Marin gas logistics

Work package 5

D5-6 LNG supply chain feasibility study –

overall report
This report summarizes the work carried out under work package 5 of the Magalog project. The study looks into the overall aspects of a small scale LNG chain from a technical and economical point of view.

In the study some basic description and explanations of LNG as a common energy commodity is given, which is an important back ground for understanding the challenges and opportunities related to a small scale LNG distribution chain, and the possibilities to introduce LNG as an alternative bunker fuel for commercial short sea shipping.

Typical terminal designs are shown and safety issues related to gas leakage is demonstrated by simulation. Five targeted harbours, which are potential LNG bunkering terminals, are also studied.

LNG is today available at several locations in Europe, and Norway is an example of how a small scale LNG chain have been developed to supply LNG to industrial users and to shipping terminals as bunker fuel.
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1. Summary and conclusions

This study is carried out under work package 5 of the Magalog project. The study looks into the overall aspects of a small scale LNG chain from a technical and economical point of view.

In the study some basic description and explanations of LNG as a common energy commodity is given, i.e. physical and chemical properties, production methods and common trading routes from a worldwide point of view. This is an important background for understanding the challenges and opportunities related to a small scale LNG distribution chain, and the possibilities to introduce LNG as an alternative bunker fuel for commercial short sea shipping.

A key issue for introduction of LNG as a bunker fuel is the availability of LNG. This report shows an increasing number of LNG import terminals in Europe, and it can be concluded that LNG as an energy source are available throughout Europe and plans exist for new terminals in the Baltic area.

LNG as a bunker fuel is already introduced in Norway and “the Norwegian way“ has been to establish a small scale production and distribution system to support the ships in concern. LNG can be transported either by small LNG ships or by truck from regional LNG production and/or storage terminals. No technological bottlenecks have been identified for these issues. One important factor for a potential customer in a small scale distribution chain is the security of supply. Today there are examples of business agreements between the Norwegian gas company Gasnor and a large import terminal in Spain, which secure a backup delivery of LNG in case of unforeseen incidents related to LNG deliveries.

LNG is already introduced as ship fuel today. Several ships are operating on LNG as fuel in Norway. New engines are being developed and LNG storage systems are available from several companies. Rules and regulations have been developed by the classification societies and interim guidelines will be issued by IMO 2009.

The feasibility of introducing LNG as bunker fuel in five targeted harbours has been studied, Bergen, Gothenburg, Lübeck, Stockholm and Świnoujście. All harbours are promising candidates for future LNG bunkering terminals.

An overall assessment of air emissions in terminal ports by using natural gas fuelled ships is carried out. Based on general emission data and typical operation profile and fuel consumption of RORO and ROPAX vessels in port, the specific emission reductions potential in port operation are assessed.

By substituting conventional fuel with natural gas a significant emission reduction can be achieve as follows: NOx 80% reduction, SOx: 99 % reduction and PM 95% reduction. The reduction potential is due to the combustion properties of natural gas.
The example shows that gas fuelled ships would have a significant effect in reducing emissions in the terminal and ports they call. Further investigations are required for each port in concern to quantify the total reduction of harmful emissions to air which can be obtained from gas fuelled ship.

From the information provided in this report it can be concluded that that no obstacles has been identified for small scale distribution of LNG in Northern Europe from a technical point of view, and LNG is an alternative ship fuel in short sea shipping in the Baltic Sea and the North Sea. The main challenge is to supply LNG to the ship terminals at competitive prices to conventional fuels. The price structure of gas compared to bunker fuels indicates that competitive gas prices can be achieved at high crude oil prices (> 70 USD/Barrel), provided that the LNG logistic chain is well utilized.
2. Introduction

Introduction of LNG as fuel for short sea shipping meets both technological and financial challenges. The supply of LNG at the customers bunkering station requires a well organized logistic chain which includes LNG production, storage and transportation. In this report results from the feasibility studies and technical reports is summarized.

The work is carried out under Work package 5 (WP 5) of the MAGALOG project, and has been a cooperation between Gasnor and MARINTEK.

This work package was aimed at analyzing the technical and economical aspect by using LNG as fuel in the Baltic Sea and setting the pace for future LNG supply logistics and logistic infrastructure. This report is summarizing all work done in work package 5 of the project.

3. The overall aspects of an LNG supply chain with starting point at Kollsnes and alternative sources

3.1 Summary

In the study some basic description and explanations of LNG as a common energy commodity is given, i.e. physical and chemical properties, production methods and common trading routes from a worldwide point of view. This is an important back ground for understanding the challenges and opportunities related to a small scale LNG distribution chain, and the possibilities to introduce LNG as an alternative bunker fuel for commercial short sea shipping.

A key issue for introduction of LNG as a bunker fuel is the availability of LNG. This report shows an increasing number of LNG import terminals in Europe, and it can be concluded that LNG as an energy source are available throughout Europe and plans exist for new terminals in the Baltic area.

LNG as a bunker fuel is already introduced in Norway and “the Norwegian way“ has been to establish a small scale production and distribution system to support the ships in concern. LNG can be transported either by small LNG ships or by truck from regional LNG production and/or storage terminals. No technological bottlenecks have been identified for these issues. One important factor for a potential customer in a small scale distribution chain is the security of supply. Today there are examples of business agreements between the Norwegian gas company Gasnor and a large import terminal in Spain, which secure a backup delivery of LNG in case of unforeseen incidents related to LNG deliveries.

LNG is already introduced as ship fuel today. Several ships are operating on LNG as fuel in Norway. New engines are being developed and LNG storage systems are available from several
companies. Rules and regulations have been developed by the classification societies and interim guidelines will be issued by IMO 2009.

From the information provided in this report it can be concluded that that no obstacles has been identified for small scale distribution of LNG in Northern Europe from a technical point of view, and LNG is an alternative ship fuel in short sea shipping in the Baltic Sea and the North Sea. The main challenge is to supply LNG to the ship terminals at competitive prices to conventional fuels. The price structure of gas compared to bunker fuels indicates that competitive gas prices can be achieved at high crude oil prices (> 70 USD/Barrel), provided that the LNG logistic chain is well utilized.

3.2 Technical aspects by using LNG as bunker fuel

3.2.1 LNG availability and trade

LNG is shipped in specially-built LNG carriers from the liquefaction plants to large LNG receiving terminals in buyer countries. Typical LNG carriers have a loading capacity from 145,000 to more than 200,000 cubic meters of LNG.

LNG is produced in a cooling process in a set of process units consisting of all equipment necessary to produce LNG from a natural gas feedstock and having a pre-determined design capacity. A simplified LNG production process is illustrated and described in Figure 3.1.

**Figure 3.1 – Simplified LNG production process, ref:** [http://www.adgas.com](http://www.adgas.com)
LNG may be stored in insulated pressure tanks. Heat leaks into such tanks will increase evaporation which results in a pressure increase in the tank. The specific volume of LNG increases as it is heated. This demands extra tank volume where the LNG can expand, meaning that a tank cannot be filled 100%. The degree of filling varies between 90-95 % dependant on type of tank and application.

3.2.2 Sources of LNG

Today we see an increasing interest for LNG as a product and LNG is available throughout the world. The main trade routes for LNG (prognoses for 2010) are illustrated in Figure 3.2.

![LNG Trade at 2010](image)

**Figure 3.2** – LNG trade prognoses at 2010, /Ref.: The Oxford Princeton Programme, 2004/

Also in the European market an increasing LNG import is observed. Main existing and planned European LNG import terminals is shown in Figure 3.3.
LNG availability is a key issue to supply the maritime market in the future. In the import terminals LNG is available in large quantities, and this may be utilized by further distribution to smaller regional storage plants and/or fuel bunkering station. The “Norwegian way” of utilizing LNG in a small scale distribution network is an example on how the LNG from the large import terminals can be used as a backup source for security of supply where the main logistics and supply is local production from smaller LNG plants.

3.2.3 The distinction of large scale LNG vs. small scale LNG

The description above is typical what could be defined as large scale LNG production and distribution, which include large production plants, large ships for LNG transportation and large LNG receiving and re-gasification plants. LNG is supplied to the energy market throughout the world. The MAGALOG project aim to look into alternative fuels for the maritime short sea shipping market, and within such a framework a small scale production and distribution of LNG may a feasible solution, which is the case in Norway.
3.2.4 Regional LNG storage and distribution plants in Norway

The LNG infrastructure in Norway has developed rapidly the latest five-six years. Today more than 30 local and regional LNG storage plants are in operation covering the coast of Norway from Oslo to Bodø as shown in Figure 3.4.

All the ship terminals can in principle be modified to become bunkering terminals at a relative small investment from a technical point of view. Assuming that there are no obstacles (commercial, capacities etc.) to modify these plants, one can conclude that LNG is available as bunkering fuel along most of the Norwegian coastline.

