MARITIME

ASSESSMENT OF SELECTED ALTERNATIVE FUELS AND TECHNOLOGIES
# TABLE OF CONTENTS

1 SUMMARY

2 BACKGROUND

3 INTRODUCTION TO ALTERNATIVE FUELS AND TECHNOLOGIES
   3.1 Which fuels are alternatives?
   3.2 CO₂ Emissions
   3.3 NOₓ
   3.4 Overall Emission behaviour
   3.5 Some thoughts on fuel pricing
   3.6 Fuel availability
   3.7 Concluding remarks

Alternative fuels
Alternative technologies

4 INTERNATIONAL REGULATIONS AND CLASS RULES

5 ALTERNATIVE FUELS AND TECHNOLOGIES – A BRIEF OVERVIEW
   5.1 Principles
   5.2 Reference fuels - HFO and MGO
   5.3 LNG
   5.4 LPG
   5.5 Methanol
   5.6 Biofuels
   5.7 Hydrogen
   5.8 Wind-assisted propulsion
   5.9 Batteries
   5.10 Fuel cells

6 WE SUPPORT YOU TO MAKE THE RIGHT DECISION

7 DNV GL CLASS SERVICES
1 SUMMARY

The shipping industry is under increasing pressure to act upon the Paris Agreement and reduce greenhouse gas (GHG) emissions. The substantial emission reductions which must be achieved over the next decades are expected to drive technology development and, in particular, the introduction of low-carbon fuels. Furthermore, authorities are increasingly paying attention to the consequences of hazardous NOx, SOx and particle emissions at the local level. Around the world, air pollution is causing serious health problems and premature death\(^1\), and local air pollution will be subject to tougher regulations over the coming years.

Reducing emissions to air and introducing new propulsion technologies are key challenges for the worldwide transport sector, including shipping. The world’s future fleet will have to rely on a broader range of fuels, propulsion solutions and energy efficiency measures.

All alternative fuel options are accompanied by benefits and challenges. This guidance paper provides an introduction to alternative fuels and technology solutions. It includes an overview of selected alternative ship fuels – LNG, LPG, methanol, biofuel and hydrogen – as well as emerging technologies such as batteries, fuel cell systems and wind-assisted propulsion.

The objective of this guidance paper is to provide decision support for investments in ships over the coming 5 to 10-year period. The paper focuses on technical parameters and limitations without accounting for local market conditions, considerations and incentive schemes which may have a significant impact on competitiveness and the uptake of alternative fuels and technologies.

2 BACKGROUND

Marine fuel currently contributes approximately 3 per cent to global man-made CO\(_2\) emissions. Most seagoing ships are still using heavy fuel oil (HFO) or marine gas oil (MGO), with a maximum sulphur limit of 3.5 per cent (mass) in force for HFO and 0.1 per cent (mass) for low-sulphur MGO.

Looking at the future with the IMO 2020 low-sulphur standards and upcoming CO\(_2\) emission regulation regime in mind, the share of conventional oil-based ship fuels will drop and the share of alternative fuels will grow.

Prerequisites for introducing a new fuel include availability of sufficient production and distribution facilities as well as an adequate bunkering infrastructure. In addition, new fuels in many cases require extensive on-board modifications and a reversal to a conventional system is complex and costly. This guidance paper intends to provide decision support to customers when selecting a fuel for the ships they order today and in coming years.
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, effective 1 January 2020, to 0.5 per cent worldwide has the potential to become a game changer. 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) (24 per cent); however, LNG represents only a small
portion (approximately 10 per cent) of the overall gas market.

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 in 2020. This raises the question 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 meet the challenges ahead.
LNG-powered vessels\(^2\) have been in operation since 2000. As of 1 March 2018, 121 LNG-fuelled ships were in operation and 127 newbuilding orders were confirmed. Biofuels (including renewables) and methanol\(^1\)\(^2\) are available at certain ports, and fully electrical/hybrid ships are emerging in the short sea, offshore and passenger segments. Based on current technology, a distinction between short-sea and deep-sea shipping should be made with regards to applicability of various fuels:

\[ \text{Short-sea shipping: Vessels typically operating in limited geographical areas on relatively short routes with frequent port calls. Due to their relatively low energy demand, these vessels are often ideal candidates for testing new fuels marked by high energy or fuel storage costs. The Norwegian ferry sector is in the process of being electrified, with about 50 battery-electric ferries to be phased in over the next few years. The use of hydrogen is also technically feasible, and the Norwegian national road authorities, supported by DNV GL, are working on the development of hydrogen applications and intend to put a new hydrogen-powered ferry into service by 2021}^{[3]} \]

\[ \text{Deep-sea shipping: This includes large, ocean-going vessels covering long routes, often without a regular schedule. These vessels require fuel that is globally available. The energy source carried on board must have a sufficiently high energy density to maximize the available cargo space. For these vessels, LNG can be a viable option once an adequate bunkering infrastructure is available globally. Sustainable biofuels, methanol and LPG can also be a choice, provided that they can be made available in the required quantities and at an adequate quality level.} \]

Based on current technology, batteries are viewed as impractical as a source of main propulsion energy for these vessels in the foreseeable future. Nuclear propulsion is technically feasible for large vessels, but there are political, societal and regulatory barriers to consider. Various sail arrangements (e.g. sail, kite, fixed-wing, Flettner rotors) have been tried on merchant vessels over the years. A new Delft study concludes that there is significant saving potential in wind-assisted propulsion on large tankers and bulk carriers (Delft, 2017).

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

<table>
<thead>
<tr>
<th></th>
<th>Yearly energy consumption in relation to diesel and gas oil 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.

\(^2\) Not including the approx. 450 LNG carriers which also run on LNG.


\(^2\) Seven 50,000 tonne deadweight vessels are being built with the first-of-its-kind MAN B&W ME-LGI two-stroke dual-fuel engine that can run on methanol, fuel oil, marine diesel oil, or gas oil: [https://www.methanex.com/about-methanol/methanol-marine-fuel#sthash.oW84bYPp.dpuf](https://www.methanex.com/about-methanol/methanol-marine-fuel#sthash.oW84bYPp.dpuf)

3.1 WHICH FUELS ARE ALTERNATIVES?

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 reasonable 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 used in 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. Batteries cannot store the huge amounts of energy needed to power a large ship. 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 benefits, fuel 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 and 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 3: CO₂ EMISSIONS OF FUEL ALTERNATIVES IN SHIPPING**

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>CO₂ Emissions; g/MJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil fuel (HFO)</td>
<td></td>
</tr>
<tr>
<td>Oil fuel (MGO)</td>
<td></td>
</tr>
<tr>
<td>LNG (from Qatar used in Europe)</td>
<td></td>
</tr>
<tr>
<td>LNG (from Qatar used in Qatar)</td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td></td>
</tr>
<tr>
<td>Methanol (from CH₄)</td>
<td></td>
</tr>
<tr>
<td>Methanol (from black liquor)</td>
<td></td>
</tr>
<tr>
<td>Biodiesel</td>
<td></td>
</tr>
<tr>
<td>Biogas (97% methane - liquefied)</td>
<td></td>
</tr>
<tr>
<td>Hydrogen (liquid - from CH₄)</td>
<td></td>
</tr>
<tr>
<td>Hydrogen (liquid - from water)</td>
<td></td>
</tr>
</tbody>
</table>

TTP - Tank to propeller
WTT - Well to tank
3.2 CO₂ EMISSIONS

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 green house gas effaced 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 comparison between the CO₂ emissions from LNG used in Qatar, close to the production site, versus LNG used in Europe reveals that the required transport of LNG does not increase the carbon footprint significantly.

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 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, Fischer-Tropsch process.

3.3 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 the diagram represent the potential emission reduction through switching from Tier II to Tier III (NOₓ%).

It is obvious that for all fuels given in the below figure, 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 switch of fuel is not sufficient to comply with the Tier III NOₓ limits.

**FIGURE 4: NOₓ EMISSIONS OF ALTERNATIVE FUELS**
3.4 OVERALL EMISSION BEHAVIOUR

Ship propulsion concepts differ in their principal emission behaviour. This is illustrated in Figure 5 below for diesel-cycle and Otto-cycle engines as well as the gas steam turbine concept as applied in the PERFECT Ship project.

1. Diesel cycle: HFO
The IMO rules can be fulfilled when applying additional technical means, but 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. 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 emission 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 on 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 principally able to reach 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.

FIGURE 5: OVERVIEW: FUEL - ENGINE SYSTEM - EMISSION

<table>
<thead>
<tr>
<th></th>
<th>HFO</th>
<th>LSHFO/MGO</th>
<th>LNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>SOₓ</td>
<td>Scrubber</td>
<td>Compliance</td>
</tr>
<tr>
<td></td>
<td>NOₓ</td>
<td>Tier III: EGR/SCR</td>
<td>Tier III: EGR/SCR</td>
</tr>
<tr>
<td></td>
<td>CO₂</td>
<td>High carbon</td>
<td>Low carbon</td>
</tr>
<tr>
<td>Otto</td>
<td>SOₓ</td>
<td></td>
<td>Future-proof</td>
</tr>
<tr>
<td></td>
<td>NOₓ</td>
<td></td>
<td>Future-proof</td>
</tr>
<tr>
<td></td>
<td>CO₂</td>
<td></td>
<td>Compliance (but CH₄ slip)</td>
</tr>
<tr>
<td>PERFECT: (COGES)</td>
<td>SOₓ</td>
<td>Compliance with 0.1 MGO</td>
<td>Future-proof</td>
</tr>
<tr>
<td></td>
<td>NOₓ</td>
<td></td>
<td>Future-proof</td>
</tr>
<tr>
<td></td>
<td>CO₂</td>
<td>High carbon</td>
<td>Future-proof (no CH₄ slip)</td>
</tr>
</tbody>
</table>
3.5 SOME THOUGHTS ON FUEL PRICING

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 market conditions, which are difficult or impossible to predict. For international shipping it should be noted that subsidies 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 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. 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. Today, nearly all hydrogen is produced from natural gas and therefore more expensive than natural gas.

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

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 price 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 produced from biomass. While dependant upon the type of biofuel and the price of the biomass, the price is typically above that of Brent crude oil.

The diagram demonstrates that only LNG and, to some extend, 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.

**FIGURE 6: ARE ALTERNATIVE FUELS TOO EXPENSIVE?**

![Qualitative price range of possible ship fuels (reference: Brent crude oil)](image)
3.6 FUEL AVAILABILITY

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.

