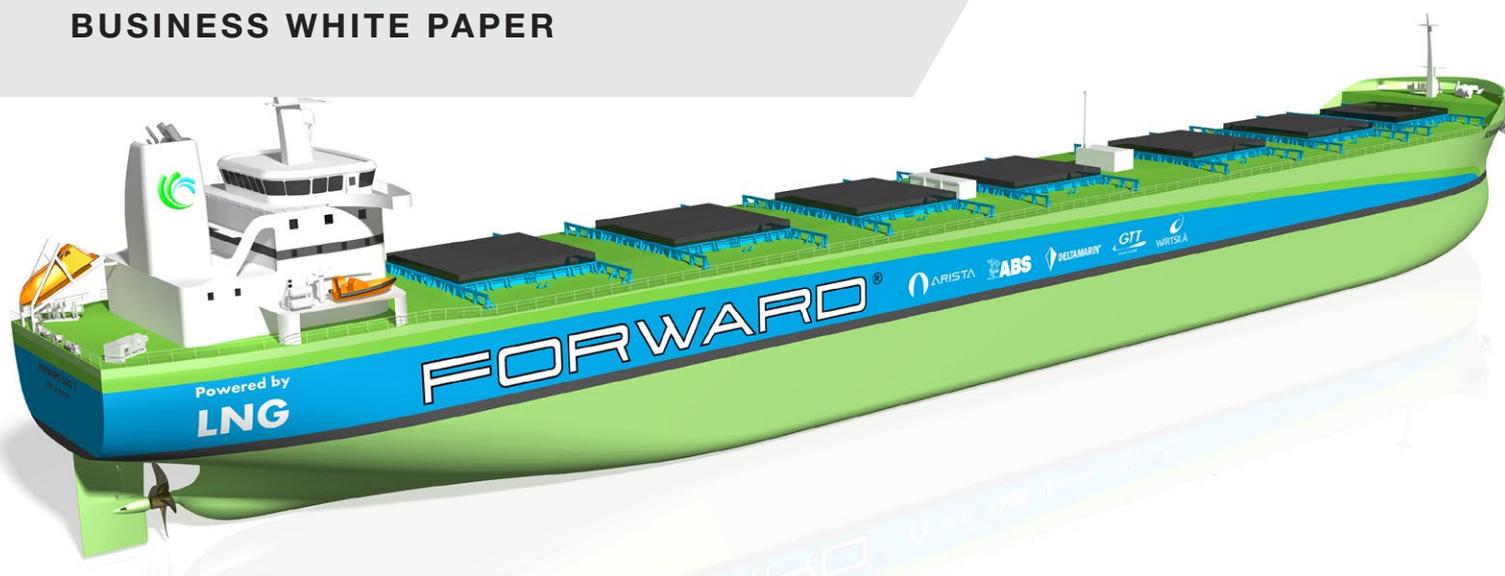


# Shipping in the 2020 era – selection of fuel and propulsion machinery

## BUSINESS WHITE PAPER



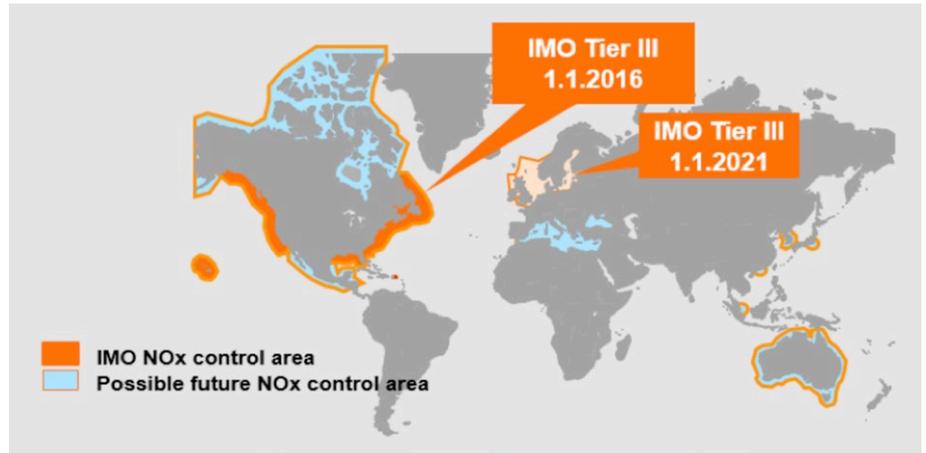
Environmental concerns have led to increasingly stringent emission legislation. What started as an onshore industry regulatory development is now impacting also the shipping industry. Shipping has lately faced multiple new regulations, and will soon be facing other major regulations. The global cap of an 0.5% maximum content of sulphur in fuel from 2020, and the IMO Tier III regulations (specifying that NOx emissions must be 80% lower than at the IMO Tier I level) within Emission Control Areas will force the shipping industry to consider alternatives beyond today's standard solutions.

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Fig.1 Emission Control Area expansions



### 1. GLOBAL MAXIMUM SULPHUR CAP OF 0.5%

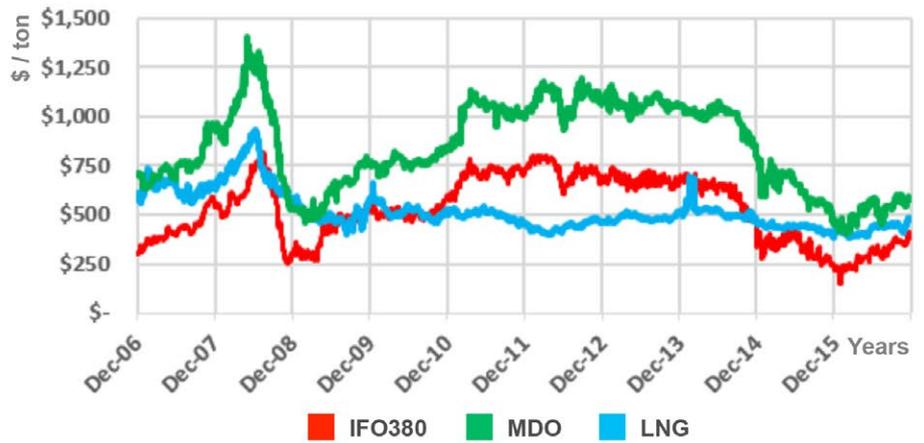
The Heavy Fuel Oil (HFO) used by marine vessels today with a maximum sulphur content of 3.5% will not meet the global sulphur cap of 0.5% coming into force from 2020. Further refining of the HFO and blending with gasoil is required to meet the maximum sulphur content of 0.5%, which also increases the price of the fuel. Low sulphur HFO is still not widely available, but the low sulphur fuels used today are Marine Diesel Oil (MDO) with a maximum sulphur content of 1%, and Marine Gas Fuel (MGO) with a maximum sulphur content of 0.1%.

The price for fuel with a maximum sulphur content of 0.5% is still open. The MDO used today can be further refined, and also the possible increased use of gasoil will enable the sulphur cap of 0.5% to be met. Therefore, the price of MDO today might be the best indicator for foreseeing the complying diesel oil price in 2020. Some oil majors are already developing low sulphur HFO, and have indicated that the price for low sulphur HFO would be somewhere between the current HFO and MDO prices. Naturally nobody yet knows for sure what the price of low sulphur fuel will be in the future, but many ship owners anticipate that it will be close to the price of MDO.

The only alternative for meeting the maximum sulphur content of 0.5% with the HFO currently available is to clean the engine exhaust gases of sulphur oxides using an SOx scrubber. Many ship owners have already opted for SOx scrubbers in their newbuildings, because the additional price for low sulphur fuel oils has, at least historically, been considerably higher than for conventional HFO. The anticipation is that the additional investment for the SOx scrubber will pay itself back within a reasonable time frame since it allows the ship to operate on conventional HFO. Figure 2 indicates the historical fuel prices on the USA's West Coast (IFO380 is generally considered to be the most commonly used HFO).