![LNG distribution in Norway](image)

**Figure 3.4** – LNG truck and ship terminals in Norway, 2008 (Source: Gasnor)
4. Transportation and storage of LNG

4.1 General design of an LNG-terminal
As a part of the MAGALOG project five harbours in the Baltic Sea area have been studied to investigate the possibilities to establish LNG bunkering terminals in these harbours. This section gives an introduction to the technical design for a small scale LNG terminal designed to supply natural gas as a fuel to ships.

4.2 Background
The most common way to transport natural gas is by pipelines, and in most countries in Europe there is a well established gas grid. This grid is in turn supplied with transmission pipelines from the gas fields. LNG (Liquefied Natural Gas) has been developed as a supplement to the gas grids for storage and transportation purposes. When natural gas is cooled below -160°C, the methane becomes liquid and are compressed 600 times compared with gas form. Thus LNG is a space efficient way to store and transport natural gas when pipelines are not a feasible solution.

Norway is a country with deep fjords, high mountains and scattered population. This means that natural gas can not be distributed to the whole country by pipelines in a cost-effective way. As an answerer to this challenge there are developed a technology for small scale LNG distribution. This includes liquefaction plants for production of LNG, small scale LNG ships and road trucks for transportation, and dedicated end user LNG terminals for storage.

The LNG distribution system was developed with industrial customers in mind, but this technology has also made it possible to make use of natural gas as a ship fuel in the form of LNG. Today there are several ships operating with LNG as fuel, and there are constructed several LNG terminal with the purpose of supplying ships with this fuel.

4.3 Storage tanks
For the storage of LNG there are used cylindrical pressurised tanks. Because of LNG’s low temperature they are built as double shell vessels with highly effective powder-vacuum or multi-layer-vacuum insulation, which ensures long time storage with limited vaporization.

The tanks are produced in a variety of dimensions and capacities depending on the storage purpose. The storage in a bunkering terminal for ships will consist of tanks with a capacity of 500 to 700m³ LNG. These tanks will have a length of about 35 meters and a diameter of about 5,5 meters. In a terminal the tanks are placed in series according to the storage capacity required. Terminals can also be design so that capacity can be increased over time by adding storage tanks.
4.4 Filling line

An insulated pipeline transports LNG between the storage tanks and the ship. The same pipeline is used for the supply of LNG from a LNG freighter to the terminal and the bunkering of a vessel from the terminal. Because the pipeline is transporting a cryogenic liquid the distance between the terminal and the quay should be as short as possible to minimize boil off. The range should preferably not exceed a maximum of about 250 meters.

The pipeline between the quay and the terminal can be placed in an underground culvert and thus allow other activity in the quay area when not bunkering are taking place.

4.5 Quay

The quay in use must meet the requirement from the ship supplying the terminal with LNG and preferably also the ships calling at the harbour that is potential users of LNG as fuel. Generally the quay should have a water depth of 10 meters.

One of the ships witch will supply LNG to the terminals are the Coral Methane. It has the capacity to transport 7500m³ LNG.

The requirements of the ships that will be bunkering LNG must be considered in each case, specially the requirements of passenger ferries and freighters in fixed returning routes, but the quay should also be able to offer bunkering to normal freight vessels witch calls to obtain bunkering service. However, if there are potential users that can not access the quay, dedicated intermediate storage solutions could also be considered.
The most feasible solution is to use existing quays so that investments in new quays can be avoided. The quay area can be used for other purposes when unloading or bunkering of LNG is not taking place. If an existing quay not can be used and new investments are necessary, a d'albe solution could be used instead of a full scale quay structure in order to reduce investments.

4.6 Gasification unit

When there are delivery of gas from the LNG-terminal into a gas grid or to a nearby gas customer, the LNG are heated and transformed from liquid to gas form. For the heating there are normally used air based evaporators. This is a stable and efficient way of heating the gas. Alternative solutions are the use of excess heat from industry if that is available nearby. Automation systems and pressure regulators ensure proper gas pressure and temperature in the downstream pipelines. The air based evaporators are operated in two alternating sets, with one set defrosting while the other is in operation. The size and number of evaporators depends on the output effect required from the terminal.

4.7 Local transportation of LNG

LNG can be transported from the terminal to ships elsewhere in the harbour, nearby industries or also other harbours in the region with LNG semi-trailers. The trailers have cryogenic tanks constructed after the same principles as the terminal storage tanks. Distribution of natural gas in the form of LNG on road trucks is well established in Norway, and is used to supply a range of industrial and other customers. The trucks in operation in Norway have a transport capacity of 50m$^3$ LNG, but this can vary according to different national transport regulations.

Not all shipping routes can call at a bunkering facility for the bunkering. For instance Ropax vessels, such as passenger ferries with daily crossings, will depend upon the bunkering taking place at the ferry terminal. There are established procedures for bunkering of ships directly from semi-trailers that are in operation on passenger ferries in Norway today. Another solution can be that LNG is stored at a smaller buffer tank dedicated for the ship in question, and that this buffer tank is supplied with trailer from the main terminal.

4.8 Terminal lay out

A standard LNG-terminal for bunkering purposes will have a lay out with five 700m$^3$ tanks in series. The gross storage capacity will be 3500m$^3$ LNG which is equal to 2 millions Sm$^3$ of natural gas or 20 GWh energy. The size of this installation will be about 50 by 50 meters. This standard lay-out will be adapted to local conditions such as capacity required, available area and the form
of delivery from the terminal. There is also possible to prepare the terminal for increased capacity by preparing for installation of additional storage tanks.

The terminal is built with all connections and valves in one side and, for safety purposes, there are built an accumulation pool in this end of the terminal. In the low probability of a leakage of LNG the liquid will be collected in this pool. There will be a safety zone of about 30 meters radius around accumulation pool. In this zone there will be restrictions on other activity that can involve ignition sources.

![Diagram of terminal lay-out](image)

**Figure 4.1 - Standard terminal lay-out with five 700m3 storage tanks.**

From the terminal there is a pipeline connection to the filling point at the quay and there is a new safety zone around the filling point. There is also an evacuation zone of 100 meters around the terminal. This area will be evacuated in the case of an incident at the terminal.
If there will be deliveries of gas into the local gas grid or to a local on shore consumption the terminal design will include evaporators for the heating of LNG and transforming to gas. Further, if there will be a regional distribution of LNG, the terminal will be equipped with a filling station for LNG road trucks. Figure 4.3 shows a lay out of a terminal with air based evaporators and a filling station for road trucks.

The technology in this terminal design is used in over 30 terminals in operation in Norway today. Storage capacity, services offered and lay out are design options that vary and will be adjusted to local conditions in each new case, but the main principles are the same.
The picture shows an example of a standard terminal lay out in operation. This terminal is built in Mosjøen in Norway and the supply of LNG to the terminal is done by ship. The main purpose of this terminal is to supply natural gas to an aluminium plant located near by, but the terminal is also prepared for further regional distribution of LNG by road trucks.

4.9 Safety
LNG has been transported and used safely worldwide for roughly 40 years and the industry has an excellent safety record. In Norway there are today over 30 small scale LNG terminals in safe operation.
The physical and chemical property of LNG determines the level of reliability and the hazards that are taken into consideration. LNG is odourless, non-toxic, non-corrosive and less dense than water. LNG vapours (primarily methane) are harder to ignite than other types of flammable liquid fuels. Above approximately -110°C LNG vapour is lighter than air. If LNG spills on the ground or on water and the vapour does not encounter an ignition source, it will warm, rise and dissipate into the atmosphere. Because of these properties, the potential hazards associated with LNG include heat from ignited LNG vapours and direct exposure of skin or equipment to a cryogenic (cold) substance.
The handling of LNG is reliable and safe do to LNGs low temperature, high ignition temperature and narrow range of ignition concentration. Further the operations are conducted according high safety standards. The terminals are designed, built and operated according the standard CEN EN 1473 Installation and equipment for liquefied natural gas - Design of onshore installations, and the Council Directive 96/82/EC on the control of major-accident hazards involving dangerous substances.

4.10 Gas leakage simulation
A gas leakage simulation has been carried out to illustrate the effect of LNG leakage from a safety point of view with the following assumption and input:

- The simulation shows a leakage of LNG (liquid) witch evaporates into gas, forms a gas cloud and rise into the air.
- The leakage illustrated is of 40 kg LNG pr second for 100 seconds.
- Total leakage is 4000 kg LNG
- About 9000 litres LNG or 5500 Sm3
- The simulation shows the situation from the leakage starts to the gas has disappeared after 200 seconds.
The model

- The model is based on a standard terminal design, with five cylindrical LNG tanks, evaporator and control room.
- Further there are included a LNG truck and a LNG supply vessel.
- The terminal has an accumulation pool.
- The blue areas is water

Gas cloud formation

- The lightest (pink) part of the cloud represents 50% of lower flammability limit (LFL).
- The darker (red) part represents the area for LFL).
- The lower flammability limit (LFL) of a fuel is the minimum composition in air which is flammable.
- Natural gas has a limited range of flammability – it will not burn in concentrations below about 5% or above about 15% when mixed with air.

