MARITIME

ALTERNATIVE FUELS AND TECHNOLOGIES FOR GREENER SHIPPING

Summary of an assessment of selected alternative fuels and technologies
1 THE FUEL CHALLENGE IN SHIPPING

International initiatives towards reducing CO₂ and other emissions are driving the research into alternatives to conventional petroleum-based ship fuels. A wide range of alternative fuels are being discussed, and technologies such as fuel cell systems and Combined Gas Turbine and Steam Turbine Integrated Electric Drive Systems (COGES), which can only be applied efficiently in conjunction with cleaner fuels, have appeared on the agenda. An impressive number of restrictions aiming to improve the environmental footprint of shipping are in force or under preparation (refer to Figure 1).

In particular, the decision of the International Maritime Organization (IMO) to limit the sulphur content of ship fuel from 1 January 2020 to 0.5 per cent worldwide has the potential to become a game changer. It creates an atmosphere of uncertainty across the industry regarding the direction to take in terms of future energy sources. As illustrated in Figure 2, the combined amount of heavy fuel oil (HFO) and marine gas oil (MGO) consumed by ships accounts for no more than 25 per cent of the global diesel fuel and petrol production (2016 figures). This is roughly equivalent to the amount of energy consumed using liquefied natural gas (LNG), which stands at 24 per cent; however, LNG represents only a small portion (approximately 10 per cent) of the overall gas market.

FIGURE 1: SHIPPING BECOMES GREENER AND MORE COMPLEX
Selected items from regulatory timeline towards 2030

- Key ports in Chinese area – 0.5% sulphur
- All ports in Chinese area – 0.5% sulphur
- Chinese area – 0.5% sulphur
- IGF Code in force
- EU CO₂ monitoring, reporting and verification
- Global fuel consumption data collection system

- Adopted
- In the pipeline, or possible

California sulphur regulations to lapse
IMO GHG strategy
Provided that the IMO regulations are enforced as of 2020, up to 48 million tonnes of ship fuel containing 0.1 per cent or less of sulphur will be consumed annually from that time onwards. Most of the fuel consumed (70 to 88 per cent) will have a sulphur content between 0.1 and 0.5 per cent. This means that low-sulphur fuel may take the role of today’s high-sulphur fuel. Assuming an installed base of about 4,000 scrubbers at that time, no more than 11 per cent of ship fuel usage will be high-sulphur fuel. Latest estimates assume only 1,000 to 1,500 scrubber installations available 2020. This raises the question as to whether high-sulphur fuel will even be available any more if only 4,000 or even less ships can use it. The next question is at what price HFO will be available.

These practical challenges related to sulphur reduction are knocking at the door. At the same time, there is an accelerating worldwide trend towards pushing down CO₂, NOₓ and particle emissions. All of these factors are reason enough to intensify the search for fuels and technologies that can help the industry to meet the challenges ahead.
Among the proposed alternative fuels for shipping, DNV GL has identified LNG, LPG, methanol, biofuel and hydrogen as the most promising solutions. Among the new technologies, we believe battery systems, fuel cell systems and wind-assisted propulsion to harbour potential for ship applications. As has been demonstrated by our PERFECT Ship concept study (refer to PERFECT Ship video available on YouTube), the well-known combined cycle gas and steam turbine technology has potential for ships in the power range above 30 MW, provided that low-sulphur fuels are widely available to the shipping sector and/or high-sulphur fuels are required to undergo extensive treatment.

Fuel cell (FC) systems for ships are under development, but it will take time for them to reach a degree of maturity sufficient for substituting main engines. Battery systems are finding their way into shipping; however, on most seagoing ships their role is limited to efficiency and flexibility enhancement. Finally, wind-assisted propulsion, while not a new technology, will require some development work to make a meaningful difference for modern vessels.

The greatest challenges are related to environmental compatibility, the availability of sufficient fuel for the requirements of shipping, fuel costs and the international rule setting by the IGF Code.

