Maritime Gas Fuel Logistics

Developing LNG as a clean fuel for ships in the Baltic and North Seas

Report from the MAGALOG project
December 2008

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The MAGALOG project team consisted of Mr Aksel Skjervheim of Gasnor as project coordinator, Captain Jörg Sträussler of Baltic Energy Forum as assisting coordinator, Mr Dariusz Wojcieszeck of the City of Swinoujście, Mr Stein Bjørlykke of Hordaland Oil and Gas, Mr Per Magne Einang of Marintek, and Mr Ralf Giercke of Stadtwerke Lübeck, all of whom contributed significantly to MAGALOG’s achievements. In addition to the team members, Mr Felix Dencker of Baltic Energy Forum, Mr Dag Stenersen of Marintek, Mr Ole Svendgård and Ms Trude Gullaksen of Gasnor made important contributions to work packages within the project. An important and substantial work has been done by Dr Erik Jarlsby of Gasnor, who wrote this report.

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Bergen, 30 December 2008

Aksel Skjervheim

Gasnor AS
A B S T R A C T

The shipping industry needs to reduce emissions from its use of fuels, which is a significant burden on air quality in coastal regions. A recent revision to the MARPOL Convention sets new limitations for ships’ engine emissions and fuel quality both globally and, more stringently, in the Baltic and North Seas. Much cleaner fuels than the conventional heavy bunker oils will be required. While a conversion to distillate fuels (gasoil) in regional shipping is widely anticipated, natural gas has environmental properties which are superior to any liquid petroleum fuel.

This report introduces LNG (liquefied natural gas) as a solution to the environmental challenge in North European shipping. It builds on experience gained from using LNG for coastal shipping in Norway, where this concept has been pioneered. Segments of North European shipping that are well suited to using LNG are identified and analysed. The required supply arrangements for making LNG available for ships are described. Five North European ports are studied as potential bunkering locations for LNG: Bergen, Gothenburg, Lübeck, Swinoujscie and Stockholm.

The report confirms LNG as a feasible source of large environmental improvement in North European shipping, and points out required next steps for its development. After an introductory phase, LNG is expected to become more cost effective than distillate fuels for ships, particularly in a high oil price scenario.

The study underlying the report was carried out in 2007-2008 in co-operation between eight North European partners, with support from the European Union under the Intelligent Energy Europe programme. MAGALOG (Maritime Gas Fuel Logistics) is the acronym chosen for the project. The conclusions and assessments expressed in this report do not necessarily reflect the views of the European Union or its agencies.
1 Introduction and summary

1.1 Project background

MAGALOG - Maritime Gas Fuel Logistics - is a study project undertaken by six parties in Northern Europe during 2007-2008 for the purpose of developing LNG (Liquefied Natural Gas) as a clean fuel for ships. The six MAGALOG partners include two municipal institutions (City of Swinoujscie, Stadtwerke Lübeck), a research institute (MARINTEK), a gas distribution company (Gasnor) and two energy development agencies (Baltic Energy Forum, Hordaland Olje og Gass).

Emissions from ships’ engines are a major source of airborne pollution in European port cities regions and near waterways, and a source of long distance airborne pollution. At the same time, increased use of shipping as a mode of medium distance transport is a desirable substitute for transport modes with higher global climate impacts.

Through the International Maritime Organization (IMO), nations have agreed to standards which are designed to significantly reduce emissions of sulphur, particles and nitrogen oxides for ships both globally and, in particular, within designated Emission Control Areas (ECA). The Baltic Sea and the North Sea (including the Channel) are Emission Control Areas in which increasingly stringent environmental standards will be introduced during 2010 – 2016.

The standards must be met by conversion to cleaner fuels for ships in addition to exhaust gas treatment. Meeting the requirements on the basis of liquid petroleum will require a switch to middle distillates (diesel etc) as the main engine fuel in ships. Middle distillates are more costly than traditional bunker fuels. The global refining industry is currently not well configured to supply middle distillates in the amounts that would be required for a global fuel conversion of ships.

LNG (liquefied natural gas) is proposed as an alternative solution to the challenge of cleaner shipping fuels, particularly for relatively short and scheduled trades in Northern Europe. The environmental qualities of LNG are superior to those of any liquid petroleum fuel. Its technical and operational viability as a fuel for ships has already been demonstrated in Norway, where a number of coastal ferries and other ships have operated on LNG for several years, with more under way. The use of LNG effectively eliminates the need for exhaust treatment, due to very low NOx-formation in the engines, as well as the absence of sulphur.

This report reviews the context and results of the MAGALOG project towards establishing the conditions for LNG to become a fuel for ships in Northern European waters. The project aims included the description of an overall LNG supply chain in terms of logistical, technical and financial viability, studies for individual ports, demand analysis and preparation for pilot actions for developing LNG as fuel for ships. The present report constitutes the main published output of the project.

The MAGALOG project has received support from the European Union under the Intelligent Energy Europe programme. The conclusions and assessments expressed in this report do not necessarily reflect the views of the European Union or its agencies. The project has been carried out during 2007 and 2008. The present report was finalised in December 2008.
1.2 LNG as a solution to the environmental challenge in shipping

The challenge of reducing pollution from ships

Automotive fuels and engines for road vehicles have been subjected to increasingly stringent environmental standards, which have contributed much to improved air quality in Europe. In contrast, international shipping has been subject to few such regulations, and a sharp discrepancy has developed between the environmental impact of fuel use in ships and road vehicles. International shipping remains a large user of low-quality, cheap heavy oils that have largely been phased out of onshore applications. This affects port cities as well as the general environment through emissions that are spread across large areas.

At the same time, increased use of ships as a mode of transport is desirable in order to reduce the overall climate impact and the burden on road and rail systems, particularly for goods at intermediate distances, such as cross-border movements within Europe. The general advantages of waterborne transport has been recognised and incorporated in European Union programmes.

As an international response to the environmental challenges in global shipping, the MARPOL (international convention for the prevention of pollution from ships) was revised in 2008 to set stricter standards for emissions from ships. Globally, sulphur content in fuels will be limited to 0.5% from 2020, compared to 4.5% now. This will greatly reduce not only sulphur emissions, but also particles (sooty smoke) from ships’ engines. New limitations will also apply to emissions of nitrogen oxides (NOx), which has implications for fuels as well as engines. Certain maritime areas will be designated as emission control areas (ECA), in which even stricter limitations shall apply. The Baltic and North Seas have been designated as ECAs, and more such areas across the world are expected to follow in the future.

In order to meet future limitations within the ECAs, ships must switch to much cleaner fuels than the heavy bunker oils they currently use. Low-sulphur distillates, similar to diesel fuel used in road vehicles, are widely anticipated as a required solution to the challenge. Such fuels tend to be 70% - 100% more costly than conventional heavy bunker fuel, and must be supplemented by exhaust treatment to stay within the NOx limits that will be required.

LNG as a solution to the environmental challenge

Liquefied natural gas (LNG) has for some years been used as fuel for a small but growing number of coastal ships in Norway: Ferries, offshore supply vessels and, from 2009, three
coast guard vessels. The natural gas is liquefied as LNG for the purpose of storage in ships’ fuel tanks. It has environmental properties that are superior to any liquid petroleum fuel.

Regulations and standards for safe installations of LNG propulsion systems in ships have been developed in Norway, and similar regulations are being developed also by the International Maritime Organization (IMO). The operational records of the LNG-fuelled Norwegian vessels are excellent.

LNG can be made available from small scale production and distribution systems, as is currently the case in Norway. Much larger quantities of LNG arrive in Europe every year through large-scale shipments and terminal systems, and enters the European natural gas pipeline system as ordinary natural gas.

Developing LNG as a clean fuel for ships will require logistical supply arrangements which must adequately meet the shipping industry’s requirements in terms of availability, reliability and costs. While LNG logistics has been established in a number of contexts and cases, including for supplying ships in Norway, it is generally more costly and requires different facilities than conventional oil bunkering operations. The introduction of LNG as ships’ fuel is likely to target particular shipping segments and ports that can be particularly suited to early introduction of this concept.

1.3 A market for LNG as fuel for ships in Northern Europe

In principle it may be possible to design any ship to run on LNG, provided that adequate and cost effective LNG supplies are secured. In practice, the introduction of LNG for ships will be constrained by two time-bound factors:

- Introduction of LNG-fuelled ships is more likely to happen by building new ships equipped for this, than by converting existing ships from conventional fuel to LNG. Ships usually have economic lives of 30 years or more, and it should therefore take at least 30-40 years to fully convert an established shipping segment. However one might see a more rapid switch to cleaner technologies within the ECAs, by transfer of more polluting ships to operation in outside waters.

- Some shipping segments will be better suited than others to introducing LNG early. An important reason for this is that the development of cost effective supply systems for LNG bunkering needs to be undertaken in steps over a length of time, focusing first on certain segments and ports.

The MAGALOG project has focused on the RoRo, RoPax and super fast vehicle-carrying vessels\(^1\) as particularly relevant segments for introducing LNG as fuel. The reasons for this include the following:

- The ships usually run on regular schedules for a large number of years, enabling them to use LNG continuously based on permanent bunkering opportunities in one or two ports only;

\(^1\)RoRo: Roll on roll off, i.e. vessels taking cargo on board as truck trailers or other rolling items. RoPax: Rolling goods and passengers. Super fast vessels are high speed RoPax vessels, usually travelling at more than 30 knots.
- RoRo and RoPax (including super fast) are large shipping segments in the Baltic and North Seas. The study has identified and analysed 370 such vessels, with annual fuel consumption estimated at 3.1 million tonnes, and typically around 10 ships expected to be added or replaced per year over the next several years.

- Total fuel consumption for the segments is expected to remain fairly stable in future years, as increasing cargo volumes are offset by a trend towards larger and more efficient vessels.

The first two RoRo vessels to operate on LNG have already been ordered by a Norwegian owner, intended for service between Western Norway, UK and the European Continent. For a substantial number of such LNG fuelled vessels to be ordered, LNG bunkering facilities must be established at more ports. Helsinki, Stockholm, Lübeck, Rostock, Zeebrugge and Gothenburg are identified as the busiest port for RoRo and RoPax shipping, and therefore as particularly relevant locations for developing LNG bunkering logistics.

If all Baltic and North Sea shipping in the RoRo, RoPax and super fast segments convert to LNG (something which is likely to require several decades for the reason explained earlier), the following emission savings can be indicated:

Table 1: Indicated reductions of air emissions resulting from full conversion of RoRo, RoPax and super fast vessels to LNG in the Baltic and North Seas.

<table>
<thead>
<tr>
<th>Tonnes per year reduction</th>
<th>SOx *)</th>
<th>NOx *)</th>
<th>PM *)</th>
<th>GHG **)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG vs conventional bunker fuel</td>
<td>215 000</td>
<td>140 000</td>
<td>25 000</td>
<td>1 million</td>
</tr>
</tbody>
</table>

*) Based on Table 2 and total fuel consumption 3.1 million tonnes as liquid fuel.

**) GHG = Greenhouse gases as CO2 equivalents. Includes offsetting effect of methane releases from LNG. Net reduction of GHG assumed 10%, ref. section 2.3.1, but there is a potential for achieving even higher GHG savings from LNG.

As an illustration, the NOx reduction that results from switching the RoRo, RoPax and superfast ferries to LNG is roughly equivalent to taking 15 million cars out of traffic, which is more than half of the number of cars in the United Kingdom.

In addition to the RoRo and RoPax segments, the study identifies certain other shipping segments which are potentially suited to using LNG, and may be able to use the same bunkering facilities, but without analysing these other sectors in the same detail:

- **Inland waterways shipping** is identified as another potentially relevant segment for LNG fuelled ships. The segment is highly fragmented in terms of ownership, and has a large share of old vessels. It is recognised as a desirable mode of transport for environmental and other reasons, but has not kept up with overall transport growth over the last several years. If and when successful efforts are made to revitalise this segment as a growing contributor to European transport requirements, it may be highly relevant for using LNG as fuel.

- **Local passenger boats and ferries** operate in and around most towns for which port studies have been made in the project.
- **Container feeder vessels** resemble RoRo vessels in that they tend to operate on fixed schedules, and may therefore operate on LNG supplied from a limited number of bunkering facilities.

The above list is non-exclusive, in the sense that many if not all types of ships may become potentially suited to using LNG as the bunkering supply system expands.

The study has identified the Baltic and North Sea ports that has the largest volume of traffic in the relevant ship segments, and which are therefore particularly relevant for developing LNG bunkering supplies. The largest ports in this respect are Helsinki, Lübeck, Stockholm, Humber, Zeebrugge and Gothenburg, all of which have scheduled visits by RoRo and RoPax ships which consume more than 200,000 tonnes of fuel per year.

### 1.4 Supply arrangements and costs for LNG bunkering

Depending on required bunkering patterns and local conditions (including space constraints), LNG can be brought on board a ship from a truck, a bunkering barge (or small vessel) or a fixed filling line. LNG bunkering from trucks and fixed filling lines are routinely undertaken in Norway. No bunkering barge for LNG has yet been constructed, but would require adaptations of existing techniques and equipment which are not expected to raise any difficult problems.

While LNG can be supplied by tanker truck over many hundred kilometers, LNG bunkering of RoRo or RoPax vessels will first of all be cost-effective when supplied by ship to an LNG terminal near the bunkering operation. The terminals and ships required for this will be much smaller than the large LNG terminals currently operating at Zeebrugge, Isle of Grain etc.

The size of ships that will be suited to delivering LNG for such purposes is unusual up to now, but several are under construction for deliveries in 2009 and onwards, including sizes of 7500m$^3$, 10000m$^3$ and 12000m$^3$ of LNG cargo capacity (including one ship chartered by Gasnor, the MAGALOG project co-ordinator). The operations undertaken in Norway and elsewhere also provide ample background and experience for the construction and safe operations of LNG terminals of relevant sizes. The safety related requirements for such operations are well understood in the industry, and do not present any problems of particular difficulty.

The LNG used as ships’ fuel in Norway so far has been supplied from small scale LNG production trains in Western Norway, the larges of which has an annual capacity of 80,000 tonnes. By contrast, the large LNG production plants which supply LNG into Europe from Algeria, Nigeria and other distant locations usually have production capacities upwards of 3 million tonnes. The small Norwegian plants are useful as a supply source of LNG at the present stage, and the existing and planned such plants still have some scope for increased supplies. If and when the use of LNG for bunkering becomes common in Northern Europe, it will require LNG beyond the existing and planned capacities at the small LNG plants.

As an alternative to building yet more capacity from small plants, it is recommended to develop supply arrangements from some of the large terminals that receive LNG from distant sources. Within the region covered by this study, such terminals presently operate at
Zeebrugge (Belgium) and Isle of Grain (UK), and more such terminals are in early execution stages in the Netherlands and Poland. One agreement for procuring LNG from a large Spanish terminal for supply on a small vessel has been made.

The competitive position of LNG versus liquid petroleum delivered for fuel to ships will depend much on the efficiency of the supply arrangements, and is likely to improve over time as a function of scale economies and the development of supply systems. LNG supplies are likely to have a cost structure resulting from which it will more easily be cost competitive against distillate fuel at high oil prices than at low oil prices, as indicated in the figure below. The figure and underlying analysis are discussed in further detail in section 4.5.

In the early stages of developing LNG as a shipping fuel, its economic viability may depend on finding applications and locations for which particular advantages in using LNG are recognised, as has indeed been the case for the coastal ferries and other established applications in Norway.

The establishment of small LNG terminals at bunkering ports may present certain challenges for two reasons: Space constraints, land ownership etc. may provide limitations on establishing the terminal at a location that will allow effective bunkering operations. EU rules on mandatory third-party access to terminals may result in a separation of terminal operatorship from the rest of the supply chain function, which may not in all cases be helpful towards developing the system.
Studies of future LNG bunkering at five North European ports

The MAGALOG project has conducted studies of possible LNG supplies for ships at five important harbours: Bergen, Gothenburg, Lübeck, Stockholm and Swinoujscie. These studies relate the regular shipping trades at the port to LNG as a potential fuel for future ships, and indicate potential locations for an LNG bunkering terminal. Some of the port studies also identify possible uses of LNG for non-shipping applications connected to these ports, which may in some cases provide synergy benefits to facilitate cost efficient logistics.

