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VESSEL EMISSION STUDY: COMPARISON OF VARIOUS ABATEMENT TECHNOLOGIES TO MEET EMISSION LEVELS FOR ECA's

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VESSEL EMISSION STUDY: COMPARISON OF VARIOUS ABATEMENT TECHNOLOGIES TO MEET EMISSION LEVELS FOR ECA's

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SUMMARY

The work covers a comparison study of three different abatement technologies to meet the IMO emission levels for the Emission Control Areas (ECA's). The study is based on retrofitting a 38,500dwt tanker and comparing low sulphur fuel, LNG as fuel and scrubber technologies. Various scenarios are treated, and a financial evaluation is made considering operational profiles, fuel prices and ECA and non-ECA operation.

1. INTRODUCTION

The International Maritime Organization (IMO) has decided that all vessels sailing in the ECA must reduce sulphur level in fuel oil to 0.1 % or clean the exhaust gas to an equivalent level by 2015. The private Danish industry initiative Green Ship of the Future launched a new study where a group of companies will work together on comparing various abatement technologies to fulfil the IMO decision. The study has been performed by the following Danish companies, which are all members of Green Ship of the Future:

- MAN Diesel & Turbo
- Alfa Laval
- Maersk Maritime Technology
- D/S NORDEN A/S
- Danish Shipowners' Association
- Schmidt Maritime ApS
- Elland Engineering ApS
- Maersk Tankers
- Lloyd's Register
- Green Ship of the Future

2. OBJECTIVE

The objective of the study is to compare potential solutions able to meet the requirements of the IMO regulations regarding SO_X in the ECA in 2015 and globally in 2020. In 2015 the requirements within the ECA areas call for a reduction of sulphur content in the fuel to 0.1 % or alternatively the equivalent level measured in the exhaust gas. Similarly in 2020, the global requirements will be a reduction of sulphur content in the fuel to 0.5 % or alternatively the equivalent level measured in the exhaust gas. A scenario with a global sulphur cap entering in 2025 has also been considered.

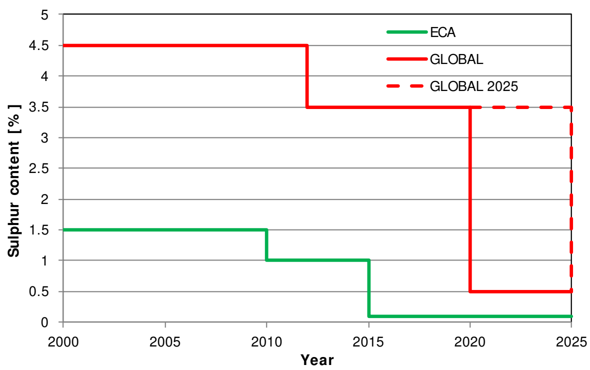

Figure 1: IMO regulation of SOx levels

The present study evaluates technical and economical feasibility of retrofit conversion into one of the following three operational modes in order to meet the future IMO SOx regulations:

- Low sulphur fuel (MGO) – Base case
- Scrubber technology
- LNG operation

The study is based on retrofit of an existing tanker.

3. REFERENCE VESSEL AND OPERATION

The vessel chosen for this study is a 38,500dwt product tanker, one of a series of 8 similar vessels. The vessel details have been provided by DS NORDEN. The service speed at design draft including 15% sea margin is 14.0 knots. More details are provided in the table below.

Main particulars		
Length (LOA)	182.86	m
Length PP (LPP)	174.50	m
Breadth (Bmld)	27.40	m
Depth (Dmld)	16.80	m
Draft (Design)	9.55	m
Draft (Scantling)	11.60	m
Deadweight (Design)	29,000	dwt
Deadweight (Scantling)	38,500	dwt
Main engine	MAN B&W 6S50MC-C	
MCR @ 127rpm	9,480	kW

Table 1: Ship main particulars.

Data from 4 vessels in the series (based upon data from DS NORDEN) indicates an average operation of 13 % in ECA (with a maximum of 17%).

Table 2 below provides information on the assumed number of operational days per year at sea and in port. In addition, for a certain percentage of time in ECA, the corresponding number of days in ECA is also shown.

Ship operation profile based upon 50 % ECA			
	Non ECA	ECA	Total
Days at sea	110	110	220
Days harbour, idling	57.5	57.5	115
Days harbour, unloading	15	15	30
Total	182.5	182.5	365

Table 2: Ship operation profile.

The average daily fuel consumption of the main engine and auxiliary engines when running on HFO or MGO is provided below in Table 3. The average fuel consumption is in the range of 60-70 % MCR.