**FIGURE 7: PRODUCTION OF POSSIBLE SHIP FUELS PER YEAR (RELATIVE ENERGY CONTENT)**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>% of today’s ship fuel (100% = energy content ship fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFO/MGO</td>
<td>160</td>
</tr>
<tr>
<td>LPG</td>
<td>140</td>
</tr>
<tr>
<td>LNG</td>
<td>120</td>
</tr>
<tr>
<td>CH₃OH</td>
<td>0</td>
</tr>
<tr>
<td>FAME</td>
<td>100</td>
</tr>
<tr>
<td>H₂</td>
<td>20</td>
</tr>
</tbody>
</table>

Approx. 10% of natural gas market
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 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 gas and steam turbine combined cycle 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 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.

3.7 CONCLUDING REMARKS

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.

SUMMARY OF KEY FINDINGS
**Biofuels**

Biofuels are derived from primary biomass or biomass residues that are converted into liquid or gaseous fuels. A large variety of processes exist for the production of conventional (first-generation) and advanced (second and third-generation) biofuels, involving a variety of feedstocks and conversions. The most promising biofuels for ships are biodiesel (e.g., HVO – hydrotreated vegetable oil, BTL – biomass-to-liquids, FAME – fatty acid methyl ester) and LBG (liquid biogas, which primarily consist of methane).

Biodiesel is most suitable for replacing MDO/MGO, LBG for replacing fossil LNG, and SVO (straight vegetable oil) for replacing HFO.

**Methanol**

With its chemical structure CH$_3$OH, methanol is the simplest alcohol with the lowest carbon content and highest hydrogen content of any liquid fuel. Methanol is a basic building block for hundreds of essential chemical commodities and is also used as a fuel for transport. It can be produced from a number of different feedstock resources like natural gas or coal, or from renewable resources such as biomass or CO$_2$ and hydrogen.

**LNG**

Liquefied natural gas (LNG) has more or less the same composition as natural gas used for households and power generation, and in the industry. Its main component is methane (CH$_4$), the hydrocarbon fuel with the lowest carbon content.

**Hydrogen**

Hydrogen (H$_2$) can be produced in several different ways, for example by electrolysis of renewable matter or by reforming natural gas. The production of hydrogen through electrolysis could be combined with the growing renewable energy sector which delivers, by its nature, intermittent power only. Conversion to hydrogen could facilitate storage and transport of this renewable energy.

Hydrogen is used in a variety of industrial processes and is currently being considered as a potential fuel for land-based transport, in particular in cars, buses, trucks and trains.

**LPG**

Liquefied petroleum gas (LPG) is by definition any mixture of propane and butane in liquid form. For instance, in the USA, the term LPG is generally associated with propane. Mixing butane and propane enables specific saturation pressure and temperature characteristics.
**ALTERNATIVE TECHNOLOGIES**

**Batteries**
Batteries provide the ability to directly store electrical energy for propulsion, opening up many other opportunities to optimize the power system. Recent advancements in battery technology and falling costs thanks to the growing worldwide demand for batteries make this technology attractive to shipping.

**Fuel cell systems**
Fuel cells convert the chemical energy contained in a fuel directly into electrical and thermal energy through electrochemical oxidation. This direct conversion process enables electrical efficiencies of up to 60 per cent, depending on the type of fuel cell and fuel used. It also minimizes vibration and noise emissions, a major setback of combustion engines.

**Wind-assisted propulsion**
For thousands of years wind was the primary energy source used to propel ships, apart from human muscles. Today, wind-assisted propulsion is understood to be a potential method of reducing the fossil energy consumption of ships. Wind is an inexhaustible source of energy.
4 INTERNATIONAL REGULATIONS AND CLASS RULES

Shipping is an international industry, and international environmental and safety standards for shipping are developed by the International Maritime Organization (IMO), a United Nations specialized agency. The International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF Code) is the mandatory IMO instrument that applies to all gaseous and other low-flashpoint fuels in shipping, and to all gas-powered ships other than gas carriers. The latter, and their use of low-flashpoint fuels, are covered by the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IMO IGC Code).

The IGF Code was adopted by the IMO in June 2015 (MSC.391[95]) and went into force on 1 January 2017. It is compulsory for all gaseous and other low-flashpoint-fuel ships and currently (2017) covers natural gas in liquid or compressed form (LNG, CNG). Regulations for methanol and low-flashpoint diesel fuels as well as for maritime fuel cells are under development.

The IGF Code contains obligatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low-flashpoint fuels, initially focusing on LNG. It addresses all areas that need special consideration for the usage of low-flashpoint fuels, taking a goal-based approach, with goals and functional requirements specified for each section to provide a basis for the design, construction and operation of ships using this type of fuel.

Technical provisions for other low-flashpoint fuels and other energy arrangements such as fuel cell systems will eventually be added to the code as new chapters. For the time being, ships installing fuel systems to operate on other types of low-flashpoint fuels will need to individually demonstrate that their design meets the IGF Code’s general requirements. Their alternative design has to be submitted according to IMO 1455 (guidelines for the approval of alternatives and equivalence as provided for in various IMO instruments) and accepted by the flag administration of the vessel. This individual, and in some cases complex process will likely have a slowing effect on the introduction of alternative fuels not yet explicitly covered by the IGF Code.

DNV GL rules addressing the requirements of the IGF Code include:

■ Mandatory Class Notation “GAS FUELLED”: Rules for classification of ships, Part 6, Chapter 2, Section 5, Gas fuelled ship installations – Gas fuelled
■ DNV GL also developed rules for gas-ready ships as well as for ships using low-flashpoint liquid fuels (e.g. methanol)
■ Voluntary Class Notation “GAS READY”: Rules for classification of ships, Part 6, Chapter 2, Section 8, Gas ready ships – Gas ready.
■ Mandatory Class Notation “LFL FUELLED”: Rules for classification of ships, Part 6, Chapter 2, Section 6, Low flashpoint liquid fuelled engines – LFL fuelled
■ Mandatory Class Notation “FC(Power)” or “FC(Safety): Rules for classification of ships, Part 6, Chapter 2, Section 3, Fuel cell installations – FC
■ In addition, DNV GL was the first classification society to develop rules for lithium-ion battery installations on board ships
■ Mandatory Class Notation(s) “BATTERY (SAFETY)” and “BATTERY (POWER)”: Rules for classification of ships, Part 6, Chapter 2, Section 1, Battery power
■ For further information regarding applicable rules for the alternative fuels and technologies covered in this guidance paper, please refer to the corresponding subsection of chapter 5. Further details can also be found in a recent DNV GL report for EMSA.
5. ALTERNATIVE FUELS AND TECHNOLOGIES - A BRIEF OVERVIEW

5.1 PRINCIPLES

To assess all fuels or technologies in a comparable manner, the information is categorized as follows:

1. **Price**: Accounts for production process, raw materials, market price and the reasoning behind it, current/foreseeable (five years) price/expected price (beyond five years)

2. **Infrastructure**: Current/future distribution network, bunkering, availability

3. **Regulation**: Existing/expected regulations, consequences

4. **Availability**: Current / possible future production as related to the requirement in shipping

5. **Environmental impact**: CO₂, NOₓ, SOₓ, particulate matter (PM) and others

6. **Technology**: Availability of current/future technology, foreseeable changes

7. **CAPEX**: Engines, storage, processing, retrofitting

8. **OPEX**: Exhaust cleaning, scrubber, additional costs for fuel change

Please note that the following gives a brief overview only. For additional information, please refer to our Web platform on alternative fuels, which will be launched later this year.
5.2 REFERENCE FUELS – HFO AND MGO

5.2.1 General
The shipping industry currently uses heavy fuel oil (HFO) and marine gas oil (MGO) as fuels; HFO has a maximum sulphur limit of 3.5 per cent (mass), while low-sulphur MGO contains 0.1 per cent (mass) or less. Ship fuel currently contributes approximately 3 per cent to global man-made CO₂ emissions. The energy demand of the shipping sector is projected to be approximately 314 million tonnes per year in 2020 (base case, MEPC 70-5.3, p. 26). With the year 2012 fuel mix, this would equate to 245 million tonnes of HFO (78 per cent) with an average sulphur content of 2.5 per cent (m/m; MEPC 70-5.3, Tab 5) and 69 million tonnes of MGO (22 per cent).

When the decision of IMO MEPC 70 to limit the sulphur content in ship fuel to 0.5 per cent takes effect in 2020, only vessels equipped with SOX scrubbers will be allowed to consume HFO (>0.5 per cent sulphur content). This will significantly reduce the global demand for high-sulphur HFO.

The fuel availability study prepared by the independent research and consultancy organization CE Delft, which served as a basis for the IMO decision, estimates that by 2020 around 4,000 vessels will operate with scrubbers installed. If this assumption is correct, only 6 per cent of the fuel mix will be HFO once the sulphur cap takes effect. However, as per March 2018 only approx. 420 vessels with scrubbers were known to be in operation or on order. This could mean that the actual percentage of HFO in the fuel mix by 2020 might be even lower than assumed by the Delft study, unless scrubber installations increase substantially in the meantime.

The Delft study also estimates that MGO with a maximum sulphur content of 0.1 per cent will account for approximately 14 per cent of the fuel mix by 2020, and that most of the fuel (80 per cent) will have a sulphur content between 0.1 and 0.5 per cent. In practical terms, these fuels can be assumed to be blends of HFO and MGO. If these predictions turn out to be accurate, the low-sulphur blend with up to 0.5 per cent sulphur will in essence replace the current high-sulphur HFO.

5.2.2 Details on specific subjects

Price

For decades, the HFO price has been below the crude oil price and the MGO price has been above that level, as Figure 8 below shows. As global demand for HFO will drop significantly after 2020, its price is assumed to fall as well. However, there might be local variations depending on the actual HFO availability in certain geographical locations. Since the majority of vessels will run on a sulphur-cap-compliant fuel, some ports and bunker suppliers might actually consider charging a premium price for continuing to deliver HFO.

Infrastructure

At present, there is a well-developed worldwide MGO and HFO supply infrastructure in place. Ships are supplied by bunker barges when in port, in most cases during cargo operations. The International Maritime Organization (IMO) expects oil-based, fuel-cap-compliant fuels to be available worldwide.
as of 2020, a notion challenged by other parties. It is uncertain whether and to what extent high-sulphur HFO will still be provided by bunker suppliers at all geographical locations beyond 2020.

Regulations

The IMO Marine Environment Protection Committee (MEPC) limited the sulphur content of ship fuel to 0.5 per cent from 2020 onward. This regulation applies worldwide.

Emission control areas (ECAs) for SOX were introduced along the North American coasts as well as in the North Sea and Baltic Sea in 2015. In these areas, the sulphur content of fuel is limited to 0.1 per cent. In the North and Baltic Seas, it is permissible to continue burning HFO and use scrubbers to clean the exhaust gas to achieve an equivalent level of sulphur emissions.

