LNG PLANTS IN THE U.S. AND ABROAD

by
Christopher F. Blazek
Richard T. Biederman

Paper Presented at
Society of Automotive Engineers
Liquefied Natural Gas TOPTEC Conference

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Abstract

The Institute of Gas Technology recently conducted a comprehensive survey of LNG production and storage facilities in North America. This survey was performed as part of IGT's LNG Observer newsletter which covers both domestic and international LNG news, reports on LNG related economics and statistics, and routinely conducts interviews with key industry leaders. In addition to providing consulting services to the LNG industry, IGT has co-sponsored the International Conference on Liquefied Natural Gas for the part 20 years.

The objective of this paper is to present a summary of our recent survey results as well as provide an overview of world LNG trade. This information is important in assessing the potential near term availability of LNG for transportation applications. The IGT LNG Survey appraised the capacity and current market activity of LNG peak shaving, satellite storage, and import receiving facilities in the United States and Canada. Information was requested from facilities on three main topics: liquefaction, storage, and regasification. Additional questions were posed regarding the year of operation, designer/contractor for liquefaction cycle and storage, source of LNG (for storage-only facilities), plans for expansion, and level of interest in providing LNG as a vehicle fuel. The IGT LNG Survey has to date received information on 56 LNG peak shaving facilities, 28 satellite storage facilities, and 4 LNG import receiving terminals.

LNG Production: A Historical Perspective

During the 1850's Kelvin and Joule discovered that gases experience temperature changes during throttling. This discovery led the way to the production of cryogenic fluids (cryogenic is defined as less than -100 °C). Faraday is reported to have first liquefied methane about 1855 during the same period that he experimented with the liquefaction of air and its constituents, as well as hydrogen. The first attempt to exploit LNG appears to belong to Russia. Around 1935 the
Ukrainian authorities decided to utilize the natural gas discovered in the south of the country, near the Sea of Azov. The area, located a great distance from the oil wells of the North Caucasus, lacked fuel for transportation. The idea of using LNG for agricultural machinery evolved. Experimental work was started at Kharkov and Dnepropetrovsk; a LNG storage tank was built and experiments were conducted with methane carburetors to test the use of LNG on tractors. The liquefaction plant employed an ethylene-methane cascade with power consumption of about 450 hp/10⁶ ft³ of natural gas liquefied.

At approximately the same time, the first plant for separating helium from natural gas was constructed in Amarillo, Texas by the U.S. Bureau of Mines. The process involved liquifying methane on a large scale, separating the helium, revaporizing the methane and then passing it into a pipeline for fuel gas distribution. This process provided pipeline operators with the prospect of liquefaction as a method for large-scale peak-load storage.

The first large-scale use of liquefaction by the gas industry, prior to World War II, was the peak-shaving plant constructed in 1941 by the East Ohio Gas Co. in Cleveland, Ohio. The disastrous loss of this plant in 1944 (200 fatalities) delayed further consideration of similar installations for some years. The cause of this loss was the failure of one of the LNG storage tanks and lack of adequate containment. This problem has been corrected for all modern LNG plants.

The next liquefaction and storage plant for peak-shaving was designed and the components largely fabricated by Dresser Industries of Dallas, Texas for use in Russia under the Land-Lease Act. In 1947, the liquefaction plant components were delivered to a site near Moscow, but before the plant could be erected or the storage tanks delivered, the Land-Lease Act was terminated. The liquefaction plant construction was then completed by Russian engineers who also designed and built the LNG storage tanks. The designs resembled those devised by Dresser Industries.

The Dresser/Russian liquefier, similar in design and capacity to the East Ohio Gas Co. facility, was not commissioned until 1954 and then operated on an experimental basis for 2 years due to limited liquid storage capacity. During this period, work involving LNG as a motor fuel was initiated and a prototype converted vehicle proved so successful that a decision was made to convert a fleet of 100 vehicles.

