Global potential of small-scale LNG distribution

A quick scan study

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Summary

During the last ten years, the application of natural gas as a transport fuel has become increasingly popular. Direct use of LNG, instead of compressed CNG, helps to extend the driving range of vehicles. This makes LNG an attractive fuel for shipping and (large) heavy-duty trucks, and a clean alternative for diesel. The essential supply chain for alternative applications of liquefied natural gas is commonly referred to as ‘small-scale LNG’ distribution (SSLNG), this way distinguishing it from the traditional large-scale intercontinental LNG transport. The International Gas Union (IGU) defines small-scale liquefaction and retail as facilities with a capacity of under 1 million ton of LNG per annum. Currently, small-scale LNG distribution infrastructure is under development in many countries for different transport segments. Its growth potential is still uncertain. The study concentrates on SSLNG off-take (retail) volumes for the pre-identified segments heavy-duty vehicles, the maritime sector and a specific part of the (stationary) electric power generation segment. The SSLNG liquefaction market is not addressed in this study.

The primary objective of this quick scan study is to determine the potential global market volumes for small-scale LNG in the period 2015-2025. The approach was based on the following steps. Firstly, the current conventional fuel volumes for the relevant substitution segments for SSLNG was determined. Secondly, describe the main drivers influencing the LNG uptake was described after which, thirdly, the LNG market shares in the future were estimated and the potential SSLNG volumes were calculated. This approach considers technical and economical independent variables, such as technical feasibility of applications, lifetime of vehicles and ships and fleet expansion rates. It does not consider future fuel price estimations. This approach is taken since fuel prices are quite dependent on other factors besides the potential volumes and availability.

Relevant markets for small-scale LNG substitution are selected by evaluating conventional fuel consumption projections per segment from key studies. It shows that the truck market is the largest relevant substitution market for small-scale LNG, reaching a fuel volume of about 62% of the total identified small-scale LNG substitution market volume in 2025. Global maritime fuel consumption, amounting to a share of 17% of fuel volume, is a sizeable market. It will become especially interesting after 2020 or 2025, when global fuel sulphur requirements will be lowered to 0.5%. Shipping in ECA (Emission Control Areas) is a small but important segment, because of the stringent environmental requirements. The oil-fuelled electric power generation market is with 17% of the identified LNG volume relatively large as well.

For road transportation, fuel cost is the main driver which is strongly dependent on excise taxation. Stringent pollutant emissions requirements such as Euro VI and US 2010 can relatively easily be met with natural gas depending on the engine technology, but also for diesel fuel the emission control technologies are well developed. One of the main drivers for LNG as a ship bunker fuel is emission regulation in combination with expected competitive fuel pricing. This applies to both shipping in ECA as well as for global shipping. $SO_x$ requirements will always be met with LNG with its very low sulphur content. In addition, $NO_x$ requirements are often met depending on the requirement and the engine technology.
For new LNG-fuelled heavy-duty (HD) vehicles a maximum potential market share for truck sales of 26% for Europe in 2015 has been determined based on energy share and estimated market share per vehicle segment. Subsequently, the determined European market share is projected on Asia-Pacific, North America and Middle-East. For Latin America and for ‘rest of the world’ lower percentages are estimated (respectively 10% and 5%). Consequently, the potential volume of LNG off-take was calculated for the total HD vehicle segment per region in 2025, by using a fleet expansion rate of 5% per year, and a replacement rate of 12% per year. For ECA ships, it is assumed that a maximum of 50% of newly-built ships is potentially suitable for fuelling by LNG. This means that in 2025, the percentage of LNG-fuelled ships is potentially 27% to 33% depending on the economic growth or fleet expansion rate (2.5 or 5%). To estimate the potential LNG market share in the deep sea or global maritime segment, a distribution of energy consumption over size categories is made. For each size category a potential LNG share for newly-built ships is estimated. For ‘oil-powered’ electric power generation a direct share is estimated per region in the world, not taking into account life time or expansion of these power stations.

With a maximum volume of 192 MTOE\(^1\) and 16% of the total energy consumption for HD vehicles in 2025, trucking is the largest global potential market for small scale LNG substitution. Since the share of excise duties in road fuel prices can be large (e.g. EU), the tipping point of natural gas versus diesel strongly depends on local tax regimes. There is additional potential for SSLNG when supplied as CNG at fuel stations. In the shipping segment, the second largest market, a maximum substitution of 17% of the conventional maritime fuel by LNG can be achieved, representing a volume of 55 MTOE per annum in 2025. Specifically shipping in ECAs is a small but important segment with 12 MTOE per annum in 2025, driven by the future stringent environmental regulations. Substitution of fuel-oil at electric power generations with SSLNG can be sizeable market, with an estimated volume of 33 MTOE in 2025.

In order to create better understanding of how the potential for SSLNG can be utilized, it is recommended to assess the local geographical aspects of dense logistical corridors for HD vehicles. Additionally, the potential for LNG-fuelled stationary electric power generation needs to be detailed, taking into account the production sizes, political influences and environmental advantages. For an optimal utilization of the SSLNG infrastructure, it is recommended to assess business cases of multi-segment supply per region e.g. combined LNG supply for bunkering, stationary power and trucking. The latter can even be enhanced when combined LNG-CNG (LCNG) fuelling stations, and potential replacement of LPG fuelled vehicles and domestic use (heating, cooking) is considered. Therefore, detailed investigation of multi-segment SSLNG supply chain is recommended.

\(^1\) MTOE = Million Tons of Oil Equivalent. 1 MTOE/annum = 0.854 MTPA-LNG based on ratios of Lower Combustion Values
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Appendices
A Current and future LNG market and prices
B Policies, initiatives and programs influencing LNG market development in main world regions
C Scenario studies
1 Introduction

1.1 Background

For decades, natural gas has been liquefied to LNG in order to transport it from continent to continent in large sea-going vessels. In this traditional purpose, LNG is re-gasified and injected into the pipe grid at the import terminal and used for conventional purposes such as heating, cooking and power production.

During the last ten years, the application of natural gas as a transport fuel has become increasingly popular. Direct use of LNG, instead of compressed CNG, helps to extend the driving range of vehicles. This makes LNG an attractive fuel for shipping and heavy-duty long-haulage trucks, and a clean alternative for diesel.

The essential supply chain for alternative applications of liquefied natural gas is commonly referred to as ‘small-scale LNG’ distribution (SSLNG), this way distinguishing it from the traditional large-scale intercontinental LNG transport. Currently, small-scale LNG distribution infrastructure is under development in many countries for different transport segments - with its growth potential still being uncertain.

The Netherlands has available large reserves of natural gas. The Netherlands Enterprise Agency RVO, aiming to improve opportunities for entrepreneurs, therefore has taken an interest in the potential of LNG and asked TNO to perform a quick scan study on the global potential of small-scale LNG.

1.2 Goal of this quick scan study

The goal of this quick scan study is to determine the potential global market volumes for small-scale LNG in the period 2015-2025. The study concentrates on SSLNG off-take (retail) volumes for the pre-identified segments heavy-duty vehicles, the maritime sector and a part of (stationary) electric power generation segments. The latter segments are chosen as relevant markets for substitution of conventional fuels (Fuel-oil) for LNG, typically supplied in smaller quantities than traditionally has been done.

In other words, the study identifies which retail LNG business cases (segment per region) are potentially attractive in terms of volumes and growth rate. Because of the limited scope of this project, recommendations will point out where additional market surveys are needed and opportunities can be expected. Also, it signals hurdles that are likely to be encountered.

The International Gas Union (IGU) defines small-scale liquefaction and retail as facilities with a capacity of under 1 million ton of LNG per annum (1 MTPA)\(^2\). 1 MTPA is the typical yearly consumption of 25,000 long-haulage trucks or one 200 MW electric power plant. This study addresses only the retail of LNG.

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\(^2\) Small-scale LNG is also referred to as “LNG retail” or “break-bulk LNG”.

\(^3\) 1 Million Tons of Oil Equivalent (MTOE) per annum = 0.854 MTPA-LNG based on ratios of Lower Combustion Values.
1.3 Approach and structure of the report

The study will assess the potential volumes of small-scale LNG (SSLNG) based on several technical and economical independent variables (drivers), such as technical feasibility of applications, lifetime of vehicles and ships and fleet expansion rates. This assessment is not based on price estimations, as it is thought these prices are quite dependent on other factors besides the potential volumes and availability.

The assessment follows the following steps, addressed in consecutive sections of the report:

- Step 1: Determination of total fuel volumes for the relevant segments SSLNG substitution (chapter 2);
- Step 2: Description of main drivers influencing the LNG uptake (chapter 3);
- Step 3: Estimation of LNG market shares in the future and calculation of potential SSLNG volumes (chapter 4).

Chapter 5 states the conclusions and recommendations.

Additionally, this report contains background information (Appendices A, B and C) on the main global regions, global drivers and earlier scenario studies. The information on the main global regions includes developments of future LNG prices and conventional fuel prices and policies, initiatives and programs stimulating or affecting small-scale LNG.
2 Relevance segments for small-scale LNG substitution

The total potential of small-scale LNG is investigated by assessing the current and future volumes of conventional fuels in fuel consuming segments that are potentially suitable for small-scale LNG substitution. In this quick scan study the following segments were assumed to be technically the most relevant:

- Road truck transport
- Inland shipping
- Shipping in Emission Control Areas
- Shipping outside Emission Control Areas
- Oil-fuelled (Fuel-Oil/Diesel) stationary electric power generation

The first four markets are all related to transport. The current and future volumes of conventional fuels in these markets will be discussed in section 2.1. For small scale LNG substitution in the power generation market we have chosen the current oil-diesel fuelled stationary power plants as being the most relevant for being replaced by small scale supplied LNG. In this study we assumed that the coal fired power generation is more likely to be replaced by larger LNG supplies. It should be noted that the power generation market can be served by small-scale LNG as well as large-scale LNG. The small-scale LNG potential in this market is investigated in section 2.2.

2.1 Energy demand for transportation per region and per segment

The total world energy demand for transport per sub-sector according to the IEA (IEA, 2013) New Policies Scenario is presented in Figure 1.

Figure 1: World transport oil demand by sub-sector in the New Policies Scenario. Source: IEA, 2013. PLDV=passenger cars and light-duty vehicles.

The energy demand for commercial transport for 2010, 2025 and 2040 per region and per sub-sector according to (ExxonMobil, 2014) is presented in Figure 2. The highest energy demand is currently in the Asia-Pacific and this is also the area with the highest projected growth. By 2040 the energy demand is expected to be more than two times larger than number 2 and 3; North America and Europe. The Asia-
Pacific includes the large countries such as China, India, Russia, Japan, South Korea and Australia. Growth rate in Asia-Pacific and Latin America is approximately 3% per year. In North America and Europe this is limited to 0.3 to 0.6% per year.

![Commercial transportation demand by region](image)

Figure 2: Energy demand by region. Source: ExxonMobil, 2014.

1 million barrels per day = 0.146 MTOE, Million Tons of Oil Equivalent

The information from Figure 2 is summarized in Table 1 for the sub-sectors ‘Heavy-Duty’, ‘Marine’ and ‘Rail’. Table 1 shows that over 70% of fuel is used for heavy-duty on-road transportation, about 20% is used for marine application and the remaining 6-7% is used for rail. Rail transport is mainly fuelled by electric energy, heavy-duty vehicles are mainly fuelled by diesel fuel and marine is mainly fuelled by HFO, MDO and MGO.

Table 1: Overview energy demand derived from (ExxonMobil, 2014).