In 2016, the North American coastlines were additionally declared NOX-restricted areas. This means that ships keel-laid after 31 December 2015 must comply with Tier III NOX requirements. The same restrictions will apply in the North Sea and Baltic Sea from 2021 onward.

Notably, the sulphur limit for automotive diesel is much lower than that for ship fuel. Across Europe, it is at 0.001 per cent, 100 to 500 times below the 2020 limit for shipping. Therefore it is likely that the shipping industry will continue to be under legislative pressure regarding the sulphur content of its fuel.

Availability

While there have been different views across the industry regarding the expected availability of sulphur-cap-compliant fuel by 2020, the IMO based its decision to implement the sulphur cap as of 2020 on an availability study performed by CE Delft. However, the reality about the availability of compliant fuels and its potential impact on prices will not be known until the industry starts consuming compliant fuel once the sulphur cap takes effect.

Environmental impact

Oil-based ship fuel has a greater environmental impact than the alternative fuels discussed in this guidance paper. The sulphur content of low-sulphur ship fuel is much higher than that of the other fuel types. Even low-sulphur fuel will produce higher particle emissions than alternative fuels. Without selective catalytic reduction (SCR), NOX emissions will also be higher, and CO2 emissions will be higher than those of most of the alternative fuels discussed here. For a quantitative comparison, please refer to chapter 3.

Technology

All ships intended to operate on high-sulphur fuel from 2020 onward will be required to clean their exhaust gases by using scrubbers. Scrubber technology is readily available. Even if the low expectations of IMO MEPC 70-5.3 regarding high-sulphur HFO consumption turn out to be true, thousands of scrubbers will have to be installed by 2020. In ECAs, the NOX emission limits will require SCRs or exhaust gas recirculation (EGR) systems, in addition to scrubbers (depending on the keel-laying date). This technology is likewise readily available.

CAPEX

Depending on the size of the engine, the investment costs for scrubbers range between 650 USD/kW (5,000 kW engine) and 150 to 100 USD/kW (40,000 kW and larger engines).

OPEX

An exhaust gas cleaning system requires energy to operate the pumps and scrubbing units to remove the SOX from the exhaust gas. This energy use is estimated to be approximately 1 to 2 per cent of the power used by the engine(s) installed on the ship. This electrical energy is generated by auxiliary diesel generator sets burning either MDO/MGO or HFO (IMO MEPC 70-INF.9, Sec 3.6.1). The OPEX without maintenance and spare parts is approximately equivalent to 0.6 to 0.7 per cent of the hypothetical fuel costs without the presence of scrubber technology (according to MEPC 70-INF.9). The operational costs of scrubbers are composed of the cost of maintenance and energy consumption. According to IMO MEPC 70/5/3, these amount to approximately 0.7 per cent of the total fuel costs (ships with more than 25 MW of shaft power).
5.3 LNG

5.3.1 General
The main component of liquefied natural gas (LNG) is methane (CH₄), the hydrocarbon fuel with the lowest carbon content and therefore with the highest potential to reduce CO₂ emissions (maximum reduction: roughly 26 per cent compared to HFO). LNG has more or less the same composition as natural gas used in households, for power generation and by the industry. The production process of LNG ensures that it is practically sulphur-free. Therefore using LNG as fuel does not produce any SOₓ emissions. Since the boiling point of LNG is approximately –163°C at 1 bar of absolute pressure, LNG must be stored in insulated tanks.

The energy density per mass (LHV in MJ/kg) is approximately 18 per cent higher than that of HFO, but the volumetric density is only 43 per cent of HFO (kg/m³). This results in roughly twice the volume compared to the same energy stored in the form of HFO. Factoring in the shape-related space requirements, cylindrical LNG tanks typically occupy three times the volume of an equivalent amount of energy stored in the form of fuel oil.

5.3.2 Details on specific subjects

Price
Natural gas hub prices worldwide (except in certain parts of East Asia) have been below the price of crude oil and HFO for the last ten years. The delivered price of LNG fuel to ships must also account for the liquefaction or break bulk cost, distribution cost and applicable profit margins. Compared to other alternative fuels, LNG seems to have reached the most competitive feedstock price level historically among all alternatives fuels. Currently, the price level is competitive with MGO, but direct competition with HFO may be difficult (refer to chapter 3, Figure 6) and Figure 9.

From 2020, high-sulphur HFO will not be permitted without a scrubber system installed, and the price of the new LSFO reference fuel is expected to be higher than HFO. Furthermore, the price of LNG is expected to be competitive with low-sulphur HFO. LNG also has the potential to compete with high-sulphur HFO and scrubbers.

Infrastructure
While still limited, the dedicated LNG bunkering infrastructure for ships is improving quite rapidly. A large share of LNG bunkering as well as LNG distribution to bunkering locations is still taking place by road. Delivery by rail would also be possible but is currently not practised. In 2017, several LNG bunker vessels where delivered for operation in key locations such as the Amsterdam, Rotterdam, Antwerp (ARA) region, the North Sea, the Baltic Sea and at the coast of Florida. Bunker vessels for other key locations such as the Western Mediterranean, the Gulf of Mexico, the Middle East, Singapore, China, South Korea and Japan are under development and will likely materialize in parallel with significant orders for LNG-fuelled deep-sea ships within the next years.

For information on LNG bunkering infrastructure, please see DNV GL’s online LNGi portal (dnvgl.com/lngi), which gives detailed and continuously updated information on all LNG bunkering points in existence or under development. LNG is in principle available worldwide (import and export terminals), and investments are underway in many places to make LNG available to ships. We expect to see a focus on developing LNG bunker vessels for refuelling seagoing ships in the near future. Bunkering by truck and permanent local depots will also continue to grow for certain trades and segments. Dual-fuel engine technology may also offer some flexibility and redundancy as the LNG bunkering network for the deep-sea fleet evolves.

FIGURE 9: FUEL PRICES

![Fuel Prices](chart.png)
Regulations
The IMO IGF Code for LNG and CNG came into force on 1 January 2017, establishing an international regulatory basis for the design and construction of LNG-fuelled ships.

Other aspects, such as bunkering of LNG-fuelled ships, are subject to national regulations and therefore need to be evaluated on a case-by-case basis. For example, only a limited number of ports have established local rules for LNG bunkering. In addition, some LNG bunkering requirements and guidelines have also been developed by SGMF, IACS and ISO.

Availability
For the foreseeable future, there are no principal limitations to production capacities that could limit the availability of LNG as ship fuel. LNG has a share of approximately 10 per cent in the overall natural gas market. LNG production capacity is set to increase significantly over the next five years. In 2016, the global LNG production capacity was approximately 320 m t/a. This figure will increase by almost 40 per cent to about 450 m t/a by 2020 (2017 World LNG report; International Gas Union [IGU]).

Environmental impact
Natural gas from LNG is the cleanest fossil fuel available today. There are no SOX emissions related to it, particle emissions are very low, the NOX emissions are lower than those of MGO or HFO, and other emissions such as HC, CO or formaldehyde from gas engines are low and can be mitigated by exhaust gas after-treatment if necessary. Nevertheless, methane release (slip) must be considered when evaluating the CO2 reduction potential of LNG as ship fuel (maximum value is roughly 26 per cent compared to HFO). Low-pressure Otto-cycle gas engines burning LNG comply with the IMO Tier III NOX limit without requiring exhaust gas treatment.

Technology
Gas engines, gas turbines and LNG storage and processing systems have been available for land installations for decades. LNG sea transport by LNG carrier also has a history going back to the middle of the last century. Developments to use LNG fuel in general shipping began early in the current century. Today, the technology required for using LNG as ship fuel is readily available. Piston engines and gas turbines, several LNG storage tank types as well as process equipment are also commercially available.

CAPEX
LNG as ship fuel is rapidly approaching the status of a fully developed technology, with various technology suppliers active in the market. As applications increase and competition between suppliers heats up, we can observe the CAPEX decreasing. CAPEX costs for LNG systems are and will continue to be higher than the expenditures associated with using a scrubber system with HFO.

OPEX
The OPEX costs for LNG systems on board ships are comparable with the operational costs of oil-fuelled systems without scrubber technology or an SCR. Gas-fuelled engine systems have about the same efficiency as conventionally-fuelled systems. For this reason, the energy consumption of an LNG-fuelled ship is roughly the same as that of an oil-fuelled ship. Maintenance of a gas-burning engine may be less expensive thanks to cleaner fuel. Currently, the maintenance intervals of conventional and gas-fuelled engines are typically the same, but with more operational experience to draw on, they may be extended for gas engines. The maintenance costs for the high-pressure gas supply system on board ships with high-pressure engines should be considered. A number of ports offer discounts to LNG-fuelled ships.
5.4 LPG

5.4.1 General
Liquefied petroleum gas (LPG) is by definition any mixture of propane and butane in liquid form. In the USA, the term LPG is generally associated with propane. Specific mixtures of butane and propane are used to achieve desired saturation, pressure and temperature characteristics.

Propane is gaseous under ambient conditions, with a boiling point of –42°C. It can be handled as a liquid by applying moderate pressure (8.4 bar at 20°C). Butane can be found in two forms: n-butane or iso-butane, which have a boiling point of –0.5°C and –12°C, respectively. Since both isomers have higher boiling points than propane, they can be liquefied at lower pressure. Regarding land-based storage, propane tanks are equipped with safety valves to keep the pressure below 25 bar. LPG fuel tanks are larger than oil tanks due to the lower density of LPG.

There are two main sources of LPG: it occurs as a by-product of oil and gas production or as a by-product of oil refinery. It is also possible to produce LPG from renewable sources, for example as a by-product of renewable diesel production.

5.4.2 Details on specific subjects

Price
Up until 2010, propane prices in the USA were very close to those of Brent crude oil, as shown in Figure 11. Since 2011, prices have decoupled due to increased LPG production as a by-product of shale oil and shale gas. The USA became a net exporter of LPG in 2012. Currently, LPG is more expensive than LNG but cheaper than low-sulphur oil.

Infrastructure
Figure 12 shows the extensive network of LPG import and export terminals in Europe. It is relatively easy to develop bunkering infrastructure at existing LPG storage locations or terminals by simply adding distribution installations. Distribution to ships can occur either from dedicated facilities or from special bunker vessels.

Regulations
The IMO IGF Code is mandatory for all gas and other low-flashpoint-fuel ships (see above). LPG is currently not included and is not on the agenda for the near future.

Technical provisions will be needed to cover particular aspects of LPG fuel. The main safety concern that must be covered is related to the density of LPG vapours,
which are heavier than air. Therefore leak detectors and special ventilation systems should be used.

The transport of LPG by sea is covered by the IMO IGC Code, which also permits the use of LPG as fuel for gas carriers.