ME consumption at sea		
HFO	28.7	t/day
MGO	27.0	t/day
AE consumption at sea		
HFO	3.7	t/day
MGO	3.5	t/day
AE consumption, harbour idling		
HFO	4.3	t/day
MGO	4.1	t/day
AE consumption, harbour unloading		
HFO	4.3	t/day
MGO	4.1	t/day

Table 3:Average fuel consumption.

4. FUEL SCENARIOS FOR OPERATION IN ECA

All scenarios considered in this study are based on a period of 10 years, spanning from 2015 to 2025. In view of the tentative date for the entry into force of the global sulphur cap of either 2020 or 2025, 2020 is considered as part of the base case, but also 2025 is considered for a number of cases in order to determine the sensitivity of investment decisions to this date.

Assuming the global sulphur cap enters into force in 2020, the base case scenario (shift to MGO in ECA) is shown in Table 4 below.

Base scenario: MGO				
	2015 - 2019		2020 - 2024	
	Non ECA	ECA	Non ECA	ECA
Consumption at sea (ME)	HFO	MGO	MGO	MGO
Consumption at sea (AE)	HFO	MGO	MGO	MGO
Consumption at port, idling (AE's)	HFO	MGO	MGO	MGO
Consumption at port, unloading (AE's)	HFO	MGO	MGO	MGO

Table 4: Base case fuel scenario.

In case the global sulphur cap enters in 2025, the MGO fuel scenario for 2020-2024 would change and be similar to the fuel scenario for 2015-2019.

The scenario for installing a scrubber system would entail running on HFO at all times for both the main engine and auxiliary engines as shown in Table 5.

Fuel scenario with Scrubber				
	2015 - 2019		2020 - 2024	
	Non ECA	ECA	Non ECA	ECA
Consumption at sea (ME)	HFO	HFO	HFO	HFO
Consumption at sea (AE)	HFO	HFO	HFO	HFO
Consumption at port, idling (AE's)	HFO	HFO	HFO	HFO
Consumption at port, unloading (AE's)	HFO	HFO	HFO	HFO

Table 5: Scrubber fuel scenario.

The scenario for enabling the use of LNG as fuel for the main engine depends on whether or not LNG is used only in ECA or also outside ECA. Due to limited tank capacity of the LNG tanks (total volume is 700 m3, externally placed on the main deck, see section 7), the range of the vessel when running on LNG is limited to around 4,500 nautical miles. The selection of 4,500 nautical miles is based upon an operation from Suez to the Baltic Sea.

If the vessel is on a trade where the distance between ports is less than this range, it is assumed that the vessel will run on LNG all the time and that LNG can be bunkered in the various ports of call. For comparison purposes analyses are also made for conditions where LNG would be used only inside ECA.

The LNG scenario for LNG used in both ECA and non-ECA is portrayed in Table 6 below, assuming the global sulphur cap as of 2020. In case LNG is used only inside ECA, MGO would be used for the main engine as of 2020 outside ECA.

Fuel scenario with LNG operation				
	2015 - 2019		2020 - 2024	
	Non ECA	ECA	Non ECA	ECA
Consumption at sea (ME)	HFO*	LNG	MGO/ LNG*	LNG
Consumption at sea (AE)	HFO	MGO	MGO	MGO
Consumption at port, idling (AE's)	HFO	MGO	MGO	MGO
Consumption at port, unloading (AE's)	HFO	MGO	MGO	MGO

Table 6: LNG operation fuel scenario.

** Selection of HFO/LNG will be based upon price and availability.*

A main factor determining the use of LNG is the fuel cost: if the LNG purchasing cost is less than HFO, then the main engine will run on LNG outside the ECA in the period 2015 – 2019, and if the cost of LNG is higher than HFO, then the vessel would run on the bunkered HFO under the same conditions (the retrofit solution has left the HFO tanks intact).

Different cost scenarios are considered for HFO, MGO and LNG.

HFO: 650 USD/t
HFO-MGO spread: +100 – +800 USD/t
LNG: 450, 550, 650 and 750 USD/t

In the financial analyses, it is assumed that whatever the selected price levels for the different fuels, they remain constant throughout the period 2015 - 2024. As mentioned in section 5 of the report, the cost difference between 0.1% and 0.5% sulphur is assumed to be negligible.

The cost of LNG will depend heavily on where it would be purchased as there is no global LNG market/pricing yet, and whether it is fixed relative to oil or gas price. Hence in view of the significant market uncertainties above, values should be considered only as indicative.

5. BASE CASE: SHIFT TO LOW SULPHUR FUEL (MGO)

The base case is defined as the reference tanker in original as-built condition; in case of operation in ECA, the vessel will shift to low sulphur fuel (MGO) in order to comply with the prevailing emission requirements. Low sulphur fuel referred to in this study comprises fuel with not more than 0.1% sulphur in the case of ECA operation as of 2015. In addition, it comprises fuel that will satisfy the global sulphur cap of 0.5% as of 2020 (or 2025). For simplicity reasons, all of these low sulphur fuels are referred to as 'MGO' (marine grade oil, i.e. distillates). The expectation is that the price difference between 0.1% and 0.5% sulphur fuel will be limited.