<table>
<thead>
<tr>
<th>MTOE/year*</th>
<th>Heavy-Duty</th>
<th>Rail</th>
<th>Marine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2025</td>
<td>2010</td>
</tr>
<tr>
<td>Asia-Pacific</td>
<td>254</td>
<td>388</td>
<td>30</td>
</tr>
<tr>
<td>North America</td>
<td>187</td>
<td>217</td>
<td>15</td>
</tr>
<tr>
<td>Europe</td>
<td>157</td>
<td>179</td>
<td>13</td>
</tr>
<tr>
<td>Latin America</td>
<td>90</td>
<td>134</td>
<td>7</td>
</tr>
<tr>
<td>Middle East</td>
<td>105</td>
<td>142</td>
<td>7</td>
</tr>
<tr>
<td>Rest of the world</td>
<td>97</td>
<td>164</td>
<td>13</td>
</tr>
<tr>
<td>Total</td>
<td>889</td>
<td>1225</td>
<td>86</td>
</tr>
<tr>
<td>Total %</td>
<td>71%</td>
<td>74%</td>
<td>7%</td>
</tr>
</tbody>
</table>

*Trucks, Rail, and Maritime volumes are based on the estimations from the ExxonMobil graph (~5% accurate). MTOE = Million Tons of Oil Equivalent; 1 MTOE=41.87 PJ

For marine, it is important to differentiate between short-sea shipping and deep-sea shipping. This is done based on an overview on 2020 worldwide bunkering from (IBIA, 2011), Figure 3. The totals of this bunkering overview are compared to the totals in Table 1.
These line up quite nicely:

- Total ExxonMobil: for 2010 and 2025 respectively 276 and 329 million MTOE\(^4\);
- Total IBIA for 2020: 316 million MTOE.

![ECA bunker remains a modest portion of total bunker demand in most regions by 2020](image)

Figure 3: Global and ECA bunker volumes for 2020. Source: IBIA, 2011.

From Figure 3 the split between global and ECA bunker fuel is calculated. Table 2 shows the results.

Table 2: Percentage of fuel bunkered for global and for ECA navigation, year 2020.

<table>
<thead>
<tr>
<th>2020</th>
<th>Global</th>
<th>ECA</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>78%</td>
<td>22%</td>
</tr>
<tr>
<td>Latin America</td>
<td>96%</td>
<td>4%</td>
</tr>
<tr>
<td>Europe</td>
<td>72%</td>
<td>28%</td>
</tr>
<tr>
<td>Middle East</td>
<td>95%</td>
<td>5%</td>
</tr>
<tr>
<td>Asia-Pacific</td>
<td>94%</td>
<td>6%</td>
</tr>
<tr>
<td>Africa, CIS and others</td>
<td>89%</td>
<td>11%</td>
</tr>
</tbody>
</table>

The ratios shown in Table 2 are subsequently applied to the totals for marine for 2025 from Table 1. The results can be found in Table 3.

---

\(^4\) MTOE = Million Tons of Oil Equivalent: 1 MTOE=41.87 PJ = 6.84 million Barrels of Oil Equivalent
Table 3: Fuel quantities for 2025 for global and ECA marine.

<table>
<thead>
<tr>
<th>2025 MTOE</th>
<th>Global</th>
<th>ECA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia-Pacific</td>
<td>140</td>
<td>9</td>
</tr>
<tr>
<td>North America</td>
<td>23</td>
<td>7</td>
</tr>
<tr>
<td>Europe</td>
<td>48</td>
<td>19</td>
</tr>
<tr>
<td>Latin America</td>
<td>29</td>
<td>1</td>
</tr>
<tr>
<td>Middle East</td>
<td>28</td>
<td>2</td>
</tr>
<tr>
<td>Rest of the world</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>289</td>
<td>40</td>
</tr>
</tbody>
</table>

2.2 Energy demand for small-scale electricity generation

In this study only a part of the electric power stations is being considered as relevant for conversion to natural gas that is being supplied by a SSLNG chain. Therefore, we selected the power segment which is currently oil-fuelled (diesel-HFO) for which the fuel supply volume, when converted to LNG, would not exceed the definition of SSLNG, meaning that the annual consumption is lower than 1 million tons (<1 MTPA) according to the IGU definition. For that reason for example coal fired power stations are not considered as a substitution segment for SSLNG. Here we assumed that the latter segment would more likely be supplied with a more traditional large-scale supply chain. Suitable oil-fuelled power stations on remote decentralized locations (along coast) such as on islands are relevant for conversion to LNG, especially when conversion to dual-fuel operation is possible. This would then also result in air quality benefits in a number of cases. Additional demand will come from most of the energy-intensive industries, such as aluminium smelters, steel factories and cement production. Out-of-the-box demand is estimated to come from non-energy-based parties, such as petrochemicals.

A global overview of the fuel used for electricity generation is presented in Table 4. Especially a part of the oil-fuelled segment could possibly be converted to SSLNG. Table 4 shows that only 5% of the global power generation is oil-fuelled. The energy input from the oil can be calculated from the TWh electricity production numbers by assuming an average efficiency of the energy conversion of 40% and converting the units from TWh to GJ or MTOE. 40% is considered realistic for the usually relatively small oil fuelled power stations. Consequently, for converting TWh values to MTOE the following equations apply:

- TWh × 85980 / Efficiency [to obtain TOE energy input]
- TWh × 0.0860 / Efficiency [to obtain MTOE energy input]

5 TOE: Tons of Oil Equivalent: 1 TOE=41.87 GJ (lower combustion value)
6 MTOE = Million Tons of Oil Equivalent: 1 MTOE=41.87 PJ
Table 4: Overview of fuel used for power generation. Source: IEA, 2013.

<table>
<thead>
<tr>
<th>Region</th>
<th>Oil (TWh)</th>
<th>Bio energy (%)</th>
<th>Gas (TWh)</th>
<th>Coal (TWh)</th>
<th>Other sources (TWh)</th>
<th>Total electricity (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>1062</td>
<td>5</td>
<td>424</td>
<td>4847</td>
<td>9139</td>
<td>6641</td>
</tr>
<tr>
<td>Europe</td>
<td>74</td>
<td>2</td>
<td>153</td>
<td>696</td>
<td>884</td>
<td>1450</td>
</tr>
<tr>
<td>OECD Americas</td>
<td>102</td>
<td>2</td>
<td>95</td>
<td>1277</td>
<td>2006</td>
<td>1844</td>
</tr>
<tr>
<td>Non OECD Asia</td>
<td>150</td>
<td>2</td>
<td>82</td>
<td>641</td>
<td>4825</td>
<td>1258</td>
</tr>
<tr>
<td>OECD Asia Oceania</td>
<td>173</td>
<td>9</td>
<td>44</td>
<td>547</td>
<td>641</td>
<td>414</td>
</tr>
<tr>
<td>Middle East</td>
<td>320</td>
<td>38</td>
<td>0</td>
<td>504</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Africa</td>
<td>71</td>
<td>10</td>
<td>1</td>
<td>228</td>
<td>263</td>
<td>129</td>
</tr>
<tr>
<td>Latin America</td>
<td>137</td>
<td>12</td>
<td>43</td>
<td>162</td>
<td>22</td>
<td>745</td>
</tr>
<tr>
<td>Eastern Europe/Eurasia</td>
<td>39</td>
<td>2</td>
<td>4</td>
<td>681</td>
<td>412</td>
<td>580</td>
</tr>
</tbody>
</table>

The energy input is presented in Table 5 below. Compared to the energy consumption for road transportation, it can be concluded that overall the energy of oil-powered electricity production is about 50% of the energy used for truck transportation. This varies, however, considerably: for Middle East it is about 66% while for North America and Europe, it amounts to some 10%.

As explained earlier, only a part of this electricity generation is considered to be relevant for substitution by SSLNG. Besides the commercial arguments (gas versus oil pricing) for substitution, other location specific drivers can be present such as local air quality requirements, availability of existing LNG infrastructure, geographical situation, strategic energy reserves policies and availability of residual fuels. In case of the oil-fuelled power segment it is important to realise that replacement by SSLNG becomes more attractive when a plant’s capacity is utilized to the maximum. Due to higher CAPEX of SSLNG storage compared to diesel, plants that are only utilized for emergency power are less attractive for conversion, commercially seen.

As a result SSLNG is most likely to be considered for decentralized (island and remote areas) base-load power stations capacity. For the latter assumption it needs to be remarked that there is always a tipping point; with increasing utilization of a SSLNG distribution network a fixed pipe-grid becomes the most viable and safe solution.
Table 5: Overview of oil-fuelled electricity generation. TWh values from Table 4 are converted assuming a power station efficiency of 40%.

<table>
<thead>
<tr>
<th>Oil Region</th>
<th>Electricity in TWh</th>
<th>Energy input MTOE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>1062</td>
<td>228</td>
</tr>
<tr>
<td>Europe</td>
<td>74</td>
<td>16</td>
</tr>
<tr>
<td>OECD Americas</td>
<td>102</td>
<td>22</td>
</tr>
<tr>
<td>Non OECD Asia</td>
<td>150</td>
<td>32</td>
</tr>
<tr>
<td>OECD Asia Oceania</td>
<td>173</td>
<td>37</td>
</tr>
<tr>
<td>Middle East</td>
<td>320</td>
<td>69</td>
</tr>
<tr>
<td>Africa</td>
<td>71</td>
<td>15</td>
</tr>
<tr>
<td>Latin America</td>
<td>137</td>
<td>29</td>
</tr>
<tr>
<td>Eastern Europe/Eurasia</td>
<td>39</td>
<td>8</td>
</tr>
</tbody>
</table>

* Million Tons of Oil Equivalent

2.3 Overview total energy consumption different markets

The results of the previous sections are combined in order to get an overview of the markets suitable for small-scale LNG. The information from the Table 1, Table 3 and Table 5 is summarised in Table 6. From Table 6 it can be concluded that the on-road commercial transportation, with 1225 MTOE in 2025, is by far the largest market. Maritime and oil-fuelled electric power generation are much smaller, both amounting to approximately 330 MTOE in the year 2025. The energy consumption shown for rail includes both electric trains as well as diesel trains. A split between these fuels is desired in order to assess the scope for LNG which would primarily replace diesel fuelled trains. In any case, with 7 MTOE/year rail appears to be a limited market for small-scale LNG. Chapter 4 will analyse the share of volumes that can be fuelled with small-scale LNG in a more detailed fashion.
Table 6: Overview of total energy consumption for markets suitable for small-scale LNG.

<table>
<thead>
<tr>
<th>MTOE/year</th>
<th>Trucks</th>
<th>Rail*</th>
<th>Maritime</th>
<th>Oil fuelled electric power</th>
<th>Total 2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia-Pacific</td>
<td>254</td>
<td>388</td>
<td>30 37</td>
<td>112 140 9 69 106</td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>187</td>
<td>217</td>
<td>15 15</td>
<td>37 23 7 22 26</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>157</td>
<td>179</td>
<td>13 13</td>
<td>67 48 19 16 18</td>
<td></td>
</tr>
<tr>
<td>Latin America</td>
<td>90</td>
<td>134</td>
<td>7 7</td>
<td>22 29 1 29 44</td>
<td></td>
</tr>
<tr>
<td>Middle East</td>
<td>105</td>
<td>142</td>
<td>7 7</td>
<td>22 28 2 69 94</td>
<td></td>
</tr>
<tr>
<td>Rest of the world</td>
<td>97</td>
<td>164</td>
<td>13 13</td>
<td>15 20 2 24 41</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>889</td>
<td>1225</td>
<td>86 94</td>
<td>276 289 40 229 327</td>
<td></td>
</tr>
<tr>
<td>Total %</td>
<td>62%</td>
<td>5%</td>
<td>15% 2%</td>
<td>17% 100%</td>
<td></td>
</tr>
</tbody>
</table>

* Diesel + electric

2.4 Conclusions

In this chapter we selected relevant energy markets for substitution by small-scale LNG supply by its size.