The IMO continues its work on the IGF Code for methanol, low-flashpoint diesel and the rules for fuel cell systems. The other fuels named above are not on the current agenda for the IGF Code. This should be taken into consideration by owners contemplating LPG or hydrogen applications in the near future.

**FIGURE 2: SHIP FUEL CONSUMPTION IS MUCH LOWER THAN DIESEL AND GAS OIL CONSUMPTION**

Yearly energy consumption in relation to diesel and gas oil consumption

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Share in consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil</td>
<td>3.05</td>
</tr>
<tr>
<td>HFO (marine)</td>
<td>0.21</td>
</tr>
<tr>
<td>MGO (marine)</td>
<td>0.04</td>
</tr>
<tr>
<td>Biogasoline (ethanol)</td>
<td>0.04</td>
</tr>
<tr>
<td>FAME (biodiesel)</td>
<td>0.02</td>
</tr>
<tr>
<td>LPG</td>
<td>0.23</td>
</tr>
<tr>
<td>Natural gas (total)</td>
<td>2.43</td>
</tr>
<tr>
<td>Gas</td>
<td>2.19</td>
</tr>
<tr>
<td>LNG</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Figures represent 2016 statistics.
3 EMISSIONS

3.1 CO₂

Figure 3 illustrates the CO₂ footprint of various fuels.

Green House Gas emissions (GHE) are measured as CO₂-equivalent emissions. Of all relevant fossil fuels, LNG produces the lowest CO₂ emissions as can be seen from Fig. However, the release of unburned methane (so-called methane slip) could annihilate the benefit over HFO and MGO because methane (CH₄) has 25 to 30 times the greenhouse gas effect compared to CO₂. Nevertheless, engine manufacturers claim that the Tank-to-Propeller (TTP) CO₂-equivalent emissions of Otto-cycle dual-fuel (DF) and pure gas engines are 10 to 20 percent below the emissions of oil-fuelled engines. Diesel-cycle gas DF engines have very low methane slip, and their TTP emissions are very close to those in the illustration. This is also the case for COGES system as proposed by the PERFECT Ship concept.

The carbon footprints of methanol and hydrogen produced from natural gas are larger than those of HFO and MGO.

The key benefit of fuels produced using regenerative energy is clearly a small carbon footprint. Among these fuels, first-generation biodiesel has a relatively low CO₂ reduction potential. However, liquefied methane produced from biomass (biogas) has extremely high CO₂ reduction potential. It should be noted that the main component of LNG is also methane; therefore, both liquefied gases are equivalent.

The cleanest fuel is hydrogen that is produced using regenerative energy. Liquefied hydrogen could be used in future shipping applications. Because of its very low energy density, its storage volume is large. This may prevent hydrogen from being used directly in international deep-sea shipping. In a sustainable energy world, where the entire energy demand is covered by regenerative, CO₂-free energy sources, hydrogen and CO₂ will be the basic ingredients for fuel production, most likely in the form of methane or diesel-like fuels produced in a Sabatier or Fischer-Tropsch process.

3.2 NOₓ

Figure 4 illustrates the influence of various ship engine technologies and fuels on NOₓ emissions. The value for HFO-fuelled Tier II diesel engines is used as a baseline (100 per cent). The values are only comparable when assuming the same rotational speed.

The bars on the right-hand side of Figure 4 represent potential emissions reduction through switching from Tier II to Tier III. It is obvious that for all fuels given in Figure 4, diesel-cycle engines must be equipped with exhaust gas treatment systems to comply with the IMO Tier III limits. Only Otto-cycle engines burning LNG or hydrogen have the potential to remain within the Tier III limits without requiring exhaust gas treatment. This means that, in most cases, a fuel switch is not sufficient to comply with the Tier III NOₓ limits.

3.3 OVERALL EMISSION BEHAVIOUR OF PROPULSION SYSTEMS

Ship propulsion concepts differ in their principal emission behaviour. This is illustrated by Figure 5 for diesel-cycle and Otto-cycle engines as well as the gas steam turbine concept applied in the PERFECT Ship project.
1. Diesel cycle: HFO
   The IMO rules can be fulfilled with added technical means, at the cost of added fuel consumption and increased CO₂ emissions caused by the scrubber and exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) equipment.