No major modifications are required in order to run on low sulphur fuel, but for extended operation on MGO, it will be necessary to install a fuel cooler to increase viscosity to a sufficient extent. The fuel cooler should have a capacity of between 25 kW and 50 kW and can be placed parallel to the fuel pre-heater of the main engine. The cost of such a cooler lies in the range of 30,000 – 50,000 USD. Attention must be paid to lubrication oil: depending on the duration of continued operation on MGO, it will be necessary to apply an appropriate type of system or cylinder oil for the main engine and auxiliary engines.

The total adaptation cost is considered negligible compared with the cost of purchasing MGO and is not taken into account in the financial analyses of the different scenarios when comparing with the option to fit a scrubber or to use LNG as fuel.

6. SCRUBBER SOLUTION

The exhaust gas scrubber system removes sulphur oxides and particulates from the exhaust gas. The scrubber system is a hybrid system being capable of operation both on fresh water and on sea water. The shift between these operation modes can be made as flying changeover while the scrubber is in operation controlled by GPS signal informing about the position of the vessel. In Figure 2, the working/installation principle is shown.

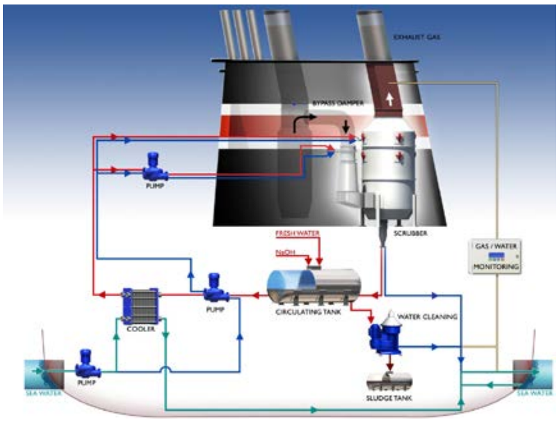

Figure 2: Scrubber installation principle.

The retrofitting of a scrubber system includes the following work onboard the ship.

Removal of the following equipment and structures:

- Funnel structure
- Deck platforms and ladder

- Exhaust gas pipes
- Free fall life boat

Installation of the following equipment and structures:

- Deck extension, pillars, ladder and platforms
- Sludge tank (internal structure tank)
- FW circulation tank
- NaOH compartment and tank
- Scrubber
- Free fall life boat
- Exhaust gas pipes, scrubber water pipes etc
- Funnel top structure
- Scrubber auxiliary machinery and pipe connections

Figure 3: Aft ship as originally built.

Figure 4: Aft ship with scrubber installed (notice enlarged funnel).

The additional fuel consumption of the auxiliary engines for operation of the scrubber including pumps is shown in Table 7. In case of ECA operation, the auxiliaries will run on MGO.

AE additional consumption		
HFO at sea	0.8	t/day
HFO harbour idling	0.2	t/day
HFO harbour unloading	0.4	t/day

Table 7: Additional fuel consumption - scrubber

The scrubber intended for NORD BUTTERFLY is designed for fully automatic operation and requires only minimal attention from the crew. In the event of a breakdown of the scrubber, the exhaust gas is sent through by-pass chimney until the scrubber is ready for operation again.

Normal operation of the scrubber system is done by means of a control panel placed in the engine control room. The scrubber can be operated in automatic mode or semi-automatic mode. When operating in auto mode, the ‘engines running’ signal starts the scrubber, and the signals from the ship’s Global Positioning System (GPS) determine whether the scrubber operates in seawater mode or freshwater mode in a predefined manner. Normally the engines fuel flow index determines the amount of sea water used in the scrubber and/or the caustic soda dosing to the system if in fresh water mode. The performance of the scrubber is measured continuously, and the adjustment of the different operational parameters is controlled accordingly.

According to the MEPC guidelines, the scrubber system will be supplied with manuals approved by the authorities, containing instruction in the proper use of the exhaust gas cleaning system and how to report the performance of the system to the authorities if demanded. The manuals in question is the SECA compliance plan, SCP-B, Onboard Monitoring Manual, OMM, and the EGC – SOx technical manual - scheme B, ETM-B.

These manuals provide the technical information to ensure proper operation and reporting of the Exhaust Gas Cleaning unit installed on board in order to comply with MARPOL Annex VI regulation 14.4. These manuals must be stored on board the ship for surveys.