With respect to relevant markets for small scale LNG substitution the following conclusions can be drawn per segment:

- The truck market is the largest relevant substitution market for small-scale LNG, reaching a fuel volume of about 62% of the total identified small-scale LNG substitution market volume in 2025.
- Global maritime, amounting to a share of 17% of fuel volume, is a sizeable market. It will become especially interesting after 2020 or 2025, when global fuel sulphur requirements will be lowered to 0.5%.
- Shipping in ECA is a small but important segment, because of the environmental requirements. More ECA’s may be put in place which would lead to a larger fuel share than currently projected.
- With 17%, the oil-fuelled electric power generation market is relatively large. Precise volumes that can be captured by small-scale LNG are however still uncertain. The same applies to rail since the 5% share includes both diesel as well as electric trains.
3 Drivers influencing the LNG market

This chapter summarizes the most important factors influencing the LNG market. For this, a number of scenario studies was briefly analyzed, a summary of which can be found in Appendix C.

3.1 Opportunities and barriers

The following opportunities for small-scale LNG are identified:

- Switching to lower sulphur fuel, which is essential in order to meet future stringent sulphur regulation, is expected to increase oil-based-fuel prices. This would make LNG more attractive due to the likely lower price level compared to MGO.
- Existing opportunities for easy-to-realize small-scale LNG infrastructure by tying in to traditional large-scale LNG terminals with break bulk facilities (loading to small LNG carriers, LNG bunker vessels and truck and rail containers) and the presence of a suitable legal framework (safety and environmental regulations). Stringent pollutant emission requirements such as for ECA’s and inland transportation.
- Large market size of suitable segments such as for short-sea shipping, inland shipping and truck transportation.
- Growth rate of these segments at emerging economies and readiness to invest.
- National objectives for realizing (growth of) small-scale LNG networks, such as in Europe (by EU subsidies).
- Incentives for the realization of LNG infrastructure or for low emissions (such as lower harbour fees, green corridors, etc.).
- Attractive excise tax for NGV’s.

The following barriers for small-scale LNG are identified:

- poor economics of the initial LNG distribution; the infrastructure needs to be put in place but the number of ships and trucks in the early phase is too small to economically exploit the infrastructure (long payback period).
- current low price difference between LNG and the conventional fuel and uncertainties of fuel price after sulphur legislation. The LNG price needs to be lower because the LNG systems and supply infrastructure are generally more expensive than those for conventional fuels.
- Current surplus in transport capacity in some ship transport segments (e.g. inland shipping EU) cause poor investment climate for new builds.
- Because of their size, LNG tanks cannot be directly integrated within the ship hull, contrary to diesel tanks. Moreover, the use of LNG in ships requires special engines. Because of this, the best opportunity for ship owners to switch to LNG as fuel is with the purchase of new ships. This in turn means that the number of new ships being built per year gives a good indication for the maximum growth rate of the LNG fleet.
3.2 Emissions legislation

3.2.1 Heavy-Duty vehicles

As pollutant emission, sulfur limits have been implemented for several decades. In the USA, this started even in the seventies of the last century for passenger cars. The massive introduction of exhaust catalysts led to more stringent fuel specifications, especially with respect to the fuel sulfur content. For diesel trucks and cars, this started at the beginning of this century. In most countries the diesel fuel sulfur content was initially set to a maximum of 350 to 500 ppm, then it was reduced to 50 ppm and as a final step to 10-15 ppm. Table 7 gives an overview of the current diesel fuel sulfur levels in the different world regions. For Brazil and China also the future steps are given. From the table, it can be concluded that currently, or within several years, a large part of the diesel fuel will virtually be sulfur-free (s<10ppm). This means that no significant SO₂ emission reduction is to be expected for automotive application.

Table 7: Diesel fuel sulphur content in different world wide regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>Year</th>
<th>Limit value ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>2006</td>
<td>15</td>
</tr>
<tr>
<td>Japan</td>
<td>2007</td>
<td>10</td>
</tr>
<tr>
<td>European Union</td>
<td>2009</td>
<td>10</td>
</tr>
<tr>
<td>Argentina</td>
<td>2011</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>2016</td>
<td>10</td>
</tr>
<tr>
<td>Brazil</td>
<td>2012</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>2013?</td>
<td>10</td>
</tr>
<tr>
<td>China</td>
<td>2011</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>2017</td>
<td>10</td>
</tr>
</tbody>
</table>

As greenhouse gas, methane emission is an important factor for emission regulation. Dependent on the engine technology, spark ignition or compression ignition (used for dual fuel), gas-fuelled engines can have a substantial methane emission. As a result, the applicable engine technologies depends on the exhaust emissions legislation and whether methane, CH₄ is included or not, as well as on the base engine technology that is commonly applied in the segment. In general for cars and HD vehicles, depending on the global region, limits are often applicable, while for shipping this is not the case. Sometimes for retrofit gas engine conversions, limits values are less stringent or they are not enforced.

The limitations of methane emissions is important in order to realize lower GHG emissions in comparison to diesel and petrol engines. If methane emissions are not mitigated the theoretical advantage of a natural gas fuel, 25% lower CO₂ due to the hydrogen to carbon ratio, can be fully lost by a high methane emission. On the other hand, engine technologies with low methane emissions can have a lower efficiency, which also increases CO₂ emissions.

For new European trucks (Euro VI), very stringent methane emissions limits apply (< 1 g/kWh). Due to this, only stoichiometric spark ignition engines are currently used. Solutions for dual-fuel engines are under development, but are probably more costly and not yet available.
3.2.2 Shipping

The IMO emissions legislation for sea shipping is focussed on the reduction of sulphur oxide (SO\textsubscript{x}) and nitrogen oxide (NO\textsubscript{x}). The coordination of this worldwide legislation is with the International Maritime Organisation (IMO) and the treaty is called MARPOL (Marine Pollution). More stringent emission limits are issued for ‘Emission Control Areas’ (ECA’s). ECA’s are in place for SO\textsubscript{x} (SECA) as well as for NO\textsubscript{x} (NECA).

Emission Control Areas currently include:
- Baltic Sea: SO\textsubscript{x}, entered into force in 2005;
- North Sea: SO\textsubscript{x}, entered into force in 2005/2006;
- North American East and West coast: NO\textsubscript{x} and SO\textsubscript{x}, entered into force in 2010/2012;
- US Caribbean ECA: NO\textsubscript{x} and SO\textsubscript{x}, entered into force in 2011/2014.

The SO\textsubscript{x} control is implemented through limits of the fuel sulphur content.

Table 8 shows the limits for both the SECA and world-wide. The SO\textsubscript{x} limits can alternatively be met by using a SO\textsubscript{x} scrubber instead of using low sulphur fuel.

Table 8: IMO fuel quality requirements in order to limit SO\textsubscript{x} emissions. Source: IMO, 2010.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SO\textsubscript{x} Emission Control Area (SECA)</td>
<td>1.50%</td>
<td>1%</td>
<td>0.10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>World-wide</td>
<td>4.50%</td>
<td>3.50%</td>
<td>0.50%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The NO\textsubscript{x} limits for different Tier classes are presented in Table 9. In 2011, Tier II entered into force. The NO\textsubscript{x} limits are 15 to 25% lower than Tier I, which entered into force in 2005. The NO\textsubscript{x} limits for Tier III are 80% lower than for Tier I. Tier III was originally planned for NECA’s for 2016, although IMO voted to postpone this to 2021.

Table 9: NO\textsubscript{x} emission limit ranges for Tier I, II and III. Source: IMO, 2010.

<table>
<thead>
<tr>
<th>NO\textsubscript{x} (g/kWh)</th>
<th>Tier I</th>
<th>Tier II</th>
<th>Tier III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2005</td>
<td>2011</td>
<td>2016-&gt; 2021</td>
</tr>
<tr>
<td>NO\textsubscript{x} Emission Control Area (NECA)</td>
<td></td>
<td></td>
<td>2-3.4</td>
</tr>
<tr>
<td>World-wide</td>
<td>9.8-17</td>
<td>7.7-14.4</td>
<td></td>
</tr>
</tbody>
</table>

For marine engines, there are currently no methane emission limits and a range of different engine technologies is available with also strongly varying methane emissions. In order to claim the GHG emissions advantage from natural gas fueled ships, it is important to mitigate methane emissions of all engines types. However, if this would be a requirement too quickly, the availability of engines will be strongly reduced and block the development of LNG for shipping.
3.3 Technology options

The key environmental regulations with impact on the fuel choice are:

- 2005: Tier I for newly-built ships;
- 2011: Tier II for newly-built ships;
- 2015: 0.1% S requirement for ECA;
- 2016/2021: Tier III NOx requirements for some ECA’s;
- 2020: global 0.5% S requirement. Depending on a review in 2018, this may be postponed until 2025. However some regions such as Europe may enforce 0.5% in their territorial waters by 2020 anyhow.

It should be noted that some of the SOx and NOx requirements up to Tier II can be met by using a fuel with an appropriate quality. Alternatively, for the SOx requirement a SOx scrubber can be used. For NOx Tier III requirements, advanced NOx emission control systems are required, such as the application of an SCR catalyst. Table 10 shows an overview of the technology options.

Table 10: Assumptions about technical options including specific emission control, if necessary. Grey cells indicate options that are not technically or economically sensible.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>SECA+Tier I</th>
<th>SECA + Tier II</th>
<th>SECA+Tier III NOx</th>
<th>Global 0.5% S</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFO</td>
<td>SOx scrubber</td>
<td></td>
<td>SCR deNOx + SOx scrubber</td>
<td></td>
</tr>
<tr>
<td>LS-HFO, MDO S&lt;0.5% S</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MGO S &lt;0.1%</td>
<td>Yes</td>
<td>Yes</td>
<td>SCR deNOx or EGR</td>
<td>Yes</td>
</tr>
<tr>
<td>LNG dual-fuel</td>
<td>Yes</td>
<td>Yes</td>
<td>optional SCR deNOx or EGR</td>
<td>Yes</td>
</tr>
<tr>
<td>LNG dedicated engine</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes, low NOx tuning</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The environmental requirements will lead to growth for a range of competing, existing and relatively new products:

- SOx scrubbers, enabling ships operators to continue using low-cost HFO;
- SCR deNOx systems, such that Tier III NOx requirements can be met in ECA’s;
- LNG dual-fuel engines: ‘flexible’ fuel engines which can use LNG in ECAs and use the most economical fuel outside an ECA;
- Dedicated LNG engines: spark-ignition and pilot diesel-injection LNG engines meeting Tier III NOx requirements;
- LNG tanks systems for ships;
- LNG bunkering ships and other facilities

Additionally, the requirements lead to an enormous growth of existing products:
- MGO;
- Low Sulphur HFO/MDO (S,0.5%)

The regulatory incentive and variety of available technical solution will open the market for new stakeholders, while the existing market players will try to hold their market share. Given the fact that the technical options have similar complexity and
specific pros and cons, it is thought to be likely that all options will capture a piece of the market. The equilibrium will probably be such that:

- Solutions that require high investments on board of the ships, such as LNG and SOX scrubbers, will be installed on large ships with high fuel consumption on a yearly basis.
- For lower of irregular consumption ship segments accepting higher fuel costs (cleaner distillates, MGO or MDO/HFO with max 0.5% sulphur) are likely being prevailed.
- The best segment for ships with dedicated LNG engines will be the SECA’s with Tier III NOx requirement, since in that case no additional NOx abatement is necessary.

In some niches this equilibrium may shift towards LNG:

- If there additional advantage for gas powered propulsion such as for cruise liners which need to meet more stringent soot emission requirements in ports and have relative large consumption of hotel electric power versus propulsion.
- If local policies stimulate cleaner ships e.g. gas-fuelled tugs to lower soot emissions in ports.
- If LNG is relatively easy available or customers require additional emission targets in charter contracts.

3.4 LNG supporting policies and scenario studies

A detailed evaluation of policies, initiatives and programs influencing LNG market development in main world regions can be found in Appendix B of this report. The main policies and initiatives supporting small scale LNG are:

- In Europe: the Directive on the deployment of alternative fuels infrastructure (COM (2013) 18);
- China, which stimulates the investments in upstream natural gas sector and LNG import facilities and offers natural gas at a 10% discount price compared to conventional fuel;
- Canada and Russia, which are aiming to increase their share in the worldwide LNG market.