2. Diesel cycle: LSHFO/MGO
   SOₓ compliance is ensured by the low SOₓ content of the fuel. EGR/SCR equipment is required for Tier III compliance. An SCR increases the CO₂ emissions.

3. Diesel cycle: LNG
   LNG is sulphur-free so there are no SOₓ emissions. The effort required to achieve Tier III compliance is lower than for oil fuel, but EGR/SCR equipment is still needed.

4. Otto cycle: LNG
   Otto-cycle medium and low-speed engines can meet Tier III requirements without additional exhaust gas treatment. Methane slip compromises the benefit in terms of CO₂ reduction, so the maximum 28 to 30 per cent improvement cannot be achieved. Engine manufacturers indicate potential CO₂ reduction values of 10 to 20 per cent over similar oil-fuelled engines.

5. The COGES concept used in the PERFECt Ship project is illustrated for comparison. It should be noted that it can only achieve efficiency improvements and a CO₂ emissions reduction similar to piston engines if the power demand is high enough (30 to 35 MW as an approximate lower limit). If this condition is met, Tier III NOₓ compliance can be achieved with internal means (dry low NOₓ burner) when operating with oil or gas. Methane slip does not occur. All things considered, the emissions of COGES systems as proposed in the PERFECt Ship project meet all foreseeable IMO limits. No external exhaust gas cleaning is needed.

   It is obvious that all propulsion concepts have their pros and cons and that all of them are able to achieve the emission limits with all fuel alternatives. The best concept for a given application needs to be determined on a case-by-case basis; it also depends on the owner’s preferences. DNV GL is prepared to assist customers in the decision-making process.

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**FIGURE 4: NOₓ EMISSIONS OF ALTERNATIVE FUELS**

- NOₓ% (diesel-cycle, Tier II engine)
- NOₓ% (Otto-cycle, Tier II engine)

**FIGURE 5: OVERVIEW: FUEL - ENGINE SYSTEM - EMISSIONS**

<table>
<thead>
<tr>
<th></th>
<th>HFO</th>
<th>LSHFO/MGO</th>
<th>LNG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diesel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOₓ</td>
<td>Scrubber</td>
<td>Compliance</td>
<td>Future-proof</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Tier III: EGR/SCR</td>
<td>Tier III: EGR/SCR</td>
<td>Tier III: EGR/SCR</td>
</tr>
<tr>
<td>CO₂</td>
<td>High carbon</td>
<td>High carbon</td>
<td>Low carbon</td>
</tr>
<tr>
<td><strong>Otto</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOₓ</td>
<td></td>
<td></td>
<td>Future-proof</td>
</tr>
<tr>
<td>NOₓ</td>
<td></td>
<td></td>
<td>Future-proof</td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td></td>
<td>Compliance (but CH₄ slip)</td>
</tr>
<tr>
<td><strong>PERFECt (COGES)</strong></td>
<td></td>
<td></td>
<td>Future-proof</td>
</tr>
<tr>
<td>SOₓ</td>
<td>Compliance with 0.1 MGO</td>
<td>Future-proof</td>
<td></td>
</tr>
<tr>
<td>NOₓ</td>
<td>Future-proof</td>
<td>Future-proof</td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>High carbon</td>
<td>Future-proof (no CH₄ slip)</td>
<td></td>
</tr>
</tbody>
</table>
In most cases, the engine technology investment is not the dominant factor for the business case. The price of fuel over the lifetime of the ship, or the desired return on investment over a given period, is often the most relevant factor. Fuel pricing depends on a number of factors, including hardly foreseeable market conditions. For international shipping, it should be noted that subsidies which are based on tax reduction for preferred fuels do not exist because ship fuels are tax-free already. It remains to be seen whether this will change, for example through the introduction of a CO2 fee scheme.

