Abstract
As a response to increasing developments in emission regulations and their impacts on shipping globally, Lloyd’s Register has commissioned a study with the aim of understanding how a global LNG bunkering infrastructure may develop.

The overall concept for the study has been to review the case for LNG as a ship propulsion fuel for deep-sea shipping by examining:

- Shipping trade patterns and current bunkering trends by most ship types and size ranges.
- Fuel consumption requirements for power generation by most ship types and ship size ranges and the potential required volume requirements.
- Availability of existing and future LNG supply channels as a possible bunker fuel globally.
- Two stakeholders’ surveys (shipowners and port operators) to understand how key industry players will respond to the regulations in short-, medium- and long-term.

The main aim of the study is to assess and identify strategic ports and locations globally for LNG bunkering infrastructure facilities and compare them with current bunkering patterns. This study is being carried out in co-operation with the company Maritime Strategies International Ltd. Subsequently, Lloyd’s Register aims to facilitate and develop expert opinion on design and technology developments and propulsion options to support key industry players.

Introduction
The year 2015 is an important year for the shipping industry. At that time stricter requirements on fuel oil sulphur content will enter into force in the Emission Control Areas (ECAs). From 2015 the maximum allowable sulphur content in fuel oils is 0.10 % in the ECAs. The confirmed ECAs are Baltic Sea, North Sea and the North American Coast together with the US Caribbean. From 2020 a global requirement of maximum 0.50 % sulphur (outside ECAs) will apply.

It is a matter of fact that the vast majority of the world merchant fleet will enter ECAs during their lifetime and since more ECAs are expected to be introduced in the future, the subject is becoming even more relevant. In this respect action is required.

There are basically three main options for future compliance with the above:

- Operation on low sulphur fuel oil/marine gas oil (MGO).
- Operation on heavy fuel oil (HFO) with an exhaust gas scrubber.
- Operation on liquefied natural gas (LNG) or alternative fuels.

In addition to the above-mentioned options there are indeed more alternative fuels (e.g. methanol, DME, nuclear etc.), but currently the general perception is that the above-mentioned are the main options.
Lloyd’s Register considers all three options as being feasible and some will be more appropriate for some ship types than others. Choice of compliance option is very much dependent on ship type and trade pattern, i.e. range, availability of LNG, percentage of expected time in ECAs, investment costs etc. Or in other words: LNG as fuel is a solution not the only solution.

Another important aspect when talking LNG as fuel is the whole infrastructure and supply chain. This is considered as a significant barrier to the widespread adoption of LNG as fuel. As many are aware there is a kind of chicken and egg situation. The gas providers/bunker suppliers are not very keen to invest in the infrastructure necessary to supply the merchant fleet with LNG if the need from the shipowners is not there and will therefore wait to invest until sufficient mass of demand is present. On the other hand the shipowners do not wish to invest in LNG-fuelled ships if the LNG is too difficult to obtain.

Objectives and Methodology of the LNG Bunkering Infrastructure Study

Lloyd’s Register has commissioned a study with the aim of understanding how LNG bunkering infrastructure may develop. Therefore our overall vision is that the study will allow Lloyd’s Register to support our clients with planning the adoption of LNG as fuel for deep-sea shipping.

The reduction of emissions from shipping needs to be approached from different geographical levels, locally with respect to air pollution from ships at ports, regionally through emission control areas and globally through global limits and coordinated action between shipbuilders, designers, shipowners, LNG suppliers, bunker suppliers and ports.

This study is looking at the subject from a global perspective and assessing the opportunities for LNG bunkering globally. In the study a top down approach has been taken in order to provide a perspective on future LNG fuel demand in deep-sea trades; looking at trading patterns, bunkering demand and LNG supply availability issues in order to derive the demand. A model to forecast the demand for LNG based on different scenarios will provide an outlook for the newbuilding demand in the future. The stages of the study are shown in Figure 1.

The overall objective is to review the case for LNG as a fuel for deep-sea shipping by:

- Defining the main global trade routes by deep-sea ship type and size range for containerships, dry bulk, tankers and passenger (cruise) ships.
- Analysis of the main global trade patterns and current bunkering hubs.
• Analysis of the distance and average bunker consumption per main trade route and equivalent LNG consumption.
• Analysis of the current global bunkering locations, looking particularly at where the main bunkering hubs are, relative to trade routes.
• Identification and mapping of all the LNG export and import terminals currently in operation and due to be opened in the future, relative to main global bunkering hubs.
• Stakeholders’ surveys (shipowners and ports) to understand how key industry stakeholders respond to the sulphur controls in the short, medium and long-term.
• Future demand for LNG-fuelled deep-sea ships and volumes of LNG consumed on deep-sea trade routes based on a proprietary interactive model.

