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Feasibility of the Hub-and-spoke principle for LNG supply chains into Northwest Europe

by

Kajal Festen-Purohit

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Abstract

Natural gas is proven to be an environmentally friendly source for energy production compared to coal and oil. This has been one of the driving forces in increasing the gas demand. Europe is heavily dependent on Russia for the gas supplies to meet the ever increasing energy demand. However, the recent political situation is forcing EU members to look for alternative sources of gas supplies sighting the increase in the gas demand. As a result of the increased demand many regasification terminals are now under construction or are in the planning stage.

Due to various reasons transporting gas over longer distances via pipeline is not feasible. Hence the gas is first liquefied and then shipped by special LNG vessels to various destinations.

Traditionally LNG is exported by means of larger vessels (145,000m^3+) carrying LNG from the exporting port to the importing port. These importing ports are typically situated at locations where the local pipelines can be easily accessed and thus the gas can be pumped into the pipeline grid as required after regasification. However, in regions where pipelines cannot be laid due to various reasons, such a transportation system is not suitable. In such cases the gas has not been used as a main energy source. In case the pipelines are already available for gas transport but the draft at the port is low, bringing in such a large LNG vessel is almost impossible. This raises a need to find a solution to bring the gas in smaller vessels to meet the draft and volume requirements.

Typically these import terminals are for larger volumes and the jetty is equipped to handle the largest possible ship that can call this port. Similar to the container shipping where the new terminals are built to handle Emma Maersk type vessels, a vessel that can carry around 15,000 containers onboard. The economies of scale in this industry is clear as these large vessels carry containers to a port that can handle such large volumes and then reload the containers onto smaller carriers. This is called the Hub-and-Spoke principle.

The main objective of this paper was to assess the feasibility of applying the Hub-and-Spoke principle to four European ports that have potential to import LNG in larger volumes and ship it further on in smaller vessels to various parts of Scandinavia.

The paper concludes that it is feasible to apply the Hub-and-Spoke principle in LNG shipping, provided that the economies of scale can be achieved at the hub ports. In particular, for terminals like Gate terminal and Zeebrugge, where additional throughput can be achieved through the tanks with only limited incremental cost, the Hub-and-Spoke concept could present an attractive additional revenue stream.

Table of contents

List of figures

List of Tables

1 Introduction

The world's hunger for energy is growing rapidly. The last few decades have witnessed energy demand increasing exponentially. Coal and oil are the most commonly used sources to generate energy. However, these sources are not environmentally friendly. The world, especially Europe, is turning towards the greener options for replacing the polluting fuels.

Natural gas has proved to be an environmentally friendly fossil fuel which can be extracted from beneath the earth crust. Traditional supply of natural gas is done via pipelines. This makes the proximity to the gas field important, as the unit price for gas increases when transported over longer distances. Liquefied natural gas (LNG) is an easy way to transport natural gas over longer distances via sea-going vessels.

Typically, the larger size (145,000m^3+) vessels carry LNG from an export terminal to an import terminal. At the import terminal the gas is stored in the liquid form till the user needs the gas. After regasification the gas is transported via pipelines to various destinations. However, it is practically impossible to supply LNG via large vessels to remote ports, where the draft in many cases is not sufficient for such large carriers. Typically, in the Baltic and Scandinavia, where the creation of Emission Control Area (ECAs) is a serious step towards cutting down emissions, alternatives to Heavy Fuel Oils (HFO) and other pollutants must be found. Using natural gas for fueling purposes could be a solution. However, the supply of LNG via large vessels is not feasible in this region.

Small Scale LNG could be an effective solution to ensure the deliveries of natural gas to the Baltic and Scandinavian markets, even to remote areas. Since LNG can be distributed in smaller parcels, it will help creating new markets such as for example fuel for transportation modes. This can also reach areas where the pipelines are difficult to be laid.

A combination of large scale LNG and small scale LNG will create a new value chain. The concept is similar to the Hub-and-Spoke principle, successfully implemented and used in the liner shipping industry. However, the question arises if it is possible to implement this principle for shipping LNG? Is it viable to do so in different regions? How complicated are the transfers from vessel to the storage tank and back to a smaller vessel? Would safety be an issue? Another question is whether Scandinavia would have enough demand to bring LNG in larger vessels or otherwise whether their demand will promote hub-and-spoke principle in this region?

If we were to find answers to all the above mentioned questions, the given timeframe would not be enough. Hence we turn our focus to the Scandinavian region, especially Norway and Sweden. The questions we would like to focus on are:

1. Is it feasible to use the Hub-and-spoke principle in Europe for the supply of LNG into Scandinavia?

2. Can Gate terminal also function as a hub terminal for the supply of LNG into Norway and Sweden?

3. Is Gate a viable choice for small scale LNG supplies into Norway and Sweden?

We have used the principle of hub-and-spoke to analyze the feasibility of Gate terminal, which is being built in the port of Rotterdam, to be used as a hub terminal. The comparative analysis was done against the Fluxys LNG terminal at Zeebrugge, the upcoming Nordic LNG terminal in Norway and a prospective terminal in Szczecin, Poland. The chosen satellite terminals are based in Sweden and Norway.

The background information for each terminal (hub and spoke) was collected from various websites and a lot of information was shared with us by Vopak Agencies. What is interesting in this industry is that the hub and spoke principle is not very popular yet, though it has been successfully applied in Japan. We believe that the geographical conditions in these two regions are very different and hence comparing the two was not deemed appropriate.

After collecting the data for various cost elements like port costs, shipping cost, FOB breakeven cost and throughput cost for all the export and hub ports, we created a model to understand the dominant factors of the various supply chain components. This model also gives a clear picture on why Gate and Zeebrugge have an advantage over Nordic LNG and Szczecin.

This study opens the door to new possibilities for LNG's new transport trend: small scale LNG. The main objective of this study is to check the feasibility of certain options for hub destinations and assess for the best alternative for LNG supplies into Scandinavia.

Chapter 2 explains the basics of natural gas and liquefied natural gas, allowing the reader to obtain a basic understanding of the critical components of the LNG supply chain, like exploration and storage, liquefaction plants, LNG carriers, LNG storage and regasification. It also gives an overview of LNG economics, LNG world demand and the liquefaction capacity, regasification capacity and the LNG export contracts. This helps in understanding the LNG world market and its operations. The chapter also explains briefly if LNG could be useful in curbing emissions.

Chapter 3 focuses on the concept of small scale LNG. It explains the difference between large scale and small scale and how they complement each other rather than competing with each other. It briefly explains the role of small LNG tankers in the supply chain. It also looks at the possible new usage of LNG for transportation modes. It discusses in detail the role of LNG in the Norwegian and Swedish markets. This chapter builds up the case for our thesis as it explains the LNG market in Norway and Sweden.

Chapter 4 gives the basic theory behind the hub-and-spoke principle and how it is used in the maritime world. The chapter also re-introduces our research questions in order to explain the methodology used by the writer of this paper. It gives a complete overview of how the supply chain is defined for the purpose of this paper and the summary of the cost model created for calculating the CAPEX and OPEX. It explains various assumptions used for the paper and how the data was collected. Furthermore, it gives basic information on the source, hub and satellite ports selected for this study. A complete model description is given here and our findings are explained. Our conclusions and suggestions are explained at the end of the chapter.

Chapter 5 states our conclusions based on our model. It also gives our recommendations for further studies and for the various industry players involved in LNG supply chain.

2 Natural Gas and Liquefied Natural Gas

Demand for energy is increasing as the world population is increasing. People require more energy for personal as well as industrial use. In the earlier days the main sources of energy were coal and oil. Natural gas follows these two the traditional means and is the third preferred source of energy. Traditionally the gas is transported via pipeline. Due to geographical and operational limitations the pipelines cannot be extended over very long distance. LNG solves this transportation limitation. This chapter provides an introduction to Natural Gas (NG) and Liquefied Natural Gas (LNG). It gives some data on the worldwide consumption and reserves of natural gas and also explains the various usages of NG and LNG. It also elaborates every aspect of the LNG supply chain while giving a complete overview of the capacities related to liquefaction and regasification until the year 2015. LNG carriers are specialized carriers for carrying LNG. This chapter highlights the growth, the trends and the importance of the LNG carrier market. It also explains the evolution of the ship size over the past years.

2.1 Natural Gas

When plant and animal matter are trapped under solid rocks for millions of years, having extremely heavy pressure over it, the natural gas is formed. Commonly known as “Gas”, the natural gas primarily consists of methane. It is found alone or together with oil under rock caps or in coal beds as coalbed methane. In its original form the gas is basically colourless and tasteless.

Being a cleaner fuel[1] its usage is increasing rapidly. It is expected to be the fastest growing component of the world’s primary energy (+2.8% per annum until the year 2025) (Othmer, 2003)

“The world’s largest reserves are located in Russia with about 47,570 bcm (billion normal cubic meters) (2006), Iran 26,370 bcm (2006), Qatar 25,790 bcm (2007), Saudi Arabia 6,568 (2006) and United Arab Emirates 5,823 (2006)”. (Source: Wikipedia)

Very few countries supply the majority of the gas as most of the reserves (71%) are located in the Middle East, Algeria, Australia, Eastern Europe and Russia. Japan tops the list of main importer followed by South Korea.

[1] Cleaner fuel: Expressed as CO_2 formed per unit of energy and less contaminates than oil or coal.

The following table shows the world-wide distribution of the Natural Gas reserves and consumption rates:

Table 1 World-wide distribution of the Natural Gas reserves and consumption rates

	Available reserves (Tcf)	Consumption rate (Tcf/Year)	Reserves/ Consumption (Years)
North America (ex Arctic)	263	27.3	**10**
Europe	201	18.5	**11**
Asia pacific	524	14.4	**36**
South & Central America	248	4.4	**56**
Former Soviet Union	2059	21.1	**98**
Africa	508	2.5	**203**
Middle East	2546	8.9	**286**
TOTAL	**6348**	**97.1**	**65**

2.1.1 Composition of Natural Gas

The Natural Gas is mainly consisting of Methane (70-90%). The other present hydrocarbons are ethane, propane and butane. Some impurities like nitrogen, carbon-dioxide and hydrogen sulphide are also present. The following table shows the typical composition of Natural Gas.

Table 2 Composition of Natural Gas

Methane	CH_4	70-90%
Ethane	C_2H_6	
Propane	C_3H_8	0-20%
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%
Rare gases	A, He, Ne, Xe	trace

Source: (www.naturalgas.org)

This composition varies from source to source. The following table shows a breakdown for some of the gas fields in different parts of the world:

Table 3 Natural Gas Composition from Some 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 Dioxide	**-**	**-**	**-**	**1.0**	**-**	**-**

Source: (Sharma, 1999)

The higher the methane content the lower the need for treatment in order to turn it into (commercial pipeline gas or) LNG. Thus from the table we can see that Alaskan gas can be used practically without any treatment. In the liquefaction process the gas is cooled to -161ºC to -163 ºC and the heavier hydrocarbons like Pentane and water would freeze and can possibly damage the process equipment. Hence it is essential to remove these substances from the gas prior to the liquefaction process.

The propane and butane components are liquefied under pressure and used as LPG. With a simple treatment process pentane and other hydrocarbons, which are present in small volumes, can be removed before the gas is condensed to liquid form.

2.1.2 Uses of Natural Gas

Natural gas demand is increasing and is used extensively in day-to-day life. It is becoming a very popular energy source. Some of the main areas for natural gas usage are:

- Residential and commercial usages: Natural gas is one of the primary sources of fuel for basic use for household applications, water heating, heating systems, offices, shops and hotels. The degree of gas usage varies per country.

- Power generation: Natural gas is a major source for power generation. It is also one of the cleanest sources of electricity generation as it produces about 30% less carbon dioxide than burning petroleum and about 45% less that burning coal.

- Transportation fuel: There are already vehicles running on compressed natural gas which is considered to be a cleaner alternative than gasoline and diesel. Even countries like India, Pakistan, Argentina, Brazil and Iran have numerous CNG (Compressed Natural Gas) run vehicles. (IANGV, 2008) LNG is now also getting popular as a fuel for water transport as well as road transport.

- Fertilizer: Natural gas is a major source in producing ammonia to be used in the fertilization process.

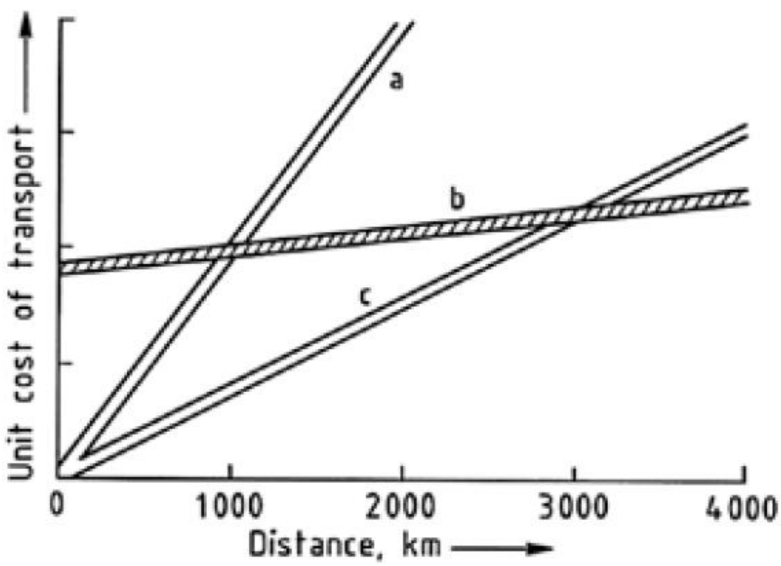
- Aviation: Tupolev, a Russian aircraft manufacturer is running a programme since mid-1970s to produce hydrogen and LNG-powered aircraft. The programme is trying to develop such aircraft for carrying passengers as well as cargo. As per the company such LNG-powered aircraft would cost around 5,000 rubles (approx. USD 218) less to operate per ton. This will also help reducing the carbon monoxide, hydrocarbon and nitrogen oxide emissions. (Wikipedia)

It also has other usage like for manufacturing glass, steel, fabrics and other products.

2.2 Liquefied Natural Gas (LNG)

When natural gas is cooled down at atmospheric pressure to a temperature of about -161º C to -163 º C (depending on the composition, it condenses into liquid which is called Liquefied Natural Gas (LNG). The gas is reduced by about 600 times in volume and thus can be easily transported by specially designed sea-going vessels as well as by train and by road. This has been a big step in changing the primary source for energy being made available at thousands of miles away from its origin. LNG also has an economic advantage over piped-gas when the distances are large say over 3000 km for on-shore pipelines and over 1000 km for off-shore pipelines. The diagram below shows the LNG advantage:

Figure 1 Cost situation of LNG (b) compared to off-shore (a) and on-shore (c) pipelines



Source: (Hansson, 2008)

In Europe, supply of natural gas is predominantly done via pipeline. However, the geographical location and the density of the pipeline network limit the total volume of this type of supply chain. To meet the ever increasing demand of LNG the focus is now moving towards LNG being transported mainly via sea routes. Technological advancements are supporting reducing dependence on the gas grid.

In World Energy Outlook published in 2002, the IEA has shown very positive trend towards the gas consumption as they expect natural gas to be the fastest growing fossil fuel, almost doubling overall gas consumption between years 2000 to 2030. (Jarlsby, 2004)

2.2.1 Processes in a LNG project and the Value Chain

Figure 2 Traditional LNG Supply Chain

Source: (Foss, 2007)

There are four main elements for the successful LNG project which play a vital role in the implementation:

i. Natural Gas Source: To ensure that the supply remains uninterrupted throughout the project life of 18 to 20 years, assurance of proven gas reserves is absolutely necessary.

ii. Liquefaction facility: This is the costliest link in the LNG chain as this includes facilities for removing liquids from natural gas, processing and the liquefaction facilities, jetty for a ship based on the largest possible vessel to call, LNG loading facilities, ensuring the deep water access and other ancillary infrastructure required like electric power, water, roads, administration facility and in some cases housing for the employees.

iii. LNG fleet of tankers: LNG vessels are special vessels which are relatively expensive and more complex than many other merchant vessels. The number of vessels that is required would depend on the distance to the import terminal or the end customer, if it is a final user. With large vessels like Q-Max (265,000m^3) it is possible to have economies of scale over standard vessels (145,000m^3).

iv. Regasification terminals: In a traditional supply chain for LNG this will be the fourth element of great importance as at this terminal the LNG will be off-loaded to a specially built tank. Here also the basic infrastructures like a jetty, tanks, regasification facilities and the pipeline connections would be necessary to build.

However, for our study purpose we are looking for a solution to a situation where LNG can be transported to areas where large vessels cannot berth. In such cases LNG can be transported via the smaller LNG vessels. For our paper we consider vessel size 10,000m^3 and below as a small vessel. This is considered as small scale LNG. The concept is not yet defined so far and hence we consider this concept as an extension of large scale LNG supply chain. The two supply chains together bring in few more elements into the picture, like:

i. Hub terminal: In case of small scale LNG, we need to have a hub terminal where LNG can be brought in with the help of larger vessels ($145,000m^3$+), off-loaded from the vessel into a tank and subsequently reloaded onto a smaller size vessel (e.g. 7,500 to $10,000m^3$). The additional required infrastructure would comprise a reload facility and possibly a new jetty.

ii. Dedicated small tankers: Similar to large scale LNG transport, the small scale LNG also requires a dedicated fleet. Recent developments have shown that these vessels could be build for multipurpose use to ensure that the vessel capacity is used in as optimal way.

iii. Satellite terminal: This is the unique element of the value chain as this terminal may perform multiple roles, like a storage terminal, a fueling station and/or a reloading facility. The uniqueness of small size will benefit this terminal for performing these various roles without overlapping the facility use. Here not only ferries but also trucks and trains can be fuelled, at the same time trailers can be loaded for LNG transport while the regasification is done for the pipeline grid.

2.2.1.1 Exploration and Storage

This is the first stage in the LNG chain without which no chain can start. This ranges from the idea development on where the gas can be found, to the financial strength to mobilize the drilling and field development activities. At this stage the explorer does face a high geologic risk. There is a chance that the natural gas resources in the area of interest either do not exist or is not enough to invest further in extracting gas from the field. The investment made at this stage is high and hence not many companies are actively involved in exploration.

2.2.1.2 Liquefaction Plants

After the exploration if the gas is found then the second stage of investments comes into picture as the gas that has to be explored is than send to the exporting port (normally via pipeline). For sending gas via ship it needs to be changed to a liquid form. This process is normally done at the port itself so that the liquid can immediately be loaded onto a vessel.

It is believed that LNG liquefaction facilities require high capital investment. However, less than 50% is capacity related and is basically a function of other factors such as site related conditions, project development and execution efforts.

Every plant is different as every location is different. Thus, it is difficult to standardize these plants. However, some major elements which are more common to these plants are as follows (Kotzot, 2007):

- a feed gas handling and treating section
- a liquefaction section
- a refrigerant section

- a fractionation section
- an LNG storage section
- a marine and LNG loading section
- a utility and offsite section

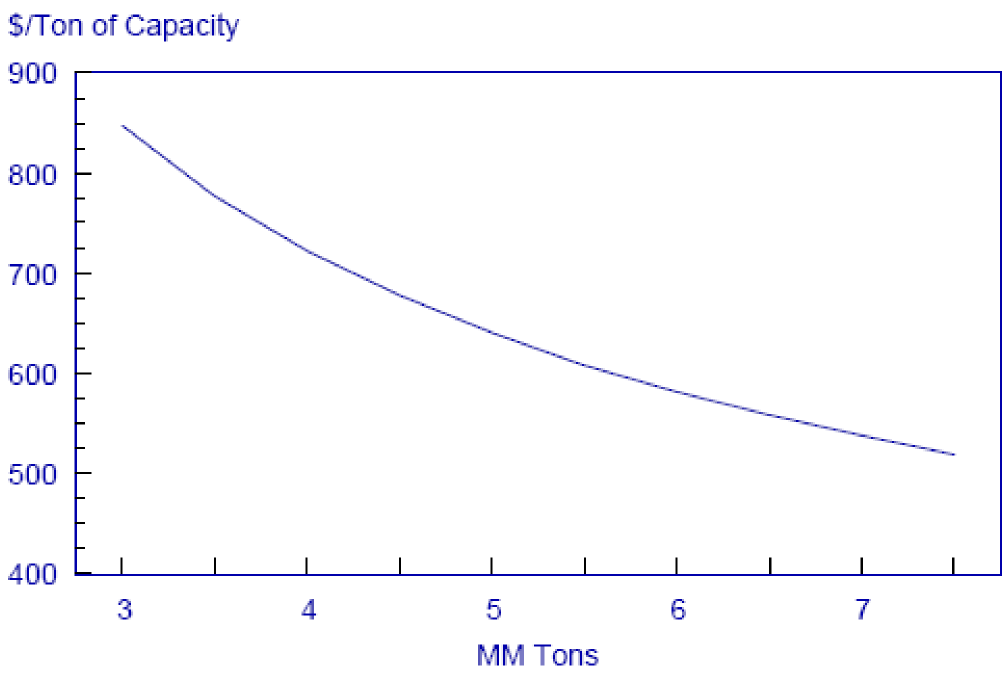
The following table gives an idea on the cost distribution for a Liquefaction facility, though these costs could vary slightly depending on the country specific costs like labour cost.

Table 4 Cost Distribution for a "Typical" Liquefaction Facility

Liquefaction Cost Distribution	Percentage of Total Cost
Gas Treating	7
Fractionation	3
Liquefaction	28
Refrigeration	14
Utilities	20
Offsite (storage, loading, flare)	27
Site preparation	1
Total	100

The economies of scale are also applicable to these liquefaction plants as the capital cost per ton of cargo reduces as the size of the plant increases. By taking typical costs from 2008, capital cost for a Greenfield liquefaction plant is plotted on the scale as shown in the following figure. The figure gives an idea on the economies of scale.

Figure 3 Illustrative Capital Cost for a Greenfield Liquefaction Plant, as a Function of Scale (million tons)

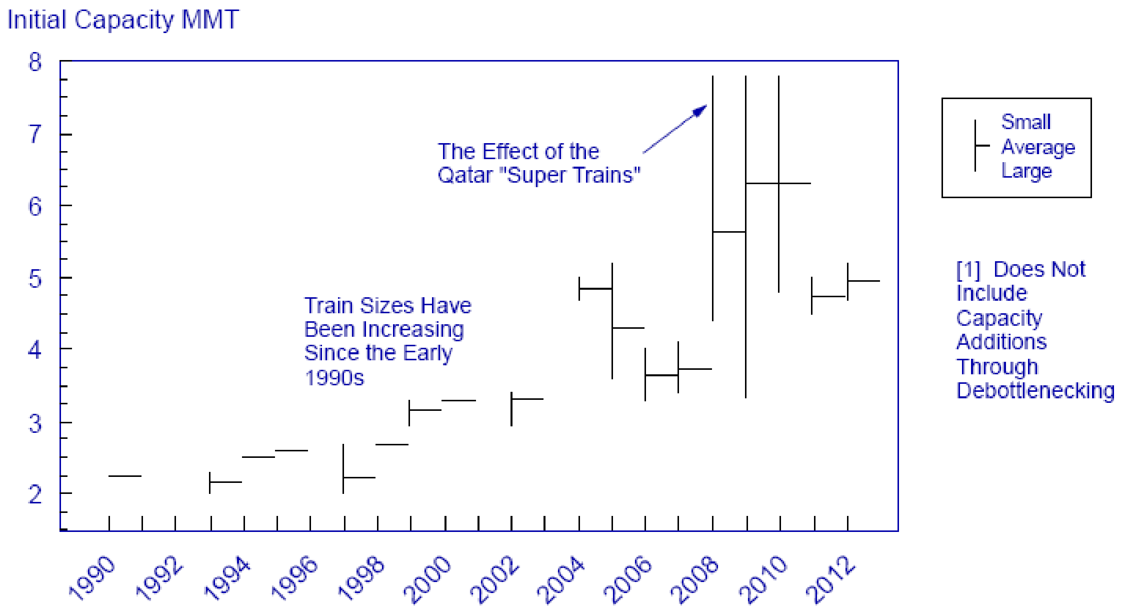


Source: (Energy Charter Secretariat, 2009)

Typical LNG Train sizes were limited to about 2.5million tons per train until late 1990 due to the compressor design. However, technological innovations have changed the situation. Now the train sizes are increasing steadily. Qatar is involved in increasing its train size quite rapidly. By 2010, six of Qatar's then running fourteen trains will see the capacity of 7.8 million tons against the largest train of 5.2 million tons today.

The following figure shows the trends mentioned above.