The restrictions illustrated in Figure 6 reveal a qualitative trend based on price history. The bars indicate the average minimum and maximum price differences to Brent crude oil. The value of 1.0 represents the Brent baseline. Various internal and external sources were used to estimate the average pricing from 2005 to 2015/2016 for the different fuels. One of the main external sources is the BP Statistical Review of World Energy.

Hydrogen is not included because nearly all hydrogen is currently produced from natural gas and therefore more expensive. When hydrogen is produced using renewable energy, it can be assumed to be much more expensive than Brent crude oil. It would only be competitive under the assumption of massive subsidies, or of heavy taxes on conventional fuels.

Historically, MGO has always been more expensive than Brent crude oil, and HFO always much cheaper than the latter.

In Europe, LNG competes directly with the price of pipeline gas. LNG that is fed into the grid cannot be more expensive than pipeline gas. The calculations for the diagram use the gas price on the European spot market as a basis for LNG price predictions. The natural gas price in Japan is always an LNG price because the country imports all of its natural gas as LNG. Today, the gas prices in Japan and Europe are gradually aligning. The European and Japanese LNG prices can be regarded as an indicator for the worldwide LNG prices, regardless of major local deviations. It should be noted that these diagrams do not account for LNG distribution costs.

Most LPG is an oil refinery product. This is one of the reasons for LPG prices to align with the oil price. The diagram is based on the US LPG prices from 2005 and 2016 and the European LPG prices between 2008 and 2015.

Today, methanol is mainly produced from natural gas. For this reason, the methanol price is typically above the gas price. The lower price in the diagram refers to methanol produced from gas, while the upper price reflects methanol produced from biomass.

Biofuels are fuels produced from biomass. While dependent on the type of biofuel and the price of the biomass, the price is typically above that of Brent crude oil.

The diagram illustrates that only LNG and, to some extent, LPG can currently compete with HFO in terms of market price. Methanol and biofuels may eventually be able to compete with MGO to some extent. Hydrogen is not price-competitive.
Apart from its price, a future fuel must be available to the market in sufficient quantity. All fuel alternatives discussed here could meet the requirements of the shipping industry for the next ten years, assuming only minor growth in shipping applications. The question is what would happen if a fuel alternative were to become so attractive that a large number of operators would want to adopt it for their ships within a short period of time.

Figure 7 gives an indication based on a comparison of the energy content of the worldwide production of specific alternative fuels with the energy need of the shipping industry. The energy consumption of the global fleet serves as the 100 per cent baseline. This comparison shows that for all alternative fuels, with the exception of LNG, a rapid rise in demand would require massive investments in production capacity. In theory, a switchover of the entire global fleet to LNG would be possible today since the current LNG production is higher than the shipping industry’s energy requirement, and the share of LNG in the total gas market is only 10 per cent. Furthermore, LPG could likewise cover the energy need of the global fleet; however, in this case no LPG would be left for other users.
6 CONCLUDING REMARKS

Environmental and price challenges are driving the interest in alternative ship fuels, but the number of realistic candidates is small. DNV GL believes LNG, LPG, methanol, biofuel and hydrogen to be the most promising candidates. Among them, LNG has already overcome the hurdles related to international legislation, and methanol and biofuels will follow suit very soon. It will be a while before LPG and hydrogen are covered by appropriate new regulations within the IMO IGF Code, as well.

The existing and upcoming environmental restrictions can be met by all alternative fuels using existing technology. Fuel cells can use all available alternative fuels and achieve efficiencies comparable to, or better than, those of current propulsion systems. However, fuel-cell technology for ships is still in its infancy. The most advanced developments to date have been achieved by the projects running under the umbrella of the e4ships lighthouse project in Germany, with Meyer Werft and ThyssenKrupp Marine Systems heading the projects for seagoing ships. Wind-assisted propulsion could potentially reduce fuel consumption, especially when used for slow ships, but the business case remains difficult. Batteries as a means to store energy can be considered as an alternative fuel source in the widest sense. They have major potential for ships

