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INTRODUCTION TO LNG

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

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Table of Contents

INTRODUCTION TO LNG[1]

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. This paper introduces the reader to LNG and briefly touches on many of the topics relating to the LNG industry. The second and third papers, ***LNG Safety and the Environment*** and ***U.S. Supply-Demand Balances and Energy Security: A Role for LNG?****,* will follow in spring 2003. All of these reports, with supplemental information, will be compiled in a complete 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. According to the U.S. Energy Information Administration (EIA), the U.S. could face a gap in supply of natural gas of about five trillion cubic feet (Tcf) by 2020. Consequently, increased imports of natural gas will be required to meet future shortfalls. Canada may not be able to sustain increasing volumes of exports to the U.S. due to Canada's own increasing demand for natural gas. The EIA expects LNG imports to reach 0.8 Tcf a year by 2020, or about three percent of our total consumption. The demand for LNG is expected to grow.

To make LNG available for use in the U.S., energy companies must invest in the LNG value chain, which is 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 in a price range of about $2.50 - $3.50 per million Btu (MMBtu) at Henry Hub in Louisiana, depending largely on shipping cost.

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 17 LNG export (liquefaction) terminals, 40 import (regasification) terminals, and 136 LNG ships altogether handling approximately 120 million metric tons of LNG every year. There are currently about 200 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. There are 113 active LNG facilities spread across the U.S. with a higher concentration of the facilities in the northeastern region.

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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 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, 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.

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 the Environment**,* will deal with the safety and security aspects of LNG operations in more detail. A third paper, ***U.S. Supply-Demand Balances and Energy Security: A Role for LNG?*** will provide 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, will be included in a complete 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 gas[2] companies store gas for peak demand that cannot be met via their typical pipeline source. This can occur during

[2] We use the term "gas" as shorthand for "natural gas." In the U.S., we often refer to gasoline, the most heavily used vehicle transportation fuel, as "gas," but gasoline is manufactured from crude oil, a different fossil fuel that is often found together with natural gas in underground reservoirs.

the winter heating season when cold fronts move through or when more natural gas is needed to generate electric power for air conditioning in the summer months. The utility companies liquefy pipeline gas when it is abundant and available at off-peak prices, or they purchase LNG from import terminals supplied from overseas liquefaction facilities. When gas demand increases, the stored LNG is converted from its liquefied state back to its gaseous state, to supplement the utility's 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 it 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 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 (CH_4). 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 pipeline grid but it could grow in the United States if LNG niche markets, such as LNG 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^{o}F (-161^{o}C) and at atmospheric pressure. Liquefaction reduces the volume by approximately 600 times[3] thus making it more economical to transport between continents in specially designed ocean vessels, whereas traditional pipeline transportation systems would be less economically attractive and could be technically or politically infeasible. 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 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 and Regasification,** to convert the LNG stored in specially made storage tanks, from the liquefied phase to the gaseous phase, ready to be moved to the final destination through the natural gas pipeline system.

Liquefaction also 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 US, which is a region lacking in underground storage, LNG is a critical part of the region's supply during cold snaps. In regions where pipeline capacity from supply areas can be very

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[3] 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 1.

expensive and use is highly seasonal, liquefaction and storage of LNG occurs during off-peak periods in order to reduce expensive pipeline capacity commitments during peak periods.[4]

Does the U.S. Need LNG?[5]

The demand for natural gas in the U.S. was boosted in the 1980s in part by the desire to diversify energy resources in the wake of global oil shocks[6]. Such demand has continued due to the clear environmental advantages of natural gas over other fossil fuels and its superior thermal efficiency when used in power generation. According to the U.S. Energy Information Administration (U.S. EIA), natural gas production in the U.S. is predicted to grow from 19.1 trillion cubic feet (Tcf)[7] in 2000 to 28.5 Tcf in 2020.[8] The total U.S. demand for natural gas is expected to rise from 22.8 Tcf in 2000 to about 33.8 Tcf by 2020 (adjusted for forecasted gains in energy efficiency and conservation). These projections suggest that the U.S. could face a gap in supply of about five Tcf by 2020. 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 reserves are constantly being discovered, but with advanced recovery technologies these fields are quickly depleted. Consequently, increased imports of natural gas will be required to meet future shortfalls.

Pipeline imports of natural gas from Canada already make up about 15 percent of total U.S. consumption. Canada may not be able to sustain increasing volumes of exports to the U.S. due to Canada's own increasing demand for natural gas and the maturation of the Western Canada Sedimentary Basin. Recent trends show that due to decreasing initial gas well productivities and high production decline rates,[9]

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[4] EIA: *U.S. LNG Markets and Uses*. November 2002. http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2002/lng2002/lngnov6.htm

[5] A full analysis of the U.S. Supply and Demand Balance will be presented in the third CEE briefing paper.

[6] 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.