Several scenario studies are done in the past. Best known studies are those from (DNV, 2012) and (Lloyds, 2012). The different scenarios show a wide range in number of ships and percentage of LNG fuel. For 2020/2025 the number of LNG fuelled ships range from 0-7% while the share of LNG fuel ranges from 0-20%. The upper side of this range is only predicted in combination with a very favourable LNG price (-70% compared to HFO). For more details refer to Appendix C. For road vehicles even fewer projections are available. (IEA, 2013) predicts for USA for CNG and LNG vehicles a market share of ± 0.7% in 2020 to about 5% in 2035.

3.5 Desired breakthroughs for LNG

The following breakthroughs for LNG are crucial to long-term success according to (NTNU, 2011), (TNO, 2011), and (Verbeek, 2013):

- Cost-effective LNG tank storage systems on board of ships and trucks. The costs of the tank systems are currently about the same as the engine cost. This is due to the fact that each tank is specially designed and produced for a single
application. It should be possible to lower this price by standardization and (small) series production or possibly by alternative insulation systems.

- More costs-effective distribution and bunkering. The number of ships is far too small to achieve cost-effective distribution. This chicken and egg situation could be solved by temporary regional and/or governmental incentives.

- Reduction of methane emission of LNG engines. Some engines, such as the more simple converted dual fuel engines, have high methane emissions which eliminate the possible GHG emission advantage of LNG. Several dedicated LNG engines, either spark-ignited or pilot diesel/dual fuel do not have this problem. Clear long-term methane emission regulations should solve this issue without killing the short-term market initiatives.

All of these technical and economic barriers are solvable with the right long-term strategies.

### 3.6 Conclusions: relevant segments for replacing conventional fuels with LNG

One of the main drivers for LNG as a bunker fuel is emission regulation in combination with competitive fuel pricing. This applies to both shipping in Emission Control Areas (ECA) as well as for global shipping. SO\(_x\) requirements will always be met with LNG with its very low sulphur content. In addition, NO\(_x\) requirements are often met depending on the requirement and the engine technology.

For road transportation fuel cost is the main driver which is strongly dependent on excise taxation. Stringent pollutant emissions requirements such as Euro VI and US 2010 can relatively easily be met with natural gas depending on the engine technology, but also for diesel fuel the emission control technologies are well developed.

The bunker LNG quantities predictions for 2020-2025 from key scenario studies vary in the range from 0% to 20% of the HFO bunker quantity. The number of LNG fuelled ships varies from below 100 to 2000 or more for the year 2020/2025.

In order for LNG to become an attractive transportation fuel, the following breakthroughs are needed:

- To develop cost-effective LNG tank storage systems on board of ships and trucks.
- To achieve more costs-effective LNG distribution for road transport and bunkering.
- Increase the availability of LNG fuelled vehicles to include more brands (e.g. for Euro V) and a wider power range.
- Since large share of excise duties (EU) in road fuel prices, tipping point natural gas versus diesel strongly depends on local tax regime.

All considered, Table 11 summarizes the conclusions and gives an overview of suitable segments and regions for the transportation markets.
Table 11: Suitable segments for small-scale LNG.

<table>
<thead>
<tr>
<th></th>
<th>Asia-Pacific / China</th>
<th>Europe</th>
<th>North America</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Long-haulage and distribution trucks</td>
<td>LNG stimulation, low costs conversion</td>
<td>CNG/LNG stimulation</td>
</tr>
<tr>
<td>2</td>
<td>Short-sea vessels</td>
<td>SECA*, highest transport volume</td>
<td>SECA*, Low CNG/LNG price</td>
</tr>
<tr>
<td>3</td>
<td>Deep-sea vessel</td>
<td>High energy consumption and transport volume</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Stationary power system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* SECA = SOx Emission Control Area

For the long term the following needs to be addressed:

- **LNG in road transport**: the most attractive sector for the use of natural gas. Today, natural gas accounts for 2% of total energy use in road transport and this use is highly concentrated in a few countries: Iran, Pakistan, Argentina, Brazil and India (68% of the global natural gas vehicle (NGV) fleet). The use in North America is growing. With supportive policy environment for NGV’s (New Policy Scenario), global sales of NGVs increase four-fold over the period up to 2035 and the share of natural gas in the road transport market reaches 2.8% in 2020 and 4.8% in 2035. (IEA, 2013).

- **LNG in maritime transport**: Stricter emissions regulations are acting in favour of LNG utilization. A new supply infrastructure would be required in the world’s major ports. Therefore IEA has a cautious view about the extent of LNG use in the maritime sector. This sector reaches just over 5 billion cubic meters (bcm) in 2035, displacing 90 kb/d of oil. (IEA, 2013, p. 516).

- **LNG in rail transport**: in North America, General Electric and Catepillar are developing an LNG-powered engine, and BNSF (US) is testing the technology. Large-scale deployment for rail transport will take time and volumes will be small. This is mainly due to the fact that the rail market itself is small: the global oil demand from rail was 0.6 mb/d in 2012. (IEA, 2013, p 516).

- **LNG in power generation**: The relevance of SSLNG for stationary power production is very uncertain since traditional large scale supply is expected to be more attractive for replacement of coal and at decentralised production there is always a favourable route of pipe-grid supply when NG off-take volumes increase.
4 Assessment of small-scale LNG potential

In this chapter the maximum potential market size for SSLNG is projected for the market segments described in chapter 2 (road vehicles, ships and stationary electric power generation). The maximum potential is dependent on:
- The fuel volume projection of chapter 2,
- The technical feasibility and the drivers for LNG, described in chapter 3;
- The fleet renewal rates for trucks and ships, as it is assumed that LNG systems are predominantly installed in new vehicles.

The assessment is not based on fuel price estimations, because of the large uncertainties with respect to prices. In general, it is expected that LNG prices will be above HFO prices, but below that of EN590 (trucks) and MGO (ships).

Below the individual segments are further analysed.

4.1 Heavy-Duty vehicles

In Figure 4 below a breakdown of energy consumption and number of vehicles is presented for the European case. This may be reasonable representative for other regions in the world, although there will be some differences. The best candidates for LNG conversion are those vehicles which consume a lot of fuel in relation to the number of vehicles. Long haul trucks would be an ideal category but a region wide LNG tank infrastructure would be needed. The driving range of a LNG truck would be about 1000 km. Other good categories would be regional delivery and coaches and (city) buses. The lower noise level of gas engines is an additional reason to use LNG. For city buses and a certain part of the regional distribution CNG might be the more favoured option.

Figure 4: Projection of share energy consumption and number of vehicles for different HD vehicle categories in Europe. Source: AEA, 2011.
Per vehicle category, maximum market shares are estimated. These are 50% of new HD vehicles for long haul and 25% for the categories coaches, buses and regional delivery. For the remaining categories, taking into the distance per year and practical issues, it is assumed that LNG is not a logical choice and consequently the potential market share is 0%. An overview and explanation of the projected maximum market shares is presented in Table 12 below. It should be noted, that a part of these vehicles would be suitable for CNG and that a part of the supply of CNG may come from LNG supplied combined LNG/CNG stations.

For Europe the projection of the potential LNG share for commercial on-road transportation is presented in Table 13. This totals 46 MTOE\(^7\), which is about 26% of the total consumption for commercial transport.

Table 12: Projection maximum potential market share for LNG for new HD vehicles.

<table>
<thead>
<tr>
<th>Europe</th>
<th>Km/year</th>
<th>Projected potential for LNG</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long haul</td>
<td>135000</td>
<td>50%</td>
<td>Most favourable business case due to high annual consumption. Often fixed routes which makes LNG re-fuelling easier.</td>
</tr>
<tr>
<td>Coaches</td>
<td>120000</td>
<td>25%</td>
<td>Favourable business case due to high annual consumption, but less often on fixed routes.</td>
</tr>
<tr>
<td>Buses</td>
<td>60000</td>
<td>25%</td>
<td>High annual consumption and fixed routes, but only relevant when supplied via L-CNG stations since CNG tanks at buses are favoured over LNG tanks.</td>
</tr>
<tr>
<td>Regional delivery</td>
<td>60000</td>
<td>25%</td>
<td>Gas fuelling popular, but only relevant when supplied via L-CNG stations since CNG tanks at regional delivery segment vehicles are favoured over LNG tanks.</td>
</tr>
<tr>
<td>Construction</td>
<td>50000</td>
<td>0%</td>
<td>Assumed that practical installation and space for LNG tanks is a major barrier for LNG application. (Replacement of LPG is not considered).</td>
</tr>
<tr>
<td>Urban &amp; service delivery</td>
<td>40000</td>
<td>0%</td>
<td>CNG generally favoured for this category. Not optimal economics due to moderate annual consumption. (L-CNG stations are not considered in urban areas).</td>
</tr>
<tr>
<td>Utility</td>
<td>25000</td>
<td>0%</td>
<td>Poor economics due to low annual consumption.</td>
</tr>
</tbody>
</table>

Table 13: Projection potential market share for LNG for new HD vehicles in Europe.

<table>
<thead>
<tr>
<th>Europe</th>
<th>Km/year</th>
<th>Energy share fleet</th>
<th>2025 MTOE</th>
<th>Potential for LNG</th>
<th>Potential MTOE</th>
<th>Potential MTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td></td>
<td>100%</td>
<td>179</td>
<td>26%</td>
<td>46</td>
<td>34</td>
</tr>
<tr>
<td>Long haul</td>
<td>135000</td>
<td>38%</td>
<td>68</td>
<td>50%</td>
<td>34.0</td>
<td>29.0</td>
</tr>
<tr>
<td>Coaches</td>
<td>120000</td>
<td>5%</td>
<td>9</td>
<td>25%</td>
<td>2.3</td>
<td>1.9</td>
</tr>
<tr>
<td>Buses</td>
<td>60000</td>
<td>7%</td>
<td>12</td>
<td>25%</td>
<td>3.0</td>
<td>2.6</td>
</tr>
<tr>
<td>Regional delivery</td>
<td>60000</td>
<td>14%</td>
<td>25</td>
<td>25%</td>
<td>6.3</td>
<td>5.3</td>
</tr>
<tr>
<td>Construction</td>
<td>50000</td>
<td>13%</td>
<td>23</td>
<td>0%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Urban &amp; service delivery</td>
<td>40000</td>
<td>17%</td>
<td>31</td>
<td>0%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Utility</td>
<td>25000</td>
<td>6%</td>
<td>10</td>
<td>0%</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^7\) MTOE = Million Tons of Oil Equivalent: 1 MTOE=41.87 PJ
The potentials for new HD vehicles in other regions in the world are estimated as follows:

- For Asia-Pacific, North America and Middle-East, the same potential market share is estimated as for Europe.
- For Latin America a lower percentage of 10% is estimated. This is partly because of the lower interest in LNG in Latin America and their strong focus on biofuels.
- For the ‘rest of the world’ a lower percentage of 5% is estimated.

It is furthermore assumed that a sufficient infrastructure for meeting these market shares for new HD vehicles, is available in 2020. Consequently a projection is done for the potential market shares of LNG consumed from 2020 to 2030. Refer to figure 18 below. In the figure, it can be seen that if the market shares for new HD vehicles are respectively 26%. 10% and 5%, the market share of the total vehicles (and fuel consumed) are respectively 19%, 7% and 4% in 2025.

In Table 14 a projection is presented for all regions in the world, using the assumptions described above. The table shows a total world-wide market potential for HD vehicles for 2025 of 192 MTOE. The largest markets are Asia, North America and Europe, Middle East.

