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An LNG project in India : setting up of an import terminal and the role of transportation

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AN LNG PROJECT IN INDIA

Setting up of an import terminal and the role of transportation

By

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India

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DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal view, and are not necessarily endorsed by the University.

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ABSTRACT

Title of dissertation: An LNG project in India: Setting up of an import terminal and the role of transportation

Natural gas is well positioned to be the choice of energy in the new millennium for the sheer reason of it being clean, economical and plentiful.

Similarly, LNG is well positioned to attract an even greater share of global gas demand as, the geographical distribution of natural gas is not even, and it may it may not always be economically and politically viable to lay down pipelines for supply of natural gas. As potential supply is plentiful, the challenge now, is to bring LNG to the market at competitive rates.

As LNG projects are long term in nature, it is necessary to have a strong LNG chain during the complete tenure of the contract, for, any weak link in the LNG chain during the life span of the contract can jeopardise the whole LNG project. Today's investment economics require a global optimisation of the LNG chain and it is not sufficient to optimise just the production capability of the liquefaction facility. LNG in itself is a high cost industry and it goes for production and transportation as well.

The dissertation describes the energy scenario in India, the requirement of natural gas and the influence of pricing on the gas trade in India. It also deals with other issues like the selection of site of an import terminal, safety, project finance, cargo handling procedures and the role of transportation in an LNG project.

Key words: Natural gas (NG), India, project finance, transportation, LNG chain, cargo handling procedures

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ABBREVIATIONS

LNG	Liquefied natural gas
BTU	British thermal unit
Bkwh	Billion kilowatt hour
Mmt	Million metric tonnes
Mcm	Million cubic meters
Mtoe	Million tonnes oil equivalent
Kgoe	Kilogram oil equivalent
O&oe	Oil and oil equivalent
CBM	Coal bed methane
GAIL	Gas Authority Of India
LPG	Liquefied petroleum gas
GOI	Government of India
CNG	Compressed natural gas
LCNG	Liquefied compressed natural gas
Psi	Per square inch
M sq. km	Million square kilometres
ONGC	Oil and Natural Gas Corporation
OIL	Oil India Limited
GLC	Gas Linkage Committee
MOU	Memorandum of Undertaking
Mtpa	Million tonnes per annum
GRA	Gas Regulatory Authority
IOC	Indian Oil Corporation
BPCL	Bharat Petroleum Corporation Limited
Tba	To be announced

ORV	Open rack vaporiser
SCV	Submerged combustion vaporiser
CIF	Cost, insurance and freight
FOB	Free on board
CO_2	Carbon-di-oxide

CHAPTER I

INTRODUCTION

To a world which had grown complacent about energy growth and oil availability, the Arab-Israeli war of 1973 and the collapse of oil prices in 1985 came as a true oil shock. Suddenly conservation and diversification of energy use away from oil to coal, nuclear power and natural gas assumed even greater critical importance. Also the fact that there is great concern about the world environment and that natural gas is considered to be the cleanest and most environmentally friendly fuel, it has gained a lot of importance.

About fifty years ago, natural gas was more or less dismissed off as a by-product of oil production. However, today because of its nature of being clean, cost effective, reliable and being available in abundance, natural gas has become the choice of most of the energy consumers in the world.

Demand for natural gas has continuously been increasing, but indigenous sources are no longer adequate to meet the total requirements, as the geographical distribution of natural gas is not even. There is a great need to transport natural gas from gas producing countries to gas consuming countries. Since it is not always possible to lay down pipelines, seaborne transport of LNG is currently the most economical way of fulfilling these needs. LNG carriers, the highly specialised ships, now form an integral part of the world energy transport picture. The containment systems developed in the late 1950s and early 1960s, have realised their initial promise and gone on to become today's designs, even though ship sizes have increased tremendously.

However, with the cost of LNG projects being tremendous, project-financing arrangements have become a formidable task beyond the means of any single company. The regulatory bodies in the consuming countries are engaged in a race against time deciding whether or not to grant approval to imports of LNG.

India has been relying on coal, lignite, crude oil and hydroelectric power as its main sources of energy. With reserves of above sources being limited and rapid industrialisation in the country, it is essential that India should look into means of an alternate source of energy before it is too late.

Though India has been trying to tap new oil field and, alternatively, to increase production of oil in the existing ones, there does not seem to be any major break through in the same, resulting in India importing more and more oil every year.

With the liberalisation policy of the Government of India, many multinational companies are venturing into major projects for development of power generation, port and infrastructure development, communications. etc, which are all energy intensive in nature.

Also, the fact that there is a tremendous pollution problem in the country, the earlier India enters into LNG trade the better.

The objective of my dissertation is to highlight the energy scenario in India, deal with various issues regarding design and development of LNG import terminal, role of sea transportation in a LNG project and project finance .

The approach used for the completion of my thesis is that Chapter 2, deals with explanation of the basic concepts of natural gas and liquefied natural gas.

Chapter 3 deals with the Indian Energy Scenario, detailing India's primary energy resources, influence of pricing on gas trade and the role of LNG in Indian context.

Chapter 4 basically deals with the LNG project finance, design and development of a LNG import terminal, site selection for LNG terminal, safety and other related issues of an import terminal.

Chapter 5 touches on the cargo handling procedures and the role of transportation in a LNG project.

Conclusions and recommendations are dealt with in Chapter 6 of the dissertation.

I would however, like to make a mention here that, LNG being a very closed trade there is a great deal of difficulty in getting information, especially regarding the financial aspects, hence the figures that have been used for making the financial analysis in the dissertation, are not very accurate as they are assumed figures.

CHAPTER II

NATURAL GAS, LIQUEFIED NATURAL GAS (LNG) & GLOBAL SEABORNE TRADE OF LNG.

Natural Gas in the last decade has been noticed to be the buzzword in the International Energy Community. Spurred on by the increasing concern for environment, Natural Gas today, enjoys the status of the cleanest and most environmentally friendly fossil fuel. It is also the world's third largest source of energy, after coal and oil.

India is getting in the business of LNG trade in a big way, hence it is imperative to study what the trends of the LNG business are in the world scenario.

The basic purpose of this chapter is to provide for a general review on natural gas, its composition and uses, to distinguish the difference between natural gas and liquefied natural gas, and define the characteristics of LNG.

2.1 NATURAL GAS

Natural gas is a general term for gases which are naturally generated and include all gases such as volcanic gas, hot spring gas, field gas, carbon dioxide gas from carbonated springs and gases that evolve during radiogenic processes.

But in a general sense, natural gas means naturally generated combustible gas whose main components are hydrocarbons. A gas that issues from coal seams in coal fields may also be included in the natural gas family under this definition, but it is usually excluded from the group in an industrial meaning.

For our study purpose we shall, however, deal with natural gas which is predominantly methane, but also present in varying proportions are smaller quantities of ethane, propane and butane. Natural gas occurs as a mixture of the gaseous minerals, including both hydrocarbon and non-hydrocarbon gases, in reservoirs beneath the earth's crust. Most of the world's crude oil fields have deposits of natural gas associated with them. As the geographical condition favourable to the formation of oil are also generally favourable to the formation of gas, this gas is called associated gas. Besides associated gas, there are also many sizeable gas fields which occur independently of any oil, or where the amounts of oil are so small that they are only of minor importance. This is called non-associated gas. The non-associated gas tends to be a purer gas with very high calorific values and its occurrence is such that it can be developed whenever suitable markets become available independently of any oil production.

Like most other fossil fuels the origin of the natural gas lies in the decaying plant and animal life over millions of years.

2.1.1 **Composition of Natural Gas**

Of the hydrocarbon gases that go in the making of the natural gas methane is most prevalent, accounting for almost 70% to 95% by volume. The other heavier hydrocarbons with higher boiling points like ethane, propane and butane make up most of the remaining. Impurities like nitrogen, carbon-di-oxide and sometimes hydrogen sulphide are also present in small quantities. The proportion of methane gives the calorific value of gas and this varies from source to source.

Table - 1, gives the breakdown of the natural gas compositions from some typical gas fields:

Table - 1

Natural gas compositions from some typical gas fields

COMPOSITIONS	ALGERIA	LIBYA	BRUNEI	NORTH SEA	IRAN	ALASKA
Methane	86.3	66.8	88.0	85.9	96.3	99.5
Ethane	7.8	19.4	5.1	8.1	1.2	0.1
Propane	3.2	9.1	4.8	2.7	0.4	-
Butane	0.6	3.5	1.8	0.9	0.2	-
Pentane & others	0.1	1.2	0.2	0.3	0.1	-
Nitrogen	-	-	0.1	0.5	1.3	0.4
Carbon-di-oxide	-	-	-	1.0	-	-

Source: Fairplay report on LNG carriers.

As can be seen from the above table, Alaskan gas with a methane content of 99.5% can be used practically without any treatment, whereas, the less purer forms of gas must be treated to remove the heavier hydrocarbons and impurities. Propane and butane are liquefied under pressure and used as LPG. Pentane and other hydrocarbons are liquids at normal atmospheric conditions and can be removed from natural gas by simple treatment processes. Gas with large amounts of pentane are known as wet gas while those which are relatively free of the hydrocarbons are called dry gas.

2.1.2 **Uses of Natural Gas**

Natural gas is presently emerging as the primary source of fuel in the energy consuming areas of the world and the main areas in which the natural gas is used are:

- Residential/commercial: natural gas is most extensively used in this sector basically for household appliances, water heating, space heating, offices, shops, hotels etc.
- Industry: natural gas in the industries is used as an under boiler fuel for steam raising and for large heating applications, in glass, ceramic and baking industries as its clean burning characteristics makes it superior to alternative fuels.
- Power generation: natural gas is used in power projects not only because of its technical advantages but also because it is convenient and economical.
- Petrochemical industry: natural gas is used as a feedstock for the manufacture of fertilisers, plastics, adhesives etc., using base chemicals like ammonia, methane and acetylene.

2.2 **LIQUEFIED NATURAL GAS (LNG)**

When natural gas is cooled to a temperature of minus 162^{o}C under the normal atmospheric pressure, it condenses into a liquid and is called Liquefied Natural Gas (LNG). LNG is about 618 times less in volume than the gaseous equivalent. It is a clear and colourless liquid having a weight of about half that of water of the same volume. It is for this reason that, if gas has to be transported, it is best done in the liquefied form.

2.2.1 **Production and Properties of LNG**

Natural gas is liquefied by an initial compression process, cooling and then expansion. The cooling process is carried out in a number of closed refrigeration cycles using a progressively lower temperature refrigerant at each stage. In the expansion process at this lower temperature, part of the gas is liquefied and the remainder is fed back to start the cycle again. This method of liquefying natural gas is called the cascade process and is most commonly used for LNG production.

LNG is a colourless transparent liquid and its chemical properties vary as the chemical composition varies as detailed in Table 2. A typical commercial grade of LNG has more or less the following properties:

Table 2

Properties of LNG

Boiling point of LNG	Generally – 157 to –163 ^{o}C. Under normal atmospheric conditions.
Boiling point of pure methane	- 161.5 ^{o}C
Specific gravity of LNG	0.47 to 0.53
Specific gravity of methane	0.415
Calorific value of LNG	25 – 34 BTU*/M^3 #
Calorific value of methane	29 BTU/ M^3
Density of dry gas/dry air	0.58 to 0.67 ##
Density of methane/dry air	0.555
Lower explosive limit (%age by volume in air)	5.3
Upper explosive limit (%age by volume in air)	14.0
Ignition temperature	595^{o}C

Source: Fairplay report on LNG Carriers

* BTU – British Thermal Unit.

more of the heavier hydrocarbons gives higher values and
more of CO_2 and/or nitrogen gives lower values.

More the heavier hydrocarbons can give higher densities.

2.2.2 **Characteristics of LNG**

The principal characteristics of LNG from the view point of storage and transportation are as follows:

1. its extremely low temperature (about -160^{o} C) requires special consideration for:

    - Employment of extremely low temperature-resisting materials.
    - Appropriate structure that allows expansion/contraction of materials and avoids heat stress caused by temperature difference.
    - Effective heat insulating systems.
    - Protection against low temperature hazards.

2. The volume of LNG has been reduced by liquefaction to 1/600 of the volume of corresponding natural gas:

    - This is very advantageous for storage and transportation
    - Tank pressure rises when boiling off.

3. LNG remains at boiling point.

    - Any deviation from equilibrium caused by temperature rising or pressure decreasing will immediately result in LNG boiling up.

4. The density of LNG is about half that of water.

5. LNG is combustible, but its vapour has a narrow range of inflamability.

   - LNG vapour, when it is in the air, forms an explosive vapour mixture. In order to prevent this, consideration has been paid not to allow the vapour to contact air. For this reason tank pressure is usually kept slightly higher than atmospheric pressure.

6. When leaked into the air, LNG evaporates quickly and condenses in the air to develop a white cloud.

7. LNG is a colourless and odourless liquid

8. LNG has a high latent heat of evaporation

9. LNG is very volatile

10. LNG's viscosity is very low

11. LNG has a high dielectric capacity and is a very poor electric conductor. It is easily electrostatically charged

12. LNG is corrosion resistant and non-toxic

13. LNG is scarcely soluble in water

14. LNG has small surface tension.

2.2.3 World Production and Consumption of LNG

The total world-wide proved natural gas reserves at the end of 1997, were in the region of 145 trillion cubic meters. Table 3 provides the details of the region-wise gas reserves in the world.

Table 3

Region-wise gas reserves

trillion cubic meters

Region	**Gas Reserves**	**Percent Share**
OECD	14.1	9.6 %
Middle East	48.9	33.7 %
Former Soviet Union	56.7	39.2 %
Rest of the world	25.1	17.5 %

Source: B.P. World Statistical Review, 1998

These proved reserves are sufficient for the next couple of hundred of years at the present levels of production. With an increase in demand, reserves in the Middle East will lead to significantly increased exports of LNG during the next decades.

Production of LNG for overseas markets is dominated by 9 countries and export of LNG by these countries from1987 to 1998 , was as detailed in Table 4.

Table 4

Major LNG Exporting countries

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
USA	1.3	1.3	1.3	1.4	1.3	1.4	1.4	1.6	1.6	1.8	1.7	1.8
Qatar	0	0	0	0	0	0	0	0	0	0	2.9	4.74
UAE	2.9	3.2	3.1	3.2	3.5	3.4	3.4	4.3	6.9	7.3	7.6	7.27
Algeria	13.3	14.9	17	19.1	18.9	19.6	20.2	18.3	18.3	19.6	24.3	24.87
Libya	0.8	1.1	1.5	1.3	1.6	1.8	1.6	1.5	1.5	1.2	1.1	0.88
Australia	0	0	0.9	3.9	5.2	6.2	6.7	8.6	9.8	10.2	9.8	10.1
Brunei	7.1	7.2	7	7.2	7	7.1	7.6	7.8	8.5	8.7	8.2	7.88
Indonesia	21.2	24.6	24.9	27.6	30	31.6	31.9	35.1	33.2	36	35.7	36.28
Malaysia	8.1	8.3	8.7	8.6	9.5	9.5	10.5	11	12.9	17.7	20.1	19.45
Total	**54.7**	**60.6**	**64.5**	**72.3**	**77**	**80.9**	**83.3**	**88.2**	**92.7**	**102.5**	**111.8**	**113.3**

Source: Clarksons

LNG is imported by a limited number of countries and these countries are basically developed nations. Table 5 elaborates countries that import LNG and the quantities imported.