[7] EIA: Short-Term Energy Outlook – September 2002.

[8] EIA: Annual Energy Outlook 2002 with Projections to 2020: http://www.eia.doe.gov.

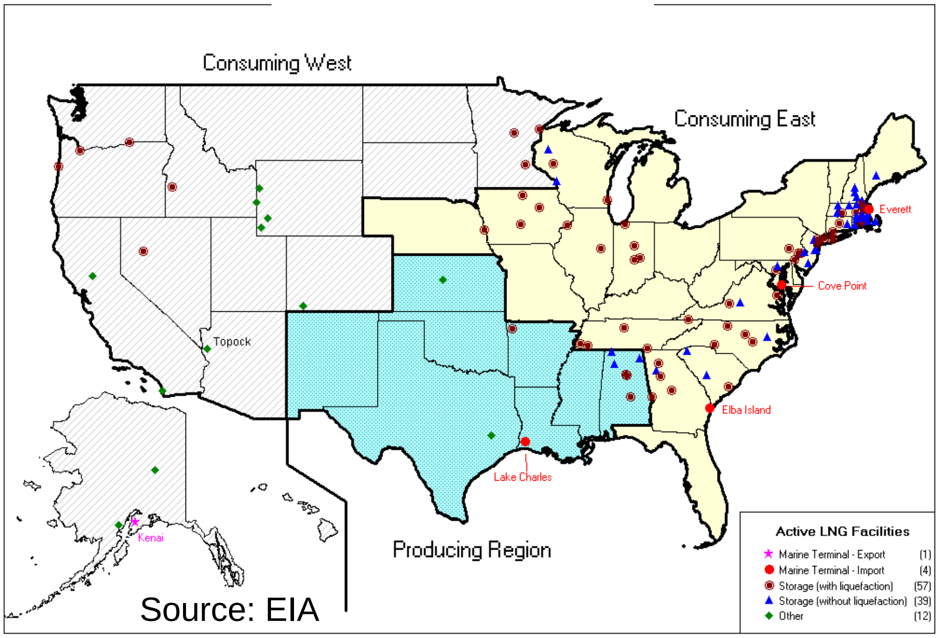
[9] Delay, Jim, Alberta Energy & Utilities Board: Alberta Natural Gas Outlook, Calgary, October 2002.

higher levels of drilling activity are necessary to maintain current production levels. Alternative sources of domestic natural gas supply include building a pipeline to provide natural gas from the North Slope of Alaska to the lower 48 U.S. states; developing onshore natural gas resources in the Rocky Mountain region, developing offshore resources in the Pacific, the Atlantic and the Eastern Gulf of Mexico Outer Continental Shelf (OCS). Natural gas from Alaska would not be competitive in the lower 48 states (and Canada) until natural gas prices increase enough to make the production and transportation system economically viable. Additionally, a gap in supply will remain even after the delivery of Alaskan gas commences, as access to much of the offshore resources in the eastern Gulf of Mexico and the onshore Rocky Mountain region is limited or prevented by federal and state laws and regulations.[10]

Currently, LNG imports account for less than one percent of the total U.S. consumption of natural gas. There are at least 113 active LNG facilities in the United States, including marine terminals, storage facilities, and operations involved in niche markets such as vehicular fuel as shown in the figure below. Most of these facilities were constructed between 1965 and 1975 and were dedicated to meeting the storage needs of local utilities. Approximately 55 local utilities own and operate LNG plants as part of their distribution networks.[11]

[10] EIA: Mid-Term Natural Gas Supply: Analysis of Federal Access Restrictions: http://www.eia.doe.gov/oiaf/servicerpt/natgas/chapter2.html - December 2001.
[11] EIA: *U.S. LNG Markets and Uses*. November 2002.

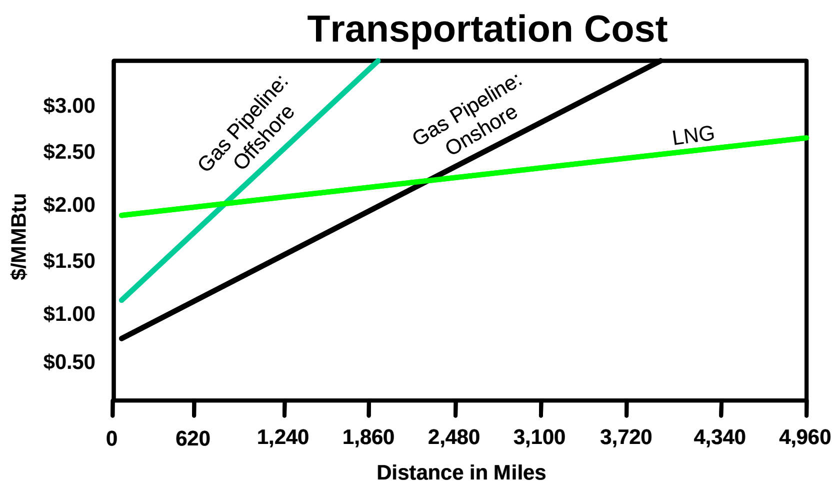
U.S. Liquefied Natural Gas Facilities



The U.S. EIA expects LNG imports to reach 0.8 Tcf a year by 2020, or about three percent of our total consumption. Although many factors can alter this outlook, the demand for LNG is expected to grow.