**Bergen (Norway)**

LNG bunkering has taken place for several years within the port district of Bergen, but not in the central port. Present LNG bunkering is for coastal ferries and offshore supply vessels, with some potential for further growth. Bergen receives 7 RoRo ships on scheduled services to the Continent, UK and other locations on the Norwegian coast, including a service for which two LNG-fuelled RoRo vessels have been ordered. Bergen has recently seen a sharp decline in RoPax traffic, reflecting a trend of more goods and fewer passengers travelling by ship.

A location for an LNG bunkering terminal will be identified in ongoing planning work by the city. Bergen is set for some further increase in LNG bunkering, but the growth potential is somewhat limited in the medium term due to limited amounts of shipping activities in the segments that can most readily use LNG.

**Gothenburg (Sweden)**

Gothenburg is a large container and RoRo port, handling 840,000 containers and 686,000 RoRo units in 2007 on increasing trends. It is also the only Scandinavian port to receive large intercontinental container vessels. It is also a large oil port (2 refineries) and an export terminal for cars. 20 vessels in the RoRo, RoPax and super fast categories call on Gothenburg within Baltic and North Sea services. They can be candidates for replacement by LNG vessels, though only 6 of them are older than 20 years. A potential also exists for using LNG for local ferries and other ships.

The Port of Göteborg and some of its large users have for several years placed large emphasis on environmental matters, and have taken a noted interest in LNG as a future shipping fuel. Several potential terminal locations have been reviewed, the most promising of which are on two adjacent islands at the Western perimeter of the port. A bunkering barge is likely to be required in combination with this terminal location.

**Lübeck and Travemünde (Germany)**

Lübeck and Travemünde are located 20km apart on the navigable river Trave. They handled 877,000 RoRo units in 2007, this being the predominant form of cargo transport there. 36 RoRo and RoPax vessels were identified as serving Lübeck on scheduled services, including 9 that are more than 25 years old and thus candidates for replacement soon. Inland shipping also calls on Lübeck, and may make use of a bunkering opportunity there.
A tentative location for a bunkering terminal has been identified, and it would require onward transport by bunkering barge or truck to the bunkering vessels. A potential is being pursued for combining an LNG bunkering terminal with a back-up facility for the city’s gas grid.

**Swinoujscie**

Swinoujscie is not a very large port for RoRo and RoPax vessels, having seven such vessels calling regularly. The port has additional traffic in bulk goods and containers. Swinoujscie however is the site for a planned large LNG import terminal, intended to supplement Poland’s natural gas imports, to be located within 2km of the main RoRo terminal. This provides an opportunity for developing cost effective supply logistics, with possible applications also for other parts of the Baltic fleets. Some small local ferries have been proposed as candidates for LNG operations when they will be replaced within a few years.

**Stockholm**

29 vessels, mainly RoPax, are identified as serving Stockholm regularly. The main routes are to Finland and other parts of the Eastern Baltic rim. 8 of these ships were older than 25 years. Ongoing and planned developments in the port facilities may strengthen the potential for using LNG, including a large RoRo and container port at Nynäshamn. This is also the location of a planned LNG import terminal, to be operational from 2011, to be supplied by ships in the small LNG size range. This facility should be capable of contributing significantly to LNG bunkering in Stockholm, but will need to be supplemented by local arrangements, as Stockholm’s port facilities are situated on 3 different locations 150 km apart.

Sweden including the Stockholm region takes a great interest in using biogas for transport fuel. The use of biogas for future local boats, of which Stockholm has many, has been proposed. LNG is already used as a supplement to biogas for some vehicle applications near Stockholm.

1.6 **Conlusions from the project**

While the present report is intended as a broad summary of issues related to LNG bunkering, the MAGALOG project work has progressed towards certain levels of practical details which are not fully reflected in this report. Following are conclusions and observations from the project:

1. Solutions for LNG bunkering for ships are identified and prepared in all targeted ports.

2. In Gothenburg, Stockholm and Lübeck, initial users are identified as well as bunkering locations.

3. Swinoujscie may offer future supply of LNG from the planned large scale LNG import terminal.

4. In Bergen LNG bunkering is in operation, and has room to expand.
5. In the Baltic and North Sea new IMO limits of SOx and NOx emissions from 2016 will make LNG as bunker fuel highly relevant and probably competitive, particularly with high oil prices and when LNG use has reached a substantial volume.

6. The long term potential for LNG as bunker fuel for RoRo and RoPax shipping in the region is around 3 million tons per year.

7. Technical solutions are available and demonstrated.

8. A degree of supportive public involvement is likely to be needed, particularly for the establishment of suitable LNG terminals at bunkering ports.

9. LNG-fuelled ships are the strongest available tool for reducing air pollution in the Baltic Sea and the North Sea.

Although the MAGALOG Project has focussed on the Baltic and North Seas, there are reasons to expect that the development of LNG bunkering in this region as highlighted by the project can be a useful precedent to similar developments also elsewhere in the waters surrounding the EU, particularly the Mediterranean if and when this ocean will be subject to similar emission limitations as are being implemented in the North and Baltic seas.

As indicated by the port study of Stockholm, the development of LNG for ships’ fuel has the potential of incorporating biogas, as a renewable energy form of similar physical properties as natural gas.
2 LNG and the environmental challenges in shipping

This chapter provides a background on the environmental challenges of air emissions from shipping and the international regulations and efforts to reduce those emissions. Also reviewed here is the general potential of LNG as a tool for achieving reduced emissions. Later chapters will review the potential for LNG more specifically in the context of North European shipping.

2.1 A short background on petroleum fuels and air emissions from ships

Concerns over air emissions from transport activity can be classified as two broad issues:

- Pollution with local and regional impacts on the environment, notably from sulphur oxides (SOx), nitrogen oxides (NOx), particulates (PM) and volatile organic compounds (VOC);
- The climate change issue, mainly associated with emissions of carbon dioxide (CO₂) and, to lesser extents, methane (CH₄) and certain other gases.

2.1.1 Pollution from ships’ fuels

In a global perspective ships are not the dominant source of pollution to air. However, since most ships follow corridors, close to shore, they a major contributors to poor air qualities in coastal regions.

“...ships give off as much sulphur as all the cars, lorries and factories in Europe put together.

By 2010, up to 40% of air pollution over land could come from ships.

Airborne sulphur is a major cause of acid rain that harms crops and buildings.

It also forms particles which are breathed deep into people's lungs and shown to increase the risk of heart attacks and respiratory problems.

Governments have made laws to achieve huge cuts in sulphur from cars, buses, lorries, factories and power stations.

But ships have evaded legislation, partly because they appeared to be a relatively minor source and partly because of the complexity of addressing an international industry based across many countries, some of them outside of Europe.” (Roger Harrabin BBC environment correspondent, June 2003)
Particulates are the most visible and directly perceived form of pollution \((\text{Figure 1})\), whereas emissions of SO\(_x\), NO\(_x\) and VOC are less visible but may harm human health, cause acidity in inland waters and other detrimental effects.

According to data submitted to the International Maritime Organization (IMO) in 1990, global shipping accounted for significant shares of airborne pollution:

**Sulphur emissions** from ships’ exhausts were estimated at 4.5 to 6.5 million tons per year - about 4 percent of total global sulphur emissions. Emissions over open seas are spread out and effects moderate, but on certain routes the emissions create environmental problems, including English Channel, South China Sea, Strait of Malacca.

**Nitrogen oxide emissions** from ships were put at around 5 million tons per year - about 7 percent of total global emissions.

Shipping’s global contributions to these emissions are believed to be no less in 2008 than 20 years ago. Global shipping activity has increased, and being an international business conducted on the high seas, it has not been subject to such stringent environmental standards as have been introduced within many national jurisdictions. In contrast, various onshore activities which generate the non-shipping emissions are increasingly regulated to reduce pollution, which has had significant and favourable effects on air quality particularly in the European Union.

As of 2008, heavy residual oil remains the predominant propulsion fuel in international shipping. As the “bottom part of the oil barrel”, these heavy oils are generally much cheaper than the lighter distillate products, with prices averaging around 50% of European quality gasoil in 2007. They are also much dirtier in terms of generating SO\(_x\), NO\(_x\) and particulate emissions when combusted.

Whereas a sulphur limitation of 50 ppm is now common for diesel in Europe, for which the refining industry has had to undertake large investments in processing equipment, international shipping may use bunker fuels with up to 4.5% (45,000 ppm) of sulphur. NO\(_x\) and particulate emissions from engine fuels depend on the engine as well as the fuel, but are generally also much higher for heavy oils than for middle distillates.

LNG is a significantly cleaner fuel than even middle distillates, producing virtually no sulphur or particle emissions and generally lower NO\(_x\).

Since the oil price increases of the 1970s, heavy fuel oil has to a large extent been phased out from onshore applications in Europe. It has been widely replaced by natural gas, and to lesser extents by LPG, coal (in power generation), biomass and district heating. The refining industry is increasingly called upon to deliver light transportation fuels, notably diesel, petrol and jet fuel, whereas stationary energy needs for space heating, industrial processes and power generation are increasingly covered by energy sources other than liquid petroleum. Refineries have installed catalytic crackers and other equipment to convert the heavy residues to light transport fuels, but are usually left with some cracked residues which they cannot easily upgrade. The lightly regulated shipping sector has become the last major outlet for those unclean heavy fractions.
2.1.2 Shipping and the climate issue

Shipping is estimated to generate 2.7% of global anthropogenic CO$_2$ emissions, sufficient to stimulate international regulatory measures intended to control those emissions (section 2.2). Alternative fuels such as heavy fuel oil and LNG differ somewhat in contribution to climate gas emissions, but the differences are generally less pronounced than is the case for pollutants as reviewed above (section 2.3).

Perhaps more importantly in the climate context, the use of ship transport for relatively short distances within Europe can substitute other modes of transport having larger climate impacts, notably road transport. It is believed that an optimal transport mix with respect to climate gas impacts would have less land transportation and more seaway transportation than is currently taking place in Europe. Shifting cargo from road to ship is an established European strategy, which is reflected in plans for the European Commission to support projects under the labels of “European maritime transport space without barriers” and “Motorways of the Sea”, for which financial support mechanisms are introduced. Increased use of short sea shipping in Europe strengthens the need for clean fuel solutions for the future shipping fleet.

2.2 MARPOL: International regulations of air emissions from ships

While the shipping sector is recognised as a significant source of air emissions, its regulation poses different institutional challenges than regulations within national jurisdictions, and has lagged behind such regulations within many nations. Important progress on regulating emissions from international shipping has recently been achieved, and provides a stimulus to considering LNG as a clean fuel for ships.

2.2.1 The international framework

The International Maritime Organization, IMO (www.imo.org), part of the United Nations system, provides the main organisational framework for addressing issues of air emissions from global shipping. The main legal framework for the purpose is the MARPOL (international convention for the prevention of pollution from ships), including its six annexes which address different kinds of pollution from ships.

Annex VI of MARPOL concerns air emissions, and a revision has recently been adopted (October 2008) by IMO’s Maritime Environment Protection Committee, which comprises representatives of some 100 national governments. Though making no specific references to LNG, the changes can have important implications for the use of LNG in ships by setting requirements that can be met with LNG. The MARPOL Annex VI revisions are designed to bring significant reductions in emissions from ships of sulphur oxides, nitrogen oxides and particulates, taking effect in steps between 2010 and 2020.

The MARPOL Annex VI revisions have been welcomed by organisations representing the shipping industry internationally, such as BIMCO, INTERTANKO and several national shipping associations. Shipping interests had previously expressed concerns that a lack of global regulations would trigger individual and disparate environmental regulations in harbour states, which would create inefficiencies and complications for international shipping.
The revised MARPOL Annex VI sets a global limitation on sulphur content in ships’ engine fuel. Before 2012 the limit is 4.50%. It will be reduced to 3.50% from 2012 and progressively down to 0.50% from 2020, subject to a feasibility review to be completed by 2018. The outcome of the feasibility review may defer the last reduction to 2025.

The Baltic Sea and the North Sea have previously been designated as Sulphur Emission Control Areas (SECA) under MARPOL (Figure 2), to be renamed as Emission Control Areas (ECA) as restrictions are expanded to cover other pollutants than sulphur. Within the ECA, more restrictive limitations on sulphur in ships’ fuels apply: Currently 1.50%, 1.00% from 1 July 2010 and 0.10% from 1 January 2015 (Figure 3).

It is expected that the refining industry will be able to supply the low-sulphur fuels required for the Baltic and North Seas, but similar reductions on a global scale would present a large challenge for the refining industry. It is expected that the reduced sulphur content in fuels will also lead to large reductions in particulate matter emissions.

For nitrogen oxides (NOx), emissions depend not only on the fuel quality but also largely on engine design and operating conditions. IMO stipulates limits on NOx emissions in g/kWh which decline with increasing engine speed in revolutions per minute. A limitation of 17 g/kWh at lowest speed was stipulated in the Annex VI before the 2008 revision. For ships constructed after 1 January 2016 and operating within an ECA, the limitation will be 3.4 g/kWh at lowest speed, approaching 2 g/kWh at high engine speed (Figure 5). By comparison, a NOx limitation of 2.0 g/kWh applies to heavy vehicles in Europe under the EURO V standards.
It is widely expected that the MARPOL limitations applicable to the Baltic and North Seas, as well as to future ECAs, will require that conventional heavy fuel oils are discontinued as ships’ fuels. Distillate fuels (gasoil range) provide a much better basis for meeting those limitations, but even distillates used in modern engines are likely to exceed NOx limitations unless supplemented by additional installations such as exhaust cleaning systems on the ships.
2.2.3 Efforts to regulate climate gas emissions from global shipping

Climate gas emissions are not specifically addressed by the October 2008 revisions to MARPOL Annex VI, but are pursued as a separate issue by IMO and its Marine Environment Protection Committee (MEPC). It is expected to result in some kind of linkage of ships’ emissions to an international permit system for CO\(_2\) emissions. Next review of the issue by the MEPC is scheduled for July 2009.

International shipping falls outside the climate gas limitations stipulated for 2008-2012 under the Kyoto Protocol. Preparations are under way for a climate gas control system to follow the Kyoto Protocol provisions after 2012, with the aim of reaching a new global climate agreement in Copenhagen in December 2009. The need to include emissions from international transport in such a system is widely recognised.

2.3 LNG as a solution to environmental challenges in shipping

This section reviews certain general conditions for applying LNG as a solution to the environmental challenges and regulatory requirements described above. LNG is described in terms of its environmental properties, technical feasibility and potential availability of LNG as a fuel for ships.

2.3.1 Physical and environmental properties

LNG (Liquefied Natural Gas) is natural gas that has been cooled to obtain liquid form, requiring a temperature near -162\(^\circ\)C. This is done for the purpose of transporting the natural gas on tanker ships constructed for that purpose, usually across long distances from producing locations to consuming regions. LNG is re-heated to gaseous form before combustion in an engine or, if imported as part of general gas supply, before inserted into the gas pipeline grid.

The main component of LNG is methane (CH\(_4\)), around 90%, with the balance being largely ethane (C\(_2\)H\(_6\)). LNG contains no components that would be toxic or cause severe pollution. The composition of LNG is generally the same as other natural gas, except that LNG has been purified of certain components of natural gas that would cause problems at the very low...
temperatures. The main physical properties of LNG are shown in Appendix 1. Physical properties vary slightly for product from different origins.

LNG (and natural gas generally) is a cleaner fuel than any other fossil fuel. This has favourable implications for the natural environment and for operating conditions in the installations using gas. Table 2 compares typical emissions from LNG and liquid petroleum products which may be applied as fuel for ships.

