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Liquefied Natural Gas: Current Expansion and Perspectives

19th Informatory Note on Refrigerating Technologies

Introduction

Natural gas is set to become one of the most important primary energy sources for the 21st century. Compared with other fossil fuels, gas is relatively clean with regards to air pollution and greenhouse gas emissions and has larger proven reserves. It is expected to account for about 30% of total electricity generation by 2020 compared with 17% in 2000.¹ Similarly, its ratio for heating purposes and as automotive fuel is growing rapidly. However, the main difficulty in conveying gas to the markets is its transport over long distances. Liquefaction makes it possible to market important gas reserves located in remote areas, far away from consumer countries, as it reduces the volume: 1 litre of liquefied natural gas (LNG) corresponds roughly to 600 litres of natural gas. Hence, since its inception in the 1960s, LNG has grown significantly and makes a strong contribution to meeting the world's energy needs: it now represents nearly a quarter of worldwide gas exports² and worldwide production is expected to more than double from 2004 to 2010 and reach more than 300 million tons per annum (MTPA).³ Therefore, LNG is a fast expanding energy vector and, although currently it is commonly evaporated and compressed into long-distance pipelines, new solutions are bringing LNG directly to off-pipeline customers, thus opening a new segment of application. LNG technology is constantly evolving to meet the increasing demand and requires the use of increasingly complex technology.

Natural gas

- Basic data

Natural gas is primarily methane, with low concentrations of other hydrocarbons, water, carbon dioxide, nitrogen, oxygen and some sulphur compounds. In 2005, natural gas accounted for 23.5% of the global primary energy balance, in third position after oil (36.4%) and coal (27.8%) and before hydro electricity (6.3%) and nuclear energy (5.9%).⁴

Since the 1980s, the amount of proven reserves has kept rising and was, at the end of 2005, estimated at around 180 000 billion m³, which equals 60 years of global consumption.⁴ Much of this gas is located in regions far from consuming markets. Worldwide production of natural gas is estimated as being around 2763 billion m³. The annual increase was 1.5% in 1995 and 2.5% in 2005.⁴

- Environmental data

Within the framework of the Kyoto Protocol, Parties have agreed specific emissions reduction commitments and it is expected that greater use of cleaner energy will play an important role in meeting these commitments. These cleaner energies include natural gas and consequently LNG. Due to its chemical characteristics, natural gas is the cleanest burning fossil fuel because of its larger H₂/C ratio. It produces fewer CO₂ emissions and pollutants than either coal or fuel oil; data, calculated by the IIR enable comparison of CO₂ emission rates from each fossil oil at the same heat power: the saving in CO₂ emissions from fuel combustion for natural gas amounts to roughly 65% compared with coal and 25% compared with oil.

Table 1. Comparative CO₂ emission rates⁵

Fuel	Gas	Oil	Coal
CO ₂ emission rates (Mt of CO ₂ /Mtoe ⁽¹⁾)	2.27	2.82	3.76
Comparison between CO ₂ emission rates ⁽²⁾ (%)	0	+24.5	+65.8

⁽¹⁾ Mega tonnes oil equivalent

⁽²⁾ Based on natural gas rate

LNG properties

- Chemical data

LNG is a liquid form of the natural gas commonly used in industry and residential buildings. Natural gas is condensed by cooling it to about -161°C and typically the storage pressures range from 1.7 bars to 17.2 bars. LNG is odourless, non-toxic, non-corrosive and its density is about 450 kg/m³.

- Safety issues

Usually, LNG is not explosive in its liquid state and once it is heated and becomes gas, it is not explosive if it is unconfined. Natural gas is flammable when it exists at a 5 to 15% concentration in the air. This range is much narrower than that of hydrogen (4 to 96%) or gasoline (1 to 99%). Moreover, the auto-ignition temperature, 537°C, is much higher than that of diesel fuel (248°C).