Results

- The illustrated leakage is of 4000 kg LNG or about 5500 Sm3 natural gas.
- After 4 minutes (235 seconds) the cloud has disappeared into the air.
- The maximum extension of the gas cloud is about 250 meters from the terminal.
5. LNG/natural gas as ship fuel

5.1 LNG characteristics

LNG in the fuel tanks has to be evaporated before used as fuel. It is the gas phase with the main component methane that has to be mixed with air to be burned in an engine. Gas phase from LNG is an excellent basis for fuel in a ship engine as the content of heavier hydrocarbons is low. The Table 5.1 below shows different LNG qualities. The methane number is typically above 80 and thereby well suited for ship engine fuel.

<table>
<thead>
<tr>
<th>LNG qualities</th>
<th>Snøhvit (A)</th>
<th>Karmøy (B)</th>
<th>Kolsnes (C)</th>
<th>Tj.odden (D)</th>
<th>Zebrügge (E)</th>
<th>Brunei (F)</th>
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<th>Odlowy</th>
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</table>

Table 5.1 – LNG qualities

Characteristics for natural gas from LNG as ship fuel:
- High methane number means:
  - high power ratio with knocking margin
- Is easy to mix with air to a homogenous charge, burns with high flame velocity even at high air access. All in all beneficial for obtaining:
  - high efficiency
  - no smoke/particulates
  - low NOx
- Contains no sulphur, meaning no SOx emission

5.2 Exhaust emissions
Natural gas is an excellent fuel for internal combustion engine. The combustion properties of natural gas make it possible to design gas fuelled engines with high efficiency and low exhaust emissions. Comparison of exhaust emissions of natural gas operation and MDO operation shows the differences in exhaust emissions from the two types of bunker fuel.

![Figure 5.2 – Specific emissions from ship engines burning MDO or natural gas.](image)

5.3 State of the art technology for gas engines
Two main natural gas engines concept are available. This is the Duel fuel (DF) gas engines and the spark ignited (SI) gas engine.

DF engine
Market leader in production of the DF engine is Wärtsilä Finland OY. The Wärtsilä 32DF and Wärtsilä 50DF are designed to operate on both gas and liquid fuel. These engines offer fuel flexibility together with high efficiency, low exhaust gas emissions and safe operation.

Dual-fuel engines are capable of switching from one fuel to the other without interruption in power generation. The engines operate on the lean-burn principle: the mixture of air and gas in the
cylinder is lean, which means that there is more air than needed for complete combustion. Lean combustion increases efficiency and reduces NOx emissions. Higher output is reached while avoiding knocking or pre-ignition.

The NOx emissions of Wärtsilä DF engines in gas operation are approximately 1/10th of those of a standard engine while the CO2 emissions are also low due to the clean gas fuel burned and the high efficiency of the engine.

<table>
<thead>
<tr>
<th>Dual-fuel engines</th>
<th></th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Wärtsilä 32DF</td>
<td>(2,010 - 6,300 kW)</td>
<td></td>
</tr>
<tr>
<td>Wärtsilä 50DF</td>
<td>(5,700 - 17,100 kW)</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.2 – Wärtsilä Duel Fuel engines /ref Wärtsilä/

Wärtsilä dual-fuel engines have been installed in LNG carriers and on board two FPSOs. Furthermore, the offshore supply vessels Viking Energy and Stril Pioner are equipped with dual-fuel-electric machinery installations and use LNG as fuel. Furthermore more than 23 dual-fuel engines are in service or on order in land-based power plants. (ref. Wärtsilä, October 2006).

SI Engine
The lean-burn gas engines (SG) from Wärtsilä feature port admission of gas, prechamber with controlled gas flow as well as individual cylinder control of gas charge and ignition timing. This choice of concept along with extensive research in combustion and combustion control has made it possible to elevate the efficiency from 40% to more than 45% in the bigger engine models. The Wärtsilä 34SG engine has the lean-burn technology and a cylinder configuration from 12 to 20V34SG. The engine is today not available for marine application.

The Rolls Royce Bergen KVGS spark-ignited, lean-burn gas engine is installed in more than 150 power plants throughout the world. The lean-burn principle of the engine operation is unique in its combination of high power and high efficiency coupled with reduced exhaust emission. The KVGS engine is being developed for marine application and a total of 16 engines are in operations from 2007 on five Norwegian ferries.

<table>
<thead>
<tr>
<th></th>
<th>In-line</th>
<th>Vee design</th>
<th>Output (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion</td>
<td>6, 8 &amp; 9 cyl</td>
<td>12, 16 &amp; 18 cyl</td>
<td>1215 - 4010</td>
</tr>
<tr>
<td>Generator sets</td>
<td>5, 6, 8 &amp; 9 cyl</td>
<td>12, 16 &amp; 18 cyl</td>
<td>885 - 3975</td>
</tr>
<tr>
<td>Lean-burn gas engine</td>
<td>6, 8 &amp; 9 cyl</td>
<td>12, 16 &amp; 18 cyl</td>
<td>1053 - 3600</td>
</tr>
</tbody>
</table>

Table 5.3 – K-engines from Rolls Royce Bergen, /Ref: Rolls Royce Marine/
5.4 Alternative propulsion systems, mechanical vs. gas electric propulsion

All natural gas powered ships which have been built until 2008 have been designed with a gas-electric propulsion plant, (i.e. diesel-electric concept for conventional (non-natural gas) vessels). This concept causes the combustion engines to always operate on a fixed engine speed (rpm) generating electric power at 50 or 60 Hz. It should be noted that this simplifies the regulation of the combustion engine as the engine speed (rpm) shall always remain constant to supply electric power at 50 or 60 Hz.

For a diesel-mechanical concept, which is used for most ships today, the engines will have to alter the engine speed (rpm) to achieve the vessel target speed at any time. In a diesel – mechanical (or gas-mechanical) configuration there are dedicated combustion engines providing propulsion power to propellers via reduction gears and shaft lines. In addition there are separate auxiliary engines generating electric power to other onboard consumers.

A gas-mechanical concept is today under development, and will be available from Wärtsilä and Rolls Royce Marine in 2010/2011.

5.5 Fuel system

The fuel system for an LNG fuelled ship is characterized by using large vacuum insulated storage tanks operating at a pressure of app.10 bar.

The following systems and/or components are required in a LNG storage system:

- LNG tank- and bunkering system
- LNG evaporation system
- Trim heating system
- Gas detection system
- Remote control and monitoring system
- Ventilation and nitrogen purging system

So far only some 10 gas fuelled ships have been put into operation, and the gas fuelling system has been supplied as a turn key system. Only a few suppliers have been in the market so far, which results in a relatively high price tag on this system. During the last year, new suppliers have flagged their interest for this market, which will result in increased competition and presumably lower unit costs for the gas fuelling system. At the end this will benefit the gas fuelled ship concept.

A schematic layout of a LNG system is shown in Figure 5.3.
5.6 Safety system

The safety of the gas systems on board is of vital importance. This includes all onboard gas systems, including connected piping, ventilation, re-fueling stations, etc. Introduction of LNG as fuel on board shall not influence of the safety level of the ship compared to a conventional design with traditional bunker fuel on board. International and national rules, regulations and guidelines have been developed to secure that gas fuelled ships are being build to the highest safety standard.

The IMO’s “Interim guidelines on safety for natural gas-fuelled engine installations in ships” allows for two different design principles for configuration of the machinery spaces when it deals with safety.

These two alternative system configurations are described as follows:

1. **Gas safe machinery spaces (inherently safe design):** Arrangements in machinery spaces are such that the spaces are considered gas safe under all conditions, normal as well as abnormal conditions, i.e. inherently gas safe.

2. **ESD-protected machinery spaces (ESD design):** Arrangements in machinery spaces are such that the spaces are considered non-hazardous under normal conditions, but under certain abnormal conditions may have the potential to become hazardous. In the event of
abnormal conditions involving gas hazards, emergency shutdown (ESD) of non-safe equipment (ignition sources) and machinery is to be automatically executed while equipment or machinery in use or active during these conditions are to be of a certified safe type.

Inherently safe main engines are today being developed by major engine manufacturers, and this seems to be a cost efficient design, which reduces the overall investment cost on a gas fuelled ship compared to the ESD design.

5.7 Rules and regulations

5.7.1 International regulations
Norway started the process in IMO to develop international regulations in 2005, and a draft IMO guideline was proposed in 2007, which is a somewhat simpler version of similar Norwegian rules. These are being considered for worldwide application through an IMO resolution, and according to normal IMO practice the next step will be issuing guidelines for approving gas as a fuel, expected in 2009.

5.7.2 Classification rules
Classification societies do have applicable rules and regulations for approving the construction of this vessel. (DnV; Class notation GAS FUELLED, Pt. 6. Ch. 13, others societies are also developing rules.)

5.8 Conclusions – technical issues
More than ten gas fuelled ships are already in operation, and several new gas-fuelled ships are under construction. LNG has proven to be a feasible fuel for these projects.

Gas storage systems and gas fuelled engines are available from major suppliers. From a technical point of view, an LNG fuelled ship can be built on commercial conditions, and no technical obstacles are identified.