### Availability

According to the World LPG Association, global LPG production in 2015 was 284 million tonnes, or 310 million tonnes of oil equivalent. This is slightly higher than the global demand for marine fuel. Production has been increasing by approximately 2 per cent annually over the last decade.

The production increase has been most profound in North America and the Middle East. Only 9 per cent of LPG is used as transportation fuel for road vehicles, half of it in South Korea. Other uses of LPG include homes (cooking and heating), the chemical and other industries, and refineries.

In regional terms, Asia accounts for the largest share of LPG consumption. It is expected that at the current production level, the demand for shipping can be safely covered until 2030, provided that demand for LPG as ship fuel will grow slowly initially and remain at a moderate level.

### Environmental impact

LPG combustion results in CO₂ emissions that are approximately 16 per cent lower than those of HFO. When accounting for the complete life cycle, including fuel production, the CO₂ savings amount to roughly 17 per cent.

The global warming potential of propane and butane as greenhouse gases is three to four times higher than that of CO₂. This has to be taken into consideration when addressing the issue of unburned LPG potentially escaping into the atmosphere (LPG slip). At the same time, using LPG virtually eliminates sulphur emissions. LPG is also expected to reduce particulate matter (PM) emissions significantly. The reduction of NOₓ emissions depends on the technology applied.

For a two-stroke diesel engine, the NOₓ emissions can be expected to be reduced by 10 to 20 per cent compared to HFO, whereas for a four-stroke Otto-cycle engine, the expected reduction is more significant and may be below Tier III NOₓ limits. To comply with these standards, a two-stroke diesel-cycle engine would have to be equipped with EGR or SCR systems. Both solutions are commercially available.

### Technology

There are three main options for using LPG as ship fuel: in a two-stroke diesel-cycle engine; in an four-stroke, lean-burn Otto-cycle engine; or in a gas turbine. Currently, only a single two-stroke diesel engine model is commercially available, the MAN ME-LGI series. In 2017, a Wärtsilä four-stroke engine was commissioned for stationary power generation (34SG series). This engine had to be derated to maintain a safe knock margin. An alternative technology offered by Wärtsilä consists in the installation of a gas reformer to turn LPG and steam into methane by mixing them with CO₂ and hydrogen. This mixture can then be used in a regular gas or dual-fuel engine without derating.

LPG can be stored under pressure or refrigerated. It will not always be available in the temperature and pressure range a ship can handle. Therefore the bunkering vessel and the ship to be bunkered must carry the necessary equipment and installations for safe bunkering. A pressurized LPG fuel tank is the preferred solution due to its simplicity, and because the vessel can bunker more easily using either pressurized tanks or semi-refrigerated tanks without major modifications.

### CAPEX

The cost of installing LPG systems on board a vessel (e.g. internal combustion engine, fuel tanks, process system) is roughly half that of an LNG system if pressurized type C tanks are used in both cases. This is because there is no need for special materials that are able to handle cryogenic temperatures.

On large ships, the cost difference between LNG and LPG systems is lower if the LPG is stored in pressurized type C tanks, which are more expensive than large prismatic tanks. Alternatively, LPG can be stored at low temperatures in low-pressure tanks, which require thermal insulation.

### OPEX

The operational costs for LPG systems are expected to be comparable with those of oil-fuelled vessels without a scrubber system. Practical experiences are currently not available.
5.5 METHANOL

5.5.1 General

Methanol, with the chemical structure CH$_3$OH, is the simplest alcohol with the lowest carbon content and highest hydrogen content of any liquid fuel. Methanol is a liquid between 176 and 338 Kelvin (−93°C to +65°C) at atmospheric pressure.

It is a basic building block for hundreds of essential chemical commodities that contribute to our daily lives, such as building materials, plastic packaging, paints and coatings. It is also a transport fuel and a hydrogen carrier for fuel cells.

Methanol can be produced from several different feedstock resources, mainly natural gas or coal, but also from renewable resources like black liquor from pulp and paper mills, forest thinning or agricultural waste, and even directly from CO$_2$ that is captured from power plants.

When produced from natural gas, a combination of steam reforming and partial oxidation is typically applied, with an energy efficiency up to about 70 per cent (defined as energy stored in the methanol versus energy provided by natural gas).

Methanol produced from gasification of coal relies on a cheap, widely available resource, but the greenhouse gas (GHG) emissions are about twice as high as from natural gas. Due to its density and lower heating value (19.5 MJ/kg), methanol fuel tanks have a size approximately 2.5 larger than oil tanks for the same energy content. Methanol has a flashpoint of 11°C to 12°C and is considered a low-flashpoint fuel.

Producing methanol from coal may bring the price down, but it increases GHG emissions drastically. Methanol is easy to produce from hydrogen and CO$_2$. Therefore the production of methanol from renewable energy makes it a green ship fuel. The costs are currently higher than the costs of methanol synthesis from methane.

5.5.2 Details on specific subjects

Price

From 2010 to 2013, methanol prices per unit of energy content were between European HFO and MGO prices. Since then, methanol prices have slightly increased (and are now back to 2013 levels) and, at the same time, the drop in oil prices has made methanol more expensive than distillate marine fuels.

Since methanol is typically produced from natural gas, its price per mass unit is usually coupled to natural gas prices and is higher in relation to energy content.

Producing methanol from coal may bring the price down, but it increases GHG emissions drastically. Methanol is easy to produce from hydrogen and CO$_2$. Therefore the production of methanol from renewable energy makes it a green ship fuel. The costs are currently higher than the costs of methanol synthesis from methane.

Infrastructure

Distribution to ships can be accomplished either by truck or by bunker vessel. In the port of Gothenburg, Stena Lines has created a dedicated area for bunkering the vessel Stena Germanica, which includes a few simple safety barriers to avoid problems in case of a leak.

In Germany, the first methanol infrastructure chain, from production using renewable energy to trucking and ship bunkering through to consumption in a fuel cell system on board the inland passenger vessel MS Innogy, was launched in August 2017.

Regulations

For shipping, the main applicable guideline is the IGF Code, which is compulsory for all gas and other low-flashpoint-fuel ships. The chapter for methanol is currently under development. However, the IGF Code provides a means to approve a methanol fuel system by following the alternative-design approach. In addition, DNV GL has published rules for low-flashpoint fuels that address methanol.

Availability

The global methanol demand was approximately 80 million tonnes in 2016, twice the 2006 amount. The production capacity is more than 110 million tonnes. The energy content of these 110 million tonnes is equal to approximately 55 million tonnes of oil. Most of the methanol is currently consumed in Asia (more than 60 per cent of global demand), where demand has been increasing for the last few years.

Approximately 30 per cent is used in North America, Western Europe and the Middle East, and this figure has been largely stable over the past decade. It is expected that the current production can safely cover the demand for shipping until 2030, assuming that the demand for methanol as ship fuel will grow slowly initially and remain at a moderate level.

Environmental impact

Methanol combustion in an internal combustion engine reduces CO$_2$ emissions (tank-to-propeller [TTP] value) by approximately 10 per cent compared to oil.
The exact value may differ depending on whether methanol is compared with HFO or distillate fuel. When considering the complete life cycle (well-to-tank [WTT] and TTP) including the production of the fuel from natural gas, the total CO₂ emissions are equivalent to or slightly higher (in the order of 5 per cent) than the corresponding emissions of oil-based fuels.

The WTT emissions of methanol from renewable sources (biomass) are significantly lower compared to production from natural gas. Using methanol virtually eliminates sulphur emissions and meets the sulphur emission cap.

It is also expected that particulate matter (PM) emissions will be significantly lower. The reduction of NOₓ emissions depends on the technology used. In the case of a two-stroke diesel engine, the NOₓ emissions can be expected to be approximately 30 per cent lower than those of HFO, whereas in the case of a four-stroke Otto-cycle engine, the expected reduction is in the order of 60 per cent, but not below Tier III NOₓ limits. To comply with these standards, EGR or SCR systems should be used. Both solutions are commercially available.

**Technology**

There are two main options for using methanol as fuel in conventional ship engines: in a two-stroke diesel-cycle engine or in a four-stroke, lean-burn Otto-cycle engine.

Similar to LPG, only a single two-stroke diesel engine is currently commercially available, the MAN ME-LGI series, which is now in operation on methanol tankers. Wärtsilä four-stroke engines are in operation on board the passenger ferry *Stena Germanica*. Another possibility would be to use methanol in fuel cells (see section 5.10 on fuel cells). A test installation has been running on the Viking Line ferry *MS Mariella* since 2017.

Methanol is a liquid fuel and can be stored in standard fuel tanks for liquid fuels, with certain modifications to accommodate its low-flashpoint properties and the requirements currently under development for the IGF Code at the IMO. Fuel tanks should be provided with an arrangement for safe inert gas purging and gas freeing.

**CAPEX**

The additional costs of installing methanol systems on board a vessel (e.g. internal combustion engine, fuel tanks, piping) is roughly one third that of the additional costs associated with LNG systems. This is because there is no need for special materials able to handle cryogenic temperatures or for pressurized fuel tanks.

**OPEX**

The operational costs for methanol systems are expected to be comparable with those for oil-fuelled vessels without scrubber technology. Due to the small number of ships running on methanol, practical experiences are limited.
5.6 BIOFUELS

5.6.1 General
Biofuels are derived from primary biomass or biomass residues that are converted into liquid or gaseous fuels. A large variety of processes exist for the production of conventional (first-generation) and advanced (second and third-generation) biofuels, involving a variety of feedstocks and conversions.

The production of biofuel is commonly categorized based on the carbon source:

1. First-generation biofuels: sources include sugar, starch or lipid directly extracted from plants
2. Second-generation biofuels: derived from woody crops, purpose-grown non-food feedstock, and wastes/residues
3. Third-generation biofuels: derived from aquatic autotrophic organisms (e.g. algae)

The competition with food production is frequently cited as an obstacle for biofuels. This is only an issue in the case of first-generation fuels. Advanced biofuels are considered more sustainable since they do not compete with food crops.

The characteristics of biofuels vary and cannot be summarized in brief. However, conventional biofuels typically have lower energy content and lower greenhouse gas (GHG) emissions than conventional marine fuels. NOx emissions may be higher.

The most promising biofuels for ships are biodiesel (e.g. hydrotreated vegetable oil [HVO], biomass-to-liquids [BTL], fatty acid methyl ester [FAME]) and liquefied biogas (LBG). Biodiesel is most suitable for replacing MDO/MGO, LBG is the best replacement of fossil LNG, and straight vegetable oil (SVO) can substitute HFO.

Since 2006, several demonstration projects have tested the technical feasibility of various FAME biodiesel blends in shipping. Challenges reported for FAME biofuels include fuel instability, corrosion, susceptibility to microbial growth, and poor cold-flow properties. Recently, ferries operating in Norway have started to use HVO biodiesel.