Table 5

Major LNG Importing countries

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
USA	0	0.6	1.3	2.5	1.9	1.3	2.3	1.5	0.6	1.2	2	2.21
UK	0	0	0	0.1	0	0	0	0	0	0	0	0
Belgium	2.7	2.9	3.68	3.9	4.1	4.6	4.3	4	4.2	4	4.5	4.14
France	8.9	9	8.98	9.31	9.2	9.2	9	7.7	8.4	7.8	9.2	10.18
Italy	0	0.2	0.3	0.03	0.1	0.6	0.3	0.2	0.1	0	1.9	2.07
Spain	2.5	3.3	3.86	4.5	5.2	5.7	5.9	6.4	7.1	6.9	6.7	6.29
Turkey	0	0	0	0	0	0	0	0.4	1.4	2.3	2.9	3.24
Japan	40.1	41.9	43.68	47.94	50.7	52.7	53.1	56.8	57.9	63.8	64.3	65.96
S.Korea	0.5	2.7	2.7	3.1	3.7	4.6	6.1	7.9	9.43	12.98	15.7	14.18
Taiwan	0	0	0	1	2.1	2.2	2.3	3	3.5	3.4	4.1	4.98
Total	**54.7**	**60.6**	**64.5**	**72.3**	**77**	**80.9**	**83.3**	**88.2**	**92.7**	**102.5**	**111.8**	**113.3**

Source: Clarksons

From the above it can be seen that the European market for LNG is quite stable as gas is distributed by the utility companies for household cooking and heating also.

Japan, Taiwan and Korea are importing about 72 % of the world LNG and their consumption is expected to continue to increase in the coming years.

While LNG requirements of Europe are catered to by Algeria, CIS (Former USSR) and within Europe, the requirements of Japan are met for by the Middle East, Indonesia and Malaysia. USA gets its supply of LNG from within or from Canada.

India is planning to import its LNG from Qatar, Bangladesh, Oman, Middle East, etc. To find out what is the requirement of importing LNG in India , we shall in the next chapter deal with the present energy scenario and the proposed upcoming projects for LNG, in India.

CHAPTER III

INDIAN ENERGY SCENARIO AND LNG

Energy plays a vital role in the development of a country be it a developed or developing country. It plays an important role in enabling and sustaining development most obviously by under pinning the economic growth of a nation and raising overall standards of living. In developing countries energy is crucial to economic and social aspirations but access to reliable commercial energy sources remain limited. Building an effective energy sector is costly and complex particularly when limited financial resources must also meet other pressing development needs. Energy is also essential for fuelling power generation plants, construction, domestic consumption, heating, transportation, industrialisation etc. As India is developing at a very fast pace and is going in for industrialisation, power generation, construction etc in a big way, it has a tremendous appetite for energy. India primarily depends on coal and oil for its energy and it is time that now gas be looked at as an major alternate source of energy. In this chapter we shall try to analyse the role that gas could play in Indian energy scenario.

3.1 PRIMARY ENERGY CONSUMPTION IN INDIA

Prior to defining the role of gas in the Indian energy scenario it is necessary to define existing primary energy resources in India. Primary energy resources are divided into Non-commercial primary energy resources and Commercial primary energy resources, which can be explained in brief as follows:

3.1.1 Non Commercial Primary Energy Resources:

- Fuel wood is an important source of energy for cooking and heating in rural parts of India. The total forest area in the country adds up to nearly 75 million hectares. However, due to cutting down of forests there has been a gradual deforestation with adverse impact on environment.
- Fuel wood is supplemented by dung and crop residues in meeting the domestic energy needs of rural areas. The annual availability of wet dung is estimated to be about 960 million tonnes. Total availability of crop residues is estimated to be 450-500 million tonnes. The draught animal population in the country has been estimated at 70 million and animal energy continues to be used in agriculture operations and for rural transportation.

3.1.2 Commercial Primary Energy Resources:

- **Coal**: India accounts for about 0.8 percent of total geological reserves and 5.7 percent of proven reserves of coal in the world. The geological reserves in the country are estimated to be about 205 billion tonnes and proven mineable reserves are estimated to be 72.7 billion tonnes.

- **Lignite**: Lignite reserves are estimated to be at 27.45 billion tonnes and lignite deposits have been found to be suitable for power generation. Considerable emphasis has been laid on exploration of lignite in some states of India as they are located at a considerable distance from the coal fields.

- **Oil and Natural Gas**: India has about 0.04 percent of the worlds proven reserves of hydrocarbons. The prognosticated geological resources of hydrocarbons are estimated at 21.31 billion tonnes, of which 61 percent are offshore and 39 percent on land. Out of these, the geological reserves established are, however, only about 5.32 billion tonnes. It is assumed that half of the prognosticated resource represents natural gas, of which only 12 percent has till now been established.

- **Hydro Power**: Based on a survey conducted, the hydro electric potential is estimated at 600 BKWH (billion kilowatt hour). Extensive studies to identify sites for development of pumped storage were carried out and 63 sites were identified with probable potential of about 94,000 MW. There exists another potential of 6780 MW for exploitation through mini/micro hydel schemes. A number of such schemes are under implementation.

- **Nuclear Resources**: India has uranium resources of about 10,000 MW. Apart from this, there are also large deposits of thorium available in the country. The present estimates show that the known deposits may yield 363,000 tonnes of thorium oxide. Thorium resources, which used through breeder reactors, may produce 900,000 BKWH of electricity.

- There also exists potential of coal bed methane, oil shale and gas hydrates in the country. As per the present estimates available the potential is placed at 850 billion cubic meters of coal bed methane, 6156 trillion cubic meters of gas hydrates and 600 million tonnes of oil shale.

- **Non-Conventional Resources**: A large potential of non-conventional sources of energy also exists in the country, which include bio-gas, solar PV and solar terminal, bio-mass gasifier, wind power and small hydro power, etc. The exploitation of these resources is however, negligible.

We shall now see the trends in the commercial energy production and the pattern and growth of final energy consumption, in India.

Table 6 shows the trends in production of primary commercial energy in India since 1950-51 to 1996-97

Table 6

Production of primary commercial energy in India

	Units			**Production**			
		1950-51	**1960-61**	**1970-71**	**1980-81**	**1990-91**	**1996-97**
Coal	mmt	33.00	55.67	72.95	114.01	211.73	288.65
Lignite	mmt	-	0.05	3.39	4.80	14.07	21.00
Crude oil	mmt	0.26	0.45	6.82	10.51	33.02	33.87
Natural Gas	mcm	-	-	1445.00	2358.00	17998.00	22900.00
Hydro Power	Bkwh	2.52	7.84	25.25	46.54	71.66	68.62
Nuclear Power	Bkwh	-	-	2.42	3.00	6.41	9.01
Wind Power	Bkwh	-	-	-	-	0.03	0.85

Source: Ninth five year plan Vol. 1 Energy. - Government of India
(The figures for the year 1996-97 are provisional figures)

From above it can be seen that coal continues to be the main source of primary commercial energy followed by oil and natural gas. However, with the stagnation of crude oil in the recent years, there have been additions to nuclear power generation capacity as well as power generation from nuclear power plants. Table 7 shows the pattern of energy consumption in India.

Table 7

Pattern of energy consumption in India

(percent)

Year	Primary Energy			Final Commercial Energy			
	Commercial	Non Commercial	Coal	Petroleum Products	Natural Gas	Electricity	Total
1953-54	28.4	71.6	80.1	16.7	0	3.2	100
1960-61	34.7	65.3	75.3	19.9	0	4.8	100
1970-71	40.6	59.4	56.1	34.1	0.6	9.2	100
1980-81	47.5	52.5	47.9	40.3	1.1	10.7	100
1990-91	59.9	40.1	35.9	43.6	5.5	15	100
1996-97	67.7	32.3	29.3	46.8	6.9	17	100

Source: Ninth five year plan Vol. 1 Energy. - Government of India

The total final energy consumption increased from 84.5 mtoe in 1953-54 to 284.5 mtoe in 1996-97 at an implicit rate of growth of 2.86% per annum. The share of commercial energy in the final energy consumption has increased from 24.1% to 58.2% during this period whereas that of non commercial energy has declined from 75.9% to 41.8%. In per capita terms demand for primary commercial energy was 67 kgoe in 1953-54 and had increased to 234 kgoe in 1994-95. It is expected to increase to 648 kgoe by 2011-12. Though this appears to be a considerable growth, it is very low when it is compared to international per capita energy consumption levels which are predicted to be over 5000 kgoe, in developed countries. As can be seen from the above table the share of coal is declining in the final energy consumption whereas that of oil and gas and electricity is increasing. Oil and Gas accounted for nearly 54 percent of total final energy consumption in 1996-97, which goes to prove that India is interested in investing in cleaner fuels. According to the Indian Energy Policy, India is going to stress on the development of hydroelectric power, oil and natural gas, and nuclear power, leading to lesser pollution and maximising of the natural resources. As there is a growing overall need for energy in India, indications for expansion and investment in a gas market appear to be very good.

3.2 COMPARISION BETWEEN INDIA'S OIL AND GAS RESERVES, CONSUMPTION AND PRODUCTION

Oil and gas have very similar sources and exploration techniques, hence, it is worthwhile to make a comparison between the reserves, consumption and production of the two. Also, oil and gas can be mutually substituted in a wide range of energy uses.

3.2.1 Oil reserves, consumption and production in India

Next to coal, oil is the major source of energy consumption in India and the economy of India is progressively becoming oil intensive in view of the increasing share of petroleum products in final use of commercial energy. The share of petroleum products increased from 54.9% in 1970-71 to 70.4% in 1996-97 as per the Indian Government's statistics vide Ninth five year plan, volume II, Energy. The per capita consumption of petroleum products in India is about 87 kg as against world average of 900 kg. Production of oil in India in 1987 was 645 thousand barrels daily and it increased to 730 thousand barrels daily in 1991. However, production then started to decline and fell to 620 thousand barrels daily in 1993, where after it started to increase again and stood at 790 thousand barrels daily in 1997. On the other hand, consumption for oil has been increasing year after year. Consumption of oil in 1987 was 975 thousand barrels daily and increased to 1750 thousand barrels daily in 1997. The trends in production and consumption of oil are illustrated in Table 8 below:

Table 8

Production and consumption of oil in India

(thousand barrels daily)

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Production	645	680	730	730	700	640	620	705	790	770	790
Consumption	975	1070	1165	1210	1235	1295	1315	1415	1535	1665	1750

Source: BP World Statistical Review, 1998

With a growing deficit between availability and demand for crude and petroleum products in the country there is tremendous pressure on the balance of payments. Even with a subdued international crude oil market, the import bill of the country is about 30% of its export earnings. In an oil price shock like those witnessed in 1973, 1981 and 1991, India is vulnerable to a heavy drain of foreign exchange and consequent macro-economic instability. Currently, India’s import bill for crude and petroleum products is placed at about US$ 9 billion per year and is expected to go over to US$ 10 billion (taking an oil price of US$ 17/bbi) by 2001-02. It has been observed that for every one percent increase in national income, the demand for petroleum products grew by 1.1 percent.

With proved reserves of oil at end 1997 standing at 4.3 thousand million barrels (amounting to 0.4% of proven world reserves) and keeping the fact that demand and consumption for oil is increasing faster than production, there is a need to enhance the pace of exploration and development in the oil sector and also look at an alternate source/s for exploitation.

3.2.2 Natural Gas reserves, consumption and production in India

Natural gas has in some parts of India been used since the 1960's. About 60% of natural gas is produced along with crude oil as associated gas and rest is produced as free gas. Natural gas is currently the source of half of the Liquefied petroleum gas in the country. Natural gas, being environmentally friendly and clean, has started to gain a lot of importance as a fuel/feed stock for power plants industries, iron and steel plants, etc, in India and has come to be recognised as the fuel of the next century. The reserve position of natural gas as per the statistics of the Ministry of Petroleum and Natural Gas, is as under:

Prognosticated resource base:	21 billion tonnes (+8 billion tonnes deep water)
Established geological reserve:	5.8 billion tonnes
Balance recoverable reserve:	1.3 billion tonnes (o+oe)

The resource base of hydrocarbons in the country is about 29 billion tonnes of oil and oil equivalent (o&oe) gas. Out of this only 5.8 billion tonnes of geological reserves have been established through exploration, which leaves a substantial resource base unexplored.

Table 9 illustrates the production and consumption of natural gas in the last few years.

Table 9

Production and consumption of natural gas in India

(trillion Cubic meters)

Year	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Production	7.7	8.9	10.7	12.4	14.2	15.9	16.1	17.3	18.8	20.4	21.4
Consumption	6.3	7.3	10.7	12.5	14.1	15.8	16.3	17.4	19.6	21.7	24.4

Source: BP World Statistical Review, 1998

It can be observed from the table that in the initial periods the production and consumption of natural gas has been more or less going hand in hand, but in the last few years the consumption of natural gas has been higher than production. This gap between production and consumption is likely to grow wider in the coming years.

So far, the exploration and production of oil and gas has predominantly been in the hands of two national oil companies "Oil and Natural Gas Corporation Ltd" and "Oil India Limited" and distribution of the gas has been with the national company "Gas Authority of India Ltd". However, with the growing deficit between the availability and demand of both oil and gas, Government of India has started inviting private investors to increase exploration and production efforts in the country to augment oil and gas production.

Also to harness a new source of energy, the Government of India, in 1997 approved a Coal Bed Methane (CBM) policy for exploration and exploitation of CBM gas.

3.3 INFLUENCE OF PRICING ON GAS TRADE

Natural gas as a substitute for oil, could technically absorb almost all of the fuel oil market in industry and electricity generation and the entire gas oil market in industry and the residential/commercial sectors. But in practice, the limits of technical demand for gas are set by its price relative to competing fuels and by government policies. In fact in the past use of natural gas for electricity generation had been discouraged by some governments since it was not consistent with the premium characteristics of natural gas whereas other governments sought to expand the market for natural gas by introducing pricing controls on gas or higher tax levels on competing fuels.

The price of bulk natural gas is almost invariably determined by long term contracts with producers, but end use natural gas sales are generally controlled or regulated by the governments, with the exception of sales to utilities or large industrial customers, prices for which are often negotiated independently. Virtually all governments also control and regulate prices of electricity, and there remains many instances where prices of natural gas are set by governments in order to support achievements of specific regional development or social goals unrelated to the cost of supply.

