Costs and Benefits of LNG as Ship Fuel for Container Vessels
Benefits of using LNG as ship fuel

The use of liquefied natural gas (LNG) as ship fuel has recently gained more attention in Europe, but also in Asia and the USA. There are three visible drivers which, taken together, make LNG as ship fuel one of the most promising new technologies for shipping.

- The use of LNG as ship fuel will reduce sulphur oxide (SO\(_x\)) emissions by 90-95%. This reduction level will also be mandated within the so-called Emission Control Areas (ECAs) by 2015. A similar reduction will be enforced for worldwide shipping by 2020.
- A lower carbon content of LNG compared to traditional ship fuels enables a 20-25% reduction of carbon dioxide (CO\(_2\)) emissions. Any slip of methane during bunkering or usage needs to be avoided to maintain this advantage.
- LNG is expected to be less costly than marine gas oil (MGO) which will be required to be used within the ECAs if no other technical measures are implemented to reduce the SO\(_x\) emissions. Current low LNG prices in Europe and the USA suggest that a price – based on energy content – comparable to heavy fuel oil (HFO) seems possible, even when taking into account the small scale distribution of the LNG.

Fig. 1: Emission components and reduction with EGR

Fig. 2: Gas and ship fuel prices the last 6 years
Objectives of the study
Shipowners interested in LNG as ship fuel are currently facing a number of questions regarding costs and possible benefits of using such technology. They want to know if exhaust gas treatment systems could be the preferred technical solution. At the same time, increasing ship efficiency with advanced waste heat recovery systems becomes feasible. This suite of technologies is the focus of the GL and MAN joint study on container vessel power generation systems.

Fig. 3: 4,600 TEU type container ship

Fig. 4: GL concept, LNG-fuelled container vessel
**Status of regulatory framework**

The IMO Interim Guidelines for gas as ship fuel (Resolution MSC.285(86)) contain the state-of-the-art on safety concepts for using gas as ship fuel. These are voluntary to the flag states. GL issued its own guidelines in April 2010, adding own interpretations.

The IMO subcommittee BLG is working on the International Gas as Fuel code (IGF) which will supersede the interim guidelines and is planned to enter into force with the SOLAS 2014 edition. In parallel, work started at ISO TC 67 on standards for LNG bunkering.

**Approach**

The study assumes costs for key technologies when applied to five differently sized container vessels, and predicts their benefits in comparison to a reference vessel which uses fuel required by existing and upcoming regulations depending on time and location of its operation. I.e., the reference vessel uses MGO when inside an ECA by 2015 or within EU ports. Outside an ECA, HFO is used and a low-sulphur fuel oil (LSHO) with a 0.5% sulphur content by 2020.

Costs for implementing the technologies are compared with expected benefits which are driven by fuel cost differences. If a choice is possible, the model assumes that the fuel with the lowest cost is always used. Space required by the technologies is taken into account by reducing the benefit.

Four technology variants were investigated in the study:

- Scrubber
- Scrubber and waste heat recovery (WHR)
- LNG system (bunker station, tank, gas preparation, gas line, dual-fuel engine)
- LNG system and WHR.

For each technology variant, costs and space requirements are estimated and specific fuel oil consumption is based on current knowledge. Estimates were made for each container vessel size.

The same measures to reduce NOx emissions to Tier III levels are assumed for the reference vessel and all variants and, therefore, these have no effect on the cost differences between the reference vessel and the variants.

**Ship size variants and route profiles**

Five representative container vessel sizes were selected for the study. Assumed design speeds account for the current trend towards lower speeds.

Round trips were selected for three trades: Intra-European, Europe-Latin America and Europe-Asia. The ECA exposure was used as a primary input parameter.
LNG technology and modelling assumptions

The main engine power installed is based on specific designs with given design speeds. Auxiliary engine power is taken as a fraction of the main engine power. Additional auxiliary engine power necessary for reefer containers is based on estimated reefer share. Engine loads are varied for port stays, approaches and open sea transit which, in turn, depend on the route profile.

The LNG tank volume is selected to give the vessel a half round trip endurance. This controls investment costs but increases exposure to volatile fuel prices. Costs for the LNG system include costs for tanks, bunker station, gas preparation, gas line, main engine and generator sets. LNG tanks are assumed to consume TEU slots and it results in lost earnings, assumed only for every second voyage. Medium sized container vessels (4,600 TEU and 8,500 TEU) have the largest losses with a maximum of about 3% of the total available TEU slots. Other operation costs such as crew, spare parts and maintenance are assumed to be 10% higher than the reference vessels.

Main engine technology and modelling assumptions

The MAN B&W ME-GI engine series, in terms of engine performance (output, speed, thermal efficiency, etc.), is identical with the well-established ME engine series. This means that the application potential for the ME-GI system applies to the entire ME engine range.