The conclusions of the study will provide an assessment of the potential market size for LNG-fuelled deep-sea ships based on a range of assumptions on newbuilding demand and market penetration of LNG-fuelled ships under different scenarios. This assessment will be based on an interactive spreadsheet-based calculation model.

A part of the analysis work and collection of data etc. has been carried out by Maritime Strategies International Ltd. (MSI) on behalf of Lloyd’s Register. The study is being completed in the spring of 2012.

**Delimitations of the Study**

The study does not look at the technology behind LNG-fuelled ships or the onshore supply technology for LNG bunkering, although developments in technology as a driver of LNG as fuel adoption for ships are considered. Analysis of the pricing and pricing mechanisms of fuel is beyond the scope of this study although pricing is referred to within this study.

**Shipping Trade Routes**

The global deep-sea trades for containerships, oil tankers and bulk carriers were assessed based on a simple tonne-mile calculator extracted from MSI’s models covering the containership, dry bulk and tanker sectors. For cruise ships the movements of every cruise ship in the fleet was analysed to identify the top routes/operating areas, see Table 1. In order to make the development of the model practical the main routes per ship type and size were selected with reference to the ECA transit/proximity and likelihood of LNG bunker availability.

<table>
<thead>
<tr>
<th>Bulk Carriers</th>
<th>Oil Tankers</th>
<th>Containerships</th>
<th>Cruise Ships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia – China</td>
<td>Middle East – S Asia</td>
<td>Far East – Europe Transatlantic Transpacific</td>
<td>Asia</td>
</tr>
<tr>
<td>Europe – N America</td>
<td>W Europe – N America</td>
<td></td>
<td>N Europe/Baltic</td>
</tr>
<tr>
<td>Australia – Japan</td>
<td>Middle East – China</td>
<td></td>
<td>Carib/Central America</td>
</tr>
<tr>
<td>Europe – Asia</td>
<td>W Africa – N America</td>
<td></td>
<td>Latin America</td>
</tr>
<tr>
<td>Latin America – Europe</td>
<td>Middle East – S Europe</td>
<td></td>
<td>Middle East</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>N America (E &amp; W Coast)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Oceania</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>S Eur/N Africa/East Med</td>
</tr>
</tbody>
</table>

*Table 1. The main trade routes/areas for the ship types considered.*

Clearly these are not the only amenable routes. For example, in the container sector there is likely to be significant newbuilding for deployment on the north-south trades (and feeder trades as well) which will provide opportunities for deployment of LNG technology.
Figure 2 illustrates the volume of global ship movements in a one-year period showing the network of links between ports and regions.

Figure 2. Global ship movements per year.

Current Demand for Bunkers

Figure 3 shows the location of the main bunkering hubs and location of the LNG importing and exporting terminals. Clearly there is a direct correlation between the location of primary bunkering hubs and the main shipping trade lanes. Also LNG import and export terminals are located either at these bunkering locations or close to them therefore allowing for the supply of LNG to the primary bunkering hubs.

Figure 3. Location of the main bunkering hubs and LNG terminals.

In 2010 global bunker demand was abt. 232 Mt [MSI, 2011]. This is well in line with IEA estimate of 235 Mt in 2010. The total global bunker demand represents around 5% of total oil product demand in 2010 with HFO accounting for 76% of bunkering and 24% for MGO [IEA, 2011]. Demand for MGO is highly concentrated around ECAs and is negligible elsewhere.

The distribution of bunker oil throughput by region is shown in Figure 4. Singapore, NW-Europe and the Persian Gulf account for about half of bunkering throughput globally. Looking more closely into the locations of bunkering, Table 2 shows the top 10 global bunkering locations and throughput. Singapore is the largest of the global bunkering ports.
and is located on the main trade lanes between Europe, Middle East and the Far East. These top 10 ports account for almost 40% of the global bunkering volume throughput.