Natural gas has to be priced competitively with alternative fuels at the point of burning if markets are to be secured, retained and expanded. Although the situation differs markedly from country to country, natural gas prices have often been slow to adjust to the changes in price of oil, seen in the last more than 20 years. In part, this is a reflection of the nature of natural gas business, which requires dedicated and capital intensive infrastructure and long term contract arrangements. But it is also due in some cases to specific elements of national policy alluded to above.

Two critical issues come to mind while looking at the relationship between market penetration and natural gas pricing, which are :

1. What price level, at the input to the national transmission grid, can importers afford to pay and still be able to sell the contracted quantities in a competitive market?
2. Do these prices, after deducting production and transportation costs, result in a return to producers adequate to encourage production of gas to export.

These are complex issues and precise answers to them will vary from case to case. In particular, the amount importers can reasonably be expected to pay will be affected by considerations such as:

- Age, capacity and expected utilisation rate of existing distribution systems,
- Distribution of existing and incremental natural gas supplies to alternative markets,
- Security considerations,
- Structure of domestic taxation on energy products,
- Expectations about future price developments of competing fuels.

The producers will base their decisions on whether or not to export gas, on factors such as:

- Cost of production,
- Fiscal and price regimes,
- Alternative uses.

The critical issue appears to be whether the gas producers desire for economic return can be reconciled with competitive prices in consumer/end user markets. During the late 1970s and early 1980s, this became a highly politicised issue as the producers sought to increase their export prices to oil prices on a thermal equivalent basis. Inevitably, this led to disputes between exporters and importers, which in some cases involved national governments. In 1980-86, imported natural gas prices were relatively inelastic to demand due to inflexible contract provisions and the entrenched position of buyers and sellers. As a result, LNG was priced out of many markets, especially in the United States and Western Europe. During these years, in Europe natural gas went from its historically large discount compared to crude oil, to a premium in 1986. It was only in 1989 and 1990 that natural gas returned to its traditional discounted relationship with oil. But what of the future, and in particular the relationship between pricing and trade.

Unless there is some unforeseen advancement in technology, natural gas is regarded as the least offensive of fossil fuels, while its only other real competitor, nuclear power, is discredited for its own reasons. Most experienced market observers believe that trade in natural gas will expand rapidly in future as:

- There is a definite change in regulatory attitudes to gas
- There is growth in the US and Far East spot markets
- There is a desire on behalf of producers to export as much gas as possible
- Oil production is subject to quotas and uncertainty.

There is a widespread feeling that demand for natural gas is on track for a period of sustained growth which will outpace other fossil fuels. Hence there is reason to believe that it will continue to capture an increasing share of the global energy market. Furthermore, given that there are substantial geographical differences between the areas of supply and areas of demand, worldwide trade in natural gas is likely to increase at a rate faster than consumption.

The elements favouring natural gas may be compelling enough to promote its use, even if gas prices rise to a premium over oil on a BTU basis. However, this is not to argue that development of trade will be completely immune to price, a fact which now appears to have been recognised by buyers and sellers alike. But nevertheless, gas prices in the future are unlikely to prove the stumbling block to the development of trade.

Gas Authority of India Limited was formed by the Government of India, to handle the post exploration activities relating to transmission, processing, distribution and marketing of natural gas and its fractions and byproducts. GAIL's philosophy of gas handling is based on the effort to optimise the economic use of natural gas and its fractions and with perspective, GAIL established LPG plants enroute the pipeline, where propane, pentane and SBP solvent are also produced.

The supply of gas is made under a contract, the terms and conditions of which are generally standardised. General terms and conditions of contract pertain to:

- Duration of contract
- Quantity of gas to be supplied
- Minimum guaranteed off take charges or take-or-pay clause
- Price of gas
- Transportation / service charges
- Billing and payment terms.

Until October, 1997, prices of natural gases were determined by the GOI (Government of India). However, as a part of overall liberalisation of the economy, pricing of natural gas has now been linked to international basket of LS/HS fuel oil (low sulphur/high sulphur). For the year 1997-98 the price of gas was kept at 55% of above basket. This has been increased to 65% in 1998-99 and will be increased to 75% in 1999-2000 with a view to achieving 100% parity in the following years.

3.4 ROLE OF NG/LNG IN THE INDIAN ENERGY SCENARIO:

As has been discussed and observed earlier in this chapter, coal and oil being the major sources of energy in India, and specially keeping in mind that the quality of coal is not too good, there is a great deal of pollution which is hazardous not only to the local but also the global environment. There is therefore a great potential for a cleaner fuel in India. The role that natural gas or liquefied natural gas can play in the Indian energy scenario is as discussed in the ensuing paragraphs.

Natural gas is typically the best energy value for industry. Natural gas is clean, safe to handle, and common to most equipment. What this means to industry is: low maintenance expenses due to clean burning, low liability due to its safety and ease and variety of equipment acquisition due to how common natural gas is as an energy source.

Stability is another area, which impacts economics as well. A constant supply of high quality natural gas, regardless of weather, war, embargo or other supply disruptions has enormous value to a plant. Stability also means stable prices. Natural gas prices have been historically low and are expected to remain that way for years to come. The reason for this is that the global supply is much greater than demand. Depending on a particular country's location and consumption volume, purchase of natural gas from LNG with multiple year, fixed price contracts can be made. Stability also means consistent quality. Natural gas from LNG has consistent fuel consistency, Btu value and quality. These features are essential in heating critical applications such as glass manufacturing and electronics to name a few.

Natural gas burns clean, therefore it is easy for a business to comply with tough State regulations and state air pollution laws. It reduces the expenses a business has to incur on costly smokestack cleaning devices and reduces the maintenance on all associated equipment.

Natural gas is also important for the transportation industry. Natural gas a non-reactive hydrocarbon, is refined and separated from other gases present and, since it is the only hydrocarbon that does not photo-chemically react to form ozone, it has the cleanest burning and, therefore, has a reduction in particulate matter and other emissions. LNG is also being considered widely for use in transport industry, in locomotives, buses and heavy duty trucks. Some of the lead engine manufacturers are also developing either dual fuel or dedicated fuel engines to accommodate LNG fuel use. In India CNG (compressed natural gas) is used as an alternate source of fuel. Though this is not so commonly used it is fast gaining ground. CNG is pressurised and stored in welding bottle-like tanks at pressures upto 3,600 psi. Typically, it is of the same composition as the local pipeline gas with some of water removed. CNG is delivered to engines as low pressure vapour and is often misrepresented as the only form in which natural gas can be used as vehicle fuel. CNG can easily be produced from LNG and is typically a better quality fuel than CNG from a pipeline. Advantages of LCNG(compressed natural gas from liquid natural gas) over pipeline CNG are:

- as there will be no water content, there will be no requirement for gas drying, nor fuel system contamination
- as there will be no oil in the gas no coalescing filter equipment will be required as there will not be any vehicle fuel system contamination
- as it will have consistent gas quality, every vehicle will get the same BTU and fuel composition every time they fill up
- a single cylinder pump will be required, which will lead to fewer moving parts, less reciprocating mass than in a typical compressor leading to lesser noise and greater reliability.
- We will have the ability to add LNG dispensing, thereby increasing flexibility. There will be no need to purchase an entire LNG fuel station, just LNG dispensing modules can be added.

Besides being useful in the industrial sector LNG has a very major role to play even in the community sector. A municipal supply of natural gas attracts industry to a community and attracting industry means economic development and improved quality of life for citizens. A natural gas town is where businesses want to be, and where its employees want to live.

3.5 FORECASTING OF LNG TRADE IN INDIA

Currently oil and natural gas constitutes about 38% of the energy consumption in the country and with increasing reliance on road transport and the sustained growth rate of the economy, this percentage is expected to reach over 40% in the next few years. Recently, natural gas, being environmentally friendly and clean, has gained a lot of importance in the fertiliser industry, power generation, iron and steel and in the transport industry. Natural gas requires special infrastructure for distribution and with the setting up of the Gas Authority of India Ltd, in 1984, Government of India took the initiative to create an infrastructure to transport gas to various locations in the country.

India has 26 sedimentary basins comprising both on land and offshore areas. Of the total land area of India of 3.29 m sq km an area of about 1.34 m sq km of these 26 basins is onshore and 0.38 m sq km in offshore areas. Most of the basins are under various stages of active and/or reconnoitre exploration and have been classified into 4 categories as a function of geological knowledge of basin presence and/or indication of hydrocarbons and current status of exploration.

The Oil and Natural Gas Corporation (ONGC) and Oil India Limited (OIL) are the main producers of gas. OIL is operating in the Assam and Rajasthan areas where as ONGC is operating in western offshore fields and in other States. Contracts in respect of five medium sized fields have been entered into for development through joint ventures of ONGC/OIL with private parties and contracts for 13 small fields have been signed for development by private parties. Production of gas from some of these areas has started.

Gas produced by ONGC is marketed by GAIL and gas produced by OIL is marketed by OIL, except in Rajasthan where GAIL is marketing the gas. Gas is allocated to consumers by the Ministry of Petroleum and Natural Gas on recommendations of the Gas Linkage Committee (GLC) which is an inter-ministerial committee with representatives from the Planning Commission and Ministries of Finance, Power, Chemical and Fertilisers and Steel and gas is allocated on the basis of Imputed Economic Values of gas use in various sectors.

Currently, since crude oil production has to be maintained at maximum possible levels, production of associated gas has exceeded handling capacity and this has resulted in flaring up of gas. ONGC, OIL and GAIL have now set up transportation and compression facilities in order to progressively reduce flaring of gas. OIL is also implementing a scheme of underground storage of excess gas.

Projections of gas requirements made by various agencies indicate a wide and growing gap between demand and supply. To meet this gap GOI has taken steps to import natural gas from the Middle East. An MOU was signed with Iran in 1993 and a feasibility study for laying a pipeline between Iran and India is under consideration. Due to technical and political reasons, these projects are held up. Prospects for importing gas from Bangladesh and Myanmar to eastern/southern parts of the country are also being explored.

The feasibility of importing LNG from sources such as Middle East, South East Asia, Australia etc. are being explored to meet the additional demand for gas. GOI set up a core group to study the feasibility of importing LNG and the group has recommended an integrated chain consisting of a liquefaction plant located overseas with storage and dedicated port facilities, cryogenic LNG tankers for transportation of LNG, receiving terminal with storage tanks and regasification facilities and a delivery system of pipelines and compressors to supply regasified LNG to fertiliser and other consumers. The implementation of this project is proposed in two phases with capacity in each phase being 3.5 million tpa (tonnes per annum). Five possible sources of LNG, namely Qatar, Abu Dhabi, Malaysia, Indonesia and Australia have been identified by the group.

By the end of January 1998, about 20 projects involving LNG receiving terminals had received a government stamp of approval. India lacks an efficient regulatory framework to govern the mushrooming of LNG related projects across the country. However, there are plans to set up a new Gas Regulatory Authority (GRA) whose exact remit is under discussion and a new Gas Act is also likely to come before parliament. Under the act, pricing of gas will be decided by the parties involved in a transaction and not dictated by the government as is now the case.

Conservative estimates say India will be importing at least 10 million tonnes of LNG a year by 2010. It is estimated that over the next few years India will need to add an extra 10,000 mw of electricity generating capacity a year if it is to maintain industrial growth at 7% a year. Petronet-LNG was set up by GOI in 1997 as a joint venture between India's four principal oil and gas companies GAIL, ONGC, IOC (Indian Oil Corporation) and BPCL (Bharat Petroleum Corporation). GAIL, by virtue of its status as India's monopoly gas supply agency, is the driving force behind Petronet and has drawn a draft MOU for potential consumers of 7.5 m t/y of LNG it plans to import. Petronet signed India's first ever gas deal in December'1998 when it agreed to purchase 7.5 m t/y of LNG from Ras Laffan LNG Company of Qatar. Petronet is planning to build two LNG receiving terminals at Dahej, in the western state of Gujarat and Cochin in Kerala.

Other LNG projects underway, independent of Petronet-LNG, include Enron's well advanced proposal for LNG facilities at Dabhol, British Gas's proposal at Pipavav, Total's two joint ventures with Hindustan Petroleum and Tata Electric Company and TIDCO tenders at Ennore, outside Chennai.

The proposed LNG ventures in India are as detailed in Table 10, and a map showing the proposed LNG terminals is enclosed as Annexe 1.

Table 10

Proposed LNG Joint Ventures in India

Location	Capacity Million t/y	Consortium
Ennore (Tamil Nadu)	2.5	Petronet-LNG+Partners
Mangalore (Karnataka)	2.5	Petronet-LNG+Partners
Mangalore (Karnataka)	2.5	Finolex
Cochin (Kerala)	2	Petronet-LNG
Vizag (Andhra Pradesh)	2.5	Total/Hindustan Petroleum
Trombay	2.5	Total/Tata Electric
Pipavav (Gujarat)	2.5	British Gas/Pipavav Port
Pipavav (Gujarat)	2.5	Gujarat State Govt.+Partners
Dabhol (Maharashtra)	5	Enron/Ge/Bechtel/MSEB
Ennore(Tamil Nadu)	5	Tidco+Partners
Kakinada (Andhra Pradesh)	n/a	CMS Energy/Unocal/gyk industries
Kakinada (Andhra Pradesh)	2.5	Ispat Energy
Hazira(Gujarat)	2.5	Gujarat State Government.
Dahej (Gujarat)	2.5	Petronet-LNG+Partners
Hazira(Gujarat)	5	Reliance/ELF/Tractebel
Hazira(Gujarat)	2.7	Shell/Essar
Tba	n/a	Petronet-lng+partners
Tba	n/a	Petronet-LNG+Partners
Jamnagar	5	Reliance/ELF/Tractebel

TBA: to be announced

Source: Petroleum Economist, April-1998

Most of the projects mentioned above are expected to commence by the year 2000/2002, which goes to prove that not only the private sector but also the Government realises the importance of Gas in the energy sector and is, therefore, investing heavily in the same. Also, it is seen that there are a lot of foreign investors who are ready to help.

Some of the companies have applied to set up fully-owned Indian subsidiaries and want to invest heavily in Indian LNG related and power related business in the coming years. Therefore, issues relating to project finance, design and development of import terminals are dealt with at large in the next chapter.

CHAPTER IV

LNG PROJECT FINANCE AND DESIGN AND DEVELOPMENT OF IMPORT TERMINAL

In the preceding chapter we have seen that there is a tremendous demand for energy in India and that India is in the process of initiating a number of LNG projects. Since local production of natural gas is not sufficient to meet the growing demands of gas, it is necessary to import the same. However, since every LNG project requires a tremendous amount of capital, it is not possible for a single party to undertake the entire project independently, projects are usually undertaken as a consortium of various companies and government agencies, preferably with a foreign investor. Also the investment is usually for a long period of time, ideally for 18 to 20 years. Hence, in the first part of this chapter we shall briefly deal with LNG project finance. However, since LNG trade is a very closed trade, prior to embarking on the project finance, elements in LNG project and the LNG chain shall be explained. Also since India is going to import LNG, we shall limit the scope in this chapter to the aspect of basic design data and development of LNG import terminal, selection of site, safety and other important aspects pertaining to an import terminal.