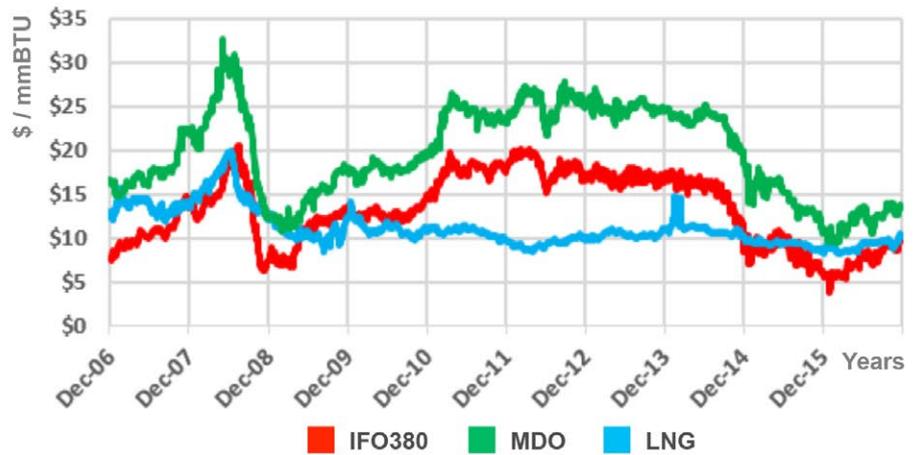
**THE ONLY ALTERNATIVE**  
for meeting the maximum sulphur content of 0.5% with the HFO currently available is to use an SOx scrubber.

Fig.2 Historical Fuel Prices on the US West Coast, HFO, MDO and LNG



**Average \$ / ton**

- IFO380 527.91
- MDO 844.81
- LNG 515.98



**Average \$ / mm BTU**

- IFO380 13.18
- MDO 19.66
- LNG 11.04

**COMPARING THE**  
historical price spread between HFO and MDO strengthens the case for anticipating that the price of low sulphur fuel will be high.

Today, there is already a sulphur cap of 0.1% within Emission Control Areas, so the industry has to some extent learned how to operate on low sulphur fuels. However, the large-scale global sulphur cap of 0.5% must anyway be considered as a major challenge for the shipping industry. Large ocean-going vessels have thus far only had to use low-sulphur fuel periodically when sailing within Emission Control Areas. At other times they have operated normally on conventional HFO. Having to permanently comply with the low sulphur legislation will lead to changes in the marine sector far more reaching than we have seen earlier.

## 2. NOX EMISSIONS - IMO TIER III WITHIN EMISSION CONTROL AREAS

In addition to the global sulphur cap of 0.5%, additional emissions legislation is also entering into force. New ships will have to comply with IMO Tier III regulations when operating within Emission Control Areas. IMO Tier III means that the NOx emissions will have to be 80% lower than those specified by the IMO Tier I levels introduced in the year 2000. New ships with keel laying after 1.1.2016 for North American waters, and keel laying after 1.1.2021 for the Northern European Emission Control Areas will have to comply with the IMO Tier III legislation. Diesel engines can only meet IMO Tier III with catalysts, i.e. Selective Catalytic Reduction units (SCR). An alternative means of meeting the IMO Tier III levels might also be to use Exhaust Gas Recirculation (EGR), although this technology has still to be further validated.

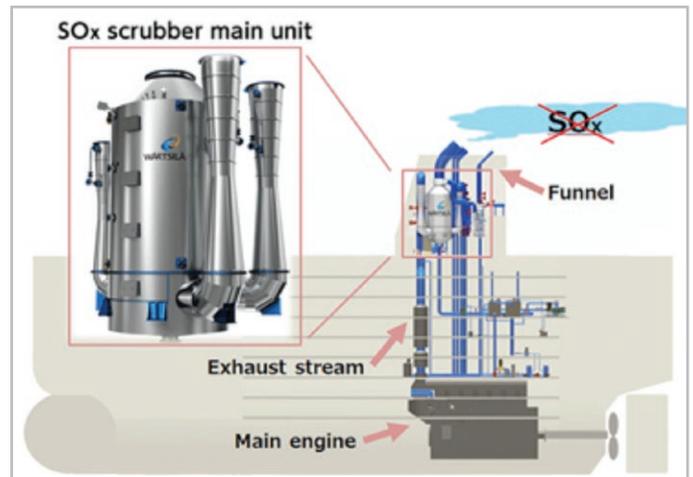
“WHILST THE BUSINESS case for investing in scrubbers may look appealing at first, it is not a long-term solution to place such complex machinery on our vessels.”

HEAD OF MAERSK OIL TRADING  
MAY 2017

## 3. INCREASING COSTS BECAUSE OF EMISSIONS LEGISLATION

Emissions legislation will increase the operational costs of shipping. If no after treatment units are installed, low sulphur diesel oil will have to be used, which is more expensive than conventional HFO. If after treatment units are installed, the cost of the ship will increase, while operating the after-treatment units will also increase operating costs. The after-treatment equipment creates an increased electrical power demand because of the additional pumps required. Additional costs for the removal of the sludge when in port will also need to be considered. Furthermore, operating with SCRs will require the use of urea, which will have to be separately bunkered. All after-treatment equipment also requires maintenance, meaning that the overall maintenance costs will also increase.

Fig.3 On the left, a high-pressure SCR unit for a Win GD 6X72 engine undergoing shop testing at Hyundai Heavy Industries. On the right, an illustration of an SOx scrubber installation on a main engine



— **“GAS IS THE CLEANEST**  
burning hydrocarbon.”  
**SHELL**

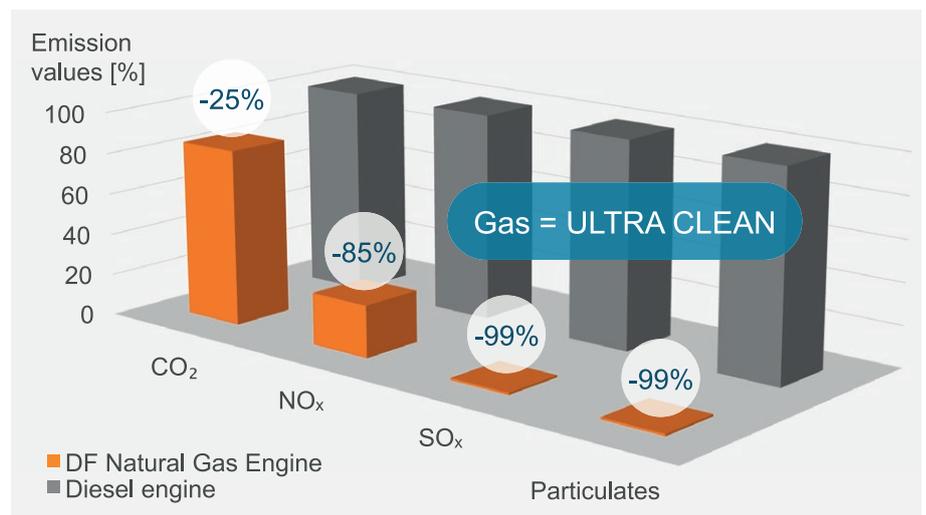
#### 4. ALTERNATIVES FUELS – LNG

Because of the anticipated cost increases for operating on diesel oil, there is growing interest in alternative fuels. Electric powered vessels, meaning battery or hybrid propulsion, will play an important role in future shipping operations, but the battery technology available today still only allows for very short distances when running purely on electricity. For example, ferries with transit times of, say, half an hour are a good fit for purely battery powered vessels.