Figure 5: Projection of share (%) of LNG fuelled HD vehicles with respectively 26%, 10% and 5% share of LNG for new trucks, fleet expansion 5% per year, replacement rate 12% per year.
Table 14. Projection of LNG potential market share for HD vehicles per annum.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total MTOE(^8)</th>
<th>Potential for LNG MTOE</th>
<th>LNG MTPA(^9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2025</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asia-Pacific</td>
<td>388</td>
<td>26%</td>
<td>19%</td>
</tr>
<tr>
<td>North America</td>
<td>217</td>
<td>26%</td>
<td>19%</td>
</tr>
<tr>
<td>Europe</td>
<td>179</td>
<td>26%</td>
<td>19%</td>
</tr>
<tr>
<td>Latin America</td>
<td>134</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>Middle East</td>
<td>142</td>
<td>26%</td>
<td>19%</td>
</tr>
<tr>
<td>Rest of the world</td>
<td>164</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>Total</td>
<td>1225</td>
<td></td>
<td>192</td>
</tr>
</tbody>
</table>

4.2 Maritime transport

This is split in ships predominantly sailing in ECA’s (generally short sea ships) and ships sailing global waters. The quantity of fuel bunkered for ECA ships is estimated to be about 40 million MTOE which is about 12% of the total amount of bunker fuel. LNG is a good option for the ECA zones, because of the likely price advantage of LNG compared to MGO and the low NOx emissions for dedicated LNG engines. HFO with SOx scrubber may be less favoured because of the handling of residues and the space requirement.

The share of LNG fuelled ships is dependent on several factors such as:
- The number new build ships
- The share of LNG among new build ships and among replaced engines
- The number of (old) diesel ships which are taken out of service.

A projection of the LNG share in the future is done for two economic cases:
1) Expansion of the fleet of 2.5% per year
2) Expansion of the fleet of 5% per year.

Additional a replacement rate of older ships of 3% is assumed for these two cases. Consequently three cases for the share of LNG of the new build ships are assumed: 50%, 25% and 10%. The results are shown in Figure 6 below.

---

\(^8\) MTOE = Million Tons of Oil Equivalent: 1 MTOE=41.87 PJ

\(^9\) 1 Million Tons of Oil Equivalent (MTOE) per annum = 0.854 MTPA-LNG based on ratios of Lower Combustion Values of oil and LNG
Figure 6: Projection of share (%) of LNG fuelled ships with respectively 50%, 25% and 10% share of LNG for new build ships:
- Top figure: fleet expansion 2.5% per year and replacement of complete ship or drive train of 3% per year
- Lower figure: fleet expansion 5% per year and replacement of complete ship or drive train of 3% per year

4.2.1 Inland ships

In Europe, the energy consumption of inland ships is about 6% of the energy consumption of HD vehicles (TREMOVE). This corresponds to about 4% of the total bunker fuel quantity. It is assumed, that inland navigation in Europe is relatively large due to the very accessible rivers such as the Rhine and the Danube and several key channels. It is assumed that inland navigation in the other parts of the world is 2% from the marine bunker fuels. The total projected energy consumption for 2025 is consequently 8 MTOE.
It is assumed that a maximum of 25% of the new ships are potentially suitable for fuelling by LNG. Consequently about 13% to 17% of the ships can be LNG fuelled by 2025 dependent on replacement rate and fleet expansion (refer to figure 19 above). The total estimated potential LNG volume is about 1.2 MTOE/year in 2025. Refer to the projection in Table 15 below.

4.2.2 ECA ships

For ECA ships, it is assumed that a maximum of 50% of new build ships is potentially suitable for fuelling by LNG. This means that in 2025, the percentage of LNG fuelled ships is potentially 27% to 33% depending on the economic growth or fleet expansion rate (2.5 or 5%). This would be equivalent to about 12 million MTOE per year (refer to the projection in Table 15 below).

4.2.3 Deep sea ships

For (non-ECA) deep sea ships, it is important to take into account the size of the ships because of the large transportation segment, the large size differences and the likely connection of fuel and emissions technology in relation to the ship size. The total energy consumption of this segment is estimated to be 289 million MTOE per year (refer to section 2.3). For this segment, it is crucial that a worldwide bunkering infrastructure is available.

A projection of the cumulative energy consumption starting with the largest ships (with the highest yearly energy consumption) is presented in Figure 7 below. The figure shows for example that the 10% of the largest vessels consume more than 60% of the fuel.

After 2020, when low sulphur MDO (S < 0.5%) becomes mandatory, several emissions control technologies can be chose such as is described in section 3.2.2. SO\textsubscript{2} scrubbers in combination with HFO or LNG fuelled engines are relatively attractive for large ships, because the investment costs are relatively lower than for smaller ships. For smaller ships low sulphur MDO is expected to be the more favourable choice.

For estimation of the potential LNG share, the deep sea or global maritime is divided in a number of energy consumption or size categories which is shown in Table 15. The largest size categories consists of 5% of the largest vessels, the next 5% of the largest ships is the second size category. Then the next 10% is the third category. The remaining 80% is in the fourth category. The total energy consumption of this last category is some 10% of the bunker fuels.

For each size category a potential LNG share for newly-built ships is estimated:
- Inland ships: 25%
  It is assumed that 25% of the ships have sufficient LNG consumption to earn back the additional investment costs.
- ECA ships: 50%
  LNG is an economic fuel, very suitable for compliance with sulphur requirements in 2015 and Tier 3 NO\textsubscript{x} compliance in 2016 or 2021.
- Deep sea ships: 10% to 50% (refer to Table 15).
Taking into account replacement rate and expansion of the fleet, the LNG share for 2025 is estimated. Refer to the Table 15 below. The total LNG potential for deep sea shipping is consequently about 42 MTOE per year, about 15% of the deep sea bunker fuels.

![RFO bunker consumption is concentrated in a small portion of long-haul vessels](image)

Figure 7: Projection of cumulative energy consumption and share of the number of vessels, starting with the largest vessels. From IBIA, 2011.

The potential LNG volume for 2025 for all maritime segments together (inland shipping, ECA shipping and global or deep sea shipping) is estimated to be 56 MTOE.
## Electric power generation

In chapter 2 an overview is presented for oil powered electric power generation. This is globally just 5% of the total electric power generation. As explained in chapter 2, this is expected to be the primary segment suitable for conversion to small scale LNG. The potential is in this case directly estimated without evaluating replacement or expansion rates. This is because of the limited insight in this segment with respect to the size of the power stations and used power source (for example combustion engine, steam turbine, gas turbine or combined cycle).

The potential is estimated for the different regions in the world such as is shown in Table 16 below. For all regions the potential volume is estimated to be 10%, except for Middle East where the volume is estimated to be 25%. The total worldwide potential is estimated to be 33 MTOE or 15% of the total oil fuelled electric power generation. It should be noted that the very large 5600 MW Shoaiba power plant in Saudi Arabia probably has a projected annual oil consumption of close to 4 MTOE, which corresponds to around 5 MTPA LNG equivalent. So this plant alone consumes around 35% of the middle east energy for electric power generation and does not qualify as small-scale LNG.

---

10 1 Million Tons of Oil Equivalent (MTOE) per annum = 0.854 MTPA-LNG based on ratios of Lower Combustion Values of oil and LNG
Table 16: Projection of potential LNG share for 2025 for oil fuelled electric power generation.
Based on Table 5, section 2.2.

<table>
<thead>
<tr>
<th>Oil fuelled electric power generation</th>
<th>Electricity TWh</th>
<th>Energy input MTOE</th>
<th>Potential share for LNG %</th>
<th>MTOE</th>
<th>MTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>74</td>
<td>16</td>
<td>10%</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>OECD Americas</td>
<td>102</td>
<td>22</td>
<td>10%</td>
<td>2.2</td>
<td>1.9</td>
</tr>
<tr>
<td>Non OECD Asia</td>
<td>150</td>
<td>32</td>
<td>10%</td>
<td>3.2</td>
<td>2.8</td>
</tr>
<tr>
<td>OECD Asia Oceania</td>
<td>173</td>
<td>37</td>
<td>10%</td>
<td>3.7</td>
<td>3.2</td>
</tr>
<tr>
<td>Middle East</td>
<td>320</td>
<td>69</td>
<td>25%</td>
<td>17.2</td>
<td>14.7</td>
</tr>
<tr>
<td>Africa</td>
<td>71</td>
<td>15</td>
<td>10%</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Latin America</td>
<td>137</td>
<td>29</td>
<td>10%</td>
<td>2.9</td>
<td>2.5</td>
</tr>
<tr>
<td>Eastern Europe/Eurasia</td>
<td>39</td>
<td>8</td>
<td>10%</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>Total / world</td>
<td>1062</td>
<td>229</td>
<td>15%</td>
<td>33</td>
<td>28</td>
</tr>
</tbody>
</table>

4.4 Conclusions: potential for small scale LNG

For HD vehicles and ships, the estimations of potential volumes for small scale LNG in 2025 is based on estimated potential shares among new builds per truck and shipping segment, in combination with replacement rates and fleet expansion. For ‘oil powered’ electric power generation a direct share is estimated per region in the world, not taking into account life time or expansion of these power stations.

In Table 17 an overview is given of the potential small scale LNG volumes for the addressed market segments. The total potential LNG volume is estimated to be 280 MTOE (Million Tons of Oil Equivalent), which is around 16% of the total fuel volume. HD vehicles is by far the largest market segment with a total of 192 MTOE (~70% of total). 1 MTOE per annum corresponds to 0.854 MTPA-LNG (Million Tons per Annum LNG), based on the rations of the Lower Combustion Values of oil and LNG.

Table 17: Overview of total worldwide potential for small scale LNG for different markets per annum.

<table>
<thead>
<tr>
<th>2025</th>
<th>Total energy consump.</th>
<th>Potential for LNG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MTOE</td>
<td>MTOE’’’ MTPA % per segment</td>
</tr>
<tr>
<td>HD vehicles</td>
<td>1225</td>
<td>192 164 16%</td>
</tr>
<tr>
<td>Maritime</td>
<td>337</td>
<td>55 47 16%</td>
</tr>
<tr>
<td>Electric power generation*</td>
<td>229</td>
<td>33 28 15%</td>
</tr>
<tr>
<td>Total</td>
<td>1791</td>
<td>280 239 16%</td>
</tr>
</tbody>
</table>

* Only oil-fuelled power generation

‘’’ MTOE = Million Tons of Oil Equivalent. 1 MTOE/annum = 0.854 MTPA-LNG based on ratios of Lower Combustion Values
5 Conclusions and recommendations

5.1 Conclusions

The primary objective of this quick scan study is to determine the potential global market volumes for small-scale LNG in the period 2015-2025. To serve this, information was collected for the main global regions regarding a) energy consumptions, b) drivers such as environmental and technological drivers and LNG policies and initiatives, and c) LNG and conventional fuel price developments.

The main drivers for small scale LNG include:

- expected lower LNG price compared to low sulphur diesel fuels; EN590 and MGO. The current large differences in LNG prices in different regions in the world are expected to converge in the future due to the increase in supply volume and the expected transition to short term contracts
- environmental regulations for both ECA and global maritime requiring lower SOx and NOx and possibly also lower CO2 emissions in the future
- value of low environmental footprint for clients and local governments (cities / harbour areas)

The following is concluded with respect to the maximum potential volume of small scale LNG for 2025 with respect to the different markets:

- The truck market is the largest potential market for small scale LNG of 192 MTOE (per annum), about 16% of the total energy consumption for HD vehicles. There is probably additional potential for SSLNG supplied as CNG at fuel stations. Since large share of excise duties (EU) in road fuel prices, tipping point natural gas versus diesel strongly depends on local tax regime.
- Maritime is with 55 MTOE (17% LNG substitution of maritime) the second largest market. Specifically shipping in ECAs is a small but important segment (12 MTOE), because of the future environmental requirements. The potential market size corresponds with the most optimistic scenarios of earlier scenario studies (DNV, Lloyds).
- Electric power generations is a sizeable market as well. An indication for the volume is 33 MTOE.
5.2 Recommendations

The following recommendations are made:

- To assess geographical details of truck market. Investigate the volumes of dense logistical corridors, especially in Asia-Pacific, detailing at local level is needed.