Caustic Soda or sodium hydroxide solution is a strongly alkaline liquid, thus making it very important to follow the health and safety guidelines. Alkalis have a decomposing effect on proteins, and it may gradually penetrate the deep tissues unless the adhered alkali is completely removed. In particular, if the eyes are exposed to an alkali, since eye tissue is rapidly affected, causing a lowering or loss of vision, great care should be taken.

Operators that handle sodium hydroxide must be required to observe the operating standard for safe operations. For this, it is necessary to provide education and training concerning safe handling of alkalis.

The emissions from the scrubber system are carefully monitored and logged in order to comply with current regional legislation and demands of relevant classification society. The scrubber control system will alarm the operator of exceeding limits.

During the operation of the scrubber in fresh water mode, the water cleaning system will generate sludge. This sludge can be treated as other normal sludge from ships' engine rooms; however it is not allowed to incinerate it onboard the vessel. If the "normal" sludge is not incinerated onboard, the sludge from the scrubber water cleaning system can be mixed with this sludge and treated in the same manner, meaning delivered to the port waste reception facilities. The amount of sludge from the scrubber water cleaning system will amount to 2.5 liters/MWh engine outpu, which is around 10 % of the "normal" sludge. The sludge from the scrubber water will be 20% solid and 80% water.

The presented scrubber installation is based upon the experience gained by Alfa Laval – Aalborg on the scrubber installation onboard the Ro-Ro vessel FICARIA SEAWAYS (formerly TOR FICARIA) (a project which is also a part of the Green Ship of the Future collaboration). Today FICARIA SEAWAYS has logged more than 4,000 hours of operation with the scrubber installation and it is still working as designed and installed.

Thus the presented scrubber installation is expected to be technically feasible and should not introduce any major problems in installation and operation onboard the vessel. Naturally there will be a need for training of the crew with respect to operation and maintenance of the scrubber installation.

Lloyd's Register has prepared a conceptual design review of the proposed installation and found no show stoppers. A more detailed design should, however be prepared before any firm conclusions on the class review can be made.

7. LNG SOLUTION

Conversion of the existing 6S50MC-C engine to ME-GI dual fuel engine requires that the MC engine is first converted to a ME-B type engine with electronically controlled fuel injection. This requires installation of hydraulic equipment for the electronically controlled fuel injection system, and replacement of the camshaft for the exhaust gas valve actuation. Further details are provided in (4).

A further benefit of converting the MC-C engine to ME-B type engine includes improved specific fuel consumption during Tier II mode operation. During conversion of the MC-C to ME-B engine, the additional GI conversion can also take place simultaneously. This requires installation of new cylinder covers with gas valves and gas control blocks, with all ancillary piping, and the gas chain pipes to supply the engine with gas. Additional control systems and instrumentation are also required to fully convert the engine to ME-B-GI type engine.

The retrofitting of a LNG system is a major undertaking and includes the following work onboard the ship:

Removal of the following equipment and structures:

- Deck pipes and electrical cable pipes in area for LNG storage tank foundation and deck houses for LNG equipment
- Grating / platform in CL at A-deck in way of new LNG storage tank foundation

Installation of the following equipment and structures:

- Foundations for LNG storage tanks
- Deck houses for LNG equipment including foundation
- Rerouting / reinstallation of deck pipes, electrical cable pipes and pipe foundations
- New grating, platforms and ladders iwo of LNG storage tanks
- Foundations for new LNG pipe system
- Main engine conversion from MC-C to ME-GI
- Fuel gas supply system
- Block and bleed valve arrangement
- Gas piping system
- Ventilation system
- Inert gas system
- Sealing oil system
- LNG tank
- Fuel gas supply system
- LNG piping system and valves
- Auxiliary systems
- Safety equipment
- Instrumentation and control system

Figure 5: Aft ship with LNG tanks.

The fuel consumption in case of LNG application is provided in Table 8 below for the main and auxiliary engines, respectively.

ME consumption at sea	
HFO	21.9 t/day
MGO pilot fuel for LNG operation	1.4 t/day
AE additional consumption	
MGO	0.3 t/day

Table 8: ME LNG & MGO consumption at sea (Data has been corrected due to less burn value).

The most crucial aspect for the future success of LNG as a fuel is the implementation of, and adherence to, adequate safety standards. Both the technical and emotional aspects of safety must be fully addressed, to ensure all persons involved in LNG handling are equipped with the correct information and can respond in the correct manner. For technical safety aspects, unified standards and specifications can go some way in ensuring safe LNG operation. Harmonisation of standards both for LNG bunkering (ISO 28460), and for LNG as a fuel (IGF code), will ensure consistent safety standards for vessels operating with LNG.