6. Financial aspects
An LNG fuelled ship is more expensive to build than a conventional ship of the same type. The extra investment cost incurred for a new-building, has to be compensated by lower operation cost to make natural gas as fuel interesting form a commercial point of view. In this chapter typical ship types which operate in the Baltic- and the North Sea has been used as case ships to investigate the feasibility of natural gas as fuel from an economic point of view. Also other aspects related to the development of future fuels are discussed.
6.1 Building costs, gas fuelled ships

Additional cost is added to a gas fuelled ship compared to a traditional fuelled ship using heavy fuel oil (HFO) or marine diesel oil (MDO). The extra cost is related to the following main components/systems:

- Fuel storage tank
- Gas engine
- Safety systems
- Approval

6.1.1 RORO-ship, gas related costs, /2/

Studies carried out at MARINTEK show an additional cost for a gas fuelled ship of 10-15% of the total cost of a conventional ship. For a typical RORO ship of 5600 DWT and L= 130 m with installed main engine power of 7 MW, the additional costs for an LNG fuelled ship is approximately 3,2 million €.

6.1.2 ROPAX ship – gas related cost, /2/

A typical ROPAX ship operating in regular routes in between North European ports is used as case ship to estimate additional cost for a gas fuelled ROPAX ship.

Main particulars, ROPAX ship:

<table>
<thead>
<tr>
<th>LOA:</th>
<th>210 m</th>
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<tbody>
<tr>
<td>B:</td>
<td>26 m</td>
</tr>
<tr>
<td>D:</td>
<td>6,5 m</td>
</tr>
<tr>
<td>DWT:</td>
<td>6000 t</td>
</tr>
<tr>
<td>Gross tonnage:</td>
<td>35000 t</td>
</tr>
</tbody>
</table>

To estimate the investment cost for a mechanical HFO diesel engine and DF gas engine information is based on price estimate from Wärtsilä and Aker Yards. Based on this information the specific engine cost (€/kW) has been used to estimate the required investment increase for a DF engine assuming that the same power range is available for the various engine types.

Additional investment for a DF machinery plant is approximately € 5,8 mill or 36% higher than a HFO plant. This will increase the total ship price with some 10%.
6.2 Marine bunker fuel

6.2.1 Future requirements to fuel qualities in SECA areas

In April 2008 revision of IMO MARPOL Annex VI was approved at MEPC 57. New requirements to fuel qualities in SECA areas imply stricter emission limits for NOx- and SOx-emissions from ships.

As can be seen from Figure 6.1 the global cap of SOx is reduced from 3.5% to 0.5% effective from 2020. This will probably mean that it is not possible to meet these limits with use of heavy fuel oil (HFO). There is an opening to employ SOx scrubbing techniques.

![Figure 6.1 - New global limitation of sulphur oxides (SOx) and limitation of SOx in emission control areas (ECA)](image)

Within the ECA (emission control area) the limit of SOx is reduced to 0.1% and this should be combined with a reduction of NOx by 80% compared to today’s level, see Figure 6.2, effective from 2016. This means that HFO will not be possible to use in the ECA’s which will among others be Baltic Sea, North Sea and most of the European waters. To meet such strict limitations in the ECA’s ships has to use low sulphur distillates with NOx exhaust gas cleaning technique (SCR) or switch to LNG as fuel.
Figure 6.2 - New IMO limitation of NOx. Tier II is a global cap of 20% reduction from today’s level and Tier III means a 80% reduction form today’s level. Tier III will be in force from 2016 in Emission Control Areas (ECA)

The implication of these stricter emissions limits will firstly increase the demand of low sulphur distillates fuel and hence higher fuel price. Ships operating in the ECA’s need to employ NOx exhaust cleaning devices which adds to capital and operation cost. Both increased fuel price and added operation costs due to exhaust cleaning, will be in favor for LNG as fuel.

6.3 LNG pricing

LNG pricing is normally linked to the crude oil prices. Price development on bunker fuel has shown a strong increase from 2004 as shown in Figure 6.3.
Natural gas as bunker fuel is today not common and there is no traditional commercial price mechanism for natural gas as bunker fuel. For ships in operation in Norway the gas price is agreed between the gas company and the ship owners on individual basis in separate contracts. However, based on international bunker prices, expected natural gas prices can be estimated.

6.3.1 European gas prices: What they represent and how they are observed

Globally, the market prices for natural gas are much less uniform and less transparent than the market prices for crude oil. The pricing of natural gas across the world is fragmented, can have large differences in price between different locations and contracts, and is readily observable only in parts.

Some short-term trade prices for European natural gas are readily observable, both from the ICE futures exchange in London and as price assessments of physical trade. Short-term prices are recorded for next-day deliveries and for specified future periods, with an emphasis on deliveries during the next month.

The readily observable, short term gas prices have the limitation of not reflecting the majority of border-crossing gas trade in Europe, which occurs under long term contracts with price indexation to oil products. Viviés (2003) found that only 5% to 10% of gas requirements in Continental Europe may be covered by short term trading arrangements. The corresponding figure for the UK may be higher.

Long term gas contract prices are generally not published. Certain published sources are sometimes referred as approximations of long term natural gas contract prices. This includes monthly price and volume statistics for German imported natural gas published by a German ministry (Bundesministerium für Wirtschaft und Technologie, www.bmwi.de), and average gas sales prices obtained by StatoilHydro for mainly long term sales of Norwegian gas, and reported in the firm’s quarterly reports (Figure 6.4). These prices represent border-crossing intra-European trade in natural gas.

Figure 6.4 shows a comparison of short-term UK and US gas prices and the StatoilHydro average prices, in which the latter may serve as an indicator of long term sales prices. The long term prices are linked mainly to gas oil and heavy fuel oil, but with a time lag of a few months. The long term contract prices exhibit less volatility than the short term prices, as evidenced particularly in 2005/2006 when there were sharp price spikes in US gas prices caused by destructive hurricanes and in European gas prices caused by concerns over Russian gas exports. Such gas-specific events hardly affect the long term gas prices at all.

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1 Previous day futures prices for UK natural gas can be viewed for free at www.theice.com. Trade in Brent crude oil and several other energy commodities are also found here. Daily price assessments from Platts, Argus and Heren for gas deliveries in the UK, Zeebrugge and certain other locations are available as subscriptions. Historical price series can also be procured at a cost.
The typical format of a modern gas contract price formula is as follows:

\[ P_n = P_0 + c_G w_G (G_m - G_0) + c_F w_F (F_m - F_0) \]

where

- \( P_n \) is the gas price to be paid for period \( n \);
- \( P_0 \) is the gas price agreed at the outset of the contract;
- \( c_G \) and \( c_F \) are conversion factors for converting the quoted price units of gas oil and fuel oil to natural gas equivalents by energy content;
- \( w_G \) and \( w_F \) are relative weights given to gas oil and fuel oil in the indexation, defined so that \( w_G + w_F = 1 \);
- \( G_m \) and \( F_m \) are price assessments observed for gas oil and fuel oil for the period \( m \), which is often an average for several months prior to period \( n \) so as to produce a time-lagged oil indexed pricing;
- \( G_0 \) and \( F_0 \) are the prices for gas oil and fuel oil determined at the outset of the contract.

A survey by the European Commission – Competition DG (2007) found that long term gas import contracts in the European Union were, on volume weighted average in 2004, linked 44.8% to gas oil, 29.5% to heavy fuel oil, 9.8% to reported short term natural gas prices, 7.4% linked to other energy prices and 8.5% on fixed prices or indexed to general inflation.
Figure 6.5 shows a comparison of prices for European gas oil, heavy fuel oil and natural gas, the latter represented by the StatoilHydro prices mentioned above. By this measure, natural gas prices have typically been 55% - 60% of gas oil prices, and near parity with heavy low-sulphur fuel oil on energy basis\(^2\), but with large variations especially in times of oil market turbulence due to the lagged indexation of gas prices to oil prices.

\(^2\) The comparisons between gas prices and petroleum fuels prices are made on the basis of gross calorific value (GCV). For a given quantity of fuel, the net calorific value (NCV) is about 5% lower for heavy fuel oil, 6% lower for gasoil and 10% lower for natural gas.

The prevailing long term approach to trading described above for European natural gas, applies similarly to world wide trade in LNG, including European imports. LNG deliveries on large (>100,000m\(^3\)) ships typically operate under 20+ year contracts. Over the past 10 years expectations of a shift towards more short-term LNG trade have frequently been heard. There has indeed been some increase in the frequency of LNG spot trades (each such trade typically covering one ship cargo), but global LNG trade remains predominantly driven by long term agreements. European LNG import contract price formulae are not officially published, but may be widely known within the industry. They also tend to be indexed to oil prices, though often to crude oil rather than refined oil products.
Figure 6.6 shows a comparison of European contracted gas prices from different sources, with Algerian LNG often indicated at a somewhat higher price level than pipeline bound contracts. The market information services3 issue regular reports on the global LNG markets, but spot deals are too few and far between to provide a basis for regular and reliable market price assessments.