4.1 LNG PROJECT FINANCE

Every LNG project comprises of several distinct elements which are necessary for the successful implementation of the project. An LNG chain has to be developed and maintained throughout the period of project. We shall deal with the basic elements in the LNG projects i.e. the LNG chain, LNG project planning and LNG project finance.

4.1.1 Elements Of LNG Projects

The main elements which are necessary for the implementation of a successful project are:

i. **Source of natural gas**: A successful LNG project must have sufficient proven reserves of natural gas to support liquefaction capacity for a minimum of 18 to 20 years. To ensure adequate deliverability of gas even at the end of the project, reserves ought to be 25 to 35 times larger than the annual capacity of the plant.

ii. **Liquefaction facility**: liquefaction facilities are large and expensive and are the costliest link of the entire chain, costing several billion dollars. A typical set of facilities would include facilities for stripping liquids from natural gas, processing and export of liquefied petroleum gas, the liquefaction facility itself, insulated pressurised LNG and LPG storage tanks with sufficient capacity to load the largest tanker expected to call, a jetty and LNG loading facilities with sheltered, deep water access to the ocean and associated infrastructure, including roads , electric power, water and housing for employees.

iii. **Dedicated fleet of tankers**: each project requires a dedicated fleet of LNG tankers, which are amongst the most expensive and complex merchant ships ever built. The number of tankers required for a project depends primarily on distance between the liquefaction plant and the customer. In general transportation costs increase with increase in distance.

iv. **Regasification terminals**: LNG can be unloaded only in specialised terminals, which typically include a jetty and unloading facilities, LNG storage equal to at least a single tanker cargo, regasification facilities and connections to pipelines to ship the gas to customers. The cost of regasification terminals varies with capacity, local construction costs and the amount and type of site preparation costs.

4.1.2 **The LNG chain**

As seen above the capital investment required for a LNG industry is massive and every individual project needs to be carefully structured with an integrated plan to ensure a robust chain with all the links forged to ensure that none of them are weak. The starting point for considering the LNG chain is the recognition that each of the elements in the chain (gas exploration and production, pipelines, liquefaction plants, loading terminals, ships, discharging facilities, terminal, sendout facilities, regasification plants final delivery facilities and end use) forms an integral part of a LNG project and can only be properly satisfied and economically used if all parts of the chain remain commercially and technically robust and compatible .

The LNG chain is made up essentially of the following links:

- The installations for production, gathering and transport of natural gas from reservoir to liquefaction plant.

- The liquefaction plant, which is normally located on the coast of the exporting country includes the following facilities:

    1. Raw gas purification units for removing matter that is corrosive, inert or likely to solidify during the liquefaction process.

2. Liquefaction units themselves, which produce the LNG for storage and tanker loading installations.

3. Utilities (heat evacuation, electricity, air, nitrogen, soft water, etc).

4. General facilities (administrative buildings, workshops, warehouses, laboratories, residential area, airport, etc.)

- Methane tankers, the number of which depends on the transport distance.

- The regasification terminal, located on the coast of the importing country which stores LNG upon unloading from methane tanker, regasifies it and delivers it to customer.

Also the LNG projects are international in character as they have multiple partners, which requires all partners to agree on the same project at the same time and also remain in agreement throughout the life of the project. Selling of LNG is not a one time transaction, but is continual in nature and will last for at least 18 to 20 years. In the same way, buyers of LNG are also limited and because of the magnitude of investments involved, such projects have been developed until now only on the basis of long term commitments. Investors in all parts of a LNG chain will thus not only need to make sure that the whole chain is complete, but also ensure that each part of the chain is thoroughly reliable and that there is no chafing between the links. The need for full reliability can be tackled through three main routes, each of which have implications for the shipping segment:

- It is prudent for the investors in each link of the chain to have some spare capacity. This can only be taken a little way, otherwise the potentially idle investment becomes an unjustifiable burden. The risk abatement benefits of over investment are normally greatest at points in the chain (eg.

Loading or discharging facilities) that would be unique if only planned to cater for normal operation.

- The cheapest, if most difficult, method of containing the set of technical risks in a chain project is to build in reliability through design, construction and the application of stringent standards for maintenance and operations. During project operation it is the ships which are highly visible to the land based facilities that they serve, they are also the facilities which are seen as most exposed to natural perils. Most importantly, the ships are involved at both the ends in the chain, i.e., at the loading and discharging ports, and hence, come under close scrutiny from both ends. The transporter can only flourish if he can command confidence of those he serves.

- The strength and reliability of an LNG chain is not just a matter of technical standards adopted but also of motivation of individual components of the chain.

Price competition plays a major role as LNG must be sold cheaply enough to compete with other forms of energy and also at a high enough price for the gas producer to make a profit. Hence, the factor that makes up the difference between two prices i.e. the capital cost of the entire LNG chain, must be kept sufficiently low and the structure of the project and the scales of reward and incentives for each part of it should be equitable to all parties.

4.1.3 Project Finance

As discussed earlier capital requirements of an LNG industry are greater than in any other sector of marine operations. There are many similarities in the geological occurrence and in exploration, development and production process for oil and gas.

However, gas differs from oil in the sense that gas projects are more costly than oil projects and the total costs of LNG projects have reached a point where the largest oil companies are also finding it difficult to finance it individually. New means of raising capital are needed and one method is widening of the equity ownership pattern in the project so that gas distribution companies in the importing countries are joined by the government agencies of the exporting countries to help oil companies finance the project.

The total capital cost of an LNG project is very high and includes all aspects of gas liquefaction, marine transportation, and regasification. As per the Fairplay Report on "LNG CARRIERS", for a 5.0 m cu.m/year trade the total cost would fall with in the range of US$ 500-1000 million depending on the voyage length. Hence, freight costs constitute major variable in delivered cost of LNG. Table 11 shows some shipping charges for some existing and projected schemes:

Table 11

Shipping charges for LNG

Source	Destination	Distance (nautical miles)	Quantity (mrd cu.m./yr.)	Shipping Price $/million BTU
Marsa el Brega	La Spezia	990	2.4	8.50
Marsa el Brega	Barcelona	1060	1.1	9.00
Marsa el Brega	New York	4540	0.3	40.50
Arzew	Cove Point	3600	6.5	33.40
Skikda	New York	3470	1.5	31.50
Iran	Japan	6770	4.0	59.00

Source: Fairplay report on LNG tankers.

The single largest cost item the LNG carrier, constitutes about 50 to 60% of the total cost in short trades and about 65 to 75 % in the longer trades. For a trade involving the export of 5.0 mrd. cu.m/year, total non marine costs would be approximately US $ 265 million, of which, the liquefaction plant and loading terminal would cost approximately US$ 230 m and the receiving terminal US$ 25m. If the trade requires 4 ships costing US $ 100m each then the total project cost would be US$ 665 m. For longer trades more vessels will be required to manage the same volume and thereby the project costs will increase for the project and ships. The operating and capital costs for a typical LNG Carrier are given in Table 12.

Table 12

LNG carrier capital and operating costs*

Item	Total cost over 20 years (million $)	Percentage of Total Cost
Capital cost	100.0	23.0
Interest charges	30.3	7.0
Crew cost	35.2	8.1
Fuel	27.3	6.3
Stores and tools	5.0	1.1
Boil off	53.2	12.2
Gas loss during loading	12.9	3.0
Vessel inerting cost	5.9	1.4
Maintenance & repair	53.5	12.3
Insurance	64.5	14.8
Port charges	31.7	7.3
General overheads	15.2	3.5
Total	**434.7**	**100.0**

Source: Fairplay Report on LNG Carriers

* The costs given above are based on 125,000 cu.m. ship with an operational life of 20 years and service speed of 20 knots engaged on a 3000 nautical mile trade. It is assumed that 30% of capital is met by equity and 70% by borrowed money and amortised over 12 years with interest charge applying to the 70% of debt. Charges associated with the building period are included. Boil off used as fuel is included as total boil off.

The final delivered price of LNG is normally quoted as the cost at the receiving terminal. This overall price is made up of various variable prices that are integral part of the total project and are incurred throughout the transfer of gas from the producer to consumer. The main heads of these prices are:

a) well head gas price
b) gas delivery costs to the liquefaction plant
c) liquefaction cost
d) marine freight charges.

There is usually some fluctuation in the non marine costs, but these prices are stable compared to widely varying marine freight costs.

The type of ownership that an LNG vessel has will affect the arrangements for financing the vessel. Until recently ownership of majority of the vessels in service or on order fell within one of the five main categories listed below:

- Government agencies of the producing countries
- Companies of importing countries that are arranging transportation
- Independents
- A consortium
- Major oil companies involved in LNG projects.

In the past, oil companies were responsible for financing a large number of projects. Now, it is, however, difficult for one company to generate all of the funds required to finance a large new LNG project. The financing of the earlier projects was carried out in a piecemeal fashion, with separate financing for liquefaction, transportation and regasification. With a view to aid the purchaser of a vessel, major shipbuilding countries of the world, USA, France and Norway, have each developed financing schemes which promote either domestic sales of ships or the export of ships.

However, now the ownership of the LNG projects has moved beyond the five independent types listed above and the new owners are multiple equity syndicates, with the gas utilities in the consuming countries, the major oil companies and the government agencies in the producing countries being the equity holders. This new ownership pattern is influenced to an extent, by the attitudes of the producer governments who wish to take a further interest in the export schemes in order to eventually assume greater control of other export activities.

Having dealt with project finance in the above paragraphs, we shall now deal with the basic design data and the development of an import terminal.

4.2 BASIC DESIGN DATA OF AN IMPORT TERMINAL

As indicated at the beginning of the chapter, we shall now study the basic design data that have to be established prior to commencement of the pre engineering phase of LNG import terminal. This is generally developed during feasibility and optimisation studies and include process engineering, ship, marine and project design data.

System evaluation and optimisation studies also require defined economic criteria, which are dependent on site location, current financial conditions, operating company guidelines etc. The basic design data is expected to include the following:

4.2.1 LNG Composition

Subject to the location of the proposed import terminal, alternate sources of LNG from existing export plants must be considered. Allowance must be made for ship boil off during transport and the subsequent effects on the properties of the LNG as delivered to the terminal.

4.2.2 Send-out Quality

Gas quality specifications generally include heating value, sulphur compounds, carbon dioxide, water content and hydrocarbon dewpoint. All potential sources of LNG are considered in assessing the range of imported LNG compositions. A review of the resultant gas product leaving the terminal is made to assess compatibility with the export gas specifications, which could be related to compatibility with existing distribution gas specifications. Blending of natural gasses from different sources within the distribution network should also be considered in assessing export gas quality.

If necessary, consideration must be given to blending lean LNG with propane or rich LNG with an inert gas, such as nitrogen, carbon dioxide or air, in order to meet the export gas quality. Care should be taken so that the introduction of components do not have an adverse effect on the export gas.

The variation in gas demand during a year is an important design parameter and is used to optimise the design of the storage, vaporisation and sendout system. Sufficient flexibility must be incorporated in the design of the terminal to enable the sendout of gas over specified capacity range. Gas utilisation varies, depending on location and application.

4.2.3 LNG ship data

Details of ships expected to deliver LNG to a terminal must be provided in order to evaluate marine and jetty requirements. Current ship sizes of up to 137,000 m^3 are in operation and larger vessels in the range of 160,000 to 200,000 m^3 are being considered for future use.

This will not only influence marine considerations and berthing facilities but will also have an impact on LNG ships unloading facilities. The design, safety and commercial criteria for ship operations generally require that a ship be unloaded in 12 hours, so that it can be turned around in 24 hours. With larger ships the unloading rates will increase, which in turn will result in larger unloading lines on the jetty and into the terminal. Facilities at liquefaction plants will also need to reflect these changes.

4.2.4 LNG tank data

Most recent LNG storage tank designs have used concrete outer tanks with either membrane or self supporting nickel steel inner tanks. The construction of larger, fewer tanks results in reconsidering in-tank pump sizing and installation philosophy.

4.3 SELECTION OF SITE FOR LNG TERMINAL

As in other industrial projects, one of the first concerns of the investor when he envisages building an LNG receiving terminal is the selection of site where the terminal will be located. The selection must combine the technical, environmental and economic aspects. Moreover, it must consider the specific characteristics of the area, in order to avoid surprises resulting from in additional and unforeseen costs during the further stages of the project. While selecting the site for an typical LNG terminal, besides the potential market survey, the legal and political context, the following issues need to be considered:

1. **Site preselection**: during the site preselection, attention needs to be paid to the onshore land availability or the possibility of reclaiming, the potential for future expansion, the topography of the land to ensure a sound geological base over which the plant foundations will be built, the on-land accessibility to the area, the tanker accessibility to the site, the surrounding (industrial area, population, environment, etc).

2. **Local site data**: the compilation of the local site data will try to determine the characteristics of all parameters that could affect the feasibility of the preselected areas, like the weather conditions ie. Temperature, wind rain, snow, storm, earthquakes etc., the sea conditions like water, draught, waves, current, tides, sea water temperature, ease of approach, dredging required, sea traffic and safe anchorage areas, etc.

3. **Geological site validation**: during this step, the suitability of the intended site will be checked with regard to soil conditions. All geological phenomena which could affect the plant feasibility, design and construction, or which could modify the risk level or the investment costs, will be reviewed. A review of the seismic faults in the vicinity and the potential soil liquefaction will be made to determine the geological site validation and area geology and soil properties.

4. **Preliminary assessment of environmental impact or limitations**: in this phase attention must be paid to surroundings and to the impact on the adjacent facilities, urban areas, etc. even though LNG is considered

as a clean industrial operation, there could be some constraints in the local regulations which could affect the terminal choice.

5. **Preliminary assessment of safety impact or limitations**: the proximity of neighbouring communities and facilities in the immediate area of the proposed terminal has to be considered from a safety as well as public relation point of view. While LNG terminals do not pose an immediate threat to surrounding communities, it is preferable to locate them as remote as possible from such areas. This is not only safer but also in most cases economical. For instance, being close to a community could make it necessary to bury the LNG tanks and this is a costly exercise and provides for little additional security to the facility. However, safety considerations can also be site specific for example if storage tanks are to be located near airports then construction in a vault may be necessary, given the combination of hazards specific to that site.

6. **Economical validation**: Proximity to an industrial environment may be convenient and economic, for instance, the possibility of using in place bunkering facilities. The potential for utilisation of other production facilities such as nitrogen and steam, if they are dependable and of acceptable quality and purity, have to be considered in the early stage of site selection. Other advantages could include the possibility of integrating two or more industries such as one providing its hot cooling water return to the LNG terminal for LNG vaporisation purposes, while receiving back low temperature cooling water, or the possible utilisation of the cold potential of the LNG in processes such as power generation, air separation, CO_2 liquefaction, hydrogen and helium production and commercial refrigeration. From an environmental stand point, an LNG terminal is a very clean facility with limited emissions of any type. The main environmental impact will be the disruption caused

by the construction of the facility itself and the major concern will rise from jetty construction and requisite dredging of the harbour and its approach. Of more concern is the discharge of cold water from LNG vaporisers into the marine ecosystem, if seawater open rack vaporisers are used. In such a case, cold water discharge should be located at a place in the sea where the dispersion characteristics would be favourable. Sometimes, the cold water discharge can be used, with a proper dispersion mechanism, to reduce the temperature rise caused by the warm water discharge from other nearby facilities, in which case, it has a favourable environmental impact.