On the emotional side, training of the crew in LNG handling and operation of LNG specific equipment is required, for example ME-GI training courses will be available, and equipment vendors will offer the same. Onshore staff will also require similar training, and in the case of LNG bunkering, the responsibilities of personnel must be clarified to ensure a safe process. A further issue is the public perception of LNG which is harder to address directly but nonetheless important to maintain that LNG is a safe alternative fuel.

Availability of LNG is also an important issue to consider when investigating such a conversion, and many projects are underway to develop LNG bunkering terminals at ports in the European ECA's. However should LNG not be available, the conversion of the main engine to ME-B-GI still allows for operation on conventional fuel oils. Full fuel flexibility provides operators with reduced risk with regard to fuel prices and availability without compromising engine performance.

Operating LNG tankers on LNG is not new. There are many years of experience in operating LNG tankers on the "Boil off gas" using steam turbines and Dual Fuel Diesel Electric (DFDE) engines. In this case, the vessel will operate on LNG fluid directly from a fuel tank, which has also been tested on smaller projects using the DFDE concept. The ME-B concept for the main engine is also proven technology, and the ME-GI concept, although developed, tested, and "In Principle" approved by class, is yet to be installed on a vessel. However, the GI technology is not new, so application of the ME-B-GI engine will not introduce any major technical challenges. Furthermore, installation of gas tanks and auxiliary equipment will be familiar to many shipyard and will smoothly facilitate vessel conversion.

Lloyd's Register has prepared a conceptual design review of the proposed installation and found no show stoppers. A more detailed design should, however be prepared before any firm conclusions on the class review can be made.

8. FINANCIAL ANALYSIS

In the following sections, the two retrofit alternatives to the base case are considered from a financial perspective. Based on the respective investment costs (CAPEX) and operating expenses (OPEX) of the retrofit options versus the added operational cost of the base case associated with the shift to MGO as required by the regulations, the net present value (NPV) and payback period are determined for opting for the scrubber or LNG solution instead of the base case. Hence the NPV and payback results are provided relative to the base case, i.e. if the NPV and payback are positive for a chosen alternative, then that solution could be financially more attractive than the base case under the selected circumstances.

To calculate the NPV and payback time, a discount rate of 9% is assumed and the savings period is 10 years (2015 – 2024). The NPV and payback results are presented as a function of fuel cost spread between MGO and HFO and as a function of percentage of operating time inside ECA's.

8.1. Scrubber solution

The CAPEX for the scrubber solution is based on the quotes from 3 shipyards.

CAPEX for scrubber installation	
Scrubber machinery and equipment	2,600,000 USD
Steel (150t) / pipe / electrical installations and modifications	2,400,000 USD
Design and classification cost	500,000 USD
Off-hire cost 20 days@17,000 USD/day	340,000 USD
TOTAL	**5,840,000 USD**

Table 9: CAPEX for scrubber installation.

Based on the given CAPEX and OPEX values, the NPV and payback period have been calculated. Figure 6 and Figure 7 show these values as a function of fuel cost spread and ECA percentage for the case with HFO costing USD 650 per tonne and the global sulphur cap entering into force in 2020. If the global cap was to enter into force in 2025 instead of 2020, the NPV would be reduced as HFO can continue to be burned throughout the whole period 2015 – 2024 outside the ECA. For comparison purposes, the payback time is shown in Figure 8 which illustrates the longer payback time in case of the 2025 date.

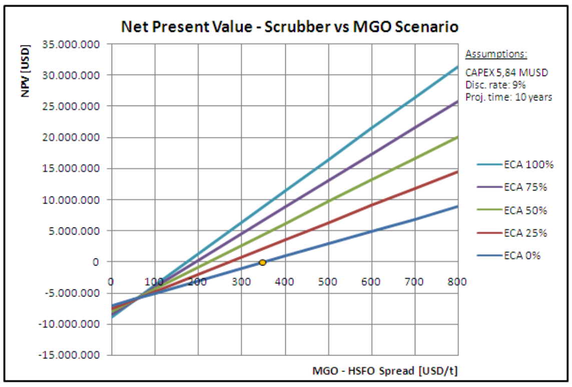

Figure 6: NPV for scrubber for HFO at USD 650/t, global sulphur cap in 2020.

Figure 7: Payback time for scrubber for HFO at USD 650/t, global sulphur cap in 2020.

Figure 8: Payback time for scrubber for HFO at USD 650/t, global sulphur cap in 2025.

From a financial perspective, the scrubber alternative is potentially attractive when the vessel would trade a reasonable amount of time inside ECA. The NPV and payback time are quite sensitive to the spread in fuel cost between HFO and MGO. For a cost spread of around 350 USD/t between HFO-MGO, the payback time is around 3 years for 100% ECA operation, a little over 4 years for 75% ECA, 6 years for 50% ECA and 8 years for 25% ECA operation (see Figure 7). If a payback time of at most 5 years would be considered acceptable, then the time spent inside ECA would have to be at least 75%; using this criterion in the case of 50% or less time spent inside ECA, it would be more attractive to shift to MGO.
For NORD BUTTERFLY with 13% ECA operation, the payback period will be approximately 9 years with a HFO-MGO spread of 350USD/t.