**Distribution of Global Bunkering Demand per Region**

<table>
<thead>
<tr>
<th>Region</th>
<th>Market Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>13%</td>
</tr>
<tr>
<td>North West Europe</td>
<td>15%</td>
</tr>
<tr>
<td>Persian Gulf</td>
<td>12%</td>
</tr>
<tr>
<td>OECD Mediterranean</td>
<td>9%</td>
</tr>
<tr>
<td>Rest of Asia</td>
<td>7%</td>
</tr>
<tr>
<td>South America Atlantic</td>
<td>7%</td>
</tr>
<tr>
<td>North America East</td>
<td>6%</td>
</tr>
<tr>
<td>South Korea</td>
<td>4%</td>
</tr>
<tr>
<td>China</td>
<td>4%</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>3%</td>
</tr>
<tr>
<td>North America West</td>
<td>3%</td>
</tr>
<tr>
<td>Other regions (&lt; 2% each)</td>
<td>17%</td>
</tr>
</tbody>
</table>

*Figure 4. Distribution of global bunker locations.*

<table>
<thead>
<tr>
<th>Port</th>
<th>Bunker throughput (Mt)</th>
<th>Market share of the top 10 ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>34.0</td>
<td>38%</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>13.0</td>
<td>15%</td>
</tr>
<tr>
<td>Fujairah</td>
<td>9.5</td>
<td>11%</td>
</tr>
<tr>
<td>Antwerp</td>
<td>6.1</td>
<td>7%</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>5.4</td>
<td>6%</td>
</tr>
<tr>
<td>Gibraltar</td>
<td>5.0</td>
<td>6%</td>
</tr>
<tr>
<td>Korea (Busan)</td>
<td>4.6</td>
<td>5%</td>
</tr>
<tr>
<td>West Africa</td>
<td>4.1</td>
<td>5%</td>
</tr>
<tr>
<td>Tokyo Bay</td>
<td>3.5</td>
<td>4%</td>
</tr>
<tr>
<td>Iran</td>
<td>3.1</td>
<td>3%</td>
</tr>
</tbody>
</table>

*Table 2. Top 10 global bunker locations by HFO throughput.*

Some market observers say that there will not be enough low-sulphur fuel/MGO supplies to meet expected demand. This too will likely lead to a rise in product prices. For this study we have assumed that bunker demand will rise from abt. 232 Mt in 2010 to abt. 430 Mt based on MSI’s forecast for the development of the global fleet up until 2025.

A survey of ship owners was carried out to get a view of their deep-sea bunkering locations along the main trade routes. *Figure 5* shows their primary bunkering locations for the deep-sea ships of the owners surveyed. As is clear from the graph, about one third of those bunkering locations identified (9 of 28) are in confirmed ECAs, therefore making the need for the ship owners to permanently reduce their emissions in the medium to long-term imperative. Comparing the current bunkering hubs to the location of the LNG terminals, it can be concluded that these are well-positioned.
Future Demand for HFO & LNG as a Fuel

In connection with the IMO regulations become more stringent shipowners are likely to gradually change fuel types and use mitigating factors in order to comply with the regulations. As mentioned above MGO is the first option for owners but future issues include supply availability, sourcing and most importantly price. Currently, MGO is abt. 300 USD/t more expensive than HFO and it is likely that this gap may increase further. The second option is abatement technologies which are primarily exhaust gas scrubbers. The increasingly more stringent regulations will force many owners to change their fuel type.

LNG Supply

Natural gas reserves are vast and widely dispersed globally compared to oil. MSI expects LNG cargo trade to rise to just under 500 Mt in 2025 compared to 219 Mt in 2010 corresponding to an increase from 9 %\(^1\) of natural gas demand to 13 % in 2025.

If – as an example – by 2025 25 % of current bunker volumes (58 Mt fuel oil) were to be converted to LNG (46 Mt), under the assumption that it is a viable option for deep-sea ships, this would increase global LNG cargo demand by abt. 10 % up to abt. 540 Mt.

Although there will be sufficient exportable surplus of natural gas to cater for demand for LNG as a fuel for ships, demand could rise quickly.

The Shipowner Survey

A shipowner survey was carried out among leading shipping companies to assess their likely adoption of LNG as a fuel and what timelines they are considering. 14 out of 26 companies responded to the survey. The information gathered showed the trading routes of each owner’s fleet by ship type and size and the options under consideration to mitigate ECA regulations in the short, medium and long-term. The survey also identified what other options shipowners were considering in terms of mitigating emissions.

\(^{1}\) Natural gas demand in 2010 was 2,858 mill. tonnes oil equivalents (TOE) and LNG cargo demand was 263 mill. TOE. Total LNG cargo demand is effectively LNG demand as there is no LNG storage and therefore all that is traded is consumed.
Based on the shipowner survey *Figure 6* shows clearly that LNG and dual-fuel engines are a long-term objective particularly for containership and cruise ship owners, but there are also a large proportion of ship owners who “don’t know” what they will do to deal with the emission regulations, especially tanker owners.

*Figure 6. Results from the shipowner survey.*
Fundamentally shipowners see the use of MGO as a short-term solution. Exhaust gas scrubbers are seen as a likely option to mitigate emissions. LNG offers a long-term option to deal with the ECA regulations and is seen as a solution particularly suited for ships on liner trades.