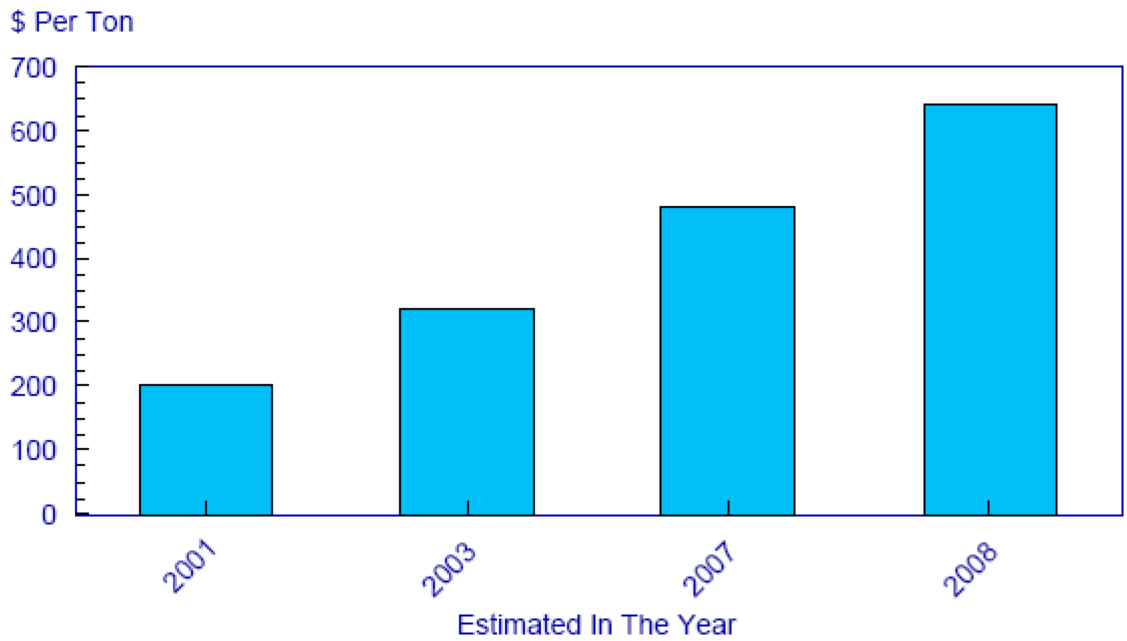
Figure 4 Changes in Liquefaction Train Sizes, by Plant Start-up date (million tons)



Source: (Energy Charter Secretariat, 2009)

The capital costs of these liquefaction plants are increasing rapidly. If a project which was to start in 2001 would start in 2008, the capital cost of this project would be more than three times compared to 2001. The following figure illustrates the capital cost estimate of a particular plant over different period.

Figure 5 Illustrative Capital Costs of a New 4.5 MMT Greenfield Liquefaction Plant, from different Time Perspectives (US$ per ton)



Source: (Energy Charter Secretariat, 2009)

Three plants worth mentioning here are Norway's Snøhvit, Russia's Sakhalin 2 and Australia's Pluto. For Norway and Russia the Arctic environment creates the construction challenge whereas Pluto is an example of remote construction. These plants' cost levels are higher than the costs mentioned in the figure 5 by 33% to 125%.

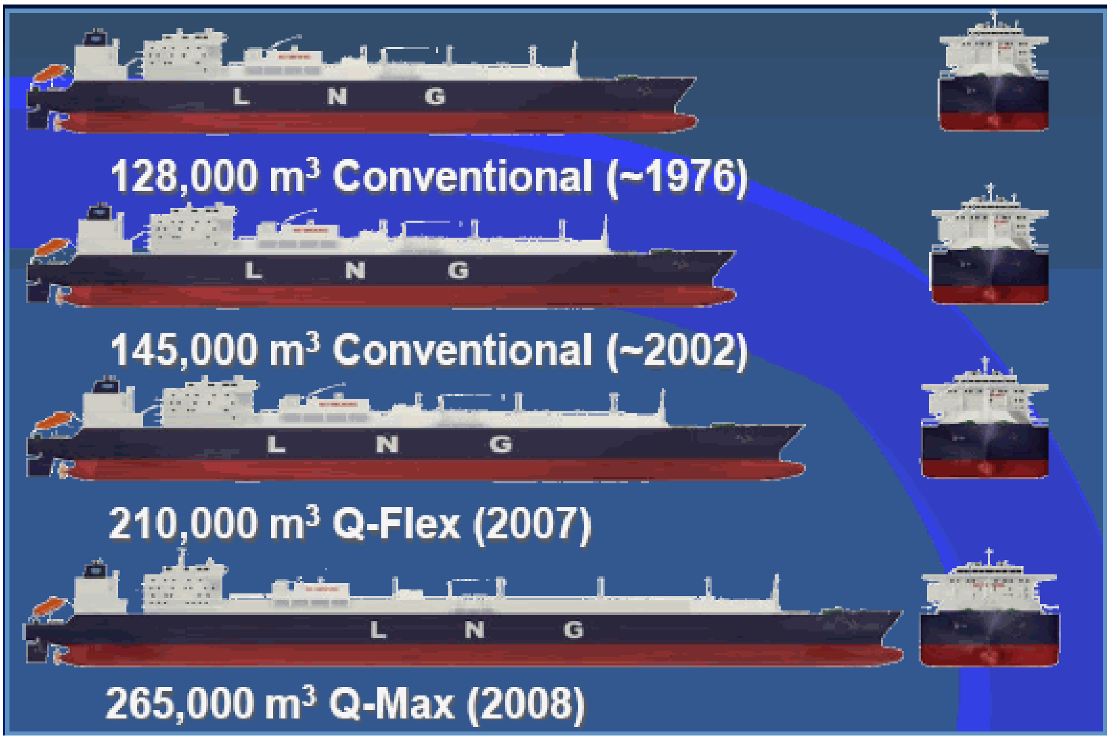
The increase in the construction cost of a liquefaction plant is an issue of a concern. Due to the increased cost not many companies are able to build the LNG terminals and that causes delays in starting a new project as well. A project that was scheduled to be ready in three years may take four years or more. This also may force the LNG exporters to use their gas for the domestic market instead of exporting it.

2.2.1.3 LNG Carriers

The first vessel to carry the LNG was "Methane Princess" which was built in 1964 at Vickers Armstrong Shipbuilding yard. The ship was owned by Shell Tankers U.K. and sailed under the Bermuda flag. This vessel sailed for about 28 years and was scrapped in India 1997.(helderline.nl)

The following figure shows the increase in the size of the LNG vessels over the past three decades. In thirty years the vessels have grown more than double in size and volume, which also is an indication of LNG industry trying to achieve economies of scale.

Figure 6 Evolution of LNG ship Size



Source: Royal Vopak

The following table gives some technical information regarding various LNG vessel sizes:

Table 5 Technical Information on LNG Vessel Sizes

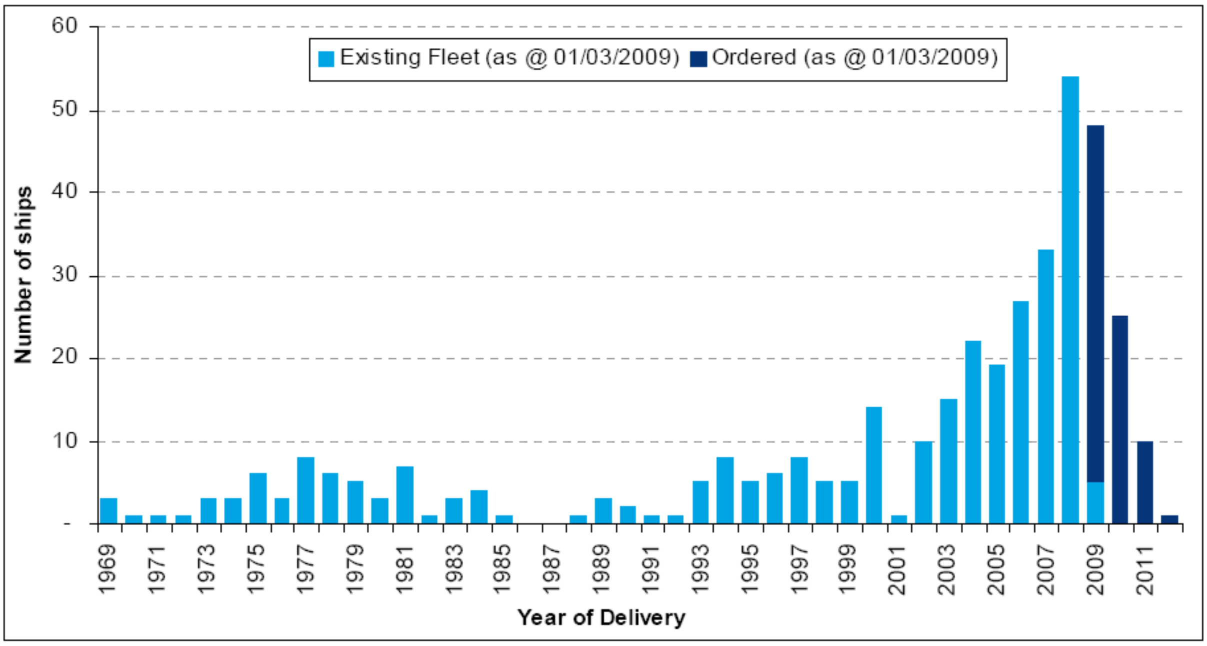
Nominal Size (m^3)	12,000	75,000	128,000	145,000	210,000 (Q-flex)	265,000 (Q-max)
Type	bullet	Memb.	Memb.	Spher.	Memb.	Memb.[2]
Length Over All (m)	140	220	279	290	315	345
Beam (m)	20	35	41	49	50	55
Design Draft(m)	7.0	9.75	11.2	11.4	12.0	12.0

[2] A membrane system is formed by installing thermal insulating material into the hull of the ship and covering the surface with a metallic membrane. The purpose of the membrane is to maintain liquid-tightness so as to prevent any leakage of the cargo liquid. (ISHIMARU J., Dec 2004)

The rapid expansion in LNG fleet in the past years continues, though the discussion can be held over low demand and lesser investments in new trains to increase LNG supply. As of April 2009 there are 317 LNG vessels of 44.13 cubic meters capacity. By April 2009 another 17 ships are expected to be delivered. There are about 38 vessels on the orderbook for 2009, 20 for 2010 and 11 for 2011 and beyond. This will add about 69 more vessels to the existing fleet size which is an increase of about 22% since the beginning of 2009. (Clarkson Research Services Limited, 2009)

Since LNG vessels are relatively young, very few vessels are scrapped every year. In 2007 only 1 and in 2008 just 4 vessels were scrapped.. The mean average age of LNG ships in existence as on 1 March 2009 was about 10.1 years. Out of 317 vessels as on that date 205 vessels were less than 10 years, which is around two third of the total fleet size. The following figure gives a clear picture on the age profile of these vessels.

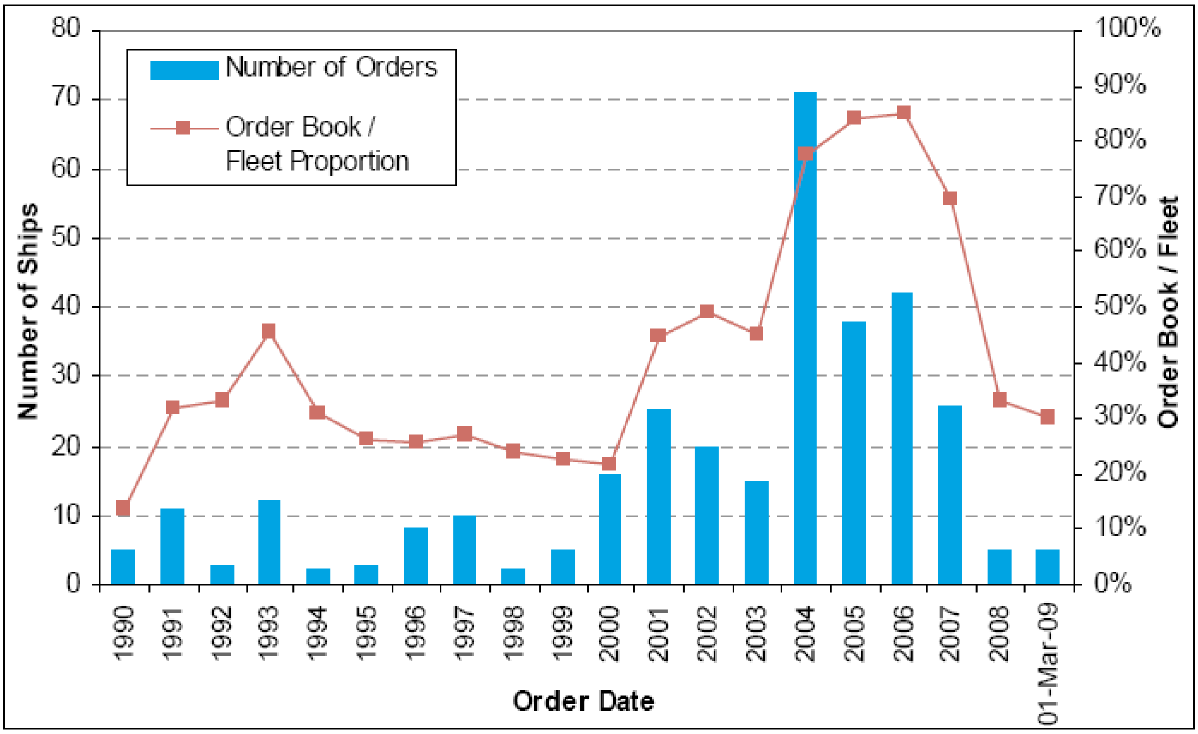
Figure 7 No. of LNG Ships delivered by year



Source: (Wood MacKenzie, 2009)

The LNG fleet expanded at an average of 12.1% per annum in the period 1994-2009 (year-on-year volume basis), in fact the last five years the expansion has been at the rate of 18.3%. However, the coming three years are expected to see a little downturn as the expansion is expected to be 9.3%. The following figure gives a clear indication on the LNG fleet ordering trend.

Figure 8 Trend of LNG Vessel orders

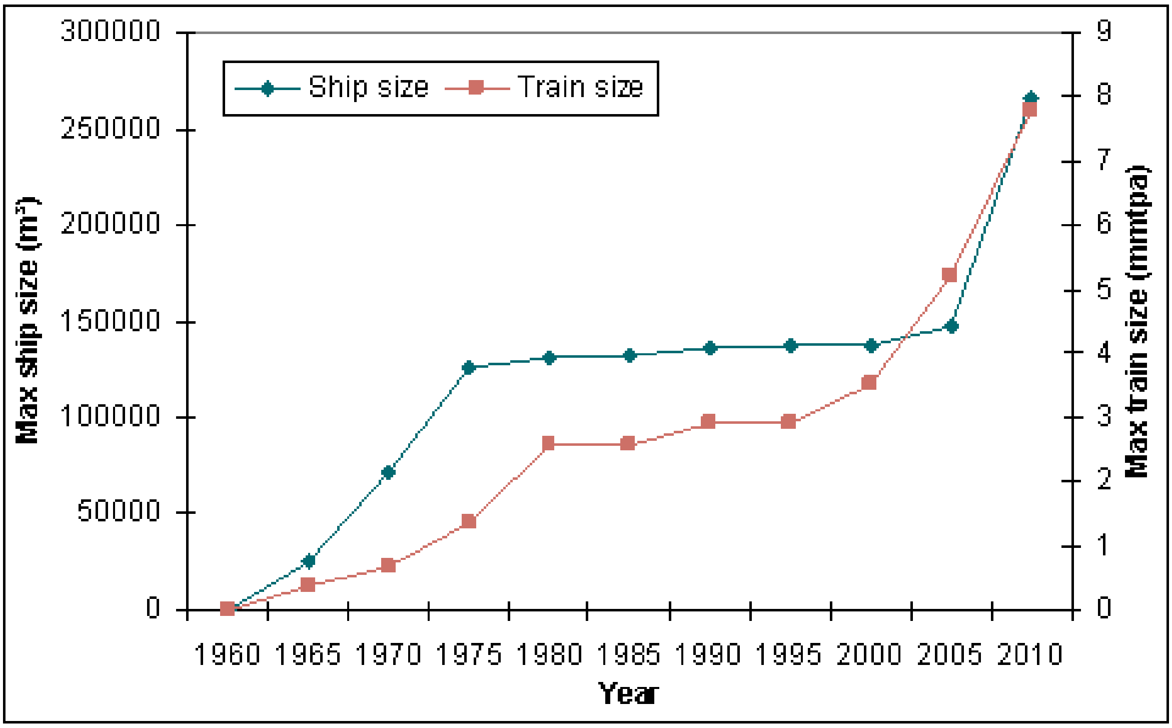


Source: (Wood MacKenzie, 2009)

The total orderbook as a proportion of the fleet has been declining. It saw a peak of about 85% in 2006, however, as on March'09 it has fallen down to almost 30%. This declining trend is expected to continue as many vessels would be ready for delivery in the remainder of 2009 and 2010. (Wood MacKenzie, 2009)

It is also interesting to notice how these vessels have evolved compared to liquefaction train size. The substantial increase is particularly driven by Qatar, who is increasing the LNG supply projects substantially. The average size of LNG vessels used to be around 145,000m^3 to 155,000m^3 till Qatar came with a unique design of around 215,000m^3 and 265,000m^3 vessels. The concept of these large vessels is comparable to the container industry where a containership is in operation to carry 15,000 boxes across the oceans for the economies of scale. The figure below is graphical representation of the evolution of LNG ship to liquefaction train size.

Figure 9 Evolution of LNG Ship Size to Liquefaction Train Size

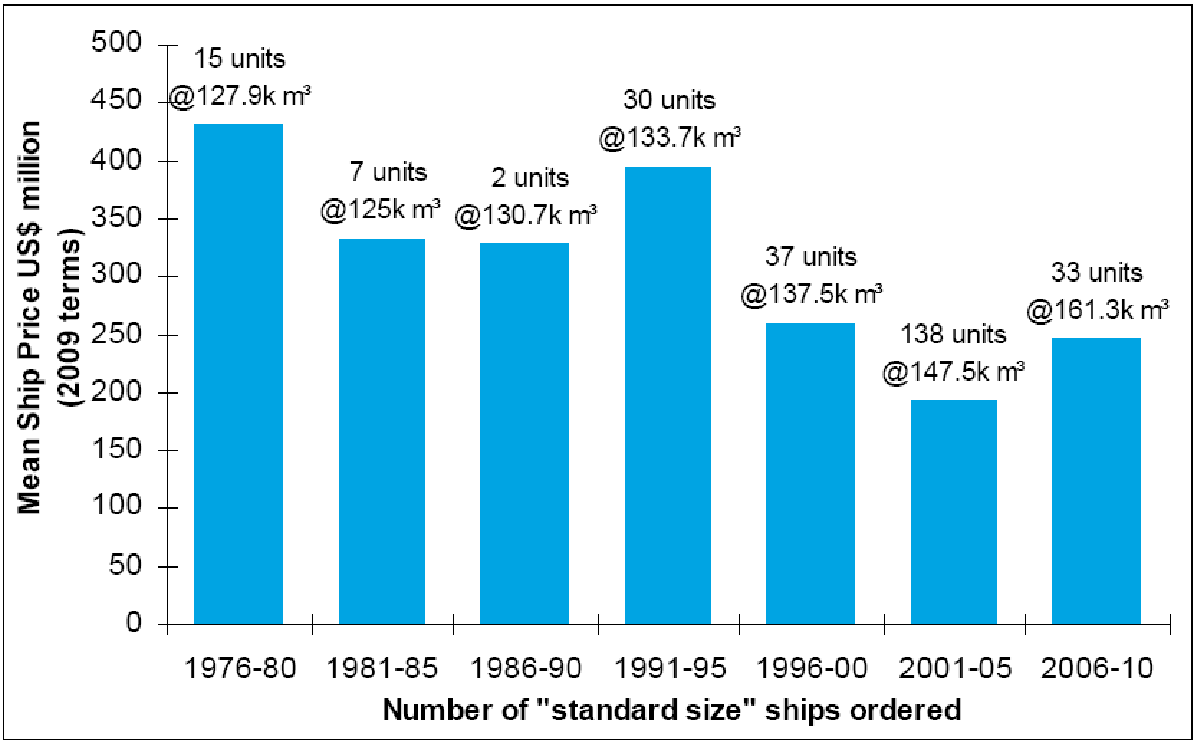


Source: (Wood MacKenzie, 2009)

Technological advancement in terms of re-gasification unit onboard the LNG vessel costs much more than the conventional LNG vessel running on the other fuel. Due to this high investments in a vessel and restrictive nature of the LNG trade, ownership of these LNG carrier is quite dispersed. There is almost no company in the world that owns more than 10% of the world LNG fleet. (Drewry Shipping Consultants Ltd., 2004)

While over the past 25-30 years the industry has seen a decline in the shipbuilding prices there have been some temporal variations. Typically in the year 1986-90 the shipbuilding capacity had increased tremendously and that increased competition amongst yards. This held the newbuild prices down. Korea is the leading LNG ship builder which was hit by the Asian financial crisis and that also brought the prices of the ships down. These were just couple of examples on why the newbuilding prices were low. Though the prices had stabilized around the beginning of 2006, the exponential increase in the orderbook of containerships, oil tankers and bulk carriers competed for the berth place with LNG. The peak was seen in early 2008. The following figure shows he mean price of standard ship size ordered over a period 1976-2010.

Figure 10 Mean Price of Standard LNG Ship Size Ordered Over a Period 1976 – 2010



Source: (Wood MacKenzie, 2009)

The main challenges and developments related to the LNG shipping industry are as follows:

- Shortage of crew: Shipping industry is already facing a challenge of having adequate number of sailors and in particular LNG as the crew required for these vessels should be well trained as they have to manage any situation endangering the vessel, cargo or the environment. As per a report released by the International Energy Agency the industry required around 4000 crew members for the LNG vessels under construction in the year 2007. (International Energy Agency, 2007) This situation needs attention and the solution could be to encourage more and more educated people to pursue sailing on such specialized ships. It is also essential to provide an adequate training to the crew in order to maintain high safety and security measures in place.
- Shipping patterns: LNG fleet stands at around 1.6-1.7% of the total world fleet, which shows a marginal role played by these vessels. However, the safety zone creations around the LNG vessels tend to disrupt the flow of traffic in specific areas. E.g.: In case of Port of Rotterdam decides to stop the

traffic movement when a LNG vessel is arriving at the port, this would result in many hours of movement time loss. Would this be economically justified? In order to justify this, the port authority may have to increase the port charges for LNG vessels, which in turn could increase the price of gas.

- LNG freight market: Traditionally the LNG carriers were built for long-term contracts which were based on a fixed route or series of routes. These contracts were typically for around 20 years. Last few years have seen a change in this trend. The contracts are now signed for about 10-15 years and it has been observed that a spot market is emerging, though very small in volume percentage, it is quite likely that it can become a regular market just like the spot market for other oil markets. This is a result of factors like tonnage built on speculation, spare LNG production capacity and continuation of seasonal LNG demand.

2.2.1.4 LNG Storage

The tank construction depends on the pressure and temperature conditions under which the LNG has to be stored. The pressurized tank can hold warmer LNG (~140-150º C) of a lower density whereas the pressure free tank can store colder LNG (-162º C) of a higher density. A pressure free tank has an advantage over the pressurized tank as the latter could require some cold flaring[3] to maintain a constant pressure level.(Hansson, 2008)

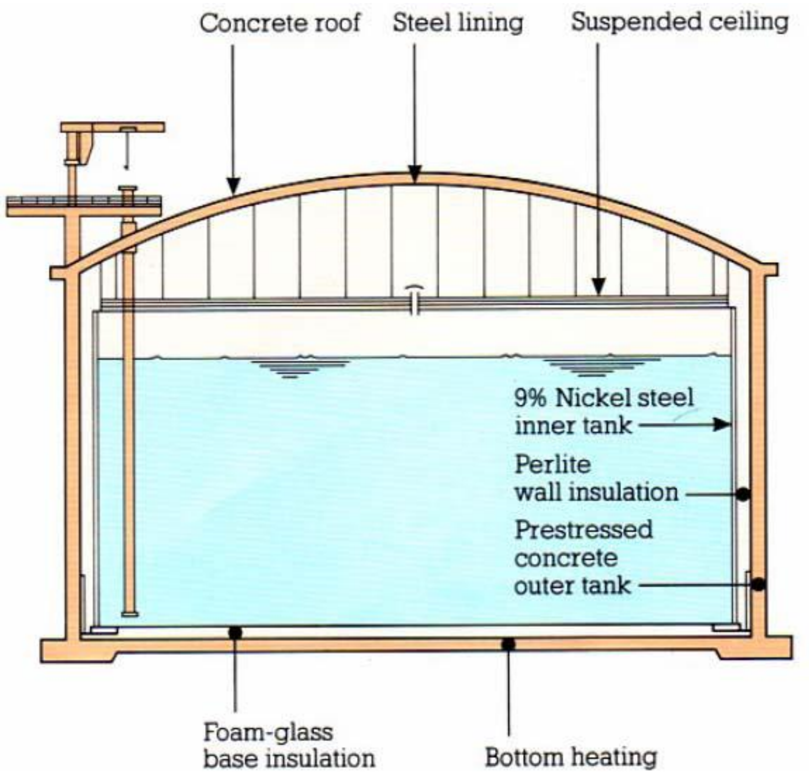
A storage tank requires an inner tank, a layer of insulation and an outer wall to fulfill the demands on heat insulation and safety. Thus the importance of insulation cannot be overlooked. To build such an inner tank 9% nickel steel is most commonly used and also aluminium can be used. This also makes it an important part of the overall costing for a LNG handling facility**.**

"Two main factors that determine the size of a tank are the demand of natural gas in the region and the size of the vessels calling at the terminal. A standard storage capacity is about 1-2 shipload, which is about 150,000 – 300,000m^3 LNG.