Is LNG a Competitive Source of Natural Gas?

There are large reserves of natural gas in areas for which there is no significant market. 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 is liquefied at these locations for shipping to areas where usage of natural gas exceeds indigenous supply. Such markets include Japan, Taiwan, Korea, 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. Liquefying natural gas and shipping it 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.[12]



Source: Institute of Gas Technology.

LNG development is especially important for countries like Nigeria and Angola. In these countries, most of the natural gas that is produced with crude oil is flared because there are few alternatives for usage or disposal of the excess gas.

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. It began operation in 1917. The first commercial liquefaction plant was built in Cleveland, Ohio, in 1941.[13] 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, 7000 Bbl aluminum prismatic tanks with balsa wood supports and insulation of plywood and urethane, carried an LNG cargo from Lake Charles, Louisiana to

[12] In this chart, 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 chart reflects the competition between natural gas transported in pipelines and natural gas transported as LNG.
[13] Platts: http://www.platts.com/features/lng/trading.shtml.

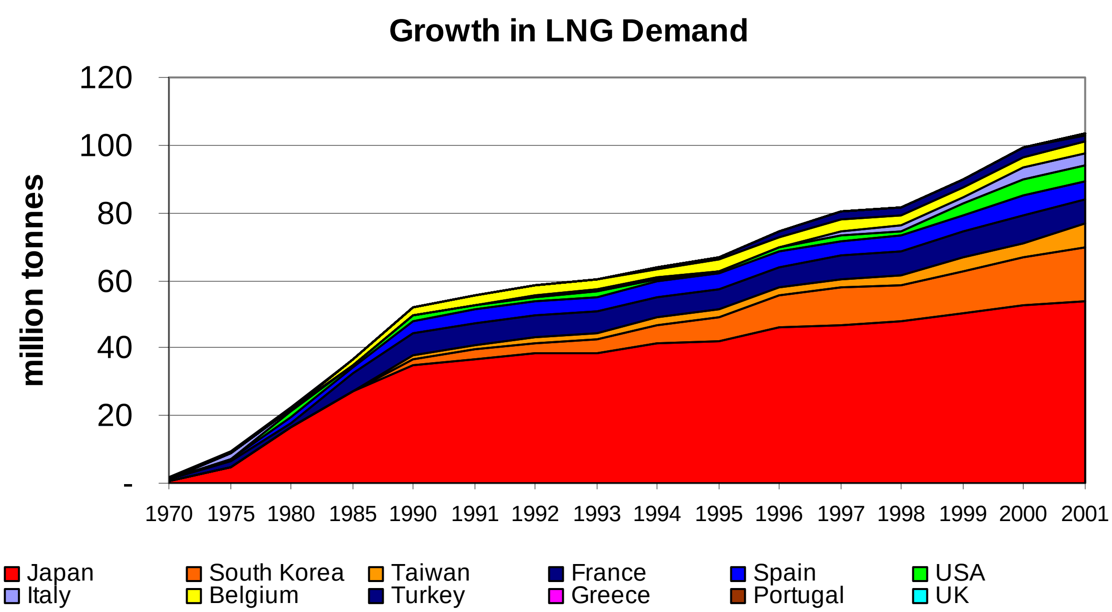
Canvey Island, United Kingdom. This event demonstrated that large quantities of liquefied natural gas could be transported safely across the ocean.

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 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 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 Tractebel 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 the southern portions 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.

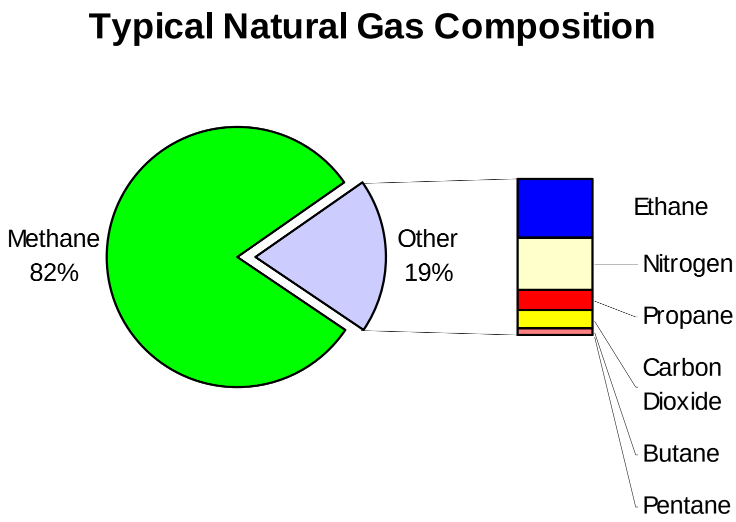


Source: Cedigaz, BP Statistical Review of World Energy June 2002

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 are being 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.