If and when cargo trade in small scale LNG becomes common at some future time, a distinct market with observable prices for such trade may emerge. Prices for small LNG cargoes in Northern Europe may then deviate from pipeline gas prices to some extent, for both short and long term contracts. Small cargo prices are likely to be higher than pipeline gas prices for most of the time, at least on a delivered basis.4 A somewhat similar phenomenon of differentiated price formation depending on delivery mode and cargo size can be observed in the North European market for liquid petroleum gases (LPG).

6.3.2 Price considerations for LNG supplied as ships’ fuel

In a framework of long term contracting for LNG for bunkering, the price of LNG would be specified in the contract. The agreed price must be commercially sustainable for buyer as well as seller, which entails two requirements:

- The use of LNG should not weaken the ship owner’s competitive position relative to using another fuel;

- The LNG seller should be able to recover his cost of supplying it.

The challenge in developing and contracting for LNG supplies will be to establish contractual terms which will meet both these requirements simultaneously. The following sections review the factors that influence the cost of supplying LNG, i.e. the second requirement above.

---

3 Platts, ICIS Heren. Petroleum Argus
4 A somewhat similar phenomenon of differentiated price formation depending on delivery mode and cargo size can be observed in the North European market for liquid petroleum gases (LPG), also reflected in regular price assessment by the market information services.
It is common in long term sale and purchase contracts to link the contract price as a formula to other observable prices that have a relevance for the parties, for instance prices of crude oil, gas oil or heavy fuel oil as quoted by Platts\(^5\). Such price linkages serve to prevent the price under a long term contract from becoming entirely divorced from market realities, which would tend to impose strains on the contractual relationship.

There are several ways in which a price formula in a long term LNG supply contract can be structured. In many cases, the long term buyer tends to seek an assurance that LNG will not become uncompetitive against traditional fuels to which LNG is seen as an alternative. If the MARPOL requirements can be met alternatively by using gas oil or LNG, then this would point towards linking the LNG contract price to reported prices for gas oil of a relevant quality. Platts’ price assessments for gas oil deliveries in North West Europe may be a relevant reference.

In some cases an LNG buyer may desire a long term fixed price, i.e. avoiding a formula that will cause the price of LNG to increase or decrease with oil prices. It is suggested that this may be achieved by still linking the LNG price to oil prices in the long term contract, while the buyer desiring a different price structure may obtain this by making additional agreements for price risk management. This can be done either by trading directly in futures markets or with financial firms which can provide such arrangements.

### 6.3.3 Determinants of the cost of supplying LNG: Overview

It can be assumed that suppliers of LNG for bunkering will not be original producers of natural gas, but will procure natural gas or LNG at an established point of supply, and undertake the logistical tasks of making it available as LNG for ships as described above. The cost of supplying LNG then has two main components:

\[
\text{Cost of LNG supply} = \text{Market based gas price} + \text{Cost of supply logistics}
\]

Supplies can be obtained from two alternative or supplementary sources; large scale and small scale LNG, with significantly different cost structures. The two main cost components indicated above will be reviewed in the two following sections, based primarily on a small scale supply system (which is already established for similar purposes) but discussing also the possible implications of moving towards supplies from large scale systems, which is a possible future development.

Unit costs of supplying LNG are stated below in Euro (€) per MWh, where MWh refers to the energy content of the LNG as gross calorific value (GCV). One tonne of LNG contains approximately 15.1 MWh as gross calorific value.

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\(^5\) Platts is an information service that provides daily assessments of market prices for a wide range of spot traded products, [www.platts.com](http://www.platts.com). Similar services are provided by Petroleum Argus ([www.argusonline.com](http://www.argusonline.com)) and ICIS Heren ([www.heren.com](http://www.heren.com)).
6.3.4 Market based gas price as a component of LNG costs for bunkering

Small scale producers of LNG in Norway procure natural gas which has been produced at offshore Norwegian fields and landed near a gas processing facility on the Norwegian coast. This gas would otherwise be transported by pipeline to the European continent or UK in order to enter the European pipeline-bound gas market. The price at which natural gas can be purchased for the purpose of small scale LNG production and ultimately for bunkering purposes, will therefore be related to European gas market prices, with a possible discount related to the avoidance of pipeline transport from Norway to the continental or UK markets.

If LNG will in the future be purchased at major European import terminal(s) to be supplied as ships’ bunker fuel, then this purchase price is also likely to be related to the European gas market prices. This is because LNG imported to Europe is generally supplied to the European pipeline-bound gas market. In practice therefore, LNG arriving at North European terminals can be assumed to have a market value similar to other natural gas in the region, irrespective of the price at which it is procured from producers overseas.

In either case, the long-term prices are more relevant than short-term prices because LNG bunkering and the supply systems set up for this purpose will be long term endeavours, and in order to avoid the extreme variations sometimes encountered in the short term market (Figure 6.4).

Long term contracted prices for natural gas have tended to be at 55% - 60% of high quality gas oil prices in Northern Europe, and this can also be indicated as a long term average price range for gas to be purchased either as input for small scale LNG production or as LNG from a large terminal. The latter is more likely to be near the high end of the range, with significant uncertainty since no such purchase agreement has yet been made in Northern Europe.

6.3.5 Supply logistics as a component of LNG costs for bunkering

The costs of supply logistics for making procured gas available as LNG for a bunkering ship must cover the 4 elements as follows:
- Small scale LNG production unless sourced from a large terminal;
- Freight to a bunkering port;
- Terminal at bunkering port;
- Bunkering operation from a terminal at bunkering port.

Cost of small scale LNG production

The last completed small scale production plant in Norway was the 80,000 tonnes/year second train at Kollsnes (owner: Gasnor), which started operations in 2007. Much of its capacity is already committed for a number of years ahead. One 300,000 tonnes/year project is ongoing in Norway. Firm and updated investment cost figures for these plants have not been published, but based on various public information, it can be put at €50 - €60 million per 100,000 tonnes of annual LNG production capacity allowing for some distortion from recent currency fluctuations.
In recent years there has been a sharp trend towards higher construction costs in the oil and gas sector, but also in other sectors, driven by rising oil prices and a strong world economy until mid-2008. As of late 2008 there is considerable uncertainty over how the recent sharp global economic downturn and drop in oil prices will affect construction costs including the cost of building new LNG capacity.

LNG production requires substantial amounts of energy, usually as electricity which can be obtained from the grid or produced locally from gas. If produced from gas, 10 – 15% of the gas feed is spent for this purpose, resulting in some surplus heat which may be applied to other purposes.

The cost of small scale LNG production from future plants may be put at a range of €7 - €12 per MWh, depending on a number of factors including cyclically influenced construction costs, energy costs, utilisation etc. High energy prices will tend to increase the costs.

If LNG supply from large terminals is achieved, then the small-scale LNG production costs can be avoided. Instead, somewhat higher ship transportation costs must be expected, because the most likely sources are at a greater distance than Western Norway. An addition of €1 per MWh for transport costs is assumed in the event of LNG sourcing from large terminals.

**Freight and terminal costs**

LNG will have to be moved to the bunkering ports, most likely by smaller LNG carriers and to be received in a terminal facility with storage capacity. Tank storage capacity must be carefully selected due to its high cost, and this should be optimised together with utilisation of shipping capacity. Discharge of one ship cargo at several terminals is a possibility, and it may be optimal in some ports to build terminal storage capacity of a smaller size than would be needed to fully discharge one ship.

MARINTEK has analysed several cases of optimal ship and terminal utilisation based on different assumptions for discharge port combinations, product origins and annual quantities. Figure 6.7 illustrates the outcome of some of the analyses, in which Gothenburg, Lübeck and Stockholm were considered as bunkering ports either separately or in combinations, and Western Norway as the source of LNG. Shipping and terminal costs for tend to be lower with higher annual quantities, and are mostly between €5 and €10 per MWh when annual supply is in excess of 80,000 tonnes per year. For smaller annual volumes, costs per MWh can be significantly higher, and they may also be adversely affected by awkward destination combinations which lead to inefficient use of capacities.
Cost of bunkering operations

The cost of performing bunkering operations, which entails the supply of LNG from a local terminal to the fuel tanks of a ship, can be conducted by truck, barge or fixed line delivery. The costs will depend on local conditions and the solution found for each port, but is expected to be comparatively modest in relation to the other cost components. A cost of €1 per MWh is assumed for this function.

Figure 6.7 - Shipping and terminal costs at different discharge port combinations and different annual quantities. Costs in € per MWh of energy in LNG. Based on calculations by MARINTEK.

6.3.6 Indications of overall costs of LNG supplies

Figure 6.8 gives indications of overall costs of LNG supplied as ships’ fuel in the Baltic region, and the cost of gas oil as a comparison. To allow for the recent wide fluctuations in the price of crude oil, the indications are given at three different crude oil price levels: $30, $90 and $150 per barrel of Brent crude. The costs of supplying LNG are indicated as high to low ranges at each oil price level.