4.4 SAFETY

Safety in an LNG terminal is a sensitive issue with not only technical ramifications but also social and political aspects. Thus it is important to address all these issues. In general, safety is the most important consideration in the design, construction and operation of an LNG import terminal. Existing design codes, standards and procedures are being continuously reviewed and updated and new standards are being developed to ensure that all new developments are incorporated, thus minimising risk and potential hazard to life and property. There is an ongoing activity in improving safety and reducing risk associated with LNG installations.

Process Hazard Analysis reviews and hazard operations studies must be used during project execution in order to ensure integrity of the facilities as they are being engineered as well as during subsequent operation. Risk evaluation and hazard analysis are employed for environmental impact assessment and to assist in site selection. This activity not only involves the LNG terminal but also extends to marine requirements for LNG ships approaching the terminal and berthing at the jetty.

Local authorities require safety assurances from all those involved in the installation of a new LNG terminal, often including independent expert opinion, before granting the necessary approvals.

For the safe operation of any LNG terminal it is vital to have a proper design of the emergency shutdown systems and communication systems as well as the monitoring and loss protection systems. Loss protection systems are designed in such a way that they respond automatically in the event of lack of operator attention.

4.5 SHIPPING AND STORAGE CAPACITY

To reduce the overall capital cost of an LNG terminal and to increase its profitability, it is necessary to optimise storage requirements, the number and capacity of ships and terminal send out capacity. This can only be achieved through a detailed shipping/storage study, which would take into account all the project parameters, sensitivities and constraints.

Some of the principal parameters required in the study of an LNG terminal are highlighted below:

For the Receiving Terminal:

- Number of berths
- Distance between sources and destinations
- Night berthing/unberthing conditions
- Statistical ship delays (number and length) due to fog, wind etc
- Average plant utilisation

For the Ships:

- Nominal size
- Average speed
- Unloading pump capacity
- Boil off per day
- Statistical unscheduled maintenance per year (number and length)
- Scheduled maintenance

For the Liquefaction Terminal:

- Liquefaction plant supply always available at the berth or statistical delay
- Berthing requirements (length and delays)

Using simulation programs, sensitivity analyses are made to find the economic optimum for a given project. Normally the first of these studies is to determine the ship requirements. In many cases the capacity of the ships chosen to deliver LNG is significantly higher than the needed delivery rate. This extra shipping capacity is usually obtained because ships must be added in integral increments of equal capacity and they cannot be matched exactly to the required terminal capacity. This extra shipping capacity is not economically optimal. For more optimal economics the terminal capacity needs to be adjusted to match the ships or vice versa. This normally has to be decided before a final decision on the storage requirements can be made, since its impact on the overall economics is much greater than the storage issue.

In determining the ship requirement it is also necessary to specify the desired availability of the terminal. It is usual to specify a 98% average terminal availability.

The 2% which is lost, is divided equally between losses due to shipping and storage and losses due to other factors related mainly to plant operation.

In the optimum study, storage capacity can be traded to some degree for ships. The cost effectiveness of this trade is highly dependent on the project. However, only a shipping simulation study can determine the economic incentive to choose increasing storage over increasing number of ships. The constraints of the project have to be considered in the study and usually storage capacity must be based on more than economic criteria, especially for a receiving terminal where there may be a requirement for maintaining a minimum strategic storage capacity.

4.6 STORAGE TANKS

There are three types of storage tanks, which presently, are most commonly used. An evaluation should be carried out for a particular location to choose the correct design. Following are the three types of storage tanks:

1. **Single containment system**: here a failure of the inner tank may result in a failure of the outer tank. The outer tank is designed for the purpose of holding insulation and for containment of vapour but not the cryogenic liquid, and is made of carbon steel. The inner tank is normally made of 9% nickel steel, which has adequate notch toughness properties. A bund is normally provided in this type of tank, to contain an LNG spill in the event of tank failure. However, the bunded area would allow the rapid vaporisation of a full spill creating a dangerous cloud formation which could drift outside the plant limit. Similarly, if ignited in place, it would create a high intensity heat radiation.

2. **Double containment system**: this system would hold the cryogenic liquid in the event of an inner tank failure, but the vapour may escape.

The outer wall is normally made of concrete (post tensioned) sometimes with an earth embankment, which will withstand the cryogenic liquid impact if the inner wall fails. A similar double containment tank consists of a single containment tank, as above, surrounded by concrete dike of same height as the tank, normally 1 to 3 meters away from the tank. This dike is able to hold the liquid in case of inner tank failure.

3. **Full containment system**: here both the liquids and vapours are contained by the outer wall and roof. Unlike the double containment tank with a carbon steel or stainless steel roof, the full containment tank typically has a reinforced concrete roof. The insulation system in the tank wall usually consists of a resilient blanket on the outside of the inner shell and perlite powder in the annular space. A carbon steel or epoxy liner covers the inside of the outer wall and performs as a vapour barrier to avoid moisture penetrating the annular space. A bottom wall system of insulation and 9% nickel plate is used extending about five meters from the bottom. The bottom foam glass insulation minimises heat leaks into the tank and it often contains heating coils to avoid frost heave problems. Alternatively, if the tank is built on an elevated base slab, bottom heating is achieved by air circulation, either natural or forced.

In the design of an LNG terminal an economic study can be made to determine the optimum design pressure of the storage tanks. The use of higher pressure tanks could allow the elimination or reduction in the capacity of ships vapour return compressors, while low pressure tanks would necessitate use of compressors. The tanks are normally protected against over pressure by control valves to the flare, trip valves on rundown lines and relief valves to the atmosphere. They are protected against vacuum by hot gas from the process plant, trip off loading pumps and boil off gas compressors and ultimately by vacuum breakers to the atmosphere.

Normally, the tanks have top connections only. No connections for pipelines or instruments are made at the sides or bottom of the tank, to ensure its mechanical integrity. The internal piping may permit top or bottom filling to minimize the possibility of stratification when feeds of different densities are fed to the same tank. The tanks are often provided with internal recirculation pumps to promote mixing of the tank content in case an unacceptable build up of superheat develops which could result in dangerous "roll over" situation.

4.7 LNG VAPORISERS

Vaporisation is generally carried out in two types of units:

- Open rack vaporisers (ORV) and
- Sub merged combustion vaporisers (SCV)

These two account for over 80% of the installed vaporisers worldwide. The balance of the vaporisers use other types of heat exchangers such as plate fin units and shell and tube units. These are usually associated with use of LNG cold recovery for electric power generation or air separation.

ORV units use seawater or river water to vaporise LNG inside vertical tubes while water runs down the outside of the tubes as films. These units are relatively expensive to install requiring extensive water supply and return systems, but are cheap to operate. In SCV units, fuel is burnt and the fuel gases heat a water bath in which a coil is located. LNG passes through the tube side of the coil and is vaporised. These units are cheaper to install but expensive to operate as they consume upto 1.5% of the vaporised LNG as fuel gas.

The decision on which type or types of vaporiser to install is generally determined on the basis of an economic study, since both types are well proven. With more LNG terminals being installed to supply base load duties, such as electric power generation, an increased use of open rack vaporisers is foreseen. The choice of vaporiser type must also consider the environmental impact of these units. ORVs export cold water and require some treatment of the water to inhibit corrosion/algae growth. The local aquatic conditions can be affected by these aspects. SCVs burn fuel and therefore contribute carbon-di-oxide to the green house effect as well as generating NOX. Noise and disposal of excess water containing treatment chemicals must also be considered.

Despite the increase in LNG receiving terminal construction activity, vendor choice is a problem area with only a small number of vendors of each of the two basic types. This can create problems where financing places restrictions on equipment supply.

4.8 VAPOUR HANDLING

Heat in-leak to storage tanks and lines on a receiving terminal produces vapour. During ship unloading, pumping energy and volumetric displacement increases vapour evolved from storage tanks. Vapours must be returned to the ship being unloaded, to maintain cargo vapour space pressure and can be used to provide fuel for fired vaporisers. Other disposal methods, other than flaring, are dependent on the possibility of routing low pressure gas to a nearby user such as a power station. However, due to variable quantity of vapour available this is usually not economic unless it is supplementing vaporised LNG being sent out at low pressure. Vapour compression to high pressures for send-out to a gas transmission system is an option but can be difficult to justify economically.

4.9 SUPPORT SYSTEMS

One of the largest utility systems on a receiving terminal is the sea water system. Sea water is used in the open rack LNG vaporisers as the heat source. Where terminals are located close to power stations, it is feasible to link the two systems. Two options can be considered:

- Hot water returned from the power station cooling system can be used to vaporise LNG, thereby reducing vaporiser size and water flow, alternatively
- Seawater supply to the power station can be cooled by extracting heat for LNG vaporisation, thereby passing the benefits on to the power station condensers.

Nitrogen is required for purging and maintenance purposes, as well as for supply as a liquid to LNG tankers. Membrane systems are being considered for application on board ships as well as in receiving terminals. Advantages of membranes include cost and ease of maintenance. Environmental pressures have resulted in consideration being given to the visual impact of pipe flares at terminals. Totally enclosed ground flares and elevated low luminosity flares are options, which are available.

4.10 COLD RECOVERY

Utilisation of the cold potential of LNG, normally wasted during vaporisation processes such as ORVs and SCVs, is of considerable interest to LNG importers, subject to the quantities of LNG involved and local economics for integration with other industries.

The different methods used for cold recovery are:

- Air separation
- Power generation
- Cryogenic crushing
- Hydrogen purification
- Desalination
- Low temperature cultivation
- Water treatment
- Improved electricity transmission efficiency.

Having dealt with in detail the basic design data and the development of an LNG import terminal, we shall now in the next chapter, discuss, the various cargo handling procedures for the safe carriage of LNG and the role of transportation in an LNG project.

CHAPTER V

CARGO HANDLING PROCEDURES AND ROLE OF TANSPORTATION IN LNG PROJECTS

Ocean carriers of LNG have been so relatively free of incidents, without any breach of containment systems and so clockwork, that, those who see it from outside tend to look on it as a routine operation without special problems or peculiar features. This is a silent tribute to the designers, builders, owners, operators and charterers of the ships and also to the LNG sellers and buyers. Those who have been closely involved with the operation of ocean carriage recognise that the shipping sector of LNG projects has carried and will continue to carry, burdens of responsibilities, which are peculiar to this trade. They will also operate under the watchful and critical eyes of those who depend on the safe, regular and reliable loadings, voyages and discharges. Thus the basic principle underlying all aspects of handling LNG is that of safety of vessel. LNG cargoes are handled in a closed system under slight positive pressure to prevent the entry of any air into the system.

5.1 CARGO HANDLING PROCEDURES

We shall discuss in brief the various cargo handling procedures for safe carriage of LNG in the following paragraphs:

5.1.1 Liquefaction of natural gas for transport

The initial stage of operations associated with bulk transport of LNG by sea to a grid terminal, is the liquefaction process. Gas is piped from producing fields to liquefaction plants, which are normally situated near the LNG loading facilities. Here the gas is purified and refrigerated to a temperature slightly below -162^{o} C, which now occupies about 1/600 of the volume of natural gas in vapour state, which enables it to be shipped over long distances. The LNG can now be stored in shore tanks or loaded directly aboard a waiting ship.

5.1.2 Inerting and drying

Before the first cargo of LNG can be loaded on board a new or recently overhauled vessel, cargo tanks, piping and void spaces between the primary and secondary barriers must be purged with an inert gas to clear away all traces of oxygen. The inert gas can be produced either by:

- Vaporising liquid nitrogen,
- Burning fuel in ship's boilers or
- Using a special inert gas generator.

5.1.3 Cooling down

Prior to loading, the inert gas is removed from tanks by introducing LNG vapour heated to about minus 20^{o} C through the top of each tank. The mixture of inert gas/LNG vapour is removed from the tank via the bottom filling line and vented to the atmosphere or to a shore installation. LNG is then sprayed from the top of the tank through the stripping/cooling down header pipe until the temperature at the bottom of the tank reaches minus 130^{o} C. This cooling down procedure is done to prevent a sudden surge of cargo boil off when the cold LNG comes in contact with the warm tank surface.

5.1.4 Cargo loading

LNG is loaded into each tank through liquid header pipes to the tank bottom. The gas displaced by LNG, as well as the vapour generated by the loading process, has to be returned to shore installations. There are safety devices to control cargo vapour pressures and liquid levels. Topping off of the cargo tank is usually done at a reduced rate preferably with trained personnel in attendance on deck to visually inspect completion of the loading operation, if possible. Overfilling is safeguarded against by self closing valves which are activated automatically at predetermined levels.

During the loading process, deballasting of ship should also be taking place, with vessels draught, trim and stability, etc being carefully monitored by an onboard safe load computer.

5.1.5 Ship underway in loaded condition

When at sea, LNG vaporises due to heat transfer through the insulation. The rate of boil off varies according to the containment system, composition of cargo, atmospheric temperatures and various other criteria. This boil off can be used as fuel in the ships engine room with any excess being vented out to the atmosphere or it can be reliquefied by onboard reliquefaction plant and reintroduced to the cargo tanks.

5.1.6 Cargo discharge

Upon mooring at discharge port, the piping which will carry the liquid ashore is cooled by pumping a small flow of LNG through the system. Once gas and liquid shore connections have been made cargo pumps are started. To keep a constant tank pressure during the unloading of LNG, gas is pumped from shore installations into the tanks. In the absence of shore based gas supplies, LNG can be vaporised on board to equalise the tank pressure.

To prevent cargo pumps from running dry, in case they are not stopped manually, an automatic device, activated by low liquid level or a drop in discharge pressure, will stop the pumps. The pumps will also stop and gas liquid valves in the tank will be shut off, if flow of gas from shore installation should cease and gas pressure in the tanks drop. During the discharge operation, ballasting of the vessel should take place.

5.1.7 Ship underway in ballast condition

After discharging has been completed, the ship must make a return ballast voyage to the port of loading. This journey can be made with cargo tanks either cold or warm. In the cold condition either a small amount of LNG is left in the tanks or the tanks are continually sprayed with LNG from a small cooling down tank. On a warm ballast voyage the cargo tanks are emptied as much as possible during discharge and allowed to warm up while at sea until about three days prior to reaching the loading port. The tanks are then cooled down using an LNG spray from the cooling down tanks until they are cold enough to receive cargo again.

5.1.8 Warming up

If access to the interior of the cargo tanks is required, the cargo tanks must be warmed from the cargo temperature to near ambient. As much LNG as possible is drawn off from the tanks by heeling and trimming the vessel to maintain suction pressure on the main pumps for as long as possible. When suction is finally lost, LNG vapour is drawn from the tanks using cargo compressors and passed through cargo heaters and sent back to tank bottom via perforated headers. At the end of the operation the temperature at the secondary barrier will be near 0^{o} C.