Renewable HVO biodiesel is a high-quality fuel in which the oxygen has been removed using hydrogen, which results in long-term stability. It is compatible with existing infrastructure and can be used in existing engines, subject to approval by the manufacturer. The GHG emissions from a life-cycle perspective are about 50 per cent lower than for diesel, and the NOX and particulate matter (PM) emissions are likewise lower. There are no sulphur emissions. Third-generation algae-based biofuels are still at the research and development stage but were tested in 2011 on the container ship Maersk Kalmar. The US navy has also carried out some testing.

5.6.2 Details on specific subjects

Price
In most cases advanced biofuels will be more expensive than fossil fuels. The potential for reducing production costs is expected to be higher for second-generation biofuels compared to the first generation where a major portion of the potential is already being realized. Prices and production volumes are the main barriers to widespread use in shipping.

Infrastructure
There is a lack of global infrastructure and bunkering facilities. Biodiesel could potentially be used as a drop-in fuel. If biofuel is available, it can be distributed using the existing distribution systems for MGO and HFO.

Liquefied methane produced from biomass (LBG) uses the same infrastructure as LNG, which is expanding. Biofuel is available in certain ports, for example in the Netherlands or Norway. Algae-based fuel production could occur close to ports and coastal areas in future.

Regulations
Annex A of the ISO 8217:2017 fuel standard addresses bio-derived products, EN 14214 and ASTM D6751 provide biodiesel standards, while the EN 590 diesel standard is relevant for high-quality diesel for automotive use.

The International Council on Combustion Engines (CIMAC) provides a guideline for ship owners and operators on managing marine distillate fuels containing up to 7 per cent v/v of FAME (biodiesel). Biofuels may eventually be covered by the IGF Code’s new chapter on low-flashpoint diesel fuels, which is on the current agenda.

Looking at the sustainability of biofuels, the EU Renewable Energy Directive includes sustainability criteria for biofuels. ISO 13065 specifies principles, criteria and indicators for the bioenergy supply chain to facilitate the assessment of environmental, social and economic sustainability aspects.
The Roundtable on Sustainable Biofuels (RSB) addressed the many sustainability questions associated with growing crops for liquid fuel production. The Global Bioenergy Partnership (GBEP) defines sustainability indicators for bioenergy, specifying three pillars: environmental, social and economic. Overall, there is a lack of globally accepted, maritime-specific standards for biofuels.

**Availability**
Global production data indicate that 32 million tonnes of biodiesel and 170 million tonnes of straight vegetable oil (SVO) are produced per year.

**Environmental impact**
The emission reduction potential of biofuels varies widely, depending on the specific feedstock, the biofuel generation, the engine type/model, and the supply chain. CO₂ reductions of up to 80 to 90 per cent for certain types of biofuels are possible, based on life-cycle assessments. The highest reduction potential is reported for advanced biofuels.

In general, biofuels have very low SO₂ emissions, but there are concerns about the overall sustainability of biofuels. These include both environmental and socio-economic issues. It is also debated to what extent biofuels lead to greenhouse gas (GHG) reduction. Several standards and initiatives address these aspects. A number of studies point to sustainable biofuels as one of only a few options available for deep-sea shipping to achieve CO₂ emission levels consistent with the 2°C climate goal.

**Technology**
Biofuels are used as drop-in fuels substituting conventional fossil fuels and are compatible with existing infrastructure and engine systems. In some cases, they require modification of infrastructure and engine systems.

Liquefied biogas (LBG) consists mainly of methane and can utilize the same technology as conventional LNG.

**CAPEX**
Additional costs related to modifications of ship engines and infrastructure for running on conventional biofuel are estimated by engine manufacturers to be less than 5 per cent of engine cost. There is no additional cost reported when running on advanced HVO.

Overall, the CAPEX for LBG would be the same as for LNG.

**OPEX**
The operational costs for biofuel systems are expected to be comparable with those for oil-fuelled vessels without scrubber technology. However, since biofuels and especially advanced biofuels will be more expensive than fossil fuels, the associated OPEX costs are expected to be higher. Additional costs may be caused by monitoring, operational practice, and staff training. This needs to be investigated further and will depend on the generation and type of biofuel.
5.7 HYDROGEN

5.7.1 General
Hydrogen (H₂) is a colourless, odourless and non-toxic gas. For use on ships, it can either be stored as a cryogenic liquid, as compressed gas, or chemically bound.

The boiling point of hydrogen is very low: 20 Kelvin (−253°C) at 1 bar. It is possible to liquefy hydrogen at temperatures up to 33 Kelvin (−240°C) by increasing the pressure towards the “critical pressure” for hydrogen, which is 13 bar. The energy density per mass (LHV of 120 MJ/kg) is approximately three times the energy density of HFO. The volumetric density of liquefied H₂ (LH₂) (71 kg/m³) is only 7 per cent that of HFO. This results in approximately five times the volume compared to the same energy stored in the form of HFO. When stored as a compressed gas, its volume is roughly ten to 15 times (depending on the pressure [700 to 300 bar]) the volume of the same amount of energy when stored as HFO.

Hydrogen is an energy carrier and a widely used chemical commodity. It can be produced from various energy sources, such as by electrolysis of renewables, or by reforming natural gas. Today, nearly all hydrogen is produced from natural gas.

For applications in the transport sector, production by reforming from natural gas is currently the most common method. If the resulting CO₂ would be captured, this could result in a zero-emission value chain for shipping.

Together with CO₂, hydrogen can be used to produce methane, which can be used similar to LNG or synthetic liquid fuels which can be used as substitutes for diesel or gasoline. Production of hydrogen by electrolysis is viewed as an opportunity to store and transport surplus renewable energy, thereby stabilizing the energy output of solar or wind power plants.

When used in combination with marine fuel cells, the emissions associated with other marine fuels could be minimized or eliminated entirely. If H₂ is generated using renewable energy, nuclear power or natural gas with carbon capture and storage, zero-emission ships are possible.

5.7.2 Details on specific subjects

Price
The cost of H₂ depends to a large extent on the price of electricity (in the case of electrolysis) or gas (in the case of reformation), as well as on the scale of the production plant.

Cost estimates from relevant literature for H₂ produced from electrolysis as reviewed by DNV GL range between 3.5 and 8.3 USD/kg (1,170 to 2,770 USD/t crude oil equivalent), averaging around 5.3 USD/kg (1,770 USD/t crude oil equivalent).

The cost of hydrogen produced through natural gas or biogas reformation ranges from 2.4 to 6.5 USD/kg, (800 to 2,170 USD/t fuel oil equivalent), averaging around 4.1 USD/kg (1,370 USD/t crude oil equivalent). These cost estimates include production, compression, storage and transport.

As a reference: a price of 70 USD per Barrel is approximately 510 USD/t fuel oil equivalent.

According to forecasts, the price of electrolysers will fall in the near future, reducing the CAPEX and consequently the production cost of hydrogen. The location of production facilities may also play a role in the cost of H₂. For example, electrolysis in areas in Norway with low electricity prices has the potential to drive the production costs down to between 3.5 and 4.1 USD/kg by 2020 (1,170 to 1,370 USD/t crude oil equivalent).

FIGURE 13: EXAMPLE OF HYDROGEN COST AT REFUELLING NOZZLE AS A FUNCTION OF THE ELECTRICITY PRICE FOR A HYDROGEN REFUELLING STATION WITH A CAPACITY OF 6,000 KG H₂/D

(EC “Guidance document on large scale hydrogen bus refuelling”, March 2017)
Infrastructure

Today, most hydrogen is produced from natural gas using a related, mainly industrial, land-based infrastructure. Since there is currently no demand for H₂ fuel, there is no distribution or bunkering infrastructure for ships. Liquefied hydrogen (LH) could be distributed in a similar manner as LNG.

Standard 40-foot containers for LH with a typical tank capacity of around 3,600 kg of hydrogen per tank are available in the market, and a liquid tank can be filled up to approximately 94 per cent of its total volume. Due to the very low boiling point of hydrogen, super-insulated pressure vessels are used for storage in liquid (cryogenic) form. Boil-off is unavoidable, and the boil-off rate, which depends on the relationship between tank surface area and volume, can be 0.3 to 0.5 per cent per day depending on technology and conditions. For stationary use, the capacity range of current LH tanks is about 400 to 6,700 kg.

Once LH storage technology for liquid hydrogen tankers (under development at Kawasaki) is available, it will be possible to store up to 88,500 kg of hydrogen per tank. A demonstration tank system will be commissioned in 2020.

Hydrogen production from electrolysis is a known and available technology that can be applied locally in port as long as an adequate supply of electrical power is available for the production process, which would eliminate the need for a long-distance distribution infrastructure. In future, LH might be transported to ports from storage sites where hydrogen is produced using surplus renewable energy, such as wind power, whenever energy production exceeds grid demand. The hydrogen produced could be stored in compressed – not liquefied – form in salt caverns and at other suitable sites. Transport would occur by road and/or pipeline depending on volume and distance.

Regulations

Hydrogen is a low-flashpoint fuel subject to the International Code for Safety of Ships using Gases or Other Low-flashpoint Fuels (IGF Code). The current edition of the IGF Code does not cover hydrogen storage. Rules for the use of hydrogen in fuel cells are under development and will be included in a future amendment to the IGF Code. For the time being, hydrogen storage and use must follow the alternative design approach in accordance with SOLAS Regulation II-1/55 to demonstrate an equivalent level of safety.

Other regulations, such as the DNV GL class rules for fuel cell (FC) installations (DNV GL Rules for classification of ships Part 6, Chapter 2, Section 3), cover design principles, material requirements, arrangement and system design, safety systems and other aspects.

Regarding the use of hydrogen, the ISO/TR 15961 “Basic considerations for the safety of hydrogen systems” provide an overview of safety-relevant considerations for H₂.

The IGC and IGF Codes cover the storage of liquefied gas on board ships, and the C-tank rules will in principle cover liquid hydrogen, but additional considerations will be necessary due to the properties of hydrogen and its very low storage temperature.

Bunkering of hydrogen-fuelled ships is subject to national regulations and therefore needs to be evaluated on a case-by-case basis. Bunkering and port regulations for bunkering H₂ fuel do not exist at this time. However, several ports do have LNG rules, and bunkering is subject to SGMF guidelines and ISO/TS 18683. It is assumed that there will be a significant overlap with future standards for hydrogen.

Availability

More than 50 million tonnes of H₂ are produced per year globally. This is about equal to the energy content of 150 million tonnes of ship fuel. Nearly all hydrogen is produced from natural gas. As hydrogen can be produced from water using electrolysis, there are no principal limitations to production capacity that could restrict the amount of available H₂ to the shipping industry.