SUMMARY OF KEY FINDINGS

1. The IMO decision to limit the sulphur content of ship fuel worldwide as of 1 January 2020 to 0.5 per cent has the potential to be a game changer.
2. There is an accelerating worldwide trend towards lower emissions of CO₂, NOₓ and particles.
3. DNV GL identified LNG, LPG, methanol, biofuel and hydrogen as the most promising alternative fuels for shipping.
4. DNV GL believes battery systems, fuel cell systems and wind-assisted propulsion have reasonable potential for ship applications.
5. As has been demonstrated by the DNV GL PERFECt Ship concept study (refer to PERFECt Ship video available on YouTube), the well-known combined cycle gas and steam turbine technology has good potential for ships in the power range above 30 MW, provided that low-sulphur fuels are widely used in shipping.
6. The major challenges for alternative fuels are related to environmental benefits, fuel availability in the quantities needed for shipping, fuel costs and the international rules within the IGF Code.
7. Of all fossil fuels, LNG produces the lowest CO₂ emissions.
8. In a sustainable energy world where all energy is produced by regenerative CO₂-neutral sources, hydrogen and CO₂ will be the basis for fuel production.
9. All propulsion concepts are capable of meeting the emission limits using any of the fuel alternatives.
10. For international shipping, it should be noted that subsidies financed by taxes on fuel for preferred fuels do not exist because there is no taxation on ship fuels.
running on short distances, and can be used to boost the efficiency of the propulsion system in any ship. However, in deep-sea shipping, batteries alone cannot substitute fuel. With low-sulphur and alternative fuels becoming more widely available, the well-known combined cycle gas and steam turbine technology represents a viable alternative for high-power ship propulsion systems.

All fuel alternatives discussed here could meet the foreseeable volume requirements for shipping over the coming years. A major increase in consumption would require an appropriate increase in production capacity; the only exception is LNG, which is available in sufficient quantities today to meet the potential requirement of the shipping industry for many years. Without taxation or subsidies, renewable fuels will find it difficult to compete with the prices of conventional fossil fuels. LNG and LPG are the only fossil fuels capable of achieving a reasonable CO₂ emissions reduction. CO₂-neutral shipping seems possible only with fuels produced from regenerative sources. If the shipping sector resorts to synthetic fuels produced from hydrogen and CO₂ using regenerative energy, the available alternatives will be liquefied methane (which is very similar to LNG) and diesel-like fuels.

7 WE SUPPORT YOU TO MAKE THE RIGHT DECISION

Our services in environmental technology and alternative fuels include:

**Fuel changeover calculator (FCO)**
DNV GL’s ship-specific FCO plots a complex numerical simulation of the fuel changeover process from conventional HFO to ultra-low sulphur fuel oil, which is typically marine gas oil (MGO). It promises a very accurate calculation and potential cost savings compared to a linear model, and also takes into account recommended maximum temperature change per minute. The FCO also offers a comprehensive package to account for documentation requirements. Receive more information at: www.dnvgl.com/maritime/advisory/Fuel-change-over-calculator.html

**ECA support**
We offer strategic advice on solutions for ECA compliance, including assistance in choosing and implementing technologies for reducing emissions and remaining in compliance in a cost-effective manner.

**Feasibility studies**
The evaluation of the technical feasibility and financial attractiveness of environmental technologies or fuels, such as LNG (LNG Ready), scrubbers, biofuel, battery systems, hydrogen, ballast water, VOC management, waste and waste water technologies.

**Technology qualification**
Determination of whether a solution is fit for its given purpose. Risk identification and risk reduction through failure mode, effect and criticality study (FMECA), hazard identification study (HAZID) or hazard and operability study (HAZOP).

**LNG intelligence portal (LNGi)**
Through our LNG intelligence portal, we offer comprehensive insights into worldwide LNG bunkering availability and market data on LNG as fuel for ships.

**Control system software testing**
The verification and testing of control system software using Hardware-in-the-Loop (HIL) technology will result in safer and more reliable automation systems and shorter commissioning times due to less software issues. Any control system can be tested, e.g. EGCS/scrubber, SCR, LNG as fuel, energy management system, ballast water treatment system.