Composition of Natural Gas and LNG

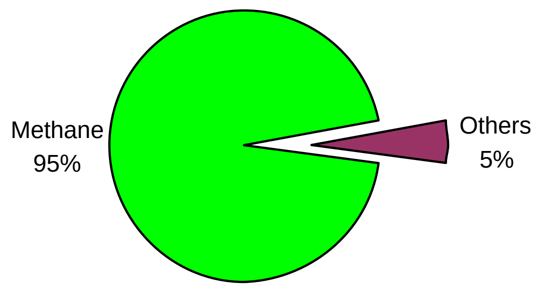
Natural gas is composed primarily of methane, but may also contain ethane, propane and heavier hydrocarbons. Small quantities of nitrogen, oxygen, carbon



dioxide, sulfur compounds, and water may also be found in natural gas. The figure above provides a typical natural gas composition.[14] The liquefaction process requires the 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^{O}F). As a result, LNG is typically made up mostly of methane as shown in the figure below.

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

Typical LNG Composition



Examples of LNG composition are shown below.

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 2 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

LNG Value Chain

Sources: BG, ALNG, CMS

Exploration and Production

According to World Oil, for the year 2001, worldwide proven reserves of natural gas were 5919 trillion cubic feet (Tcf), an increase of 8.4 percent over year 2000, and more reserves of natural gas continue to be discovered.[15] Much of this natural gas is stranded a long way from market, in countries that do not need large quantities of additional energy. The U.S. natural gas reserves increased by 3.4 percent, to 183 Tcf, between 2000 and 2001.[16] The leading countries producing natural gas and selling it to world markets in the form of LNG are Algeria, Indonesia and Qatar. Many other countries play smaller but significant and growing roles as natural gas producers and LNG exporters, such as Australia, Nigeria and Trinidad & Tobago. Countries like Angola and Venezuela are striving to reach their full potential in the global LNG marketplace, and countries like Saudi Arabia, Egypt and Iran, who have vast reserves of natural gas, could also participate as LNG exporters.

[15] World Oil, *World Trends*, August 2002.
[16] EIA: *2001 Annual Report, U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves*. Advance Summary, September 2002.
http://www.eia.doe.gov/pub/oil_gas/natural_gas/data_publications/advanced_summary_2001/adsum2001.pdf

LNG Liquefaction


Source: ALNG

Feed gas to the liquefaction plant comes from the production field. The contaminants found in produced natural gas are removed to avoid freezing up and damaging equipment when the gas is cooled to LNG temperature (-256^{o}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"). The natural gas is liquefied for shipping at a temperature of approximately -256^{o}F. By liquefying the gas, its volume is reduced by a factor of 600, which means that LNG at -256^{o}F uses 1/600th of the space required for a comparable amount of gas at room temperature and atmospheric pressure.

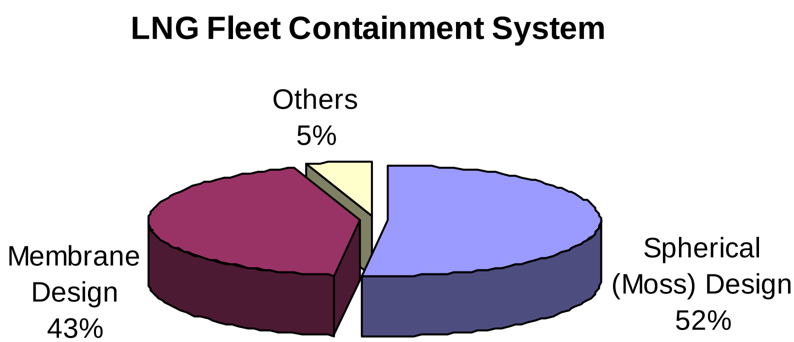
LNG is a cryogenic liquid. The term "cryogenic" means low temperature, generally below -100^{o}F. LNG is clear liquid, with a density of about 45 percent the density of water.

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% nickel steel, aluminum and pre-stressed concrete. The outer tank is generally made of carbon steel or pre-stressed concrete.