The reasons for the high-low ranges in LNG supply costs are explained in the previous subsections. For LNG production, the high-end cost represents a high estimate of small-scale LNG costs, whereas the low-end cost represents supply from large-scale terminals without the need for small-scale LNG production but with a modest extra freight cost to allow for longer sailing distance.

As can be seen from Figure 6.8, the cost of LNG will tend to vary with the price of crude oil, as do also refined products such as gas oil. Delivered LNG costs will however tend to vary less than crude oil and refined oil products, such as gas oil. As a consequence, the competitive position of LNG against liquid fuels will be stronger at high oil prices than at low oil prices.
A substantial range of high to low LNG costs is indicated for each oil price scenario. In early stages of LNG supplies for bunkering the costs are likely to be in the higher parts of the range, as supplied volumes are low and drawn mainly from small-scale LNG production. As the systems expands, and with the anticipated introduction of supplies from large-scale plants, there is a potential for bringing costs down towards the lower ends.

Figure 6.8 - Indications of costs of supplying LNG under different crude oil price scenarios.

For comparisons, gas oil costs under different oil prices are established based on regression of historical prices during 2004-2008. Gas oil costs reflect heating oil quality with max 0.1% sulphur in barge trade in the Amsterdam-Rotterdam-Antwerp range without addition of taxes or surcharges.

The diagram in Figure 6.8 does not fully reflect the comparative costs and benefits of using LNG as a fuel in replacement of gas oil. The construction of LNG-fuelled ships is currently more costly than ships on liquid fuels; on the other hand, ships running on gas oil within the Emission Control Areas will face added costs for keeping emissions within permitted limits.
6.3.7 Small scale LNG pricing

For small scale LNG contracts as is the case for the MAGALOG ships the pricing principles described above is valid. Below general description above has been further elaborated with reference values to establish relevant reference curves for small scale LNG pricing.

The correlation to natural gas prices is obtained by using information from Platts, and in this way the LNG bunker prices is expressed as a function of crude oil prices on the spot market.

Gas prices relevant for benchmarking of the MAGALOG concepts are obtained by the following simplified formula on energy basis

\[ P_{\text{LNG}} = a \times F(\text{op}) + b \]

where

- \( P_{\text{LNG}} \) – Price of LNG, ø/kWh
- Exchange rates:
  - 1 NOK = 100 ø (ø=øre)
  - 1 € = 8,0 NOK (September 2nd 2008)
  - 1 EuroCent = 8 øre
- a - constant, negotiated in contract. October 2007: a=20 ø/kWh
- F(op) – function of oil prices, Platts notations of MGO prices

\[
F(\text{op}) = \frac{\text{MGO(Platts)}_n}{\text{MGO(Platts)}_{\text{oct}07}}
\]

- MGO(Platts)_n – Platts MGO price notation in month n
- MGO(Platts)_{oct07} – Platts MGO price notation in October 2007
- n – actual time for price calculation
- b – Constant, represent non-oil related cost, (fixed production cost, transportation etc.)
  - October 2007: b=10 ø/kWh

Average MGO prices in October 2007 is: MGO(Platts)_{oct07} = 709,50 US$/ton.

Hence, LNG reference price October 2007 may be calculated as follows:

\[
P_{\text{LNG(october 07)}} = 20 \times \frac{709,50}{709,5_{\text{oct07}}} + 10 = 30 \quad [\text{ø/kWh}] \quad (2,75 \text{ €-Cent/kWh})
\]

Gas pricing versus crude oil price for the small scale and large scale markets are illustrated in Figure 6.9.
Figure 6.9 – LNG prices vs. Brent crude oil price

The illustration in Figure 6.9 shows the possible price span on LNG represented with LNG prices on the large scale Asian markets and prices which may be obtained in a small scale perspective. Actual prices will probably be in between the Japanese and small scale European prices.

Figure 6.10 – LNG and MGO prices vs. Brent Crude oil price on energy basis. (USD/NOK exchange rate 5.4)

From Figure 6.10 it can be seen that the LNG prices on energy basis is equal to MGO market prices in Norway at crude oil price of $ 40/barrel and for MGO spot prices at USD70 /barrel. Comparing MGO prices to Japanese import prices indicate a potential development of gas price in a more developed market.

Comparing international fuel prices of HFO and MGO with the market price on LNG in the developed Japanese market, an interesting trend can be observed. Today the LNG price is
cheaper than the HFO price on an energy basis as illustrated in Figure 6.11. This indicates that a higher availability of LNG as new production facilities are established will reduce the price of LNG. LNG will be more compatible to other fuels, and the domestic price level for LNG relative to MGO and HFO will probably be lower in the future than it is today.

Figure 6.11 – Comparison of LNG, HFO and MGO prices on energy basis, (Sipilä, Wärtsilä)

6.4 Economic evaluation
The gas price is a key factor in the economic evaluation of a gas fuelled ship and comparison with a conventional HFO fuelled ship. In WP 4 of the MAGALOG project, economic evaluations of a RORO and A ROPAX case ship has been done. Assuming there are no technical and regulative challenges the economic criticality by building a gas fuelled ship as the case ships referred to in this report will always be dependent upon the gas price vs. the price of conventional fuels.

Building costs: The actual cost of the gas-engine and propulsion plant may be about 30 % more expensive for the gas version compared to a conventional vessel. For the vessel as a whole this is reduced to about 10 %.

Operating costs. Fuel price: Operating costs varies slightly with a number of factors, such as maintenance, manning, and others, but the major issue is of course the price of fuel (gas). For the chosen case ships there is a balancing point around a crude oil price of USD 70/barrel. Above this price (at a certain point in time) the gas solution is advantageous and gives a faster return of investment over a typical project period (15 years used in our studies). The gas price varies with the crude oil price and the development of gas and oil price are not directly linked to each other. Uncertain future development of this ratio will be a criticality factor for the success of the gas (or
diesel) version. It should be noted to the gas-version’s advantage that the recent decision by IMO to practically ban the use of HFO in MARPOL defined special emission control areas (SECA) such as the Baltic Sea and the North Sea by 2015. From this year onwards all vessels in North Europe will practically have to switch to distillate oils with a price tag of about 80% above HFO while any gas powered vessels will not experience this jump in fuel costs in 2015.

**Taxation:** Some sources point to possible future taxation of emissions resulting from the operation of combustion engines in the marine market. Such taxations are not yet regulating the international marine market, but it is already effecting domestic Norwegian operations. Taxation or other regulation is heavily debated in IMO and other regulative bodies in Europe and cannot be excluded as a possibility for the future, but is not considered for the RORO and Ro-Pax example vessels. However, compared to conventional fuels the use of natural gas in general leads to less taxable emissions so the concept vessels will not suffer relative to conventional vessels and this is of course not a critical barrier for the concept.

Considering these cost and taxation conditions it seems in general that economic criticality is not a barrier for investing in gas powered vessels as it might have been only a few years back. From today’s standpoint with exceptional high fuel oil price (spring 2008) it seems even clearer that a gas powered vessel will compete better than a conventional vessel in an open market like the one the ships are operated in today. Also in a more regulated market, if this shall be a future scenario, the concept vessels seems more competitive due to the added environmental benefits of natural gas as a fuel compared to conventional bunker fuels. The added costs for building gas powered vessel seem to be a worthwhile investment if the market develops in the expected way, but the uncertainty of future gas (or fuel) prices are of course a critical issue. A vessel designed for switching between fuels would of course also be a safe bet if it could take advantage of the lowest cost of fuel at any given time.
7. Loading of LNG to a LNG feeder at a production plant

7.1 Introduction
In /5/ the LNG loading procedure from a LNG production plant to a LNG feeder is described based on experience from operation at Kollsnes LNG production plant and distribution of LNG with the LNG feeder “Pioneer Knutsen”. The description focus on how safety precautions are implemented in the operational routines, and indicate required time frame for loading/unloading of an LNG feeder.

7.2 The LNG feeder “M/T Pioneer Knutsen”
“Pioneer Knutsen” is the world’s smallest LNG tanker with a tank capacity of 1100 m³. The ship is owned by the Norwegian ship owner Knutsen OAS and chartered by Gasnor on a long time contract. The vessel carries natural gas from the LNG terminal at Kollsnes, outside Bergen to users in along the Norwegian coast. The “Pioneer Knutsen” is operated by a crew of six persons.

7.3 Loading procedure at Kollsnes LNG plant
Loading of the LNG feeder follows a standardized safety procedure. The ship is moored to the quay and connected to the loading hoses as shown in Figure 7.1.

Figure 7.1 – Loading of “Pioneer Knutsen” /Source: Gasnor/
The ship brings own filling hoses, and these hoses are always connected to the LNG pipe flanges of the ship.

Standardized refuelling procedure has been established and followed during loading and unloading of the ship. Based on these procedure the total loading time of the ship is approximately 6-7 hours, all included. The main time consumption is related to the loading of the ship and this is decided by the loading capacity of the ship.