The alternative fuel that looks most promising today is LNG. Natural gas production worldwide is increasing, and together with renewables, gas is taking an increasing share of the global energy market. Natural gas traded as LNG is growing by some 6 to 8% per year. Of all the fossil fuels natural gas is the cleanest, and because of emissions legislation is increasing being used for fuelling ships.

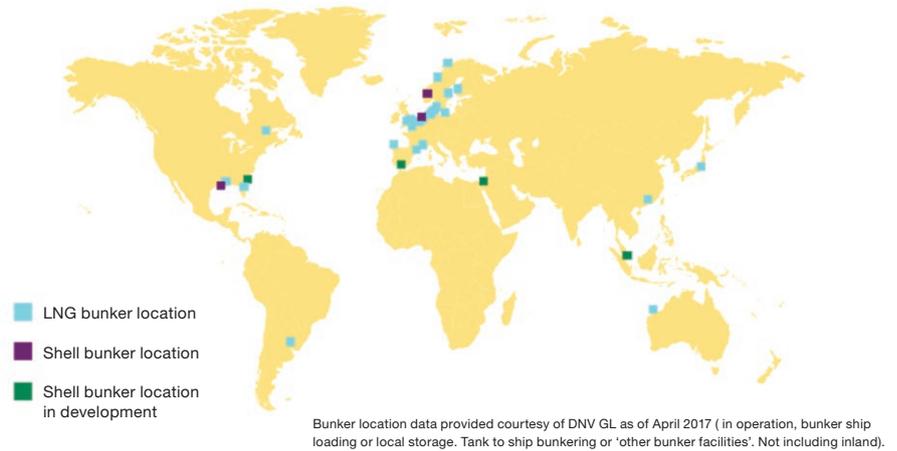
Operating on LNG delivers lower emission levels than when operating on diesel oil, as illustrated in figure 4 below. Gas or dual-fuel engines running on gas according to the Otto cycle, have a 25% lower level of CO<sub>2</sub> emissions, while NO<sub>x</sub> emissions are 85% lower than for a diesel engine. This enables compliance with the IMO Tier III levels without the need of an SCR. As LNG does not include any sulphur, it also fulfils all sulphur regulations.

Fig.4 Comparison of emission levels, gas engine vs. diesel engine



The bottleneck holding back greater LNG use has been the bunkering availability of LNG. Neither has the price of LNG always been competitive compared to conventional HFO. Today there are a little more than 100 LNG fuelled vessels in operation, and by 2019 this number will have increased to more than 200. The LNG bunkering infrastructure is, therefore, gradually improving as shown in figure 5 below. As more and more ship owners are opting for LNG as fuel for their newbuildings, LNG bunkering volumes are increasing. However, most of the LNG fuelled vessels are operating in northern Europe, but ports worldwide are also showing an increased interest in offering LNG. Figure 5 showing the global LNG marine bunker network in April 2017 is, therefore, already outdated as new LNG bunker locations have arisen since.

Fig.5 The LNG bunkering infrastructure, April 2017



## 5. THE CHOICE BETWEEN LOW SULPHUR FUEL, SOX SCRUBBERS OR LNG FOR NEWBUILDINGS

It is not easy to guess which marine fuel will be predominant in the future. The most challenging part probably is to foresee future fuel prices; how will low sulphur fuel be priced, and how will the price spread be compared to conventional HFO and LNG? There are still many open items that will need to be settled. Until this has happened we can only try to estimate what the most logical outcome could be.

Taking into consideration the higher production costs and increased use of gasoil to produce low sulphur fuel with a maximum sulphur content of 0.5%, it is likely that the price for low sulphur fuel will be high. One reference point for the price of 0.5% sulphur fuel is the price of MDO. Comparing the historical price spread between HFO and MDO presented in figure 2 earlier further strengthens the case for anticipating that the price of low sulphur fuel will be high. The IMO has published an extensive report, its "Assessment of fuel oil availability", in July 2016 (IMO MEPC 70/INF.6). In the IMO report the price of different fuels is evaluated and are shown in figure 6 below:

Fig.6 Projected Fuel Oil prices in 2020, source IMO MEPC 70/INF.6

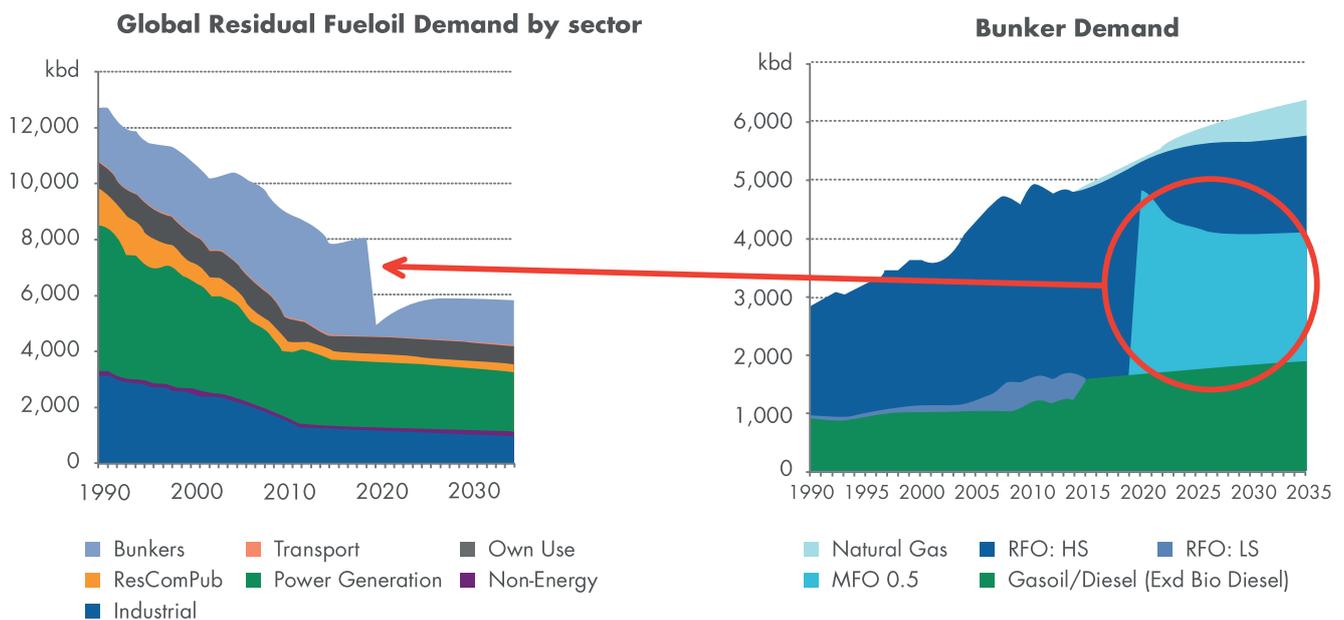
### Refinery products and crude oil prices (USD/tonnes except for Brent)

| Product                | 2010 | 2012 | 2014 | 2016 | 2018 | 2020 |
|------------------------|------|------|------|------|------|------|
| MGO 0.10% m/m SUL      | 672  | 997  | 896  | 452  | 552  | 616  |
| Fuel oil 0.50% m/m SUL | -    | -    | -    | -    | -    | 595  |
| Fuel oil 1% m/m SUL    | 625  | 918  | 809  | 390  | 497  | 569  |
| Fuel oil 3% m/m SUL    | 521  | 741  | 616  | 252  | 377  | 466  |
| Brent crude (USD/bbl)  | 80   | 112  | 99   | 49   | 63   | 77   |

Source: Stratias Advisors; CE Delft, [www.bunkerindex.com](http://www.bunkerindex.com)

The price spread shown in figure 6 between 0.5% sulphur fuel and 3% sulphur fuel is 130 USD/ton, which compared to the 10 year historical prices between HFO and MDO it is a moderate price spread. However, even with this modest price spread of 130 USD/ton, the pay-back time for SOx scrubbers will be very short compared to running on 0.5% sulphur fuel. In addition, by the end of 2019 the demand for 0.5% sulphur fuel is expected to grow from zero to approximately 75% of the global marine fuel demand. It remains to be seen how this tremendous growth in demand will work in practice, i.e. how supply will meet demand, see figure 7 below. Based on this assessment, alternatives such as SOx scrubbers or LNG should be more economically viable for newbuildings.

