators, we have benefited from the evolving international standards and codes that regulate the industry. Safety in the LNG industry is ensured by four elements that provide multiple layers of protection both for the safety of LNG industry workers and the safety of communities that surround LNG facilities. **Primary containment** is the first and most important requirement for containing the LNG product. This first layer of protection involves the use of appropriate materials for LNG facilities as well as proper engineering design of storage tanks onshore and on LNG ships and elsewhere. **Secondary containment** ensures that if leaks or spills occur at the onshore LNG facility, the LNG can be fully contained and isolated from the public. **Safeguard systems** offer a third layer of protection. The goal is to minimize the frequency and size of LNG releases both onshore and offshore and prevent harm from potential associated hazards, such as fire. For this level of safety protection, LNG operations use technologies such as high level alarms and

³⁷ www.beg.utexas.edu/energyecon/lng

multiple back-up safety systems, which include Emergency Shutdown (ESD) systems. ESD systems can identify problems and shut off operations in the event certain specified fault conditions or equipment failures occur, and which are designed to prevent or limit significantly the amount of LNG and LNG vapor that could be released. Fire and gas detection and fire fighting systems all combine to limit effects if there is a release. The LNG facility or ship operator then takes action by establishing necessary operating procedures, training, emergency response systems and regular maintenance to protect people, property and the environment from any release. Finally, LNG facility designs are required by regulation to maintain **separation distances** to separate land-based facilities from communities and other public areas. Moving safety zones are also required around LNG ships to reduce the chance of collisions with other ships.

What are the roles of federal, state and local government agencies and their jurisdictions?

The United States Coast Guard (USCG)³⁸ is responsible for assuring the safety of all marine operations at the LNG terminals and on tankers in U.S. coastal waters. The Department of Transportation (DOT)³⁹ regulates LNG tanker operations. The U.S. Federal Energy Regulatory Commission (FERC)⁴⁰ is responsible for permitting new onshore LNG regasification terminals in the U.S. and ensuring safety at these facilities through inspections and other forms of oversight. In order to maintain a competitive environment for supply and pricing, the Energy Policy Act of 2005 codified the FERC's jurisdiction. Further, FERC has fostered experimentation with market-based approaches for both siting and economic and commercial aspects of LNG import terminal operations. The FERC's jurisdiction includes authority for permitting new long distance natural gas pipelines to be developed in the U.S., as well as for safe and environmentally sound operation of the overall "interstate" natural gas pipeline system (pipelines that cross state boundaries). The U.S.

³⁸ United States Coast Guard (USCG): <http://www.uscg.mil/uscg.shtm>.

³⁹ U.S. Department of Transportation (DOT): <http://www.dot.gov/>.

⁴⁰ U.S. Federal Energy Regulatory Commission (FERC): <http://www.ferc.fed.us/>.

Environmental Protection Agency⁴¹ and state environmental agencies establish air and water standards with which the LNG industry must comply. Other federal agencies involved in environmental protection and safety protection include the U.S. Fish and Wildlife Service,⁴² U.S. Army Corps of Engineers⁴³ (for coastal facilities and wetlands), U.S. Minerals Management Service⁴⁴ (for offshore activities) and National Oceanic and Atmospheric Administration⁴⁵ (for any activities near marine sanctuaries). The U.S. Department of Energy – Office of Fossil Energy⁴⁶ helps to coordinate across federal agencies that have regulatory and policy authority for LNG.

State, county and local (municipal) agencies play roles to ensure safe and environmentally sound construction and operation of LNG industry facilities. The LNG industry is responsible for safe operations and facility security in cooperation with local police and fire departments.

How can citizens interact with industry and government to learn more?

The briefing papers of the CEE mentioned above and the online *Guide to LNG in North America* provides extensive information to public audiences interested in U.S. energy trends and energy security; LNG industry and market developments; LNG safety, security and environmental considerations; and related regulatory and policy issues. The CEE web site provides links to industry, government and public information sources. Companies with LNG operations maintain active public information offices, as do the federal agencies charged with regulatory and policy oversight.

⁴¹ U.S. Environmental Protection Agency (EPA): <http://www.epa.gov/>.

⁴² U.S. Fish and Wildlife Service: <http://www.fws.gov/>.

⁴³ U.S. Army Corps of Engineers: <http://www.usace.army.mil/>.

⁴⁴ U.S. Minerals Management Service: <http://www.mms.gov/>.