[3] Cold flaring: Evaporation through own evaporating system

The following illustration shows the design of a typical low pressure storage tank.

Figure 11 Design of a Typical Low Pressure Storage Tank

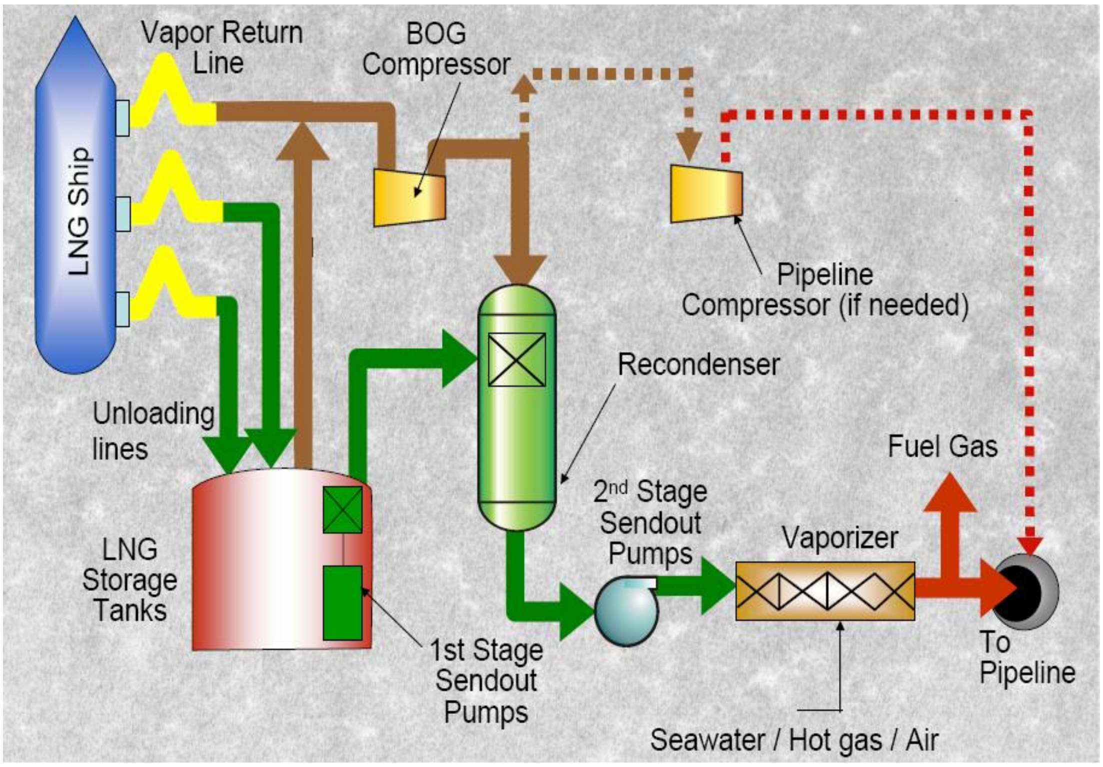


Source: (Pettersen, 2007)

2.2.1.5 Regasification

When a LNG vessel arrives at an import terminal, the vessel is unloaded in the special storage tanks, as discussed in the previous section. In the majority of the cases this liquefied gas is send out as a gas via pipeline after the liquid is evaporated to gas form. This regasification requires a special plant as well. The following figure shows the LNG terminal flow diagram which explains the position of regasification in the supply chain.

Figure 12 LNG Receiving Terminal Flow Diagram



Source: (Caswell, 2008)

In 2007 there were 13 LNG regasification terminals in 7 EU countries with a total send out capacity of 96 bcm per year. There are more regasification plants planned in Europe, which are expected to reduce the dependency of the EU on gas from Russia.

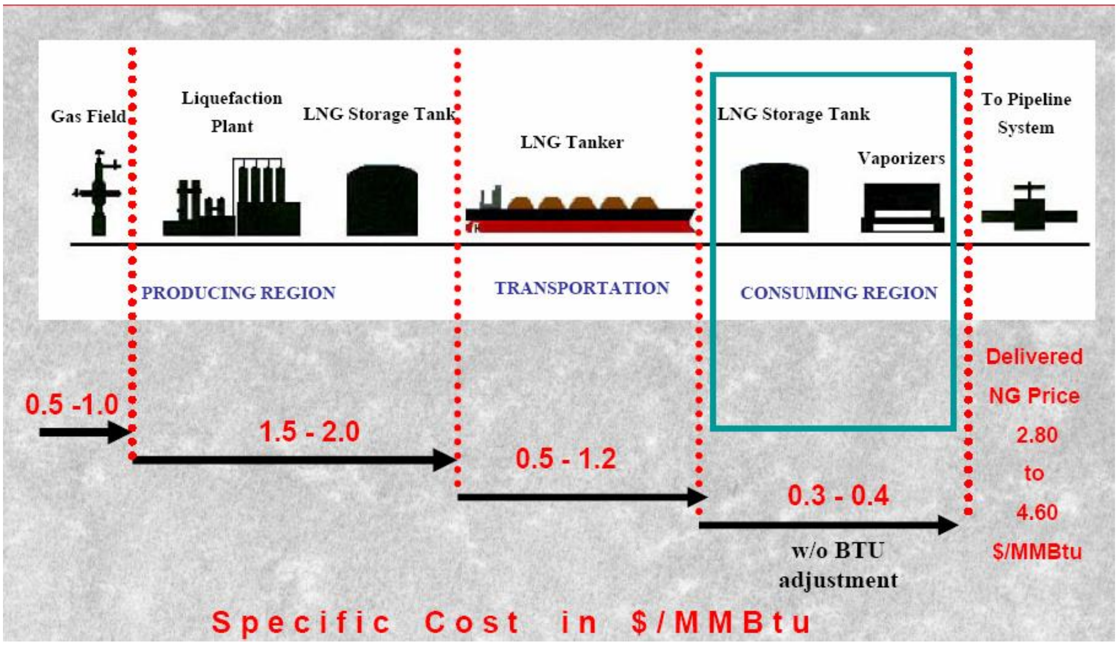
The concept of floating regasification terminal has a high potential to substantially reduce the costs, especially where the land costs are very high. This could be a potential threat to those who are interested in building LNG terminals onshore.

As already seen, every aspect of the LNG supply chain has specific cost attached to it. Although it would be difficult to generalize these costs, it is possible to make an estimate of the cost of transporting LNG from the source till it reaches the end-use via pipeline.

2.3 LNG Economics

As mentioned in the previous section, the cost for every aspect of the LNG supply chain varies depending on multiple factors. The following figure gives an indication on these related costs at each stage in the chain.

Figure 13 LNG Supply Chain Economics



Source: (Caswell, 2008)

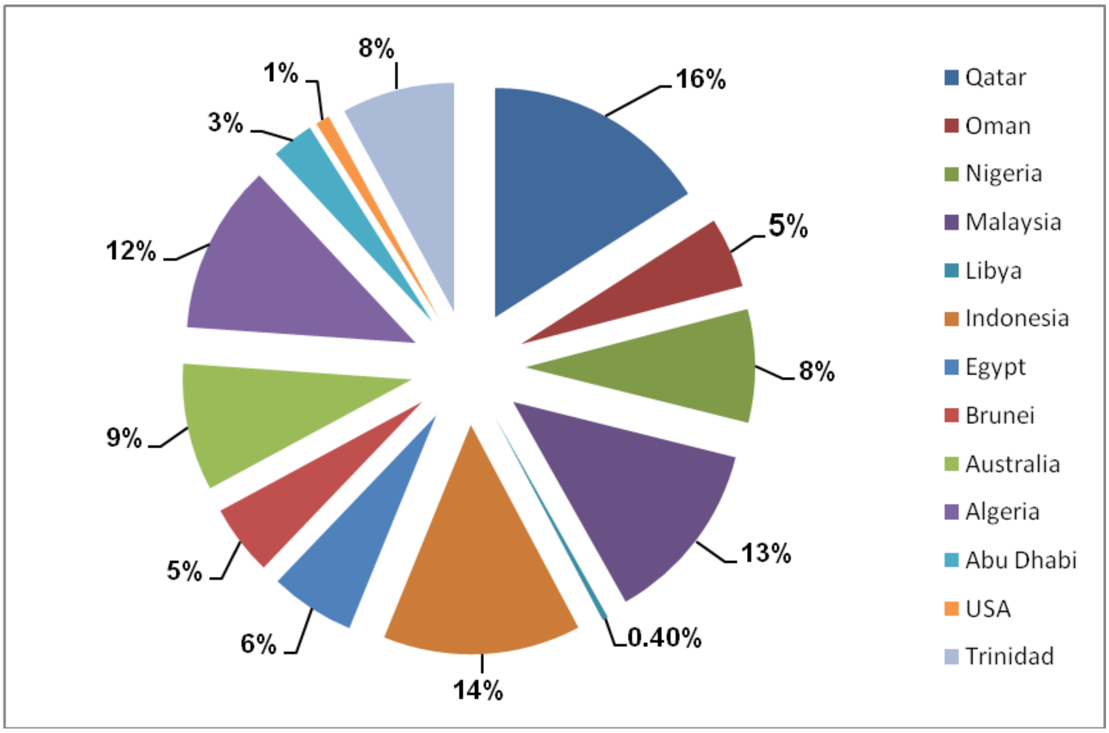
2.4 LNG: Present and Future

“Gas currently accounts for nearly a quarter of all energy consumption, and the IEA have forecast that the gas demand will grow at a faster rate than oil did over the first quarter of this century, accounting for 24% of worldwide energy use by 2030. With many regions facing future gas shortages, LNG offers an increasingly important method of bringing gas from remote reserves to the market.(Douglas Westwood - energy business analysts, 2009). There is very little doubt that the LNG demand will increase in the coming years. The question remains whether the increased demand be met in time with the expected supply and regasification projects coming onstream?

To understand the LNG market, it is essential to understand who the main players in this industry are.

The following figure shows the country-wise LNG exporters as at 2006.

Figure 14 LNG Exporting Countries (2006)

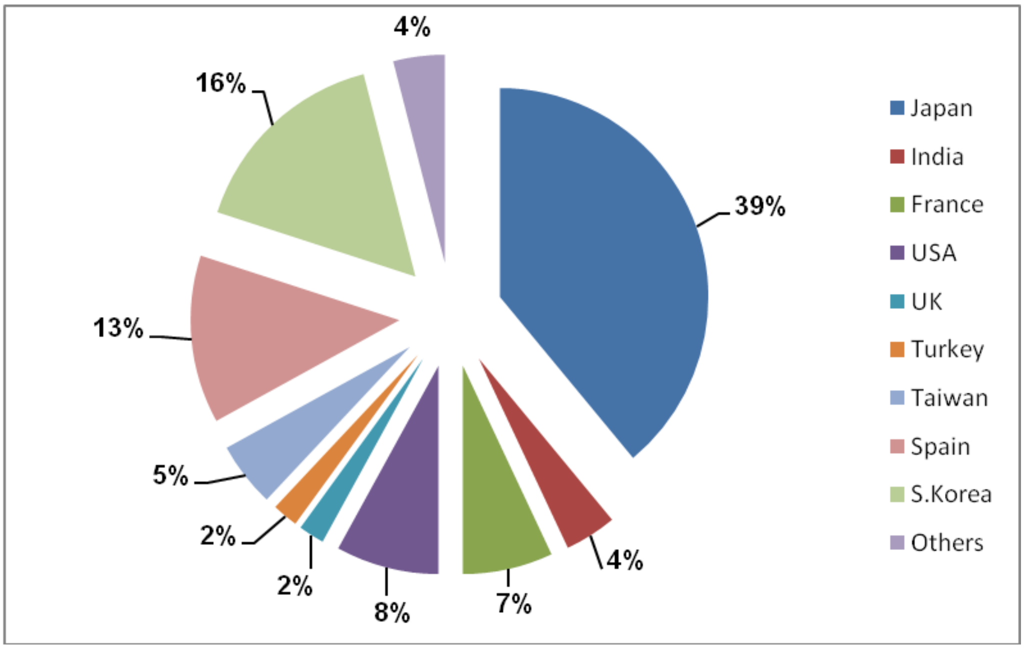


Source: (Caswell, 2008)

From the figure it is clear that Qatar is leading the list with 16%, closely followed by Indonesia (14%), Malaysia (13%) and Algeria (12%). For the European market, the main competition for Qatar is from Algeria. The other two are relatively far and this makes the gas from these countries relatively more expensive.

Japan leads the list of the importers with 39% of total LNG being imported into the country in 2006. The closest to Japan is South Korea with 16%. Spain is leading the import list in Europe for the LNG imports which shows around 13% of the total LNG trade. The following figure shows the LNG importers as at 2006:

Figure 15 LNG Importing Countries (2006)



Source: (Caswell, 2008)[4]

The next section explains the various capacities that play a vital role in the complete value chain. LNG demand is expected to increase over time and high investment in this industry make it difficult to invest in LNG without long-term contracts. These contracts are fixed for longer time provided the price is agreed upon for the entire period. Regasification infrastructure is based on the future demand. Thus, this shows a vicious cycle which is difficult to foresee.

On a regular basis Wood MacKenzie publishes data on the global overview with respect to the demand, supply and regas capacities. We have collected the data from Wood MacKenzie and summarized it to get a global overview.

[4] Other importers include Belgium, China, Dominican Republic, Greece, Italy, Mexico, Portugal, Puerto Rico

2.4.1 LNG Demand

The following table shows the expected region-wise demand from year 2000 – 2015.

Table 6 Region wise demand from 2000 - 2015 (mmscfd)

Regions	2005	2010	2015
Asia Pacific	12,111	17,752	21,870
Europe	4,772	8,445	13,146
North America	1,769	2,489	4,554
South America	0	412	576
Total	18,652	29,098	40,146

Source: (Wood MacKenzie, 2009)

The total demand has shown an increase of about 56% between the years 2005 to 2010 reaching to 29,098 mmscfd from 18,652 mmscfd. Demand in Europe is expected to grow by 77% between 2005 and 2010. During the same period demand in the South American market is expected to be around 412 mmscfd. North America and Asia Pacific regions are expected to grow by about 41% to 47%.

The total LNG demand is expected to grow by 38% between 2010 and 2015. This shows a relatively low demand compared to the previous period as demand in Asia Pacific is showing lower growth of about 23%. Europe is expected to grow by around 56%. With the growth of 83%, it is North America which shows tremendous prospects for increased LNG demand. South America will grow by about 40%. In conclusion, overall outlook for the demand is showing a positive trend.

2.4.2 LNG Liquefaction Capacity

Table 7 Region wise LNG Liquefaction Capacity (mmscfd)

Region	2005	2010	2015
Asia Pacific	7925.55	10311.62	12406.69
Europe	0.00	496.10	496.10
Middle East	4126.50	9355.42	11896.72
North Africa	3183.61	3892.57	5097.73
North America	157.30	157.30	0.00
South America	1211.21	2007.09	2326.83
West Africa	1131.35	2873.75	4214.43
Total	**17735.53**	**29093.85**	**36438.50**

Source: (Wood MacKenzie, 2009)

Project Development Status:

Table 8 LNG Liquefaction Capacity based on Project Development Status (mmscfd)

	2005	2010	2015
Onstream	17735.53	23273.14	22803.91
Under Construction	0.00	5820.71	11325.60
Probable	0.00	0.00	1597.50
Possible	0.00	0.00	711.48
Total	**17735.53**	**29093.85**	**36438.50**

Source: (Wood MacKenzie, 2009)

The total liquefaction capacity as shown in the table above is enough to meet the expected demand (as of Aug'09). The total liquefaction capacity is expected to be around 29,093.85 mmscfd by 2010 and 36,438.50 mmscfd by 2015 whereas the corresponding demand for the same period is 29,098 and 40,146 mmscfd. Till 2010 the demand and liquefaction capacities are in balance. However, the situation reverses in the period to follow. With more demand and less liquefaction the users may be forced to look for alternative energy sources and the price of LNG could increase as a result of the shortage of supply.

The total onstream capacity will increase by 31% between the years 2005 to 2010 however the period to follow is expected to show negative growth of 2%. Onstream capacity will be around 80% of the total liquefaction capacity in year 2010 and the capacity "Under construction" would be around 20%. With probable and possible projects being just 6% of the total capacity by 2015, it is quite likely that the pressure will be high on building more liquefaction capacity to ensure meeting the future demand of LNG.

2.4.3 LNG Regasification Capacities

As already mentioned earlier, the liquefaction capacity till 2015 may not be enough to meet the expected demand, whereas the regasification facilities will have a different story to say. As the investors have already started investing in such facilities, sighting the high demand growth, these facilities may not be used to their optimum due to shortage of supply in the future. The table below gives a picture that clearly shows the trend of more investments towards the infrastructure for regasification:

Table 9 Region wise LNG Regasification Capacity (mmscfd)

Region	2005	2010	2015
Asia Pacific	33,203	39,210	46,363
Europe	7,385	17,305	26,326
North America	3,494	17,038	23,691
South America	0	1,548	2,206
Total	**44,082**	**75,100**	**98,586**

Source: (Wood MacKenzie, 2009)

Investments in the period between 2005 and 2010 will account for 70% capacity increase whereas between 2010 and 2015 it will increase by only 31%. North America is expected to see an increase of nearly 400% and Europe will have an increase of around 135% whereas Asia will only increase by about 18%. For the period from 2010 to 2015 Europe will increase by 52%, North America will increase by 39% and South America will increase by 43% whereas Asia will only grow again by 18%. Regasification / liquefaction ratio is expected to be around 2.6 in 2010 and increases to 2.7 by 2015.

2.4.4 LNG Contracts

Table 10 Region wise LNG Export Contracts (mmscfd)

Export basin	2005	2010	2015
Atlantic	5382.20	7196.29	7655.50
Middle East	3894.69	4246.50	5218.52
Pacific	7904.75	8124.56	8064.18
Total	**17181.63**	**19567.34**	**20938.21**

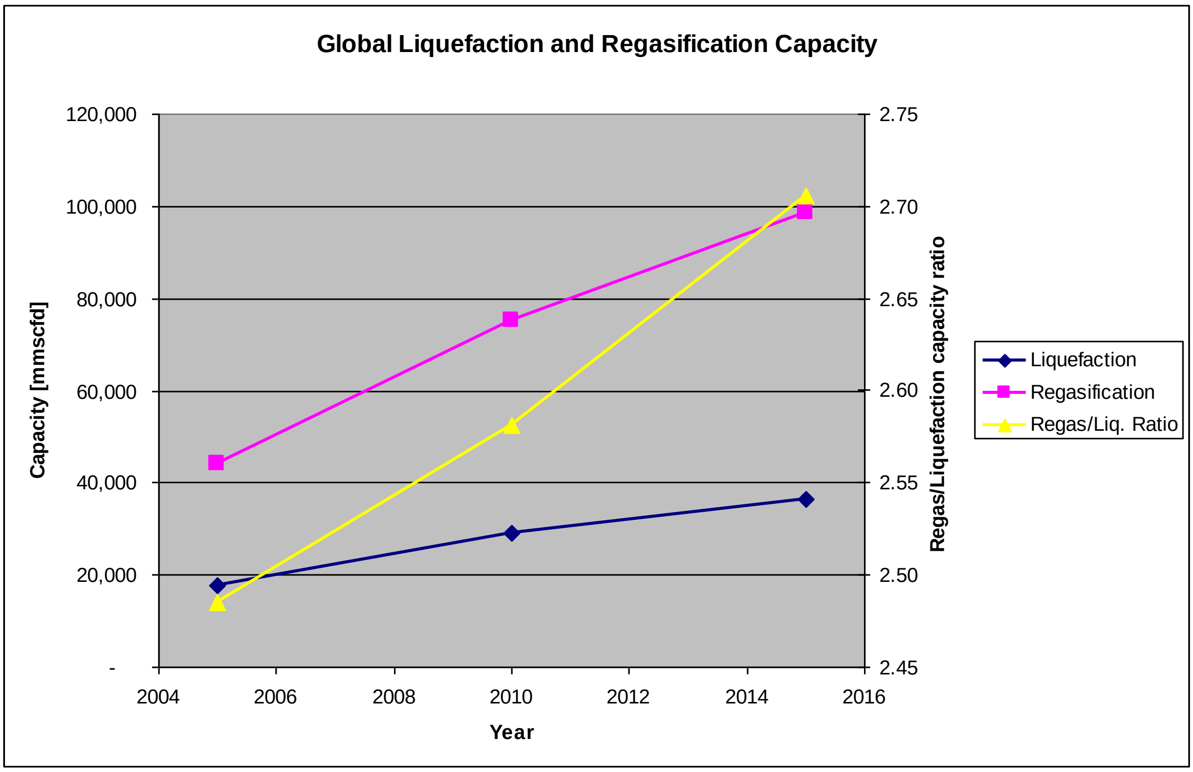
Source: (Wood MacKenzie, 2009)

As per Wood MacKenzie's report, the total contracted volume would increase by about 14% between 2005 and 2010 with Asia having about 34% increased contracts and Europe just 9%. The situation would be slightly different in the period between 2010 and 2015. The increase in total contracted volume (reported till July 2009) will be only 7% out of which 23% is contracted to Europe, 6% to Asia whereas the Pacific has shown a decrease in the contracted volume of about 1%.

Looking at the information provided on the contracts that have been closed, the volume for liquefaction could be justified. Since the process of building a new train for liquefaction is capital intensive and time consuming, immediate action should be taken to fill up this gap.

The following chart gives an overview of the liquefaction and regasification capacities between 2005 and 2015.

Figure 16 Overview of Liquefaction and Regasification Capacities from 2005 to 2015

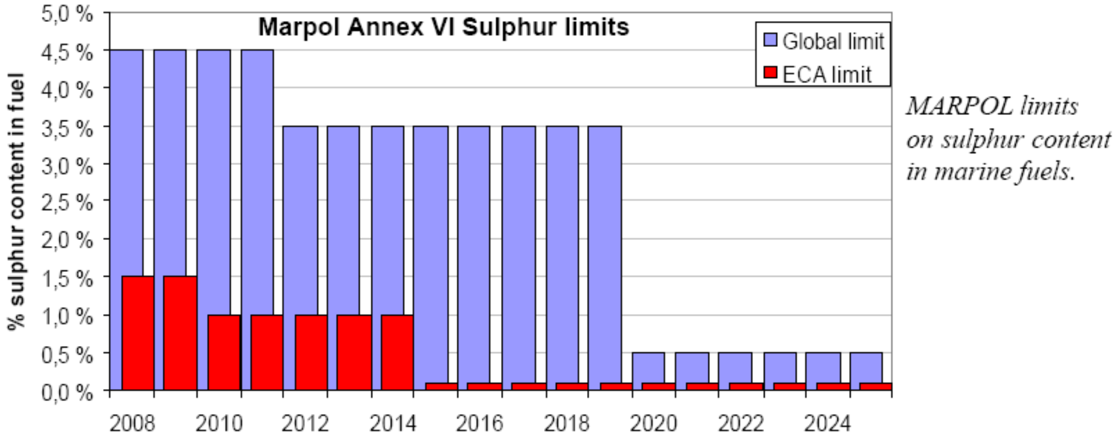


2.5 LNG: An environmental solution?

The shipping industry is under tremendous pressure as it is more and more clear that the bunkers used by the ships are highly pollutant, and steps will be required to reduce emission.

MARPOL (international convention for the prevention of pollution from ships) was revised in 2008 as the pressure to act on global warming is increasing on the shipping industry. It is revised to ensure stricter standards for shipping emissions. As per the convention, the sulphur contents in the fuel should be limited to 0.5% globally from 2020, compared to 4.5% now. The convention also applies limitations on nitrogen oxides (NOx) emissions. The Baltic and North Sea have been designated as ECAs (Emission Control Area) where stricter limitations shall apply. More such areas are expected to follow in the near future to ensure more joint efforts by the industry to take action in tackling this global problem.

Figure 17 MARPOL Limits on Sulphur Content in Marine Fuels



Source: (Maritime Gas Fuel Logistics, 2008)

To meet the standards within ECAs, it will be inevitable for the ships to switch to much cleaner fuel in place of the current heavy bunker oils. Low-sulphur distillates are expected to be the solution for this challenge; however, they cost 70-100% more than traditional bunker fuels (Maritime Gas Fuel Logistics, 2008). They also need to be supplemented by the exhaust treatment to ensure staying within the set NOx limits.