Handling LNG introduces potential safety hazards in terminals and LNG carriers. There are four typical risks: flammable vapour cloud dispersions, vapour cloud explosions, pool fires and rapid phase transition. These risks and appropriate measures are addressed in standards.^{6,7,8}

LNG: economic aspects

- Importance for the global economy

By liquefaction, the volume of natural gas is reduced by a factor of 600, which makes LNG suitable for transportation over long distances. Overseas transport started around 1960 and LNG is now an important contributor in the energy balance of some countries. In 2002, LNG accounted for a mere 6% of global natural gas consumption and about 26% of total international natural gas trade.² LNG's share of each importing country's gas supply ranges from about 2% in the USA to 100% in Japan.²

LNG is a very good energy vector due to the availability of natural gas, as well as the advantages it brings in transportation and storage. Although most potential LNG developments tend to be within existing supply areas, there is a possibility that, thanks to ease of transport over very long distances, new supplies may be developed, particularly on the Pacific coast of South America.⁹ World LNG trade is growing, driven by declining domestic natural gas resources in gas-consuming countries, the desire of these countries to diversify their sources and the desire of gas-producing countries to better commercialize their resources.

LNG is a price-competitive source of energy that could help meeting future economic needs. One ton of oil equivalent equals 41.9 TJ, one ton of LNG equals roughly 55 TJ. This means that, per unit of weight, LNG heating value per weight is 31% higher than that of oil.¹⁰ Furthermore, LNG can easily compete against pipeline gas, as energy for liquefaction and transport is comparable to that for compression and recompressions of pipeline gas. Although the price of natural gas has increased considerably over the past few years, it is still able to compete with oil prices. In 2004, LNG prices were similar to natural gas prices: 4.32 USD per GJ for natural gas and 4.91 USD per GJ LNG⁴, but excess growth driven by demand was reported by the end of 2005.

Typical LNG process

- Production and processing

A majority of the world's LNG supply comes from countries with large natural gas reserves. The main exporter of LNG is Indonesia, followed by Malaysia, Qatar and Algeria, which hold natural gas reserves representing more than 50% of the world's total. Other countries include Australia, Brunei, Libya, Nigeria, Oman, Trinidad and Tobago, the United Arab Emirates and the USA.⁴ Currently, because of the large capital expenditure involved, economics dictate that natural gas liquefaction projects for overseas transportation require large gas reserves able to produce large quantities of gas for at least 20 years.⁴ Worldwide, there were 28 LNG export terminals in 2005.¹¹

- Liquefaction

At the production site, natural gas is converted into a liquid form through a cooling process called liquefaction, achieved through several refrigeration cycles. Before liquefaction, the gas is purified from humidity, carbon dioxide, sulphur components, heavy hydrocarbons and other impurities. The purified natural gas is cooled to its atmospheric boiling point (about -161°C). The set of units where natural gas is purified and liquefied is called a train. The largest liquefaction train in operation has a production capacity of 5 million tonnes per year and trains designed for 7.8 million tonnes per year are under construction in Qatar. In 2005, there were 75 trains, which means a global LNG liquefaction capacity of roughly 160 million tonnes.¹¹ This production capacity is expected to increase to 197 million tonnes in 2007 based on the facilities under construction.² There are 3 main liquefaction processes:¹⁰

- the classical cascade, where refrigeration and liquefaction of the gas is achieved in a cascade process using three pure refrigerants: propane, ethylene and methane;
- the single flow mixed refrigerant process, where the mixed refrigerant made up of nitrogen, methane, ethane, propane and isopentane, is compressed and circulates using a single compression train;
- the propane precooled mixed refrigerant process where precooling is achieved by a multi-stage propane cycle and liquefaction and subcooling are accomplished by a two-stage mixed refrigerant cycle, which is so far the most common process, used since 1972 in 8 different countries.

Other processes have been developed but are not yet in operation:

- the cascade mixed refrigerant cycle, where three mixed refrigerant cycles are used for precooling, liquefaction, subcooling;
- the dual mixed refrigerant process, where both the precooling and the liquefaction cycles use mixed refrigerants;
- the AP-X process, based on the propane precooled mixed refrigerant process with a separate nitrogen cycle for subcooling.

- Transport

Because of its relatively high density, it is possible to transport LNG from remote production areas to consumer areas more easily than using conventional gas pipelines. In international trade, LNG is transported in double-hulled ships, specifically designed to handle the low temperature of LNG, to a receiving terminal where it is stored and regasified. These carriers are insulated to limit the amount of LNG that boils off or evaporates. This boil-off gas is sometimes used to supplement fuel for the carriers or it is re-liquefied by an on-board liquefier. LNG carriers are up to 300 metres long and require a minimum water depth of 12 metres when fully loaded. In May 2005, 181 LNG tankers were operating, with another 74 under construction for delivery in the 2005-2007 time frame.¹² Construction costs have dropped from 280 million USD in 1995 (for a 138 000-cubic-metre-capacity ship) to 150 to 160 million USD in 2005 (still more than double the cost of a crude oil tanker).¹²