**Table 2: Indicated emissions to air from LNG and liquid petroleum fuels for ships**

*Emissions related to engine output in kWh. Typical medium speed engines built after year 2000 without exhaust cleaning. Emissions vary with fuel quality and engine type.*

<table>
<thead>
<tr>
<th>Fuel type</th>
<th>SOx (g/kWh)</th>
<th>NOx (g/kWh)</th>
<th>PM (g/kWh)</th>
<th>CO2 (g/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual oil 3.5% sulphur</td>
<td>13</td>
<td>9-12</td>
<td>1,5</td>
<td>580-630</td>
</tr>
<tr>
<td>Marine diesel oil, 0.5%S</td>
<td>2</td>
<td>8-11</td>
<td>0.25-0.5</td>
<td>580-630</td>
</tr>
<tr>
<td>Gasoil, 0.1% sulphur</td>
<td>0.4</td>
<td>8-11</td>
<td>0.15-0.25</td>
<td>580-630</td>
</tr>
<tr>
<td>Natural gas (LNG)</td>
<td>0</td>
<td>2</td>
<td>–0</td>
<td>430-480</td>
</tr>
</tbody>
</table>

*Source: Marintek*

Natural gas is an excellent fuel for internal combustion engines, due to several fuel properties which make it possible to design gas fuelled engines with high efficiency and low exhaust emissions. Following are technical features of natural gas used as a ship fuel:

- High methane number, allowing a high power ratio within the knocking margin;
- Easily mixed with air to obtain a homogenous charge, which burns with high flame velocity even at high air access. This avoids high peak temperatures and pressures during combustion, resulting in reduced emissions of NOx of as much as 90% in comparison with residual oil or marine diesel oil. It also allows for high efficiency.
- Contains no sulphur, therefore no SOx emissions, and no particulate matter.

LNG with the main component methane (CH$_4$) is a molecule of simple structure that burns with less CO$_2$ emissions compared to the more complex molecules of liquid fuels such as diesel. Stoichiometric combustion of natural gas yields 9.5% CO$_2$, whereas diesel yields 13.4% CO$_2$. The simplicity of the constituent molecules and absence of sulphur in natural gas also result in the avoidance of particle emissions.

**Climate impact**

An environmental downside for using natural gas as a fuel for ships is a tendency to emit more un-combusted hydrocarbons from the engine exhaust. This is related to low flame temperatures when burning a lean gas/air mixture, which keeps NOx emissions low but tends to create quenching zones. Un-combusted gas from these quenching zones ends up as hydrocarbons (mainly methane) in the exhaust.
Natural gas as an engine fuel emits significantly less carbon dioxide than petroleum fuels, as indicated in Table 2. The benefit of this in terms of the climate impact is partly offset by the tendency to emit more hydrocarbons in the exhaust. The overall climate benefit of using natural gas (LNG) as a substitute for oil is estimated at 0% - 15%, and gas engines can be designed and operated to reach the higher parts of that range. (Source: Marintek)

2.3.2 Technical feasibility of using LNG as fuel for ships

LNG is not yet widely used as a fuel for ships, but it is used sufficiently to establish a base of experience as well as an increasing base of available equipment. There are two contexts in which LNG is currently used as a fuel for ships:

- In large LNG carriers, using gas that evaporates from the cargo (boil-off gas) and alternating with the use of heavy bunker fuel when there is insufficient boil-off gas (including return journeys).

- In coastal vessels in Norway, most of which are not LNG carriers but utilise LNG either as a stand-alone fuel system or with liquid petroleum as back-up.

Use of boil-off gas in large LNG carriers is in most cases based on steam turbine propulsion, which is a less effective propulsion technology than internal combustion engines. Recently, internal combustion engines with dual-fuel capability (natural gas and fuel oil) have been introduced which more effectively utilise the LNG boil-off, supplemented with regular bunker fuel.

Figure 5: The "Bergensfjord", an LNG powered coastal ferry operating in Norway since early 2007. Photo from Fjord1
The coastal vessels using LNG in Norway as of late 2008 include 6 car ferries (Figure 5), 3 supply ships for offshore petroleum installations (Figure 6), 1 coast guard vessel and 1 small LNG carrier. The number is set to exceed 20 LNG-powered ships including vessels which are currently (2008) on order or planned. Some of these vessels use engines with spark ignition. Other engines use ignition by a small diesel portion in the fuel, and can alternatively run on diesel oil alone.

Wärtsilä and Rolls Royce Marine are currently the leading manufacturers of gas or dual-fuel powered engines for ships (Figure 7). In addition, a number of established diesel engine manufacturers have developed or are developing gas versions of their engines. The engines currently installed are of the gas-electric concept, i.e. they generate electric power which is then applied to electric motors providing the propulsion. The ships’ engines from Wärtsilä and Rolls Royce have similarities with engines installed for combined heat and power plants at numerous onshore locations.

Studies carried out at MARINTEK indicate additional costs for a gas fuelled ship of 10-15% of the total cost of a conventional ship. For a typical RoRo ship of 5600 DWT, the additional costs for a ship capable of alternating between LNG and liquid fuel (HFO or diesel), is estimated €3.2 million.

This cost difference indicated in may be reduced in the future as more such ships are built and by selecting single-fuel LNG propulsion rather than dual-fuel capability. The comparison in the table is made against a conventional engine operating on heavy fuel oil. Future oil-fuelled
engines designed to meet MARPOL Annex VI requirements in the Emission Control Areas (section 2.2), are likely to run on distillates not HFO, and to require exhaust cleaning systems to keep emissions within permitted limits. The extra costs that this will require, are also likely to make the cost comparison with LNG fuelled engines more favourable for LNG than indicated above.

**Design regulations for LNG powered ships**

The Norwegian Maritime Directorate in 2002 issued a regulation for ships with internal combustion engine(s) fuelled by natural gas.\(^2\) The regulation was a result of pioneering work undertaken in co-operation between the authority and ship owners. The regulation concerns the construction and operation of LNG fuelled ships under Norwegian registry. It provides for passive safety measures, protection of the gas related equipment against mechanical and other hazards, arrangement of the bunkering equipment, required ventilation, fire protection, structural strength, operations and training.

The Norwegian regulation from 2002 was preceded in 2001 by a set of rules on gas fuelled engine installations by Det Norske Veritas, a classification bureau (DNV 2002).

The International Maritime Organization (IMO) has initiated work on developing provisions for gas-fuelled ships, following a Norwegian proposal. *Draft Interim Guidelines covering gas-fuelled ships* are in a process of continued work and review by the Subcommittee on Bulk Liquids and Gases (BLG). An intent of issuing such interim guidelines in 2009 has been expressed.

### 2.3.3 Availability of LNG

There are two alternative concepts for supplying LNG that can be used as ships’ fuel:

1. By producing LNG from natural gas within reasonable distance from bunkering locations, i.e. within Northern Europe (Small scale LNG);
2. By purchasing LNG that is imported to Europe from distant sources (Large scale LNG).

To date, the LNG supplied as ships’ fuel in Norway has originated only as small scale LNG, but there are reasons to expect supplies from large scale LNG to become increasingly relevant in the future. This will establish the potential for supplying large sections of North European shipping with LNG for fuel.

\(^{2}\) FOR 2002-06-17 nr 644: Forskrift for lasteskip hvor forbrenningsmotorer drives med naturgass.
As of 2008, there are four LNG production plants at three locations in Western Norway with a combined annual capacity of 150,000 tonnes, and individually ranging from 10,000 to 80,000 tonnes (Figure 8). A new plant is being constructed with an annual capacity of 300,000 tonnes. These plants and their associated logistical arrangements are appropriately referred to as small scale LNG, since most LNG production plants that form the basis for the bulk of international LNG trade have annual capacities upwards of 3 million tonnes. They are supplied with natural gas by pipelines from North Sea fields, which is purified and liquefied in the LNG plants.

The Norwegian small scale LNG plants have been constructed not only for the purpose of supplying ships, but for supplying onshore users such as industrial plants, as an alternative to building pipelines. Pipelines is the standard solution for supplying natural gas globally except for very long distances, but would be prohibitively expensive in large parts of Scandinavia given the rugged terrain and limited volume offtake prospects, for which reasons small scale LNG has a particular relevance there.

Supplies to ships currently occupy some 25% of the capacity of existing Norwegian small scale LNG plants. The new 300,000 t/y plant being constructed at Risavika, near Stavanger, is believed to have significant yet uncommitted capacity that may possibly be applied to supplying ships. Several parties have expressed intents of constructing more LNG capacity in Norway if supported by market conditions. Gasnor (one of the MAGALOG partners) owns some 90% of present small scale LNG capacity in Norway, whereas a different group will own the new 300,000 t/y plant.

Minor capacities for producing LNG on a small scale exist in certain other European countries, including Scotland, Poland and Russia, but are not known to have been applied as ships’ fuel.
In 2007, only 0.1% of the LNG handled in Europe originated from the small plants in Norway. The other 99.9% were imported to Europe from distant origins, with Algeria, Nigeria, Qatar, Egypt and Trinidad as the largest sources. Spain and France were the largest European importers of LNG, accounting for 45% and 24% of total imports (calculated from BP 2008).

The LNG imported to Europe is moved on ships having a cargo capacity usually upwards of 125,000 m³ (corresponding to 850 GWh of energy), and is received at correspondingly large terminals such as Zeebrugge in Belgium and Isle of Grain in England. The LNG is generally regasified at these terminals and fed into the main natural gas pipeline grid, thus supplementing gas arriving by pipeline from Russia, Algeria and European sources. Natural gas imported as LNG accounted for 12% of gas consumption in the EU in 2007 (BP 2008).

Figure 9 shows the locations of large LNG import terminals in Europe, as well as three terminals for LNG exports in Algeria and Northern Norway. In addition to the terminals currently in operation or in construction shown in Figure 9, several additional LNG import terminals have been proposed and are in various stages of planning, including projects in Poland, the Netherlands and France.
Loading LNG from large terminals may emerge as an attractive supplement to small scale LNG for supplies as ships’ fuel, and may provide added scope and security of supply as well as cost benefits particularly as volumes grow. In MAGALOG’s assessment this will be feasible, though requiring that certain challenges must be overcome as reviewed in chapter 4.

**The global availability of natural gas**

Since LNG is refrigerated natural gas, its long term availability depends ultimately on global gas reserves. The global resource situation for natural gas is better than for oil in terms of reserves-to-production ratio and geographical spread. According to BP’s Statistical Review of World Energy (*BP 2008*), the world’s proven gas reserves stood at 177 trillion Sm³ at the end of 2007. This is 60 times the world’s gas production during 2007.

By comparison, the global oil reserves were similar to gas reserves by energy content, but were only 42 times the world’s oil production during 2007. While 61% of proved oil reserves were in the Middle East, which has given cause for concern over the political exposure of global oil supply, the corresponding number for natural gas was 41%. Russia is the world’s largest reserve holder and producer of natural gas, a position which Saudi Arabia holds for crude oil.

Norway, which is Europe’s largest producer of both oil and natural gas outside Russia, currently has increasing gas production but declining oil production. Norway’s proved gas reserves at the end of 2007 were 33 times its gas production during that year.

**2.4 Summary: LNG and the environmental challenges in shipping**

The international shipping industry faces a large challenge in reducing air emissions from its use of fuels. The challenge is embodied in MARPOL Annex VI, as revised in 2008, mandating increasingly stringent limitations on sulphur and NOx emissions globally, and with the Baltic and North Seas designated as Emission Control Areas with particularly stringent restrictions. LNG as a ships’ fuel has environmental qualities which will not only meet, but clearly exceed the most stringent standards, and which would contribute greatly to improved air quality in port cities. The technical feasibility of LNG as a ships’ fuel has been demonstrated in the Norwegian coastal ships that run on LNG.

LNG for ships can be supplied from small scale LNG systems, which has been developed in Norway, and from large scale LNG trade linked to major import terminals. The following chapters will further assess these possibilities and the potential market for LNG as ships’ fuel in a North European scope.
3 A potential market for LNG for ships in Northern Europe

This chapter provides an assessment of a potential market for LNG for ships in Northern Europe. The approach applied is described in section 3.1, followed by a discussion of the segments of shipping that form the basis for assessing the potential market (section 3.2). A potential for LNG utilisation in ships is presented in section 3.3, and conclusions drawn in section 3.4.

The main analysis presented in this chapter is based on an underlying report provided by MARINTEK as part of the MAGALOG project.

3.1 Assessing the potential market: Approach

While one may, at least in principle, envisage more or less the entire global shipping fleet fuelled by LNG at some point in the future, the MAGALOG project is directed at goals that can be achieved in manageable steps: To incrementally expand the scope of LNG fuelled shipping in terms of shipping segments, geography and number of ships. The purpose of this chapter is therefore to describe a potential for LNG-fuelled shipping based on conditions that can be identified and established in a reasonable time frame.

The time horizon selected for this study is 0 – 15 years. Ships usually have an economic life of 30 years or more, and existing fleets of ships are distributed over such age spans. Enabling a ship to run on LNG requires major preparations that can generally be made most effectively while constructing the new ship, while retrofitting an existing conventionally fuelled ship to run on LNG is likely to face more difficult economics in most cases. The MAGALOG project does not anticipate such retrofits to take place to any large extent (section 3.3.4). As a consequence, no existing category of ships can be expected to convert fully to LNG over the next 15 years. Instead, the project focuses on categories of ships in which a preference for LNG can be established within few years, resulting from which a substantial number of ships running on LNG can realistically be obtained within 15 years (2023).

The limited development of LNG as ships’ fuel that has been achieved to date, has focussed on certain narrow segments of the shipping industry that presented themselves as particularly suited to start utilising LNG at an early stage. The first such segment was coastal ferries (the Glutra from 2000; 5 more ferries from 2007), followed by offshore supply vessels and, from late 2008, coast guard vessels. The geographical scope is still (2008) limited to Norway.

For LNG fuelled shipping to expand, several hurdles must be overcome with regard to the types of ships that will use it:

(a) Engine technology and ship design for LNG propulsion;
(b) Supply system for adequate, practical and secure availability of LNG for the ships;
(c) Economic competitiveness against alternatives.

Item (a) will not be a major focus of this report’s assessment, partly because the MAGALOG project has selected another focus (logistics), but partly also because significant achievements have already been made with regard to LNG fuelled engines and ship design which, together
with further developments in progress at several manufacturers, give reasons to assume that this will not be an enduring obstacle.

Concerning item (b) above, it is recognised already at this stage that making LNG more widely available will require substantial investments in supply arrangements. It will not, in a foreseeable future, be as widely available as liquid petroleum products are today, but can be made more selectively available at locations where there will be sufficient demand to justify the cost of supply arrangements, thus addressing also item (c) above. This forms an important premise for assessing the potential market, i.e. identifying segments of ships that can be designed to operate on LNG without requiring LNG to be available beyond a somewhat limited selection of bunkering locations, at least in the next several years.

The study in this chapter is geographically limited to the Baltic and North Seas, but contains also a discussion concerning shipping on inland waterways in Europe.

3.2 Shipping segments potentially suited to LNG (0 – 15 years time frame)

This section identifies and describes segments of ships which have been selected for the MAGALOG study as suited to LNG as fuel.

3.2.1 Criteria for ships potentially suited to LNG

Based on the premise developed above that LNG supplies to ships can be made available at a limited but increasing set of bunkering locations, as well as the environmental considerations from chapter 2, the type of ships that can be considered potential LNG users in a 0 – 15 years time frame should satisfy the following criteria:

(i) Serving regular sailing patterns, allowing for repeated bunkering at a limited number of locations;

(ii) Significant environmental benefits from clean fuels;

(iii) No particular constraint to feasibility of installing LNG fuel system.

3.2.2 Shipping segments potentially suited to LNG

Following is a non-exhaustive list of shipping segments in which one may expect to find a significant number of ships satisfying the criteria above:

**Established for LNG use in Norway:**
1. Coastal ferries for vehicles + passengers;
2. Offshore supply vessels for North Sea petroleum activities;
3. Coast guard and other vessels in public service.

**Not yet established for LNG use:**
4. Container feeder ships;
5. Ships for rolling cargo (RoRo) in international liner service;
6. Vehicle and passenger ferries (RoPax) in international liner service;
7. High speed (‘super fast’) vessels for vehicles and passengers;
8. Barges and other cargo vessels for inland waterways;
9. Small bulk and tanker vessels;
10. Passenger boats;
11. Tug boats and ice breakers;
12. Fishing boats.

MAGALOG’s work has focused on segments 5, 6 and 7 above, i.e. RoRo, RoPax and super fast vessels in scheduled service between ports mainly within the Baltic and North seas. Comments are also provided on segment 8, the inland cargo vessels. Segments 3, 10, 11 and 12 are potential LNG users but clearly smaller in fuel consumption volume than the cargo segments, and therefore not focused in the present analysis. Segment 4, container feeder ships, have many operational similarities with RoRo vessels, and there is a significant amount of scheduled traffic in feeder vessels. They have not been specifically included in this study, but the results concerning RoRo ships are believed to be extendable to container feeder ships.