The second major development in the growth of LNG technology was the decision by the British Gas Council in 1963 to transport LNG from Algeria to England to help meet the energy needs of their growing economy. The first commercial cargo of LNG arrived at Canvey Island in the UK from Algeria on October 12, 1964 on the Methane Princess. The basic idea was proved sound; better materials of construction, new storage methods and safer handling techniques contributed to the success of this concept. The demonstrated feasibility of ocean transport of LNG spawned a host of similar projects that benefited other areas of the world to a far greater extent than first anticipated.
U.S. LNG Peak Shaving Plants

Based on the technology advances of the early 60's a rapid growth in the LNG industry occurred during the next decade (1968 to 1978). During this period over 50 LNG peak shaving facilities were constructed in North America alone, and nearly 70 worldwide. In the United States, LNG plants were constructed primarily for peak shaving operations. Peak shaving is a method used by local gas distribution companies to supplement pipeline supplied natural gas. Peak shaving generally supplies a limited amount of gas during short term extreme cold weather periods. This method has proven to be an attractive alternative to increasing natural gas transmission line capacities to meet peak seasonal demand. In addition, the availability of alternative supply options offer the utilities a degree of operating flexibility. These LNG liquefaction plants may also serve satellite LNG storage facilities. These satellite storage plants assist in gas distribution during peak shaving periods. Other peak shaving methods available to the utilities include propane/air peak shaving and synthetic natural gas (SNG) peak shaving. SNG was primarily produced by the partial oxidation of naphtha. Currently LNG peak shaving accounts for nearly 85% of all peak shaving sendout in the U.S. while propane/air is the chief alternative. SNG peak shaving is presently used only in Hawaii.

The liquefaction of natural gas is a mature industry in the U.S. Periodically, the Institute of Gas Technology surveys existing North American LNG facilities as a means of monitoring the industry. Recently IGT updated its LNG Survey. This survey appraised the capacity and current market activity of LNG peak shaving, satellite storage, and import receiving facilities in the United States and Canada. Information was requested from facilities on three main topics: liquefaction, storage, and regasification. Additional questions were posed regarding the year of operation, designer/contractor for liquefaction cycle and storage, source of LNG (for storage-only facilities), plans for expansion, and level of interest in providing LNG as a vehicle fuel.

Survey Results

The IGT LNG Survey contains information on all 56 LNG peak shaving facilities, 28 satellite storage facilities, and 4 LNG import receiving terminals in the U.S. and Canada. In some cases, recent information was provided available and data reported is replicated from IGT's previous 1989 survey. In addition, the survey contains information on a number of facilities that are not currently operating; reasons for shutdown include mechanical maintenance, lack of demand for LNG peak shaving, and expansion/retrofitting. As can be seen in Figure 1, the average first year of operation for LNG facilities in the survey was 1973. The range of years of construction extend from 1965 to 1991.

Among peak shaving plants in the U.S. with on-site liquefaction equipment, the type of liquefaction cycle was found to be the following: 41% of facilities use mixed refrigerant cascade (MRC) or mixed refrigerant liquefier (MRL), 31% reported expander-type liquefiers, 15% use cascade or modified cascade, and 6% reported "other" liquefaction cycles such as integrated cascade.
refrigeration or dual Joule-Thompson (J.T). A number of facilities reported having more than one type of liquefaction cycle currently in use. Major liquefaction process designers include Chicago Bridge & Iron (CBI) with a 30% market share, Air Liquide (16%) and Pritchard (14%), while storage contractors were CBI with a 60% share and Pittsburgh-Des Moines (PDM) with a 34% share.

Peak shaving facilities in the U.S. operated by utilities range in size from 13,395 Nm$^3$/day (inlet natural gas capacity) for a single train dual J-T cycle unit to 388,455 Nm$^3$/day (gas) for a single train mixed refrigerant cycle. As shown in Figure 2, the typical facility in the U.S. has a liquefaction production capacity between 35 and 1,196 Nm$^3$/day (liquid). The LNG facility with the largest liquefaction capacity is operated by the Philadelphia Gas Co. These facilities typically include gas purification equipment, liquefaction trains, storage tanks, vaporizers, and boil-off recovery.

Due to the cryogenic conditions required for LNG production (-260 °F) a number of natural gas constituents may solidify, causing fouling and plugging problems. These constituents are removed prior to liquefaction using a number of techniques. For instance, a molecular sieve synthetic zeolite adsorbent dehydrator would be used to lower the dew point of the incoming gas to between -100 and -150 °F. Although water and carbon dioxide are the primary constituents which must be removed from natural gas, other unwanted compounds that may be present must also be removed. These include glycol, amines, oxygen, methanol, heavy straight chain hydrocarbons, hydrogen sulfide and odorants. A representative range of design inlet natural gas composition is presented in Table 1. As can be seen the most stringent requirements are for oxygen and the heavier hydrocarbons (butane +). Other major constituents such as carbon dioxide and water are removed in the gas conditioning operation. The composition of the final LNG output is therefore markedly different from the inlet natural gas composition. Table 2 presents a typical LNG composition produced by a LNG peak shaving facility. As can be seen the LNG consists primarily of methane and ethane. The remaining constituents are heavier hydrocarbons and traces of nitrogen.