LNG is known to shipping as a commodity which was carried around the world by the LNG ships, until recently when some LNG-tankers used LNG to burn-off gas for fuel and combustion purposes.

“Maritime Gas Fuel Logistics” - a study report published in December 2008 by the MAGALOG project conducted on behalf of the European Commission stresses on the fact that LNG is a solution to the environmental challenges in North European shipping. The base for this study is taken from the existing, though on a small scale, practice of using LNG for coastal shipping in Norway. The study confirms that the environmental qualities of LNG are superior to those of any liquid petroleum fuel. This is particularly highlighted as LNG is sulphur-free and also helps in very low NOx-formation in the engines, thereby eliminating the need for exhaust treatment.

According to the MAGALOG report, the coming 5-10 years will witness more and more short sea ships being converted to using LNG as a fuel. The reason for this development can best be explained by the following:

- SECA (Sulphur Emission Control Area) in the Baltic Sea (2006) and the North Sea (2007) only permit a maximum content of 1.5% sulphur in ships’ fuels. It expects other areas such as the Mediterranean to follow this practice.
- Norway has levied 15Kr/kg for NOx and this is expected to increase further.
- Swedish ports, such as Stockholm and Gothenburg are charging different harbour dues to promote greener ships.
- No real solution has been found so far to slowdown the climate change due to shipping and aviation.

* Emission cleaning technologies are not able to make dramatic impact to meet the future environmental requirement.

Benefits of using LNG as a ship fuel (Maritime Gas Fuel Logistics, 2008):
* 100% less particle emissions
* 100% less sulphur oxide emissions
* 70% less nitrogen oxide emissions
* 25% less greenhouse gas emissions
* No particle filters
* No NOx reduction technology required

Some Norwegian companies are already laying the foundation of using LNG as a fuel for those ships which are regularly calling at the coastal ports. Engineering companies are gearing up to meet the challenge for LNG fuelled engines and recently a dual fuel engine has been introduced. The world's first ferry running on natural gas "Glutra" began its service in January 2000.

Some examples of LNG fuelled ships:

2 "Viking Energy" model vessels 2 "Viking Adavant" model vessels

5 "Bergensfjord" model vessels

There are also LNG Ro-Ro vessels on the drawing board like the one shown below:

Photos courtesy of Eidesvik AS, Bømlo,Norway, Fjord1 Nordvestlandske, Florø, Norway, Marintek, Trondheim, Norway

The potential of using LNG as a fuel is beneficial to the environment, however, it may be more expensive than the HFO. Also the vessels which are LNG fueled need the fueling facilities at the ports of call. Since the number of such LNG ferries is limited, transportation of LNG to these faraway ports could be an expensive logistical affair. At the same time, to ensure economies of scale, the larger volumes are required. Thus, if more and more vessels turn green and use LNG as fuel, more LNG could be transported even to remote ports, thereby ensuring reduced costs.

The challenge will be to compare the price of LNG as a fuel against the conventional liquid fuels. It could be a result of the ongoing developments and commercial processes, and may vary overtime. LNG as a bunker fuel for RoRo, RoPax and other forms of shipping could be considered in the similar way as the traditional long-term LNG supply contracts. Since the initial investment for such infrastructure is relatively high, long term commitments must be obtained. Investments in LNG driven ships will depend on LNG supply, and the recovery of the LNG supply investments depends on serving such ships. To overcome this proverbial “Chicken and the egg” problem, government incentives and regulations are required to promote LNG as the preferred ship fuel.

There are two main elements to ensure the commercial viability of LNG as a fuel:

1. If LNG is being used as a fuel, it should not work against the ship owner’s competitive position relative to the use of other fuels;

2. The LNG seller should be able to recover its supply cost.

If LNG has to be procured from European import terminals, the purchase price will be related to the European gas market prices. LNG imported into Europe is generally for the pipeline supplies, hence when the same LNG arrives at North European terminals, can be assumed to have a similar market value as the other natural gas in the region. At the same time, the gas produced by Norway is transported through pipelines to Europe or UK, and thus enters the European pipeline market. Keeping this in mind, the natural gas purchased for small scale LNG production, and ultimately for bunkering purposes, can easily be compared to the European gas market as well, where the price for pipeline transportation can be reduced.

As recent as 17th September 2009 an article was published in PortGotNews. As per the article Göteborg Energi is working to establish an LNG terminal along with a Norwegian company Gasnor and the Port of Gothenburg which is planned to commence operations in 2013. Magnus Kårestedt, chief executive of the Port Gothenburg mentioned that this is considered as an integral part of the development of alternative fuels and this investment fits in well with the vision of the Oil Harbour to evolve into an energy harbour. Anders Hedenstedt, President of Göteborg Energi confirmed their interest in this terminal development and went on to say that they had identified the LNG market in Western Sweden and have plans to commence sales. They will also establish and operate an LNG storage facility at the Port of Gothenburg. The article also mentioned that LNG reduces sulphur, nitrogen and particulate matter emissions by almost 100 per cent compared with heavy oil. The emission of carbon dioxide would be reduced by approximately 25 per cent. (Port of

Göteborg, 2009) This article supports our argument of LNG being used as an alternative fuel and it also shows the interest of various parties in Swedish market. While presently people are looking at using biofuels as alternative to regular fuel or electrically driven vehicles, a lot of work still needs to be done to promote biofuels as alternative vis-à-vis LNG.

LNG has made it easier to transport gas over longer distances, thereby facilitating an increasingly broader usage of the gas. LNG is a clean fuel for transport when compared to bunker fuel or HFO, however, its use is limited as shipping, transport and storage of LNG is complicated and costly, especially in view of the low temperature of the LNG and the resulting equipment requirements and safety precautions. The high level of investment for establishing an LNG supply chain implies that economies of scale need to be pursued in order to achieve competitive unit cost for the gas. At the same time, players in the supply chain have traditionally required long term contractual arrangements in order to reduce the exposure on their investments. In conclusion, we can state the capital intensity of LNG solutions has been prohibitively high for some of the small scale applications of LNG to become economically feasible.

3 Small Scale LNG

Though the concept of small scale LNG is not well defined, companies like I.M.Skaugen SE (Norway) expresses their view as “The concept increases the market for natural gas by distributing LNG from either a LNG plant, LNG import terminal or directly from a LNG carrier using a combination of both sea and land based transport directly to the end-user” (I. M. Skaugen SE). For our paper we focus on the shipping part of this explanation, thus we consider small scale LNG as the smaller volumes transported by smaller vessels and the chain is the extension of the large supply chain.

This chapter introduces the concept of small scale LNG from our perspective. It also highlights the importance of the combined supply chains, large scale and small scale, for transporting LNG to smaller destinations. It explains how a small scale tanker is different from a large scale tanker and the importance of such small tankers. It compares in brief the economies of scale for large versus small scale tankers. It explains the possible option of using LNG as a fuel for transportation modes and how small scale LNG would be useful in promoting this environmentally friendly fuel. The chapter also introduces the two Scandinavian markets, namely Norway and Sweden where we believe the concept of small scale LNG can be applied to.

3.1 What is Small Scale LNG?

Since the concept of Small Scale LNG is relatively new, it is difficult to draw a line as to where Large Scale LNG changes to Small Scale LNG. There is no definition available for small scale or large scale LNG chains. Thus for the purpose of this paper we consider LNG carried by the tankers smaller than 10,000m^3 as small scale LNG distribution. The supply chain, in this case, is extended and is not competing against larger volumes. The idea here is similar to that of break-bulk, where volumes could be brought by larger vessels to a large storage terminal and then in smaller parcels taken to a satellite terminal.

In Norway, many efforts are being made towards promoting more and more usage of Natural Gas. To ensure adequate supply of the gas, Norway not only produces the gas but also in future would import the gas. At this point in time, Norway produces gas with three small scale and one large scale LNG production plant. With the help of smaller vessels (like 1,100m^3, 7,500 m^3 and 10,000 m^3 vessels) this LNG is supplied to smaller terminals for further use as fuel for ferries, trucks, buses or as pipeline gas to single end users. The concept of small scale LNG production is well thought through for smaller customers, however, there are limitations to it, which are among others:

1. Limited Volumes: due to the smaller size the volumes transported in this case are limited. Though the frequency of round trips can be increased to move more volume, volume per transit is limited.

2. Impact on price: since the production and distribution cost of small scale LNG is higher compared to large scale LNG, the end-user cost will be relatively higher.
3. Distance to market: the concept is designed to serve remote areas and areas where pipelines would be very expensive to build. With smaller loading capacity of vessels there would be less economies of scale.
4. In case of a shutdown of a small LNG plant, the customer impact would be very high due to the limited availability of other LNG sources.

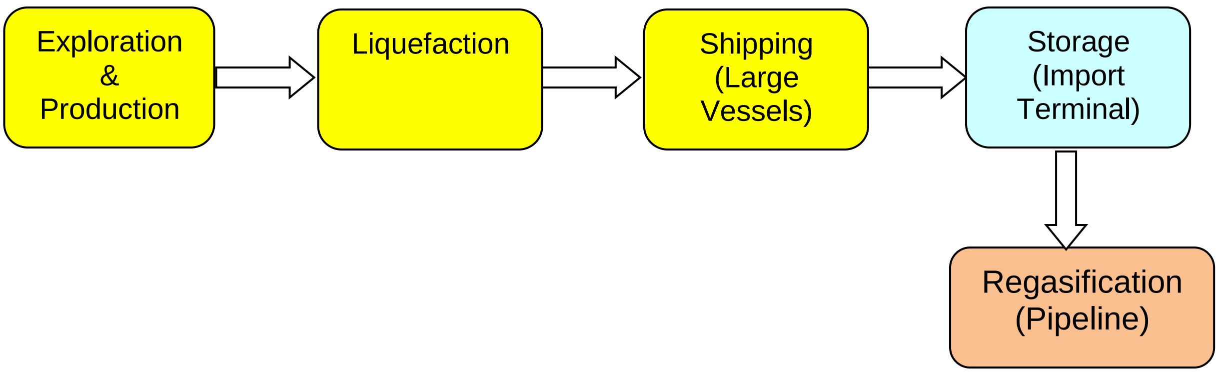
To counter these problems, an alternative solution is possible, which can bring the benefits of large scale LNG production to the small scale LNG supply chain.

A regular supply chain for LNG starts at the source where Natural Gas is converted into liquid form and is shipped across the ocean to a large importing terminal. A large LNG vessel normally has a carrying capacity of 145,000 m^3 to about 265,000m^3. At the import terminal the LNG is stored in tanks which can typically store about 2-3 shiploads and one week sendout capacity of LNG to ensure enough shipping flexibility and no shortage of supply into pipeline grid. After regasification, the gas is send via pipeline to multiple end-users at various destinations.

This large scale LNG could be piped to the small scale market, however the pipeline has its own limitation when it comes to transporting gas over longer distances. This requires new solutions for transporting LNG to a port as close as possible to the small scale market. In our case the solution can be small scale LNG. Large scale LNG and small scale LNG are not competing but complementing each other since small scale LNG is basically an extension of the large scale LNG supply chain. It helps in overcoming the downstream distribution and logistical difficulties faced by Large Scale supply chains.

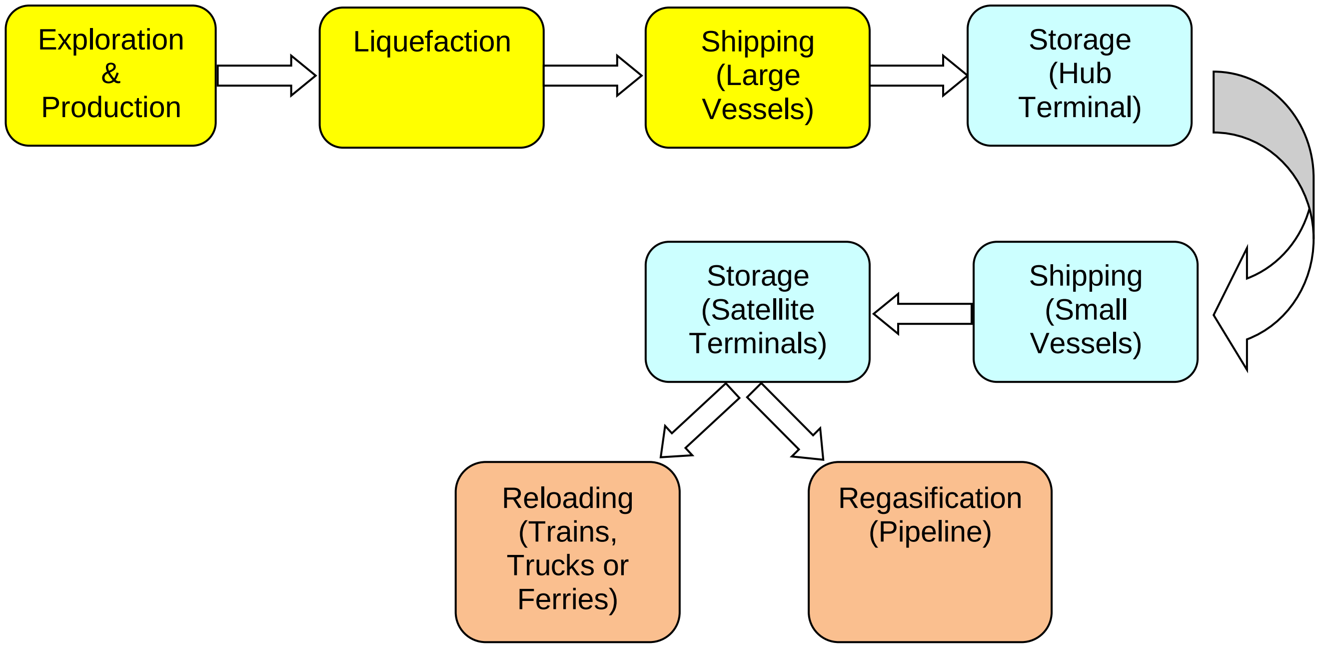
Large Scale LNG Supply Chain:

Figure 18 Large Scale LNG Supply Chain



Small Scale LNG Value Chain:

Figure 19 Large Scale LNG + Small Scale LNG = A New LNG Value Chain



The idea is to extend the entire supply chain of large scale LNG with a small scale LNG supply chain and so enhancing the value chain. In the large scale supply chain the import terminal stores the LNG and, after regasification, sends the gas out via pipeline. In the new value chain, the import terminal will be treated as a ***"Hub Terminal"*** where LNG will be stored for reloading into smaller vessels and then shipping it out to a ***"Satellite Terminal"***. From this terminal LNG will either be re-loaded onto trains, trucks or ferries, or after regasification would be send-out via pipelines. This justifies the new chain being addressed as a value chain, as this chain extends the use of LNG to remote destinations, thus increasing the usage of LNG.

For economies of scale, larger volumes are required, however, small scale LNG as a concept is helping to increase the market for distribution of Natural Gas. This also gives a unique opportunity to some industries, power plants and other energy users which are currently not connected with gas pipelines and which are interested in turning towards more environmentally friendly energy sources. Before the small scale concept came into existence these users were forced to use fossil fuels like HFO, naphtha and LPG. However, now they have an option to choose LNG or Natural Gas.

Since small scale LNG distribution is assumed to be relatively more expensive, at the same time it brings environmental advantages in terms of reducing emissions.

Some key benefits of small scale LNG compared to large scale LNG are mentioned below:

- **Faster to mobilize:**
    - Smaller terminals are faster to built and also faster to commission.
    - Small vessels can be build in relatively lesser time, thus could be available faster than larger vessels.

- **Cost and Capital efficient**:
    - Relatively low infrastructure cost.
    - Since smaller in size, it is easier to customize the facility as per the demand.

- **More flexibility:**
    - Multiple vessels of various sizes can be used to increase and adjust the capacity. e.g.: A combination of a milk-run with a 10,000m^3 vessel could meet a regular demand based on a fixed schedule. In addition a 1,100m^3 vessel can help meeting specific requirements for irregular demand of much smaller terminals.
    - Capacity can be build over time and the process can be done in steps. Thus reducing high upfront investments for large scale terminals.
    - More likely to serve as an alternative to conventional fuels for transportation than large scale LNG.

- **Higher margins:**
    - This helps serving those customers who were not being served by the pipeline.
    - In many cases the LNG can be brought directly to the end-user

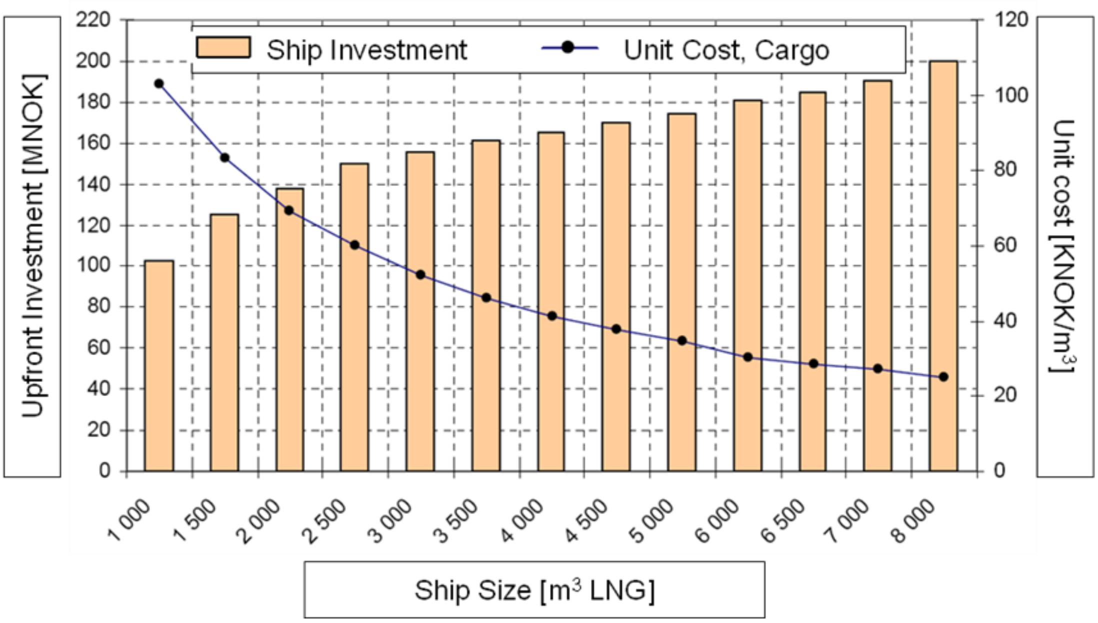
- **Environmental benefits**:
    - More use of LNG, in areas where gas was not present at first, reduces the emissions and makes it a preferred energy source.

3.2 Small Scale LNG tankers

Small-scale LNG is already a reality in Japan with vessels like “Shinju Maru No. 1 (2500m^3) and in Norway with “Pioneer Knutsen (1100 m^3). The concept is not new, however, there are not many of such small tankers in use today.

The following figure gives an overview of the estimated investment cost for small scale LNG ships in relation to their size ranging from 1000 m^3 to 8000m^3 of LNG.

Figure 20 Estimated Investment Costs for Small Scale LNG Ships



Source: (ENOVA SF, 2005)

The reference year used for the above table is 2003. Accordingly, the new building prices today are likely to be higher, since the steel prices have risen in the past few years while the orderbook was rather full. It is likely that a vessel of 6000m^3, shown here as 180 million NOK, would cost 200 million NOK.(ENOVA SF, 2005). Though the recession might suggest otherwise, there are few indications of any deviation so far.

3.3 Small Scale LNG: an alternate fuel for transportation modes

LNG as a fuel for Transport:

Since the gas use is limited in areas where pipelines are not laid or are difficult to access, the need for shipping LNG is also limited. However, LNG can be used for other applications as well which can prove to be a driving force in promoting small scale LNG.

One of the most promising applications of small scale LNG is its use as a fuel for various modes of transport like ferries, trucks, trains, barges, airplanes, cars, etc. In many countries CNG (Compressed Natural Gas) is successfully used as a fuel in place of HFO or diesel and hence the infrastructure is now partly in place. In case of promoting LNG as a fuel for transport modes infrastructure needs to be set-up. According to Mr. Blaazer and Mr. Kuin of LNG Europe BV, the political willingness and the industry support would play a vital role in ensuring reduced emissions without reducing the road traffic. EU has a number of policies in place to handle the emissions problem, however, implementation is delayed till the last possible deadline. All depends on political will, unless it is economical to do so!

According to Mr. Blaazer and Mr. Kuin another important aspect of LNG as a fuel is its quality. When LNG is regasified and is send through the pipeline, the quality issues are less critical. However, when the same is used as fuel in mid and small sized engines the quality is of prime importance. Thus quality checks are critical. When such checking has to be done at every stage of the value chain, the end product gets more expensive. Though they believe that in the coming 5 years the Dutch LNG fuel market for the trucks could be in the range of 20,000 – 25,000 tons, it is only seen as the beginning. The future of such fuel usage is a result of many factors coming together such as the initiative and support of the government, transport industry and such other players that can make a difference in generating demand. Since the company is interested in the demand of LNG for truck transport, they also foresee the large scale usage of LNG as fuel in other modes of transport. Countries like Germany and Sweden require their garbage trucks to run on CNG. LNG Europe believes that even the Dutch government will consider such requirement in the near future and instead of CNG it will be LNG.

3.4 Norwegian and Swedish LNG Market

3.4.1 LNG in Norway

Norway is one of the gas exporting countries. Its proximity to the Swedish market makes it a preferred supplier. Like other places in the world, Norway is also increasing the gas production and it is expected to continue this increase in the coming years.

Norway is becoming a role-model in the distribution system due to the large number of small-scale LNG receiving terminals scattered along its coast. The Norwegian landscape makes it difficult to build a pipeline network. It is not only challenging but also very costly which ultimately makes the gas more expensive. This limitation is supporting the increased focus on the small-scale LNG shipping.

The profile of the users in Norway is typically that of local industries and towns. For these users the requirements are also relatively smaller and hence the large vessels (75,000 m^3 – 265,000m^3) exceed their demand by many folds. For this market a small vessel is already in operation which carries 1100m^3 of LNG. The vessel is called “Pioneer Knutsen and is operated by Gasnor. Another vessel called “Coral

Methane", which can carry 7500 m^3, is now in operation as well. This vessel cannot only carry LNG but can also carry LPG and Ethylene. This feature will help reduce the empty time of the vessel. In case there is no LNG cargo, the vessel can still carry ethylene or LPG. The vessel is owned by Anthony Veder, a Dutch company and is leased to Gasnor for 15 years.

Melkøya is an island situated just off Hammerfest and is also home to Norway's largest LNG production facility. This facility is co-owned and operated by StatoilHydro. This LNG production plant uses Natural Gas from the Snøhvit field. The planned annual production capacity of this plant is 65 TWh making it big enough for large-scale shipping and transportation. The transport of LNG will be covered by four new vessels of 140,000 m^3 each (Snøhvit - The world's northernmost LNG project, 2008). It is likely that some of the LNG would be distributed around the Nordic polar with the help of a small scale LNG distribution network.(Hansson, 2008)

At present, there are three plants operational in the small-scale category, out of which Kollsnes (1580 GWh/y) and Karmøy (280 GWh/y) are operated by Gasnor and Tjeldbergodden (250 GWh/y) is operated by StatoilHydro.