- Storage

In production plants and in reception terminals, LNG is stored in specifically built insulated flat bottom storage tanks, operating at atmospheric pressure. These tanks can be above or below ground and keep the liquid at very low temperatures to minimize evaporation. The largest tanks currently in operation are 160 000 m³ above ground and 200 000 m³ under ground. The tanks are insulated by special powder insulation, filled between the inner and outer shells. As with the ships, the boil-off gas can be collected and used as a fuel source in the facility. In 2005, worldwide, there were 50 LNG import terminals in Asia (India, Japan, South Korea, Taiwan), Europe (Belgium, France, Greece, Italy, Portugal, Spain, Turkey, United Kingdom), North America (the United States) and South America (Dominican Republic, Puerto Rico).¹³ In 2005, the main LNG importers were Asia with 64.8%, in particular Japan with 40.4%, and Europe with 25.2% of total imports.⁴ However, the LNG market is undergoing global expansion.

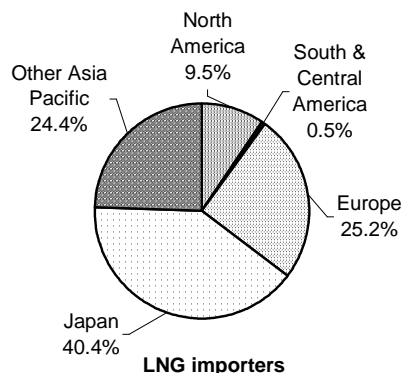


Figure 1. LNG imports per area expressed as a percentage (Total $188.81 \cdot 10^9 \text{ m}^3$)⁴

- **Regasification and distribution**

At the import terminal, LNG is warmed to a point where it converts back to its gaseous state. This is accomplished using special exchangers fed with high-pressure pumps for achieving the final gas pressure. Two types of exchangers are used mainly: open-rack vaporizers (ORV) using sea water and submerged combustion vaporizers (SCV) that are water baths heated by combustion of fuel gas. While 2% of the imported gas is used as fuel gas for LNG vaporization under 50 bar pressure, nearly all the gas is distributed to end-users via a conventional gas pipeline network with recompressing stations at distances 150 to 250 km. Organizing direct distribution of LNG from import terminals to end-users by road trailers or rail cars will be a challenge in the years to come.

- **Local liquefiers**

LNG may also be produced by liquefying gas taken from a pipeline or from a small local well.¹⁴ The typical capacity of such installations is 40 to 100 tonnes/day. Some of them are used as peak-shaving plants, for liquefaction of gas in periods of low demand, and for vaporization back into pipeline, when the demand is high. The others are used for further distribution of LNG to satellite plants. It can be based again on a mixed refrigerant cycle, or it can be a straddle plant, in parallel to a pressure-reduction station, where the gas is throttled from the transit pipeline to a local net, thus using the available pressure energy for liquefaction.

- **Small scale distribution**^{3,15}

LNG from marine terminals or from local liquefiers can be further distributed for one of the following purposes:

- satellite plants: LNG may be transported in special tanker trucks to small facilities, called satellite plants,^{15,16} where it is stored and regasified into a local pipeline for heating or process technology. This system may be very beneficial for countries with no existing or insufficient pipeline infrastructures. There are still a lot of opportunities enabling developing countries to speed up their industrial growth. LNG is also used in industrialized countries where opportunities abound for gas delivery to scattered settlements and areas where natural protection is in force. Some satellite plants can be operated for peak shaving or for back-up purposes in parallel to delivery by pipeline;
- vehicle fueling LNG¹⁴: distribution to vehicle fueling stations is done by road trailers, where CNG (compressed natural gas) vehicles are fueled, for which a vacuum-insulated storage tank, a small high-pressure pump and a vaporizer are the distinguishing components. Alternatively, LNG can be fueled directly to on-board insulated fuel tanks with on-board vaporizers. Due to its high density and low pressure, LNG is used as a transportation fuel enabling lower vehicle dead weight and longer running as well as providing cheaper means of fuelling, as LNG is about 30% cheaper than diesel and benefits from lower tax rates.¹⁶

Development perspectives and challenges

- **Reducing costs and improving efficiency**

LNG production and transport still require important investments and the large liquefaction process represents 50% of the investment cost in the entire LNG value chain. For instance, the cost of a large liquefaction train with a capacity of 4.7 million tons per annum was referenced as $1.5 \cdot 10^9$ USD (average current costs are $250 \cdot 10^6$ USD/MTPA)¹⁷. The cost of an LNG tanker with $138\,000 \text{ m}^3$ cargo volume is $0.2 \cdot 10^9$ USD.² The cost of a regasification plant is $0.3 \cdot 10^9$ USD¹⁰, or $0.5 \cdot 10^9$ (for a 6 MTPA)¹⁸.