Plant utilization for surveyed facilities was classified into two groups: liquefaction equipment utilization and regasification facility utilization. The overall utilization rate for liquefaction equipment was estimated to be 86% among facilities that operated in 1990 (facilities not operating in 1990 were excluded from the averaging calculation). Utilization rate for regasification equipment was 51% among facilities operating in 1990. As presented in Figure 3, regasification capacity ranges from as low as 4,020 Nm$^3$/hr to 637,200 Nm$^3$/hr. As would be expected most of the satellite facilities have regasification capacities below 50,000 Nm$^3$/hr while the liquefaction plant regasification capacity is distributed across the entire range. Regasification capability is provided by direct-fired, submerged, shell and tube, or other type of regasifier. Typically, multiple regasifiers are installed at each facility to meet demand surges and to provide redundancy in the event of failure.
Table 1. Range of Inlet Gas Compositions for Peak Shaving LNG Plants.
(Composition presented as volume % unless noted otherwise)

<table>
<thead>
<tr>
<th>Component</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>81.3 - 97.5</td>
</tr>
<tr>
<td>Ethane</td>
<td>2.0 - 7.0</td>
</tr>
<tr>
<td>Propane</td>
<td>0.27 - 3.0</td>
</tr>
<tr>
<td>Iso-butane</td>
<td>0.03 - 0.32</td>
</tr>
<tr>
<td>N-butane</td>
<td>0.01 - 0.25</td>
</tr>
<tr>
<td>N-pentane</td>
<td>0.01 - 0.90</td>
</tr>
<tr>
<td>Hexane</td>
<td>0.02 - 0.17</td>
</tr>
<tr>
<td>Water</td>
<td>3.5 - 20 #/MMcf</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.26 - 10.0</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0 - 10 ppm</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>0.47 - 1.50</td>
</tr>
<tr>
<td>Total Sulfur</td>
<td>0 - 1.2 #/MMcf</td>
</tr>
</tbody>
</table>

Table 2. Typical Peak Shaving Plant LNG Composition.

<table>
<thead>
<tr>
<th>Component</th>
<th>Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>95.3</td>
</tr>
<tr>
<td>Ethane</td>
<td>4.1</td>
</tr>
<tr>
<td>Propane</td>
<td>0.43</td>
</tr>
<tr>
<td>Iso-butane</td>
<td>0.04</td>
</tr>
<tr>
<td>N-butane</td>
<td>0.04</td>
</tr>
<tr>
<td>Iso-pentane</td>
<td>0.01</td>
</tr>
<tr>
<td>N-pentane</td>
<td>0.01</td>
</tr>
<tr>
<td>Hexane +</td>
<td>0.05</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.02</td>
</tr>
</tbody>
</table>

LNG for the regasification operation is supplied from on-site storage, both at liquefaction plants and satellite storage facilities. As presented in Figure 4, on-site storage capacity ranges from 209 m³ at the smallest satellite facility to 186,086 m³ at the largest liquefaction facility and nearly 300,000 m³ at the largest U.S. import receiving terminal at Lake Charles, LA. As would be expected, the satellite facilities have the least amount of storage.

Among LNG satellite storage facilities the average distance from the source of LNG was 150 miles. However, one respondent indicated an LNG shipping distance of 1050 miles. LNG transporters are semi-trailer cargo haulers and are regulated by a number of agencies. They are frameless trailers with a sub-frame for the running gear with a bolted 5th-wheel plate. The LNG tank design is based on cryogenic technology used to transport liquefied gases such as nitrogen, oxygen, hydrogen, etc. The tanks are jacketed vessels with an ASME coded inner pressure vessel. The jacketed casing provides vacuum and insulation- and structural support for the trailer (similar to the design of LNG storage tanks). The cryogenic inner vessel is fabricated from stainless steel, nine percent nickel steel, or aluminum alloys. These materials exhibit the required minimum impact
strength at sub-zero temperatures. For safety in handling the LNG, air-operated shut-off valves are used in combination with manual valves on all liquid lines. Insulated tank trucks are covered by a number of standards including CGA-341.