5.1.9 Inerting and aerating

Once the warm up operation is completed, inert gas can be injected at the tank bottom and the LNG vapour/inert gas mixture extracted from the tank top and sent to shore installation or vented to atmosphere. Cargo piping and machinery used in this process are purged at the same time. The inerting is considered completed when the methane content of the remaining gas is so low that it cannot produce a combustible mixture when mixed with air.

Average times required for various aspects of cargo handling are given in Table 13 below.

Table 13
Average time required for cargo handling operations on LNG carriers

Operation	**Time (hours)**
Purging air with inert gas	24
Replacing inert gas with cargo gas	16
Cooling down	10
Loading	12
Discharging (including stripping)	16
Stripping of tank (prior warm up)	4
Warm up (from 160^{o} C. to ambient)	38
Purging cargo gas with inert gas	24
Aerating	20

Source: Fairplay Report on LNG carriers.

5.1.10 Storage and regasification:

Upon discharge from the carrier, LNG is either piped to storage tanks or pumped to a regasification plant before entering the distribution grid in the consuming area. Until recently the basic method of storing LNG has been in double walled metal tanks above ground. This comparatively cheap way of storage may be replaced, in the near future, by below ground pre-stressed concrete tanks.

During regasification, LNG is vaporised by indirect heat exchange with river or sea water. The temperature of LNG is raised from below its boiling point of about minus 161^{o} C. to ambient temperature.

5.1.11 Cargo handling equipment

The cargo handling equipment for LNG are as follows:

- Cargo pumps
- Gas compressors
- Heat exchangers
- Inert gas systems
- Boil off fuel systems
- Cargo piping and
- Reliquefaction plants

Having discussed the cargo handling procedures we shall now look at the role of transportation in the LNG project .

5.2 ROLE OF TRANSPORTATION IN AN LNG PROJECT

LNG carriers have come a long way in design, from the time the first vessel METHANE PIONEER, was converted from an American C1 freighter to a 5000 cu.m. LNG carrier, when she was fitted with free standing aluminium alloy tanks insulated with a sandwich of plywood and balsa to the modern carriers of about 135,000 cu.m. A brief history of the development of the LNG Carriers, who play a major role in the transportation of the LNG is given below:

5.2.1 Brief history of LNG carriers

The combination of influences which provided the stimulus for the seaborne transport of Natural Gas were several. First was the host countries growing disenchantment with the oil companies practice of flaring up the unwanted associated gas at their fields. This practice was wide spread and the reaction equally so. As early as in the 1940’s it was appreciated that energy and therefore income was being wasted. The political pressures then began to stimulate studies, for way and means of recovering or conserving the wasted gas. One thing was clear that there was no local outlet for it. Re-injection back into the reservoir was one solution, but was not practical or even economical in most cases. Piping it to the nearest industrial consumer was another alternative but most fields were too remote for suitable markets for this to be economically viable. Transporting it by sea was the third and perhaps the least attractive solution.

The second main influence was commercial and ran on parallel lines to that of the first. If technology could be developed by which the flared gas could be collected and sold at a competitive price there would be a commercial interest in doing so.

In 1845, Michael Faraday first liquefied Methane. LNG, however, began to be exploited only about a century later i.e. in 1941. The first LNG plant was built in

Clevland, Ohio, where gas was being stored in tanks utilising 3.5 percent nickel low carbon steel primary barriers. However, as it was noticed that these tanks suffered fatigue and failed catastrophically, causing considerable local damage and loss of life making it unsuitable for the use of LNG. It was only in the 1950s, when the demand for natural gas to be transported to the countries outside the US was felt, that the experiments in seaborne shipments were initiated.

In 1951, the Chairman of the Union stockyards of Chicago, was convinced that it would be possible to liquefy gas and transfer it to barges and transport it to Chicago where it would be stored and regasified. The missing link i.e. of river transport could be solved. The first serious attempt to transport LNG occurred in 1952, when, Constock Liquid Methane Corporation, was formed to transport LNG from Louisiana to Chicago, where a 6000 Cu. M barge called "METHANE", equipped with 5 vertical cylindrical balsa lined tanks was built and extensively tested. It was, however, found that balsa lining on coming in contact with methane was being severely damaged and hence the project had to be abandoned for economic reasons.

In 1957, Constock was joined by North Thames Gas Board to test the feasibility of large scale sea transportation of LNG. They converted an American CI freighter to a 5000 cu. M LNG carrier and named her "METHANE PIONEER". The vessel was fitted with free standing aluminium alloy tanks insulated with a sandwich of plywood and balsa. In early 1959, the vessel carried its first assignment. In 1961, however, this experiment was put at a halt after carrying 6 additional cargoes.

Encouraged by this success, Shell joined in the ownership of Constock and formed the Conch International Methane Limited and its technical organisation, Conch Methane services. British Gas Council, joined Conch in joint venture and they commissioned 2 purpose built LNG carriers "METHANE PRINCESS" and "METHANE PROGRESS", both of 27,400 cu. M capacity, in 1961. These ships had larger number of tanks than Methane Pioneer, but they both used the same type of containment system as of Methane Pioneer.

During the development of the Constock's pilot project the companies in France, Including Gaz De France, who were interested in transporting the Algerian Gas to France, came together and formed a company "Methane Transport". After studying and deciding that the laying of pipeline would not be economical, they fitted an old liberty ship with different types of tanks and various pieces of cargo handling equipment for testing purpose. The shipload tests began in 1962 and lasted for 5 months. Based on the evaluation of the tanks it was found that of the three types a) prismatic tank of aluminium alloy b) multilobed tanks of 9 percent nickel steel and c) cylindrical tank of 9 percent nickel steel, it was found that the one at c) was the best. Orders was then placed for a 25,500 cu. M capacity ship, which went into service in March, 1965 carrying LNG from Arzew to Le-Havre. Another major oil company ESSO, became interested in the LNG markets in Spain and Italy in the early 1960s and they developed a free standing prismatic double walled tank system with aluminium primary and secondary barriers, which was used in four of their 40,000 cu.m vessels.

As up to this time all the containment systems used the self supporting or free standing tanks i.e. tanks which are independent of ships hull and capable of supporting their own weight as well as withstanding static and dynamic loads imposed by the contained load, in 1960s, the research work began on the membrane system, which utilised a thin metallic membrane which was non self supporting. The membrane was attached indirectly to the ships structure through a load bearing insulation. The static and dynamic forces associated with liquid cargo were directly transmitted to the ship structure through the insulation rather than through the free standing tanks and key structures. This system gave opportunity for larger space utilisation and lesser amounts of expensive steel. After a lot of experiments that had been carried out since 1950's although there were many variations developed, today there are basically only 2 accepted membrane type systems. Lorentzen and Det Norske Veritas in Norway carried out the earliest experiments with membrane in the late 50's using formed aluminium sheets and wood insulators.

A French company, Technigaz, had acquired the Lorentzan design and changed liner and insulation materials to stainless steel and PVC foam respectively and this became known as the Technigaz Membrane System. At the same time Gaz De France along with other French interests had turned to membrane research and they developed a system composed of 2 metallic barriers of Invar (36 percent nickle steel) in association with two insulation layers. This insulation was basically plywood boxes filled with perlite. After observing the systems behaviour orders for 2 large 71,500 cu.m LNG carriers was placed with Kockum's in Malmö, in Sweden to be built on design of Gaz Transport.

In 1967 Conch International and Gazocean joined forces to form Conch Ocean, which developed a membrane system which utilised Conch balsa panel insulation system in conjunction with Technigaz's stainless steel membrane. This system incorporating refinements and minor changes was extremely successful and secured a lot of orders.

The Norwegian yard of Moss Verft amalgamated with Kvaerner Group, in 1969 and at the request of the ship owner Leif Hoegh, the new group started investigating the feasibility of an LNG vessel utilising the spherical free-standing tank system. This design utilised a reduced secondary barrier as the primary barrier could be constructed to such fine stress and leakage limits. It is now called the Kvaerner Moss Sphere System and is one of the more popular methods of carrying LNG. Most of the vessels being constructed by this method are in the 125/130,000 cu.m capacity range.

5.2.2 Cargo containment systems

The IMO Code identifies 5 different types of cargo containment systems:

i. Independent tanks
ii. Membrane tanks
iii. Semi-membrane tanks
iv. Integral tanks
v. Internal insulation tanks.

The Independent and membrane types of containment systems are of most significance and majority of LNG's built to date utilise one or other of these two types. Differences between the two types of containment systems are as highlighted in Annexe II

The Moss spherical type of containment system is most popular and about 50% of LNG tankers have this type of containment.

Table 14 gives the distribution of the cargo containment systems, based on the number of vessel given.

Table 14

Distribution of cargo containment systems

Type of cargo containment system	Percentage
Moss-Rosenberg	56.5%
Gaztransport	31.5%
Technigaz	8.7
IHI	1.7%
Others	2.0%

Source: Various

5.2.3 Existing fleet of LNG carriers

The world LNG fleet at the end of 1998, comprised of 108 ships with a combined capacity of 11.725 cu.m. Table 15 gives the break up in main size categories:

Table 15

Main size categories of ships

No.	Type	Size	Total cubic meters
15	Small	Less than 50,000 cu.m	484,500
15	Medium	Between 60 - 90,000 cu.m	1,158,600
78	Large	Between 120 - 135,000 cu.m	10,081,400

Source: Lloyds Shipping Economist- Feb1999

The world LNG fleet including the tonnage on order, presently stands at 129 vessels, with the average age of the vessels being 12 years and having a total capacity of 14,348,616 cubic meters. Considering the age profile of the world's LNG fleet, and the fact that even the old vessels are fully committed for some time to come it appears that natural gas will become an increasingly important source of energy as the next century progresses. Because of the special nature of trade and cargoes, the economic life of a gas carrier is greater than that of other vessels. As the LNG vessels are well maintained their theoretical life may be upto 40 years.

Annexe - III details the list of vessels, type of vessel, the year of built, capacity and owner of vessels. As discussed earlier, LNG vessels being very expensive, are not built for speculation but are built to service a specific sales contract, with a typical duration of 18 to 20 years.

5.2.4 LNG shipbuilding yards:

As there is a increase in the LNG trade and there are no vessels which are available on spot markets it is essential to know about the LNG shipbuilding yards. The LNG shipbuilding yards are detailed in Table 16 below:

Table 16

World LNG shipbuilding yards

Country	Yard	Design
Japan	Mitsubishi Mitsui Kawasaki IHI NKK	Moss Moss Moss SPB Technigaz
Korea	Hyundai HI Hanjin HI/Daewoo	Moss Gaz Transport
Finland	Kvaerner Masa	Moss
France	Chantiers de L'Atlantique	Gaz Transport

Source: Clarksons

Having dealt with the existing fleet of the LNG carriers and the LNG shipyards we shall now have a look at the LNG costs which have become an increasingly important element in the commercial viability of both new and expansion projects. Mr J. Parker of Jonathan Packer & Associates, Brigton, UK, in a seminar mentioned that, as a proportion of the delivered price of LNG the shipping costs represent 15% to 50% of the delivered price, depending on the distance. Clearly it is important to contain the cost of transportation if projects are to be viable, particularly those where LNG has to travel a long way to the market.

5.3 COST STRUCTURE OF LNG TRANSPORTATION

LNG transportation costs are a key variable in the overall project viability. LNG tankers are expensive to build to the extent that the cost of the ships may be the single largest item in the cost of the entire project.

The three main components of the cost of shipping LNG are:

- Direct ship operating costs : i.e. crew, insurance, maintenance, store and lubes and administration costs,
- Voyage costs: i.e. port charges and cost of boil off gas and fuel oil used,
- Ship capital cost.

The above are dealt with in brief as under:

5.3.1 Direct operating cost:

Crew cost: since LNG carriers are very sophisticated and need to have the highest calibre of crews to ensure their safe operations, the manning costs of LNG carriers are very high. Crew costs consist of several direct and indirect expenses including crew salaries and wages, leave pay, travelling, victualling, insurance cover as well as employers contributions to pensions and social securities.

Insurance: the main areas where insurance is sought by the LNG operators are, Hull and Machinery Insurance (H&M) for the physical loss or damage to vessel, and Protection and Indemnity Insurance (P&I) against third party liabilities.

The level of H&M premium payments are dependent on the owner's claim record and on the assessed hull value of the ship.

Insurance costs are not directly dependent on the size of the vessel, though they do tend to increase with size and this is particularly true with the P&I component. H&M costs on the other hand, tend to increase with the value of the ship.

Repair and maintenance: this is usually the second largest expenditure after manning. A variety of different motives and influences affect repair and maintenance expenditure. At the most fundamental level are the statutory requirements of government and classification societies, which generally mean that a vessel must be drydocked at least once every five years to undergo a periodic survey. Additionally however, there are occasions when unscheduled docking must be undertaken because of damage or breakdowns, while interim docking must also be performed to improve vessel performance through repainting to hull, or through upgrading the equipment or machinery.

Stores and lubes: stores include a wide list of consumable items which are mainly categorised into five main groups:

a) marine stores: like paints, ropes, wires, deck tools, fresh water etc

b) engine stores: like chemicals, gases, electrical consumables and engine room stores,

c) stewards rooms stores: like cleaning materials, linen, cutlery, soft furnishing etc.
d) lubricating oils,
e) nitrogen: which is used during the voyage to keep the LNGC's spaces inert. Owing to increase in ambient temperature and pressure, nitrogen losses occur through a pressure relief valve, and the hold spaces are then refilled once the temperature and pressure fall.

Administration costs: they are hard to estimate as they vary widely from company to company.

5.3.2 Voyage costs

Port charges: is the expenditure incurred by vessels in port and tends to be very complex. The complexities arise due to variety of individual cost components involved. Port costs can, however, be categorised in to one of the following types:

a) costs incurred by the LNG carrier itself
b) costs attributed to cargo handling
c) costs arising from under or over performance.

The actual costs incurred when loading and discharging will vary from installation to installation, depending on the ship size and location. Port costs for LNG tankers are relatively higher than that for other vessels and this is partly due to the need for tugs and safety vessels to accompany them safely in and out of port.

Boil off gas and fuel oil: LNG carriers utilise part of their cargo as fuel whilst at sea. During transportation cargo is maintained at just below its liquefaction temperature (below 161^{o} C) and this is often referred to as boil off gas. The boil off gas is utilised as fuel for the main engines because alternative methods of disposal are not feasible.

The total quantity of boil off gas available during a voyage depends on three factors:

a) volume of cargo being carried
b) length of voyage
c) type of containment system.

When steaming, boil off gas is available in both the ballast and the loaded legs of the voyage. The fuel requirements of an LNG carrier in port, are met entirely by bunker fuel oil and marine diesel oil.