If there were clear goals, guidelines and intentions for supply then it is probable that the proportion of shipowners that do not know may turn to developing LNG-fuelled ships. Having said that, the future demand for LNG as a fuel may not be dependent on technology or availability of supply but quite simply on price which is likely to be a determinant of supply availability, which itself is already the key factor of existing bunkering locations. Bunkering hubs throughput is primarily driven by low competitive pricing, with location being a secondary driver of demand.

The Port Survey

The port survey examining the LNG bunkering infrastructure developments was completed by the end of 2011. The intention was to provide an assessment of the outlook of ports of LNG as a viable fuel option for deep-sea shipping and what plans they may have to provide LNG bunkering in the future. In total 25 ports were approached of which 14 responded.

Almost two-thirds (62%) of the ports see themselves as drivers of change in the use of LNG as a fuel and 54% of the ports have carried out research into LNG bunkering.

The further main results from the port survey are summarised in Figure 7 below.
Many of the respondent ports are ‘landlord ports’. As a result port services such as bunkering operations within the terminals are carried out by third-parties. Majority of the ports however agrees that they will have to provide the necessary regulatory environment for LNG bunkering. Subsequently, ports are considered to be key drivers in the development of LNG bunkering operations.

Furthermore, most ports conceded that any development of LNG bunkering in the port would have to be done alongside private investors and third-party operators (bunker suppliers etc.). The key driver of a change to LNG from the ports’ perspective is demand and therefore will have to be driven by the shipowners. European ports have carried out most work and research into LNG as fuel and provision of LNG bunkering facilities. Consequently, they have a clearer view that LNG bunkering is likely to happen starting with short-sea shipping and may eventually cascade into deep-sea trade facilitated by regulations. However, the key driver, demand, is highly dependent on pricing of LNG and its comparable price difference with competing fuels like HFO and MGO.

It is quite obvious from the responses that although ports know about the possibility of LNG as a fuel in the future, there is a consensus that it is still too early for the ports to offer firm answers on their plans as it simply does not feature in any long-term strategy but will be dealt with as soon as LNG becomes a clearer option as a marine fuel.

The Model
Based on the above collected information from the owners and ports, all the strands of this study will be brought together:

- Demand – the main trade routes, bunker consumption volumes and equivalent LNG.
- Supply – availability (exportable surplus).
- Bunker locations – identified locations for LNG bunkering, most suitable ships for deep-sea LNG bunkering.
- Factors that will drive LNG bunkering in deep-sea shipping identified through the two stakeholders surveys.

Figure 7. Results from the port survey.
This has lead to the development of a model that allows sensitivities to different input assumptions (factors driving LNG bunkering demand and supply) to be tested. LNG bunkering demand on any given trade route is assumed to be a function of:

1. Regulatory pressure to burn cleaner fuels within designated waters,
2. Availability of LNG bunkers at key ports and
3. Deployment of newbuildings on selected trade routes.

The key components of the model are dynamic and interactive with the user able to change conditions based on a changing regulatory environment, technological developments or pricing of fuel and equipment. Overall this gives a view on demand for LNG-fuelled newbuildings up to 2025.

The model is currently subject for a validation being carried out both internally in LR and with external players in the industry.

**Conclusions**

As the global emissions regulations become more stringent demand for low sulphur fuel oil/MGO will increase but with limited capacity to cater for the increase in demand, supply is likely to be constrained. This will force owners to look at alternative sources of fuel or abatement technologies.

The result from the deep-sea shipowners’ survey shows that LNG-fuelled ships are a viable option in the long-term particularly for containerships and cruise ships. However, there is still some doubt among tanker owners with many saying they “don’t know” what mitigating technologies they will use in the future. Solutions will be ship type and trade route specific, i.e. LNG is a solution not the only solution.

Existing global bunkering ports are well positioned to supply LNG for ships with nearly all located close to a LNG import or export terminal and along the main trade routes. Some ports already have plans to develop LNG bunkering infrastructure.

The ports are aware of the LNG as a fuel possibility and they see demand, price and location near an ECA as the driving factors.

Lloyd’s Register is pleased to be in the fore front of the development of LNG as a fuel and we are already working with the industry partners in order to make this happen. Lloyd’s Register is looking very much forward to the finalisation and validation of the model in the spring of 2012 and the results will create a basis for the newbuilding market outlook as well.

**References**

International Energy Agency: “Medium-Term Oil and Gas Markets 2011”.
Maritime Strategies International: “LNG Bunkering in Deep-Sea Shipping, December 2011”.

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