3.2.3 Cargo ships in liner service (RoRo etc)

RoRo (Roll on, roll off) vessels carry cargo on wheels, such as road trailers with or without the truck. They usually do not carry the truck driver, and cargo is usually brought on board and on shore by port crew. Some RoRo vessels also carry containers as deck load.

![Figure 10: Loading a trailer onto a Ro-Ro vessel. Photo from Finnlines.](image)

The study has identified 182 cargo ships serving ports in the Baltic and North Seas on regular schedules. Some of them also serve ports outside this area, but the study does not include long distance trade such as container ships connecting Europe and Asia. Many of these ships are RoRo (Roll on / Roll off) ships having also the capacity to carry containers on deck and a range of cargo types in hold (Figure 10).

The RoRo ships identified have an average engine effect of 12,000 kW. Typical operating speeds are 15-20 knots. One-third of these ships were more than 20 years old, and a substantial need for replacements will arise in the next several years.
The first order for RoRo vessels with LNG propulsion was placed in September 2008, as Sea-Cargo AS ordered two such vessels for deliveries in 2009 and 2010 from a yard in India. The 5600 tonnes dwt ships will have a single Rolls-Royce spark-ignition gas engine and 2x240 m³ LNG tanks (*Figure 11*). They are intended for use between Western Norway, UK and the Continent.

*Figure 11: LNG-fuelled RoRo vessel ordered for North Sea trade. Illustration from Sea-Cargo AS*

### 3.2.4 Passenger and vehicle carriers (RoPax)

The term *RoPax* (Rolling goods and passenger vessels) is often used as a subset of RoRo vessels. In this report the terms are used for different vessel types: RoRo vessels do not carry passengers (also not the truck drivers), whereas RoPax vessels do.

The study has identified 189 ships carrying vehicles and passengers, serving the Baltic and North Seas on regular schedules, including 26 high speed vessels. They carry trucks, cars and passengers, and other goods in some cases. No orders for LNG-fuelled vessels in this category have been placed as of late 2008.

The identified regular RoPax ships (*example in figure 12*) have installed engine power averaging 20,000 kW, usually operating at speeds around or above 20 knots, depending on schedule requirements.

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3 The category is defined not to include short range domestic routes, such as the coastal ferries shown in Figure 4.
3.2.5 High speed (“Super fast”) vessels for vehicles and passengers

High speed vessels are used for carrying cars and passengers across the English Channel and several routes in the Kattegat and Baltic Sea, typically travelling at speeds above 30 knots (example in figure 13). The identified vessels had average engine power of 25,000 kW. Many of these vessels have dual or triple hulls and a lightweight construction. Many use gas turbines fuelled by diesel oil for propulsion, because of the compact size and low weight of turbines in comparison with reciprocating engines.

Most of the superfast vessels currently operating in Northern Europe, were constructed in the 1990s. Few such ships have been launched after year 2000. Replacement of existing superfast vessels should not be required to any large extent over the next 10 years, but new such vessels may be launched in replacement of existing conventional RoPax vessels where higher speed is desirable, or in response to increasing demand.

Although no such LNG-powered vessel has been ordered as of 2008, LNG is expected to have particular relevance for this category of ships. Turbines are generally well suited to using natural gas as fuel. Most existing vessels were ordered at times of oil price below $20 per barrel. Without switching to a clean fuel these ships will be environmentally challenged not least due to the high fuel consumption in relation to the amount of cargo carried.
3.3 **RoRo, RoPax and super fast ships as a potential market for LNG**

This section presents a quantified analysis of the potential for using LNG as a fuel for cargo and passenger ships in the Baltic and North Seas.

### 3.3.1 Methodology

The MAGALOG study has surveyed cargo flows in Northern Europe on regular routes, corresponding mainly to the RoRo, RoPax and super fast ships, with respect to calls at port, sailing times, frequencies, operators, fleet composition and operators’ development plans.

As a basis for assessing the possibilities of LNG powered vessels and an adequate LNG distribution network, the survey established data on the following parameters:

- Number and details of vessels operating at scheduled routes in short sea shipping;
- Annual passages on these routes;
- Estimate bunker fuel volume on these routes in the Baltic and North Sea area;
- Annual amount of polluting emissions on these routes (CO2, NOx and particles).

The transport volumes and trade patterns in the areas subject to this study are well documented in previous studies such as the Baltic Maritime Outlook (SAI et al 2006). The vessels operating in the area are monitored and documented through the “Safe Sea Net” system of the European Maritime Safety Agency (www.emsa.eu.int), which covers vessels larger than 300 gross tonnes as well as certain smaller vessels. The list of the vessels is not 100% accurate, but sufficient for recommendations.

The survey is based on open sources (public databases, ship owner’s home pages etc), which have been accepted at face value. It represents the situation as of 01.01.2007, and though some later changes have been observed, no significant change in the overall situation is seen. Voyages carried out by alternating vessels on short term basis are incorporated in the numbers for the vessels mainly operating the routes. Seasonal variations in routes are compensated.

An average fuel consumption of 185 g/kWh has been assumed for liquid petroleum fuels in ships’ engines. In reality, this varies between 160 g/kWh in modern, highly efficient engines and 210 g/kWh in older engines. 85% engine power utilisation has been assumed as operational speed.

The study has also considered the potential for shifting from land-based transport to seaborne transports. This is an established policy goal for the European Community in order to address problems of congestion, emissions and other issues related to road transportation (European Communities 2001).

Potential ports for establishing LNG distribution infrastructure are identified, based on the survey results and predictions of future development trends.
3.3.2 Fuel consumption and developments of RoRo and RoPax shipping

Figure 14 show "snap shots" of shipping activity in the North Sea and Baltic Sea, including all types of shipping as registered by satellite.

![Figure 14: Snapshots of shipping activity in the North Sea and Baltic Sea. Source: HELCOM, Finland.](image)

Liner RoRo and RoPax shipping in the Baltic and North Seas are estimated by the MAGALOG project to consume 3.1 million tonnes of heavy bunker fuel per year, of which some 60% for the RoPax ships (Table 3).

<table>
<thead>
<tr>
<th></th>
<th>Baltic Sea</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoRo ships</td>
<td>557 000</td>
<td>1 202 000</td>
</tr>
<tr>
<td>RoPax and super fast ships</td>
<td>719 000</td>
<td>1 904 000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1 276 000</td>
<td>3 106 000</td>
</tr>
</tbody>
</table>

Table 3: Annual bunker fuel consumption, RoRo and RoPax shipping

*Baltic and North Seas. Tonnes, 2007.*

The fuel consumption in each sea is estimated to represent the fuel burned by ships while sailing on that sea regardless of the voyage port of origin and destination.

The Baltic Maritime Outlook *(SAI et al. 2006)* pointed to several development trends which have been observable for the Baltic region over the last several years and were expected to continue:

- An increasing share of the transport of general cargo is performed by RoRo and container carrying vessels in liner service.
- The trend in ship size is towards bigger vessels with a focus on cargo.
- The amounts of landed cargo increased by 3% per year during 2000-2004. The number of port calls however decreased by 2% per year, due to increasing size of ships.

The Baltic Maritime Outlook also noted an expectation of stronger-than-average growth in maritime transportation in the Baltic due to strong growth in Eastern economies and initiatives to transfer cargo from land to sea. For the period 2003 – 2020 it projected 85% growth in total
maritime transports within the Baltic Sea region, and somewhat lower growth in maritime transports into and out of the region.

The service life of a ship is usually assumed to be around 30 years, although some ships remain in service for some time beyond that age. The average age of the RoRo and RoPax ships was 15.5 years, and one-third were older than 20 years (Figure 15).

The MAGALOG project makes the following expectations for the development of RoRo, RoPax and super fast shipping in the region during the decade starting in 2010:

- Freight quantities will continue to grow. The number of ships and their fuel consumption will however be stagnant due to the offsetting effects of larger and more efficient ships.
- Some 10 new ships per year will be delivered for liner RoRo and RoPax services in the region.

### 3.3.3 Ports with significant liner traffic

For the purpose of assessing ports in which it may be relevant to develop LNG bunkering logistics, the ships and number of calls for scheduled lines in the RoRo, RoPax and super fast categories were identified for each port. Based on information on the ships and their scheduled services, their annual fuel consumption can be estimated and associated with their ports of call.

Helsinki, Stockholm, Lübeck and Rostock are the busiest Baltic ports for these categories of shipping, all with more than 6,000 calls per year. The North Sea ports were generally less busy for this shipping segment, led by Zeebrugge, Gothenburg and the Humber region.
3.3.4 The process of converting to LNG

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 to day 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.

3.4 Inland shipping as a potential market for LNG

The potential for developing LNG-fuelled ships for traffic on rivers, canals on lakes in Europe is briefly reviewed in this section.

According to the report ”Prospects for Inland Navigation within the Enlarged Europe” (Buck Consultants International et al. 2004), there were more than 20,000 vessels and barges registered for inland waterways transportation in Europe (Figure 16). More than 450 million tonnes of cargo were moved on European inland waterways in 2005, of which some 90% in Germany, Netherlands and Belgium. This is a large contribution to meeting overall transport requirements in Europe, and provides important benefits of reduced air pollution and reduced burden on infrastructure compared to the alternatives of rail and road transport.

There are however indications that the inland transportation sector is lagging behind other economic and environmental developments:
- Slow growth: Measured as tonne-kilometres, inland waterways transportation increased by only 15% from 1996 to 2004, whereas road transport increased by 55% over the same period.

- Old fleet: The average age of self-propelled dry bulk ships for European inland waterways was 37 years in year 2005; however, the engine and other important equipment has in many cases been replaced (European Communities, 2006).

- Fragmented fleet structure including a high proportion of single-vessel owners/operators, many of whom have limited financial capacities for innovation and investments.

**Figure 16: The Rhine Corridor of European inland waterways.**

Map and photo: INE

www.inlandnavigation.org

Distillate oils such as Marine diesel oil are common fuels for inland vessels. Such fuels have better environmental properties than the heavy fuel oils commonly used in ocean shipping. If inland vessels are to comply with similar environmental requirements as those applicable in the Emission Control Areas under MARPOL (section 2.2 above), they will need to convert to higher-quality and higher-cost grades of gasoil, or to a cleaner fuel such as LNG.

The European Commission’s NAIADES programme (European Communities 2006) highlighted a need for modernisation and innovation in inland waterways transport in order to achieve its growth potential and associated environmental benefits.

As part of the IPST programme, MARINTEK proposed designs for a new vessel for inland waterways transport (Lindstad and Uthaug 2003; Hamworthy KSE AB et al 2003). With a 2050 tonnes payload and 1400 kW main engine power to reach 28 knots operating speed, the vessel was intended for conventional diesel propulsion, but can readily be modified for LNG.

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*Improved Port/Ship Interface*
propulsion. This would allow faster and more extensive inland waterways transport as an alternative to road and rail, while avoiding increased emissions from inland ships, which often travel near areas of large population.

As an illustration of magnitudes, the MAGALOG project has estimated that the addition of 120 such inland vessels per year would offset the projected annual growth in road transport projected in the EU for the next several years. While not regarded as a realistic expectation as such, along with the numeric size and advanced age of the inland waterways fleet it provides an indication that this segment has the potential of developing as a substantial market for LNG for ships’ fuel if the required conditions are established with regard to logistics, cost competitiveness and design.

For the use of LNG as fuel for inland shipping, national or European standards will need to be developed. The standards and regulations developed for Norwegian shipping (section 2.3.2) may be a useful reference in this regard.

The MAGALOG project has elected not to pursue the use of LNG for this segment beyond pointing out that a significant potential is deemed to exist in terms of volume as well as environmental benefits.

3.5 Summary: A potential market for LNG for ships

Short sea liner shipping, represented chiefly by the RoRo, RoPax and super fast segments of ships, has structural features that may be conducive to a major conversion to LNG as fuel, based on conditions that are already present or can be established shortly. The first order for LNG-fuelled RoRo ships for the North Sea was placed in September 2008.

The annual fuel consumption for such ships in the Baltic and North Seas is 3.1 million tonnes, not expected to change much over the next several years. This quantity corresponds to 5% of European LNG imports during 2007.

Conversion to LNG can be accomplished by building new ships in response to new demand or as older ships need replacement. This is expected to occur at some 10 ships per year over the next decade.

Helsinki, Stockholm, Lübeck, Rostock, Zeebrugge and Gothenburg are identified as the busiest port for RoRo and RoPax shipping, and therefore as particularly relevant locations for developing LNG bunkering logistics.

Inland waterways shipping is highlighted as another potentially relevant segment for LNG fuelled ships, if successful efforts are made to revitalise this segment as a growing contributor to European transport requirements.
4 Supply arrangements and costs for LNG for shipping

This chapter describes the arrangements necessary for making LNG available for bunkering for North European shipping. Section 4.1 through 4.4 describe the elements of the supply system, progressing in reverse order from the bunkering operation back to the origin of product. Indications of costs are given in section 4.5. Section 4.6 discusses the development of LNG supplies for bunkering as a sequence of decisions dependent on certain conditions.

4.1 Bunkering operation

Bunkering operations concern the transfer of LNG into the fuel tank of a vessel, i.e. the final stage of the supply process. Table 6 provides indications of the amount of LNG required per week for different types of vessels.

<table>
<thead>
<tr>
<th>Ship type</th>
<th>kW engine</th>
<th>m3 LNG per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoRo</td>
<td>12 000</td>
<td>400</td>
</tr>
<tr>
<td>RoPax (regular)</td>
<td>20 000</td>
<td>700</td>
</tr>
<tr>
<td>Super fast</td>
<td>25 000</td>
<td>900</td>
</tr>
</tbody>
</table>

ASSUMPTIONS: Average 75% of time spent at sea; 85% average engine utilisation. kW engine sizes are close to averages for existing vessels in the Baltic and North Seas. 1 m3 of LNG corresponds to 0.45 tonnes.

Depending on circumstances in the bunkering port and the quantities of LNG to be supplied, three types of bunkering arrangements may be considered:

(1) Bunkering from tanker truck
(2) Bunkering from tanker barge
(3) Bunkering from fixed filling lines.

The first and third alternatives are currently being used for LNG propelled vessels in Norway. Such bunkering operations have been carried out for several years without any major problem, but certain possibilities for improvement are recognised.

4.1.1 Bunkering from tanker truck

3 out of 6 coastal ferries currently running on LNG in Norway (2008) are regularly fuelled from tanker trucks parked alongside the vessel. Bunkering usually takes place at night when the ferries are out of service (Figure 17). A tanker truck can deliver 55 m3 of LNG (1300 GJ of energy). The LNG is pumped from the tanker truck, and the loading operation from one tanker is usually accomplished in 1 1/2 hours. The larger ferries have 2 x 120 m3 of LNG tanks, and can therefore receive several tanker loads of fuel if necessary.

Bunkering from a tanker truck is normally less speedy than other alternatives, but has the advantage of flexibility. It requires that the tanker truck can be parked on the jetty next to the ship with a possibility of connecting via a flexible hose, and be shielded from other operations while bunkering is ongoing.
4.1.2  Bunkering from tanker barge

Conventional bunker fuels are commonly delivered to ships from a barge, which may be self-propelled ships or barges dependent on towage (Figure 18).

LNG bunkering from a barge may provide for efficient bunkering of vessels at different locations around a harbour area. If the ship is moored alongside, the bunkering operation will be carried out from the other side of the ship.
No LNG bunkering barge has been commissioned as of 2008. A tentative study has indicated that feasible designs for such barges can be made.

4.1.3 Bunkering from fixed filling lines

If ships can be bunkered predominantly at one location, and there is available space to install permanent LNG tanks within short distance\(^5\), then bunkering from fixed onshore tanks is a relevant option. This is currently done at two locations in Norway: At Halhjem, where 3 LNG-powered ferries are bunkered (Figure 19); and at the Coast Center Base, where offshore supply vessels running on LNG are bunkered.

![Figure 19: LNG bunkering arrangement from permanent tanks for the coastal ferries at Halhjem, Norway. Photos: Gasnor](image)

At Halhjem ferry port, the ferries are bunkered from 2 x 500 m\(^3\) fixed tanks via a 150 m insulated LNG pipeline. The connection of the shore pipe system to the ship’s fuel tank system occurs via a flange. The ships have 2 x 120 m\(^3\) LNG fuel tanks. With the pumping capacity and tank pressure conditions installed at Halhjem, bunkering occurs at around 100 m\(^3\) per hour. It will be possible to design systems for faster bunkering if required.