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 -256ºF. Three types of cargo containment systems have evolved as modern standards. These are:

- The spherical (Moss) design
- The membrane design
- The structural prismatic design



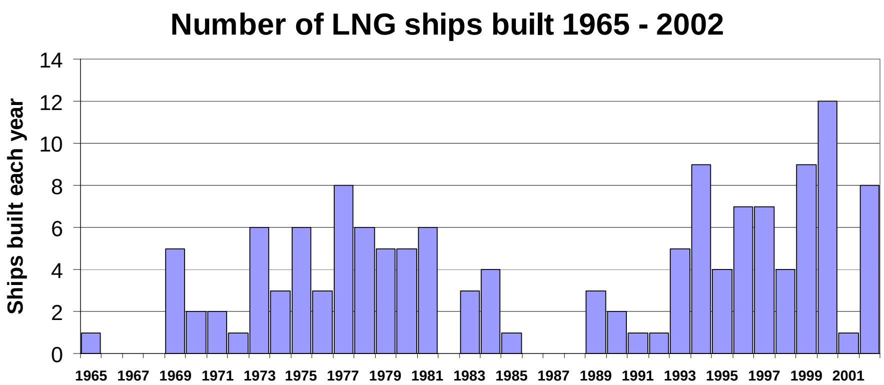
Source: LNGOneWorld

The figure above shows that currently most of the LNG ships use spherical (Moss) tanks, and they are easily identifiable as LNG ships because the top half of the tanks are visible above the deck. The typical LNG carrier can transport about 125,000 - 138,000 cubic meters of LNG,[17] 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. This ship size is similar to that of an aircraft carrier but significantly smaller than that of a Very Large Crude *oil* Carrier (VLCC). LNG tankers are generally less

[17] Typically, LNG ship size is designated by cubic meters of liquid capacity.

polluting than other shipping vessels because they burn natural gas in addition to fuel oil as a fuel source for propulsion.

The LNG shipping market is expanding. According to LNGOneWorld,[18] as of December 2002, there were 136 existing tankers, with 57 on order. Twelve new



Source: LNGOneWorld

LNG tankers were ordered in 2002 of which eight tankers have been delivered. About 20 percent of the fleet is less than five years old. The LNG tanker fleet size is estimated to continue to grow to 193 tankers by 2006.

Storage and Regasification

Source: CMS

To return LNG to a gaseous state, it is fed into a regasification plant. On arrival at the receiving terminal in its liquid state, LNG is pumped first to a double-walled storage tank, similar to those used in the liquefaction plant, at atmospheric pressure, then pumped at high pressure through various terminal components where it is warmed in a controlled environment. The LNG is warmed by passing it through pipes heated by direct-fired heaters, seawater or through pipes that are in heated water. The vaporized gas is then

[18]LNGOneWorld: http://www.lngoneworld.com/LNGV1.nsf/Members/Index.html.

regulated for pressure and enters the U.S. pipeline system as natural gas. Finally, residential and commercial consumers receive natural gas for daily use from local gas utilities or in the form of electricity.

How Much Does LNG Cost?

One major reason for the resurgence of interest in LNG in the U.S. is that costs have come down significantly during the past several years. Natural gas can be economically produced and delivered to the U.S. as LNG in a price range of about $2.50 - $3.50 per million Btu (MMBtu) depending largely on shipping cost.

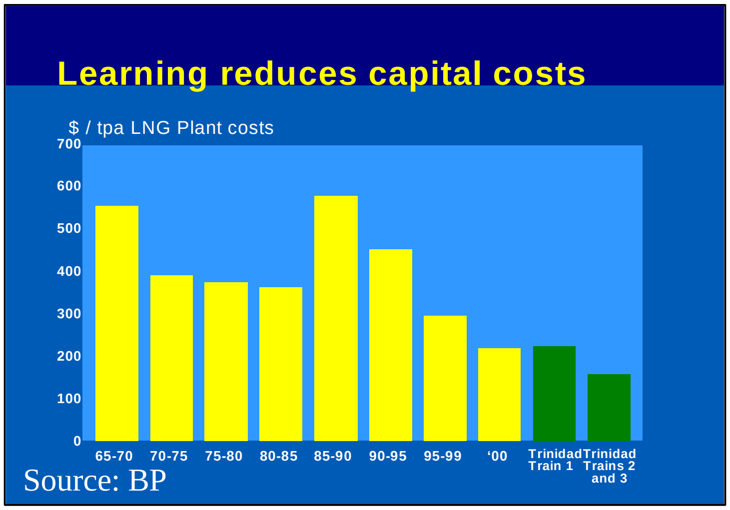
LNG Value Chain

EXPLORATION & PRODUCTION	LIQUEFACTION	SHIPPING	REGASIFICATION & STORAGE
\$0.5-\$1.0/MMBtu	\$0.8 - \$1.20/MMBtu	\$0.4 - \$1.0/MMBtu	\$0.3-\$0.5/MMBtu

Sources: BG, ALNG, CMS

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. Drilling and completion of complex well architectures allow petroleum engineers to target more precisely these accumulations and to maximize oil and gas reservoir recovery using multi-branched well architecture and intelligent completion systems. Improved sub-sea facilities allow companies to produce natural gas from deep below the surface of the ocean.