Discharging LNG from the vessel to a local bunkering terminal would in principle require the same procedure as for loading the ship. Total discharge time is dependant of the pump capacity of the ship, but approximately one hour has to be added due to operational procedures and safety precautions.

Bunkering of a gas fuelled ship will need to follow approximately the same routines as for loading of an LNG feeder. To minimize the bunkering time it is important that the bunkering terminal is designed with sufficient pump capacity. This should be based on the design requirements from all involved parties on a case-to-case basis.
8. Transporting of LNG from Kollsnes and alternative origins to terminal ports

8.1 Introduction
When a ship owner considers LNG as fuel in his fleet he will carefully consider the technical economical feasibility, safety and LNG bunkering possibilities in terminal ports.

Availability of LNG as bunkers is of course a premise that has to be in place, not only availability in general but dedicated to terminal ports included in the ship sailing route. An increased number of LNG bunkering facilities are a mutual type of matter. If the driving forces for LNG as ship fuel are strong enough, the number of bunkering facilities will follow more or less automatically. On the other hand the market has to be confident that bunkering will be in place when it is needed.

The Baltic Sea is highly interesting when it comes using LNG as ship fuel. The LNG availability in Norway and Northern Europe could be a basis for establishing an LNG bunkering infrastructure in the Baltic Sea.

8.2 LNG availability in the Baltic and North Sea
Today no LNG bunkering facilities for ships outside Norway is known, and it is likely that such facilities will be required in central ports in Northern Europe to increase the availability and flexibility of LNG as bunker fuel.

Assuming an increased interest for LNG as bunkers in the North European short sea shipping, a similar infrastructure as already available in Norway should be established. It is not possible to point out where initial bunkering stations should be built. This will be dependant on the project and LNG volumes which can be realized in the various areas. To indicate the price effect of transporting LNG from various production plants to the customers in the Baltic Sea some analysis have been done with a logistic simulation tool developed at MARINTEK.

Alternative receiving harbors have been chosen in these cases, Lübeck and Gothenburg and Stockholm.

The main source of LNG is assumed to be the Kollsnes LNG production plant and from a planned import terminal in Swinoujscie, Poland. Based on the assumption of required LNG-volumes at specific Baltic harbours, a transport model is used for calculations of transportation cost for various scenarios of supply to the alternative receiving harbours.

The following scenarios have been defined

1. Kollsnes - Lübeck
2. Kollsnes - Gothenburg – Lübeck
3. Kollsnes - Lübeck - Stockholm  
4. Kollsnes - Gothenburg - Lübeck - Stockholm  
5. Swinoujscie - Lübeck - Gothenburg  
6. Swinoujscie - Stockholm

### 8.3 Scenarios investigation

Case scenarios are simulated to investigate the economic feasibility of supplying LNG to numerous harbors in the Baltic Sea. LNG is distributed by a given ship to a storage hub in the actual harbor. Typically a low volume scenario and a high volume scenario are simulated. The main output from the simulations is the calculated shipping and storage cost expressed as a rate of NOK/ton LNG handled in the logistic chain. This rate is a clear indicator of the LNG chain feasibility as the shipping and storage cost has a major effect on the final LNG price to the customer.

The actual harbors are chosen based on:  
- the ship traffic basis and thereby possible yearly LNG bunkers volume (refr: WP4.1)  
- the strategic location and possible LNG market for other industrial purposes

Distributions chains with supply from the LNG plant at Kollsnes to possible LNG hubs in Gothenburg, Lübeck, Svinemünde and Stockholm are investigated as case scenarios.

The simulation of a LNG chain by ship transport needs a set of general input parameters as shown in Table 8.1.
Table 8.1 - General parameters

8.4 Results

The simulation results are presented in Table 8.2.
<table>
<thead>
<tr>
<th>Case</th>
<th>LNG logistic chain -- transport by ship 7500m³</th>
<th>shipping NOK/ton</th>
<th>storage NOK/ton</th>
<th>total NOK/ton</th>
<th>total pr. year MNOK/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 a</td>
<td>40 000 tons from Kolsnes to Lübeck</td>
<td>1407</td>
<td>1244</td>
<td>2651</td>
<td>107</td>
</tr>
<tr>
<td>1 b</td>
<td>120 000 tons from Kolsnes to Lübeck</td>
<td>538</td>
<td>417</td>
<td>955</td>
<td>115</td>
</tr>
<tr>
<td>2 a</td>
<td>80,000 tons from Kolsnes to Lübeck and Gothenburg (roundtrip 40,000 to Lübeck, 40,000 to Gothenburg)</td>
<td>756</td>
<td>407</td>
<td>1163</td>
<td>94</td>
</tr>
<tr>
<td>2 b</td>
<td>200,000 tons from Kolsnes to Lübeck and Gothenburg (roundtrip, 120,000 to Lübeck, 80,000 to Gothenburg)</td>
<td>365</td>
<td>164</td>
<td>529</td>
<td>106</td>
</tr>
<tr>
<td>3 a</td>
<td>70,000 tons from Kolsnes to Lübeck and Stockholm (40,000 to Lübeck, 30,000 to Stockholm)</td>
<td>890</td>
<td>493</td>
<td>1383</td>
<td>97</td>
</tr>
<tr>
<td>3 b</td>
<td>163,000 tons from Kolsnes to Lübeck and Stockholm (roundtrip, 120,000 to Lübeck, 43,000 to Stockholm)</td>
<td>465</td>
<td>258</td>
<td>723</td>
<td>118</td>
</tr>
<tr>
<td>3 c</td>
<td>180,000 tons from Kolsnes to Lübeck and Stockholm (direct shipping, 120,000 to Lübeck, 60,000 to Stockholm)</td>
<td>694</td>
<td>611</td>
<td>1305</td>
<td>175</td>
</tr>
<tr>
<td>4 a</td>
<td>110,000 tons from Kolsnes to Lübeck, Gothenburg and Stockholm (roundtrip 40,000 to Lübeck, 40,000 to Gothenburg, 30,000 tons to Stockholm)</td>
<td>619</td>
<td>323</td>
<td>942</td>
<td>104</td>
</tr>
<tr>
<td>4 b</td>
<td>160,000 tons from Kolsnes to Lübeck, Gothenburg and Stockholm (roundtrip operation, 74,000 tons to Lübeck, 50,000 to Gothenburg and 36,000 tons to Stockholm)</td>
<td>470</td>
<td>215</td>
<td>685</td>
<td>110</td>
</tr>
<tr>
<td>5 a</td>
<td>80,000 tons from Svinemünde to Lübeck and Gothenburg (roundtrip, 40,000 to Lübeck, 40,000 to Gothenburg)</td>
<td>708</td>
<td>410</td>
<td>1118</td>
<td>90</td>
</tr>
<tr>
<td>5 b</td>
<td>200,000 tons from Svinemünde to Lübeck and Gothenburg (roundtrip, 120,000 to Lübeck, 80,000 to Gothenburg)</td>
<td>313</td>
<td>164</td>
<td>477</td>
<td>95</td>
</tr>
<tr>
<td>6 a</td>
<td>30,000 tons from Svinemünde to Stockholm</td>
<td>1807</td>
<td>1669</td>
<td>3476</td>
<td>104</td>
</tr>
<tr>
<td>6 b</td>
<td>60,000 tons from Svinemünde to Stockholm</td>
<td>930</td>
<td>835</td>
<td>1765</td>
<td>106</td>
</tr>
</tbody>
</table>

**Table 8.2 - Distribution cost to hub**
Comments to Table 8.2:
- The storage tank volume at a hub is optimized according to the actual LNG volume throughput from the hub.
- The yearly investment and operational cost for the storage plant is included in the cost calculation and expressed as a cost pr. ton of the LNG throughput.
- The vessel yearly capital cost: 36 MNOK

In reference /5/ more data from the logistic simulation is included.

8.5 Comments to results
To minimize the shipping cost in the Baltic LNG logistic chain it is of major importance, not surprisingly, to utilize the vessel capacity. For the actual vessel with the cargo capacity of 7500m3 LNG and loading at Kolsnes LNG plant, a yearly shipping quantity should be in the range of 160000 to 200000 tons pr. year. For a shorter roundtrip by picking up LNG in Svinemünde, the vessel yearly capacity will be significant higher, close to 400000 ton pr. year.

A ship fuel market of this magnitude in the Baltic region is foreseen as a possible scenario (ref. WP4.1) especially with the high and lasting fuel oil prices, but not realistic from day one. To boost the necessary volumes from day one, industrial LNG users in the hub areas will be of great help.

The maximum theoretical vessel capacity:
- cases 1a, 1b, 2a, 2b: approx. 240000 tons/year
- cases 3a, 3b, 4a, 4b: approx. 160000 tons/year
- cases 3c: approx. 216000 tons/year
- cases 5a, 5b: approx. 420000 tons/year
- cases 6a, 6b: approx. 390000 tons/year

With the LNG market volume foreseen at the different hubs it is more cost effective to serve the hubs by roundtrip sailing than direct delivery.