4.2 LNG terminal at bunkering port

An LNG terminal at a bunkering port is a local facility from which LNG can be supplied for delivery to ships by truck, barge or permanent filling lines (section 4.1). Such an LNG terminal will be a much smaller installation than the large-scale LNG import terminals such as Zeebrugge etc (section 2.3.3).

4.2.1 Functions of an LNG terminal at bunkering port

An LNG terminal serving bunkering operations must provide the following functions:

---

\(^5\) A distance of 250 m is indicated as a practical maximum between storage tank and ship’s side
(1) Receipt of LNG, most likely by ship delivery, but also with possibility of truck delivery. Rail delivery may also be considered in the future, if any large North European LNG import terminal will install rail export facilities for LNG (not yet the case).

(2) Storage for a quantity of LNG which will allow for the required bunkering operations with suitable delivery intervals.

(3) Supply of LNG for the required bunkering operations; i.e. bunkering by truck, barge or permanent filling line (section 4.1).

(4) If the terminal will also serve to provide gas for local non-transport applications, for instance, a back-up or peak-shaving function for local gas supplies, then re-gasification and pipeline offtake must be provided for.

(5) The terminal must be located, constructed and operated to comply with all applicable regulations and generally to ensure a high level of safety.

4.2.2 Location of LNG terminals

Two considerations guide the selection of location for an LNG terminal for bunkering purposes:

- The need to efficiently provide the required functions of the terminal (section 4.2.1);

- Availability of suitable locations with regard to space requirements, safety zone, accessibility, city planning regulations and compatibility with other local land use.

The second consideration will in some cases impose constraints on where terminals may be located, and lead to locations which are less than ideal with regard to the first consideration. The issue is further discussed with respect to particular ports in chapter 5.

There are mutual interdependencies between the constraints on locating an LNG terminal and the type of bunkering operations that can be performed (section 4.2.1), which are briefly reviewed here:

Among the bunkering operations identified above, bunkering by truck is least dependent on having a local terminal, as long as LNG can be loaded at a point of supply within suitable driving distance. This suitable driving distance is not sharply defined and depends on the quantities and regularity of LNG to be supplied; the distance should be short if quantities are large. For one of the Norwegian ferry operations, LNG is supplied by truck over a distance of 80 km requiring on average close to 1 truck per day, which is clearly within practical limitations and does not cause any particular difficulty.

Bunkering by barge can be better suited to relatively large quantities, but is more dependent on having a nearby terminal than is the case for truck bunkering. Barges generally operate within shielded waters, and must therefore receive and supply LNG within a port area that can be covered without crossing open seas.
Bunkering from a fixed filling line requires an LNG terminal to be located close to the point of bunkering (indicated as 250 metres). If such a terminal cannot be established sufficiently close to the regular berth of ships to be bunkered, then fixed line bunkering would require that ships relocate to another berth near the terminal for the purpose of bunkering, which is likely to be constrained by scheduling considerations for the ships.

4.2.3 Receipt and delivery of LNG at a terminal

An LNG terminal requires facilities for berthing a ship that will supply the LNG to the terminal, transfer of LNG from the ship to storage tanks, and for unloading trucks to the terminal. The same facilities can usually be applied in the reverse, i.e. for delivering LNG from the terminal as fuel to ships, a bunkering barge or trucks.

Jetty

A quay or jetty is needed for receiving LNG supplied by ships and, preferably, also for bunkering purposes. One ship that is intended to supply LNG to terminals, the “Coral Methane” (section 4.3), has a length of 118m, breadth of 18.6m and draft of 6.3m laden. The terminal must be accessible by at least this size of vessel, and preferably also larger vessels. Large RoRo vessels operating in the region have lengths of around 200m and maximum mean draughts around 7.5m, and the ability to load such vessels from fixed lines directly from a terminal would be an advantage.

In many cases an existing jetty can be fitted with LNG loading and unloading equipment, which can be installed so as to minimise or avoid any interference with other operations when not used for LNG operations. It may be relevant in some cases to consider a simplified jetty solution, such as using Duc d’Albes for support, in order to keep investment costs low.

Figure 20: Flexible hoses for loading and discharging the 1100 m³ LNG carrier "Pioneer Knutsen". The two hoses are for LNG transfer and vapour return. Photo from Gasnor.
Transfer lines and ship-shore connection

LNG is transferred between the ship and the storage tank(s) in an insulated pipeline, usually accompanied by a vapour return line. The same pipeline may be used for the supply of LNG from a LNG freighter to the terminal and the bunkering of a vessel from the terminal. Due to the large temperature differential between the LNG (-162°C) and ambient temperature, the distance between the terminal and the point of bunkering at the jetty should be short in order to minimise heating of the LNG. The pipeline between the quay and the terminal can be placed in an underground culvert in order to avoid interference with other activities.

The connection between the transfer line and the ship can be accomplished by flexible hoses (Figure 20). This is a viable solution for the relatively modest flow rates of LNG likely to be required for bunkering operations. Terminals handling large LNG vessels employ hoses mounted on loading arms.

Truck loading and unloading

An LNG terminal for bunkering purposes should have the capability of receiving as well as delivering LNG by tanker truck. Facilities for loading and unloading tanker trucks have been installed at a number of small LNG terminals in Norway and elsewhere. Flexible hoses are used for the transfer between the truck and the terminal (Figures 20, 21).

Figure 21: Loading operations for both ship and tanker truck at the Kollsnes LNG plant, Norway. Photo from Gasnor.

4.2.4 Storage tanks

Storage tank(s) for LNG tends to be the predominant feature of an LNG terminal in terms of physical size as well as construction cost. The high requirements for temperature insulation result in high costs for LNG tanks in comparison with tanks for other fluids. When planning an LNG supply system, particular care must be taken to select an appropriate size of tank
capacity consistent with the magnitude and frequency of bunkering operations, size and frequency of incoming shipments and considerations of security of supply.

Two alternative tank concepts may be relevant for LNG terminals for bunkering purposes, depending chiefly on the tank volume required: Pressurised tanks and atmospheric tanks.

Pressurised tanks are designed to hold pressure of a few bars in addition to the cryogenic temperature. They are cylindrical steel structures, mounted either horizontally or vertically, and pre-fabricated before shipment to the point of installation. Pressurised LNG tanks have been installed in Norway with volumes ranging from 20m$^3$ to 683m$^3$, the latter being the largest such tanks installed as of 2008. Several tanks may be installed together. A tank farm can be increased or reduced in size by adding or removing tanks according to requirements and within local space constraints. Pressurised tanks tend to be best suited to relatively small storage volumes. The installation shown in Figure 22 is the largest pressurised LNG tank facility to date, with a total of 3415m$^3$ gross tank volume.

**Figure 22:** LNG terminal at Mosjøen aluminium plant, Norway. 5 x 683 m$^3$ pressurised tanks. Photo from Gasnor.

**Figure 23:** Vertical LNG tank at a small terminal for truck operations. Photo from Gasnor.
Atmospheric tanks are designed to hold the LNG at below boiling point and ambient pressure (Figure 24). They are constructed on location, and usually cannot be removed from there for re-installation elsewhere (as is possible with pressurised tanks). Atmospheric tanks are generally larger than the pressurised tanks, and preferred for larger required storage volumes.

In both pressurised and atmospheric tanks the tank volume of LNG that can be filled and emptied in the course of normal operations, is less than the gross volume. The differences are at least 10%.

4.2.5 Regasification

If natural gas will be supplied for other local purposes in addition to LNG bunkering, it will most likely need to be gasified so as to enter a gas pipeline grid and reach the user in ordinary gaseous state. In small scale LNG systems, the regasification is usually achieved by heat exchange with the surrounding air, thus avoiding the need to use procured energy for this purpose. In some cases where surplus heat is available from a nearby manufacturing operation, it may be convenient to use heated water from such an operation for regasification. It is also possible to provide added heat from boilers.

Regasification units are seen in Figures 22 and 23 as erect aluminium structures behind the tanks. Cold LNG is led through the regasifiers, which transmit heat from the surrounding air causing the LNG to vaporise and reach close to ambient temperature.

4.2.6 Terminal lay out

Figure 25 is an indicated layout description for a terminal consisting of 5 x 683m³ pressurised tanks. This is similar to the installation shown in Figure 22, but without the regasification units unless local gas supply will be needed in addition to LNG for bunkering. This size and configuration is potentially relevant for a port where a number of RoRo and RoPax ships are
to be bunker with LNG on a regular basis, and may be expanded if necessary. A 5 x 683m$^3$ facility can be filled with LNG containing 73 TJ of energy, corresponding to some 1700 tonnes of heavy bunker oil.

The size of such an installation will be about 50m x 50m. This standard lay-out will be adapted to local conditions. The terminal is built with all connections and valves at one end and, for safety purposes, an accumulation pool is also provided at that 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 30m radius around accumulation pool. In this zone there will be restrictions on other activity that can involve ignition sources.

An insulated LNG pipeline, probably submerged in a duct, connects the terminal with the ship connection point at the jetty. There is also a small safety zone around the connection point. There is also an evacuation zone of 100m around the terminal, which is prepared for evacuation in the case of an incident at the terminal.
Figure 26 shows an example of a 5 x 683m³ terminal with truck filling facilities and regasification for gas delivery to local uses by pipeline.

A terminal of this kind does not require operating personnel to be normally present at the terminal itself, and direct interventions are rarely needed. They are equipped for remote monitoring and control. At the Norwegian installations, discharge and filling operations are generally handled by ship and truck personnel. In some cases it may be relevant to agree on routines for monitoring and certain operations to be provided by a nearby industrial or logistical operation. The bunkering operations are likely to require manned interventions.

### 4.2.7 Safety precautions

LNG facilities must be constructed and operated with due consideration to the nature of LNG as a combustible substance with high energy content, and therefore hazardous substance. The requirements in this regard are well understood in the industry. There have been no serious incidents at the more than 30 small LNG terminals operating in Norway.

The physical properties of LNG readily allow for safe and clean operations when adequate precautions are made. The physical conditions under which ignition and explosion or fire of LNG can occur, are more narrow than for other hydrocarbon fuels; i.e. LNG fumes are hard to ignite due to high temperature and narrow range of gas/air concentration required for ignition. It is odourless, non-toxic, non-corrosive and less dense than water. At temperatures warmer than -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. The potential hazards associated with LNG include heat from ignited LNG vapours and the direct exposure of skin or equipment to a cryogenic (cold) substance.

The terminals will be 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.

As part of the MAGALOG Project, Safetec Nordic AS (www.safetec.no) was commissioned to carry out simulations of a leakage from an LNG tank at a specified terminal configuration and weather conditions. The leak, assumed as 4000 kg of LNG, would initially be collected as a liquid in the accumulation pool of the terminal. It was calculated to evaporate and form a gas cloud that would initially remain close to the ground but then rise and dissipate in the air within 200 seconds. At that stage the gas would no longer be capable of ignition.

### 4.3 LNG transportation

LNG is transported by ship or by truck. Rail transportation of LNG is currently not done in Northern Europe.
4.3.1 LNG transportation by ship

Most LNG transportation globally is done on ships in the large-scale category, more than 100,000 m$^3$. Such ships would be definitely outsized for supplying such terminals as are described in the previous section. There is currently only one ship operating in Europe that would be sufficiently small for such supplies, but more ships are under way.

The smallest LNG carrier in the world, and the only small-scale vessel operating in Europe as of 2008, is the 1100 m$^3$ “Pioneer Knutsen” (Figure 21). It is owned by shipping company Knutsen OAS Shipping, built in 2003 and operates under a long term charter to Gasnor AS. It is used for loading LNG at the Kollsnes LNG plant for delivery to small LNG terminals in Norway. As of 2008, 8 terminals can receive shipments from the “Pioneer Knutsen”.

The “Pioneer Knutsen” is not assumed to be suitable for loading at large LNG terminals. It has however been used in transhipment operations where LNG was transferred from a large vessel onto the “Pioneer Knutsen” for delivery to the small coastal terminals. This is a type of operation that can be undertaken in unusual circumstances.

2 or 3 LNG carriers slightly larger than the “Pioneer Knutsen” operate in Japan.

Several combined gas carriers are under construction or ordered that can potentially be used for supplying LNG to terminals used for bunkering in Northern Europe. The 7500 m$^3$ “Coral Methane” (figure 27) will be delivered in 2009 to owners Anthony Veder for a long term charter to Gasnor. The “Coral Methane” is intended primarily for Gasnor’s LNG supply system in Northern Europe, including the possibility of loading LNG at large terminals. The vessel has the capability of carrying other gases besides LNG (ethylene, propylene, LPG, etc), and may be utilised for such purposes if not fully employed in LNG.

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6 Gasnor AS is coordinating partner of the MAGALOG project.
Ship owners Skaugen have a series of at least six 10,000m$^3$ and 12,000m$^3$ gas carriers under construction and orders from a Chinese yard, for delivery around 2010. They will have the capability to carry LNG besides other gases. Skaugen has established a partnership with the owners of the LNG plant under construction at Risavika, Norway, for transporting and marketing LNG from there.

The "Coral Methane" and the Skaugen ships will have larger cargo capacities than are likely to be required for LNG terminals such as described in the previous section, at least for some years. An efficient utilisation of these ships therefore depends on developing suitable possibilities for combination voyages where the ships can discharge at more than one terminal.

### 4.3.2 LNG transportation by truck

The LNG tanker trucks appearing in figures 21-23 can carry 55m$^3$ of LNG. They are widely used in the Norwegian supply system as a supplement to ship deliveries by the "Pioneer Knutsen". Truck deliveries have on several occasions been made from Western Norway to as far as Eastern Sweden, a distance of 1100km. Trucking is a reliable and flexible mode of transporting LNG. It tends to be less cost effective than ship transportation if volumes are sufficiently large and long-term to justify the cost of a terminal for receiving ship deliveries.

### 4.4 LNG production and availability

Natural gas is combustible gas occurring in underground reservoirs and consisting mainly of methane (CH$_4$). LNG is natural gas that has been cooled to liquid form, at close to -162°C, for the purpose of transportation and/or storage. By liquefaction, the gas is condensed to about 1/600 of the original volume, and it is this reduction in volume that makes LNG relevant for transportation and storage. Further physical properties are listed in Appendix 1.

It is not expected to be necessary to construct LNG production facilities for the explicit purpose of bunkering ships. LNG can be obtained from two categories of production systems which have been or will be established for other purposes, i.e. small scale and large scale systems as introduced in section 2.3.3, although the application as ships’ fuel may have significance for capacity decisions for such production systems.

#### 4.4.1 The LNG production process

Natural gas that enters the large integrated European gas pipeline system, must meet certain quality requirements. To that end, gas that has been produced from underground reservoirs is processed in order to remove or reduce unwanted components such as water, carbon dioxide, other non-hydrocarbon gases as well as natural gas liquids (propane and heavier hydrocarbon molecules).

Gas that is to be converted to LNG must also be processed to remove such components, and at more stringent requirements in order to be compatible with the very low temperature of LNG (-162°C). As a consequence, LNG has a similar composition as ordinary natural gas but tends to have even less impurities and C3+ hydrocarbons. The composition of LNG has some
variations depending on its origin, mainly in the ratio of ethane ($C_2H_6$) to methane ($CH_4$) and the presence of small quantities of other substances.

The process of LNG production entails the following steps:

1. Gas receipt and metering;
2. Removal of acid gases: CO2, SO2;
3. Dehydration;
4. Separation of natural gas liquids (C3+ hydrocarbons);
5. Liquefaction by cooling;
6. Storage and loading to transport vehicles.

The cooling process requires substantial amounts of energy to drive compressors, and 10 – 15% of the gas received may be spent for this purpose.

4.4.2 LNG from large scale supply systems

Large scale LNG systems is the term used here to represent the majority of LNG flows that are well established globally as well as in Europe, as introduced in section 2.3.3. The European terminals for large scale LNG are shown on a map in Figure 9. Figure 28 shows the global trade flows of natural gas by pipeline (indicated in red) and as LNG (blue).