Norway's second largest LNG plant is under construction at Risavika, near Stavanger. The project is called Nordic LNG and is owned by Lyse Gass, I.M.Skaugen and few other companies. The planned capacity is 4.5TWh/year with the possibility of expansion to double the capacity. The plant will be operational from 2010 and the distribution of LNG will be done by 10,000m3 ships and by trucks.(Hansson, 2008)

The following figure shows an overview of the Norwegian LNG infrastructure:

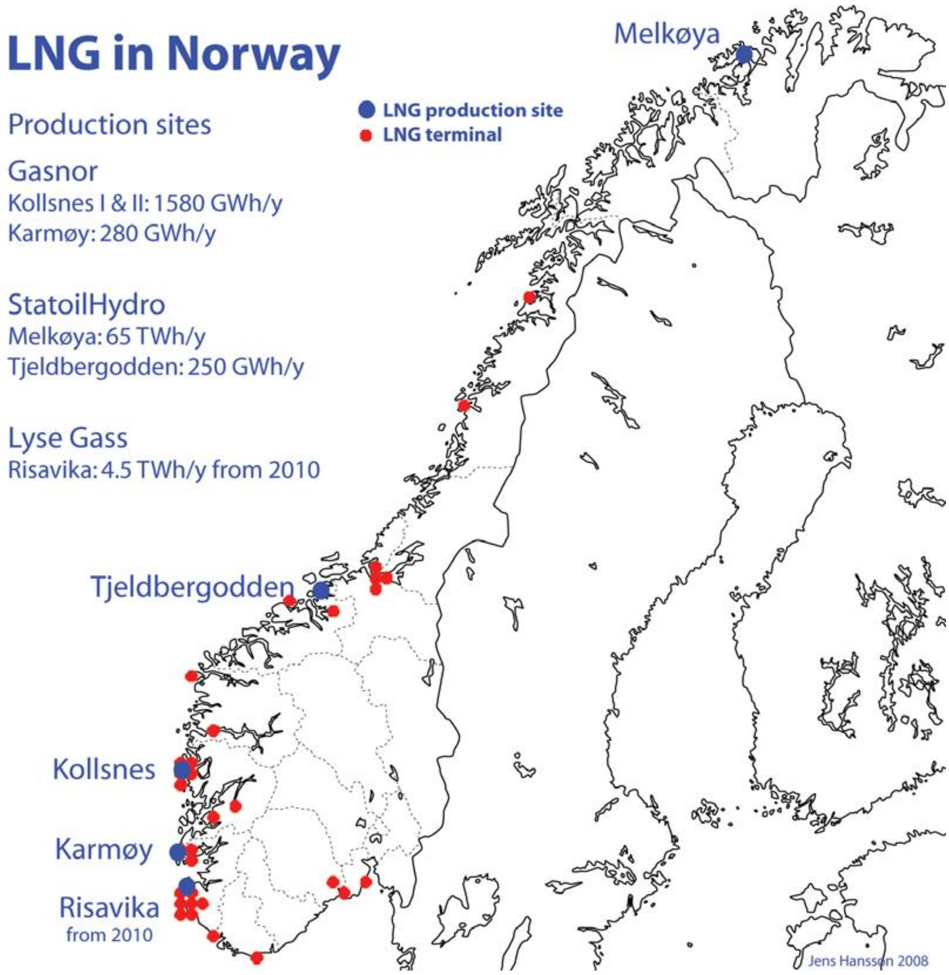


Figure 21 an Overview of the Norwegian LNG Infrastructure

Source: (Hansson, 2008)

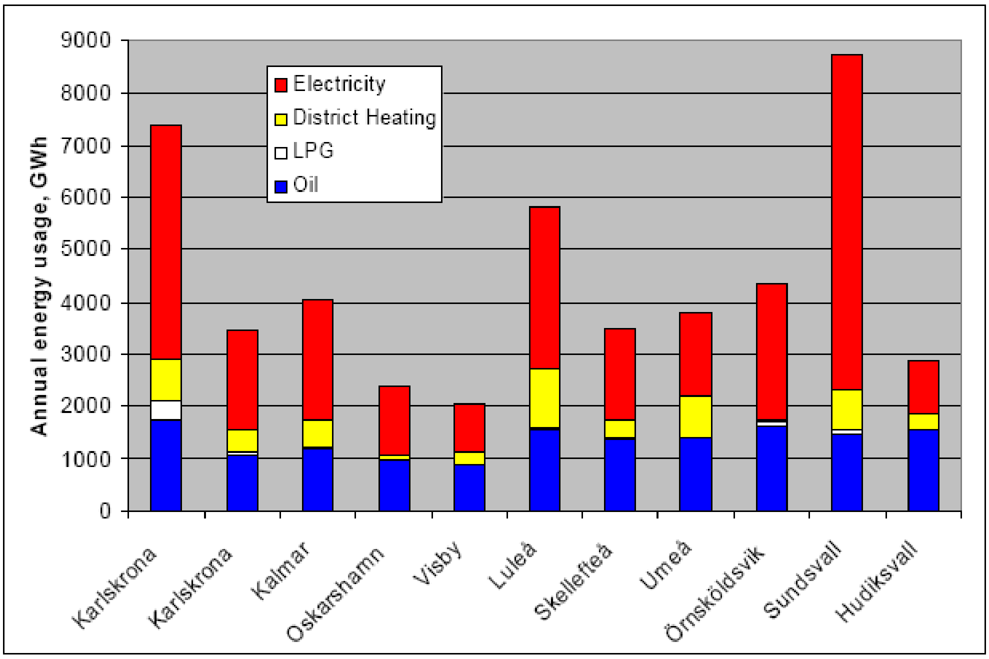
3.4.2 LNG in Sweden

Sweden, typically, had been using oil for about 70% of its primary energy demand. Though some initiatives were taken to import LNG as early as 1973-74, the government then saw few advantages of turning to gas instead of oil. Subsequently in 1980, after Denmark discovered some gas, a contract was signed with Denmark to import Natural Gas by pipeline. This was also another hurdle in establishing a large-scale LNG import terminal.

Sweden, just like Europe could opt for a better energy supply mix which will reduce the dependency on specific suppliers while bringing more flexibility. Also, the dependency on a transit country for a pipeline is a limitation in increasing the supply of Natural Gas. Compared to Norway, the energy politics in Sweden are relatively unpredictable, which also deters further large investments in LNG import terminals across Sweden. Natural Gas covers about 2% of the energy demand in Sweden against 20% in Europe.(Hansson, 2008) "Currently there are just three small LNG users in Sweden, using it as back up for vehicle fuel biogas, and located in Linköping, Uppsala and Stockholm." (Hansson, 2008)

A study has been carried out by Näslund, ed. *LNG i Sverige*. 2006, Institutionen för Energivetenskaper, LTH - Lund, which shows the fuel used for various districts for heating and industrial purposes. The study was partly carried out to analyse the potential LNG terminal locations. The following figure shows the municipal energy balances presented by Statistiska Centralbyrån and have been collected in Näslund's *LNG i Sverige.*

Figure 22 Annual Energy Usages around some Potential LNG Terminals along the Swedish Coast



Source: (Hansson, 2008)

As per the study, replacing only oil and LPG with Natural Gas, the potential is around 200-400 GWh for each of the mentioned 11 terminals, making it around 4.8-5.9 TWh together.(Näslund, 2006)

Figure 23 Present Swedish gas network and the stretches planned or under construction

Source:(Hansson, 2008)

The above figure shows the Swedish gas network, which is limited; therefore ample potential exists to complement pipeline gas with LNG.

LNG has a high potential for various usages in Norway and Sweden, especially to be used as fuel. Since the LNG requirement in these countries is relatively lesser, carrying LNG via small vessels proves to be an ideal solution. Small scale supply chain requires a connection to large scale supply chain in order to benefit from the part economies of scale.

4 Economies for Small scale LNG

This chapter introduces the Hub-and-Spoke principle. It explains the advantages and disadvantages of this principle and the port selection criteria. The chapter elaborates the research questions. It explains various aspects which are critical to this model like the supply chain definition and the hub-costing model. It also explains the complications on data collection. The chapter addresses the reasoning behind choosing the LNG export ports, the hub ports and the satellite ports for this model, as well as the important cost elements for each of the three port groups, being exporting port, hub port and satellite port. The main findings of the thesis are explained here and the chapter is concluded by giving some conclusions and recommendations to the various parties involved in this supply chain.

4.1 Introduction

Research Question:

Since LNG is gaining momentum as being a preferred fuel for various applications, the demand for LNG is expected to increase worldwide. Keeping this in mind Royal Vopak is investing in their first LNG terminal called Gate Terminal at the Rotterdam Maasvlakte. The terminal will be operational from mid 2011. The terminal has already leased its existing capacity and thus has little to worry about the business in the short-run. However, LNG is well in demand for various applications and this is expected to grow faster compared to the other energy sources. It takes about 4-5 years to build a new LNG terminal, including the time required for the initial studies. Gate terminal has no spare capacity (as of Aug'09). However, if Vopak wants to serve a higher share of the market, providing additional services could be considered. If we keep this in mind, the small scale LNG does appear to fit this requirement. This new business needs to be evaluated against the other competition that exists for Gate Terminal. In order to do so various questions could be asked, like:

Is it feasible to use the Hub-and-Spoke principle in Europe for the supply of LNG into Scandinavia?

Can Gate terminal also function as a hub terminal for the supply of LNG into Norway and Sweden?

Is Gate a viable choice for small scale LNG supplies into Norway and Sweden?

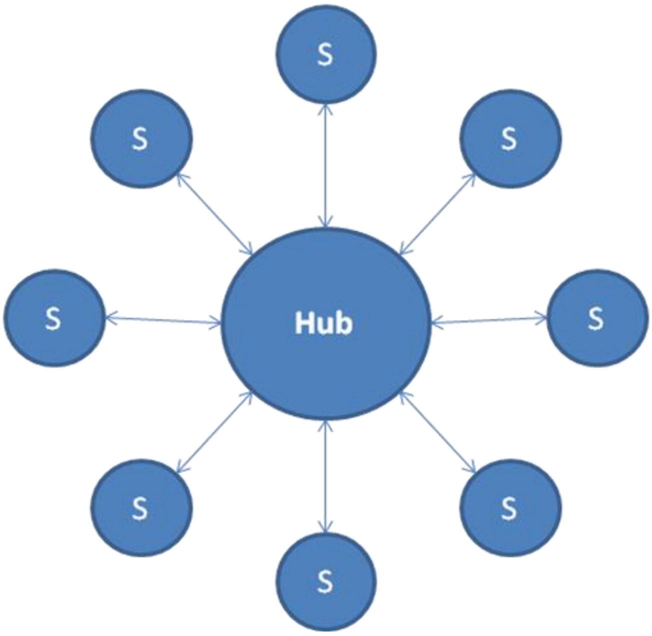
To answer these questions it is essential to analyse the complete LNG supply chain from an export port to a satellite port via a hub port. In such supply chain a large volume of LNG would be brought to a port which stores it for reloading onto small vessels which will carry LNG further to various destinations with smaller requirements. The concept is taken from the container shipping where the large number of containers is brought to a hub from where they are taken by feeder vessels to smaller destinations. This principle is known as "Hub-and-Spoke".

4.2 Hub-and-spoke principle

The hub and spoke principle derives its name from a bicycle wheel, which consists of a number of spokes jutting outward from a central hub. In the abstract sense, a location is selected to be a hub, and the paths that lead from points of origin and destination are considered spokes. Because of the efficiency (and relative inflexibility) of the model, it requires that the products being distributed are routed through a central hub before reaching their final destination. The model is used extensively by the transport and freight industry.(http://en.allexperts.com)

Fred Smith, the founder of FedEx pioneered the hub-and-spoke model in mid-70's for the overnight delivery. UPS and Airborne followed this example shortly and thus the freight industry started using this extensively. Similarly, Delta Air Lines used this model to compete against Eastern Air Lines and thus introduced this model to the airline industry. Thus the model is now being used also by the airline industry for transporting the passengers as well as their cargo. (http://en.allexperts.com)

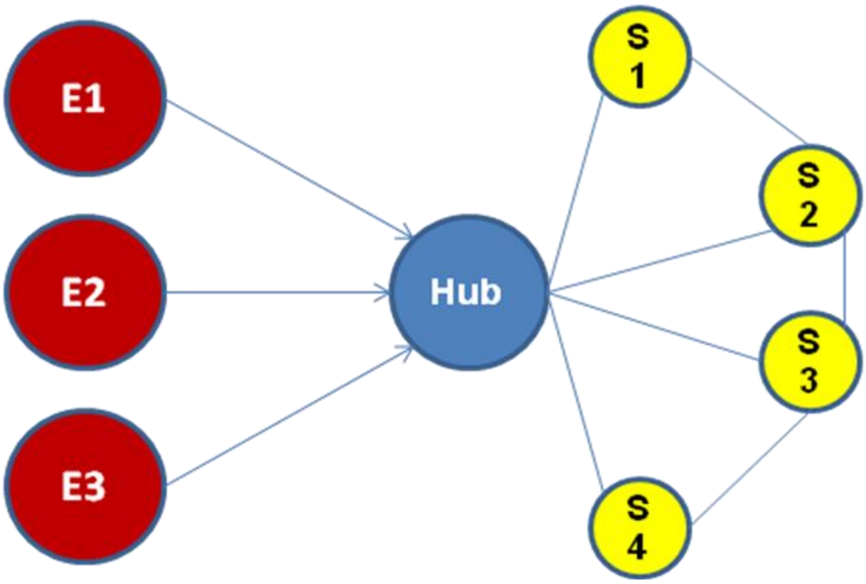
Figure 24 Hub-and-spoke: bicycle wheel



The principle is now being applied in the maritime industry but mainly for the container carriers due to increased cargo traffic and the expansion of the global trade. In the maritime industry the major ports are usually selected as hub ports based on their location and the demand for freight shipping. While the other ports serve as feeder ports, i.e. spoke ports. With the large mother vessels the cargo is shipped on the main lines, providing services between the hub ports, while the smaller vessels are used on the feeder lines to provide the service between a hub port and its feeder ports. Main lines are usually shipping services between two continents or regions, such as the Trans-Pacific Service, the Trans-Atlantic Service, the Asia–Europe Service, and the Asia–Australia Service. On the other hand, feeder lines are mainly for collecting or distributing freight within a continent or region, such as the China–Japan Feeder Service, the Singapore–Surabaja Feeder Service and others. (Chaug-Ing Hsu, 2007). The major advantage of this principle is that the goods can reach those places where it is not possible or not feasible to go with larger modes of transportation.

A similar concept may also apply for transportation of Natural gas. Long distance pipelines are not feasible (as discussed earlier) plus geographical complications can also make it difficult to lay pipelines in many countries like Norway. Since Natural Gas can be converted into LNG, the gas can be transported by larger vessels to a hub port where LNG can be stored for further shipment to smaller satellites. LNG can then either be regasified for sending via local pipe-grids or used for other purposes like fueling at the terminal for trucks, barges and ferries or carried further by road transport or by trains to other fueling stations.

Figure 25 Hub-and-spoke model



The above figure gives an idea about the hub-and-spoke model for our paper. E1, E2 and E3 depict our export ports. From these export ports the large LNG carrier will take LNG to a hub port. From the hub port LNG will be shipped to satellite ports shown as S1, S2, S3 and S4.

However, the question arises how efficient the hub-and-spoke concept would be as opposed to a traditional direct supply chain, which is depicted in the following figure.

Figure 26 Direct supply chain

Arguably, for large cargo parcels a direct end-to-end supply chain would be preferable, as it avoids the transshipment expenses and associated port cost at the hub. Furthermore, it potentially saves on charter hire for the days the vessel would otherwise need for the hub operation. As a matter of fact, most of today's LNG supply chains are indeed based on this straightforward direct end-to-end model. However, the one characteristic most of these direct supply chains have in common is a sufficiently large scale.

This large scale is absent for the import satellite ports we are considering in this study. For the import satellite ports that we will introduce in section 4.3.1., based on discussions with Vopak, an annual requirement of 0.475 bcma has been estimated. This is less than 5% of the annual throughput that Gate terminal will ultimately handle. Similarly, the size of vessels that will in due course supply Gate range between 145,000m^3 and 265,000m^3 versus much smaller 10,000m^3 ships that are presently deployed to supply LNG to certain Baltic locations.

Even if the draft at the satellite ports would permit larger ships to enter, the jetty configuration at these ports must also be suitable to accommodate the large LNG carriers. Furthermore, the storage capacity at the import location would need to be at least 15 times larger to accommodate e.g. a 145,000m^3 vessel as opposed to a 10,000m^3 ship. Clearly, this pushes up the investment at the satellite ports in a significant manner, thereby reducing the competitiveness of LNG as alternate fuel.

Alternatively, one could deploy the small 10,000m^3 type vessels in a direct end-to-end service from the exporting location to an import destination. However, shipping cost are not linearly proportional to the size of the vessel, and as a matter of fact, large ships enjoy significant economies of scale. Accordingly, maintaining a long-haul service with small ships would be prohibitively expensive.

Having said all this, analogous to the hub-and-spoke versus end-to-end trade-offs in other industries, at a certain volume of LNG the breakeven point would be reached, whereby both concepts would be equally valued in terms of costing. For the purposes of this study, however, we focus on small scale import locations where one would still be far from reaching a breakeven position – if at all permitted by the port infrastructure and draft restrictions.

The main advantages of hub-and-spoke are:

- Extension of the coverage
- Benefiting from the economies of scale
- Demand creation

Some disadvantages of hub-and-spoke are:

- Congestion at the terminal: increased traffic at the jetty and in the port as not only the large but also the smaller vessels call the terminal regularly.
- Higher risk: due to increased traffic some ports may have difficulty handling the increased number of vessels which may increase the chance of accidents.
- Difficulties in co-ordination: co-ordination with various vessel operators makes this a complicated operation which may create some communication challenges.

To implement the Hub-and-Spoke concept we need to select the right ports to be used as a hub port. The main port selection criteria could be looked at from various perspectives:

- Cost: in this case the main cost drivers are:
    - Land Lease/ Purchase
    - WACC
    - Labour cost
    - Potential for synergies
    - Local political, regulatory and financial climate

Tariffs for the above mentioned services would only constitute a fraction of the overall supply chain cost, however, the weekend rates or holiday rates could be critical as the economics can change if those tariffs are more than 50-70% higher than the regular service rates.

- Performance: the port performance would play a vital role as the productivity and the turnaround time may add more expenses to the vessel operating costs. If at a port the productivity is lower, this may increase the turnaround time, which could reduce the number of trips a vessel can make in a year. This will reduce the earnings of the vessel and economies of scale could not be achieved.

- Infrastructure: the draught at the terminal and the jetty size would determine the size of a vessel which can call the terminal. If the draught and jetty fail to meet the future changes in respect of larger vessels and the productivity drops due to increased volume then it would turn out to be a negative aspect of the port selection.

- Marketing: in case of LNG, the hub port is to be chosen for further shipment into satellite terminals, however, for the future prospects it is essential to see if the port is well connected to the hinterland. This will increase the possibilities of more business. Thus in case of any future changes in relation to the satellites, the product could be used by other markets.

4.3 Methodology

Based on the Hub-and-spoke principle, we evaluate the entire value chain mentioned in our model. In order to do so, the following approach was used:

1. Supply Chain definition:
    a. LNG Export ports
    b. Hub ports
    c. Satellite ports

2. Creation of a hub costing model to get the terminal tariff to be charged by the various hub terminals.

3. Data Collection:
    a. FOB Cost
    b. Shipping cost: Large Scale and Small Scale
    c. Port dues and costs
    d. Throughput costs

4. Evaluation of a complete supply chain

5. Findings and recommendations

4.3.1 Supply Chain definition

To compare the large scale LNG with an extension of small scale LNG vis-à-vis a pipeline grid, we need to concentrate on the areas where the concept of small scale is already considered as an important future concept. For the purpose of this study, it has been decided to compare the supply chain starting at the source liquefaction terminal and reaching upto a satellite terminal[5] via a hub terminal.

The model looks at the three main LNG exporters:

1. Qatargas
2. Algeria LNG
3. Snøhvit

The mentioned exporters have a proven record of supplies into Europe and with the focus on emissions more demand is expected to arise in Europe. Qatargas has an advantage over the other suppliers as they are building large vessels like Q Max which will enjoy the economies of scale with 265,000m3 LNG transport capacity against 145,000m^3 vessels operated by Algeria and Snøhvit. However, only ship size does not determine the economies and the competitive position of an LNG plant. As in case of Algeria, they have been supplying gas for almost two decades and thus it is a fair assumption that their investment has been recovered. (Wood

[5] In this case a ship is considered to leave a hub port however it does not enter a satellite terminal. Hence the calculation takes into account the shipping cost from hub to a satellite terminal but not the port charges at the satellite terminal.

MacKenzie, 2009) In case of Snøhvit, the export market is USA and UK. Thus it does not directly compete for the European market with Algeria, while Qatargas is situated at greater distance to the American market compared to the Snøhvit plant.

It is assumed that in case of a situation change, Snøhvit will become a supplier which will compete for the Scandinavian market with Qatargas and Algeria.

These sources will supply LNG to the following hub ports:

1. Gate Terminal, the Netherlands
2. Zeebrugge Terminal, Belgium
3. Nordic LNG, Norway
4. Szczecin LNG, Poland

To analyse a complete value chain, a hub terminal will play an important role, as it is here where the larger vessel will call the port, as well as the smaller vessels. What makes it more critical for these ports is that the facilities are normally designed keeping in mind the business that is expected in the near future whereas a storage facility can be used for additional business as well.

For our model we assume that the Gate and Zeebrugge ports need not invest in new tanks or a new jetty at this stage. The additional business of small scale LNG can be accommodated by the existing LNG storage facilities. By doing so, the expenses at these terminals in terms of Capex and Opex will be proportioned to the new business. Contrary, Nordic LNG and Szczecin would require comparatively higher Capex as these facilities would be built as dedicated hub facilities without the economies of scale being derived from supply into the hinterland pipeline grid.

Another assumption is that Gate and Zeebrugge will use the existing operational staff thus the Opex will also be charged proportionately whereas for Nordic LNG and Szczecin operational expenses will specifically be towards the new business, making it more expensive.

Nordic LNG will have a new liquefaction facility by 2010. It will also have an infrastructure including a storage tank. However, this facility is designed for small scale LNG only. Thus the assumption is if Nordic LNG wants to become a hub terminal it will require a new infrastructure to meet the requirements of loading, unloading and storage.

The small scale LNG is pioneered at Norway. As Norway and its neighboring countries are well focused on the environment, we assume that the demand for LNG in these countries will increase for various purposes. Keeping this in mind, I chose the following places where satellite terminals can be developed:

1. Gothenburg, Sweden
2. Nynashamn, Sweden
3. Bergen, Norway
4. Oxelosund, Sweden

Scandinavian countries are pro-environment compared to other countries in the world. The governments in this part of the world are looking at supporting green fuels and reducing emissions. The MAGALOG report talks about this in detail. As part of this study, various ports were considered as future LNG bunkering ports in North Europe, amongst others are Bergen, Gothenburg, Lubeck and Travemunde, Swinoujscie and Stockholm. For our study we decided to look at above mentioned four places. Since Nynashamn is expecting a new small scale LNG terminal, it became important to evaluate it in our supply chain as a potential satellite terminal. The geographical location of this satellite makes it suitable to also feed the Finnish market in the future.

4.3.2 Cost Model

To access the overall costing of the supply chain we have broken the supply chain down in its various constituent components. Subsequently, the costs for the various components have been assessed. The following supply chain components are recognized:

1. From export port to a hub port
   (i) Port cost at export port
   (ii) FOB breakeven cost (i.e. effectively the cost of the LNG)
   (iii) Shipping cost from export port to hub port

2. From hub port to a satellite port
   (i) Port cost at hub for the import vessel
   (ii) Throughput cost at a hub
   (iii) Port cost at hub for a small export vessel
   (iv) Shipping cost from a hub port to a satellite port

3. At satellite port
   (i) Port cost for an import vessel
   (ii) Throughput cost

4. Total Cost 1 + 2 + 3

All these costs are assessed per unit mmbtu throughput. Most of the costs could be derived from the various data sources as explained in the next section (4.3.3). However, for assessing the throughput cost at the hub a specific cashflow model was developed.

This cashflow model calculates the required revenues per mmbtu throughput to achieve a predetermined minimum return (IRR), on the basis of the following input assumptions:

- Investment sum per mmbtu throughput capacity (based on proprietary research by Vopak LNG department)

- Operational expenses per mmbtu throughput capacity (based on proprietary research by Vopak LNG department)
- Tax rate of the pertaining country
- Residual value is estimated at eight times EBITDA
- Twenty years commercial contracts

The investment sums have been estimated on the assumption that a hub will be dedicated to small scale LNG only i.e. without the benefit of accommodating import pipeline gas as well. For Gate and Zeebrugge, however, in practice the incremental investments would be very limited to facilitate liquid to liquid throughput through the terminal.

4.3.3 Data Collection and confidentiality

Though collecting data for this paper has proven to be a challenging task, we did succeed in collecting the majority of it. Since the work is done with Royal Vopak's cooperation the data has not been disclosed in this paper to ensure the confidentiality.

a. FOB Cost [1(ii)[6]]

Normally the LNG is supplied based on the long term contracts, of about 20 years, and its FOB value varies based on the contract terms, like importing country, volume of LNG to be imported, etc. The great variances in contract terms result in great variances of the FOB cost, even for the same LNG source. To avoid such problems and to achieve a better benchmark it has been decided to look at FOB Breakeven figures which can be obtained from Wood MacKenzie's website where the analysis is explained in detail.

Qatar has many different LNG production trains and in some cases there is no FOB breakeven given as the data is not disclosed. However, the most reasonable data calculation was shown for Qatargas by Wood MacKenzie, which we decided to use for our calculations.

Algerian data is not published anywhere as most of the control is enjoyed by the government. Also Wood MacKenzie does not regularly publish the figures for Algeria. However, while discussing this matter with Wood MacKenzie's analyst, we figured out that since the Algerian LNG has been supplied for almost two decades, it would be reasonable to assume that the CAPEX has already been recovered by now and Wood MacKenzie's FOB estimate would be a fair amount for our calculation purposes.

Snøhvit does have a disadvantage in terms of size, which makes this plant relatively more expensive compared to the other two exporting terminals. The figure has been taken from Wood MacKenzie to maintain consistency in the data source and calculations.