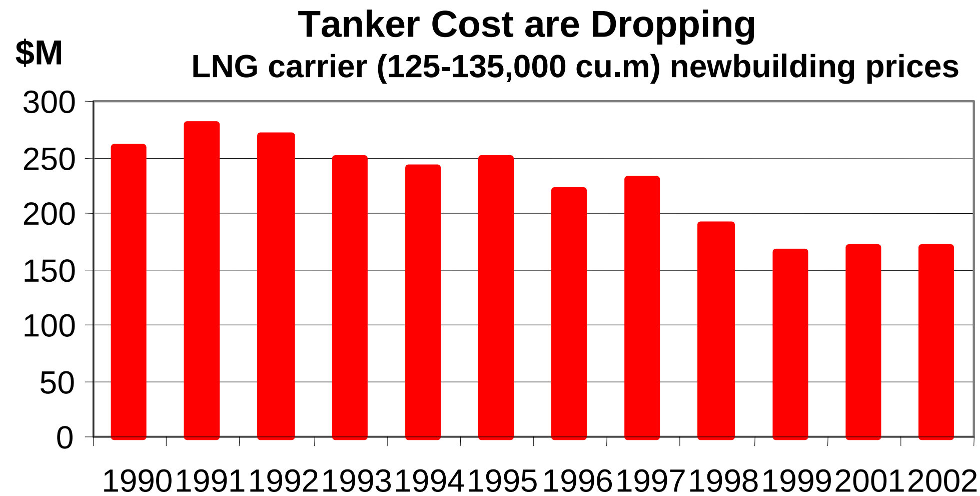
Further along the LNG value chain, technical innovations have also reduced the costs of LNG liquefaction and shipping, allowing more LNG projects to achieve commercial viability. For example, liquefaction costs have been lowered by as much as 35 percent because of the introduction of competing technologies and



economies of scale. Design efficiencies and technology improvements have all contributed to improved project economics. BP's Trinidad LNG Train 1, completed in June 1999, set a new benchmark for LNG unit capital cost at less than $200/ton[19] of annual plant capacity, as shown in the figure above. Trinidad Atlantic Train 2 was completed in August 2002, two months ahead of schedule and Train 3, currently under construction is scheduled to come on stream second quarter of 2003. The capital cost of Trains 2 and 3 is expected to be about $165/ton of capacity.

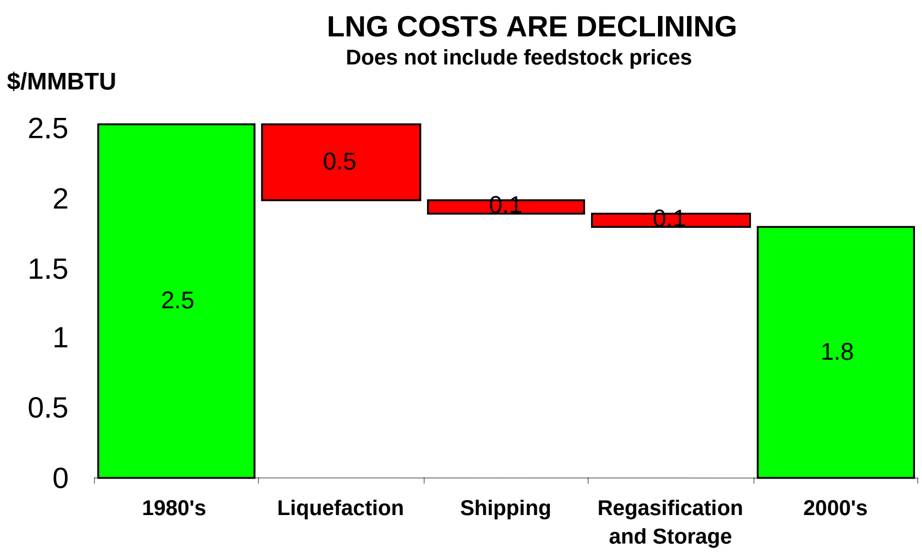
In ship design, new technologies are also helping to reduce costs. New propulsion systems are aimed to replace the traditional steam turbine engines with smaller units that are more efficient which will not only reduce fuel costs but will also increase cargo carrying capacity. Enhanced tanker efficiencies – longer operating lives, improved safety technology and improved fuel efficiency – have lowered shipping costs substantially. Shipyard expansions in the Far East and increased competition among shipbuilders have lowered LNG tanker costs by 40 percent from their peak.

[19] Williams, Bob; *Trinidad and Tobago LNG follows initial success with aggressive expansion plans*, Oil & Gas Journal, March 11, 2002. A "train" is typical terminology for LNG liquefaction plants, which are often added as separate units as a facility grows.