A hub in Stockholm with assumed capacity of 30000-40000 ton/year can be served at less cost by a roundtrip from Kollsnes via Lübeck than by the same vessel used in direct transport from Svinemünde.

The storage cost contributes significant to the total distribution cost and is certainly affected by the throughput volume of LNG. The higher volume, the lower specific storage cost.
9. Targeted harbour studies

In the project five targeted harbours have been studied closer. These are: Bergen, Gothenburg, Lübeck, Swinou, and Stockholm. Main conclusions for these harbours as LNG terminals are referred below.

9.1 Bergen

Bergen Harbour, covering also the nearby harbours of Sotra, Øygarden and Mongstad, is one of the busiest ports of western Norway. RoPax traffic includes regular international routes to Denmark, Iceland and Great Britain and a daily domestic route to Kirkenes.

Most of the regular RoPax and RoRo activities are directed towards the inner port of Bergen. A number of semi regular cargo transports are directed towards the oil bases at CCB and Mongstad, and do represent a future LNG market potential. In this area, the RoRo vessels seem to be the vessels to be closest to replacement based on an age evaluation.

There are three harbour areas of interest for establishing a LNG terminal for bunkering purposes in the Bergen area. These are the inner harbour of Bergen, The Coast Center Base (CCB) which is an offshore supply base, and the Kollsnes area where a LNG production plant is located. Of these the Kollsnes area seems to be the most promising locality.

Due to the number of vessels calling at the Bergen area, the strategically location along the fairway, and the possibility for supply of LNG from local LNG production, Bergen is an interesting location for a LNG bunkering facility.

9.2 Gothenburg

The Port of Göteborg is located on the west coast of Sweden in northern Europe. The port is a combined river and sea port and there are more than 10,000 calls annually. Of these about 800 are RoRo vessels, and about 5000 are RoPax vessels. In the waters outside the Port of Göteborg 400 vessels with 15000 passengers are passing each day on average.

In Gothenburg there is every year bunkering of oil witch equals about 1 million tons of LNG (14 TWh). We can as an example say that 5% of this can be converted into LNG. This will constitute a potential long term market of 50,000 tons of LNG (700 GWh) a year.

On short term there are small ferries and local shipping witch is of most interest for LNG as fuel. Local shipping operates within the SECA area, and river-sea-vessels also contribute to air pollution in the Gothenburg area. On medium term large vessels, RORO-vessels and feeder traffic are an interesting market for LNG as fuel. These vessels operate mainly within the SECA area. The difference between these vessels and those constituting a potential on short term, is that these vessels operates on routes that are exposed to competition, and that some of them are dependent on the possibility to bunker in more than one harbour.
To offer LNG as a fuel it is necessary to establish a terminal for LNG. Locations are considered in connection with RoPax terminals, in the existing oil harbour in Ryehamnen and in connection with the new developments at Hjertholmen and Risholmen. Further studies are required before making a final decision, but at this point the area at Risholmen seems to be the best location for establishing a new LNG terminal for bunkering purposes.

All together Gothenburg is a promising harbour for introducing LNG as fuel for ships.

9.3 Lübeck

Due to its large and growing RoRo and RoPax scheduled shipping, Lübeck is clearly a relevant port for early development of LNG bunkering. Conversion to LNG is likely to occur over a large number of years, with a modest rate of introduction over the next 10 years, due to the fairly young age profile of the fleet serving Lübeck. The possibility to use a LNG terminal as a backup for the gas supply for the city of Lübeck can mean an additional factor contributing to establishing bunkering possibilities in Lübeck.

There are identified potential locations for a LNG terminal for bunkering purposes in the harbour area of Lübeck. Both Lehmankai I and III offer available areas and adequate quays, but the locations are at some distance from the Baltic Sea and the Ropax terminal lat Skandinavienkai. The preferred location for a LNG terminal is at Skandinavienkai is a short distance from the Baltic Sea and the location for the Ropax terminal. There is identified a possible area for a LNG terminal at Skandinavienkai, but there is limited space available and further studies is required to confirm that this location is feasible.

9.4 Stockholm

The Port of Stockholm is the central port for freight and passengers to and from Finland, Russia and the Baltic states. The Ports of Stockholm Group comprises the ports in Stockholm, Kapellskär and Nynäshamn. Stockholm is an interesting market for the introduction of LNG as a ship fuel due to the high number of RoPax and ferries operating on this port. The RoRo potentials seem on the other hand low. A total of 425.000 tonnes of fuel are estimated used on the lines operating on Stockholm.

The Ports of Stockholm has an active environmental policy and is a frontrunner in this issue. Environmentally differentiated port dues are applied as a financial incentive to support and encourage shipping companies to try and reduce environmental impact.

The existing oil harbours Ludden and Berg oljehamn, and the former oil depot at Stora Höggarn are potential locations for a LNG terminal for bunkering purposes. There are however possible obstacles and further studies are necessary before a final conclusion regarding location are made. Altogether Stockholm represents an interesting possibility in the introduction of LNG as fuel for ships.
9.5 Świnoujście

Świnoujście together with Szczecin seaports create one of the largest port complexes at the Baltic Sea. The advantage of the Port of Świnoujście is his strategic location on the shortest route from Scandinavia to Central and Southern Europe and across the Baltic Sea from Russia and Finland to Germany and Western Europe. There is also an excellent connection with Berlin via the inland waterway network.

One of the most interesting developments in the Port of Świnoujście is the construction of a new import terminal for LNG. The main part of the LNG will be regasified for supply to the Polish gas grid, but there are also plans for reloading of LNG for small scale transportation. The central location of the terminal in the Baltic sea area and the possibility for reloading of LNG for small scale transportation makes Świnoujście interesting as a source for supplying LNG as fuel to the Baltic sea area.

The possibility to establish bunkering facilities in connection with the new import terminal should be investigated further, but as of now, the most promising location for a bunkering terminal is at The Maritime Base of Liquid Fuels. Here there are handling of other petroleum products today, there is a quay that can be used and location is in short range from the port entry.

The market for LNG as a fuel in Świnoujście is limited on short terms. The local ferries are due for renewal and running them on LNG is of interest. The fuel consumption of the ferries is limited, but the possibility to supply LNG should be investigated further. On longer terms there is RoPax connections which will be of interest for LNG as a fuel.

The most interesting opportunity in Świnoujście regarding LNG as a ship fuel is the possibility to supply the Baltic sea are from the new import terminal for LNG, and this should be elaborated further.

10. Environmental effect of LNG in port

An overall assessment of air emissions in terminal ports by using natural gas fuelled ships is carried out, /4/. Based on general emission data and typical operation profile and fuel consumption of RORO and ROPAX vessels in port, the specific emission reductions potential in port operation are assessed.

By substituting conventional fuel with natural gas a significant emission reduction can be achieve as follows: NOx 80% reduction, SOx: 99 % reduction and PM 95% reduction. The reduction potential is due to the combustion properties of natural gas.

Assuming a future scenario for market penetration of 25% for gas fuelled ship operating in the terminals and port of Lübeck the potential emission reduction has been calculated as follows:
<table>
<thead>
<tr>
<th>Operation mode</th>
<th>NOx-emission</th>
<th>SOx emission</th>
<th>PM-emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t/year</td>
<td>t/year</td>
<td>t/year</td>
</tr>
<tr>
<td>Emissions per ship, 2008</td>
<td>48</td>
<td>22</td>
<td>1.6</td>
</tr>
<tr>
<td>Reduction potential, LNG operation, %</td>
<td>80%</td>
<td>99%</td>
<td>95%</td>
</tr>
<tr>
<td>Reduction potential, LNG operation, t/year, per ship</td>
<td>38.4</td>
<td>21.7</td>
<td>1.5</td>
</tr>
<tr>
<td>Reduction potential, LNG operation for 15 ships, t/year, total</td>
<td>576</td>
<td>327</td>
<td>23</td>
</tr>
</tbody>
</table>

The example shows that gas fuelled ships would have a significant effect in reducing emissions in the terminal and ports they call. Further investigations are required for each port in concern to quantify the total reduction of harmful emissions to air which can be obtained from gas fuelled ship.
11. References

/1/ Rogde, T.: Short Sea shipping in Europe. Study of ship and transport volumes in the Baltic Sea, the North Sea and on Inland waterways in Europe. MAGALOG WP4 – Delivery D4.1

/2/ Stenersen, Jarslby: D4-2 Economical and Environmental effect of LNG fuelled ships
   MAGALOG WP4 – Delivery D4.2

/3/ Stenersen: D4-3 Analysis of competitive strength of LNG as ship fuel compared to fossil fuels and alternative fuels, MAGALOG report, WP4

/4/ Stenersen: D5-5 Environmental studies - assessment of air emissions in terminal ports

/5/ Stenersen: D5-1 The overall aspects of an LNG supply chain with starting point at Kollsnes and alternative sources, MAGALOG report, WP5

/6/ Harbour study – Bergen

/7/ Harbour study – Gothenburg

/8/ Harbour study – Lübeck

/9/ Harbour study, Stockholm

/10/ Harbour study - Świnoujście