5.3.3 Ship Capital Cost

The capital costs depend on the delivered price of the LNG carrier and its cost of finance. The capital cost element on delivery of a new ship will amount to nearly 75% of the total annual costs, depending on the cost of financing. The price of new LNG carriers followed the shipping and shipbuilding cycle with a peak in 1979/80 and again in 1989/90 on an upward trend. Most existing large 125-130,000 m^3 carriers were delivered during 1975 to 1983 period at contract prices of US $ 100m rising to US $130m. Prices of large LNG carriers remained relatively stable through the 1980s at around US $170m due to the depressed shipbuilding and shipping market with severe shipyard over capacity. The reduction in shipyard capacity by 1988 and an increase in shipyard orders, particularly for very large tankers pushed the price of LNG carriers to as high as US $275 m.

5.4 PRESENT AND FUTURE OF LNG CARRIERS

From the above it can be observed that the LNG carriers have been tried and developed over a period of time and the standard size of the vessels that is being used in today's market is the 125,000 - 135,000 cu.m vessel. The tanker size has increased from some 40,000 cu.m for the first generation to a range of 120,000 to 135,000 cu.m the standard size being used in today's market. A further increase is being planned. The next move is expected to be from 125,000 to 165,000 cu.m, but 200,000 cu.m designs are already under consideration and moving from 125,000 cu.m to 200,000 cu.m could result in an investment saving of around 15%.

Besides the various studies being conducted to reduce the cost of LNG projects by increasing the size of vessel, studies are also being conducted using different containment systems, to reduce the cost of LNG projects. Kvaerner Masa Yard (KMY), has designed a new LNG tanker for the next decade, by which LNG shipping can be made more efficient while maintaining the sector's excellent safety record. The main elements in the yards improved design are, expanding cargo capacity by stretching the tanks, reducing the level of cargo boil-off, installing on beard reliquefaction units, using diesel-electric power plants and fitting improved propeller systems.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

- From the foregoing chapters it is seen that natural gas is the cleanest fuel and can be considered to be the fuel of choice of the new millennium.

- India needs natural gas in view of the increasing energy shortage that the country is facing and the fact that there is a huge potential demand, which will be constrained by the availability of supplies.

- LNG imports appear to be the best option to satisfy the increasing gas demand. However, there are enormous difficulties related to the organisation of the LNG chain and to the marketability of the imported gas in India.

- The overwhelming focus on gas import efforts should not lead to the underestimation of India's domestic gas supply potential.

- The LNG trade is of a long term nature ideally having contracts for 20 or more years. With the emergence of new potential suppliers and buyers and the cost of developing LNG projects may require new, lower cost supply strategies for bringing buyers and sellers together in ways that provide acceptable LNG economics for both parties. Thus the challenge will now be to bring LNG market at competitive prices, which will occur only if interested parties co-operate in a participatory manner in the LNG chain.

- With the liberalisation policy of the Government of India, many multinational companies are venturing into major projects for development of power generation, port and infrastructure development, communications, etc., which are all energy intensive increasing the need for import of oil or gas.

- In order to cater to the every increasing demand for energy in India, the oil industry is exploring possibilities of alternate fuel. A Joint Venture of 4 major oil public sector units has been formed by the government to create infrastructure for import and marketing of LNG.

- Indian government has given approval to over 20 LNG projects with potential to import upto 50 million tonnes per annum. Realistically though, it appears that India will be importing about 15 million tonnes per annum by 2010.

- Also several proposals are on the planning and discussion stage with regard to import of natural gas through pipelines from the Middle East countries such as Oman, Iran and Qatar. While transportation of natural gas from Iran through an overland pipeline crossing Pakistan into India offers an excellent economic advantage to both the countries, the political scenario of the countries, to embark upon such a commercial venture, does not seem to be forthcoming. Also the deep sea route of pipeline from Qatar/Oman to India, appears too forbidding for an engineering design to achieve, apart from the huge investment cost involved and the risk thereof.

6.2 RECOMMENDATIONS

The following recommendations are made for the development and growth of LNG trade in India.

- There should be deregulation in a phased manner, of the gas market, so that the foreign and private sector companies can construct their own LNG terminals and gas pipelines.

- Since some of the gas is being flared for want of infrastructure, measures should be taken to accelerate the exploration for more gas reserves and also the national gas producers should be paid a price related to the cost of imported gas, so that the amount of flared gas would be greatly reduced and there would be increase in the indigenous gas availability.

- In light of the fact that it does not seem possible to lay the pipe lines for transportation of LNG to India, the next option is to carry the LNG by sea in the specialised LNG carriers.

- Technical studies on shipping distances, ship sizes and number of ships required to transport various LNG quantities to target markets must be made along with commercial assumptions of ship operations like bare boat charter, time charter, country and frequency of drydocking, nationality of crew, nationality of registry, risk of loss, insurance coverage, terms of delivery - ex-ship, CIF, FOB, etc to determine a unit of shipping cost.

- There should be policy initiatives and fiscal incentives from the Government of India to encourage investment in LNG import facilities and for a firm commitment of projects, contracts should be established between buyers and sellers, Government and regulatory bodies consent be granted, financial arrangements be established and construction of required gas production and liquefaction facilities be arranged.

- Since LNG trade has been enjoying a rapid growth over 30 years and one of the key reasons has been the design of safe and environmentally acceptable LNG receiving terminals, design of safe, expandable and cost effective LNG receiving terminal should be made and implemented at the earliest.

Bibliography

Alaves, B and Girard, L and Nedelka, D (1993). The computer program HARDES: a user-friendly integrated safety tool by LNG plant designers and operators in risk assessment. *Gas Tech Conference 1993.*

Angas, G B (1980). Physical dangers related to LNG transportation. *International Marine Safety Symposium 1980*. page 49

B.C. Gas Industry. Learn about Natural Gas. *http://www.bcgas.co/html/about_util_learn.html* (3/28/99)

Beale, J. Non Traditional Sources and Uses of LNG. *http://www.ch-iv.com/lng/gd97ppr.htm* (3/29/99)

Boudet, R (1994). What is new in LNG Marine Transportation. *Gas Tech Conference 1994.* 25-28 October1994, Kuala Lumpur.

Chiu, CH (1996). LPG recovery in baseload LNG plant. *Gas Tech Conference 1996*. 03-06 December 1996, Vienna.

Collins, S and Heyse, J and Cazalet, F and Dalmazzore, M (1995). *11th International Conference on Liquefied Natural Gas.* 3-6 July 1995, Birmingham.

Corkhill, M (1975). *LNG Carriers: The ships and their market.* London: Fairplay Publications Ltd.

Cornot-Gandolphe, S and Rojey, A and Raimbault, C (1995). *Development Prospects for International LNG Trade. 11th International Conference on Liquefied Natural Gas*. 3-6 July 1995, Birmingham.

Dahl, K (1977). *LNG Transportation: Some problems have been cleared up, only to be replaced by others. Oil Gas Scandinavian Magazine.* Vol5, no3, 1997, page 4.

Discovery Zone. Liquefied Natural Gas. *http://www.shell.co…/content/o,1384,1097-1137,00.html* (3/29/99).

Dubar, C and Forcey, T and Humpreys, V. *Offshore-1997, Major advantages to siting LNG Plant offshore*. Vol 58, no 8, page 116.

Energy. Ninth five year plan (1997-2002). Vol II. *http://www.nic.in/ninthplan1/vol2/v2c6.htm*. (4/10/99).

Fairplay (1999 a). More LNG ships needed: but obsolescence is a worry. *Fairplay*. January 1999, pp 50-51.

Fairplay (1999 b). Will new designs keep things contained. *Fairplay*. January 1999, page 52.

Fairplay (1999 c). Long life gas ships. *Fairplay*. January 1999, page 48.

Fairplay (1999 d). New ways to keep cool. *Fairplay*. January 1999, page 46.

Fairplay Solutions (1999). Dusted down after 17 years. *Fairplay Solutions*. January 1999, pp 12-14.

Fairplay Solutions (1999). Norwegian owner adopts LNG propulsion. *Fairplay Solutions*. May 1999, page 8.

Fairplay (1999). *Heading offshore: Unions lobby to stop gas ships leaving. Fairplay*. February 1999, page 12.

Fairplay (1999 a). Science outstrips LNG investment. *Fairplay*. February 1999, pp 22-23.

Fairplay (1999 b). Ice with implications. *Fairplay*. February 1999, page 24.

Fairplay (1999). BHP sells Timor Sea assets: Phillips looks to LNG prospects. *Fairplay*. April 1999, page 35.

Ffooks, R (1979). *Natural Gas by Sea: The development of a new technology*. London: Gentry Books Limited.

Findlater, AE and Prew, LR (1977). Operational Experience with LNG ships. *5th International Conference on Liquefied Natural Gas*. 29 Aug-1st Sept, Dusseldorf.

Garguet, M and Harre, R and Courtay, R (1994). *A cost effective solution to next generation LNG Carriers. Gas Tech Conference*. 25-28 October 1994, Kuala Lumpur- Malaysia.

Gas Authority Of India Ltd. Areas of Business. *http://www.nic.in/gail/areas.htm* (4/10/99).

Gotaas-Larsen Shipping Corporation (1997). *LNG world overview, 1997: The authoritative guide to the current and future liquefied natural gas market.* Gotaas-Larsen publication.

Harper, CM (1994). Quantitative risk analysis for the selection of cost effective mitigation measures to improve LNG production availability. *Gas Tech Conference.* 25-28 October 1994, Kuala Lumpur- Malaysia.

Hawkshaw, HJ and Flower, AR (1995). Will new LNG supplies be developed to meet Asian LNG demand to 2015?. *11th International Conference on Liquefied Natural Gas*. 3-6 July 1995, Birmingham.

Hazardous Cargo Bulletin (1996). Carrying Liquefied Cargoes: It's a gas!. *Hazardous Cargo Bulletin.* November 1996, page 18.

Hazardous Cargo Bulletin (1999). LNG Tankers: The next generation. *Hazardous Cargo Bulletin.* March 1999, page 27.

Hill, DK and Durr, CA and Vega, FF and Frankie, M. *Shipping simulation as related to the LNG Chain.* M.W. Kellogg Company, Houston, Texas, USA.

Hisazumi, Y and Yamasaki, Y (1995). Natural Gas reliquefaction: storage, sendout system, using mixed alcohol as refrigerant. *11th International Conference on Liquefied Natural Gas.* 3-6 July 1995, Birmingham.

Iversen, HH and Borgaas, B. *Can the cost of LNG transportation be reduced? Optimising the ship/terminal/storage equation provides a solution.* Kraerner Moss Technology a.s. Oslo, Norway.

Kinder, RD (1995). Worldwide LNG Trade: Expansion in the 21st Century. *11th International Conference on Liquefied Natural Gas.* 3-6 July 1995, Birmingham.

Lloyds Shipping Economist (1999). New capacity in the pipeline. *Lloyds Shipping Economist.* February 1999, pp 30-32.

LNG Journal (1999). Progress in India. *LNG Journal*, 1999, pp 4-5.

LNG Journal. Project Development- The LNG sales and purchase agreement. *LNG Journal*, pp 24-29.

LNG Journal. Site selection for LNG receiving terminals and their geological assessment. *LNG Journal*, pp 10-13.

Ministry of Petroleum and Natural Gas (1999). *http://petroleum.nic.in* (15/5/99).

Oil and Gas Journal (1997). *Design advanced for large-scale, economic, floating LNG plant. Oil and Gas Journal*, Vol 95, no 26, page 66.

Okumura, Y and Fujitani, T and Akoki, E and Kondo, AA and Ishikawajima, I (1996). LNG transportation economy with SPB technology, *Gas Tech Conference.* 03-06 December 1996, Vienna.

Peebles (1995). Are the boom years of LNG over. *11th International Conference on Liquefied Natural Gas*. 3-6 July 1995, Birmingham.

Petroleum Economist (1999). Untitled. *Petroleum Economist*, January 1999, page 46.

Petronet Economist (1998). Foreign Investors prefer the Petronet-LNG option. *Petronet Economist*, April 1998, pp 44-45.

Press Information Bureau. *Government of India: Latest Releases.* *http://www.nic.in/latestrelease* (4/10/99).

Renaudin, G and Dufresne, DP (1994). Recent developments in LNG. *Gas Tech Conference*. 25-28 October 1994, Kuala Lumpur.

rsbody. Growth of Indian Petroleum. *http://petroleum.nic.in/petroleum/psbody.htm* (4/10/99).

rsbody. Refineries in India. *http://www.nic.in/petroleum/rsbody.htm* (6/11/99).

Seaborne Trade and Transport (1992). *Trading in LNG and Natural Gas: Global patterns and prospects.* Seaborne Trade and Publications, Drewry Publications.

Shell Briefing Service (1989). Energy in Profile. *Shell Briefing Service*. No 3, pp 1-3.

Shell Briefing Service (1992). Liquefied Natural Gas. *Shell Briefing Service*. pp 1-8

Shell Briefing Service (1995). Energy in Profile. *Shell Briefing Service*. No 2, pp 4-6.

Shell Briefing Service (1988). Natural Gas. *Shell Briefing Service*. No 4, page 2.

Ship Care (1999). Owners play high stakes. *Ship Care*. February/March 1999, pp 42-43.

Society of International Gas Tankers and Terminal Operators Limited (1997). *Site selection and design for LNG ports and jetties: Information paper No. 14.* London: Wright Marine Technology.

Sullivan and Mutch (1995). Managing uncertainty in world-wide LNG demand: we know less than we think. *11th International Conference on Liquefied Natural Gas.* 3-6 July 1995, Birmingham.

Tardre, N (1990). As demand heats up, the LNG trade expands. *Eurooil*, vol 1, no 8, 1990, page 30.

The Baltic Magazine, (1999). Gas fired shipping. *The Baltic Magazine,* Article 8.

Trade Winds (1999). India calls for slash in LNG charter rates. *Trade winds*. June 1999, page 23.

Trade Winds (1999). Fighting for the LNG pie: The front line. *Trade Winds*. March 1999, pp 20-21.

Umekawa, N and Tokoro, I and Kobayashi, T (1995). Small Size LNG Project. *11th International Conference on Liquefied Natural Gas.* 3-6 July 1995, Birmingham.

Vedeler, A (1977). LNG Transportation- From a shipowners viewpoint. *Norwegian Shipping News.* no 14, page 9.