The high sensitivity of financial benefit to spread in fuel cost is illustrated in Figure 7. If the spread between HFO and MGO is 300 USD/t instead of 350 USD/t, the payback period increases from 3 to 4 years for the 100% ECA case and from 6 to 7 years for the 50% ECA case.

As shown in Figure 8, the payback numbers are similar if the global sulphur cap would enter into force in 2025 instead of 2020, provided the vessel would spend at least 75% of its time inside ECA; for a lesser percentage in ECA, the payback time is longer than for the 2020 date scenario.

It should be noted that the preceding figures apply to an assumed HFO cost of 650 USD/t. As one might expect the absolute HFO cost to have an influence on NPV and payback time, Figure 9 illustrates the sensitivity of the scrubber payback time to absolute cost of HFO for selected operation percentages in ECA and where a spread of USD 350 is taken between MGO and HFO.

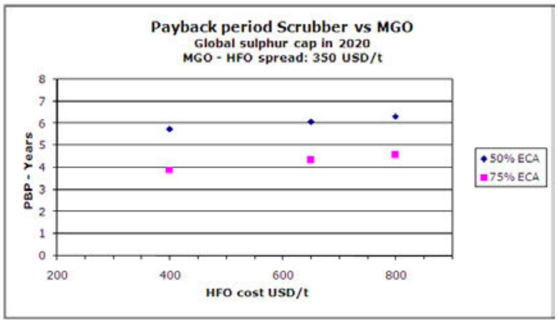

Figure 9: Payback period as a function of HFO cost, global sulphur cap in 2020.

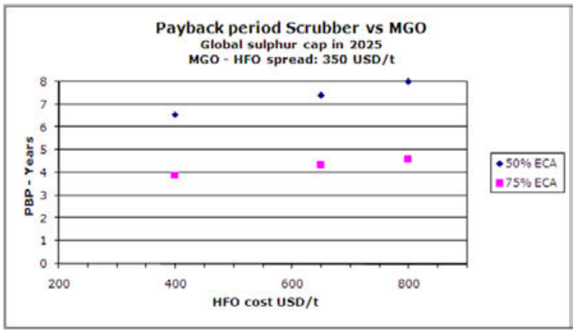

Figure 10: Payback period as a function of HFO cost, global sulphur cap in 2025.

Figure 9 suggests that the payback time of the scrubber option is not very sensitive to changes in absolute cost of HFO in the case of the global sulphur cap in 2020. For the global cap in 2025, the payback time is more sensitive to HFO cost level when the vessel operates 50% or less inside ECA's, see Figure 10.

The sensitivity of the payback time to changes in CAPEX of the scrubber installation is illustrated in Figure 11.

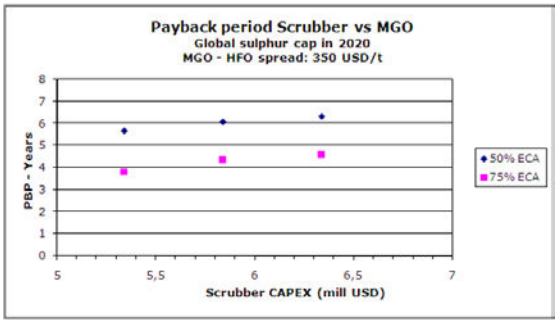

Figure 11: Payback time as a function of CAPEX

In Figure 11, a change in CAPEX of half a million dollars (around 10% of original amount) is shown to have limited influence (around 10% change) on the payback period compared to the sensibility of the HFO-MGO spread.

8.2. LNG solution

The following table (Table 16) shows the investment cost of the LNG conversion. The cost is estimated by the design team based upon equipment costs as steel weight.

CAPEX for LNG installation	
LNG machinery and equipment, main engine conversion	4,300,000 USD
Steel (300t)	2,000,000 USD
Design and classification cost	500,000 USD
Off-hire cost 40 days@17,000 USD/day	680,000 USD
TOTAL	**7,560,000 USD**

Figure 12: CAPEX LNG installation.

Based on the resulting CAPEX and OPEX values, the NPV and payback period have been calculated for different scenarios. Figure 13, Figure 14 and Figure 15 show these values as a function of fuel cost spread between MGO and HFO where the HFO cost is taken as USD 650/t and LNG at USD 550/t and global sulfur cap date is 2020. For comparison, Figure 15 shows the payback time values for the same conditions except that here it is assumed that LNG is burned only inside the ECA.