Environmental impact

There are energy losses associated with H₂ production and possible compression or liquefaction. When H₂ is generated from renewable or nuclear power using an efficient supply chain, it can be a low-emission alternative fuel for shipping. Current development initiatives explore hydrogen production from natural gas while safely capturing and storing the resulting CO₂ (CCS).

Hydrogen used in fuel cells as energy converters does not produce any CO₂ emissions and could eliminate NOₓ, SOₓ and particulate matter (PM) emissions from ships. Hydrogen-fuelled internal combustion engines for marine applications could also minimize greenhouse gas (GHG) emissions, while NOₓ emissions cannot be avoided when using combustion engines.
Power generation systems based on H₂ may eventually be an alternative to today’s fossil-fuel-based systems. While fuel cells are considered the key technology for hydrogen, other applications are also under consideration, including gas turbines or internal combustion engines in stand-alone operation or in arrangements incorporating fuel cells.

Hydrogen-fuelled internal combustion engines for marine applications are said to be less efficient than diesel engines. Possibly larger-scale industrial and maritime applications combined with waste heat recovery solutions might be better suited for high-temperature technologies such as solid oxide fuel cells (SOFC) or even industrial systems using molten carbonate fuel cells.

Fuel cells combined with batteries (and possibly super capacitors) adding peak-shaving effects are a promising option. Even proton exchange membrane fuel cells (PEMFC), thanks to their flexible materials, could improve fuel cell lifetime significantly when protected against the harshest load gradients. SOFC must be applied in a hybrid environment using peak-shaving technology to be a realistic alternative for shipping.

Conventional energy converters like piston engines will have similar added CAPEX costs as LNG-fuelled engines. Storage tanks for LH₂ will be significantly more expensive due to lower storage temperatures, higher insulation quality and fewer maritime applications than LNG. All other equipment (e.g. piping, ventilation, heat exchangers, pumps) will have similar costs as in LNG systems.

Conventional systems like piston engines or turbines running on hydrogen will have comparable OPEX to those for oil-fuelled systems. The price of H₂ varies because the current market for hydrogen is part of the industrial gases market where individual contracts apply.

Fuel prices might depend on energy prices for H₂ production and logistics costs (see above). Logistics costs might be considerably higher than for LNG or other gases. This might change when hydrogen production using surplus intermittent renewable energy is stepped up.

When hydrogen is produced locally by electrolysis, the distribution costs are marginal. The lifetime of energy converters (e.g. fuel cells) is shorter than that of piston engines or turbines and depends on fuel quality and system operation management. The expected crew training requirements could be comparable to those of LNG/CNG.

One thing batteries and hydrogen have in common is that they represent potential game changers that become increasingly relevant when the cost of pollution (GHG or local pollutants) rises significantly and/or where strict emission limits apply.
In such a situation, the key parameters for fuel comparison might change. This has been experienced in the case of battery-powered ferries in Norway, for example, which can be very price competitive (OPEX) with conventional fuels. At the same time, they require a very different infrastructure, which is typically associated with innovative, fast-charging technology at every stop and conventional charging when the ferry is not in use (e.g. overnight).

The energy chain perspective is important. Two main production paths can be assumed for hydrogen:
- Hydrogen produced from natural gas, the most common production method today (in future possibly combined with CCS)
- Hydrogen produced by electrolysis using renewable energy

In both cases, conversion of the original energy source to hydrogen will mean that some energy is lost.

In an energy environment marked by a growing renewable energy sector, hydrogen and batteries complement each other. Batteries are a suitable means to store relatively small amounts of energy for a shorter duration, whereas energy conversion to hydrogen is better for long-term (e.g. seasonal) storage of larger volumes of energy (e.g. using underground caverns).
5.8 WIND-ASSISTED PROPULSION

5.8.1 General
Wind-assisted propulsion is today considered a means to reduce a ship’s consumption of fossil energy.

From the time man began travelling across large bodies of water until the advent of fossil fuels, sails were the primary means of ship propulsion. Today, the entire worldwide maritime trade relies on fossil fuels. As efforts to curb pollution and climate change intensify, the commercial shipping world is looking at wind as an inexhaustible power source, at least in a supporting role, with renewed interest.

Some of the sail technologies available today are the result of long-term development, driven in part by competitive racing such as the America’s Cup (rigid wing sails), or by the need for short-handed automated sailing (DynaRig). Other, older developments were all but forgotten until rediscovered by the merchant shipping industry recently (Flettner rotor). Innovative approaches have been developed specifically for modern commercial ships (kites).

Practical experience exists with two of these methods, which are currently in use: kites, and the Flettner rotor. The DynaRig principle is being used by some large sailing yachts.

5.8.2 Details on specific subjects

Price
There are obviously no direct fuel costs involved in using wind to propel a ship. Most wind-assisted propulsion systems require a secondary source of energy to be operated:

- Flettner rotors need to be started up by motors to develop their aerodynamic thrust forces.
- Soft and solid sail systems require a certain amount of energy for hoisting and dropping as well as for position adjustments to achieve the optimum angle of attack.
- Kites need to be launched, inflated, controlled and retracted by external means.

In all of these cases, the amount of energy required for operation is very small in relation to the propulsion power these devices generate.

For calculating the business case, the availability of wind and therefore the operation area of wind-assisted vessels is the most relevant factor (see “Availability” to the right).
Infrastructure
There is no infrastructure required to make use of wind as an energy source. Specialized knowledge may be required for maintenance and repair work, most of which may not be possible on board. Depending on the size of an installed wind propulsion system, there may be restrictions for passing under bridges.

In addition, certain types of wind assistance systems may impede ship loading and unloading.

Regulations
The SOLAS Convention does not exclude the use of wind as a power source, provided a ship does not solely rely on it. In today’s economic environment, cross-oceanic trade must adhere to strict schedules. Exclusive dependence on wind would not be feasible. Therefore a propulsion engine is required to compensate for or buffer time losses when wind conditions are inadequate.

Any evaluation of a potential wind application must account for the implications regarding the safety of seafarers and compliance with current international standards. Current energy efficiency regulations are not prescriptive.

The way the EEDI Index is determined leaves room for new technology developments and for the choice of means to achieve specific targets or objectives. This includes the potential use of wind as a power source, either in the form of wind propulsion systems or in hybrid systems.

There is no international rule for the design and construction of sail propulsion systems. However, DNV GL has issued Design Guidelines for Certification and Classification Procedures associated with:

- Flettner rotors (document MCADE0452-001)
- Wing rigs (document MCADE0452-003) installed on seagoing ships

A similar guideline for DynaRig systems is currently under development.

These technical standards may additionally serve as a means to satisfy statutory regulations and requirements, which may not necessarily in all aspects be prepared for wind-assisted propulsion.

DNV GL class notations for sail assistance systems on seagoing ships are in preparation.

Availability
The availability of wind as a power source is unlimited. However, the quantity and quality of this energy source is not constant. As a meteorological phenomenon, the strength and direction of wind is subject to frequent change. Global trade routes with relatively constant, high wind conditions are best suited for profitable use of this energy source, especially when combined with weather routing based on global weather patterns and local forecasts.

Environmental impact
A wind propulsion system can reduce fuel consumption. The energy savings achieved are directly proportionate to the reduction of fuel-related CO\textsubscript{2}, NO\textsubscript{x}, SO\textsubscript{x}, particulate matter (PM) and other emissions.

Technology
After an absence of about 100 years, the rediscovery of wind propulsion for seagoing ships is tantamount to a relaunch of a forgotten technology.

Various technologies are currently in some kind of project or trial stage; some solutions are commercially available and can even be retrofitted. The following choice of technologies does not intend to exclude other, innovative or further developed approaches and does not claim to be comprehensive.

- The Flettner rotor, also called Flettner sail or rotor sail, is named after its German inventor Anton Flettner who developed the concept in the 1920s.
Its physical principle consists in the generation of aerodynamic thrust using a rotating cylinder (Magnus effect). The technology is well developed, and Flettner rotors have been installed on eight ships since the time of their invention.

- Based on a design concept by German engineer Wilhelm Prölls in the 1960s, the DynaRig employs automated soft sails. It can serve as a ship’s primary propulsion system when weather conditions allow, provided that the purpose and design of the ship are optimized accordingly. DynaRigs are currently commercially available for mega sailing yachts (Maltese Falcon, Oceanco Y172), and there are projects to develop a DynaRig for seagoing ships.

- The rigid wing sail technology is based on the concept of using vertically-arranged, fixed symmetrical aerofoils on a ship to generate aerodynamic thrust. There have been numerous initiatives pursuing this concept but no full-scale installation on a commercial vessel.

- Kites use aerodynamic forces generated by producing an apparent wind speed higher than that experienced at a stationary position on board a sailing vessel, by causing the kite to enter a state of dynamic movement. Employment and deployment of a kite can be automated. The technology has been commercially available since the early 2010s.

CAPEX
Wind propulsion systems utilize renewable energy to assist primary propulsion units and save fossil fuel. The multitude of technologies and their varying dominance in connection with the drive to reduce energy consumption is too varied for this paper to provide detailed guidance regarding the costs involved, or a comparison thereof.

When conceptualizing a particular system, including all its parameters, ideally geared towards a pre-selected choice of trade routes, it is possible to estimate or determine investment expenditures as well as operational costs in addition to the fuel-saving potential.

OPEX
OPEX are related to the maintenance of the wind-assisted propulsion system and the replacement of components at the end of their lifetime. Energy costs related to operation are small but need to be figured in nevertheless.
5.9 BATTERIES

5.9.1 General
Batteries and hybrid power plants represent a transformation in the way energy is used and distributed on board vessels. Electric power systems using batteries are more controllable, and easier to optimize in terms of performance, safety and fuel efficiency. As ship power systems become increasingly electrified, and as battery technology improves and becomes more affordable, new opportunities emerge.

Fully electric ships represent a leap forward in power system design, but at present they are only feasible in limited applications such as ferries and short-sea shipping. The feasibility of all-electric operation for other vessels is typically limited either by the size of the required battery system or its cost. Unsurprisingly, the same limitations apply to many other uses of battery systems, as well. Further research and development work is urgently needed to achieve significant improvements to this technology.

5.9.2 Details on specific subjects

Price
Battery prices are decreasing rapidly – almost too fast for accurate characterization – while significant performance improvements can be observed at least in some market areas. These cost reductions are primarily driven by demand in the automotive and consumer electronics industries. Prices of market-leading lithium-ion battery cells have dropped by more than 50 per cent over the course of 2016, but prices continue to range widely, dependent upon performance, technology and application. Total battery system prices for large installations, such as in shipping, comprise both the lithium-ion battery cells themselves and the cost of system integration, including module construction, battery control hardware and software, power electronics, thermal management, and testing. The figure below indicates trends in battery cell pricing as well as potential trajectories for full maritime systems (AC, including power electronics).