[6] Refer to Section 4.3.2

b. Shipping cost: large scale and small scale [1(iii) + 2(iv)[7]]

The value chain consists of two different sets of shipping costs, from the source to the hub terminal and from the hub terminal to the satellite terminal. The shipping cost is highly dependent on the volume carried by the vessel: for larger vessels the shipping cost per unit would be lower than for smaller vessels. Traditionally LNG is carried by 145,000m^3 vessels from the source to the import terminal. We have also used the shipping data from Wood MacKenzie(Wood MacKenzie, 2009).

Since Qatargas already has vessels larger than the size mentioned above, it was necessary for an objective comparison to take the new vessel sizes i.e. 210,000m^3 Q-Flex and 265,000m^3 Q-Max into account. This data was also taken from the Wood MacKenzie website.

Since the concept of small scale LNG is relatively new, not many professional firms have looked at the shipping cost for this industry. Though the concept is very popular in Japan, the costs could not be compared. Hansson of Svenskt Gasteknist Center in Sweden studied the use of LNG as an alternative energy source in Sweden wherein he has calculated the cost of small scale LNG shipping.(Hansson, 2008). For the calculation of small scale shipping I have used the same data. The conversion from US Dollar to Swedish Kroner was based on the exchange rate of June 25, 2008 and for my model the conversion is based on the Aug 12, 2009 exchange rate from US Dollar to Euro, which was 1 USD = 0.7041 Euro.

c. Port dues and costs [1(i) + 2(i) (iii) + 3(i)[8]]

Since the mentioned export terminals have been exporting LNG for some time now, the data could be obtained from Vopak Agencies Rotterdam B.V.

The only existing LNG import terminal that has been incorporated in this study is Zeebrugge. Gate and Nordic are in the construction stage and Szczecin is still in the design phase. Hence getting realistic data of port dues, except for Zeebrugge was difficult. However, with the help of Vopak Agencies Rotterdam B.V the information was obtained on Zeebrugge, Gate terminal, Szczecin and Bergen. Other satellite terminals do not have an existing LNG facility and this makes it difficult to have data on specific satellite terminals.

d. Throughput costs [2(ii) + 3(ii)[9]]

There is no data readily available for the port dues as well. In fact, the throughput cost of Zeebrugge was also difficult to obtain. To ensure that data can be compared I created a Hub costing model. Based on the model the terminal tariff was calculated and then converted as throughput cost in Euros per mmbtu. Various assumptions were made to ensure comparable grounds.

[7] Refer to section 4.3.2
[8] Refer to section 4.3.2
[9] Refer to section 4.3.2

A summary of the data collection is given below. The data which was collected is shown as C (collected data), A (assumption), NA (not available) and NR (data not required). The complete value chain is broken down into three segments:

1. Chain from an export port to a hub port
2. Chain from a hub port to a satellite port
3. At a satellite port

1. From an export port to a hub port:

Assumptions:

i. The exporting port is denoted in the model by (EP)
ii. Large vessels (145,000m3 to 265,000m3) are used for transporting LNG.
iii. Port cost (EP) is charged at the exporting port for large vessels.
iv. At this stage the vessel has left the export port, however, it has not yet entered the hub port. Thus port cost at a hub port is not included.
v. Shipping cost (L) is based on the larger vessel.

Table 11 Data Collection: from Export Port to Hub Port

	FOB Cost	Port Cost (EP)	Shipping Cost (L)
Qatar	C	C	C
Algeria	C	C	C
Snøhvit	C	C	C

2. From a hub port to a satellite port:

Assumptions:

i. A hub port is denoted in the model by (HP)
ii. A hub port is called by a large as well as by a small vessel.
iii. Port cost (HP-L) is charged to a large vessel carrying LNG to the hub port.
iv. Port cost (HP-S) is charged to a small vessel which will carry LNG to the small satellites.
v. Shipping cost (S) is based on a small size vessel.
vi. At this stage the vessel has left a hub port, however, it has not yet entered a satellite port. Thus port cost at a satellite port is not included.

Table 12 Data Collection: from Hub Port to Satellite Port

	Port Cost (HP-L)	Throughput Cost	Port cost (HP-S)	Shipping Cost (S)
Gate	C	C	C	C
Zeebrugge	C	C	C	C
Nordic LNG	C	C	A	C
Szczecin	C	C	C	C

3. **At a satellite Port:**

Assumptions:

1. Terminal cost charged per mmbtu at Gothenburg will be the same for Nynashamn.
2. Based on the cashflow model throughput cost for Nynashamn has been derived.

Table 13 Data Collection: At Satellite Port

At Satellite	Port Cost	Throughput Cost
Gothenburg	C	NA
Nynashamn	A	C
Bergen	NA	NA
Oxelosund	NA	NA

Although there are no indications that the port costs for Bergen and Oxelosund are completely different, we only used Nynashamn as satellite port in the supply chain comparisons due to data availability.

To understand the complete model, we have also broken down the port costs and shipping cost per mmbtu at the hub port. The following table gives the information on port costs based on various vessel sizes used for the model.

Table 14 Data Collection: Port Costs per vessel size

Ship size (cbm)	1,100	7,500	10,000	210,000	265,000
Qatar	NR	NR	NR	C	C
Algeria	NR	NR	NR	C	C
Snøhvit	NR	NR	NR	C	C
Gate	C	C	C	C	C
Zeebrugge	C	C	C	C	C
Nordic	A	A	A	A	A
Szczecin	C	C	C	C	C
Gothenburg	C	C	C	NR	NR
Nynashamn	A	A	A	NR	NR
Bergen	NA	NA	NA	NR	NR
Oxelosund	NA	NA	NA	NR	NR

4.4 Information on source, hub and satellite terminals

4.4.1 LNG Sources

(1) Qatargas, Qatar

Shell discovered the North Field in 1971 but, at that time, the gas could not be commercially exploited, hence Shell withdrew from the license. Qatargas was formed in 1984 and was the first LNG project in Qatar. After signing the first long term Gas Sales and Purchase Agreement (GSPA) in January 1994 with Chubu Electric of Japan the work for the upstream project started in 1995. In November 1996 Train 1 started up and produced the first LNG cargo which was delivered to Chubu Electric in 1997. Two more trains, Train 2 and 3 started up in January 1997 and in January 1998 respectively. The 3 trains' capacity was increased to 9.7mmtpa in 2005 replacing the earlier capacity of 7.7. mmtpa.

The Qatargas LNG plant is owned and operated by Qatargas, a consortium consisting of Qatar Petroleum (65%), ExxonMobil (10%), Total (10%), Marubeni (7.5%) and Mitsui (7.5%). The main functions of the company are:

- To purchase natural gas from the government at the plant gate
- To process the gas into LNG
- To secure customers for the project's LNG
- To arrange for the transportation of LNG to customers (where appropriate)

Qatargas operates from a port called Ras Laffan. It owns three LNG trains and the total plant capacity is 9.7 mmtpa.

Qatargas is steadily progressing in the construction of its 4th train. This train is the first of four new mega trains planned and is expected to start LNG production in 2009.

Qatargas typically has been a supplier to the Japanese market. With the spare capacity expected to increase, the focus is now turning towards the European market. This is an interesting development as this makes Qatargas a player who would be willing to compete with other LNG suppliers for this market.

Qatargas has been a pioneer in introducing vessels which can carry 210,000m^3 – 265,000m^3 LNG against the traditional vessel size of max. 165,000m^3.

(2) Algeria LNG, Algeria

Algeria delivered the first LNG cargo to the UK in 1964, becoming the world's first LNG exporting country. There are four operational LNG plants in Algeria situated on three sites (Arzew, Bethioua and Skikda) which form Algeria LNG. The two largest plants, GL1Z and GL2Z are situated in Bethioua. The original and the smallest plant, GL4Z is situated in Arzew, and GL1K is located at Skikda. Sonatrach has 100% ownership of all the elements of Algeria LNG. The Algeria LNG facilities are supplied by Sonatrach operated fields including Hassi R'Mel, Rhourde Nouss and Alrar. The majority of Algerian LNG is destined for Europe. The recent past has seen some cargo being delivered to the USA and Asia.

Algeria LNG runs 19 trains and has 5 berths available. The maximum LNG carrier size available is 165,000m^3. Sonatrach operates a fleet of four LNG carriers to deliver Algerian LNG, with significant volumes also being lifted by buyers directly on an FOB basis using their own shipping capacity. This fleet has a total capacity of around 421,000 m^3 of LNG and is owned by Hyproc Shipping Company, a wholly-owned subsidiary of Sonatrach.

Since the Algerian LNG plants are controlled exclusively by the government, no data was available for the cash flow analysis. As such there is no analysis of the breakeven costs.

(3) Snøhvit, Norway

The Snøhvit LNG project is an integrated upstream, pipeline and liquefaction development. The LNG plant is located on Melkøya Island in northern Norway and is supplied by gas from the offshore Snøhvit, Askeladd and Albatross fields in the Hammerfest Basin. The project began operations in October 2007 with the volumes primarily destined for the US and Europe.

In 1984 the Upstream Snøhvit field was discovered. It took almost 20 years after the discovery of gas to the delivery of the first LNG volume from this project. The Norwegian Parliament approved the project in 2002. Though in July 2005 the processing facilities were winched successfully, StatoilHydro had announced further delays and cost overruns of about NKr 7 billion (US$1 billion), increasing the project cost to over NKr 58 billion (US$ 8.8 billion).(Wood MacKenzie, 2009) On 20 October 2007 Snøhvit LNG loaded its first cargo.

The plant is operated by StatoilHydro and is owned by StatoilHydro (33.53%), Norway State DFI (30%), Total (18.40%), GDF SUEZ (12%), Hess Corporation (3.26%) and RWE Dea (2.81%). The number of trains available is one with a plant capacity of 4.10 mmtpa and one berth. The maximum LNG carrier size is 148,000 m^3.

The Snøhvit LNG plant has experienced regular shutdowns due to various technical problems, reducing the project's output significantly. The plant was shut down in November 2007 due to seawater leakage into one of the heat exchangers. These problems are expected to continue until 2010.

4.4.2 Hub Terminals

(1) GATE Terminal, The Netherlands

GATE Terminal (Gas Access To Europe) is a project company formed by N. V. Nederlandse Gasunie (Gasunie) and Koninklijk Vopak N.V. (Vopak). The GATE LNG regas terminal will be located at the north-west section of the Maasvlakte in the port of Rotterdam. The combination of a major gas transport company, Gasunie and an international terminal company , specialized in the storage and handling of liquid and gaseous chemical and oil products, Vopak, gives this partnership a unique advantage for developing a successful LNG regas terminal.

The terminal is planned to be commissioned in the third quarter of 2011. The storage tanks are presently under construction and scheduled for completion by 2010, followed by the jetty, pipeline connections and vaporizers.

The owners of GATE terminal are Gasunie (40%), Royal Vopak (40%), DONG Energy (5%), E.ON Ruhrgas (5%), Essent (5%) and OMV (5%). The terminal has one berth and three tanks with a total storage capacity of 540,000m^3. The total regas capacity is 9.6 mmtpa.

Because of its access to the existing pipeline grid, its strategic location at the Maasvlakte and the expansion plans already thought of, this terminal has a unique advantage of being a preferred terminal for additional LNG storage and hub possibilities.

(2) Zeebrugge LNG Terminal, Belgium

"The Zeebrugge LNG terminal has a surface area of 40ha and it is operated by Fluxys. The terminal handles LNG carriers up to LOA 350m, beam up to 55m and a draught of up to 12m."[10]

LNG deliveries have a seasonal pattern, especially in July and August when deliveries dip. However, the strategic location of this hub makes it easier for the capacity holders to buy pipeline gas to cover any shortfall during the peak period.

A new development was announced by fluxys in July 2008, when they stated their plans to offer loading services at the terminal. In addition to their existing unloading

[10] Generated from Lloyd's Register – Fairplay Ports and Terminals Guide on 30 Jul 2009

services, this loading service would benefit their customers who were seeking to exploit the commercial opportunities in other markets.

With an unloading capacity up to 12,000 m^3 LNG/hour, the Fluxys LNG terminal can handle almost all different types of vessels with different capacities. The jetty consists of four LNG 16” unloading arms and one vapour return arm.[11]

The terminal is in use for a long time and this gives the terminal operator a unique advantage for venturing into the new trend of small scale LNG as it generates more demand for the planned capacity extensions.

The terminal has one berth and 4 tanks with a total storage capacity of 403,000m^3. The total nominal regas capacity is 6.8 mmtpa and the peak regas capacity is 9.6 mmtpa.

(3) Nordic LNG, Norway

In July 2007 Lyse and IM Skaugen entered into a joint-venture called “Nordic LNG” with an understanding that Lyse will build, own and operate the LNG plant with its partners while IM Skaugen will build, own and operate the required ships for the transportation. The JV will be responsible for marketing, sales and for the logistics (terminal, land-based transport and local storage) of LNG. The project is expected to be fully operational from the second quarter of 2010.

The plant is located just outside Stavanger on the western coast of Norway about 452km south west of Oslo. The initial capacity is around 300,000 tpy and it can be extended to 600,000 tpy. The storage tank capacity is 30,000 cbm LNG. The draught alongside the port is 10.8m. “Boil-off” gas will be fed into the local pipeline grid and accordingly the terminal will just have marginal flaring. (www.skaugen.com)

(4) Szczecin, Poland

Poland has limited indigenous gas production and has to import approximately 75% of its gas requirements.(Wood MacKenzie, 2009) The majority of this import comes from Russia and a limited quantity of gas is received from Germany and Turkmenistan. To reduce this dependency on a single supplier, the country has planned an LNG terminal at the Port of Swinoujscie and the terminal is called Szczecin. The expected cost of building this terminal is €450m.

The terminal is expected to receive piped gas from Norway and in January 2007 Poland signed a memorandum of cooperation with Algeria on the possible future supplies of Algerian LNG to Poland.

The operations are expected to begin in the fourth quarter of 2012. The initial terminal capacity is expected to be around 304 mmcfd (2.4 mmtpa). Various possible sources of supply are Algeria, Egypt, Libya, Nigeria, Norway and Qatar. However, the existing Russian gas pipeline exposure would limit the future portfolio for diversified supplies for LNG imports in the short and medium term.

[11] interoperability of LNG

4.4.3 Satellite Terminals

(1) Gothenburg, Sweden

Gothenburg is Sweden's second largest city after Stockholm, and Scandinavia's largest RoRo and RoPax port. It is located at the end of the Göta River and is a central location for the Baltic and North Sea basin. It plays a major role in exporting Swedish industrial manufacturing goods as within Scandinavia only Gothenburg can receive large container vessels of up to 12,000 TEU.

The port has various terminals, among which a RoRo terminal, a container terminal, a car terminal and an oil terminal which serves two refineries of Shell and Preem. It also has older facilities for passenger and cargo ferry traffic.

Since the Port authority and its users put lot of emphasis on the environment, it does have a significant potential for being developed as a LNG bunkering terminal.

(2) Nynashamn, Sweden

Nynäshamns Gasterminal AB, owned by Swedish companies AGA, Fortum and Nynas, is building the first LNG terminal at Nynäshamn near south of Stockholm. This terminal will import about 250,000 tonnes of LNG annually and is expected to be on-line by mid 2011. The estimated cost of building the plant is around SEK 1 billion (€100 million).

This terminal is designed to serve smaller users as the LNG will be supplied by small coastal carriers. These smaller carriers are expected to carry the LNG from larger terminals such as Nordic LNG near Stavanger, Norway.

The facility will be able to handle carriers up to LOA 160m and draught of up to 9m. The storage tank design capacity is 20,000m^3. (www.dywidag-international.com)

Sighting the environmental issues, the natural gas will be used to replace the petroleum for the city-gas production and it is expected that the Nynas refinery will also use the gas in the hydrogen gas production.(www.lngpedia.com)

(3) Oxelosund, Sweden

The Oxelosund LNG terminal will be situated on the east coast of Sweden and is about 100km south of Stockholm. The main Oxelosund port can berth a vessel with LOA 260m, beam 41m and of draught up to 15.5m.The expected capacity is app. billion Nm^3 per annum.

The LNG project got the governmental approval in June 2005 and its construction started in 2007. The terminal is expected to go into commercial operation from

January 2009. This terminal will be capable of receiving the largest LNG tankers in operation today. The first deliveries are expected in 2010.

(4) Bergen, Norway

Bergen is located on the South West coast of Norway and is about 479km west of Oslo. The port can berth a vessel up to LOA 294m and draught up to 12.20m.(World Shipping Register)

The port is regularly called by Ro-Ro vessels, supply vessels, cruise ships and passenger boats. It also has some traffic of the Coast Guard from the naval base outside Bergen and many small coastal cargo vessels call the port as well.

The potential to convert these vessels to LNG fuel could make Bergen an attractive port for satellite services.

4.5 Model description

The model gives an overview of every cost element that plays a role in combining the large and small scale LNG value chains. The typical cost break-up is as follows:

A. ***Exporting Port:*** The main cost elements attached to this terminal are FOB Cost, port costs and the shipping cost towards the Hub terminal.

FOB breakeven Cost: For the purpose of our model, the FOB breakeven cost is taken to ensure no different prices charged to different buyers by the same exporting terminal. The values taken for this purpose are:

Qatargas: US $ [confidential]/mmbtu
Algeria: US $ [confidential]/mmbtu
Snøhvit: US $ [confidential]/mmbtu

While analyzing the supply chain from Qatargas to Nynashamn via Gate terminal, the FOB cost is as high as 42.5% whereas the FOB in case of Snøhvit to Nynashamn via Nordic LNG or Szczecin is as high as 48.5%. Algerian FOB is not more than 30.5% of the total supply chain.

Port Costs: Different ports have different cost structures, however, there are some standard services that each port provides and charges for, like tugs, harbour dues, pilotage and mooring. In this model port costs also includes light dues and state agent fees in case of Qatar whereas Zeebrugge charges for a standby Firetug and waste fees in addition to the other charges.

Shipping cost: this concerns the cost for large 210,000m^3 and 265,000m^3 vessels to carry LNG from the export port to a hub port.

B. ***Hub Port:*** This terminal plays a pivotal role in the complete value chain as at this terminal the LNG is transshipped from the large vessel to the small vessels. This terminal also has the facility for large scale storage. The cost elements at this stage include port costs, throughput cost and shipping cost towards the satellite terminal.

Port Costs: At this port larger vessels are charged for bringing the LNG to the hub and smaller vessels are charged for reloading this LNG. Port costs have the same cost elements as mentioned in the part of exporting port.

Throughput Cost: To estimate the throughput cost, a hub costing model was developed. This model allows us to calculate the throughput cost which the hub will need to change in order to cover the investments and operational expenses related to the offloading of large scale carriers, storing its content and loading small scale carriers.

Shipping Cost: To carry LNG from a hub terminal to satellite terminals, different vessel sizes are analyzed like 1,100m3, 7,500m3 and 10,000m3. Based on a basic calculation which was derived from an earlier study done by Hansson,(Hansson, 2008) the shipping cost has been calculated per mmbtu per km. Subsequently, based on the distances between the hub port and a satellite port total shipping cost was calculated for the small scale LNG.

C. Satellite Port: This terminal could be used for different purposes like small-scale storage, regasification for pipeline, as fueling station for ferries, trucks and trains or reloading on a trailer for further supplies of LNG to remote destinations. The main cost elements would be based on the port costs as well as the further usage of LNG. If the LNG would be regasified and send via pipeline then the costs would include the regasification cost. If LNG would be used as fuel for ferries, trucks or trains then a throughput cost would be calculated similar to the calculations for a hub port. In case of further transport to a fueling station via trailers, throughput cost will be added to the port costs.

For comparison purposes, various scenarios could be created. In case of pipeline, the price of pipeline gas should be compared with the entire value chain cost. In case of usage of LNG as fuel, it should be compared with the heavy fuel oils (HFO) or bunker price. The variety of potential end usages for LNG is a complicating factor in assessing the competitiveness of LNG as alternative energy source. Due to limited time of this study, some assumptions have been made and the value chain is compared.

For the analysis of the entire value chain we have calculated the various aforementioned cost elements as a percentage of the total cost. This exercise gives very interesting information which is discussed in the following section.

4.6 Results

As our study involved three export ports, four hub ports and one satellite port, it was essential to obtain a comprehensive view on all the supply chains. These chains should have comparable units to ensure that the results can easily be interpreted. In order to do so, we converted the absolute values into an index which helped in comparing the chains with each other, without revealing the actual numbers.

As discussed earlier, Qatargas is already shipping LNG via 210,000m^3 and 265,000m^3 vessels, whereas Algeria LNG and Snøhvit are unable to berth such large vessels due to the draft restrictions. Thus, export of LNG is done via relatively smaller vessels. For our study, we considered that Algeria LNG and Snøhvit use 145,000m^3 vessels for carrying their cargo to a hub port.

The following table shows the break-up of the cost index. For each source the four available hub options are indexed and the last column shows the respective total of the various supply chains. The lower the total index, the lower the final cost of LNG and vice versa.

Table 15 Total Cost Index

Index			Shipping cost		Throughput cost		Average	
Qatar	**Q Flex (210,000m^3)**	**FOB**	**to Hub**	**to Satellite**	**at hub**	**at Satellite**	**Port Cost**	**Total**
	Gate	28	15	2	19	48	3	116
	Zeebrugge	28	15	2	21	48	6	120
	Nordic	28	16	2	54	48	5	153
	Szczecin	28	16	1	68	48	4	165
Algeria	**145,000m^3**							
	Gate	14	4	2	19	48	4	91
	Zeebrugge	14	4	2	21	48	6	95
	Nordic	14	5	2	54	48	5	128
	Szczecin	14	5	1	68	48	4	141
Snøhvit	**145,000m^3**							
	Nordic	58	2	2	54	48	5	169
	Szczecin	58	4	1	68	48	5	183

The following charts give a graphical overview of the cost-index for the three export sources.