LNG transporters range in size from 6,000 to 12,500 U.S. gallon capacity. LNG transport by road has matured and has a good safety record with millions of miles and no fatalities. As an example, in 1982 DistriGas operated 68 trailers of double-tank construction with evacuated perlite insulation. The trailers were constructed by Process Engineering, J. Russel Engineering Works, Ryan Ind. and Lox Equipment Co. These trailers transported on average 206.64 million gallons of LNG an average of 1 million miles per year with over 18,900 average loadings per year.

Satellite storage facilities can be either field erected or shop fabricated as presented in Figure 5. Smaller storage facilities are shop fabricated using one or several tanks with LNG capacities of 190 to 209 m³. Larger storage tanks are field erected and range from 1,590 to 95,500 m³ liquid volume. Shop Fabricated LNG storage tanks which would be installed at fleet sites would typically be of the jacketed type with an ASME coded inner pressure vessel. The jacket provides vacuum and insulation along with structural support and isolation of the cryogenic inner vessel. LNG tanks range in the size from 5.68 m³ to 209 m³ capacity. Smaller tanks are designed for operating pressures of up to 150 psi. This higher operating pressure eliminates the need for sendout pumps and boil-off compressors.

Materials of construction for the tank are selected on the basis of service temperature, operating conditions and economics. The jacket casing may be fabricated from low carbon steel that conforms to ASME pressure vessel specifications. Piping is usually stainless steel for both inside and outside connections to the tank. Valves are also stainless steel and all liquid lines must have safety shut-off actuators for local and remote control. Larger field erected metal tanks have been constructed with capacities of up to 200,000 m³. These types of tanks would be used at satellite, peak-shaving and base load facilities.

Regasification units are typically operated well below capacity; this reflects a large installed capacity which is designed to provide peak shaving operators with the ability to meet very large surges in gas demand. These surges typically occur during the heating season and are weather dependant. Liquefaction equipment, on the other hand, typically operates more than six months of the year and is not designed to meet brief surges in demand. Storage operations are usually managed to be full at the start of the heating season and near depletion by spring. During warm winters it is not uncommon to see no utilization of the LNG peak shaving facility. As shown in Figure 6, yearly sendout plant day utilization for the total U.S. can range from 400 to nearly 750 days per year. The average for each individual plant, however is typically near 10 sendout plant days per year with only a few operators reporting average yearly plant utilizations of more than 20 sendout days. Individual
plants reported yearly sendout days for the period of 1984 to 1989 ranging from 0 to 200 days per year.

As presented in Figure 7, many of the LNG facilities surveyed are located along the east coast of the U.S. Furthermore, a majority of the satellite storage facilities are located in the New England States. The next largest concentration of LNG facilities is in the Midwest, followed by the South with only a handful of facilities in the West and Canada. The best opportunity for large scale availability of LNG is from the 4 LNG receiving terminals located operated by Distrigas in Boston, Columbia/Shell at Cove Point, MD., Sonat at Elba Island, GA., and by Trunkline LNG in Lake Charles, LA. as shown in Figure 8. Table 3 presents a summary of the annual volume, storage and regasification capacity of these facilities. As can be seen, the combined projected maximum annual LNG capacity of these four facilities is over 15 million cubic meters.

Table 3. U.S. Import/Receiving Terminals

<table>
<thead>
<tr>
<th>Company &amp; Plant Site</th>
<th>LNG Source &amp; Annual Vol., m^3</th>
<th>Storage Capacity, m^3</th>
<th>Regasification Capacity, m^3/hr</th>
<th>Year of Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Columbia LNG/Shell Oil Co. Cove Point, MD.</td>
<td>Algeria 4,250,000 (projected)</td>
<td>238,500</td>
<td>1,180,000</td>
<td>1977</td>
</tr>
<tr>
<td>Distrigas Everett, MA.</td>
<td>Algeria 2,000,000 (maximum)</td>
<td>154,850</td>
<td>315,000</td>
<td>1971</td>
</tr>
<tr>
<td>Southern Energy Elba Island, GA</td>
<td>N/A</td>
<td>189,000</td>
<td>637,000</td>
<td>1977</td>
</tr>
<tr>
<td>Trunkline LNG Lake Charles, LA</td>
<td>Algeria 6,900,000 (maximum)</td>
<td>286,113</td>
<td>825,000</td>
<td>1982</td>
</tr>
</tbody>
</table>