- To detail the potential for LNG fuelled stationary electric power generation taking into account the production sizes, political influences and environmental advantages. Especially in the Middle East opportunities are influenced by local situations.

- To assess business cases of regional small scale supply chain for multi segments e.g. combined LNG supply for bunkering, stationary power and trucking.

- To investigate two new potential market segments for SSLNG supply:
  - CNG cars, buses and trucks, e.g. via combined LNG-CNG (LCNG) fuelling stations, including possible replacement of LPG fuelled vehicles by CNG.
  - Domestic use (heating, cooking), including replacement of domestic LP-Gas.

- To work on some of the key barriers for LNG as a transportation fuel, such as:
  - Realise a comprehensive distribution infrastructure for both road transport and maritime.
  - Develop more costs-effective LNG storage systems on board of trucks and ships.
  - Work with engine producers on future reduction of methane emissions of marine engines. This is important in order to claim the benefit of lower GHG emission with LNG. For trucks it is important to increase the availability of LNG-fuelled vehicles.
6 References

AEA, 2011

DNV, 2012

EU, 2009
EU energy trends to 2030, Update 2009.

EU, 2013

ExxonMobil, 2014

Gazprom, 2012
“LNG as future transport fuel in Europe” 4th Annual Baltic Energy Summit Tallinn, 14th November 2012, GAZPROM Germania GmbH.

GE, 2013

IBIA, 2011
“How will the Increased Demand for MGO affect Bunker Prices and Fuel Availability in Europe ?” IBIA convention Barcelona 2rd November 2011 Mark Avis, Pervin & Gertz

IEA, 2013

IMO, 2010
MARPOL Regulations for the Prevention of Air Pollution from Ships, Annex VI, 1 July 2010. For a quick review on IMO Sulfur Content of Fuels and NOx Emission Standards for shipping, visit https://www.dieselnet.com/standards/inter/imo.php.

Lloyds, 2012

NTNU, 2011
PFC, 2013

TNO, 2011

TREMOVE
TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. http://www.tmleuven.be/methode/tremove/home.htm

UNECE, 2014
Regulation No. 110, Revision 3.

Verbeek, 2013
Signature

Delft, 12 September 2014

Bas van den Beemt
BD manager Oil and Gas | Offshore production and LNG

Ruud Verbeek
Author
A Current and future LNG market and prices

A.1 World-wide large scale LNG market, transport and trade routes

LNG global liquefaction capacity nowadays is estimated to be around 290 mmpta (Figure 8). Almost one third of this amount is provided by three countries together: Qatar, Algeria and Iran, with the Middle East being currently the main export-region of the LNG in the world. Southeast Asia (Indonesia, Malaysia and Australia) is the next worldwide region providing the second highest share of LNG export.

Looking into the future, there is a number of new actors emerging on the LNG market which will change the LNG trade patterns within the upcoming 10-15 years. Worldwide there are currently 12 export plants under construction with a combined capacity of over 130 bcm per year and with a forecasted operational start date between 2015-2018 (IEA, 2013). The main expected market new-comers are:

- Australia, where 2/3 of the current global LNG infrastructure investment is happening, with 3 export projects already operating and 7 under construction. Recently the speed of the project development has slightly slowed down due to the higher than expected costs. Still, IEA forecasts Australian’s LNG production to raise up to 150 bcm in 2035 (IEA, 2013). Australia is expected to push Qatar the coming years from the number 1 spot.
- North American region with USA and Canada where the net LNG export volumes are expected to be 50 bcm and 45 bcm respectively by 2035.
- Russian Federation has announced its plans to at least double its current LNG production by 2020 reaching than 9% of the world LNG production.
- South-East Africa, where Mozambique has emerged as a main gas player for the future.
- East Mediterranean, where Israel, Cyprus and Lebanon vying for a place in the global LNG exporting list.

Development of the production capacities in these countries as well as an increase of the production capacities of existing exporting countries will further increase LNG
global liquefaction capacity up to almost 550 mmtpa in 2025. Figure 9 further confirms these trends and provide more detailed forecasts per main LNG producing country until 2022.

Figure 9: Future outlook on consumption and production of LNG. Source: Gazprom, 2012.

Countries on another side of the trade lines, representing the biggest LNG importers are: Japan, Korea, China, India and EU. Therefore, most of the LNG production is still far from its destination markets. Emergence of the new market players, reduction of production capacities of existing ones and other factors, such as short-term market conditions, innovative price schemes, fewer destination clauses and national energy or LNG support policies (appendix B) will change existing LNG trade patterns in the next years. Figure 10 illustrates the view on the global LNG network in 2020 as presented by (GE, 2013).

Australia, Qatar, USA and Russia are seen as the main LNG exporters sharing established LNG consumption markets: e.g. Japan, India, EU, China and South Korea. Compared to nowadays, some of the countries are already reducing their export volumes due to the rapidly increasing domestic demand. The latter trend will also impact future LNG transport and trade routes.
Pricing mechanisms applied to LNG in different countries will have a certain impact on the redistribution of the main exporters market shares. For example, unlike the pricing system used by the most established LNG exporters, US LNG export prices are not based according to oil indexation, but on the (at present) cheaper US Henry Hub spot price plus a liquefaction fee and with no destination restrictions. Asian LNG buyers are likely to turn to LNG exports from USA in order to ease their reliance on the oil-indexed, long-term contracts that suppliers such as Qatar normally offer. Although it is not sure that this will reshape the current LNG trading pattern completely. Nevertheless trade patterns will change partially and gradually, mainly due to increased volumes available, competition and political considerations. In the meantime, overall patterns will stay the same, volumes and price settings can and will change for sure.

This rapid current and future LNG market overview confirms that the LNG market is already well established and LNG supply is present in almost all of the world regions. Small scale LNG projects can be therefore easily supported by the large scale LNG infrastructure.

A.2 Current and future LNG prices

Historically most of the internationally traded gas, whether shipped by pipeline or as LNG, is sold under long-term contracts (10-25 years) in the European and Asian markets. American gas prices always have had their own contract structures, based on Henry Hub prices and a totally free internal trade market availability. For Europe and Asia, the main reason for long-term contracts has been the high capital cost of new and existing gas infrastructures and the need for continuous supply. Usage of the long-term capacity reservation contracts helps to mitigate construction risks and lower the cost of capital, leaving little room for spot transactions. The lack of high volume competition also supported the overall picture. LNG gas prices in these contracts are usually indexed to the prices of oil as a main competing fuel.
Nowadays this trend is starting to change with some regions of the world indexing natural gas and LNG prices to published spot prices of gas, usually in the country or region where gas is delivered. As reported by IEA (IEA, 2013), a growing share of traded gas worldwide is sold on a spot basis, i.e. cash sales of a specified volume of gas at a fixed price for immediate delivery. Considering the difference in the price mechanisms, in this section we study the current and future LNG prices in relation to oil and natural gas prices.

The total LNG supply chain value is defined by exploration and production, liquefaction, transport, regasification and sales costs. The end user prices for LNG will additionally depend on elements such as transport and distribution costs and for HD vehicles on taxes (excise duties and VAT). Especially the tax part varies a lot per region of the world and is individual for each country. Usually this part is in a big proportion responsible for the huge gaps between worldwide LNG prices levels. At the EU level a certain harmonization is provided by the EU energy tax directive, but still the energy taxation policy with final identification of the tax levels is in the responsibility of each Member State.

A.2.1 Current LNG prices and pricing mechanisms

As indicated above, there are currently several major LNG pricing mechanisms in different world regions:

- North American prices, where LNG price determination is more or less disconnected from the oil reference and follows the trends of existing gas-to-gas competition;

- In Europe traditionally long term oil-indexed contracts were used. Nowadays the share of the hub-based pricing (gas sold with reference to the prices at European gas trading hubs) is growing which is expected to result in lower import prices (IEA, 2013). At the same time, despite of this last trend, a degree of correlation between gas and oil prices could persist in Europe as a result of indirect gas price linkages with the Asia-Pacific markets (IEA, 2013).

- In the Asia Pacific region LNG prices are still fixed within the long-term crude oil indexed contracts. These contracts also have destination clauses that limit the ability of buyers to divert cargoes to other markets.

Looking at the historic trends, we can see that natural gas prices tend to follow closely the development pattern of the oil prices (Figure 11). As reported by (IEA, 2013), the world is experiencing a sustained period of high oil prices that is without parallel in oil market history: Brent crude oil has averaged over $110/barrel in real terms since 2011.
Figure 11: World fossil fuel prices. Source: EU, 2009.

Figure 12 illustrates natural gas prices in different countries, reflecting also the price differences between the three main natural gas markets in the world: North America, Asia-Pacific and Europe. Since mid-2008 the gap between the prices starts to widened considerably.

Prices in North America have fallen thanks to the spectacular growth in domestic shale gas production. Asia-Pacific prices are higher due to the so-called “Asian premium” – that includes cost component for the long-haul shipping of gas, high charges applied to the use of LNG terminals and the absence of competition from piped gas.
In the recent years these prices tend to rise further mostly due to prevalence of oil-price indexation at a time of persistently high oil prices (IEA, 2013).

Figure 13: LNG prices in the EU, Japan and Korea. Source: EU, 2013.

Figure 13 illustrates LNG prices in some countries (representing Asia-Pacific and EU region) over the last 5 years. The same trend as with the natural gas prices can be observed.

A.2.2 Future of LNG prices

As mentioned above, the LNG formation price mechanisms are currently undergoing some changes. At the same time, IEA (IEA, 2013) highlights the "chicken-and-egg problem": "in regions without an efficient trading market, long-term oil-indexed contracts are a logical choice to get projects on the ground, but this has the effect of hindering the development of markets (perpetuating a lack of confidence among producers in the reliability of the price generated through trading markets). Around 80% of the LNG from the twelve projects under construction worldwide has already been contracted on a long-term basis and (with the exception of gas from the single US project among the twelve – Sabine Pass) all of this gas has been sold under contracts with oil indexation". Therefore, in the foreseen future the LNG prices will still be referenced to oil prices.

Looking in this respect on the oil prices (Figure 11), their further growth in the future is forecasted. Figure 14 illustrates two boundary cases according to the (IEA, 2013) estimations (New policies scenario and low oil price case). Within the current policy scenario (the one that reflects the situation when government policies that had been enacted or adopted by mid-2012 continue unchanged) oil prices per barrel will develop with the following pace: $120/barrel in 2020; $127/barrel in 2025; $136/barrel in 2030; $145/barrel in 2035.
Figure 14: Oil price and oil demand trajectories in the low oil price and new policies scenario. Source: IEA (2013)

Figure 15 depicts the development of the natural gas prices until 2035 in three countries in the IEA New Policies Scenario.

Figure 15: Natural gas prices by region in the new policies scenario. Source: IEA, 2013.

Large geographical spreads in prices persist, with 2035 gas prices in North America being $6.8 per million British thermal units (in year 2012 dollars), $12.7/MBtu in Europe and $14.9/MBtu in Asia-Pacific. The North American prices remain the lowest because of the relatively low cost of the unconventional resources. In 2035, prices in Japan are more than double compared to those in US.

Contrarily to the IEA forecast, Lloyds Register (Lloyds, 2012) showed converging LNG prices in three main regions in the world (North America, Europe and Asia).

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Scenario where existing policies are maintained and recently announced commitments and plans, including those yet to be formally adopted, are implemented in a cautious manner.
In their scenarios, the LNG price differences are eliminated in 2025. (IEA, 2013) also identified conditions under which convergence between pricing mechanisms and prices could be more pronounced. This basically means a situation when the different regional gas markets make a more rapid transition to the point at which they all respond to a single global price signal. This is possible, with (1) a larger volume of LNG export from North America (exceeding 100 bcm by the latter part of the 2020s); (2) new supply contracts weakening or breaking the link with oil-price indexation, and an accelerated pace of regulatory change for the gas sector across the Asia-Pacific region; (3) an easing of costs of constructing liquefaction plants and of shipping LNG in order to keep down the costs of moving gas between markets.