Fig.7 Illustration of the transition to 0.5% Low Sulphur Fuel (Shell)



While it can be foreseen that the price of 0.5% sulphur fuel will be high, the choice between SOx scrubbers and LNG is challenging because it is also difficult to foresee the price spread between conventional HFO and LNG. Both alternatives, SOx scrubbers and LNG fuel will drive up newbuilding costs compared to today's standard ship specifications. LNG fuelled ships will, in most cases, be the most expensive alternative, and this is mainly because of the price for the LNG fuel tank system. The price of LNG fuel tank systems has decreased, and continues to do so as the technology becomes more mature, but nevertheless the additional price for an LNG fuel tank system is still considerable. As LNG fuelled ships are generally always more expensive than HFO fuelled ships equipped with after-treatment units, it means that the operating costs for LNG must be lower in order to make the use of LNG profitable.

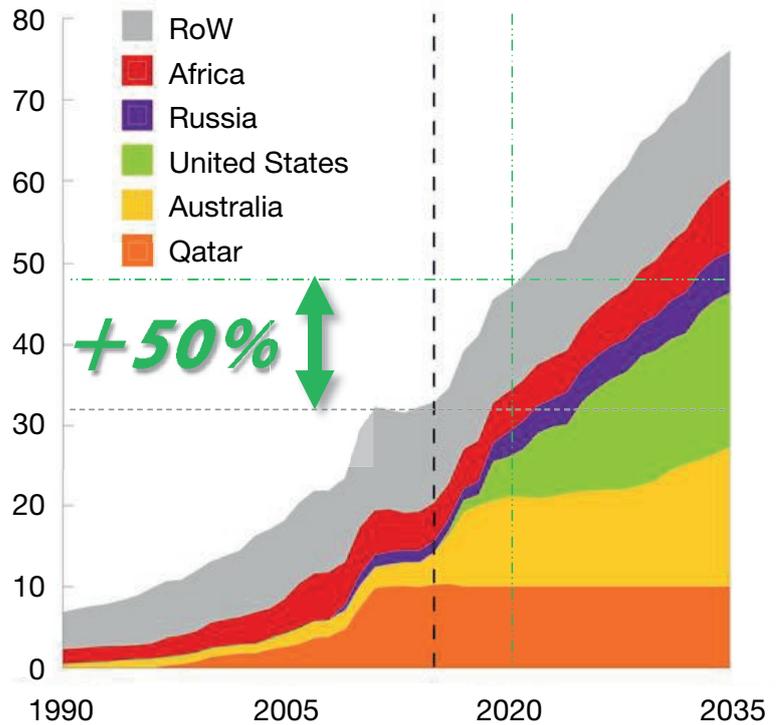
It is not easy to forecast how the price of LNG will develop, but it should be supply-demand driven. And one thing that we do know is that there will be a high increase in the supply of LNG between now and 2020, which should put pressure on LNG prices worldwide. Figure 8 below shows an expected 50% increase in the global LNG supply between now and 2020.

**“THE COSTS OF** compliance will be significant as the huge demand shift from HFO to LFO is likely to increase bunker costs by up to four times their current level.”

**WOOD MACKENZIE RESEARCH**  
MARCH 2017

Fig.8 The growth in the global supply of LNG from 2017 to 2020 is projected to be +50% (Shell)

— **“THE EXPECTED**  
increase in the global supply  
of LNG between now and 2020  
is +50%.”  
**SHELL**



LNG pricing is difficult to assess as LNG prices are seldom yet published. Some suppliers of LNG are pricing it compared to the price of diesel oil products, for example as a discount from the price of MDO. The price spread varies somewhat geographically, but it already gives a good basis from which to estimate it over the coming two years or so.

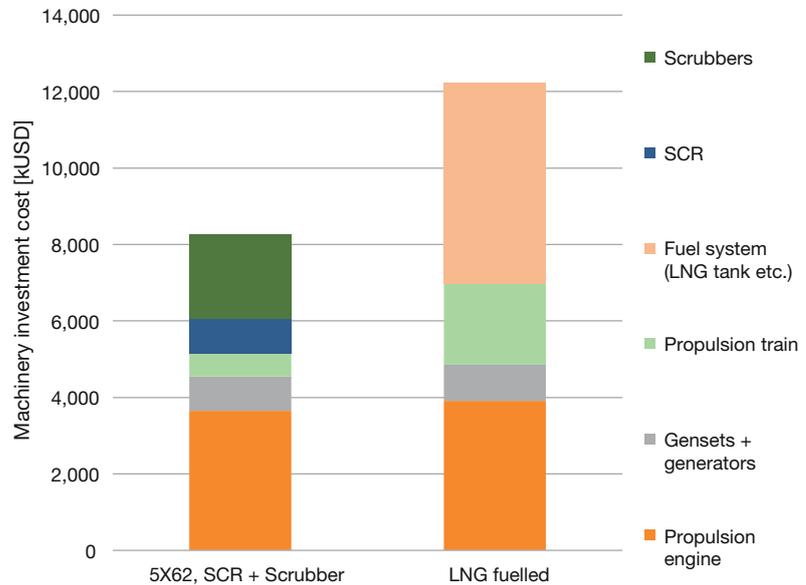
— **“LNG TO OUTPACE OIL**  
trades by 2030.”  
**DNV GL**  
**JANUARY 2018**

For a complete life-cycle analysis between different fuels, consideration should also be given to the fact that the use of LNG also gives the possibility for cost savings. When using LNG as the primary fuel, HFO boosters are not needed and, therefore, steam systems and boilers can often also be eliminated unless they are needed for other heating purposes. Operational expenses with LNG can also be lowered, since by operating on LNG the time between engine overhauls can be lengthened, which in turn reduces maintenance costs. Furthermore, LNG does not need to be separated, as is the case for HFO since approximately 1.5% of the HFO is separated in HFO separators. For a complete life-cycle analysis these “hidden benefits with LNG” also need to be considered.

## 6. CASE EXAMPLE – 82K DWT BULKERS

Bulk carriers (or bulkers) represent one of the main shipping segments. A Kamsarmax bulker is used here as a case example for comparing the selection between SOx scrubbers and LNG fuel. The comparison in figure 9 shows the cost structure difference between an HFO engine with a hybrid SOx scrubber and SCR, and an LNG machinery alternative.