Carmakers have set a price goal of 100 USD/kWh for lithium-ion cells by 2020, and based on market predictions this goal might be achieved. This development may correlate to maritime system costs as low as 200 USD/kWh, although additional cost margins may remain in place in this market segment.

One primary objective for battery storage systems will be to further increase energy density for new applications, followed by a continued downward trend of prices, if at a lower rate.

Lithium-ion will likely remain the leading technology for many years. Other technologies may reach market maturity and supersede lithium-ion technology if they prove to be price competitive.

In terms of future price development, a closer look at the raw materials is instructive:

- Graphite is a widely-used material, with 70 to 80 per cent currently coming from China. Facing stricter environmental regulation, this may result in a price increase and the development of new mines.
- The cobalt market was previously small but is now growing rapidly. Over 50 per cent of the global cobalt supply currently comes from the Congo in Africa, with companies seeking more humanely-acquired alternatives.
- For lithium, large amounts exist but only one-third is considered economically accessible, primarily from salty, briny lakes, and the evaporation process can be lengthy. Still, based on total availability and underutilized sources in Chile, China and Australia, lithium supplies appear reliable for the long term.
- Nickel is a relatively expensive component in lithium-ion manufacture. It is a valuable metal used widely as a component of stainless steel. New demand from innovative technologies can cause price spikes, while an oversupply will cause prices to drop. Overall, the market is well-developed.

![FIGURE 15: BATTERY PRICES](image-url)
Infrastructure

Given the absence of consumption costs, batteries do not face the same type of supply or infrastructure requirements as other, more traditional energy sources. The infrastructure required for battery systems on board ships mainly consists in providing an adequate charging grid. Depending on the application, the battery size and required charging times can increase power demand. For instance, charging 1,000 kWh (approximately equivalent to 100 litres of oil-based fuel) in 30 minutes requires 2,000 kW of power; charging the same amount of energy in 10 minutes requires 6,000 kW of shore power. This often puts a considerable load on the local electrical network and may require additional resources.

In general, the existing on-shore power supply infrastructure can be used to supply electricity to ships. Another key aspect is that a battery system is essentially a device that stores DC electricity and interfaces to the power grid with standardized power electronics hardware. This means that once the electrical system has been established for a given installation, it is nominally a straightforward process to replace the batteries with a new, updated or replacement technology. Therefore the electrical infrastructure for battery systems is easily reused and the nature of the technology enables a high degree of interchangeability.

Regulations

The primary focus of relevant regulations is the safety of battery systems and installations. DNV GL was the first classification society to develop such rules and is actively engaged in research programmes to continue refining and developing these requirements. Other classification societies have since developed rules of their own, but nothing noteworthy has been achieved at the IMO level so far. The year 2016 saw a significant increase in maritime-specific regulations. These requirements have resulted in higher development (testing, approval) costs, which have significantly increased system safety levels. It is likely that more economical ways of producing the same capabilities may be available in the future. Shore connections for charging are predominantly governed by regulations and requirements established for the electric grid.

Environmental impact

Batteries produce zero emissions during operation, but as with every production process, the manufacture of batteries is energy-intensive. Several studies have investigated the CO₂-equivalent emissions of both conventional and battery system life cycles. For the maritime case, as summarized below, the environmental benefit of batteries is overwhelming. In a study for the Norwegian NOₓ fund, the environmental payback period compared to a traditional drive configuration was calculated for a hybrid platform supply vessel (PSV) and an electric ferry.

For the hybrid PSV, the environmental payback period for global warming potential (GWP) and NOₓ is 1.5 and 0.3 months, respectively. For the fully electric ferry, the environmental payback period for GWP and NOₓ is 1.4 and 0.3 months, respectively, when using the Norwegian electricity mix. For the EU electricity mix, the GWP payback time increased to 2.5 months, and for a global electricity mix to just under one year.

In addition, lithium-ion battery recycling has proven to be feasible, with several companies providing this service. The current focus is on aluminium and copper recovery, as this provides the greatest revenue stream, with the low price of mined lithium proving to be highly competitive. The full potential of such processes is limited primarily by the current low inflow of recycled, used or decommissioned batteries - refurbishment is presently a more common end-of-life service resulting in an even better environmental footprint.

Technology

Developments during the past five years have occurred primarily as a result of improved manufacturing processes and quality control, as well as incremental improvements in existing (cathode) chemistries and combinations. Iron phosphate (LFP) and nickel cobalt manganese (NCM) have proven to lead the market. These developments have been paralleled with continually improving knowledge regarding the complex electrochemical processes of batteries, leading to optimized design and utilization. Additionally, new developments have now entered the market representing developments on the anode side - the use of silicon or titanium - representing the opposing objectives of more affordable energy density and high performance, respectively.

Availability

The automotive industry is driving battery manufacture and cell development. As a result, the infrastructure catering to these demands is improving and can be regarded as ready to meet a significant demand increase from the maritime sector, as well. The existence of many companies specifically serving the maritime sector additionally points to a more than adequate manufacturing infrastructure.
The stringent requirements of the maritime industry have greatly advanced the level of safety that lithium-ion battery systems can provide, particularly with regard to propagation and off-gas handling. Solid electrolyte technologies are among the most promising, pending advancements, and may present significant advantages with regard to safety. Although this advancement will need to prove capable of living up to the tough maritime performance requirements, the improved level of safety they may provide would certainly be an asset to the maritime industry.

Maritime applications are often much more demanding on lithium-ion battery performance than other industries such as consumer electronics or stationary/grid support. These needs depend on the application, but many maritime systems require much higher power levels and much longer life cycles than may be acceptable for other lithium-ion battery systems. These requirements represent a need in maritime systems that is a diversion from the pressure to improve cost and energy density, which drives much of the current technology development.

New technologies which may represent a large or disruptive change in the market may be as much as ten years away. The most evident technological advancements are expected to be the result of continued incremental improvements in terms of cost and performance of existing battery types. Furthermore, many of the technologies that appear to be on the horizon are likely to struggle with the maritime environment and application requirements, pushing their penetration of this market back further than others.

**CAPEx**

System integration costs for battery systems are often significant and should be taken into account at an early stage of adoption. Beyond the storage system purchase price (including power electronics), the total cost includes: purchase changes (PMS/IAS/DP), installation at yard (including electrical), FMEA, switchboard modification, commissioning and testing. All these collateral aspects combined can sum up to equal the cost of the full battery system itself. The lifetime of batteries is highly dependent on the duty cycle for which they are used, relative to the size of the battery.

For instance, a smaller battery will have reduced CAPEX but for a given application, will not last as long as a larger battery. Thus, sizing is a key aspect of battery system procurement. DNV GL has performed testing and modelling using a verification tool called Battery XT to assess these complex interrelated aspects. The life cycle additionally depends on battery chemistry - there are many different types of lithium-ion batteries - and also varies significantly based on manufacturer or vendor. Systems are most typically engineered and warranted for ten years of operational life.

**OPEX**

Beyond efficiency, the OPEX costs are driven by electricity prices, which vary significantly from region to region. Norway prices are typically around 0.12 USD/kWh, while EU prices range from 0.09 to 0.30 USD/kWh. Compared to marine diesel, assuming 11,800 kWh/t, and an average of 600 USD/t, the cost is 0.05 USD/kWh. However, the efficiency of using this energy in a battery-driven ship is significantly higher than that of a conventionally-propelled ship, causing lower energy consumption and cost. As a result, the OPEX of an electric ship can be lower than its conventionally-powered equivalent. The efficiency of an electrical propulsion system will be approximately 76 to 85 per cent of the electrical energy provided from shore. A typical diesel generator set will have a fuel efficiency of 40 to 45 per cent, so the battery system is about twice as efficient as a diesel generator.

The efficiency of battery systems ranges from 85 to 95 per cent (round trip), while power electronics often have a 95 per cent efficiency. Power taken from the shore will likely see losses of 15 to 24 per cent by the time it reaches the propulsion motors, depending on the associated components and operation. By comparison, diesel propulsion systems rarely have an efficiency exceeding 50 per cent, especially in consideration of the redundancy requirements and low loading.
5.10 FUEL CELLS

5.10.1 General
Fuel cells offer high electrical efficiencies of up to 60 per cent, as well as lower noise and vibration emissions than conventional engines. The main components of a fuel cell power system are the fuel cells which convert the chemical energy stored in the fuel directly into electrical and thermal energy by electrochemical oxidation. This direct conversion enables electrical efficiencies of up to 60 per cent, depending on the fuel cell type and fuel used.

There are several different fuel cell technologies, including alkaline fuel cells (AFC), proton exchange membrane fuel cells (PEMFC), high-temperature PEMFCs (HT-PEMFC), direct methanol fuel cells (DMFC), phosphoric acid fuel cells (PAFC), molten carbonate fuel cells (MCFC) and solid oxide fuel cells (SOFC). The three most promising fuel cell technologies for maritime use are SOFC, PEMFC and HT-PEMFC.

Fuel reformers convert the original fuel into hydrogen-rich fuel for use in the fuel cells. In addition to pure hydrogen, fuel reformers enable the use of fuels such as natural gas, methanol and low-flashpoint diesel.

The fuel cell is working in a combustion-free electrochemical process. Only a reforming process might involve a small amount of fuel combustion. Consequently, cell technology can reduce emissions to air dramatically.

5.10.2 Details on specific subjects

Price
Mass production, which is expected to occur beyond 2022, should allow production costs to reach a competitive level, as shown in Figure 17 below. Development projects are underway, and the most promising project for maritime fuel cells, e4ships, is aiming for a market launch in 2022. With increased production, the impact of material costs will become a dominant factor in fuel cell prices. Maintenance and operational costs will reach a competitive level after fuel cell durability reaches the same level as the longevity of combustion engines.

Infrastructure
Currently, relevant services are provided by the fuel cell manufacturers. With the exception of fuel cell systems for military submarines, all present fuel cell systems in shipping are non-commercial prototype installations. The most advanced projects regarding future commercial application are those of the e4ships lighthouse project. Commercialization will include guarantee and lifetime technical support. A service network similar to that for diesel engines has yet to be established, but infrastructure development is expected to start at the time of the prospective market launch beyond 2022.

Regulations
The international rule base for the design and construction of maritime fuel cell applications is currently under development at the IMO as part of the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code). Existing class rules form the basis of special permits. The current international regulatory framework is geared towards combustion engines. Apart from some class rules, there is no binding international regulatory framework for maritime fuel cell applications.

The requirements for fuel cell installations which are under development at the IMO might be integrated into the IGF Code within the scope of its first revision in 2020 at the earliest. Fuel storage and fuel supply systems must comply with the related chapters of the IGF Code, which currently covers LNG and compressed natural gas (CNG). Regulations for methanol and low-flashpoint diesel are likewise under development and may be included in the 2020 revision of the IGF Code, as well.