As regards LNG prices, they are forecasted to follow the same development pattern as natural gas prices. Increase of the quantity of LNG that is available without commitment to a specific destination, can make LNG pricing more flexible. (IEA, 2013) indicates that when this LNG is free to seek (or find) the most advantageous sales price at any given moment, it has the potential to arbitrage (reduce) price differences between markets. This increases the depth and liquidity of short-term trade.

A.3 Conclusions

Although LNG is traded nowadays all over the world, there are currently three major LNG trade markets: North America, Asia-Pacific and Europe. Opening of the new liquefaction facilities, domestic LNG markets supply and demand trends and energy policy priorities of the exporting and importing countries will change trading and transport routes in upcoming future.

Some further changes are expected as well in the price formation mechanisms for LNG. Today North America has a hub-based gas pricing, with prices reflecting global gas supply and demand. LNG trade in Asia-Pacific and Europe is mainly a subject of the long-term contracts with the oil-indexed prices. In Europe gas trade starts to move to gas-to gas competition and this trend is expected to be reinforced in the future. The same is expected for the Asia-Pacific market, with gas contracting structure becoming more flexible and some alternatives to oil indexation gaining a weight.

LNG price differences between the main markets North America, Europe and Asia are currently huge (up to a factor of 6). It can be concluded that the long term LNG prices will remain uncertain. LNG prices between the main markets may or may not converge to a uniform price within the next decade. If not a price difference of up to a factor of two may remain for around 2030. The LNG price coupling with the oil price, currently strong in Asia, may diminish in the future.
B Policies, initiatives and programs influencing LNG market development in main world regions

Different countries have a range of policies and initiatives supporting directly or indirectly the development of the LNG usage. First, these are major infrastructure projects that countries decide to support and develop, as described in chapter 3. Second, there is a range of policies that directly target promotion and development of LNG infrastructures or LNG trade. Finally, some policies and programs have an indirect impact on LNG development by acting on other fuel promotion or limitation (e.g. promotion of renewable fuels). More and more regions in the world establish energy efficiency programs setting up targets aiming to reduce overall energy demand which also have an impact on the development of individual energy sources. As confirmed by IEA, 2013 “historical evidence from countries where NGVs successfully entered the market or failed (e.g. New Zealand) suggest that besides the availability of natural gas resources and/or an extensive network of gas pipelines, long lasting and targeted policy support is essential in order to overcome initial hurdles to investment”.

In this chapter we highlight main policy developments or main on-going issues around LNG development in different world regions that might have an impact on the global future development of LNG trade and market shares.

B.1 Europe

The EU has quite a comprehensive strategy and policy shaping the future development of its energy market. The main policy directions that have an impact on the future of LNG development are defined within a set of policy documents.

On the most fundamental level, the common rules for the transmission, distribution, supply and storage of natural gas (including LNG) are established within the Directive 2009/73/EC. This directive also lays down the natural gas market functioning and organisation rules, access regulation and all other relevant criteria and procedures of the sector operation.

In the framework of the recent Clean Power for Transport package, aiming to facilitate the development of a single market for alternative fuels for transport in Europe, COM (2013)17 “European alternative fuel strategy” sets out a comprehensive strategy on how to promote and support alternative to oil energy sources in all modes of transport. LNG is seen as a promising fuel for road, rail and waterborne transport and is addressed as an energy source to be further developed.

Within the same policy package, the Directive on the deployment of alternative fuels infrastructure (COM (2013) 18), requires MS to provide minimum infrastructure for alternative fuels, including the one for LNG. Specifically, Article 6 of this Communication prescribes that Member States shall ensure that publicly accessible LNG refueling points for maritime and inland waterway transport are to be provided in all maritime ports of the TEN-T core network by December 2020, in inland ports by December 2025 and that heavy duty motor vehicles running on LNG can travel all along the roads on the TEN-T core network provided with established refueling infrastructure within the distances not exceeding 400 km by December 2020 at latest.
A Staff Working Document on Actions towards a comprehensive EU framework on LNG for shipping (SWD(2013) 4) looks more in detail in LNG as an alternative fuel for shipping and defines the steps to develop the market conditions and the necessary regulations, codes and standards for a broad market uptake of LNG as clean fuel in the EU shipping sector.

On the top of above-mentioned, recently approved amendments to the UNECE Regulation 110 represent an important advancement for the promotion of the LNG-powered vehicles. These amendments allow mutual recognition of the LNG vehicles certification in Europe and establish safety requirements for on-board LNG systems (storage tanks, vaporizers, pressure regulator, valves, fuel lines, fittings, etc.) as well as requirements for the LNG storage tank on minimum holding time. Despite the fact that the Regulation specifically references Europe, the work of the UNECE has global implications. This development represents an important achievement that will provide significant growth in the global natural gas vehicle industry over the coming years (UNECE, 2014).

Some EU policy actions have an indirect impact on the LNG development, via setting up development priorities or targets for other energy sources or regulating prices of different energy carriers. Some examples are:

- The Directive 2009/28/EC on renewable energy sets targets for all Member States such that the EU will reach a 20% share of energy from renewable sources by 2020 and a 10% share of renewable energy specifically in the transport sector.
- Once adopted as an official act, COM (2011) 169/3, updating existing Energy Taxation Directive (2003/96/EC) will have a direct impact on the energy pricing and subsidizing in EU. The Communication proposes to restructure the way energy products are taxed in EU with a background objective to promote energy efficiency and more environmentally friendly products. It also includes proposals in changing the minimum tax levels of different energy products trying to remove existing imbalances.
- New energy efficiency directive (2012/27/EU) establishes the EU 2020 energy consumption of no more than 1 474 Mtoe primary energy or no more than 1 078 Mtoe of final energy' and absolute numbers of energy consumption per member state.

B.2 North America

Important developments for the LNG industry are currently happening in USA and Canada.

In USA several Energy Policy Acts have been passed (1992, 2005, 2007) that include grants and tax incentives for conservation and use of alternative fuels, increasing fuel economy demands and promoting renewable energy sources. The most recent American Recovery and Reinvestment Act (2009) in its areas relative to energy has a strong focus on the support and development of renewable energy sources, biofuels, electric vehicles and in general improvement of national energy efficiency. In general, there is no an economy-wide energy efficiency target, but 24 states have adopted long term energy saving targets (IEA, 2013, p 286). Energy Efficiency Resource Standards (applied to electricity and natural gas utilities) establish specific, long-term targets for energy savings that utilities or non-utility program administrators must meet through customer energy efficiency programs. In its energy efficiency programs USA is also actively focusing on the road transport
energy efficiency improvement. Besides this, there is currently a debate on the development of the energy tax reform and its potential impact on oil and gas prices. The U.S. LNG industry is regulated by the Federal Energy Regulatory Commission, the Department of Transportation, the U.S. Coast Guard and the Department of Homeland Security, and some other agencies that ensure that vessels, facilities and personnel provide and deliver safe operations and transport. Main on-going discussion around LNG in USA is about the volume of the LNG export to non-FTA countries. Development of unconventional gas production allows to have a substantial increase in natural gas exports from USA. A debate is unfolding whether this should be prevented or discouraged, with main arguments “pro” being a potentially very profitable business opportunity and GDP increase and arguments “contra”, such as the increase of the natural gas and electricity prices or a decline of energy security. The government is currently showing support for an extensive LNG export development and support for new policies are to be expected (http://www.platts.com).

In Canada, while the energy strategy documents are prepared by province and territories, illustrating individual character of each jurisdiction, they also correspond to the main national energy policy priorities established by Canada’s National Energy Board. These include awareness, benefit, efficiency, development, diversification, electricity, emissions, leadership, innovation and security. The construction and operation of LNG terminals generally fall under provincial regulation, while the export of LNG is federally regulated. Currently Canada is reconsidering its LNG market development as there is no more such a demand of natural gas in any of it forms from USA that has been for years Canada’s major LNG importer. Therefore Canada has to look for the new export markets and there are more and more negotiations on-going with Asia-Pacific region and specifically China.

B.3 Asia – Pacific

Asia-Pacific region is one of the largest LNG importing-region in the world with Japan and China becoming major LNG market players. A number of policy developments have been recently introduced in China, which could have an effect on national LNG market developments. First, within China’s 11th Five Year Plan an energy intensity reduction target by 16% by 2015 has been adopted. The plan also aims to double the share of gas in the country’s primary energy mix. In parallel, almost $21 billion of tax incentives for industrial energy efficiency investments was provided (IEA, 2013, p 275). Secondly, by its energy price reform the Chinese government tries to liberalize wholesale gas pricing in order to encourage investments in the upstream sector and in pipeline and LNG import facilities. Under the previously existing system, wellhead gas prices and pipeline transportation tariffs have been set by the central government on cost-plus basis. The price reform (in process of being implemented, 2012-2015) aims to establish a single maximum price at the city gate for each location. That price will be linked to the prices of imported fuels: 60% to fuel oil and 40% to liquefied petroleum gas, with a 10% discount to encourage gas use. Wellhead prices will be liberalized, allowing producers of all types of gas to negotiate prices with buyers on a net-back basis, taking account of the cost of transportation. Currently it is expected that due to this reform, natural gas prices will raise (15% in 2014 and another 20% in 2015) (http://www.reuters.com/article/2013/11/15/china-energy-reform-idUSL4N0J00PT20131115).
Japan is currently the world’s largest LNG importer. On the general level, Innovative Strategy for Energy and the Environment (released in 2012) calls for a greater focus on improving energy efficiency and setting a target to cut electricity demand by 10% in 2030 compared to 2010. In November 2013, legislation successfully passed to start electricity sector reform in 2015. Nuclear energy, which used to account for 30% of Japan’s electric power, was discarded after the Fukushima incident. However, the last months, the Japanese government is re-orientating its policies to reopening some of its nuclear plants again. The new bill is designed to break up monopolies, curb electricity prices and facilitate the development of renewable energy through a series of liberal reforms.

Another consequence of the Fukushima disaster and the closing of the nuclear power generation plants is the compensation of the market by the higher shares of oil and natural gas, with a focus on LNG. The government has chosen LNG as its first fuel-of-choice for power generation to substitute for the lost nuclear generation which is also highlighted in the Innovative Strategy. Many of Japan's existing LNG contracts date from the 1970s and 1980s are expiring, forcing Japan to renegotiate term contracts or locate shorter-term supply.

**B.4 Latin America**

Recently in almost all Latin America countries energy policy reforms took place, with the focus in general terms on the market-oriented policies emphasizing privatization, liberalization and fiscal discipline. In general, Latin America is relatively new to the LNG market. We are focusing on the development of the policies affecting LNG development in Brazil as one of the potential LNG markets and highlight some other important to LNG developments in Latin America.

Brazil’s consumption of energy is rising steadily following the patterns of its growing population and booming economy. In order to control this growth, the recently published National Energy Efficiency Plan sets a target to reduce projected power consumption in the country by 10% by 2030. The same plan also includes the National Programme for Energy Conservation (PROCEL), the National Programme for Rational Use of Oil Products and Natural Gas (CONPET), and an extension of the scope of efficiency standards for equipment and machinery. Brazil has a very well developed strategy on the renewable energy development with a set of policy documents, incentive mechanisms (e.g. PROINFA, REIDI) and tax incentives relative to renewable energy.

Even though oil production still remains a priority, Brazilian government came to the view that domestic gas resources are an important strategic asset as well, actively implementing policies for increasing natural gas supply, restricting gas sharing and expanding gas pipeline infrastructure (Ten-Year Plan for Expansion of Gas Pipelines – PEMAT). Currently the natural gas sector in Brazil is regulated by the Law no. 11.909 (of 3/4/2009). The LNG sector development receives a national government support as well as development and opening of the new LNG terminals.