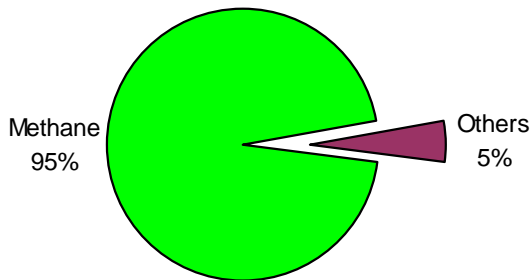
⁴⁵ U.S. National Oceanic and Atmospheric Administration: <http://www.noaa.gov/>.

⁴⁶ U.S. Department of Energy – Office of Fossil Energy: <http://www.fe.doe.gov/>.

Appendix 1: Other Fuel Terminologies

LNG is often confused with other terminologies such as Natural Gas Liquids (NGLs), Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG), Gas-to-Liquids (GTL).

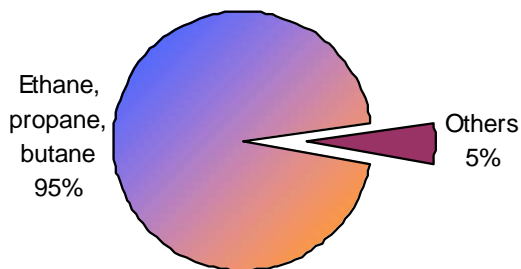
LNG Composition



15% when mixed with air.

LNG is made up of mostly methane as shown in the figure below. The liquefaction process requires the removal of the non-methane components like carbon dioxide, water, butane, pentane and heavier components from the produced natural gas. LNG is odorless, colorless, non-corrosive, and non-toxic. When vaporized it burns only in concentrations of 5% to

NGL Composition



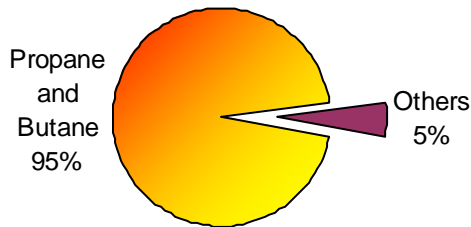
the gas to meet the pipeline specification. LNG shipped to the U.S. generally must

Natural gas liquids (NGLs) are made up mostly of molecules that are heavier than methane. These molecules liquefy more readily than methane. NGLs are the hydrocarbon molecules that begin with ethane and increase in size as additional carbon atoms are added. In the U.S. NGLs are typically extracted during the processing of natural gas for industrial uses and in order for

meet pipeline heating value specifications, that is, it must contain only moderate quantities of NGLs. If LNG is shipped with NGLs, the NGLs must be removed upon receipt or blended with lean gas or nitrogen before the natural gas can enter the U.S. pipeline system. Few locations (only the Lake Charles, Louisiana receiving terminal in the U.S., for instance) are near processing facilities that can take LNG cargos that are "rich" with NGLs.

However, the LNG heat content specification in Japan, Korea and other Asian countries is higher than in the U.S. or Europe. For these countries, NGLs are left in the LNG and, in some circumstances, LPG is added to the vaporized LNG at the receiving terminal to increase the heat content.

LPG Composition



LNG is not the same as **Liquefied Petroleum Gas (LPG)**. LPG is often incorrectly called propane. In fact, LPG is predominantly a mixture of propane and butane in a liquid state at room temperatures when under moderate pressures of less than 200 psig (pounds per square inch gauge (psig) is a common measure of pressure). The common interchanging of the terms LPG

and propane is explained by the fact that in the U.S. and Canada LPG consists primarily of propane. In many European countries, however, the propane content in LPG can be lower than 50 per cent.

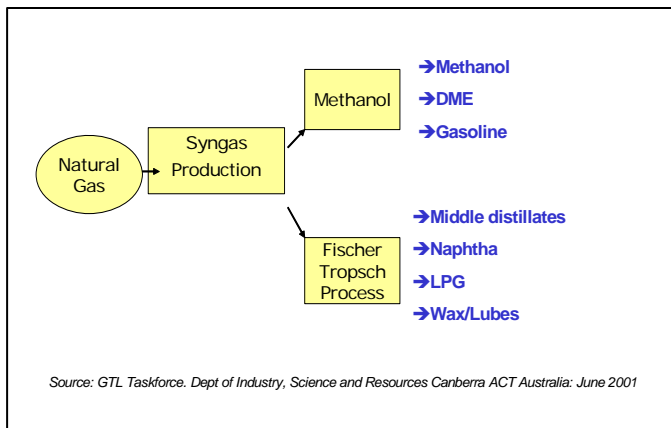
In Europe, LPG has been used as fuel in light duty vehicles for many years. Many petrol or gasoline stations have LPG pumps as well as pumps to distribute gasoline.

LPG is highly flammable and must therefore be stored away from sources of ignition and in a well-ventilated area, so that any leak can disperse safely. A special chemical, mercaptan, is added to give LPG its distinctive, unpleasant smell so that a leak can be detected. The concentration of the chemical is such that an LPG leak can be smelled when the concentration is well below the lower limit of flammability.