Source: LNGOneWorld 2001©

Competition among builders also is driving down costs for new regasification plants. Regasification costs have fallen about 18 percent.[20] The result of all these improvements is that the overall cost of LNG delivery has been reduced by almost 30 percent during the last 20 years.



Sources: El Paso

[20] Harmon, Harvey, Vice President, El Paso Global LNG, *The Dawn of New Golden Age for LNG*, IAEE Houston Meeting, February 2002.

The decline in costs and the general growth in LNG trade should allow natural gas to play an increasingly larger role in meeting U.S. energy demand. Today, LNG competes with pipeline gas in the North American and European markets, creating the benefits of competitive pricing for consumers, and it competes against other forms of energy like oil in Asian markets.

Is LNG a Safe Fuel?[21]

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 200 peakshaving and LNG storage facilities worldwide,[22] 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 6).

The need for additional natural gas supplies, including the reopening of existing LNG facilities at Cove Point, MD and Elba Island, GA, 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 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* will provide details on the LNG industry safety record and incidents.

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[21] A second briefing paper, *LNG Safety and the Environment*, will address comprehensively the worldwide safety and security record of the industry as well as the U.S. policy and regulatory safeguards.

[22] CH-IV International: *Safety History of International LNG Operations*, June 2002.

What is the safety record of the LNG industry?

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

Overall, the LNG industry has an excellent safety record compared to refineries and other petrochemical plants. Worldwide, there are 17 LNG export (liquefaction) terminals, 40 import (regasification) terminals, and 136 LNG ships, altogether handling approximately 120 million metric tons of LNG every year. LNG has been safely delivered across the ocean for over 40 years. In that time there have been over 33,000 LNG carrier voyages, covering more than 60 million miles, without major accidents or safety problems either in port or on the high seas. LNG carriers frequently transit high traffic density areas. For example in 2000, one cargo entered Tokyo Bay every 20 hours, on average, and one cargo a week entered Boston harbor.[23] The LNG industry has had to meet stringent standards set by countries such as the U.S., Japan, Australia, and European nations.

According to the U.S. Department of Energy,[24] 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 cargo loss; that is, repairs were quickly made and leaks were avoided. There have been no LNG shipboard fatalities.

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.

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[23] Phil Bainbridge, VP BP Global LNG, *LNG in North America and the Global Context,* IELE/AIPN Meeting University of Houston, October 2002.
[24] Juckett, Don, U.S. Department of Energy, *Properties of LNG*. LNG Workshop, MD, 2002.

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."[25] A recent report by the engineering consulting firm, PTL,[26] concluded that, 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 crack failure in their 35-year history.

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. 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 1973[27] determined the accident was clearly a construction accident and not an "LNG accident".

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[25] 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.
[26] Lewis, James P, Outtrim, Patricia A., Lewis, William W., and Perry, Lui Xin, PTL: *LNG, The Basics*, Report prepared for BP, May 2001.
[27] Fire Department of the City of New York, *Report of Texas Eastern LNG Tank Fatal Fire and Roof Collapse, February 10, 1973*, July 1973.

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."[28]

Cove Point, Maryland, October 1979[29]

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.

This was an isolated accident caused by a very specific set of circumstances. The National Transportation Safety Board[30] 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.

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[28] New York Energy Planning Board, *Report on Issues Regarding the Existing New York Liquefied Natural Gas Moratorium*, November 1998.
[29] The content in this section is taken from CH-IV International Report *Safety History of International LNG Operations*, June 2002.
[30] National Transportation Safety Board Report, *Columbia LNG Corporation Explosion and Fire; Cove Point, MD; October 6, 1979*, NTSB-PAR-80-2, April 16, 1980.

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*[31] 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."

The over 40 years of experience without significant incidents caused by LNG, liquefaction plants, LNG carriers, cargoes, and 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 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.

The second CEE briefing paper will detail and evaluate 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.

[31] 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.

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

The United States Coast Guard (USCG)[32] 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)[33] regulates LNG tanker operations. The U.S. Federal Energy Regulatory Commission (FERC)[34] is responsible for permitting new 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 FERC is considering its role concerning the commercial arrangements by which producers of LNG have access to U.S. terminals. 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. Environmental Protection Agency[35] 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,[36] U.S. Army Corps of Engineers[37] (for coastal facilities and wetlands), U.S. Minerals Management Service[38] (for offshore activities) and National Oceanic and Atmospheric Administration[39] (for any activities near marine sanctuaries). The U.S. Department of Energy – Office of Fossil Energy[40] 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

[32] United States Coast Guard (USCG): http://www.uscg.mil/uscg.shtm.
[33] U.S. Department of Transportation (DOT): http://www.dot.gov/.
[34] U.S. Federal Energy Regulatory Commission (FERC): http://www.ferc.fed.us/.
[35] U.S. Environmental Protection Agency (EPA): http://www.epa.gov/.
[36] U.S. Fish and Wildlife Service: http://www.fws.gov/.
[37] U.S. Army Corps of Engineers: http://www.usace.army.mil/.
[38] U.S. Minerals Management Service: http://www.mms.gov/.
[39] U.S. National Oceanic and Atmospheric Administration: http://www.noaa.gov/.
[40] U.S. Department of Energy – Office of Fossil Energy: http://www.fe.doe.gov/.