Fig.9 Comparison on investment costs for two machinery alternatives: SOx scrubber with SCR vs. a LNG fuelled vessel



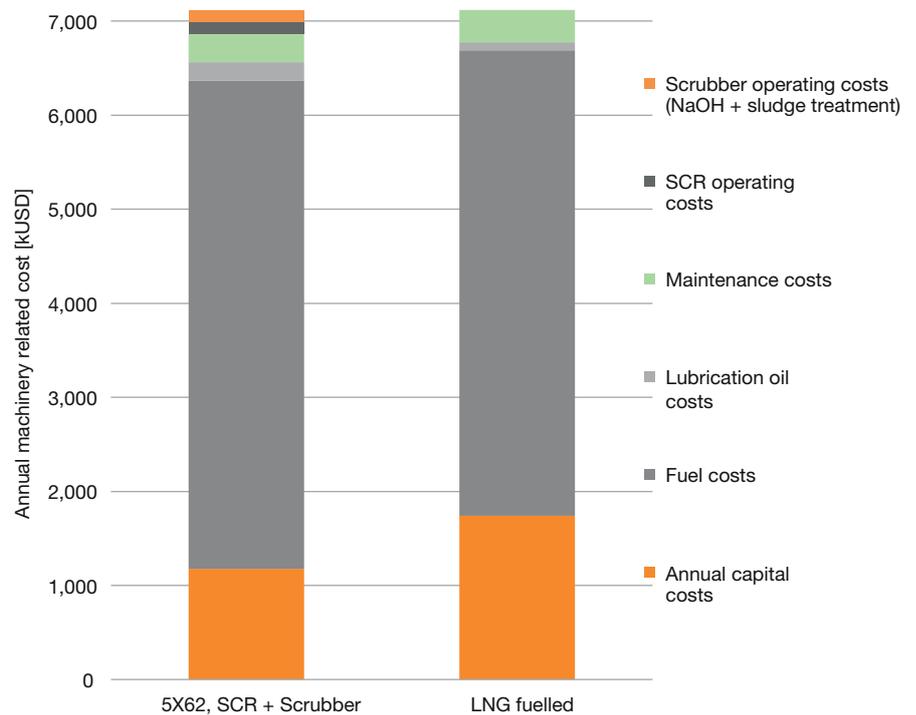
### THE COSTS OF

after treatment systems is moderate when compared to the cost of LNG fuel tank systems.

The SOx scrubber and SCR increase the total vessel costs when compared to standard bulker designs today. The additional costs for the after-treatment system are still moderate in comparison to the additional costs for the LNG fuel tank system. As there is not a lot of free space on a bulker it may also mean that in order to keep the same cargo capacity, the ship's length has to be increased and this will also increase the price for the LNG alternative. The size of the LNG fuel tanks has a major impact on the price for the LNG alternative, and in this example the operating range on LNG is set at 11,000 nm at a service speed of 14.5 kn.

The additional price for having LNG fuelled machinery in this case example for a Kamsarmax bulker means that, in order to be viable, it must be cheaper to operate on LNG. Otherwise the additional investment will never pay itself back. An acceptable pay-back time for the additional investment will vary from project to project, but in this example a pay-back period of ten years has been used and only the machinery investment costs illustrated in figure 9 have been used. It has further been assumed that the interest rate is 7%. Based on the historical fuel oil prices on the USA's West Coast shown in figure 2, and the projected HFO price in 2020 by the IMO, the price of conventional HFO could be at around 500 USD/ton. Based on this, and the difference in total vessel costs, it is possible to calculate break-even prices for LNG, meaning the price of LNG that equates to the operating costs for a given HFO price over a time span of ten years. Figure 10 below illustrates a comparison based on an HFO price of 500 USD/ton, giving a break-even price for LNG of 12.3 USD/mmBTU. This means that with the given assumptions, it will be cheaper to operate on conventional HFO using a SOx scrubber and SCR if the price of HFO is 500 USD/ton and the price of LNG is >12.3 USD/mmBTU. Conversely, it would be cheaper to operate on LNG if the price of LNG is <12.3 USD/mmBTU (and the price of HFO is 500 USD/ton).

**Fig.10** Break-even costs for a conventional HFO alternative using an SOx scrubber and SCRs compared to an LNG fuelled alternative based on an HFO price of 500 USD/ton. Considering both CapEx and OpEx costs, the break-even price for LNG is 12.3 USD/mmBTU.



The break-even calculation includes some assumptions as regards the operating profile, and therefore, the operating hours for the SCRs and for the SOx scrubber in closed-loop. Furthermore, the comparison is based on an existing design and includes an additional hotel load for the scrubber pumps, HFO separator losses, etc., i.e. the calculations are on a detailed level. The main purpose of the calculation is to demonstrate how a comparison can be made for different fuel oils requiring different investment costs. The input parameters will vary for different projects and this will naturally affect the end results. The break-even calculation can be used in projects where the price of the LNG is negotiated to be directly linked to the price of a diesel oil product, or even directly linked to the price of conventional HFO.

As LNG is typically priced in USD/mmBTU, it is challenging to understand the actual price without further conversions. 12.3 USD/mmBTU corresponds to 42 USD/MWh. The corresponding LNG price in tonnes is approximately 575 USD/ton, but the higher energy content of LNG has also to be considered. The energy content of LNG is more than 20% greater than for conventional HFO, and approximately 15% greater than that of Marine Gas Oil.

Any conclusion in the selection between HFO with after treatment units and LNG depends mainly on the price difference between HFO and LNG. As per the projected fuel oil prices today, operation on LNG looks very attractive on a long-term basis. Operating on HFO with after treatment systems looks more attractive in the short-term because of the lower investment costs.

**OPERATING ON LNG** looks very attractive on a long-term basis, while operating on HFO with after treatment systems looks more attractive in the short-term because of the lower investment costs.

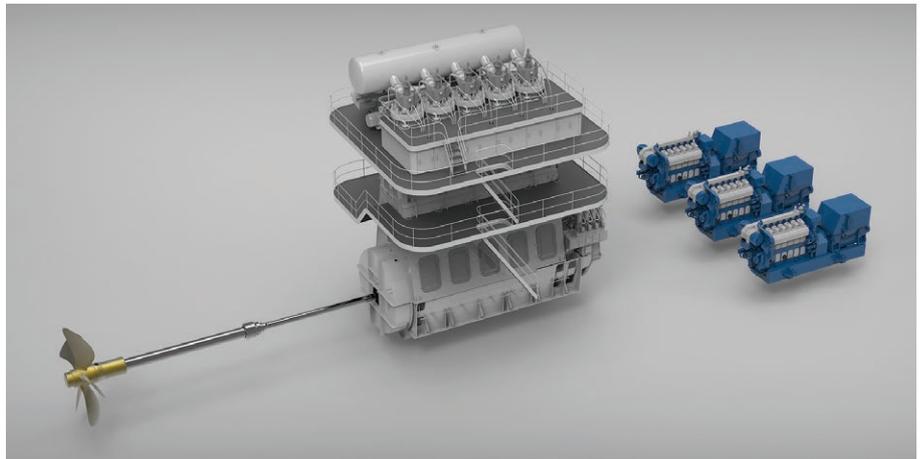
## 7. LNG FUELLED 82K DWT BULKER – OPTIMIZATION OF THE PROPULSION MACHINERY

Standard bulk carrier designs today have a single 2-stroke main engine directly connected to a Fixed Pitch Propeller and have three auxiliary gensets. This has been the industry standard since the change from steam turbine machineries. For LNG fuelled bulkers, the general idea thus far has been to change only the 2-stroke main engine and aux gensets to operate on LNG, but further optimization is possible. It is easy to pinpoint the weak points with the traditional 2-stroke machinery arrangement. First of all it is very static, having only one optimization point, i.e. fully laden at service speed, although it is generally known that the actual operation is very seldom at the optimization point. Secondly, the redundancy level is not optimal with only one main engine, and furthermore gas fuelled 2-stroke engines have only been in operation since 2016, meaning it is still a new technology under development. The third argument is actually cost optimization. Why not do it cheaper if possible to achieve the same outcome? 2-stroke engines are today often heavily derated, meaning the service speed is typically around 60% of the R1 rating. In addition, there are three auxiliary gensets with poor efficiency covering the hotel load, and typically only one of the auxiliary gensets is in operation. It is, therefore, a very poor utilization of the total installed power. For diesel fuelled ships it has not been considered as being particularly crucial to have over-powered engines, but since gas fuelled engines are more expensive than diesel engines, it becomes more important for LNG fuelled ships.

**IT IS EASY TO PINPOINT** the weak points with the traditional 2-stroke machinery arrangement.

An LNG fuelled Kamsarmax bulker with a 2-stroke main engine could comprise a WinGD 5X62DF main engine and three Wärtsilä 6L20DF gensets. The R1 rating of the 5X62DF is 11.925 kW, but here it would be derated to CMCR 9030 kW at 82 rpm. The output of each auxiliary genset is 1.110 kW, so the total available power (considering the R1 rating) would be 15.255 kW, as illustrated in figure 11 below.