Worldwide, LPG is used heavily for domestic purposes such as cooking and heating water.



LNG is not the same as **compressed natural gas (CNG)**. CNG is natural gas that is pressurized and stored in welding bottle-like tanks at pressures up to 3,600 psig. Typically, CNG is the same composition as pipeline quality natural gas, i.e., the gas has been dehydrated (water removed) and all other elements reduced to traces so that corrosion is prevented. CNG is often used as a vehicle transportation fuel and is delivered to an engine as low-pressure vapor (up to 300 psig). CNG is often misrepresented as the only form of natural gas that can be used as vehicle fuel. However, LPG and LNG are also common transport fuels.



LNG is also not synonymous with **Gas-to-Liquids (GTL)**. GTL refers to the conversion of natural gas to products like methanol, dimethyl ether (DME), middle distillates (diesel and jet fuel), specialty chemicals and waxes. While the technology for producing each of these distinct products was

developed years ago, only methanol is currently in widespread commercial production. DME and specialty lubricants and waxes from natural gas are in limited commercial production. Middle distillate can be directly substituted for diesel fuel in existing compression ignition engines. The advantage of GTL diesel is that it contains almost no sulfur or aromatics and is well suited to meet current and proposed cleaner fuel requirements of developed economies.

Appendix 2: Conversion Table

Conversion Units	<i>Source: BP Statistical Review of U.S. Energy June 2002</i>					
Natural gas (NG) and LNG	To: 1 billion cubic meters NG	1 billion cubic feet NG	1 million tons oil equivalent	1 million tons LNG	1 trillion British thermal units (Btus)	1 million barrels oil equivalent (Boe)
From:	Multiply by:					
1 billion cubic meters NG	1	35.3	0.90	0.73	36	6.29
1 billion cubic feet NG	0.028	1	0.026	0.021	1.03	0.18
1 million tons oil equivalent	1.111	39.2	1	0.81	40.4	7.33
1 million tons LNG	1.38	48.7	1.23	1	52.0	8.68
1 trillion British thermal units (Btus)	0.028	0.98	0.025	0.02	1	0.17
1 million barrels oil equivalent (Boe)	0.16	5.61	0.14	0.12	5.8	1

Example: To convert **FROM** 1 million tons of LNG **TO** billion cubic feet of natural gas multiply by 48.7 (100 million tons of **LNG** equals roughly 5,000 billion cubic feet of **natural gas**).

Appendix 3: Glossary of Terms^{47,48}

TERM	DEFINITION
British Thermal Unit (BTU)	A Btu is the amount of heat required to change the temperature of one pound of water one degree Fahrenheit.
Cryogenic	Refers to low temperature and low temperature technology. There is no precise temperature for an upper boundary but -100°F is often used.
Density	A description of oil by some measurement of its volume to weight ratio. The industry usually relies on two expressions of oil's volume-weight relationship-specific gravity and API degrees. The larger a specific gravity number and the smaller an API number, the denser the oil.
Fahrenheit degrees (F)	A temperature scale according to which water boils at 212 and freezes at 32 Fahrenheit degrees. Convert to Centigrade degrees (C) by the following formula: $(F-32)/1.8 = C$.
Impoundment	Spill control for tank content designed to limit the liquid travel in case of release. May also refer to spill control for LNG piping or transfer operations.
Middle distillates	Products heavier than motor gasoline/naphtha and lighter than residual fuel oil. This range includes heating oil, diesel, kerosene, and jet kero.
Mole Percent	Mole is a short form of molecular weight. Mole fraction or mole percent is the number of moles of a component of a mixture divided by the total number of moles in the mixture.
MTPA	Million Tonnes per Annum. Tonnes or Metric Ton is approximately 2.47 cubic meter of LNG.
MW	Molecular Weight
Peakshaving LNG Facility	A facility for both storing and vaporizing LNG intended to operate on an intermittent basis to meet relatively short term peak gas demands. A peakshaving plant may also have liquefaction capacity, which is usually quite small compared to vaporization capacity at such facility.
Stranded Gas	Gas is considered stranded when it is not near its customer and a pipeline is not economically justified.
Sweetening	Processing to remove sulfur. Hydrodesulfurization, for instance, can produce sweet catfeed. Caustic washing can sweeten sour natural gasolines to make them suitable for motor gasoline blending.

⁴⁷ Phillips Petroleum Company, <http://www.phillips66.com/lng/LNGglossary.htm>.

⁴⁸ Poten & Partners, http://www.poten.com/?URL=ut_glossary.asp.