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 future briefing papers of the CEE mentioned above and *The Guide to LNG in North America* will provide extensive information to public audiences interested in U.S. energy trends and security; LNG industry and market developments; LNG safety, security and environmental considerations; and related regulatory and policy issues. The CEE web site http://www.beg.utexas.edu/energyecon/lng/ will provide 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.

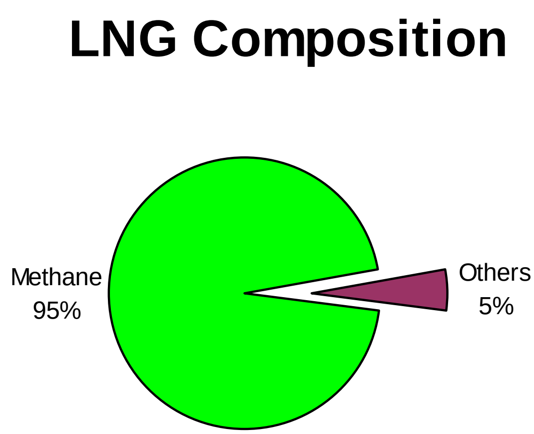
Appendix 1: Conversion Table

Conversion Units	*Source: BP Statistical Review of U.S. Energy June 2002*					
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

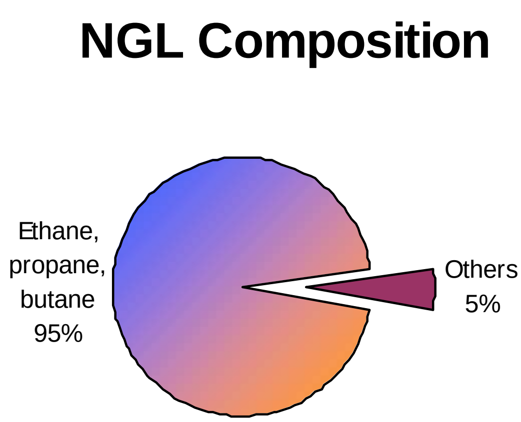
Example: To convert **FROM** 1 million tons of LNG **TO** billion cubic feet of natural gas multiply by 48.7 (100 million tons of **LNG** equals roughly 5000 billion cubic feet of **natural gas**).

Appendix 2: 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).



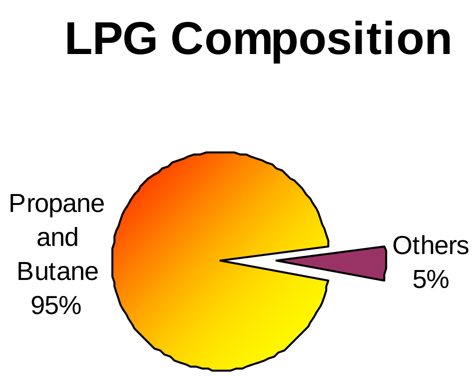
LNG is made up of mostly methane as shown in the figure below. The liquefaction process requires the removal of the non-methane components like carbon dioxide, water, butane, pentane and heavier components from the produced natural gas. LNG is odorless, colorless, non-corrosive, and non-toxic. When vaporized it burns only in concentrations of 5% to 15% when mixed with air.



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

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.

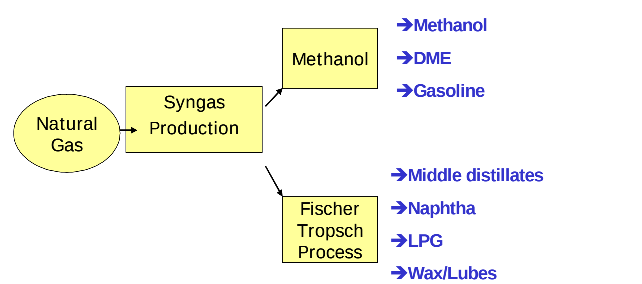


In Europe, LPG has been used as fuel in light duty vehicles for many years. Many petrol or gasoline stations have LPG pumps as well as pumps to distribute gasoline.

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.



Source: GTL Taskforce. Dept of Industry, Science and Resources Canberra ACT Australia: June 2001

Appendix 3: Glossary of Terms[41,42]

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^{o}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.

[41] Phillips Petroleum Company, http://www.phillips66.com/lng/LNGglossary.htm.
[42] Poten & Partners, http://www.poten.com/?URL=ut_glossary.asp.