**Fig.11** Illustration of an LNG fuelled machinery consisting of WinGD 5X62DF main engines and three Wärtsilä 6L20DF auxiliary gensets.

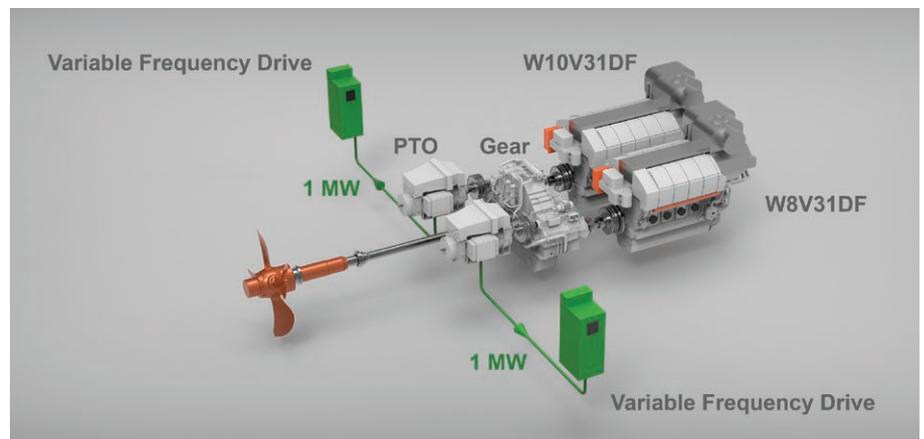


**THERE IS NO NEED**

for any auxiliary genset to be installed, since all the electricity needed onboard would be generated by PTOs.

A further optimized LNG fuelled Kamsarmax bulker would consist of only two 4-stroke main engines simultaneously utilized for both propulsion and hotel load. An optimum 4-stroke machinery arrangement would consist of a Wärtsilä 8V31DF and a Wärtsilä 10V31DF main engine. The power output of these engines is 4.400 + 5.500 kW, giving a total of 9.900 kW installed power. Both main engines are connected to a reduction gear box, and the reduction gear box is connected to a Controllable Pitch Propeller. There is no need for any auxiliary genset to be installed, but instead PTOs (generators connected to the gear box) would generate all the electricity needed onboard. The PTOs would also be used in port, whereby the propulsion line is disconnected from the gear box and one of the engines could be used to generate electricity only. Each PTO is connected to a frequency converter, which makes it possible to run the main engines at variable speeds. Operation at variable speeds gives a lower fuel oil consumption for the engines at part loads, and additionally it increases the propeller efficiency at part load.

Fig.12 Illustration of an LNG fuelled machinery arrangement consisting of one Wärtsilä 10V31DF and one Wärtsilä 8V31DF main engine



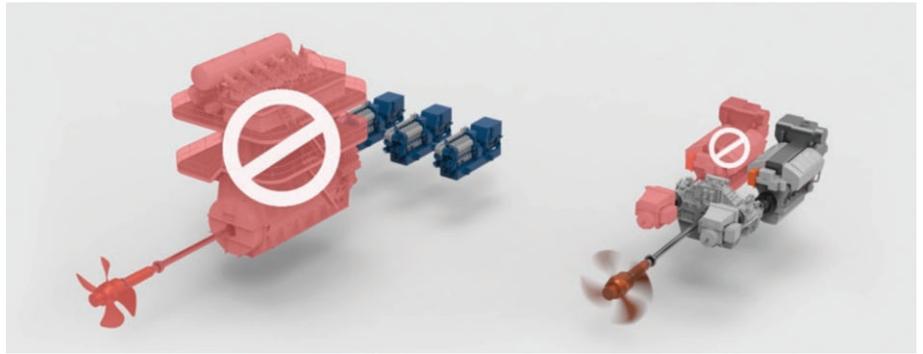
The main reasons for switching from a conventional 2-stroke main engine concept to a 4-stroke main engine concept for a LNG fuelled machinery are:

- Proven gas engine technology
- Increased flexibility
- Cost optimization

Proven gas engine technology: 4-stroke dual-fuel engines from Wärtsilä have been in operation since 1996 and have already accumulated more than 16 million running hours. The 4-stroke dual-fuel engine technology has developed enormously since the first engines were delivered in 1996. It is, therefore, an already fully proven technology compared to 2-stroke dual-fuel engines that have very recently only entered the market.

Increased flexibility: The redundancy level is increased with two main engines. If the larger 4-stroke engine is out of operation, the vessel will still be able to keep a service speed of >11 kn. Today's standard with one 2-S main engine means that in case of a main engine failure, the vessel is out of operation. The 4-stroke engine concept also offers increased service flexibility as one of the main engines can be overhauled during sailing.

Fig.13 1-1 size comparison of a conventional 2-stroke main engine machinery arrangement compared with that having 4-stroke main engine machinery.

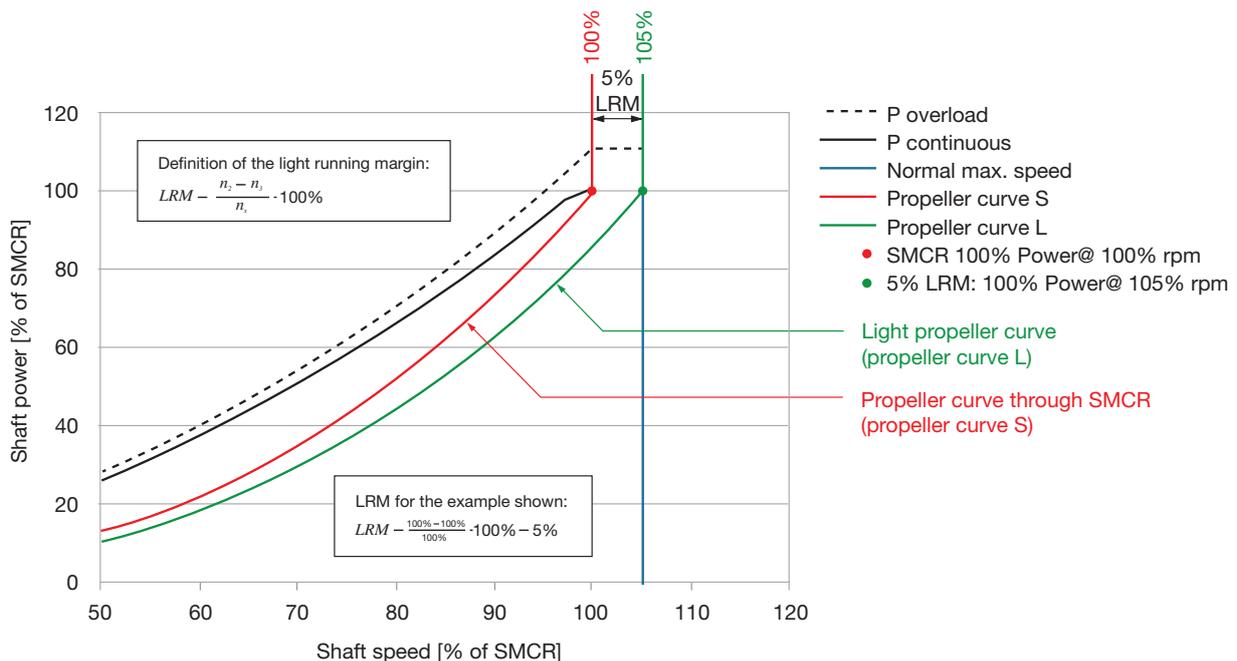


**THE DRAWBACK WITH**

an FPP is that it is very static and therefore higher margins must be used, which reduce efficiency.