The large terminals in Europe can be potential sources of LNG for bunkering purposes (section 2.3.3), and the fuel requirement for the entire RoRo and RoPax fleet in the Baltic and North Seas would correspond to no more than 5% of European LNG imports in 2007 (section 3.5). LNG trade has traditionally had a large role in East Asia, but is currently on a rising trend also in the Atlantic basin.

Figure 28: Major trade movements of natural gas, billion cubic metres, 2007. Source: BP (2008)
Before the large LNG terminals can be firmly established as a supply source for bunkering purposes, certain challenges need to be overcome. Such a supply function would require operations at the large terminals for which they were not originally designed, but there are clear indications that it can be done.

The large scale LNG flows serve to move natural gas into major markets (such as Western Europe) from producing locations that are too distant for pipeline connection. Supplying LNG as ships’ fuel from large terminals would entail certain operational challenges, since the large terminals have been configured to receive LNG and send out regasified natural gas, whereas this would require sending out LNG. Also, the tanker ships that will be suited to supply LNG as ships’ fuel will be much smaller than the LNG tanker ships normally handled at the large terminals.

Supplying LNG for bunkering operations from such terminals can be done in limited quantities by trucking operations, for which several large terminals are equipped, or by lifting LNG onto a suitably sized ship. Ship operations rather than trucking will be needed unless the bunkering operation is located in short distance of the large terminal, or requires small quantities only.

Partners in MAGALOG have been in contact with the operators of several large LNG terminals in Europe. Some such terminals, but not all, can be technically suited to loading small LNG ships with no or small modifications only.

In addition to the technical conditions, there are procedural hurdles to be overcome before small LNG ships can be loaded. The competent authorities may have issued permits that cover discharging large ships, but not loading small ships. With terminals that have several users (which most do), procedures for capacity utilisation and berthing slots have been drawn up in a manner that is suited to regular arrivals of large ships, but may not be well suited to loading small ships. Furthermore, the tariff schedules for using terminals are in some cases structured so as to make calls by small ships disproportionately expensive.

In MAGALOG’s assessment, these technical and procedural hurdles can eventually be overcome for many if not all large LNG terminals in or near Northern Europe. There has been a growing awareness among large terminal operators and LNG trading firms of the possibility of redistributing LNG from such terminals.
An early step towards this is an agreement announced in 2008 between Spanish energy firm Iberdrola (seller) and Gasnor (buyer), which provides for LNG from Spanish terminals to be supplied into Gasnor’s system from 2009. A 7500 m$^3$ LNG tanker ship, the "Coral Methane", is constructed for ship owners Anthony Veder for a long term charter to Gasnor, and will be used for loading the LNG at the large terminals.

In the long run it will be desirable to have the possibility of also accessing LNG at terminals closer to Northern European bunkering operations than Spain. There are encouraging indications that this will be possible, but it has not as of 2008 been established as a certainty.

### 4.4.3 LNG from small scale LNG systems

The concept of small scale LNG systems was introduced briefly in section 2.3.3. No precise limit has been established between large scale and small scale systems, but there is currently a large size gap separating the two: Currently existing or ordered LNG ships are, with the exceptions of a few very old ships, either more than 100,000 m$^3$ or less than 13,000 m$^3$ of size. Small scale LNG distribution takes place across relatively short distances, mostly within a country, as an alternative or predecessor to pipeline gas distribution.

Small scale LNG distribution by ship currently takes place in Norway and Japan, and by truck in several other countries. In some countries (such as Spain, Turkey and Japan), small-scale LNG is short-distance distribution of LNG that has arrived in the country as large-scale LNG on long distance ships, whereas in other countries (such as Norway and the U.S.A.), LNG is produced locally on a small scale for the purpose of this form of distribution.

**Figure 30: Small LNG production plants in Norway.**

- **Tjeldbergodden**: 15,000 tonnes/year (StatoilHydro)
  - Truck loading only
- **Kollsnes**: 80,000+40,000 tonnes/year (Gasnor)
  - Ship+truck loading
- **Karmøy**: 20,000 tonnes/year (Gasnor)
  - Truck loading only

*In construction - operational 2010:*

- **Risavika**: 300,000 tonnes/year (Skangass)
  - Ship+truck loading

The coastal ferries and offshore supply vessels currently running on LNG in Norway (section 2.3.2) are all supplied from small scale LNG plants (Figure 30). These LNG bunkering operations were developed at times and at locations where large-scale LNG was not established as an alternative available for this purpose. Small-scale LNG can thus have
important advantages in terms of feasibility, especially before small-scale liftings from large terminals is a firmly established option. The format of small-scale LNG is also more readily compatible than the large-scale operations with the magnitude and nature of ship bunkering.

The small scale LNG systems in Southern Norway have certain features that have implications for their cost structure. As feedstock they use gas which has been produced at Norwegian offshore fields, and which would be destined for Continental or UK markets by pipeline if not used to produce LNG. The market value of natural gas is often assumed to be derived on a netback basis based on alternative sales or energy use. The production of LNG on such a small scale is normally assumed to be disadvantaged in terms of unit cost of production relative to large LNG plants, which usually have more than 3 million tonnes of annual capacity compared to the 80,000 tonnes of the largest small-scale production train currently operating. However, this effect may in some cases be overshadowed by large demand-driven variations in oil and gas related construction costs in recent years, as well as cost overruns associated with certain large LNG projects.

4.5 Contractual arrangements and price of LNG

It is not possible at this time to provide a precise statement of the cost of LNG that will be supplied as fuel for ships. The costs that can be agreed, will emerge from ongoing development and commercial processes, and will vary over time. This section will review the mechanisms and conditions that are likely to influence the terms at which LNG can be provided, and provide some indications of costs.

4.5.1 Format of trade: Long term contracting

Generally, international trade in natural gas (including LNG) tends to be much more long term oriented than trade in oil and oil products. Much of the cross-border trade in natural gas occurs under agreements of 20 years or longer duration. Price is then agreed as a formula indexed to other observable price parameters, mainly crude oil or refined oil products, to ensure that there is a favourable relationship between the cost of natural gas and the cost of the products against which natural gas has to compete in end-user markets.

A main reason for this long term orientation of natural gas trade is the need to install costly infrastructure for transporting the gas, either by pipeline or as LNG. The long term deals afford the gas sellers an assurance of being able to amortise such costly investments, while also affording gas buyers and users, who must often also make significant investments in equipment for using the gas, an assurance of being supplied at predictable terms.

The small scale LNG developments in Scandinavia has to a large extent also been governed by a long term approach to contracting. Many of the agreements are of more than 10 years duration. The supply and use of LNG for industry and coastal shipping requires significant specific investment by the gas supplier as well as the gas user. Agreements for sale and purchase of gas are then made in parallel with such investment decisions, and with a time horizon that covers a significant part of the economic life of such investments.

LNG as a bunker fuel for RoRo, RoPax and certain other forms of shipping is considered suitable for a similar long term approach to contracting. It requires specific investments to be
made in ships that will be dependent on using LNG, and in supply facilities that will be
dependent on serving such ships in order to recover investments. As long as ship owners will
face a limited choice of suppliers that can provide LNG, and gas suppliers will face a limited
choice of ship owners that can provide utilisation of the infrastructure, long term agreements
for supplying LNG can provide a basis for such investment decisions by both parties.

It is conceivable that short term contracting for LNG can become common at some stage in
the future. This will probably require that LNG as fuel for ships has become more widely
established, with a multitude of LNG suppliers and buyers being present in important ports. It
will take a number of years for this to become a reality.

4.5.2 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.\(^7\) 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 31). These prices represent border-crossing
intra-European trade in natural gas.

Figure 31 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 gasoil 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.

\(^7\) 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 gasoil and fuel oil to natural gas equivalents by energy content;
- \( w_G \) and \( w_F \) are relative weights given to gasoil and fuel oil in the indexation, defined so that \( w_G + w_F = 1 \);
- \( G_m \) and \( F_m \) are price assessments observed for gasoil 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 gasoil 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 gasoil, 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 32 shows a comparison of prices for European gasoil, 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 gasoil prices, and near parity with heavy low-
sulphur fuel oil on energy basis\textsuperscript{8}, but with large variations especially in times of oil market
turbulence due to the lagged indexation of gas prices to oil prices.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure32}
\caption{Monthly averages of prices for European gasoil, low sulphur heavy fuel oil and natural
gas. Converted to € per MWh gross calorific value. Sources: EIA, ICE, StatoilHydro.}
\end{figure}

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\textsuperscript{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.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure33}
quoting data from Heren.}
\end{figure}

\textsuperscript{8} 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.
Figure 33 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 services 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. 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).

4.5.3 The requirement of third party access

The European Union, in its Gas Directive, requires that gas infrastructure such as pipelines and LNG terminals be accessible by any party on non-discriminating terms. Small LNG terminals, such as described in section 4.2, are not exempt from this requirement of third-party access, although it is likely that the authors of the Directive had primarily large terminals in mind.

This is a potential complication with regard to reaching decisions on the construction of such terminals, because it tends to separate decisions on terminal capacity from the other parts of the supply chain of which such terminals form an integral part. Parties that have planned large LNG import terminals have resolved this by conducting "open season" procedures prior to final investment decisions on such terminals, which result in long term agreements for terminal capacity utilisation after several parties have had the opportunity of expressing their interest in such long term agreements.

A resolution of the third-party access requirements may be sought on similar lines for the small terminals intended for LNG bunkering purposes. It is also conceivable that a party may undertake to build and own such terminals against payment of utilisation fees by terminal users, similar to the way that many storage facilities for oil and chemicals are operated. This possibility has not been exhaustively investigated by the MAGALOG project, and is not likely to fundamentally change the challenges or economics of LNG supply.

4.5.4 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:

9 Platts, ICIS Heren. Petroleum Argus
10 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.
- 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.

It is common in long term sales 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, gasoil or heavy fuel oil as quoted by Platts\textsuperscript{12}. 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 gasoil or LNG as described in section 2.3, then this would point towards linking the LNG contract price to reported prices for gasoil of a relevant quality. Platts’ price assessments for gasoil 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.

**4.5.5 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 (section 4.4), 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.

\textsuperscript{12} Platts is an information service that provides daily assessments of market prices for a wide range of spot traded products, www.platts.com. Similar services are provided by Petroleum Argus (www.argusonline.com) and ICIS Heren (www.heren.com).
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.

4.5.6 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 (section 4.5.2), 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 31).

Long term contracted prices for natural gas have tended to be at 55% - 60% of high quality gasoil 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.

4.5.7 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 reviewed in above sections 4.1 to 4.4:
- 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 can be put at €50 - €60 million per 100,000 tonnes of annual LNG production capacity based on various public information, 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 €8 - €14 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 terminaling costs**

LNG will have to be moved to the bunkering ports, most likely by LNG carriers such as the 7500m3 vessel described in section 4.3.1, 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.

As part of the MAGALOG project, MARINTEK analysed several cases of optimal ship and terminal utilisation based on different assumptions for discharge port combinations, product origins and annual quantities. Figure 34 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. Costs for shipping and terminaling tends to be lower with higher annual quantities, and are mostly between €5 and €12 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 are expected to be comparatively modest in relation to the other cost components. A cost of €1 per MWh is assumed for this function.

*Figure 34: Shipping and terminaling costs at different discharge port combinations and different annual quantities. Costs in € per MWh of energy in LNG. Based on calculations by MARINTEK.*

### 4.5.8 Indications of overall costs of LNG supplies

Figure 35 gives indications of overall costs of LNG supplied as ships’ fuel in the Baltic region, and the cost of gasoil 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 sub-sections. 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 35, the cost of LNG will tend to vary with the price of crude oil, as do also refined products such as gasoil. Delivered LNG costs will however tend to vary less than crude oil and refined oil products, such as gasoil. 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 are 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.
The diagram in Figure 35 does not fully reflect the comparative costs and benefits of using LNG as a fuel in replacement of gasoil. The construction of LNG-fuelled ships is currently more costly than ships on liquid fuels; on the other hand, ships running on gasoil within the Emission Control Areas will face added costs for keeping emissions within permitted limits (section 2.3.2).

**Figure 35: Indications of costs of supplying LNG under different oil price scenarios.**

For comparisons, gasoil costs under different oil prices are established based on regression of historical prices during 2004-2008. Gasoil costs reflect heating oil quality with max 0.1% sulphur in barge trade in the Amsterdam-Rotterdam-Antwerp range with an addition of €40 per tonne for distribution and bunkering.

4.6 The process of developing LNG as ships’ fuel

For LNG to become firmly established and widely used as a fuel for ships in Northern Europe, several tasks must be resolved more or less in parallel, each requiring significant investment decisions:

(1) Ships to operate on LNG must be ordered by ship owners;

(2) Terminals and local bunkering operations must be established at key ports;

(3) Supplies of LNG must be ascertained, from small-scale production and/or large terminals;

(4) Transport capacity for moving LNG to bunkering capacity must be acquired.

These tasks are to an extent mutually dependent; however, there is scope for some tasks to be developed ahead of the others. At the present stage the third and fourth item above are not
immediately critical, as there is likely to be some capacity available for supplying and transporting LNG for ships based on what is already in progress, but eventually there will be a need for more LNG supplies as well as more transport capacity for it.

At present LNG can be bunkered in Western Norway. LNG bunkering elsewhere is possible based on long-distance truck haulage of LNG, which would not be very cost efficient. For effective large-volume bunkering, permanent terminal facilities at bunkering port will be required.

The next critical steps in the development process will need to be the ordering of ships to run on LNG for particular regular routes, and the establishment of bunkering facilities to serve these. A long term LNG supply agreement between an LNG supplier and a ship operator must be accompanied by other agreements concerning the construction of ships, availability of land for a terminal, and required permits.

In the early stages of establishing ships’ bunkering outside Norway, the economics of supply will represent a challenge as indicated in figure 35, and the challenge is augmented by the prospects of oil prices approaching the lower end of the scenarios indicated in the figure. There are prospects of improving economics as the system develops. No firm solution to the challenge of initially weak comparative economics of LNG will be proposed here, but is likely to require a combination of three approaches:

- First, finding applications of LNG as ships’ fuel for which there are particular incentives or cost advantages;

- Second, a willingness by involved parties to take a long term perspective on comparative economics;

- Third, public incentives towards a preference for LNG as the most environmentally friendly fuel for ships.
5 Studies of future LNG bunkering at North European ports

The MAGALOG Project has carried out studies of five North European ports with regard to their potentials as future LNG bunkering locations. The ports are Bergen, Gothenburg, Lübeck, Swinoujscie and Stockholm (Figure 36). The studies identify the amount of shipping that call regularly on the ports, and for which a substantial degree of conversion can be achievable over the next 15 years. Also reviewed are the possibilities of locating relevant LNG bunkering facilities at the port, and the next development steps required.

5.1 Future LNG bunkering port: Bergen

Bergen is Norway’s second largest city, after Oslo. Its central harbour has well preserved buildings documenting Bergen’s legacy as a Hanseatic city (Figure 37).

5.1.1 Situation

Bergen’s port facilities are well shielded from the North Sea by a series of islands. The Port of Bergen is organised as a company owned by the City of Bergen and some nearby municipalities.

In addition to the main central port of the city itself, the Port of Bergen also covers important port facilities at Mongstad (oil refinery and offshore petroleum supply base), Sture (oil export terminal) and the CCB offshore petroleum supply base (Figure 38). The CCB base is the bunkering port for two LNG-fuelled supply vessels serving North Sea petroleum installations (Figure 6). Three LNG-fuelled ferries bunker at the Halhjem ferry port (Figure 19). The largest small-scale LNG production site at Kollsnes (Figure 21) is also within the Bergen port district, though the jetty facility at the LNG site is not administered by the Port of Bergen.
The scheduled shipping lines call at the central port near the city centre, which also is a favoured destination for cruise vessels in summer (Figures 39 and 40). Onward connections for international cargo via Bergen are by domestic small transport vessels, railway towards Oslo and the road network.

5.1.2 Ship traffic and potential use of LNG

The Bergen port district received 26 231 ship calls and 95 million gross tons in 2007, which places it among the larger ports in Northern Europe. However, much of the tonnage and calls
were in categories of ships that are considered unlikely to be among the early converters to LNG: Tanker ships for crude oil and petroleum products, cruise ships and small express passenger boats.