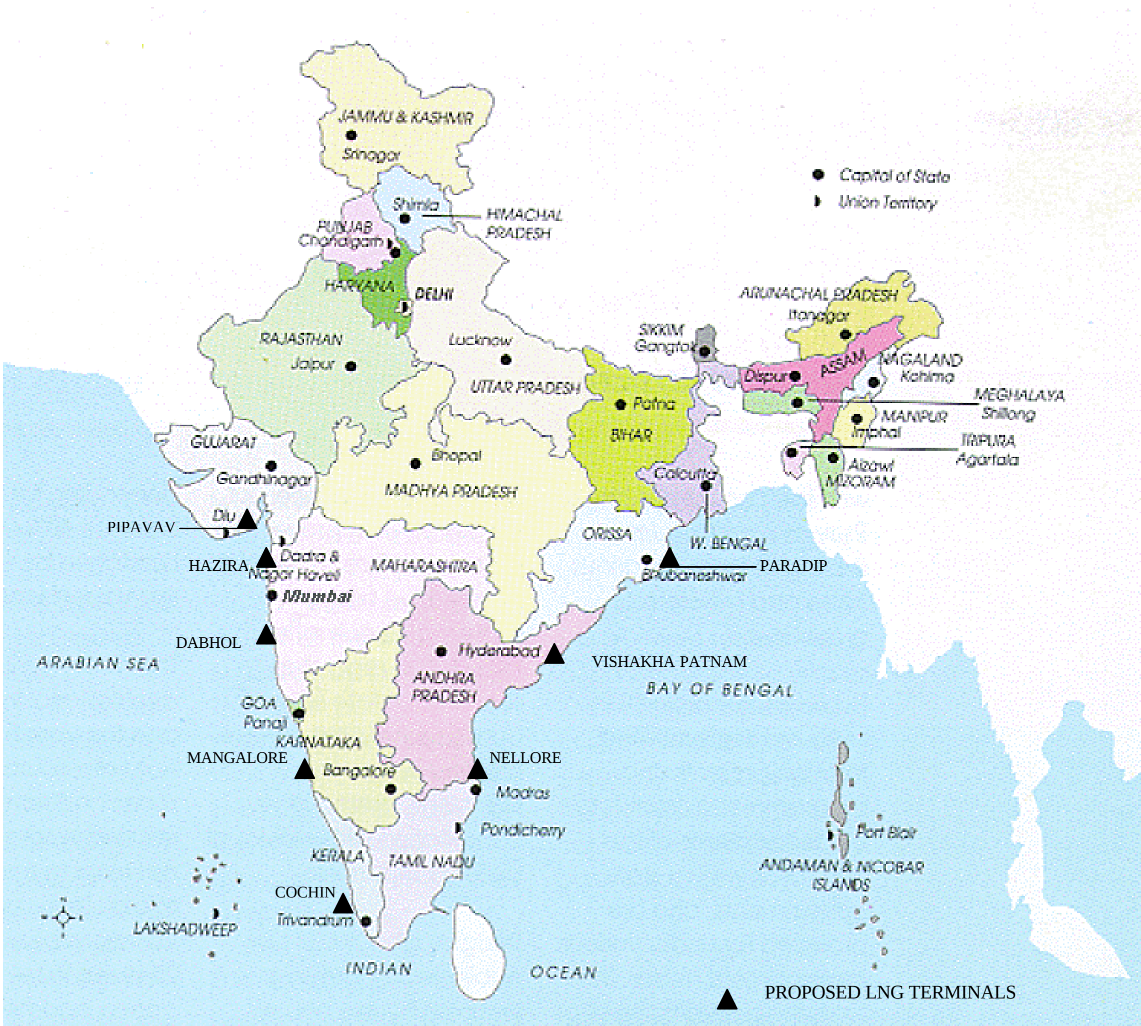
Voigt. FR (1994). The world gas market: Challenges for 2000 and beyond. *Gas Tech Conference.* 25-28 October 1994, Kuala Lumpur.

Wooler, RG (1975). *Marine Transportation of LNG and Related Products.* UK: Cornell Maritime Press. Inc.

Yoshida, S (1988). *World's LNG situation and LNG carriers*. Japan: Japan Maritime Research Institute.

ANNEXE I

Proposed LNG terminals in India



ANNEXE-II

Comparison of membrane type and moss spherical type Cargo containment system

Technical area	Membrane type		Moss spherical type
	Technigaz	**Gaz Transport**	**Kvaerner**
LNG containment system	Containment system as an integrated tank consists of metalic membrane and load bearing independent insulation layers directly supported by the hull structure.	Same as Technigaz	Containment system consists of an unstiffened spherical shell supported at the equator by a ring stiffened skirt.
Cargo tank/insulation	Integrated membrane tanks consist of a primary barrier and a secondary barrier - - Primary barrier- corrugated stainless steel membrane of 1.2 mm thickness supported by the insulation. - Secondary barrier: Aluminium foil between glass cloth layers (triplex) is arranged between the two layers of insulation.	Integrated membrane tanks consist of a primary and a secondary barrier: - Primary barrier:- 0.7 mm thick Invar Sheets (36% Nickel steel alloy), about 0.5 m. wide, with upturned edges welded to each other through fixing tongues. - Secondary barrier: - same as primary barrier.	The self supporting spherical tanks are built in aluminium with shell thickness of 30-70 mm. The polystyrene or poly urethane insulation is arranged on the outside of, and attached to the tank. The partial secondary barrier (according to IMC Code) consists of a metal foil on the insulation protecting the hull and a drip tray arranged at the lowest point of insulation to collect and evaporate small leaks.
Licensor	Gaz transport and Technigaz/ France		Kvaerner Maritime/ Norway

Source: LNG World Overview, 1997.

ANNEXE-III

Existing Fleet of LNG Tankers

D- Trading O- On Order

Status	Type	Vessel Name	YOB	Capacity	Owner
D	Exxon	SNAM Palmaria	1969	41,000	AGIP spa
		Laieta	1970	40,000	Auxiliar Maritime del Nort
		LNG Elba	1970	41,000	Agip Spa
		No of vessels of Type : Exxon		**3**	**Average Age : 29 years**
		Total Capacity	**1,22,000**		**Average Size: 40,667**
D	GT	Methane Arctic	1969	71,500	British Gas
		Methane Polar	1969	71,500	British Gas
		Hassi R'Mel	1971	40,850	SNTM-Hyproc
		Annabella	1975	35,500	Chemikalien Seetrans
		Isabella	1975	35,500	Chemikalien Seetrans
		Bubuk	1975	77,670	Brunei Shell Tankers
		Bilis	1975	77,731	Brunei Shell Tankers
		LNG Lagos	1976	122,000	Nigeria LNG Co. Ltd
		LNG Port Harcourt	1977	122,000	Nigeria LNG Co. Ltd
		Edouard L.D.	1977	129,299	Louis Dreyfus
		Labri Ben M'Hidi	1977	129,767	SNTM-Hyproc
		LNG Capricorn	1978	126,300	Energy Transport
		Methania	1978	131,260	Exmar BV
		Bachir Chihani	1979	129,767	SNTM-Hyproc
		Mourad Didouche	1980	126,300	SNTM-Hyproc
		Tenaga Dua	1980	130,000	Malaysia Int. Shipping
		Tenaga Satu	1980	130,000	Malaysia Int. Shipping
		Ramdane Abane	1981	126,130	SNTM-Hyproc
		Tenaga Empat	1981	130,000	Malaysia Int. Shipping
		Tenaga Lima	1981	130,000	Malaysia Int. Shipping
		Tenaga Tiga	1981	130,000	Malaysia Int. Shipping
		LNG Bonny	1981	133,000	Nigeria LNG Co. Ltd
		LNG Finima	1984	133,000	Nigeria LNG Co. Ltd
		Puteri Delima	1994	130.405	Petronas
		Puteri Intan	1994	130,405	Petronas
		Puteri Nilam	1995	130,405	Petronas
		Hanjin Pyeong Teak	1995	130,600	Hanjin Shipping Co.
		LNG Portovenere	1996	65,000	AGIP Spa
		Puteri Zamrud	1996	130,405	Petronas

		Puteri Firus	1997	130,405	Petronas
		LNG Lerici	1998	65,000	AGIP Spa
		No of vessels of Type : GT		**31**	**Average Age : 17 years**
		Total Capacity	**3,381,589**		**Average Size: 109,082**
D	Moss	Havfru	1973	29,388	Bergesen dy ASA
		Norman Lady	1973	87,600	Leif Hoegh
		Century	1974	29,588	Bergesen dy ASA
		Mystic Lady	1974	87,600	Leif Hoegh
		Hilli	1975	126,227	Osprey Maritime Europe L
		Gimi	1976	126,277	Osprey Maritime Europe L
		Hoegh Gamdria	1977	125,820	Leif Hoegh
		Golar Freeze	1977	125,858	Osprey Maritime Europe L
		LNG Aquarius	1977	126,300	Energy Transport
		LNG Aries	1977	126,300	Energy Transport
		Khannur	1977	126,360	Osprey Maritime Europe L
		LNG Gemini	1978	126,300	Energy Transport
		LNG Leo	1978	126,400	Energy Transport
		LNG Taurus	1979	126,300	Energy Transport
		LNG Libra	1979	126,400	Energy Transport
		LNG Virgo	1979	126,400	Energy Transport
		Lake Charles	1980	126,530	Lachmar
		Louisiana	1980	126,530	Lachmar
		Golar spirit	1981	129,000	Osprey Maritime Europe L
		Bishu Maru	1981	125,000	Kawasaki Kisen
		Banshu Maru	1983	125,542	Nippon Yusen Kisha
		Echigo Maru	1983	125,568	Nippon Yusen Kisha
		Dewa Maru	1984	125,000	Kawasaki Kisen
		Senshu Maru	1984	125,000	Mitsui OSK
		Kotowaka Maru	1984	125,199	Nippon Yusen Kisha
		Wakaba Maru	1985	125,000	Mitsui OSK
		Northwest Sanderling	1989	127,525	Australia LNG
		Northwest Swift	1989	127,590	Australia LNG
		Northwest Swallow	1989	127,708	Australia LNG
		Northwest Snipe	1990	127,747	Australia LNG
		Ekaputra	1990	136,400	PT Humpuss Transport
		Northwest Shearwater	1991	127,500	Australia LNG
		Northwest Seaeagle	1992	127,452	Australia LNG
		Northwest Sandpiper	1993	127,500	Australia LNG
		LNG Flora	1993	127,705	Nippon Yusen Kisha
		Hyundai Utopia	1994	125,182	Hyundai Merchant Marine
		YK Sovereign	1994	127,125	SK Shipping Co. Ltd
		Dwiputra	1994	127,386	PT Humpuss Transport

		LNG Vesta	1994	127,547	Mitsui OSK
		Northwest Strompetrel	1994	127,606	Australia LNG
		Shahamah	1994	135,496	AbuDhabi National Gas C
		Al Khaznah	1994	135,496	National Gas Shipping Co.
		Mubaraz	1995	137,000	AbuDhabi National Gas C
		Ghasha	1995	137,514	AbuDhabi National Gas C
		Ish	1995	137,540	AbuDhabi National Gas C
		Al Hamra	1996	137,000	National Gas Shipping Co.
		Surya Aki	1996	19,474	PT Humpuss Transport
		Hyundai Greenpia	1996	125,000	Hyundai Merchant Marine
		Mraweh	1996	137,000	AbuDhabi National Gas C
		Al Khor	1996	137,354	Qatar Liquefied Gas
		Al Zubarah	1996	137,573	Qatar Liquefied Gas
		Umm Al Ashtan	1997	137,000	AbuDhabi National Gas C
		Al Wajbah	1997	137,354	Qatar Liquefied Gas
		Al Uskrah	1998	135,000	Qatar Liquefied Gas
		Zekreet	1998	135,000	Qatar Liquefied Gas
		Al Wakrah	1998	135,358	Qatar Liquefied Gas
		Broog	1998	137,529	Qatar Liquefied Gas
		Al Rayyan	1997	135,358	Qatar Liquefied Gas
		NKK 153	1998	18,800	Asia LNG Transport
		No of vessels of Type : Moss		**59**	**Average Age : 11 years**
		Total Capacity	**7,147,306**		**Average Size: 121,141**
D	other	Cinderella	1965	25,500	Chemikalien Seetrans
		No of vessels of Type : other		**1**	**Average Age : 34 years**
		Total Capacity	**25,500**		**Average Size: 25,500**
D	SPB	Arzew	1978	126,540	Argent Marine Operations
		Artic Sun	1993	89,880	Marathon Oil
		Polar Eagle	1993	89,880	Marathon Oil
		No of vessels of Type : SPB		**3**	**Average Age : 11 years**
		Total Capacity	**306,300**		**Average Size: 102,100**
D	TG	Descartes	1971	50,000	Gazocean
		Bebatik	1972	75,060	Brunei Shell Tankers
		Tellier	1973	40,081	Compagnie Generale Marit

		Bekulan	1973	75,070	Brunei Shell Tankers
		Bekalang	1973	75,080	Brunei Shell Tankers
		Belais	1974	75,040	Brunei Shell Tankers
		Belanak	1975	75,000	Brunei Shell Tankers
		Mostefa Ben Boulaid	1976	125,260	SNTM-Hyproc
		Southern	1978	126,540	Argent Marine Operations
		Matthew	1979	126,540	Cabot LNG
		Aman Bintulu	1993	18,928	Asia LNG Transport
		Aman sendai	1997	18,928	Asia LNG Transport
		Aman Hakata	1998	18,800	Asia LNG Transport
		No of vessels of Type : TG		**13**	**Average Age : 20 years**
		Total Capacity	**900,327**		**Average Size: 69,256**
O		Sam 1207	1999	135,000	SK Shipping Co Ltd
		Hanjin 054	1999	138,200	Hanjin Shipping Co
		NKK 192	2000	22,000	Mitsui OSK
		Hanjin HI 061	2000	135,000	Hanjin Shipping Co
		Hanjin HI 062	2000	135,000	Hanjin Shipping Co
		Samsung 1258	2000	135,000	SK Shipping Co Ltd
		Samsung 1259	2000	135,000	SK Shipping Co Ltd
		No of vessels of Type :		**7**	**Average Age : -1 Years**
		Total Capacity	**835,200**		**Average Size: 119,314**
O		Daewoo 2202	1999	138,000	SK Shipping Co Ltd
	GT	Daewoo 2203	1999	138,000	Korea Line
		Daewoo 2204	2000	135,000	Korea Line
		No of vessels of Type : GT		**3**	**Average Age : 0 Years**
		Total Capacity	**411,000**		**Average Size: 137,000**
O		Golar Matsu	1999	135,000	Osprey Maritime Europe L
	Moss	Hyundai Dreampia	1999	135,000	Hyundai Merchant Marine
		Hyundai H I 1074	1999	135,000	Hyundai Merchant Marine
		KHI 1470	1999	137,000	Qatar Liquefied Gas
		Mitsubishi 2091	1999	137,354	Qatar Liquefied Gas
		Hyundai HI 1156	2000	135,000	Hyundai Merchant Marine
		Hyundai HI 1157	2000	135,000	Hyundai Merchant Marine
		Mitsubishi 2157	2000	135,000	Osaka Gas Co. Ltd

		Mitsubishi 2117	2000	137,100	Qatar Liquefied Gas
		No of vessels of Type : Moss		**9**	**Average Age : -1 Years**
		Total Capacity	**1,219,454**		**Average Size: 135,495**
			<u>FLEET TOTALS</u>		
		Total no. of vessels	**129**		**Average Age: 12 years**
		Total Capacity	**14,348,616**		**Average Size: 111,230**

Source . Clarksons