Based on the LNG production capacity of the existing peak shaving plants surveyed, the availability of LNG for the transportation market appears limited. Given a typical plant with a 250 m^3/day LNG production capacity and assuming that roughly 50% of this capacity could be diverted to the transportation fuels market, the facility would only be capable of providing the equivalent of just over 20,000 gallons of gasoline on a daily basis. This certainly could sustain a large heavy duty vehicle fleet or several demonstration programs. However, large LNG market expansion could not be supported by existing peak shaving plants. Furthermore, very few LNG facilities in our survey reported having any near term plans for expansion. In fact, many of the plants, especially the import receiving terminals were idle during much of the 1980's. Most expansion plans involve installing additional vaporizers or pumps to enhance sendout reliability, or expanding regasification piping. No large-scale facility expansions involving additional liquefaction capacity are currently underway. On a brighter note, many respondents to IGT's survey indicated a great interest in

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providing LNG to vehicle refueling stations. This desire was particularly strong among large, under-utilized facility operators. While most respondents were somewhat skeptical about prospects for a significant LNG vehicle fuel market in the near future, several are already involved in demonstration projects or are actively marketing to fleet operators in their service territory. Some respondents believe that the vehicle fuel market is the only significant expansion opportunity on the horizon for LNG. Areas of possible market penetration include transit buses, class 7 and 8 trucks, locomotives, and ferries.

Activity has picked up recently for LNG import receiving terminals. Both the Trunkline LNG and Distrigas LNG receiving terminals are in operation. Deliveries of Algerian LNG may eventually resume to the mothballed terminal at Cove Point, Maryland, which received its last cargo in 1980. This terminal is owned by Columbia Gas Systems, Inc., and the Shell Oil Co. However, Columbia has announced its intention to get out of the LNG business, following its filing for bankruptcy protection. Shell has an option to purchase the remaining shares and is currently renegotiating its agreement to import 4 million cubic meters of LNG from Algeria, originally scheduled to begin in 1993. After the LNG is regasified it could be marketed to pipelines, distribution companies, and large industrial users. Three major interstate pipelines connect with the terminal: Columbia Gas Systems, Transcontinental Gas Pipe Line, and Consolidated Natural Gas. A fourth receiving terminal, Southern Energy’s facility on Elba Island, Georgia, remains closed. However, discussions are underway to possibly reopen this facility by 1994 to service the expansion of Florida Gas Transmission Co.‘s proposed pipeline expansion into Florida.

In addition to the contiguous U.S. LNG facilities, an LNG production facility is located in Kenai, Alaska. This facility, operated by Phillips-Marathon, produces approximately 1 million metric tons per year of LNG for export to Negishi, Japan. A second Alaskan LNG production facility is currently in the planning stage. This facility, by Yukon Pacific Corp., will export Alaska’s North Slope natural gas via the planned Trans-Alaska Gas System (TAGS) to Anderson Bay where it will be liquefied for export to Pacific Rim countries.

In general the future market growth for LNG in the U.S. looks bright. As presented in Figure 9, LNG utilization in the U.S. is projected to increase dramatically over the next two decades. Forecasts of LNG imports have been prepared by the American Gas Association, US Energy Information Administration, Gas Research Institute, and the National Energy Board of Canada. These estimates are compared here for two years: 2000 and 2010. The US EIA projects the largest level of LNG imports -- 0.8 and 1.3 trillion cubic feet (TCF) in 2000 and 2010, respectively. This is an increase from a previous EIA projection of 0.5 and 0.8 TCF. The Gas Research Institute, in their 1992 forecast, is projecting 0.8 and 1.2 TCF. This represents an increase from their 1991 forecast of 0.8 and 1.0 TCF. GRI’s new projections are based upon a belief that average city gate prices for LNG will rise from $2.31 per million Btu in 1990 to $3.44 by 2000 and $4.87 by 2010. GRI further
believes that an LNG price of $3.50 per million Btu represents a threshold, and that when this price is exceeded LNG capacity expansion will become feasible. The National Energy Board of Canada anticipates more modest growth of LNG imports, to .3 and .6 TCF in 2000 and 2010, respectively. NEB cites factors such as LNG import capacity constraints and a lack of deepwater ports suitable for new LNG receiving terminals. Furthermore, NEB believes that exporting nations will not build additional facilities if LNG prices are below 80% of crude oil prices. Forecasts by the American Gas Association are below GRI's but slightly above NEB's, with LNG imports projected to be .4 and .6 TCF in 2000 and 2010, respectively.