**RoRo and RoPax**

7 RoRo vessels, of shipping companies Sea-Cargo and Nor Lines, call on Bergen regularly. 5 of these ships are more than 25 years old. Containers are carried as deck cargo on the RoRo vessels. One of these firms (Sea-Cargo) has ordered two LNG-fuelled RoRo vessels that may be deployed for such routes. RoRo traffic is on an increasing trend along with the number of containers handled (98,161 TEU in 2007; an increase of 13% from the previous year following several years of similar increases). The RoRo vessels serve routes that include several Norwegian ports and ports on the European Continent and/or Britain.

The RoRo traffic uses the central port area. The port authority is actively pursuing growth in RoRo traffic, with construction work ongoing for a new RoRo ramp and adjacent handling areas at Jekteviken in the central port area.

Bergen is the Southern terminal point of the Norwegian coastal shipping service “Hurtigruten”, with daily departures for a week-long round trip to Kirkenes on the Russian border, and with many local stops. These vessels carry passengers, some vehicles and general cargo. This fleet was renewed in the 1990s with an increased orientation towards the tourist passenger segment, and are not likely to be renewed for many years yet.

International ferry traffic on Bergen has seen a recent sharp decrease, as routes to Britain and Iceland have been discontinued in 2008. For 2009, Bergen is set to have only one regular international RoPax departure; to Denmark.

**Other shipping segments**

Oil tankers calling on the large terminals at Mongstad and Sture (including the refinery at Mongstad) represent large tonnage but on a falling trend since the oil fields feeding the terminals are past their peak production.
Also addressing the petroleum sector is the large supply base at CCB and a smaller base at Mongstad. Two LNG-fuelled offshore supply vessels take on fuel at CCB. These vessels were constructed by two different ship owners to serve under long term charters with the oil company Statoil (now StatoilHydro), under which StatoilHydro procures fuel for the vessels. The reduction in NOx emissions resulting from the choice of LNG as fuel was agreed with the pollution authority as a substitute for emission reduction measures that would have been required elsewhere in Statoil’s system. There is some scope and expectations for increasing the use of LNG in offshore supply vessels. With the current state of bunkering facilities this is mainly suited to vessels that are constructed to serve specified offshore fields over a long period of time.

One LNG-fuelled Coast Guard vessel stationed at a naval base just outside Bergen will be operational from 2009. It will take on LNG regularly at the Kollsnes LNG production plant. Two other LNG-fuelled Coast Guard vessels are also being commissioned for operations from Northern Norway.

Bergen’s central harbour and some lesser harbours in the area are frequent ports of call by a number of small coastal cargo vessels. Many of these ships are comparatively old, and many are owned by small firms. This segment can be considered a candidate for conversion to LNG once LNG has become more firmly established as a fuel option.

Bergen had 231 calls by cruise ships in 2007. The city’s scenic situation, attractive city centre and location among the Fjords of Western Norway makes it a favoured destination for cruise traffic. Sooty smoke from cruise ships’ engines have been recognised as an undesirable source of pollution in Bergen and in the fjords (Figure 39). Cruise ships tend to have a wide range of service, and are therefore not expected to be among early converters to LNG fuel.

Bergen has several scheduled passenger boat services towards the South (Stavanger), North (Måløy) and some fjords. These are diesel fuelled, dual hull vessels travelling at more than 30 knots. Being passenger boats only, they are much smaller than the “super fast” category of passenger and vehicle carriers (figure 13). They may be candidates for LNG fuel in the future, but requiring design work to address the space constraints in these vessels.

5.1.3 Development of LNG bunkering

LNG bunkering is installed at the CCB base, currently serving only the offshore petroleum supply vessels. LNG bunkering can also be developed at the Kollsnes LNG production plant. Both CCB and the Kollsnes plant are located North of Bergen at the main coastal waterway, which is used by smaller ships preferring to avoid the open seas where possible. They may therefore be convenient points of LNG bunkering for vessels passing this way without having to call on the port of Bergen.

The city authority has commissioned a plan for the central harbour (Kommunedelplan), intended to reconcile future harbour requirements with other city development needs. The plan is not finalised as of 2008. It is expected to provide for a LNG bunkering terminal within the central harbour facilities.

The idea of providing electricity from shore to ships has been launched and will be considered in conjunction with the central harbour plan, including the possibility of supplying the
electricity from a combined heat and power plant, which may supply the surplus heat to the city’s district heating system.

5.1.4 Summary and conclusions: Future LNG bunkering in Bergen

LNG bunkering is already established for coastal ferries (at Halhjem), offshore supply vessels (at the CCB base) and from 2009 a coast guard vessel (at Kollsnes) within the Bergen port district, though not yet in the city’s central harbour. There is scope for increased use of LNG for the established purposes at the three existing bunkering points.

Bergen is set to become an LNG bunkering port for RoRo vessels probably from 2010/2011. Plans for this are in progress. Beyond the present scope of established LNG use and RoRo traffic, LNG use in ships may increase as a result of shifting more cargo from road to sea and from a renewal of the domestic cargo and passenger vessels.

5.2 Future LNG bunkering port: Gothenburg

Gothenburg (Göteborg) is Sweden’s second largest city after Stockholm, and Scandinavia’s largest port in terms of RoRo and RoPax calls.

5.2.1 Situation

Gothenburg is located where the Göta River ends in the Kattegat. It is a central location in the Baltic and North Sea basin, and the Port of Göteborg pursues the ambition of being a main regional cargo hub for Northern Europe. It is the only Scandinavian port to receive large intercontinental container vessels (12,000 TEU vessels). It is also a major point of exports for
key Swedish industrial manufactures, notably cars and paper. The river and associated canal system are navigable by small commercial vessels to the large lake of Vänern (Figure 41).

The modern port facilities are concentrated on the northern bank of the river mouth. This includes a RoRo terminal, container terminal, car terminal and oil terminal for two refineries (Shell and Preem). Older facilities, for passenger and cargo ferry traffic, are located further upstream (Figures 42, 43). The old city centre is on the South bank of the river.

The Port of Göteborg is connected to roads of motorway standard in four directions. A large rail cargo station is located in the container terminal, providing long good access to the Swedish rail system.

The Port of Göteborg operates as a port authority as well as stevedoring company covering much of the port facilities indicated in figure 42. Some facilities are owned by other firms. The Port of Göteborg (www.portgot.se) is incorporated as a company fully owned by the City of Gothenburg.

5.2.2 Ship traffic and potential use of LNG

Table 7 provides statistics for the traffic at the Port of Göteborg in recent years. Following is a discussion of shipping activities for which LNG fuel is expected to be potentially relevant in a 10-years time frame.
Table 7: Statistics, Port of Göteborg, 2006 and 2007. Source: www.portgot.se

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2007</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Export</td>
<td>Import</td>
</tr>
<tr>
<td>Container (teu)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>full</td>
<td>338 260</td>
<td>309 224</td>
</tr>
<tr>
<td>empty</td>
<td>58 224</td>
<td>105 800</td>
</tr>
<tr>
<td>Total</td>
<td>396 484</td>
<td>415 024</td>
</tr>
<tr>
<td>Ro/ro-units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>full</td>
<td>295 933</td>
<td>256 131</td>
</tr>
<tr>
<td>empty</td>
<td>42 610</td>
<td>47 966</td>
</tr>
<tr>
<td>Total</td>
<td>339 543</td>
<td>304 097</td>
</tr>
<tr>
<td>Cars</td>
<td>212 692</td>
<td>115 803</td>
</tr>
<tr>
<td>Oil (1000 tonnes)</td>
<td>8 392</td>
<td>12 239</td>
</tr>
<tr>
<td>Passengers (1000)</td>
<td></td>
<td>2 187</td>
</tr>
<tr>
<td>Total, (1000 tonnes)</td>
<td>19 801</td>
<td>20 804</td>
</tr>
</tbody>
</table>

**RoRo and RoPax**

14 RoRo, 5 regular RoPax and one super fast vessel are noted as calling on Gothenburg on regular schedules within the Baltic and North Seas. RoPax destinations are Frederikshavn, which is a short distance across to Denmark, and Kiel. RoRo destinations are Zeebrugge, Gent, Immingham, Tilbury, Lübeck and Finland. The RoPax and super fast vessels are operated by Stena Line. RoRo vessels are operated by Stena, Cobelfret and DFDS Tor Line. Average vessel age in this segment was 12 years, with 6 vessels at least 20 years old.

**Other shipping segments**

Gothenburg receives container feeder vessels related to its long-distance, large container ship traffic. As potential LNG users they can have similar potential advantages as RoRo vessels.

A number of local car ferries operate in Gothenburg’s surroundings and archipelago. They can be candidates for future use of LNG when replaced with new ferries, and the conversion of existing ferries to LNG can also be considered. Fuel consumption in these small ferries is limited; in the order of 500 tonnes per year of LNG.

Some small cargo vessels operate regularly in the Gothenburg region including the nearby shielded coast and the Göta river up to Lake Vänern. It should be feasible to introduce LNG fuelled vessels for such services when the existing ones need replacement or supplement. The region has large manufacturing industries, including cars and trucks (Volvo and SAAB), and there is a desire to move cargo from road and rail to water within these shuttle distances. The local energy company, Göteborg Energi, will require some small bulk shipping capacity for supplying biomass for a gasification plant, which may well be designed to operate on LNG.

Gothenburg receives some large liner cargo ships, notably car carriers and large container carriers for intercontinental and long distance traffic. Dual-fuel capability of such vessels in
the future may enable them to run on LNG while in ECA waters in Northern Europe and, in the future, other areas (such as North American waters likely to introduce ECAs). LNG for use in such ships is a possibility, though not assumed likely in the short term.

Oil tankers include crude carriers and smaller refined product carriers. Although not considered likely to switch to LNG as the regular propulsion fuel in the mean term, there is a particular issue of fuel consumption when pumping oil in port, particular with crude carriers discharging at the Gothenburg refineries. The resulting emissions are accounted for and attributed as port emissions, and could be significantly reduced with gas. A specific solution for this has yet to be developed.

5.2.3 Development of LNG bunkering

The port authority and large users of the Port of Göteborg have for a number of years placed a large emphasis on environmental qualities. This provides a favourable starting point for developing the conditions required for using LNG in ships calling there regularly. The Port is certified according to the ISO 14001 environmental standard, and has been internationally acknowledged for its environmental work. A case in point is the provision of electricity from shore to regular RoRo ships. A number of companies which are large users (as cargo owners) of the port have jointly developed requirements for the environmental impact of transportation (Clean Shipping Project 2007).

If LNG bunkering starts with local ferries or small cargo vessels, and for as long as this is limited to a small number of vessels, it will be feasible to supply LNG by truck from an LNG terminal which is in preparation in Østfold, Norway. One small ferry will require some 25
annual truck loads with a driving distance of 210 km from Sarpsborg. RoRo or RoPax shipping will require larger volumes for which supply by ship will be appropriate, and for this purpose an LNG terminal needs to be planned for in the Port of Göteborg.

Several locations have been identified that may be potentially suitable. The most promising such locations are on either of the small isles of Hjärtholmen and Risholmen, which are on the North Western perimeter of the port areas, with landfilled connection to mainland and with some oil and port installations already present (indicated by red circle in Figure 42). An LNG terminal here would also require bunkering barge(s) or small shore tanks near the relevant bunkering locations to carry out bunkering operations.

5.2.4 Summary and conclusions: Future LNG bunkering in Gothenburg

Gothenburg has a clear potential for developing significant LNG bunkering, due to its established pattern of port utilisation and the high priority given to environmental issues. The next steps required to achieve this, are:

- Develop proposals for LNG use in local small shipping, including local ferries, biomass bulk feeders and other inland/coastal cargo vessels;
- Identify location and plan for an LNG terminal for receiving LNG by ship in the Gothenburg port;
- Establish long term LNG supply contracts with ship owners (primarily RoRo and RoPax) as a basis for constructing LNG-fuelled ships and constructing the LNG terminal.

5.3 Future LNG bunkering port: Lübeck and Travemünde

Lübeck is a historic city with a maritime history dating back to the Hanseatic times, and has large and modern port facilities. References below to Lübeck as a port include the smaller town of Travemünde, which is covered by the same port organisation.

5.3.1 Situation

The City of Lübeck is located on the River Trave, 20km upstream from the river mouth on the Baltic Sea. Lübeck’s “daughter city” Travemünde is located at the river mouth, and is also a seaside recreational resort (Figure 44). The nearest larger city is Hamburg, 50km to the South-West of Lübeck.

The largest port facility is the Skandinavienkai, near Travemünde, which handles 2/3 of the overall cargo tonnage including the ferry traffic (Figure 45). Three port facilities handle large quantities of paper, much of which is imported from Finland and Sweden (Nordlandkai, Schlutup, Konstinkai). Seelandkai is a recent facility handling containers and rolling cargo.
Lübeck is well connected to the German transport networks of rail, roads and waterways, the latter via the Elbe-Lübeck canal. Numerous cargo trains per week link Lübeck with major economic centres on the European continent.
The Lübeck Port Company (LHG – Lübecker Hafen-Gesellschaft) is majority owned by the Hanseatic City of Lübeck. LHG operates five major port facilities between Lübeck and Travemünde. In addition, there are port facilities operated by other entities (Lehmannkai, containerport) which handle 10% of total cargo tons.

5.3.2 Ship traffic and potential use of LNG

RoRo and RoPax

Much of the traffic is provided as trailers on RoRo and RoPax vessels. In 2007, Lübeck’s port received or discharged 877,722 trucks and trailers, half of which were unaccompanied trailers. The number has increased by an average of 4.3% from 2000. Increases were also noted in the number of containers, new cars and quantity of paper. Over the same period there were significant reductions in the numbers of passengers, passengers’ cars and railcars shipped.

Scheduled RoRo and RoPax shipping constitute a dominant part of Lübeck’s port calls. It is one of the busiest Baltic ports in these segments. The Port of Lübeck claims more than 150 weekly departures, of which 85 have been identified and analysed by the MAGALOG project. These routes are served by 36 different vessels. Table 8 indicates the weekly sailings from Lübeck to destinations in and near the Baltic Sea, identified by MAGALOG’s analysis as of September 2007.

| Table 8: Weekly RoRo and RoPax sailings from Lübeck–Travemünde (September 2007) |
|---|---|---|---|---|---|---|
| Skandinavienkai (Travemünde) | M | T | W | T | F | S |
| Helsinki | X | X | X | X | X | X |
| Turku | X | X | X | X | X | X |
| Göteborg | X | X | X | X | X | X |
| Malmö | X | X | X | X | X | X |
| Trelleborg | X | X | X | X | X | X |
| Helsingborg | X | X | X | X | X | X |
| Riga | X | X | X | X | X | X |
| Oslo | X | X | X | X | X | X |
| Nordlandkai/ Seelandkai/ Lehmannkai II | | | | | | |
| Helsinki | X | | X | | | |
| Kotka | | X | | X | | |
| Hamina | | X | | X | | |
| Rauma | | X | | X | | |
| Kemi/Oulu | | X | | X | | |
| Paldiski | | X | | X | | |
| Hanko | | X | | X | | |
| Paldiski | | X | | X | | |
| Halstattvik/Braviken | | | | | | |
| St. Petersburg | | | | | | |

Source: Marintek

The shipping companies operating the Lübeck trades included DFDS Tor Line, Finnlines, Scandlines, Stena Line, Transfennica and TT Line. Of the 36 vessels identified as serving these routes, 20 were 12 years or younger, while 9 vessels were more than 25 years old.

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RoRo and RoPax shipping are generally considered a candidate for conversion to LNG as fuel, as reviewed in Chapter 4. Since a large part of the fleet serving Lübeck is relatively young, a massive conversion is not likely to occur over the next 10 years. However, there is a sufficient number of aged ships, as well as prospects for further traffic growth, which should provide opportunities for introducing LNG gradually to the many ships serving Lübeck.

Other shipping segments

Lübeck is connected to the inland waterways network via the Elbe-Lübeck canal (Figure 47), and offers the opportunity for cargo transfers between Baltic shipping and inland navigation. As reviewed in section 3.4 the inland navigation sector represents a potential market for using LNG, which would have significant environmental benefits. This will require innovations and investments in the sector which do not appear as imminent at present.