Specific fuel oil consumption is specified for different engine sizes, fuels and engine loads.
The control concept of the ME-GI engines comprises three different fuel modes:

- The fuel-oil-only mode is well-known from the ME engine and, in this mode, the engine operates on fuel oil only, and the engine is considered to be “gas safe”

- The minimum fuel mode has been developed for gas operation. In this mode, the system controls the amount of gas fuel, combined with the use of a minimum preset amount of fuel oil (pilot oil) which is set at 5% approximately. Both heavy fuel oil and marine diesel oil can be used as pilot oil. The minimum pilot oil percentage is determined from 100% engine load. When the engine passes the lower load limit, the engine returns to fuel-oil-only mode. If a failure occurs in the gas system, this will result in a gas shutdown and a return to the fuel-oil only mode

- Specific fuel mode, where any mix of gas and fuel oil is possible.
**Scrubber technology and modelling assumptions**

This study assumes usage of wet scrubbers to reduce SO\textsubscript{x} emissions by scrubbing the exhaust gas from the engines with sea water. The exhaust is led from the turbocharger into a large scrubber placed in the funnel of the ship, downstream the exhaust gas boiler. The exhaust is led through an array of seawater droplets which will wash the sulphur out of the exhaust gas. The cleaning water will fall to the bottom of the scrubber and is discharged into the sea. The exhaust will travel up into the funnel passing through a reheater to prevent steam from being visible in the exhaust. If the ship is sailing in an area where it is not allowed to discharge the used water into the sea, it is possible to use a closed loop system with fresh water. If the closed loop is engaged, the water will be recirculated and a water cleaning system will be engaged. The cleaning system contains a centrifuge for particle removal, and NaOH is added to the circulated water, for neutralising the sulphuric acid, which will develop when washing the sulphur out of the exhaust gas with fresh water.

Scrubbers are assumed to be used only when needed to meet required emission limits, i.e. inside ECAs, in EU-ports and globally by 2020. Their operating costs depend on operation time and engine loads. An average cost for open and closed loop scrubbers of 5 USD/MWh was used. Lost TEU slots depend on the space required for the scrubber installation. Up to 0.3% of the total available TEU slots are assumed to be lost. This is assumed to apply only every second voyage. Other operation costs such as crew, spare parts and maintenance are assumed to be 20% higher than the reference vessels.

**Waste heat recovery technology and modelling assumptions**

The waste heat recovery (WHR) system consists of an exhaust gas heated boiler supplying steam to a steam turbine. To boost the electrical output, the system can be extended with a gas turbine utilising the energy in the exhaust gas not used by the turbocharger. To obtain the highest electrical production, the optimal solution is to use a dual steam pressure system or even a triple steam pressure system if the engine is equipped with a system for exhaust gas recirculation. Waste heat recovery systems are modelled to reduce specific fuel consumption. Savings depend on engine load and ship size. A maximum benefit of 13% was assumed for the largest vessels at 75% MCR.

Lost TEU slots depend on the space required for the WHR installation. For the smaller vessels (2,500 TEU and 4,600 TEU), up to 0.4% of the total available TEU slots are assumed to be lost. This is assumed to apply only every second voyage. Other operation costs such as crew, spare parts and maintenance are assumed to be 15% higher than the reference vessels.

**Use of distillate fuels**

Running on distillate fuels for a long period of time is the straightforward solution to comply with the forthcoming emission regulations on sulphur. The fuel system needs to be fitted with a cooler or a chiller configuration to meet the viscosity limits for the engine. A suitable cylinder oil will also be required. For running in non-ECAs, the fuel system must also be able to cope with the new fuel (LSHO with 0.5% sulphur) that might be introduced.
Fuel price scenario

The basic assumption for the fuel price scenario is a continuous price increase due to expected increase in oil and gas production costs. MGO and LSHO are expected to increase faster than HFO and LNG with stronger increase in demand. The starting year for the fuel price scenario is 2010 and 650 USD/t (=15.3 USD/mmBTU) for HFO and 900 USD/t (=21.2 USD/mmBTU) for MGO are set. LNG is set at 13 USD/mmBTU which includes small scale distribution costs of 4 USD/mmBTU. It is assumed that distribution costs do not increase over time.

Results

Annual cost advantages, compared to the reference vessel using the required fuels depending on time and location, can be computed using the assumptions described above for each technology and vessel size. Cost advantages are the sum of fuel cost savings, additional operating costs and lost (negative) earnings. For a 2,500 TEU regional vessel operating 65% inside European ECAs, significant cost advantages are predicted using LNG or scrubber by 2015 when strict fuel quality requirements enter into force. The payback time is shorter for solutions without WHR due to its relatively high investment costs.
**Results – payback time**

Benefits of technologies such as LNG or scrubber depend strongly on their usage. The higher the ECA exposure, the shorter the payback time for all variants, with operation start in 2015. The payback time is shorter for smaller container vessels (2,500 TEU and 4,600 TEU). This is caused by the relatively smaller investment for the LNG system compared to large vessels. With a 65% ECA exposure, the LNG system payback time below 2 years can be achieved for smaller vessels.