Outside of Brazil an important development for the LNG market is the on-going Panama Canal extension. An expanded Canal has the potential to alter trade routes worldwide, and transform partially global LNG markets, allowing close to 90% of the world’s LNG vessel fleet to pass through by 2015, providing significant potential time and cost savings to LNG buyers and producers in and around the USA.
Currently the project is only 72% complete and the original deadline of October 2014 has been pushed to July next year.

B.5 Rest of the world

Due to the high abundance of energy resources and low energy prices, energy efficiency has not historically been a key priority of the Middle East and some Northern African countries. The Middle East does have plentiful gas reserves, but these are heavily concentrated among three countries: Iran, Qatar, and Iraq. Qatar is the major one of these that exports gas as LNG. The UAE has been the first LNG exporter in the GCC region, still largely exporting it to Japan. Oman and Yemen are also small LNG exporters. Potentially Iran could be a major LNG exporter, but international sanction regimes are currently prohibiting the country to put the necessary projects and contracts in place.

There is currently a moratorium on new projects in Qatar’s massive North Field while operators continue to examine ways of sustaining high levels of output over the longer term. The moratorium, initially scheduled to end in 2008, will run through at least 2015 after several extensions.

Saudi Arabia government together with IEA is currently working on energy efficiency policies, focusing on buildings, appliances and transport. Saudi Arabia, the Islamic Republic of Iran, the United Arab Emirates and Oman – all oil exporters - decided to diversify their energy supply mix through nuclear and solar power generation, by importing gas or LNG, and in some countries a mixture of all of these energy alternatives.

In general, the Middle East relies heavily on fossil fuel subsidies which inflate demand, distort economies, reduce incentives to improve efficiency and encourage carbon emissions by keeping the price of fossil fuels far lower than renewable energy.

Russian Federation is showing more and more interest in the LNG export production, aiming to double its share in the global LNG market (targeting mainly Asian markets) by 2020 from its current 4.5%. In this respect and as a part of Russia’s declared strategy of diversifying the markets for its domestic gas it has recently published a new LNG policy opening up LNG export to other private companies that Gazprom. The government is as well implementing a number of additional measures to stimulate the LNG projects (e.g. including granting the Yamal LNG project an exemption from the tax on the extraction of fossil fuels and natural gas (NDPI) in relation to gas processed into LNG, as long as production does not exceed 250 bcm as well as an exemption from export duty).

B.6 Conclusions

There are on-going energy policy/strategy developments in all of the world regions, prioritizing different set of objectives. Majority of countries are focused on the overall energy efficiency improvement and subsequent reduction of the national energy consumption. As stated in the (IEA, 2013) report if the targets of energy efficiency policies in the EU, China, the United States and Japan are achieved, that will account for 53% reduction in the global energy demand. These type of trends
are important to consider while looking at the perspective of the niche market developments.

A number of countries prioritize the development of the natural gas share in the national energy matrix mix; some are definitely focused on the further development of the LNG export/import facilities introducing. More and more countries introduce the targets for the renewable energy utilization within their energy mix matrixes. Another tendency observed are policy measures addressing fossil fuel consumption subsidies and prices (Figure 16).

Figure 16: Fossil fuel consumption subsidies in 2012 and recent developments in selected countries. Source: IEA (2012)

All together these trends form the context for the potential development of the energy market in different parts of the world, defining national priorities for the development of one or another energy source type. Consideration of these policy outlooks help to form a reliable forecast for the small scale LNG production.

The most important worldwide small scale LNG initiatives are:

- **Europe:**
  Directive on the deployment of alternative fuels infrastructure (COM (2013) 18), requiring EU Member States to provide minimum infrastructure for LNG:
  - LNG refueling points for maritime transport in all maritime ports of the TEN-T core network by December 2020, and for inland ports by December 2025.
  - LNG refueling points for heavy duty vehicles all along the roads on the TEN-T core network by December 2020.
- North America:
  - USA is increasing its national natural gas and LNG production, with a strong focus on the potential export of these resources.
  - LNG in USA is available at a very competitive price compared to diesel fuel and compared to other LNG exporting countries prices.
  - Canada is looking for export markets for LNG outside of the North America (e.g. Asia).

- Asia
  - China tries to liberalize wholesale gas pricing in order to encourage investment in the upstream sector and in pipeline and LNG import facilities. A 10% discount is offered for gas compared to petrol and diesel in order to encourage gas use.
  - Japan is focusing on LNG as the first fuel choice to replace nuclear power share in the energy mix.

- Latin America
  - Panama Canal extension will have a major influence on the reorganisation of the LNG transport routes.

- Rest of the world
  - Russian Federation, aims to double its share in the global LNG market (targeting mainly Asian markets) by 2020 from its current 4.5%.
C Scenario studies

C.1 Maritime sector

Some guidelines for the potential future LNG size market in the maritime sector are given by existing scenario studies.

C.1.1 (DNV, 2012): Shipping 2020

The main variables in this scenario study are (DNV 2012):

- Economic growth;
- Fuel prices, such as price ratio LNG/HFO and MGO/HFO. In some cases, the LNG price is higher than HFO and in other cases it is lower;
- Environmental regulations and awareness.

The study defines four scenarios:

- High economic growth and high LNG price. This results in about 650 LNG ships in 2020
- High economic growth and low LNG price (-70% compared to HFO). This results in 5000 LNG ships in 2020.
- Low economic growth and high LNG price (+10% compared to HFO). This results in about 100 LNG ships in 2020.
- Low economic growth and low LNG price (-30% compared to HFO). This results in 1650 LNG ships in 2020.

The extremes of these scenarios are presented in Table 18.

C.1.2 (Lloyds, 2012): LNG-fuelled deep-sea shipping

The study (Lloyds 2012) is focussed on the outlook until 2025 for LNG bunkering and LNG-fuelled new build demands. It evaluates three scenarios:

- Base scenario: results in about 650 LNG fuelled ships in 2025. Medium LNG price: $900 /ton in 2025;

An overview of the two extreme scenarios from studies, (DNV, 2020) and (Lloyds, 2012) is presented in Table 18. This includes the number of ships, LNG volumes and fuel prices.

Table 18: Projections for the extreme scenarios for two scenario studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>LNG ships</th>
<th>LNG % of fleet</th>
<th>LNG % of HFO</th>
<th>Year</th>
<th>LNG price $/ton</th>
<th>HFO price $/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNV 2012</td>
<td>100 - 5000</td>
<td>0.2% - 7%</td>
<td>1% - 20%</td>
<td>2020</td>
<td>400 - 1100</td>
<td>300 - 1200</td>
</tr>
<tr>
<td>Lloyds 2012</td>
<td>13 - 2000</td>
<td>0 - 3%</td>
<td>0.2% - 8%</td>
<td>2025</td>
<td>670 - 1120</td>
<td>1200</td>
</tr>
</tbody>
</table>
C.1.3 \textit{(TNO, 2011): chain analysis study}

In \cite{tno2011} an economic comparison was done for 3 types of ships:
- An 800 TUE container short-sea vessel
- A TUG port ship
- A 200 TUE container inland vessel

The LNG driveline was estimated to be a factor of \(\sim 1.5\) to \(\sim 2.0\) higher than the diesel driveline. This included the costs of engine, aftertreatment and tank costs.

The economic comparison included a projection of the necessary price advantage of LNG in order to achieve payback periods of 5 and of 10 years. The results are shown in Table 19. This shows only for the short-sea and the inland vessel a realistic price discount of 2 to 4.5 EUR/mmBTU for LNG compared to MGO and EN590.

\begin{table}
\centering
\caption{Break-even price of LNG vs diesel fuels (in Euro/MMBTU) for the three cases in the 2016 onwards situation (for short sea from 2015 onwards). Source \cite{tno2011}.}
\begin{tabular}{|c|c|c|}
\hline
Case (liquid fuel) & Needed LNG discount to break even [EUR] (in relation to relevant diesel) & \\
& … in 5 years & … in 10 years & \\
\hline
Short sea (MGO) & 4.4 & 2.5 & \\
Tug (EN590) & 20.6 & 10.3 & \\
Inland ship (EN590) & 3.9 & 2.1 & \\
\hline
\end{tabular}
\end{table}

C.1.4 \textit{Natural gas in transport 2013}

CE Delft, ECN and TNO conducted this study, where environmental performance and costs were evaluated for all modes of transport; from passenger cars to deep-sea ships. The fuels included fuels produced from natural gas such as LNG, CNG, H\textsubscript{2}, electricity and also conventional fuels \cite{verbeek2013}.

An inland ship and three types of sea ships, i.e. container ships with respectively 800, 5500 and 15000 TEU, were included. The fuel price assumption for 2025 are included in Table 20. Only for the short-sea ship operating in an ECA, the sum of operational and capital costs were lower for LNG than for diesel fuel (MGO). For deep-sea shipping with HFO as reference, operation on HFO was more economical. The costs of a SO\textsubscript{x} scrubber were not taken into account. Operation on LNG in most cases lead to large environmental benefits such as for SO\textsubscript{x}, NO\textsubscript{x} and particulates, as is shown in Figure 17.

\begin{table}
\centering
\caption{Fuel price assumption for ‘Natural gas in transport’. Source: \cite{verbeek2013}.}
\begin{tabular}{|c|c|c|c|}
\hline
2025 & MGO & HFO & LNG & \\
& & & Low & High & \\
\hline
Price including distribution EUR/TOE & 762 & 482 & 595 & 641 & \\
\hline
\end{tabular}
\end{table}
C.2 Scenario studies road transport

Some guidelines for the potential future LNG size market in the road transport sector are given by existing scenario studies.

- **LNG in road transport, North America:** LNG may be a financially attractive option as the higher initial cost of an LNG truck, compared to a conventional vehicle (of up to $75000) can be recouped over time by the fuel-cost savings: the payback period is currently estimated at around 2 to 4 years for long-haul trucks. The payback period depends on the number of miles travelled, the price differential between diesel and LNG, the incremental cost of the vehicle and its residual value (Figure ). In the US, most trucking companies are very small, with limited financial resources and borrowing power and may be reluctant or simply unable to adopt what is still a relatively unproven technology. Trucks are often operated for only 6 to 8 years on average. (IEA, 2013) projects LNG and CNG use in road transport to grow quickly in the US, but still being just 0.7% of the total fuel use in road transport in 2020, displacing around 70 kb/d of oil use, and 5% in 2035 (450 kb/d). (IEA, 2013)

  In the US, continued low natural gas prices, relative to oil, are also expected to push up gas use (mainly LNG) in heavy trucks, with road transport demand rising rapidly post 2020 to more than 25bbcm by 2035. (IEA, 2013, p 107)

- **LNG in road transport, China:** The number of NGV’s in China reached around 2 mln at the end of 2012. Most of those NGV’s are CNG light-duty vehicles). The use of LNG is also increasing and is estimated to approximate 71,000 LNG vehicles, of which 60% are trucks, on the road in China at the end of 2012. The number of LNG refueling stations amounts to over 800. The sales of LNG HDVs in China increased by 60% in 2012. The purchase of LNG long-haul trucks in China breaks even after 1-2 years at current prices and average mileage, despite prevalent use of gasoline-type engines in China’s LNG trucks today.
(which entails very high consumption penalty). However, the payback periods are set to rise sharply with the current roll-out of gas pricing reforms which are expected to lead to a significant increase in natural gas prices in most regions. The IEA forecast for growth of the natural gas in road transport use in China by 2020 is mainly due to the CNG usage in taxis and urban buses and some LNG use by HDVs.

- **LNG in road transport, Europe:** Based on the IEA 2013 study, the expected payback periods for LNG for long-haul trucks is projected to be 2 – 4 years.

![Figure 15.11](image)

**Figure 15.11** Natural gas demand for road transport by selected regions in the New Policies Scenario

![Figure 20](image)

**Figure 20:** Estimated payback time periods of LNG-powered long-haul trucks in selected markets, 2011 and 2020. Source: IEA, 2013.