Figure 27 Export from Qatargas using 210,000m³ vessels

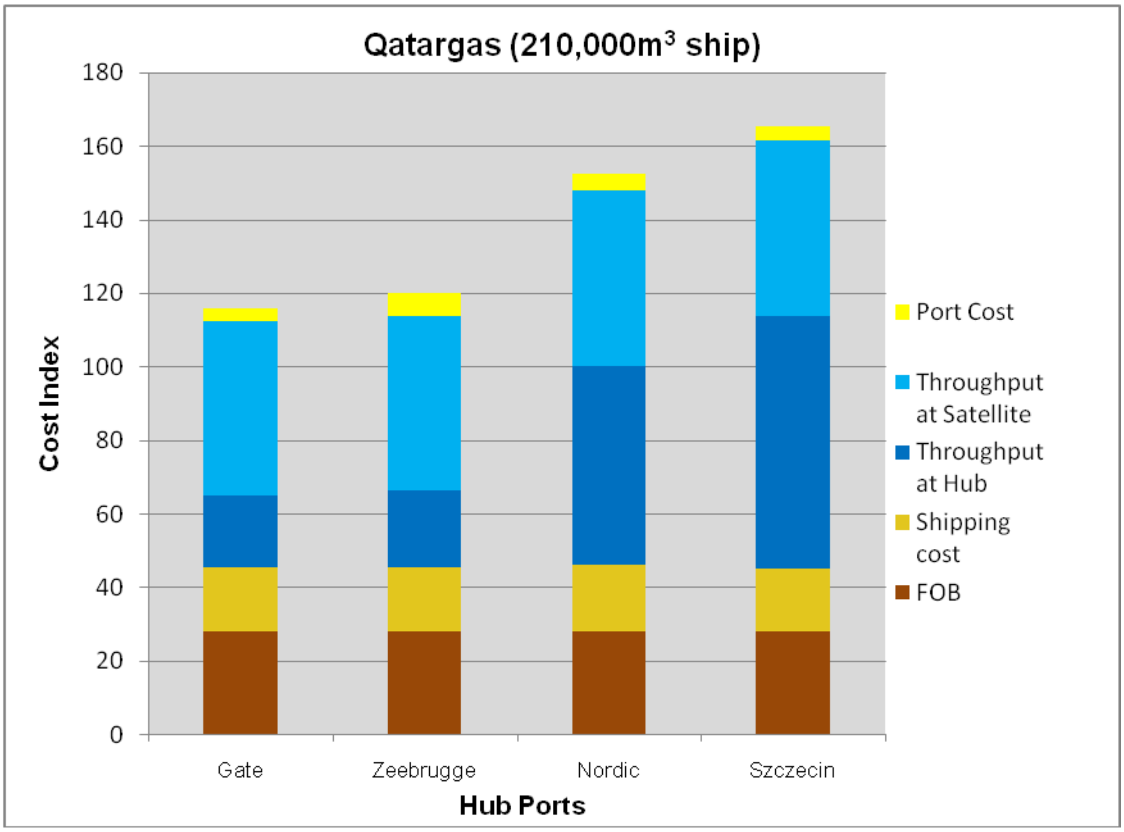


Figure 28 Export from Algeria LNG using 145,000m^3 vessels

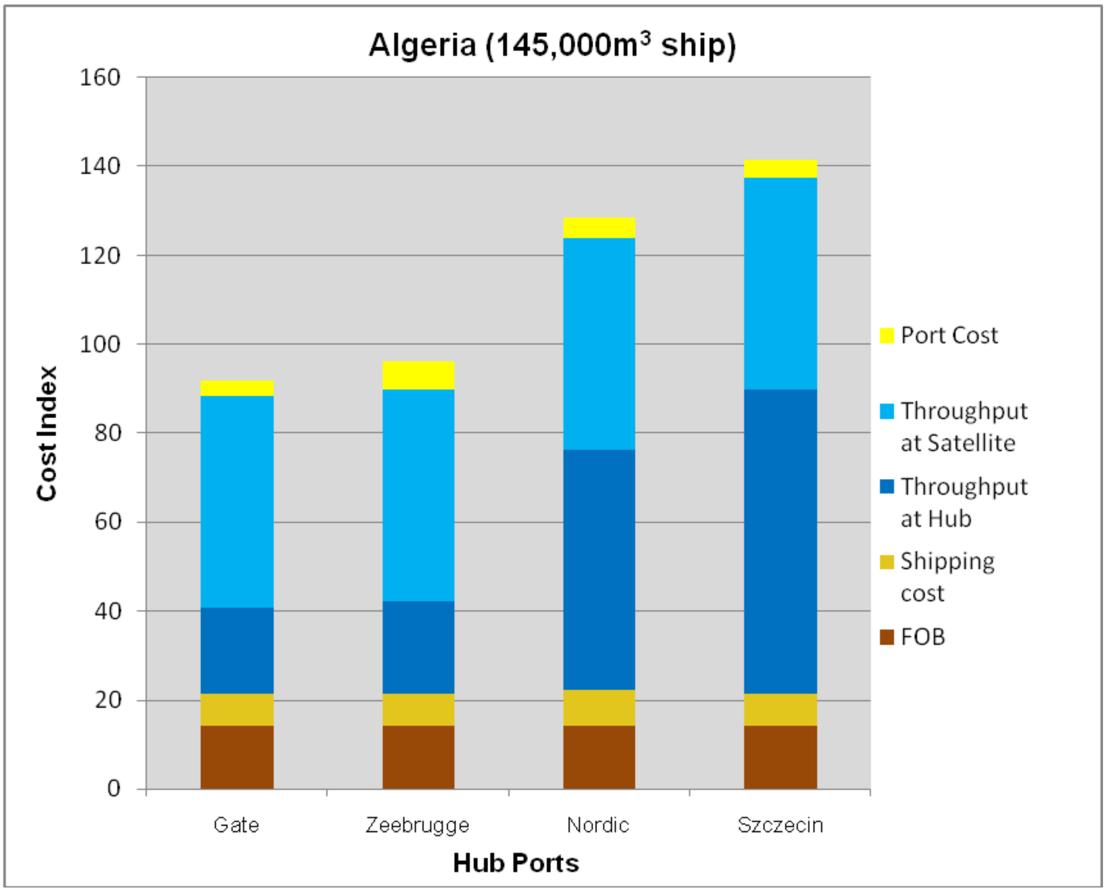
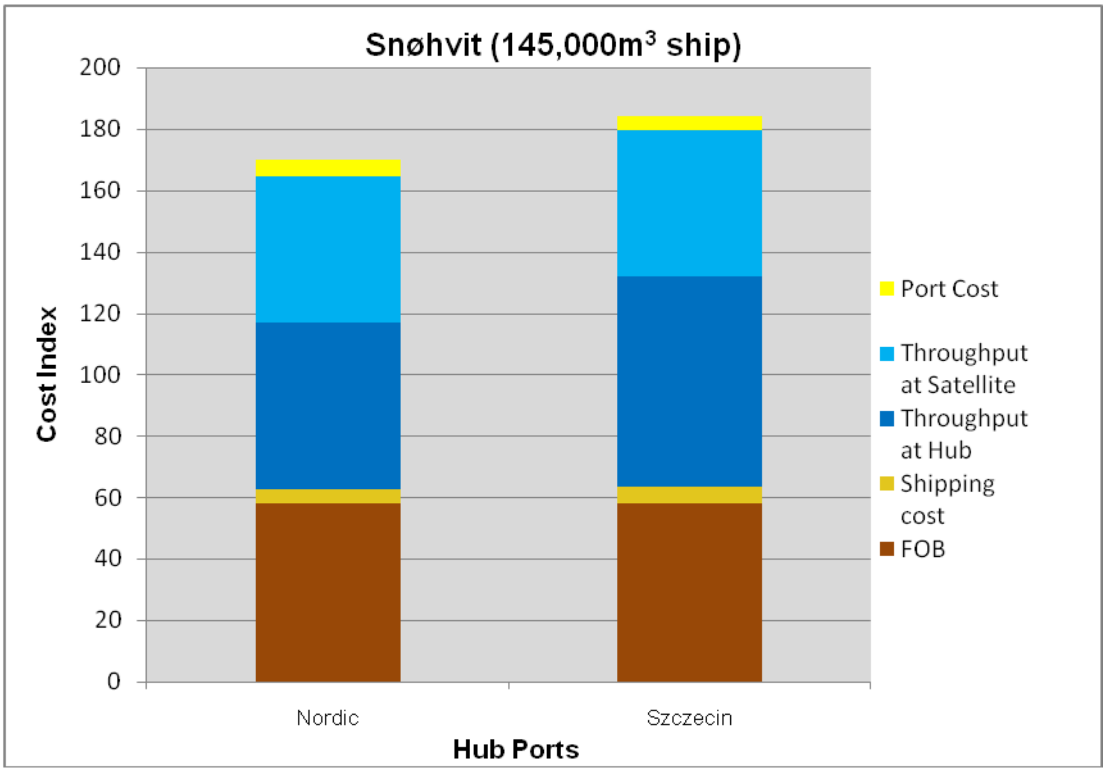


Figure 29 Export from Snøhvit using 145,000m³ vessels



FOB Costs:

As per figure 28 Snøhvit shows an index of 58 for FOB cost against the total index of 169 and 183 for Nordic LNG and Szczecin respectively. This makes it a significant part of the value chain, whereas as per figure 27, Algeria only shows index 14 against the total index ranging from 91 to 141 from the four selected hubs. As shown in figure 26, Qatar is somewhere in between Algeria and Snøhvit with index 28.

The production cost for Algeria LNG is low because the facility is old and largely depreciated. Hence, the FOB break-even for Algeria LNG is very low.

In addition, we would conclude that economies of scale are an important factor in determining the break-even FOB cost. The facility at Qatargas is more than twice the size of Snøhvit. This is also reflected in the FOB cost as the FOB cost for the Qatargas facility is less than half of the Snøhvit FOB cost.

Shipping costs:

The Algeria and Snøhvit supply chains show very low indexes for the total shipping costs[12]. From Algeria (figure 27) the index is between 6 and 7 and for Snøhvit (figure 28) it is between 4 and 5. In case of Qatar (figure 26) this is relatively high with a range between 17 and 18. What is also noticeable is that the majority of the shipping cost for the Qatar supply chains is from the export port to the hub ports. The shipping cost from a hub port to a satellite port is relatively lower.

There is a remarkable difference in shipping cost from Qatargas to Gate terminal (15) (figure 26) as compared to shipping cost from Algeria LNG to Gate terminal (5) (figure 27). 3.5 is explained by the relatively lower cost for 145,000m^3 vessels at the time these were ordered versus high newbuilding prices of 210,000m^3 size vessels, which reportedly were ordered at the time when the orderbook was full.

The second large component is the Suez transit fees (both ways), which explains 5.0 of the difference in the index.

Thirdly is the slightly longer round voyage time which accounts for 1.5 in the difference.

Throughput costs:

Throughput cost forms a very large part of the entire supply chain. If the total throughput is considered that were studied, it is more than half of the total index for all the chains.

Gate and Zeebrugge are comparable in size and as a result the throughput cost at these terminals is very similar. Contrary, the terminals at Nordic LNG and Szczecin are only a fraction of the size of Gate/ Zeebrugge. Consequently they do not have

[12] Total shipping costs include shipping costs from an export port to a hub port and from a hub port to a satellite port.

the advantage of economies of scale which is reflected by the throughput cost being more than two times higher.

Furthermore, considering Gate and Zeebrugge are primarily functioning as import ports for pipeline gas, arguably the incremental throughput cost at these ports would only be a fraction of the numbers presented herein. This would give them a great competitive advantage.

Since we have considered only one satellite it is difficult to draw a comparative conclusion. However, in the overall supply chain the satellite throughput cost is still a large component ranging between 26 to 52% of the total cost index.

Port costs:

This index forms a very small part of the total cost index. This cost shows the total port cost which includes port costs for large as well as small vessels entering and leaving a hub port.

We can see that the port costs at Zeebrugge are higher than those at the Gate terminal. The total port cost index for Zeebrugge is 6, whereas the Gate port indexes are just 3 and 4 from Qatar and Algeria respectively (figure 26 and 27 respectively).

5 Conclusions and recommendations

5.1 Conclusion

In this study, we examined the LNG supply chain on the basis of the Hub-and-spoke principle i.e. evaluating the supply chain from an export port to a satellite port via a hub port. The main purpose was to study the feasibility of Gate terminal being used as a hub terminal vis-à-vis Zeebrugge, Nordic LNG and Szczecin for supplies to various satellites in Scandinavia.

Natural gas is an important source of energy and the possibility of liquefying the gas has increased its usage. The LNG is sulphur-free and has a very low NOx, making it a better alternative fuel to replace the heavy fuel oils (HFOs). However, LNG would cost almost 70-100% more than HFOs.

Traditionally, the LNG supply chain has been from an export port to an import port, deploying large vessels specially designed to carry LNG. These vessels are relatively young and are growing in size. The latest vessel introduced by Qatar is the Q-max with a capacity of 265,000m^3. The main advantage is to achieve economies of scale. The LNG carrier market has its own specific challenges, such as the shortage of trained crew, seasonal shipping patterns as well as the changing freight market.

The demand for gas is increasing. European gas demand is expected grow by 77% between 2005 and 2010 and by 50% between 2010 and 2015. Exporters like Qatargas and Algeria are already supplying LNG to Europe, but also Snøhvit has started making in-roads into the European market. The proximity of Snøhvit should make it more economical for the supplies into Europe compared to the other two players, however, our study shows otherwise. The main factor here is the production cost. The production costs of Algeria LNG and Qatargas are based on larger volumes as their production is for large import destinations. Snøhvit, on the other hand, is relatively a smaller facility which does not enjoy the same economies of scale benefits.

The quantity of LNG required as a fuel in Scandinavia is currently very limited. Accordingly, the larger LNG vessels are not economical, and instead the requirement is more for small scale supplies. By applying the hub-and-spoke principle we can transport LNG from an exporting port to a satellite port via a hub port. Resulting from our model, Gate terminal and Zeebrugge are in a relatively better position as hub ports than Nordic LNG and Szczecin. This is mainly due to the larger size of the terminal infrastructure and the fact that the additional investments to facilitate the hub function would be limited. For example, no additional regasification capacity would be required at the hubs, and the liquid-to-liquid transshipment of the LNG would only slightly increase the throughputs through the storage tanks. The volume per satellite is around 0.475 bcma versus 9.0 bcma for Gate.

Another important cost element is the throughput cost. This cost is almost half or even lower for Gate and Zeebrugge compared to Nordic LNG and Szczecin. The port costs are more-or-less similar and are also relatively low indexed.

Consequently, these port costs do not have a material impact on the model outcome.

This also raises another question with regard to the viability of direct supplies to the satellite terminals rather than going via hub. While theoretically it will be possible to do so, the main issue is the limited volume required at the satellite ports. These limited volumes only warrant vessels which are a factor 10 to 20 smaller than the ships that will eventually supply Gate. Consequently, using large ships to supply the satellites would make the gas prohibitively expensive on a per unit bcma. Either the load factor of these ships would only be a fraction of their design capacities, or, alternatively, the satellites would require far greater storage facilities at much higher cost. On a practical point, the draft at many satellite ports is insufficient to accommodate the larger LNG carriers.

By bringing LNG via smaller vessels to the satellite ports, the storage can be build according to demand. A satellite port can be used as a fuel station for ferries, reloading on to trucks for smaller fuel stations or the LNG can be regasified and send out via the pipeline grids. This increases the reach of gas usage.

Norway and Sweden are actively pursuing options to cut down emissions and LNG is deemed a prudent choice. The countries foresee a tremendous growth in the LNG market and are investing for the future in the infrastructure to ensure meeting the future demand. This study demonstrates that small scale LNG via the hub-and-spoke concept could well serve the green pursuit of Norway and Sweden. The message is clear “LNG is good for the environment. It has tremendous potential to be used as a prime energy source and as alternative fuel.”

Conclusion of the research questions:

Is it feasible to use the Hub-and-Spoke principle in Europe for the supply of LNG into Scandinavia, especially using Gate terminal as a hub terminal?

In principle it is feasible to use the Hub-and-spoke concept. However, in case of the Gate terminal additional permits need to be obtained for re-loading the small LNG vessels. The present terminals are designed on the basis of the send-out capacity into the pipeline grid. Increasing the liquid in – liquid out throughput turns of a terminal would not affect this maximum send-out capacity and hence could deliver an attractive incremental revenue source for a terminal, depending on how the commercial contracts are structured. A big factor in the commercial viability of the Hub-and-Spoke concept is the scale and cost of an ultimate satellite terminal and the competitiveness with alternative (energy) sources.

We can also conclude that in principle, through its scale Gate is well positioned to act as an efficient hub, however, this is presently not covered by the existing commercial contracts. Accordingly, it is not clear who will benefit the most from the hub function.

Further we can also conclude that Compared to other terminals that we have considered, Gate is a competitive hub. Even more when disregarding the allocated hub cost as the incremental hub cost would be very limited in practice. However, at this stage we cannot say anything on the price competitiveness of the gas delivered to the end-user, in particular when considering that Gate has ample pricing flexibility. This is own to the fact that the Gate investments will already be recovered via the existing off-take contracts for gas delivery into the grid.

5.2 Recommendations

5.2.1 Recommendations for further studies

While this study demonstrated that the Hub-and-Spoke concept could be attractive to existing terminal such as Gate and Zeebrugge, the ultimate feasibility of the concept depends on the competitiveness of the supplied LNG with existing sources of energy at the import market. Further research would be required to assess the competitiveness of LNG as energy source for each import destination separately.

This study only looked at Sweden and Norway, which has limited piped and liquefied gas markets while the volume growth expected in coming years does not justify the large investments for LNG infrastructure. We would suggest a further analysis of not only the Swedish and Norwegian market but also the possibility of adding additional supply chain termination points (Satellite terminals) may be in Denmark, in Germany (e.g. Rostock) or in the north of Holland (e.g. Eemshaven) in order to increase the hub terminals' throughput.

The main cost element at hub and satellite ports is the throughput cost. Large import facilities like Gate terminal and Zeebrugge have economies of scale due to their large size. Since Nordic LNG and Szczecin are dedicated new facilities which have to be built from scratch for throughput volumes which are very low (0.475 bcma) versus the 9bcma Gate terminal. These dedicated hub terminals face a challenge of relatively higher investments for smaller volumes. These diseconomies of scale may be overcome by having these terminals be used for additional gas markets such as pipeline supply. Therefore we would recommend a further detailed study towards the future demand of NG in particular for these two hub ports.

The proximity of Szczecin to Russia introduces the risk of pipeline competition from Russia. For the purpose of our study we have not evaluated the Russian influence at this port. Therefore we suggest that a study covering Russian future plans and the possible supplies from Russia are looked at. The outcome may have a substantial impact on the decision making process regarding the import of LNG into the respective hub terminals and where these should be located.

Small scale LNG is a relatively new concept and so are many of the LNG applications it plans to serve. We believe that this industry can have new inventions in terms of technology and can also witness new and innovative usage of LNG, e.g. using LNG not only as a fuel for ferries but also for barges sailing the inland waterways or road transportation. Hence, we suggest that a new study with respect to use of LNG for these ends should be carried out.

This study has its limitations in terms of exploring the possible hubs in Europe and Scandinavia. To have a clearer picture, we suggest a comprehensive study which should include many more potential hub ports, like Isle of Grain, South Hook and Rostock. In addition we suggest to study further the utilization of the Hub-and-spoke principle at other locations that show similar reasons for this way of supplying the market to be a promising principle: The Greek or Indonesian archipelago, the Canary Islands or Northern East Canada for instance.

A full supply chain analysis should also contain a comparison with LNG's alternatives as an energy source: piped gas and fuel oil, hydro power and nuclear power for instance. However, this comparison truly requires an in-depth analysis of the associated CAPEX, OPEX and fuel market prices in order not to be comparing apples with pears. An additional complexity here is the market price developments on the longer term in order to make sure any Hub-and-Spoke system are not put out of business in due course.

Higher ship engine emissions are a matter of concern to the EU. Europe is looking at various possibilities to cut down these emissions, and Scandinavia, in particular, is already taking various measures to reduce them. This increases the chances of LNG being used as a fuel replacing HFO. However the situation needs further investigation. One needs to calculate the growth pattern of the LNG market due to this development. The future study should not only estimate LNG as a fuel but should also focus on identifying the types of vessels which could be converted to LNG fuel and also the newbuild which can have LNG compatible engines. A similar kind of study has already been done as MAGALOG (LNG a clean fuel for ships). However this study only focuses on Scandinavia.

Our study is focused on three LNG sources. In case a hub/ satellite client wants to explore the options we suggest that they should incorporate more LNG exporting countries, e.g. Indonesia

For the larger vessels it is most cost effective to carry cargo to one destination only. However for the smaller vessels carrying cargo to satellites, milk-run would be suggested. This will help in accumulating cargo for several destinations. However a detailed study for this would help in comparing the cost structure for milk-run by small vessel versus a small vessel carrying a cargo separately for each satellite from a hub port.

A larger vessel is expected to call a hub terminal once in 1 – 2 months if only delivering cargo for the small scale market. This implies its jetty to be under-utilized which on turn allows for amply slots at the jetty to be used for the smaller vessels serving the satellites. However this study does not include the regulatory limitations for such frequent jetty usage for LNG. It also does not specify at each hub if the port authority permits these small scale LNG vessel to enter its waters. We suggest a study with the respective port authorities to check the feasibility of small scale LNG.

The emerging alternative to onshore LNG receiving terminal is a floating regasification terminal. Our study does not include any analysis on FSRU (Floating storage and regasification unit). It is likely that such floating units could prove to be a major competition to the onshore LNG importing terminal investors. We would recommend a study to analyse the future of such FSRUs and the potential threat to the onshore LNG storage facilities.

5.2.2 Recommendations for the players in the supply chain

Qatar is enjoying the economies of scale due to large vessel sizes of 210,000m^3.and 265,000m^3. Algeria and Snøhvit have draft restrictions and hence they cannot load such large vessels. We would recommend them to look at the possibilities of increasing the vessel size which can be loaded at their terminals to increase their economy of scale.

To optimize the use of the hubs and satellite ports we suggest that these hub and/ or satellite investors/ operators investigate the concept of multi-user and not to restrict their business to captive purposes.

Though the port cost is a very small part in the entire supply chain, we recommend that Zeebrugge, Nordic LNG and Szczecin reconsider their port costs, as this might enhance their competitive position.

5.3 Sensitivity analysis

Since the difference in supply chain costs between the dedicated hubs and the large scale conventional terminals is so large, a sensitivity analysis would only be useful within each group. Accordingly, it was decided not to include sensitivity analysis within the scope of this research.

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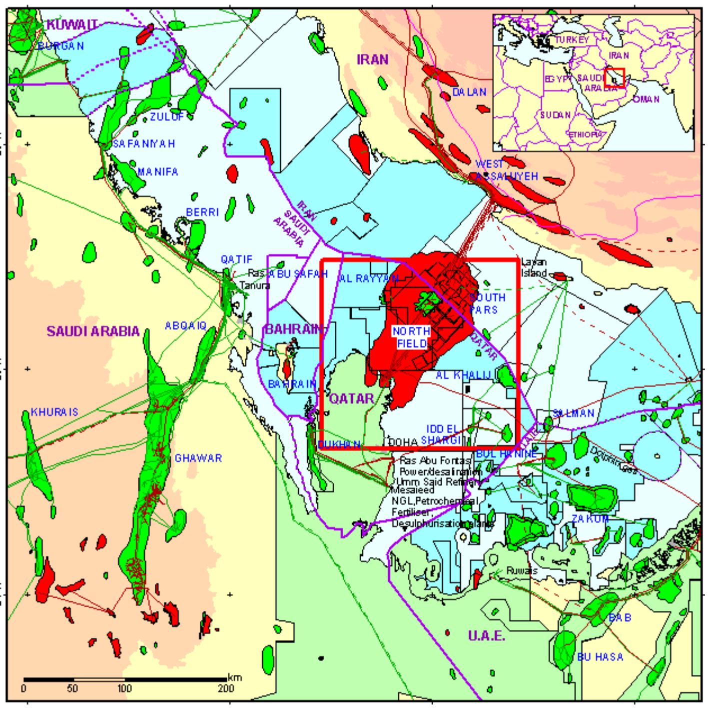
7. Appendices

a. *Source, hub and satellite terminal information:*

i. Source terminals:

1. Qatargas, Qatar

Figure 30 Location of Qatargas



Source: (Wood MacKenzie, 2009)

Key Facts:

Project Status	**Onstream**
Project Start-up	November 1996
FOB Breakeven[1]	US$ [confidential]/mmbtu

Upstream		
Initial Reserves[2]	22,500 mmbbl Liquids	900 tcf Gas
Remaining Reserves[2]	21,865 mmbbl Liquids	883 tcf Gas

Liquefaction Plant	
No. of trains	3
Total Plant Capacity	9.7 mmtpa
Port Name	Ras Laffan

1. Discounted at 12% nominal to 01/01/2009.
2. Gas reserves quoted are those for the whole of the North Field (Qatar). These reserves are also used to supply all other Qatari gas projects.

Economic Summary:

	Capital Costs[1] (US$M)	Total Net Present Value[2] (US$M)	Remaining Present Value[2] (US$M)	IRR (%)
Upstream	1,990	5,357	3,586	18.1
Plant	3,897	25,322	14,500	26.7
Total	5,743	30,679	18,086	

1. Costs in 2009 real terms. 2. Discounted at 10% to 1/1/2009

Breakeven Economics (US$/mmbtu)

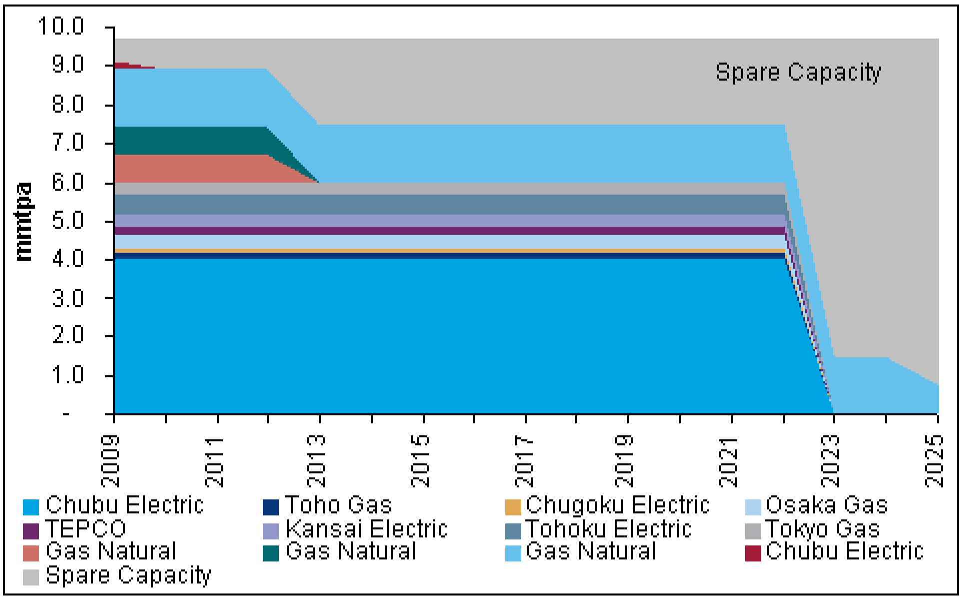
	Post-Tax with Liquids		
Discount Rate	10%	12%	15%
Upstream	0.53	0.53	0.53
Plant (Feedgas)	1.07	1.29	1.66
Breakeven FOB		[confidential]	
Plant (LNG Output)	1.23	1.48	1.91
Breakeven FOB (Overall)		[confidential]	

Source: (Wood MacKenzie, 2009)

LNG Contracts:

The following figure shows the spare capacity at Qatargas which doubles by 2012.