A comparison of the different technologies shows that the LNG system offers a shorter payback time than a scrubber for the 2,500 TEU vessel (using the standard fuel price scenario). The payback time is longer for variants with WHR due to higher investment costs.

At ECA operation shares lower than 20%, the scrubber system payback time is longer than 60 months which indicates that payback is achieved only after the introduction of the LSHO quality standard in 2020.
4,600 TEU vessels, operating 11% inside of an ECA, also offer a shorter payback time for LNG systems compared to the scrubber installation. Similar to 2,500 TEU vessels, a WHR system does not shorten the payback time. WHR systems offer larger benefits for large vessels with high installed engine power and associated savings. Therefore, the payback time for the LNG system or scrubber when applied to a 14,000 TEU vessel is shorter with a WHR system implemented.

The LNG system offers a shorter payback time than the scrubber system for large vessels (using the standard fuel price scenario). Only at higher ECA operation shares (which are unlikely), the scrubber solution has a shorter payback time than the LNG system.

This documents that, when standard assumptions are used, LNG systems offer shorter payback times than scrubber systems.
The drivers – LNG tank cost and LNG price

The largest share of the additional investment is related to the LNG tank. In this study, a type C tank is assumed to be fitted for the 2,500 TEU vessel and type B prismatic tanks are considered for the larger vessels. Smaller type C tanks are expected to have higher specific costs than larger type B tanks. The payback time for larger vessels shows a stronger dependency on the specific LNG tank costs than for smaller vessels.

A comparison of the LNG and scrubber systems’ payback time for 2,500 TEU vessels shows that even at high LNG tank costs the payback time is shorter for the LNG system (when the standard fuel price scenario is used).

For larger vessels, specific tank costs above 3,000 USD/m³ result in unfavourably payback times compared to the scrubber system.

Considering the still not widely available LNG supply infrastructure for ships, changes in LNG distribution costs are considered to affect the payback time for LNG systems. In general, the


payback time for larger vessels with relatively larger LNG system costs depends strongly on the LNG price (delivered to the ship). At price parity of HFO and LNG, based on the energy content, the payback time for larger vessels is longer than 60 months (indicating a breakeven is possible only when the 2020 fuel standard is in force.)

For the 2,500 TEU vessel, a comparison of payback times for the scrubber and for the LNG system, and varying LNG prices, shows that the LNG system is attractive as long as LNG (delivered to the ship) is as expensive as or cheaper than HFO, when the fuels are compared on their energy contents. (In January 2012, the LNG wholesale price in Zeebrugge was at 10.6 USD/mmBTU and HFO in Rotterdam was at 15.7 USD/mmBTU, indicating that LNG as ship fuel appears commercially attractive vs. HFO in Europe.)

Fig. 20: Payback time for LNG system

Fig. 21: Payback time for 2,500 TEU vessels
Conclusion

The use of LNG as ship fuel promises a lower emission level and, given the right circumstances, lower fuel costs. The attractiveness of LNG as ship fuel compared to scrubber systems is dominated by three parameters:

- Investment costs for LNG tank system
- Price difference between LNG and HFO
- Share of operation inside ECA.

With a 65% ECA exposure, the LNG system payback time below 2 years is predicted for the smaller vessel sizes (using the standard fuel price scenario).

For the 2,500 TEU vessel, a comparison of payback times for the scrubber and for the LNG system, and varying LNG prices, shows that the LNG system is attractive as long as LNG (delivered to the ship) is as expensive as or cheaper than HFO, when the fuels are compared on their energy content.

For larger vessels typically operating at smaller ECA shares, e.g. a 14,000 TEU vessel, the LNG system has the shortest payback time (when the standard fuel price scenario is used), and the use of a WHR system further reduces the payback time.

The price of LNG delivered to the ship is difficult to predict. Base LNG prices vary from the USA to Japan by a factor of four. European base LNG prices appear attractive at around 10 USD/mmBTU even with small-scale distribution costs added. An LNG price of up to 15 USD/mmBTU could give LNG systems a competitive advantage against scrubbers in terms of payback for the smaller vessels considered in this study.

Small-scale LNG distribution is just starting to become available in Europe (outside Norway) and it remains to be seen which LNG fuel price levels will be established.

The model to predict costs and benefits for LNG systems, scrubbers and WHR systems on board container vessels offers extensive possibilities to study additional variants. Options include different vessel sizes, route profiles, incl. ECA operation shares and other LNG tank configurations.

LNG as ship fuel has become a reality in international shipping. The product carrier Bit Viking started operation using LNG in October 2011. She is classed by GL.

Fig. 22: DSME LNG-fuelled container ship
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