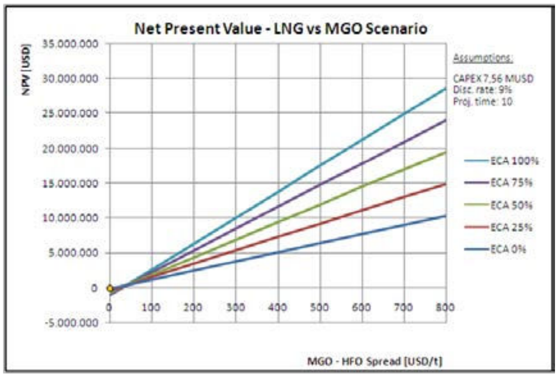

Figure 13: NPV for LNG alternative, operation on LNG inside and outside ECA after 2020; HFO cost USD 650/t, LNG cost USD 550/t, global sulphur cap in 2020.

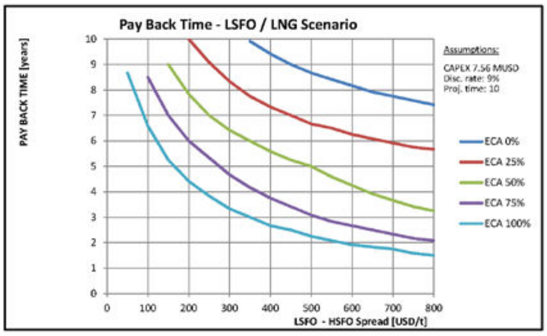

Figure 14: Payback period for LNG alternative, ***operation on LNG inside and outside ECA after 2020****; HFO cost USD 650/t, LNG cost USD 550/t, global sulphur cap in 2020.*

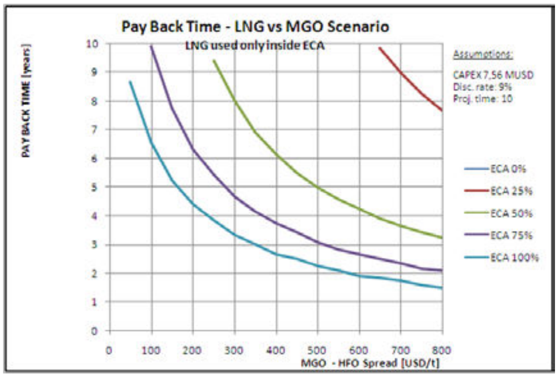

Figure 15: Payback period for LNG alternative, ***operation on LNG only inside ECA****; HFO cost USD 650/t, LNG cost USD 550/t, global sulphur cap in 2020.*

The financial benefit of the LNG alternative will depend on the spread between HFO and MGO, as illustrated in Figure 16, Figure 17 and Figure 18. If LNG would be used only as a fuel inside ECA, the payback time would so long that this option would be of interest only in case of a high percentage of ECA operation (exceeding 75%), see Figure 15, then the payback time are in the same order as for the scrubber for a cost spread of 350 USD/t between MGO and HFO and for a cost of 550 USD/t for LNG.

For NORD BUTTERFLY with only 13% ECA operation, the payback period will be very long (above 10 years) if LNG was only used inside ECA. If the LNG is used both inside and outside ECA after 2020, the payback period will be approximately 9 years assuming a HFO-MGO spread of 350 USD/t and a LNG price of 550 USD/t. If the ECA operation is 50% the payback time will be about 6 years.

To illustrate the sensitivity of the LNG alternative to the purchasing cost of LNG, Figure 16 shows the payback values as a function of LNG cost varying from 450 to 750 USD/t for two selected operational percentages inside ECA's.

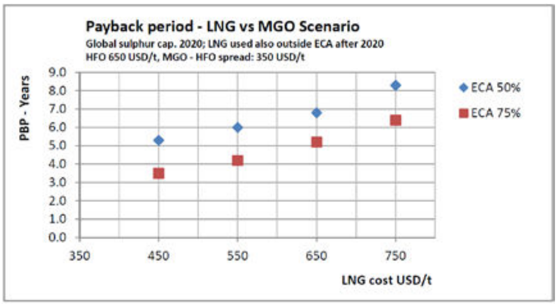

Figure 16: Payback time as a function of LNG cost.

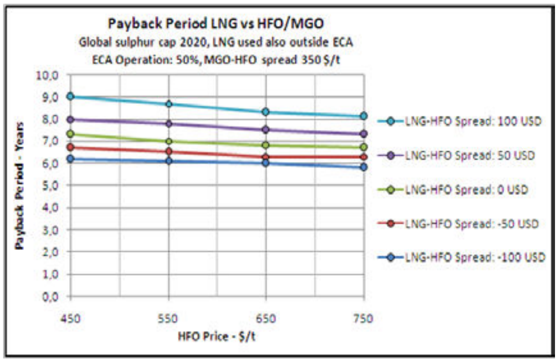

Figure 17: Payback time LNG vs. HFO/MGO.