**International LNG Trade**

There are currently 17 operational base-load LNG plants in the world. Table 4 summarizes the international LNG trade that these plants supported in 1990. As can be seen, the four largest LNG exporting countries (Indonesia, Algeria, Malaysia, and Brunei) account for nearly 86% of the world's LNG export production. In terms of importing countries, Japan dominates the demand for LNG with nearly two-thirds of the world market followed by France, a distant second. The United States accounted for only 2% of the world production and 3.35% of the world demand. Total production/demand in 1990 was 53.019 million metric tons. This represents a 13% growth from 1989. This growth is related to the start-up of contracts between Pertamina and the Chinese Petroleum Corp. of Taiwan, which received 12 cargos in 1990; the first complete year for exports from Australia to Japan; and the first full year of the Sonotrach-Trunkline project. Furthermore, this growth occurred despite the end of three projects: deliveries from Algeria (Arzew) to France (Le Havre), spot sales by Algeria to Japan, and export from Libya to Italy.

<table>
<thead>
<tr>
<th>Exporting Country</th>
<th>Production</th>
<th>%</th>
<th>Importing Country</th>
<th>Demand</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indonesia</td>
<td>20.352</td>
<td>38.39</td>
<td>Japan</td>
<td>35.083</td>
<td>66.17</td>
</tr>
<tr>
<td>Algeria</td>
<td>13.986</td>
<td>26.38</td>
<td>France</td>
<td>6.864</td>
<td>12.95</td>
</tr>
<tr>
<td>Malaysia</td>
<td>6.264</td>
<td>11.81</td>
<td>Spain</td>
<td>3.318</td>
<td>6.26</td>
</tr>
<tr>
<td>Brunei</td>
<td>5.217</td>
<td>9.84</td>
<td>Belgium</td>
<td>2.923</td>
<td>5.51</td>
</tr>
<tr>
<td>Australia</td>
<td>2.905</td>
<td>5.48</td>
<td>Korea</td>
<td>2.281</td>
<td>4.30</td>
</tr>
<tr>
<td>Abu Dhabi</td>
<td>2.291</td>
<td>4.32</td>
<td>United States</td>
<td>1.775</td>
<td>3.35</td>
</tr>
<tr>
<td>United States</td>
<td>1.057</td>
<td>1.99</td>
<td>Taiwan</td>
<td>0.772</td>
<td>1.36</td>
</tr>
<tr>
<td>Libya</td>
<td>0.947</td>
<td>1.79</td>
<td>United Kingdom</td>
<td>0.036</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Italy</td>
<td>0.017</td>
<td>0.03</td>
</tr>
</tbody>
</table>

As can be seen in Figure 10, world wide LNG exports have increased steadily since 1977. Indonesia and Malaysia represent the largest growth in production and exports. Figure 11 presents LNG import statistics for the same period. As would be expected, Japan dominated the demand growth in this period.
The delivered cost for LNG can vary significantly depending on the contract terms, competing energy prices, shipping distance and quantity delivered. Figure 12 presents the historical cost of LNG imported to Japan, the largest market, relative to world crude oil prices. This figure indicates that LNG prices have closely tracked crude oil prices from 1975 to 1988. October 1991 prices in the Asian LNG market varied from $3.21 to $3.74/mmBtu. These prices represent a gradual decline in LNG prices which tracked the reduction in world crude prices during 1991.

Figure 13 presents the supply/demand conditions for LNG tankers during the period of 1980 to 1988, and shows that tanker capacity exceeded demand. Of the 65 LNG tankers available during that period, 10 were laid-up during part or all of the period. Currently there are 71 LNG tankers with 19 new tankers on order. New tanker orders have recently been placed by Japan to meet future LNG demand in that country. New vessels coming on-line have a capacity of 125,000 m³ or larger and a speed of approximately 20 knots. Older vessels are typically declassified after 25 years of service.