FIGURE 17: POTENTIAL SCALE EFFECTS OF MASS PRODUCTION ON FUEL CELL STACK COSTS

Source: Proton Motors (2014)
Availability
Fuel cell systems are currently available in small numbers from several manufacturers.

While the availability situation for materials for fuel cells themselves is not critical, the availability of suitable fuels in larger amounts will be essential for the technology to be adopted widely.

Environmental impact
The fuels typically used in fuel cells eliminate NOX, SOX and particulate matter (PM) emissions nearly to zero. Due to the high efficiency of fuel cells, a reduction of CO2 emissions by 30 per cent is possible. An example is shown in Figure 18. When using pure hydrogen as a fuel, tank-to-propeller (TTP) emissions of CO2, NOX, SOX and PM are zero.

Technology
Only small maritime fuel cell applications with an electrical power output of up to 100 kW are currently in operation. Current research and development work aims to make maritime fuel cell systems marketable and scalable from 2022. It should be noted that the lifetime of fuel cell systems and reformer units has not yet been shown to be satisfactory. Since 2016, a methanol fuel cell system has been in operation on board the passenger ferry MS Mariella which is operated by Viking Line between Helsinki and Stockholm.

Another methanol fuel cell system is installed on board MS Innogy, an inland passenger vessel operated by the White Fleet Baldeneysee and Innogy. Proton exchange membrane (PEM) technology in particular has reached a development level comparable with the dimension of automotive engines and capable of handling ship load changes well.

Fuel cells combined with batteries (and possibly super capacitors) adding peak-shaving effects are a promising option. Even proton exchange membrane fuel cells (PEMFC), thanks to their flexible materials, could improve fuel cell lifetime significantly when protected against the harshest load gradients. Solid oxide fuel cells (SOFC) must be applied in a hybrid environment using peak-shaving technology to be a realistic alternative for shipping.

CAPEX
Fuel cell technology is still under development. Current installation costs are between 3,000 and 4,500 USD/kW of installed electrical power. Ongoing developments are aiming to reduce installation costs by up to 1,000 USD/kW of installed electrical power by 2022 to be competitive with modern diesel engine installations. The reason PEM cells are dramatically cheaper than other fuel cell types is the automotive industry’s massive investments in this technology over the past 15 to 20 years. While still too expensive for the car market, the cost of PEM fuel cells has dropped to a level that is attractive for ship applications.

The expected cost of automotive PEM fuel cell systems based on current technology is approximately 280 USD/kW when manufactured at a volume of 20,000 units/year. This number reflects the cost of the complete fuel cell system. To build a complete ship system that meets regulatory requirements it will be necessary to integrate additional safety and interface components. Similar strategic goals are being pursued in Europe: in its 2016 annual work plan and budget, the Fuel Cell and Hydrogen Joint Undertaking (FCH JU) aims to achieve a fuel cell system production cost of 100 USD/kW at an annual production output of 50,000 units.

OPEX
The overall efficiency from fuel to propeller will be slightly higher for fuel cells than for combustion engines. The operational costs will be competitive when:
- fuel cells reach about the same durability as combustion engines until requiring a general overhaul,
- the cost and time of a fuel cell exchange is equal to those of a general engine overhaul, and
- the primary fuel prices will be competitive with MGO.

It should be noted that fuel cells may require less maintenance than conventional combustion engines and turbines.
ADVISORY SERVICES

DNV GL Advisory can support customers in a variety of services for assisting with the upcoming fuel shift. For optimized compliance, we provide low sulphur decision-making support tailored to your specific conditions, operation and requirements.

To comply with stricter environmental regulations and limit costs, shipowners need to evaluate alternatives to traditional fuels and technologies. But which option is best for a ship’s actual operational setting?

As marine and industrial engineers, economists and environmental specialists, DNV GL has the deep knowledge across multiple disciplines to offer reliable solutions.

We advise the maritime sector on environmental regulations and compliance options, we measure and benchmark your environmental performance, support you in making the best business decisions on environmental technology, and help turn environmental performance into a marketing advantage.

As a designated technical advisor for various governmental initiatives to reduce ship emissions, we have deep knowledge of the regulatory policies and technical solutions.

If incidents damage the fuel systems and other related systems, we can help alleviate the problem. We have a wide range of experience with troubleshooting, both on a design level and on board the ship. DNV GL engineers can help customers to find root causes for the problem and recommend modifications to reduce future damage in terms of costs and/or even off-hire.

For more information, please contact environmentadvisory@dnvgl.com

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).

Triple-E

Triple-E is an environmental and energy efficiency rating scheme for ships. As an independent verification tool, it measures a vessel’s environmental performance, covering management, operation and design.

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.

Our services in environmental technology and alternative fuels include:

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.
The DNV GL Academy offers a training course designed to help overcome the challenges the challenges of fuel switching in ECAs by discussing the issues related to the change-over in detail.

Air pollution from ships in practice
The course objective is to gain advanced knowledge about exhaust emission legislation, abatement technology and alternative fuels.

Low sulphur fuel - basics and experience
Participants will gain detailed knowledge for managing the international requirements regarding sulphur reduction for ship newbuildings and ships in service.

Gas as ship fuel
The course will give participants an overview about the current developments in the field of gas as ship fuel.

SOx Exhaust Gas Cleaning (EGCS) - in practice
Become familiar with different SOx EGCS technologies available on the market, and understand applicable requirements regarding SOx EGCS according to MARPOL Annex VI & MEPC.259(68).

For more information, please visit our training web page: www.dnvgl.com/maritime-academy
Scrubber Ready

DNV GL has created a class notation to help shipowners prepare their newbuildings for the installation of a scrubber. It ensures that the necessary preparations are in place for a smooth and cost-efficient scrubber retrofit at a later stage. The notation can be awarded to ships that have planned and partly prepared for the installation of an exhaust gas cleaning system (EGCS) for the removal of SO\textsubscript{x} at a later date. The notation identifies the general type and category of scrubber systems that can be installed on the vessel. It also details the level of scrubber readiness, with the minimum scope attesting that the space available and future installation arrangement meet class and statutory requirements. This can be expanded to include more extensive preparations, through to a complete review of the scrubber documentation according to main class rules, including the certification and installation of piping and subsystems. For shipyards, working with the Scrubber ready standard gives an easy framework within which to offer future-ready ship designs to the market.

Gas Ready notation

LNG as ship fuel is spreading rapidly through the maritime world. To be more flexible and competitive, you need to ensure your newbuilding is ready for future LNG conversions. Based on the experience we have gained from our LNG Ready Service, as well as the 50 LNG-fuelled vessels we already have in class with our Gas fuelled notation, we have developed the new Gas Ready notation. This notation enables you to ensure that a future LNG-fuelled version of your vessel complies with the relevant safety and operational requirements. It also helps you specify and quantify the level of investment you are making at the newbuilding stage.

The basic notation – with nominators D and MEc – GAS READY (D, MEc) – verifies that the vessel is in compliance with the relevant rules in terms of its overall design for future LNG fuel operations, and that the main engine can be converted or operate on gas fuel.

You can also choose to add extra optional levels to the newbuilding under the notation – putting the vessel further along the LNG track and thereby speeding up and simplifying a later conversion.
Gas Fuelled notation
The Gas Fuelled notation’s requirements cover all aspects of the gas-fuel installation, from the ship’s gas-fuel bunkering connection all the way up to and including all gas consumers. The rules are applicable to installations where natural gas is used as fuel. Other gases are subject to special consideration. The class notation is mandatory for any newbuilding being built with gas as fuel, either with gas-only or dual-fuel concepts.

Low Flashpoint Liquid (LFL) fuelled
Methanol is a low flashpoint liquid (LFL) fuel that is gaining interest in the market because it does not contain sulphur and is therefore suitable for meeting the existing 0.1% SO₂ Emission Control Area requirements. Methanol has a flashpoint of about 12 degrees Celsius, and vessels will be assigned the additional notation LFL FUELLED to demonstrate their compliance with the safety requirements set out in the industry-first rules published by DNV GL in June 2013.

DNV GL was the first classification society to publish LFL rules and sees methanol as part of the future energy mix for shipping. As well as having low SO₂ and NOₓ emissions, a methanol fuel system is easy to retrofit on a ship.

DNV GL has been involved in newbuilding projects from the early design stage, working together with the shipowner, engine maker and yard to ensure an equivalent level of safety to that of a conventional fuel oil system. DNV GL has made use of its long experience with LFL cargo handling on chemical tankers and offshore supply vessels designed to transport low flashpoint cargo and its experience with alternative fuels from 15 years of working with gas-fuelled ship installations. This is a mandatory class notation for ships using methyl alcohol or ethyl alcohol as fuel.
Regional Maritime offices

Américas
1400 Ravello Dr.
Katy, TX 77449
USA
Phone: +1 2813961000
houston.maritime@dnvgl.com

Greater China
1591 Hong Qiao Road
House No.9
200336 Shanghai, China
Phone: +86 21 3208 4518
marketing.rgc@dnvgl.com

North Europe
Johan Berentsens vei 109-111
Postbox 7400
5020 Bergen, Norway
Phone: +47 55943600
bergen.maritime@dnvgl.com

South East Europe & Middle East
5, Aitolikou Street
18545 Piraeus, Greece
Phone: +30 210 4100200
piraeus@dnvgl.com

West Europe incl. Germany
Brooktorkai 18
20457 Hamburg
Germany
Phone: +49 40 361495609
region.west-europe@dnvgl.com

Korea & Japan
7th/8th Floor, Haeundae I-Park C1 Unit,
38, Marine city 2-ro, Haeundae-Gu
48120 Busan, Republic of Korea
Phone: +82 51 6107700
busan.maritime.region@dnvgl.com

South East Asia & India
16 Science Park Drive
118227 Singapore
Singapore
Phone: +65 65 083750
sng.fis@dnvgl.com

DNV GL AS
NO-1322 Høvik, Norway
Phone: +47 67 579900
www.dnvgl.com

DNV GL - Maritime
Brooktorkai 18
20457 Hamburg, Germany
Phone: +49 40 361490
www.dnvgl.com/maritime

DNV GL
DNV GL is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. Operating in more than 100 countries, our professionals are dedicated to helping customers in the maritime, oil & gas, power and renewables and other industries to make the world safer, smarter and greener.

DNV GL is the world’s leading classification society and a recognized advisor for the maritime industry. We enhance safety, quality, energy efficiency and environmental performance of the global shipping industry – across all vessel types and offshore structures. We invest heavily in research and development to find solutions, together with the industry, that address strategic, operational or regulatory challenges.

©DNV GL 04/2018  ID 1765300