A main driver for selecting the LNG alternative will be the cost of LNG. As illustrated in Figure 16 and Figure 17, the payback time is highly sensitive to LNG price under the assumed conditions: if LNG can be purchased at a cost that is 100 USD or 200 USD below that of HFO, the LNG alternative is financially attractive for ECA operation of at least 50%, assuming that a payback time of not more than 5-6 years is acceptable; if the LNG cost is comparable to HFO at 650 USD/t, the LNG option is attractive for ECA operation of at least 75%; if LNG is more expensive than HFO, the LNG option is interesting only for very high operational percentages inside ECA. Figure 17 also shows the high sensitivity to the LNG-HFO price spread increasing the payback period by 0.5-1 years by changing the LNG-HFO spread by 50 USD/t.

With regards to the installed engine model, this is an important issue for the conversion to LNG. Newer engine models with electronically controlled injection are cheaper (in the order of USD 800,000) to convert to LNG operation. However, a CAPEX study similar to the one for the scrubber solution has been conducted and also shows a payback period change of 0.5 years for a CAPEX change of 500.000 USD.

9. DISCUSSION

The choice of whether or not to retrofit a scrubber system or LNG plant on the chosen product tanker will depend on technical, operational and financial considerations. From a technical and operational perspective, the base case of shifting to a high grade, low sulphur fuel (MGO) to comply with future SOx regulations should not present any major issues, provided consideration is given to fuel cooling and proper lubrication oil for the main and auxiliary engines under prolonged operation; no other vessel modifications are necessary.

Concerning the alternative of installing a scrubber system, it is feasible from a technical perspective: there is sufficient space in the funnel area to place the main scrubber components and in the engine room for pumps and ducts. The main and auxiliary engines are connected to one main scrubber system, enabling the vessel to burn HFO at all times. It will be necessary to develop proper controls and operating procedures of the system when inside an ECA, depending on the relevant mode of operation (closed loop or open loop). In the case of closed loop operation, it will be necessary to ensure proper dosage of caustic soda and storage and removal of the resulting sludge. Based on estimates provided by some shipyards, the cost of retrofitting the scrubber system is approximately the same as for the equipment investment cost. There will be a modest increase in operational expenses due to required pumping power and caustic soda usage in case of closed-loop operation. It is expected that the system can run with a intervals between overhauls.

Concerning the option of converting to LNG as a fuel, a number of factors will influence the decision to select this option. From a technical perspective, the installation is feasible but quite complex, see under section 7. From an operational perspective, there are many additional issues to be considered, including: specially trained and qualified crew, LNG bunkering procedures, safety during operation and bunkering, bunkering locations, gas venting, limited maximum range when running on LNG, maintenance of system components.

10. CONCLUDING REMARKS

Firstly it can be concluded that it is possible to reduce or remove SOx by converting an existing tanker.

For NORD BUTTERFLY with 13% (maximum 17%) ECA operation, the payback periods will be long, and the most favourable from an economical point of view will be to switch to MGO when operating in ECA.

The payback period of the scrubber is primarily sensitive to the price spread between HFO and MGO and no less sensitive to CAPEX and the absolute HFO price. 100% and 50% ECA operation give a payback period of respectively 3 and 6 years, assuming an HFO-MGO spread of 350 USD/t. If the global sulphur cap is applied in 2025 the payback period will be increased by about 1.5 years.
The LNG solution is about 1.7mio. USD more expensive than the scrubber solution. If LNG is only used only inside ECA, the payback periods are long, expect for 100% ECA operation. If LNG is also used outside ECA after 2020, the business case become more interesting with a payback period of 3 years and 6 years for 100% and 50% ECA operation respectively, this assuming a HFO-MGO price spread of 350 USD/t and an absolute HFO price of 650 USD/t and LNG price of 550 USD/t. As for the scrubber solution the payback period most sensitive to the HFO-MGO spread. But it is also sensitive to the LNG price relative to HFO, and this price difference is very difficult to foresee as the LNG infrastructure is also fairly unknown. The LNG solution could be come more attractive if the main engine was originally an ME-engine, hence the MC to ME conversion of 800,000USD could be saved. The LNG solution could also be more attractive as a new building.

11. FUTURE ACTIVITIES

Since the start of the ECA project, new technology has arrived on the scene, and the use of methanol in a dual fuel engine and/or using DME (dimethyl ether) based upon onboard conversion of methanol looks to be another alternative.

In the coming period Green Ship of the Future work on implementing a comparison of the present solutions with both a methanol/dual fuel engine solution and a DME solution in the present study together with a group of partners.

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