International trade of LNG is projected to increase significantly during the next two decades as shown in Figure 14. The environmental benefits and availability of natural gas are expected to drive market growth. In addition, the growing diversity of LNG supply sources should ensure long-term stability in the international market. Western Europe, Japan, and the U.S. represent the largest growth markets. While Algeria and Indonesia are dominant in international export markets (as shown in Table 4), countries such as Nigeria, Papua New Guinea, China, Qatar, Norway, and Venezuela are expected to play an increasing role in meeting the projected future demand for LNG. Growth of the international LNG market is currently constrained by shipping capacity rather than by liquefaction capacity or demand. However the cost of new liquefaction facilities (up to $2 billion dollars each) as well as new tankers (around $250 million each) may also constrain supply. This is a particular problem for the United States due to the shipping distance involved from major exporting nations.

In terms of natural gas supply for LNG facilities, Figures 15 and 16 show that sufficient worldwide natural gas reserves exist to meet long term demand. World proven reserves amounted to over 4,200 TCF in 1990. This is divided between Western Europe with nearly 2,000 TCF (including the former U.S.S.R.), the Mideast with over 1,300 TCF, and North America with nearly 350 TCF. In comparison, the U.S. natural gas demand in 1991 was roughly 19 TCF. World wide natural gas resources are currently so abundant that considerable quantities of gas are currently reinjected, vented or flared. As presented in Figure 16, nearly 11.8 TCF were reinjected, vented or flared during 1990. Reinjection rates are high in the U.S. (Alaska), Algeria, Indonesia, Canada and Norway. Nearly 1.4 TCF was flared or vented in Russia and Nigeria alone.
Figure 1. YEAR OF CONSTRUCTION FOR LNG FACILITIES

Figure 2. LIQUEFACTION CAPACITY OF LNG FACILITIES
Figure 3. REGASIFICATION CAPACITY OF LNG FACILITIES

Figure 4. STORAGE CAPACITY OF LNG FACILITIES
Figure 5. **TYPE OF STORAGE AT LNG SATELLITE STORAGE FACILITIES**

Figure 6. **LNG PEAKSHAVING ACTIVITY IN THE U.S.**
Figure 7. LOCATION OF LNG FACILITIES

Figure 8. U.S. LNG RECEIVING TERMINALS
Figure 9. PROJECTIONS OF U.S. LNG IMPORTS

Figure 10. LIQUID NATURAL GAS EXPORTS

Source: Lloyds Shipping Economist
Figure 11. LIQUID NATURAL GAS IMPORTS

Figure 12. HISTORICAL LNG / CRUDE OIL PRICING
Figure 13. LNG CARRIER SUPPLY / DEMAND

Figure 14. WORLD LNG DEMAND FORECAST
Figure 15. WORLD NATURAL GAS USED FOR REINJECTION OR VENTED & FLARED

Figure 16. WORLD PROVED NATURAL GAS RESERVES
Terminology and Conversion Factors

\[
\begin{align*}
\text{Scf} &= \text{Standard Cubic Foot} \\
1 \text{ Nm}^3 &= \text{Normal Cubic Meter} \\
&= 35.31 \text{ Standard Cubic Feet} \\
&= 264.2 \text{ Gallons of LNG} \\
&= 0.431 \text{ Metric Tons of LNG} \\
&= 21,830 \text{ Scf of Natural Gas} \\
\text{Mcf} &= \text{Thousand Cubic Feet} \\
\text{MMcf} &= \text{Million Cubic Feet} \\
&= 0.0283 \text{ Million Cubic Meters} \\
\text{MMcf/d} &= \text{Million Cubic Feet per Day} \\
\text{Bcf} &= \text{Billion Cubic Feet} \\
\text{Tcf} &= \text{Trillion Cubic Feet} \\
1 \text{ MT/y} &= \text{Million Tonnes (metric tons) per Year} \\
&= 1.35 \text{ Billion Cubic Meters per Year} \\
&= 52.9 \text{ Billion Cubic Feet per Year} \\
\text{(Gasoline)} \\
\text{Gal Equiv.} &= 1.4 \text{ Gallons of LNG} \\
&= 115.7 \text{ Scf of Natural Gas} \\
1 \text{ Therm} &= 0.858 \text{ Gallons LNG (1034 Btu/Scf gas)}
\end{align*}
\]