5.3.3 Development of LNG bunkering

The introduction of LNG bunkering can have particular relevance for Lübeck as a contribution to cleaner air, and as a solution to the environmental challenge that ship owners must address. Lübeck has experienced a large increase in harbour traffic over the last 30 years. While being a welcome contribution to trade and to the overall environmental impact of transportation, the increased harbour traffic has imposed an added burden on air quality in and around Lübeck. The added emissions affect the people and general environment of the region, and may also affect Travemünde’s position as a seaside resort.

LNG transportation would be subject to the legislative regulations covering transportation of gases, which is well established in Germany as LPG movements on road, rail and water. No regulatory issues that might have blocked the use of LNG were identified. For the use of LNG as fuel for domestic shipping, German or EU standards will need to be developed.
LNG bunkering in Lübeck is likely to target RoRo and RoPax vessels. Due to the volumes required for any such vessel, it would require the establishment of a terminal for LNG that can receive supplies by ship, while truck supplies from a distant source can be possible in exceptional circumstances but hardly economical on a regular basis. A tentative terminal location has been identified, though not (probably) at the most widely used port facility due to space constraints, and would therefore require onward transport of LNG by barge or truck to bunkering vessels. A terminal can be expanded by the addition of tank space as may be required by increasing LNG bunkering volumes.

5.3.4 Summary and conclusions: Future LNG bunkering in 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.

Next steps towards establishing LNG bunkering at Lübeck include the following:

- Confirm a suitable location for an LNG terminal, and prepare a specific design for it;
- Establish long term LNG supply contracts with ship owners as a basis for constructing LNG-fuelled ships and constructing the LNG terminal.

5.4 Future LNG bunkering port: Swinoujscie

Swinoujscie is a seaside town of 40,000 inhabitants that has been reconstructed after the destructions of World War 2 as a modern port and vacation destination.

5.4.1 Situation

Swinoujscie is connected with the larger city of Szczecin by a 60km navigation channel of 14m depth and 180m width along the river Swina. (Figure 48). It is an important transit point for cargo movements between Scandinavia and Poland as well as Central Europe and Eastern parts of Germany.

The ports of Swinoujscie and Szczecin are jointly administered by the Szczecin and Swinoujscie Seaports Authority. 7514 ships arrived in the ports in 2007, of which 61% in Swinoujscie.

In addition to good road and rail connections, Swinoujscie and Szczecin are well connected by inland waterways to Berlin and the waterways of Continental Europe. Railways provided 60% of the interconnected transportation in 2007, while 32% were by truck and 8% by barges. Investments are in
preparation for improving the road and rail infrastructure as well as port facilities. The nearest airport is at Szczecin.

Bulk products such as coal, grain and iron provide about half of the tonnage shipped at Swinoujscie and Szczecin, while general cargo provided 42% in 2007 (Table 9). A significant portion of general cargo is in transit to or from Germany, the Czech Republic, and other Central European countries. Containerised goods, steel exports and paper imports are important contributors to the general cargo tonnage. Both Swinoujscie and Szczecin have terminals for containers, general cargo and various bulk products.

Table 9: Cargo imported and exported at Swinoujscie and Szczecin.

<table>
<thead>
<tr>
<th>Cargo</th>
<th>2006</th>
<th>2007</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>5 088</td>
<td>4 322</td>
<td>23 %</td>
</tr>
<tr>
<td>Iron ore</td>
<td>1 349</td>
<td>1 086</td>
<td>6 %</td>
</tr>
<tr>
<td>Other bulk</td>
<td>2 676</td>
<td>2 899</td>
<td>15 %</td>
</tr>
<tr>
<td>Grain</td>
<td>1 813</td>
<td>1 516</td>
<td>8 %</td>
</tr>
<tr>
<td>Timber</td>
<td>42</td>
<td>65</td>
<td>0 %</td>
</tr>
<tr>
<td>General cargo</td>
<td>7 541</td>
<td>7 818</td>
<td>42 %</td>
</tr>
<tr>
<td>including by ferries</td>
<td>4 391</td>
<td>4 891</td>
<td>26 %</td>
</tr>
<tr>
<td>Petroleum products</td>
<td>698</td>
<td>1 018</td>
<td>5 %</td>
</tr>
<tr>
<td><strong>Total sales within port in Szczecin and Swinoujscie</strong></td>
<td><strong>19 207</strong></td>
<td><strong>18 725</strong></td>
<td><strong>100 %</strong></td>
</tr>
</tbody>
</table>

Source: Port Szczecin-Swinoujscie citing Statistical office in Szczecin

There are currently substantial areas of underutilised lands near the Swinoujscie port facilities, particularly East of the outer port entrance. Part of this land will be used for a large LNG terminal, whose construction has been initiated for completion in 2008 (section 5.4.3).
5.4.2 Ship traffic and potential use of LNG

RoRo and RoPax

Cargo by RoRo and RoPax at Swinoujscie increased by 11% from 2006 to 2007, continuing an increasing trend of several years. Two RoRo and five RoPax vessels are identified as serving Swinoujscie regularly, on several daily departures to Ystad (Sweden) and Trelleborg (Sweden) and less frequent departures to Copenhagen (Denmark), Nynäshamn (Sweden) and Rønne (Denmark). These vessels are operated by Polish companies Unity Line and Polish Baltic Shipping (Polferries). Three of the RoPax vessels are fairly new, whereas the other four vessels are past or approaching 30 years of age. They are likely to need replacement soon, and their replacements can be candidates for LNG fuel use.
Other vessels

Swinoujscie and Szczecin have several scheduled services of container feeder and general cargo ships on routes within the Baltic and North Seas, with weekly or less frequent departures. They include paper transports from Finland and Sweden.

As there are no bridges across the river Swina near Swinoujscie, local transport across the river is provided by ferries at two crossings. Several ferries require replacements over the next few years, and LNG propulsion for these has been proposed for consideration by the municipality.

5.4.3 Development of LNG bunkering

LNG bunkering at Swinoujscie is made particularly relevant by a large LNG import terminal being planned for Swinoujscie. The terminal will be located at short distance from the Eastern breakwater at the port entrance. The terminal will contribute to Poland’s general supply of
natural gas for the domestic pipeline system, with a view to reducing the country’s dependence on Russian imports. The LNG import project was initiated by PNGiG, which is the largest domestic oil and gas supplier in Poland. Ownership of the LNG terminal project has been placed with a company established for that purpose, whereas PNGiG will endeavour to secure LNG imports for the terminal. The project has entered FEED phase and is scheduled for completion in 2012.

The LNG terminal can be expanded in phases as demand requires. Most of the gas will be regasified for the Polish pipeline system, but preparations are made for exporting a lesser fraction as LNG on truck and rail, which will also enable supplies for LNG bunkering with relative ease.

Detailed plans for bunkering logistics at Swinoujscie must be worked out, with due consideration to the LNG terminal plans. For the eventuality that a dedicated terminal for bunkering will be needed, two locations have been identified as potentially suited: An area adjacent to the planned large terminal, and an existing marine fuel terminal on the West bank five km up the Swina.

5.4.4 Summary and conclusions: Future LNG bunkering in Swinoujscie

The amount of relevant scheduled shipping at Swinoujscie is distinctly less than at Lübeck, but there are some scheduled RoRo and RoPax services that can be considered for LNG. The large LNG terminal being planned there creates the possibility of a cost effective supply arrangement. Next steps towards developing Swinoujscie as part of a supply system for LNG bunkering include the following:

- Plans for LNG logistics for bunkering purposes at Swinoujscie, preferably including the possibility of liftings established at the LNG terminal;
- Establish the possibility of LNG purchase from the terminal;
- Pursue LNG as fuel for new local ferries across the Swina;
- Propose LNG as a fuel option for future ships to serve Swinoujscie on regular schedules.

5.5 Future LNG bunkering port: Stockholm

Stockholm is Sweden’s capital and largest city and has about 1.3 inhabitants, surrounding communities and suburbs included. It is located at a large archipelago and a short river connection to the Lake Mälaren.

5.5.1 Situation

The port authority of Stockholm (Stockholms Hamnar) encompasses port facilities at three distinct locations: The Stockholm city ports, Nynäshamn (60 km South of the city) and

13 Front end engineering & design
Kappelskär (90 km North-East of the city) (Figure 52). While not among the largest Baltic ports, Stockholm is an important port for passengers, cars and cargo across the Baltic to Finland, Russia and the Baltic states.

Ports in central Stockholm include 54 quays with a total length of 16,000m, including two container berths and nine RoRo berths. The ports in the City of Stockholm are used by large RoPax ferries to Finland and the Baltic states (Figure 53), as well as smaller ships serving the archipelago. Of more than 5000 annual calls at Stockholm’s central ports, 2/3 are RoPax ships, while cruise ships and other passenger ships provide much of the rest. There are limited...
amounts of container traffic at Stockholm’s central ports. Stockholm also has terminal facilities for refined petroleum products which are received by tanker ships.

Emissions to air as well as noise are sensitive issues in relation to ship traffic particularly in the central ports of Stockholm. The port applies differentiated port fees depending on fuel qualities used and other emissions related parameters, as an incentive for shipping companies to reduce their environmental impacts.

The port authority of Stockholm has launched a major redevelopment of the port facilities at Värtahamnen, at the North Eastern perimeter of central Stockholm. The purposes of this redevelopment are to streamline port operations in the city and to release land for attractive residential and commercial developments.

Kappelskär is a RoRo and RoPax terminal for fast connections to the Eastern shores of the Baltic as well as the Åland archipelago between Finland and Sweden (Figure 54). The emphasis here is on cargo movements by truck, and there is no rail connection. There are plans for expanding this port facility for more RoPax and RoRo traffic.

![Figure 54: The RoRo and RoPax terminal at Kappelskär, North of Stockholm.](Photo: Christian Lagereke - Stockholms Hamnar)

Nynäshamn, 60 km South of the city, currently has port facilities serving the island of Gotland and connections to Poland and Latvia (RoPax). It is also the site of a oil refinery, owned by Nynäs Petroleum, specialised in heavy-end products such as bitumen (asphalt). The port at Nynäshamn has rail connection.

The port at Nynäshamn is undergoing a major expansion for handling containers and rolling goods, with an adjacent industrial park and logistics centre. This is due to added demand in the region, and because of space and environmental constraints in the central Stockholm ports. The first phase of the expansion will be operational from 2010, while further expansions are indicated over a number of future years (Figure 55).

An LNG import terminal is planned at Nynäshamn, adjacent to the oil refinery, for operations from 2010. With 20,000m$^3$ of LNG tank capacity, the terminal will not be suited to receive large-scale LNG tankers (125,000+ m$^3$), but should be well suited to receiving LNG ships within the 7,500 – 12,000 size range (section 4.3).
5.5.2 Ship traffic and potential use of LNG

RoRo and RoPax

29 vessels, mainly RoPax, are identified as operating on regular schedules out of Stockholm. Their average age was 17.5 years, 8 were older than 25 years, and the rest were fairly evenly distributed in terms of age. The vessels serve daily departures to Finnish destinations as well as Tallinn and Riga (Estonia and Latvia). As the existing vessels need replacement, the new ones can be candidates for LNG use.

The leading shipping firms operating scheduled services from Stockholm are Silja Line, Viking Line and Finnlines. Polferries and Baltic Scandinavia lines have smaller positions.

For the 10 months of January-October 2008 in comparison with the same months in 2007, traffic from Stockholm across the Baltic increased by 2% for passengers (reaching 9.4 million passengers) and 1% for goods (reaching 5.7 million tons). A certain weakening of goods traffic was evident towards the end of the period, possibly attributable to world economic developments.

Other vessel categories

Container traffic in Stockholm’s port is currently limited to 30,000 – 40,000 TEU per year, predominantly for imported goods from outside Europe which is transferred to feeder services at large container ports such as Hamburg and Bremerhaven. Establishment of the new container and RoRo port at Nynäshamn provides a potential for significant increases in container traffic in the area, in response to a global trend towards more containerised trade. A market analysis by Transek (2005) stipulated three scenarios with annual container traffic in the Stockholm port district of 84,000 to 178,000 TEU, which in all cases represent significant increases resulting from the improved port facilities. Container feeder shipping has similar advantages as RoRo shipping as potential users of LNG.
Sweden has developed a significant utilisation of biogas as a renewable fuel for several purposes, including for buses and other vehicles. Use of biogas for such purposes presents many similar challenges as using LNG, and LNG may also supplement biogas for such purposes. Stockholm has a number of local boat services for the archipelago (Figure 56) as well as part of the city’s transport system. They include boats for passengers only or in combination with cars and cargo. The largest owner of such boats is a company owned by public institutions (Waxholmsbolaget). City politicians have expressed an interest in introducing boats fuelled by biogas.

5.5.3 Development of LNG bunkering

Small quantities of LNG have for some time been transported by truck from Norway to small terminals near Stockholm, where the LNG has been used as back-up for biogas as transport fuel for public vehicles. For small volumes or exceptional circumstances, such truck transports from Norway can be undertaken, but they are unlikely to be economic for any large volumes including fuel for any RoPax or RoRo vessel.

In a scenario of extensive conversion to LNG of RoPax as well as other scheduled ships in the Stockholm region, LNG bunkering operations must be provided for at the central port and Kappelskär as well as Nynäshamn. RoPax vessels run on tight schedules, and generally cannot make an extra stop for bunkering. Thus they need the bunkering to take place at the RoPax terminal. However, RoPax terminals often are busy areas where it may be difficult to find a suitable location for a LNG bunkering facility. Small tank capacities and/or bunkering barge for bunkering purposes adjacent to the three ports will probably be needed in the future, and it would be useful to identify possible locations soon.

5.5.4 Summary and conclusions: Future LNG bunkering in Stockholm

LNG bunkering in the three constituent ports of Stockholm will be relevant and a significant contribution to cleaner air for the city. The most important potential is with the RoPax ships serving Finnish and Baltic destinations. Increasing RoRo and container traffic related to expansions at Nynäshamn and Kappelskär also provide a growing potential for LNG, as well as local boats which may use a combination of LNG and liquefied biogas.

Effective local solutions for the bunkering operations need to be worked out, and may be a critical issue in the development of LNG bunkering particularly for RoPax vessels.
References


Appendix 1: LNG physical properties and units of measurement

Typical physical properties of LNG and natural gas
Values vary slightly with origin of product

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Liquid form (per m$^3$)</th>
<th>Gaseous form (per Sm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling point</td>
<td>Celsius</td>
<td>-162</td>
<td></td>
</tr>
<tr>
<td>Volume factor, gas / liquid</td>
<td>Sm$^3$ / m$^3$</td>
<td>615</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>kg / m$^3$</td>
<td>452</td>
<td>0.735</td>
</tr>
<tr>
<td>Energy content: Gross caloric</td>
<td>MWh / tonne</td>
<td></td>
<td></td>
</tr>
<tr>
<td>value (GCV)</td>
<td>kWh / m$^3$</td>
<td>6833</td>
<td>11.11</td>
</tr>
<tr>
<td>Energy content: Gross caloric</td>
<td>MJ / m$^3$</td>
<td>24600</td>
<td>40.00</td>
</tr>
<tr>
<td>value (GCV)</td>
<td>MJ / m$^3$</td>
<td>22361</td>
<td>36.36</td>
</tr>
<tr>
<td>CO$_2$ emissions per energy</td>
<td>g / MJ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>content (NCV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explosion limit, concentration</td>
<td>% (volume)</td>
<td>5 – 15 %</td>
<td></td>
</tr>
<tr>
<td>Ignition temperature</td>
<td>Celsius</td>
<td>595</td>
<td></td>
</tr>
</tbody>
</table>

Units of measurement applied to natural gas

Natural gas internationally is measured in a variety of units, which include units of energy as well as units of volume. Conversions can be made using the following factors:

**Energy conversions**

1 kWh (kilowatt-hour) = 3.6 MJ (Mega-Joules)
1 MMBTU (million British thermal units) = 1055.056 MJ (Mega-Joules)

British thermal units usually refer to energy measured as Gross calorific value (GCV).

**Volume conversions**

1 Sm$^3$ (standard cubic meter) = 35.3014 scf (standard cubic feet)
1 Nm$^3$ (normal cubic meter) = 1.0549 Sm$^3$ (standard cubic meter)

One Sm$^3$ of gas is the quantity of gas occupying one cubic meter at 15°C and 1.01325 bar.
One Nm$^3$ of gas is the quantity of gas occupying one cubic meter at 0°C and 1.01325 bar.