Hence, in order for LNG to remain competitive, production costs must be reduced through technological developments as well as improvements in the design and construction of the entire plant.¹⁰ Complete LNG complexes currently cost between $2\text{-}5 \cdot 10^9$ USD each, and costs have already been reduced significantly since the mid 1990s. For example, liquefaction costs were around 560 USD/tonne in 1995 and were reduced to 222 USD/tonne in 2004.¹⁹ Developments increasing efficiency include the use of liquid expanders, enabling power reduction for the liquefier process, or alternately an increase in output for the same power.¹⁹

- **Changes with regard to construction and capacity**

It seems likely that future LNG export terminals will be larger, based in remote locations with no infrastructure and subjected to extreme weather conditions. Therefore, conventional construction approaches will no longer be cost- and time-effective. Innovative efficient solutions are being developed. For example, recently, the major part of an LNG process plant was developed in a very compact form on a purpose-built barge that can be transported after assembly to the production site where it will serve as a permanent base and foundation for a new LNG process plant.⁷ Other projects are developed with modularization of the facility. Plant capacities presently reach 5 million tonnes LNG/year and designs are aiming for 7.8 million tonnes LNG per year.¹⁹ Storage tanks are also increasing in size: presently around $120\,000\text{-}160\,000 \text{ m}^3$.

- **Contract trends**

Currently, the LNG market is driven by long-term contracts, on a 20-25-year scale. However, they have become increasingly flexible in recent years. Some newer long-term contracts are designed to provide only a base supply of LNG, which can be supplemented by short-term contracts during periods of high demand. Medium-term and short-term contracts (or spot LNG trading) are emerging:

growth has risen from 1% of the LNG market in 1992 to 8% in 2002 and could reach over 15% in the next decade.² For the short-term market to expand, uncommitted ships and flexible contracts are required. These trends should promote LNG as a fuel of choice, either as the main fuel generator, or as a back-up system to compensate shortages at peak times.

- Optimizing the safety

Sustainable design implies LNG processes with highest safety, possibly by using non-hydrocarbon refrigerants in the natural gas liquefaction processes.

Conclusion

LNG technology has been in use since the 1960s and is constantly evolving. The three main trends likely to shape the future of LNG trading are:

- emergence of new markets and commitments forcing buyers to seek more flexible supplies and use energy mixes;
- reductions in the cost of LNG, now able to compete with conventional pipeline gas;
- development of short-term LNG trading.

Although LNG is still expensive to produce and transport, efforts (technological as well as contractual) are being made to reduce these costs and to increase process efficiency. Nevertheless, LNG is already competitive compared with diesel fuel, LPG and oil in many countries. Furthermore, the environmental benefits of natural gas and the technical/economic advantages of gas liquefaction should potentially allow LNG to become a major energy vector.

Recommendations

- LNG has a real potential for becoming a major player in tomorrow's global energy strategies, as it has many advantages and may help in mitigating global warming.
- These advantages are preponderant in countries where there are no energetic resources and which are far located from production areas. In these cases, LNG is one of the only possibilities making it possible to address rising energy demands.
- LNG should also be considered as an efficient and cost-competitive alternative transportation fuel. The infrastructures for this application are being implemented and this should be promoted.
- LNG costs are still relatively high and contracts are not yet sufficiently flexible. Efforts should be made to promote short-term contracts. LNG could then also be promoted to become a major player in developing countries.
- Research should be promoted in order to try to further reduce the construction and operating costs of LNG facilities while increasing safety and environmental integrity (sustainable design).
- More research on LNG and its uses should be carried out and results disseminated internationally. In this respect, international conferences involving scientific and industrial experts and engineers, such as those organized by the IIR, contribute to the dissemination of up-to-date scientific knowledge and the promotion of this fast expanding energy vector.

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