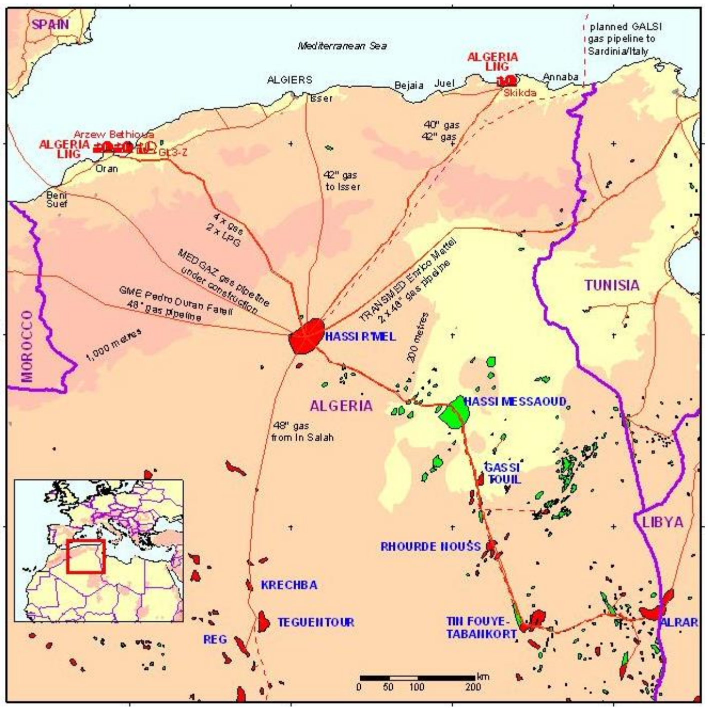
Figure 31 Spare capacity - Qatargas



Source: (Wood MacKenzie, 2009)

2. Algeria LNG, Algeria

Figure 32 Location of Algeria LNG



Source: (Wood MacKenzie, 2009)

Key Facts:

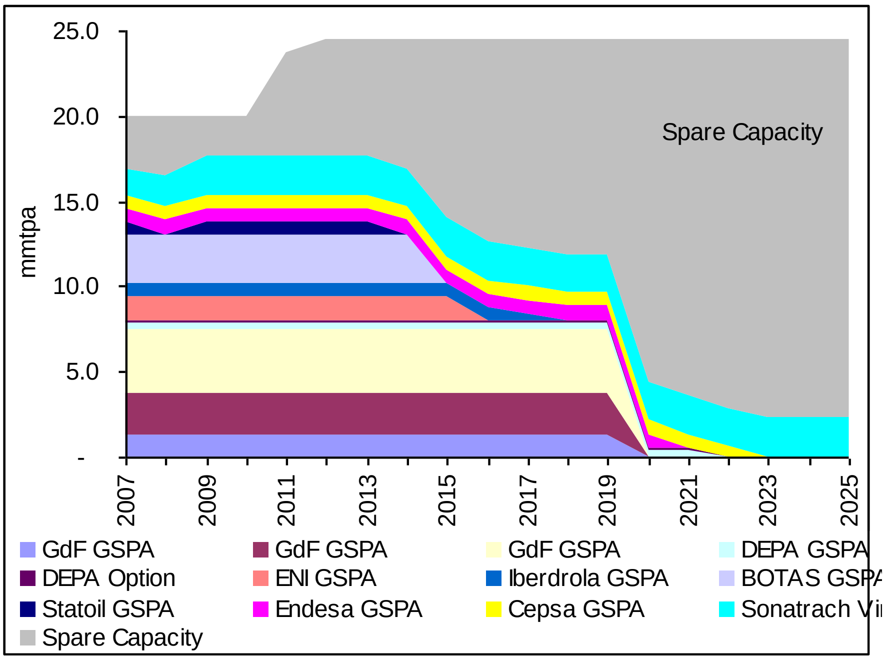
Nominal Plant Capacity	25.2 mmtpa
No. of trains	19
Berths	5
Max. LNG Carrier Size	165,000m^3
Storage Capacity	679,000m^3
No. of Storage Tanks	12

Source: (Wood MacKenzie, 2009)

LNG Contracts:

Algeria LNG has witnessed spare capacity since 2007. The future plans include the increase in liquefaction capacity by 2011.

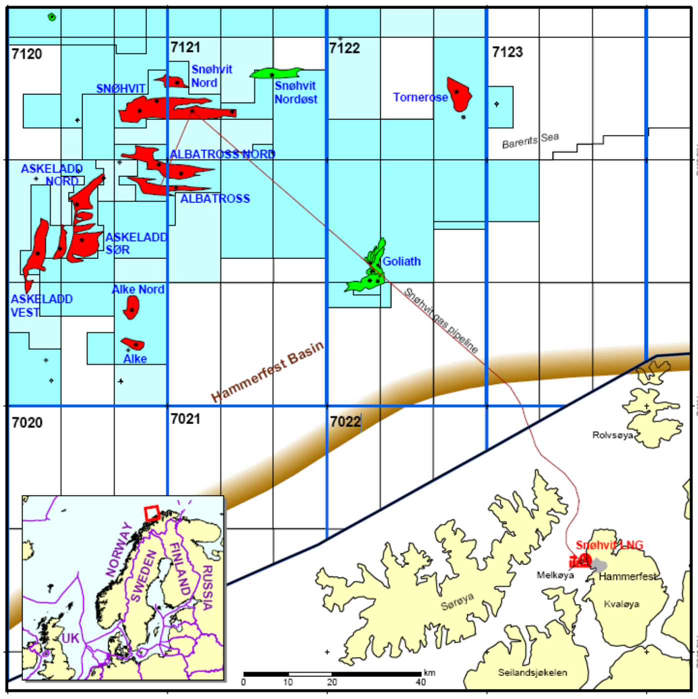
Figure 33 Spare Capacity - Algeria LNG



Source: (Wood MacKenzie, 2009)

3. Snøhvit, Norway

Figure 34 Location of Snøhvit



Source: (Wood MacKenzie, 2009)

Key Facts:

Status	Onstream	
Operator	StatoilHydro	
Participants	StatoilHydro	33.53%
	Norway State DFI	30.00%
	Total	18.40%
	GDF SUEZ	12.00%
	Hess Corporation	3.26%
	RWE Dea	2.81%

Nominal Plant Capacity	4.10 mmtpa
No. of Trains	1
Berths	1
Max. LNG Carrier Size	148,000 m^3
Storage Capacity	250,000 m^3
No. of Storage Tanks	2

Source: (Wood MacKenzie, 2009)

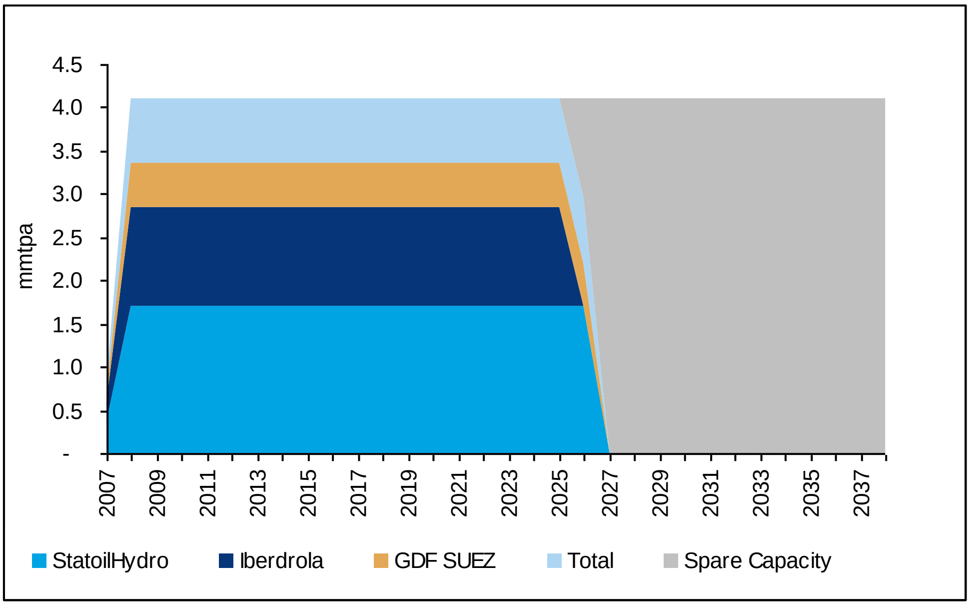
Limiting factor:

As per the Wood MacKenzie's report the entire capacity of 4.1 mmtpa is contracted till 2025. This could potentially be a limiting factor for the plant to supply LNG to more European customers, unless the plant capacity is increased or existing clients resell part of their contract capacity.

LNG Purchase Arrangements:

Buyer	Duration	Annual Delivery Volumes (mmtpa)	Sales Point
StatoilHydro	2007-2025	1.71	FOB
Iberdola	2007-2026	1.15	FOB
Total	2007-2026	0.75	FOB
GDF SUEZ	2007-2026	0.49	FOB

Figure 35 Spare Capacity - Snøhvit



Source: (Wood MacKenzie, 2009)

Economic Summary:

Summary	
Total Capex (US$ M, 2009 terms)	13,132
Total Opex (US$ M, 2009 terms)	12,027

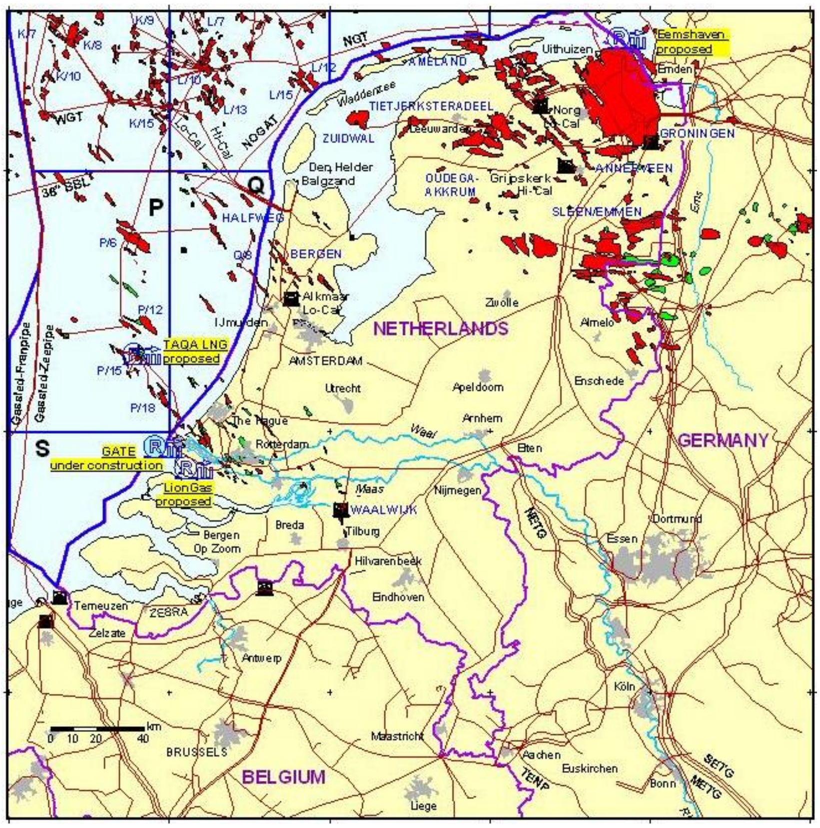
DCF Analysis	8%	10%	12%
Total NPV (US$ M)	4,221	2,972	1,897
Remaining NPV (1/1/2009)	6,591	5,722	5,057
IRR (%)		16.11	

Source: (Wood MacKenzie, 2009)

ii. Hub Terminals

1. GATE Terminal, The Netherlands

Figure 36 Location of Gate Terminal



Key Facts:

Infrastructure Summary

Status			**Under Construction**
Location			Netherlands
			Maasvlakte, Port of Rotterdam
Berths		**Storage**	
No. of Berths	1	No. of Tanks	3
Max. LNG Ship Size (m^3)	265,000	Capacity (m^3)	540,000
Regas		**(mmscfd)**	**(mmtpa)**
Nominal Capacity		1,226	9.6
Peak Capacity		1,226	9.6

Corporate Summary

Owners	
Gasunie	40%
Royal Vopak	40%
DONG Energy	5%
E.ON Ruhrgas	5%
Essent	5%
OMV	5%

Capacity Holders Phase	Company	Start Year	Expiry Year	Capacity (mmscfd)	Capacity (mmtpa)
Initial Phase	DONG Energy	2011	2041	307	2.4
Initial Phase	E.ON Ruhrgas	2011	2041	307	2.4
Initial Phase	Essent	2011	2041	307	2.4
Initial Phase	EconGas	2011	2041	307	2.4

(Source: (Wood MacKenzie, 2009) latest update: June 2009

2. Zeebrugge LNG Terminal, Belgium

Figure 37 Location of Zeebrugge LNG

Key Facts:

Infrastructure Summary

Status			Operational
Location			Belgium
			Port of Zeebrugge
Berths		**Storage**	
No. of Berths	1	No. of Tanks	4
Max. LNG Ship Size (m^3)	210,000	Capacity (m^3)	403,000
Send out Capacity		**(mmcfd)**	**(mmtpa)**
Nominal Capacity		870	6.8
Peak Capacity		1,197	9.6

Corporate Summary

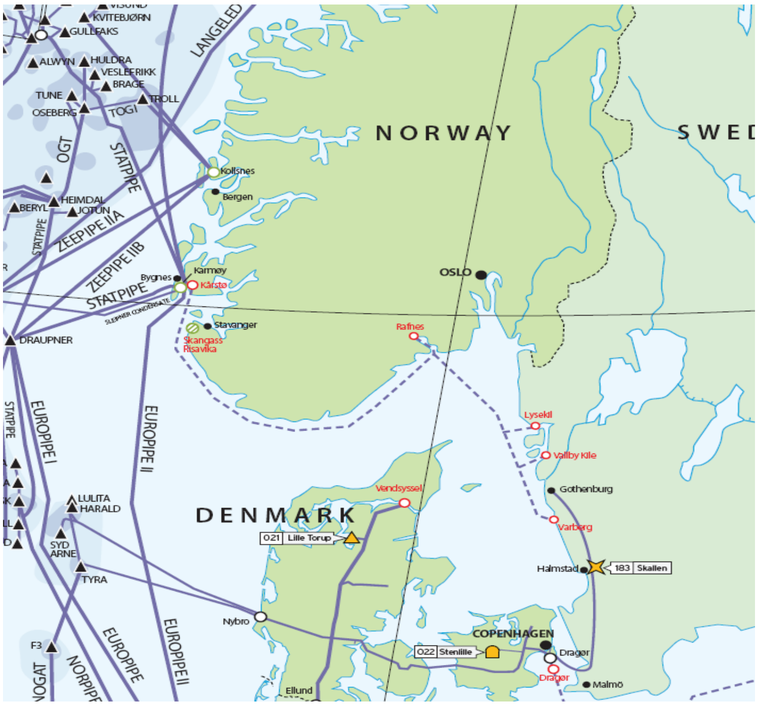
Owners	
Fluxys LNG	1000%

Capacity Holders		(mmcfd)	(mmpta)
	GDFSuez	179	1.4
	Distrigas	256	2.0
	EDF (until Jan 2012)	435	3.4
	Qatar Petroleum/ ExxonMobil (from Jan 2012)	435	3.4

Source: (Wood MacKenzie, 2009)

3. Nordic LNG, Norway

Figure 38 Location of Nordic LNG



4. Szczecin, Poland

Figure 39 Location of Szczecin

Key facts:

Project Name	Polskie LNG
Location	Port of Swinoujscie, Szczecin
Status	Proposed
Sponsor(s)	PGNiG
Proposed Capacity (approx.)	304 mmcfd (2.4 mmtpa)
Capacity Holder(s)	PGNiG
Storage Capacity	N/A
Max Ship Size	N/A

iii. Satellite Terminals

1. Gothenburg, Sweden

Gothenburg is Sweden's second largest city after Stockholm, and Scandinavia's largest RoRo and RoPax port. It is located at the end of the Göta River and is a central location for the Baltic and North Sea basin. It plays a major role in exporting Swedish industrial manufacturing goods as within Scandinavia only Gothenburg can receive large container vessels of up to 12,000 TEU.

The port has various terminals, among which a RoRo terminal, a container terminal, a car terminal and an oil terminal which serves two refineries of Shell and Preem. It also has older facilities for passenger and cargo ferry traffic.

The Port of Göteborg is fully owned by the City of Gothenburg. It is a port authority as well as a stevedoring company.

Background information:

The port is called regularly by 14 RoRo, 5 RoPax and 1 super fast vessel. Average age of these RoRo vessels is about 13 years and 6 of these vessels are at least 20 years old.(Maritime Gas Fuel Logistics, 2008). This makes this fleet a candidate for renewal, possibly by LNG.

The port receives feeder vessels to transport the containers over long-distances. This segment can also be attractive for turning to LNG fuel.

A similar trend is possible for local car ferries. These small ferries can consume around 500 tonnes of LNG per annum.

Some large manufacturing industries, including cars and trucks (VOLVO and SAAB), are looking to move from road and rail to water for shuttle distances; small cargo vessels are used. This is also an attractive segment for LNG to be used as fuel.

Since the Port authority and its users put lot of emphasis on the environment, it does have a significant potential for being developed as a LNG bunkering terminal.

Figure 40 Aerial photo of Gothenburg's port. Red circle indicates Hjärtholmen (left) and Risholmen, which are indicated as potential sites for an LNG bunkering terminal

Source: (Maritime Gas Fuel Logistics, 2008)

2. **Nynashamn, Sweden**

Key Facts:

Nynäshamns Gasterminal AB, owned by Swedish companies AGA, Fortum and Nynas, is building the first LNG terminal at Nynäshamn near south of Stockholm. This terminal will import about 250,000 tonnes of LNG annually and is expected to be on-line by mid 2011. The estimated cost of building the plant is around SEK 1 billion (€100 million).

This terminal is designed to serve smaller users as the LNG will be supplied by small coastal carriers. These smaller carriers are expected to carry the LNG from larger terminals such as Nordic LNG near Stavanger, Norway.

The facility will be able to handle carriers up to LOA 160m and draught of up to 9m. The storage tank design capacity is 20,000m^3. (www.dywidag-international.com)

Sighting the environmental issues, the natural gas will be used to replace the petroleum for the city-gas production and it is expected that the Nynas refinery will also use the gas in the hydrogen gas production.(www.lngpedia.com)

3. **Oxelosund, Sweden**

Key facts:

The Oxelosund LNG terminal will be situated on the east coast of Sweden and is about 100km south of Stockholm. The main Oxelosund port can berth a vessel with

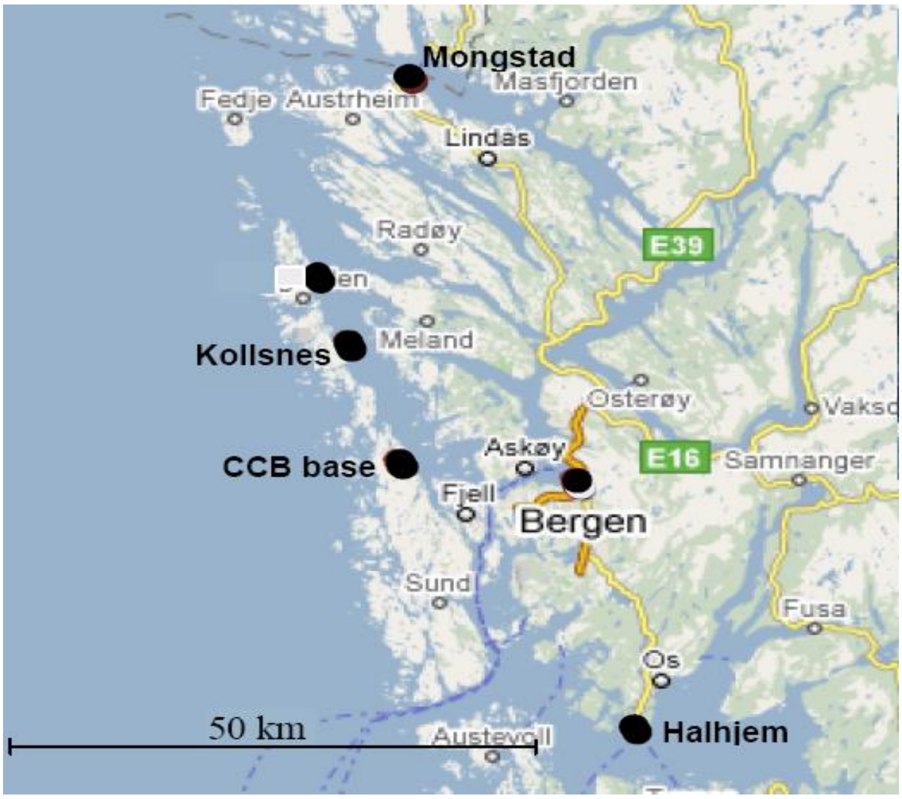
LOA 260m, beam 41m and of draught up to 15.5m.The expected capacity is app. billion Nm^3 per annum.

The LNG project got the governmental approval in June 2005 and its construction started in 2007. The terminal is expected to go into commercial operation from January 2009. This terminal will be capable of receiving the largest LNG tankers in operation today. The first deliveries are expected in 2010.

4. Bergen, Norway

Bergen is located on the South West coast of Norway and is about 479km west of Oslo. The port can berth a vessel up to LOA 294m and draught up to 12.20m.(World Shipping Register)

Figure 41 Map of the Bergen port district with location of important port facilities



Source: (Maritime Gas Fuel Logistics, 2008)

Bergen, Norway's second largest city after Oslo, is home to one of the important ports in Norway. Port of Bergen is owned by the City of Bergen and some other nearby municipalities. It covers some important facilities which are mentioned below:

- Mongstad: Oil refinery and offshore petroleum supply base
- Sture: oil export terminal

- CCB offshore petroleum supply base
- CCB base: Bunkering port for two LNG-fuelled supply vessel serving the North Sea petroleum installations
- Halhjem: Three LNG-fuelled ferried bunker at this ferry port.
- Kollsnes: This is the largest small-scale LNG production site, which is also within the Port of Bergen's district.
- Cruise vessels call this port especially in the summer as the port is near the city center.

Background information:

The Bergen port district is regularly called by 7 RoRo vessels out of which 5 ships are more than 25 years old. Sea Cargo, one of the owners of these vessels has already ordered two LNG-fuelled RoRo vessels.

As mentioned earlier, there are two LNG-fuelled offshore supply vessels, which are helping to reduce the emissions of NOx. It is possible that more such supply vessels could increase the use of LNG in this port.

From early 2009, one LNG-fuelled Coast Guard vessel has been stationed at a naval base outside Bergen and two other such vessels are also being commissioned for future operations. Many small coastal cargo vessels also call this port. Many of these ships are owned by smaller firms. This is also a segment which can see conversion to LNG fuel as many of these ships are relatively old.

Around 231 cruise ships called Bergen in 2007 as the city provides a good attraction for tourists. As these cruise ships have wide service range, they are less likely to convert to LNG fuel in coming years.

Many passenger boats, which are relatively smaller then the cruise ships, are regularly scheduled for South (Stavanger), North (Maloy) and to some fjords. These are diesel boats and are potentially candidates for early conversion to LNG fuel.

All these factors make Bergen an attractive port for making satellite services, keeping the future growth in mind.

b. *Cost model*

FINANCIAL PARAMETERS

Depreciation period for CAPEX	20	years
Profit Tax rate	25.5%	of EBT
EBTDA-multiplier for termination value of the Hub terminal	8	years of last annual cash flow

TERMINAL PARAMETERS

terminal CAPEX	XXX	MM€
terminal OPEX	XXX	MM€/BCM
Terminal tariff	XXX	MM€/BCM

Project IRR	**%**	

Volumes

year	
Terminal throughput [BCMA]	0.475

Revenue

year	
Paid heat revenue [MM€/yr]	XXX

Tax

year	
Revenue	XXX
Opex	XXX
Earnings before tax and depreciation (EBTDA)	XXX
Depreciation	XXX
Earnings before tax (EBT)	XXX
Tax [MM€]	XXX

Cash Flow

year	
Operational cash flow	XXX
Revenue	XXX
Opex	XXX
Tax	XXX
TOTAL OPERATIONAL [MM€]	XXX
Investment cash flow	XXX
Capex	XXX
Termination value	XXX
TOTAL INVESTMENT [MM€]	XXX
Operational + Investment cash flow	XXX

Remarks for the cost model:

- Assumed is that all CAPEX is spent before the Hub becomes operational. Model can be extended to allow for a CAPEX expenditure pattern over time if desired.
- All CAPEX associated with the Hub service to be taken into account. In case the Hub concerns a revamped existing terminal, all CAPEX associated with the Hub service should also be taken into account. Historical CAPEX associated with existing hardware should be calculated as if it is installed today.
- All money figures to be inserted as money of the day
- Input to be provided on the sheet tabs "In & Output" and "Volumes" only
- Profit Tax rate to be applied as valid for the Hub's country
- Definition project IRR: if IRR = WACC, then NPV is zero

- IRR's to apply for the various Hub locations:

  The Netherlands: 12%
  Belgium: 12%
  Poland: 16%
  Norway & Sweden: 12%

- Profit Tax Rates to apply for the various Hub locations:

  The Netherlands: 25.5%
  Belgium: 33.99%
  Poland: 19%
  Norway & Sweden: 28%