However, the major reason why the 4-stroke engine concept offers increased flexibility is because of having a CPP installed instead of a FPP as for the 2-stroke concept. With a CPP, the manoeuvrability is better than with a FPP, but more importantly, with a CPP it is possible to optimize the efficiency of the engine and propeller according to the actual operating conditions. A variable speed CPP can have comparable Open Water efficiency as a FPP. The drawback with a FPP is that it is very static and, therefore, higher margins must be used which might reduce efficiency. The design of the FPP is typically at laden condition and at service speed. For the design of the FPP, the main engine loading limitations must be considered in order to make sure that the engine is never over-loaded. To that margins are then added to make sure that the 2-stroke engine will never be over-loaded, regardless of a dirty hull, heavy sea conditions, etc. In addition, 2-stroke engine makers recommend a Light Running Margin of 4 – 10%, and typically a 10% LRM is applied. The LRM is applied to give some further margins for avoid overloading the engine, and also to have a faster load acceleration (especially important to minimize the time spent in the barred rpm range). The drawback with the additional margins is that the propulsion efficiency is significantly decreased when the propeller rpm is increased.

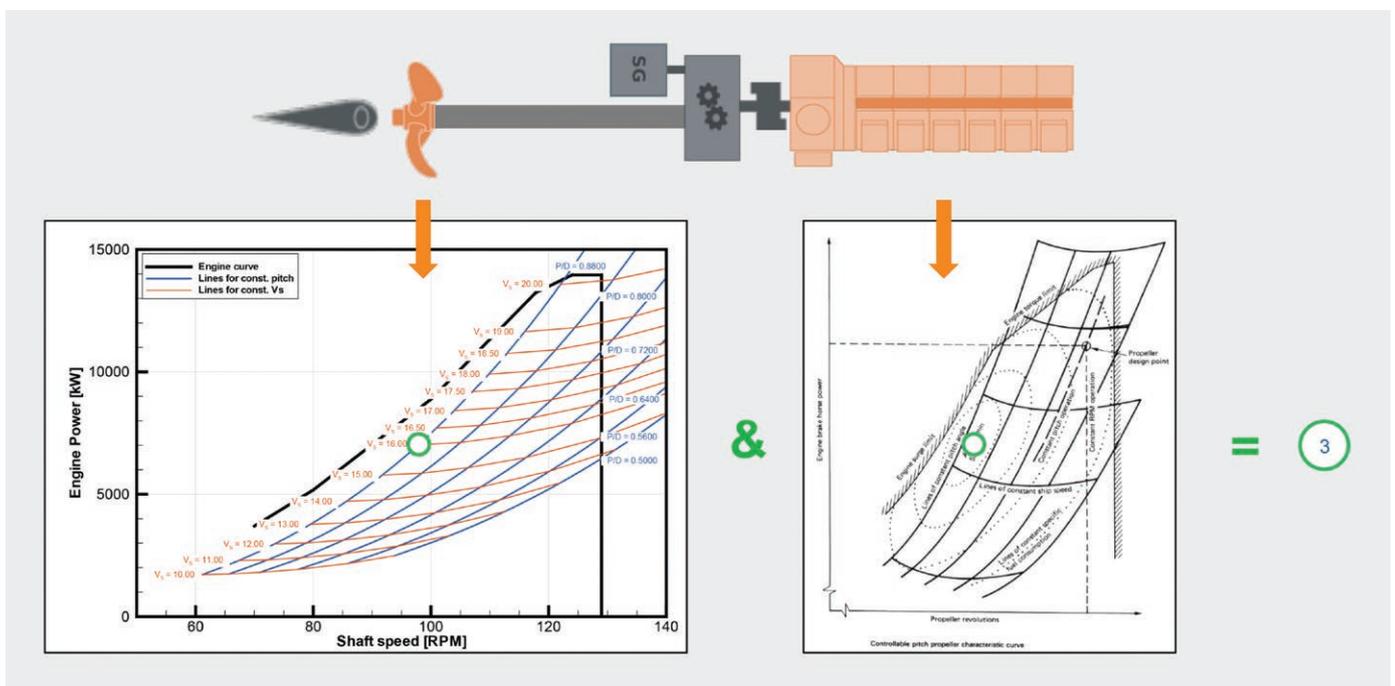
Fig.14 Example of an engine load diagram with a 5% Light Running Margin



The benefit of a CPP is the flexibility provided, and with the newly developed active combinator there is no need to apply unfavorable margins.

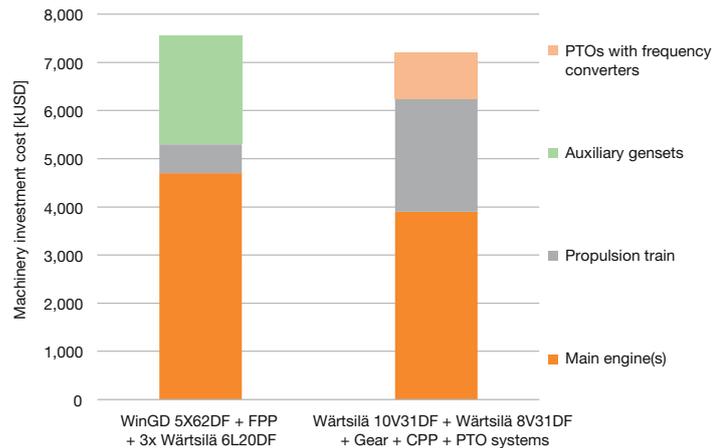
The active combinator minimizes the fuel consumption during transit sailing modes, based on the principle that equal thrust can be achieved at more fuel optimised propeller pitch and engine speeds compared to a static combinator mode. The 4-S main engines continuously communicate with the smart propulsion control system, allowing the propeller and engine to operate in the most efficient and safe way, in accordance with the actual (environmental) conditions. This is not possible with a FPP as the design is fixed and margins for worst case scenarios have to be applied, without any possibilities to make adjustments.

Fig.15 An active combinator automatically optimizes the pitch setting and engine rpm to minimize fuel consumption.



Cost optimization: The 4-stroke engine concept has a lower installed power, and this is also the main reason why the 4-stroke engine concept is more cost efficient than a 2-stroke concept. Figure 16 below shows a cost comparison between a 2-stroke concept with 5X62DF main engines with an FPP and 3 x Wärtsilä 6L20DF auxiliary gensets, and a 4-stroke concept with one 10V31DF and one 8V31DF main engine connected to a reduction gear box and CPP, including the costs for the PTO converter systems.

Fig.16 Comparison of LNG fuelled machinery investment costs, 2-stroke vs 4-stroke



The machinery investment cost comparison in figure 16 above includes the main equipment only, without auxiliary equipment. When the auxiliary equipment is also included in the comparison, the cost difference between the 4-stroke concept and the 2-stroke concept is higher. The lower installed power and fewer engines installed with the 4-stroke engine concept requires less and smaller auxiliary equipment than the 2-stroke concept. Costs can therefore be lower with a 4-stroke concept, but how about fuel consumption? Can a 4-stroke concept be competitive against a 2-stroke on fuel consumption?

Fuel costs contribute a major share of the total operating expenses for a Kamsarmax bulk carrier. Therefore, the fuel efficiency is of great importance. The Specific Fuel Oil Consumption for a 2-stroke engine is generally always better than for a 4-stroke engine. A 4-stroke concept also requires a reduction gear box, which further reduces the efficiency to the propeller as compared to the 2-stroke engine that is directly connected to the propeller. In addition, the open water efficiency of a CPP is generally lower than that of a FPP. Figure 17 below shows a comparison in energy efficiency between the 2-stroke concept and the 4-stroke concept. The loss in efficiency over the reduction gear box is 2% (a one stage gear is applied) and the CPP is calculated to have a 1% lower open water efficiency compared to the FPP used in the 2-stroke concept. As the 4-stroke concept has a reduction gear box it offers the possibility to go lower down in propeller rpm than the rating field of the 2-stroke engine allows. Thereby the propeller efficiency for the 4-stroke concept can be higher than for the 2-stroke concept, but as this advantage does not apply for all projects it has not been included in the comparison below.

Fig.17 Comparison of LNG fuelled machinery's energy efficiency, 2-stroke vs 4-stroke

| 14.5 kn                       | WinGD 5X62DF with FPP |        |           | Wärtsilä 10V31DF + Wärtsilä 8V31DF with CPP |                        |        |
|-------------------------------|-----------------------|--------|-----------|---|------------------------|--------|
| Power on propeller            | 7600                  | kW     |           |   | 7600                   | kW     |
| Gear losses                   | 0%                    |        |           |   | 2%                     |        |
| Propeller losses (CPP vs FPP) | 0%                    |        |           |   | 1%                     |        |
| Active combinator gain        | 0%                    |        |           |   | -2%                    |        |
| Shaft losses                  | 1%                    |        |           |   | 1%                     |        |
| Engine power for propulsion   | 7677                  | kW     |           |   | 7755                   | kW     |
| Hotel load                    | with aux. genset      | 635    | kW        | with PTO                                    | 500                    | kW     |
| Electric losses               |                       | 7%     |           |   | 7%                     |        |
| Engine power for hotel load   |                       | 683    | kW        |   | 538                    | kW     |
| Total main engine power       | 7677                  | kW     |           |   | 8293                   | kW     |
| Engines running               | 5X62DF                |        | 1x 6L20DF |   | 1x 10V31DF + 1x 8V31DF |        |
| Engine output CMCR @82 rpm    | 9030                  | kW     | 1110      | kW  | 9900                   | kW     |
| Engine load %                 | 85.0%                 |        | 61.5%     |   | 83.8%                  |        |
| Engine consumption, 5% tol.   | 7109                  | kJ/kWh | 9060      | kJ/kWh                                      | 7220                   | kJ/kWh |
|                               | 54574                 | MJ/h   | 6186      | MJ/h  |                        |        |
| Total energy consumption      | 60760                 | MJ/h   |           |   | 59874                  | MJ/h   |
| Difference to 5X62DF          | 0%                    |        |           |   | -1.5%                  |        |

## THE TOTAL ENERGY

efficiency of the 4-stroke concept is better when taking into consideration the energy required for propulsion and for the hotel load.

The starting point is that the power on the propeller is the same. The 4-stroke concept loses in efficiency compared to the 2-stroke concept because of the reduction gear and the CPP, but the efficiency gain because of the active combinator being applied is approximately 2%. The total engine power needed to achieve 14.5 kn is still higher for the 4-stroke concept.

In addition the hotel load must be included in the comparison. One major difference here is that the 4-stroke concept utilizes the main engines to produce the hotel load, while the 2-stroke concept utilizes the auxiliary gensets. The other major difference is the higher hotel load required for the 2-stroke concept, which is here +135 kW. The 4-stroke engines have built-on pumps, i.e. lube oil, HT- and LT-cooling water pumps, while the 2-stroke engine uses separate electrical pumps installed separate from the engine in the engine room. The pumps built onto the engine are more efficient, but they increase the specific fuel oil consumption. The energy consumption for the 4-stroke engines used in the comparison includes the engine built-on pumps.

The 2-stroke engine has a higher efficiency from engine to propeller, and the specific fuel oil consumption for the 2-stroke engine is better than for the 4-stroke engines. However, the higher hotel load and the poor efficiency of the auxiliary gensets in meeting the hotel load outweighs these gains for the 2-stroke concept compared to the 4-stroke concept. The total energy efficiency of the 4-stroke concept is better when both the energy required for propulsion and the energy required for the hotel load are considered. The use of the main engines at variable speeds to produce electricity onboard is superior compared to the use of small auxiliary gensets running at a constant speed. This makes the major difference when comparing the 2-stroke and 4-stroke concepts.

**Note 1:** A PTO could also be applied for the 2-stroke concept, which would increase the efficiency of the 2-stroke concept as well. However, for 2-stroke engines the PTO is installed on the shaft, meaning that it is a low-speed generator with a nominal speed of around 80 rpm. For the 4-stroke concept, the PTOs are connected to the gear box and thus the nominal speed is typically 1800 rpm. A slow-speed generator is much bigger in size than a high-speed generator, and the price is therefore many times higher. This is the main reason why 4-stroke installations typically always include PTOs and why they are less frequently used on 2-stroke installations. With a 4-stroke installation, it is also possible to use the PTOs in port as the propulsion line can be disconnected, but this is not possible with a 2-stroke installation and the auxiliary gensets must, therefore, anyway be included with the 2-stroke concept. Taking these facts into consideration, the use of a PTO for a 2-stroke concept always increases the investment costs, and the pay-back time is typically quite long.

**Note 2:** Maintenance and lube oil costs are not included in the comparisons, because reliable data for maintenance costs for the 2-stroke concept were not available. Maintenance costs for 2-stroke engines are generally considered to be lower than for 4-stroke engines. On the other hand, lube oil costs are lower for the 4-stroke concept as no cylinder oil is required. Thus, the total cost difference for maintenance and lube oil was assumed to be negligible.

**Note 3:** A 2-stroke engine from MAN could also be used in the comparison instead of the WinGD engine. However, the total CapEx level will increase as the MAN ME-GI engine requires an SCR to comply with IMO Tier III. In addition, the hotel load is considerably higher with an ME-GI engine because of the High Pressure gas system. Therefore, for this comparison, the ME-GI engine was considered to be less competitive than the WinGD engine used in the comparison.

Furthermore, the 4-stroke machinery is very compact in size compared to a conventional 2-stroke concept, as can be seen from the 1-1 size comparison in figure 13. The 2-stroke main engine weighs roughly three times more than the 4-stroke machinery, but even more important are the space savings. In the case example here for a Kamsarmax bulker, replacing the 2-S engines with 4-S engines will provide a large empty space above the engines. This empty space can be utilized for increasing the cargo capacity.

## 8. CONCLUSIONS

For newbuildings today, emissions legislation is a game-changer. It can be foreseen that the price of low sulphur fuels will be high, and for this reason machinery alternatives with either after-treatment systems or LNG fuelled machinery must be seriously considered. The emissions legislation will in any case increase shipping costs, but the machinery choice for newbuildings is currently probably more challenging than ever before.

Based on the evaluations made in this paper, the use of LNG as fuel appears to be attractive, although the investment costs with LNG will be significantly higher. Future fuel prices are crucial, but the forecasted global increase in LNG supply should mean that the LNG price is kept at modest levels. The worldwide availability of LNG is still an open question, but then again, none of the LNG fuelled vessels delivered thus far have faced or are expecting problems with LNG availability. The same availability challenge also faces newbuilds with SOx scrubbers, i.e. will high-sulphur HFO still be widely available after 2020 when shipping is undergoing the transformation from using high sulphur fuel to using low sulphur fuel. The use of SOx scrubbers may look like the “easy alternative”, but when the actual consequences of higher hotel loads, additional costs for chemicals (NaOH) when operating in closed loop mode, and sludge disposal are considered, it is not that easy. Scrubber operation in open loop is more cost effective, but today there are many areas that no longer allow, or are planning to put a ban on, open-loop use, which also means that the operating costs for the scrubber will most likely increase.

2-stroke main diesel engines have for a long time been the standard in shipping. However, 2-stroke main engines might not be the optimum solution for all LNG fuelled ships. Proven technology, increased flexibility, and cost optimization are very strong arguments for choosing 4-stroke machinery. The shipping industry has always been rather conservative because of the massive capital investments required, but early adapters to the changes now being experienced will also have the opportunity to earn unusually large profits.