GREEN SHIP OF THE FUTURE

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

Technical report

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Technical Report

"ECA Retrofit Technology"

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INDHOLD **SIDE**

1. Introduction

The International Maritime Organization (IMO) has decided that all vessels sailing in the Emission Control Areas (ECA) must reduce sulphur level in fuel oil to 0.1% or clean the exhaust gas to an equivalent level by 2015. The private-public Danish industry initiative Green Ship of the Future now launches a new study where a group of companies will work together on comparing various abatement technologies to fulfil the IMO decision. The objective of the project is to set up practical solutions as well as uncovering the financial aspects regarding installation, operation and maintenance of the three most realistic alternatives:

- Low-sulphur fuel/distillate
- LNG as fuel
- Scrubber technology

In the study, the use of low-sulphur fuel/distillate will function as reference case as to the feasibility of the other two investigated solutions. The alternative solutions will be evaluated by means of various scenarios considering operational profiles and fuel prices, and the evaluation will take into account that the vessel will be sailing in both ECA and non-ECA waters.

2. Objective

The objective of the study is to compare the 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 ECA 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.

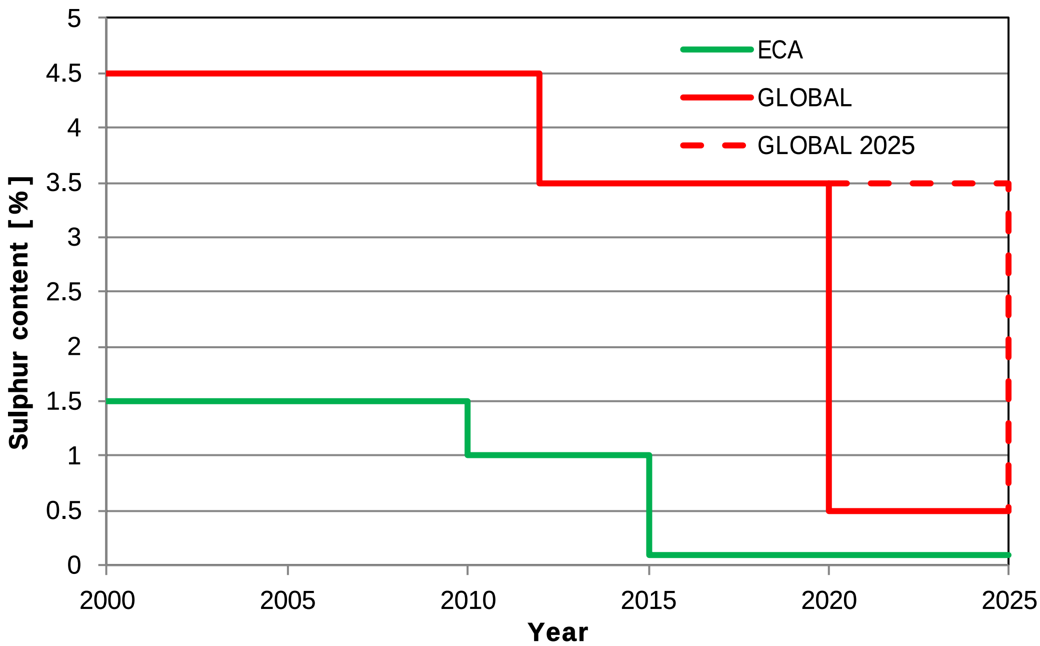

Figure 1 IMO regulation of SOx levels

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 regulations:

- Low-sulphur fuel (MGO) – Base case
- Scrubber technology while operating on HFO
- LNG operation

The study is based on an existing 38,500 DWT tanker vessel, NORD BUTTERFLY, from D/S NORDEN.

3. Partnership

The study has been performed by the following Danish companies which are all members of the Danish private-public initiative Green Ship of the Future:

- MAN Diesel & Turbo
- Alfa Laval – Aalborg (formerly Aalborg Industries)
- 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

Furthermore the project has received input and support from the shipyards Fayard A/S (Denmark), Motorenwerke Bremerhaven AG (Germany) and Guangzhou Shipyard International Co., Ltd. (China).

4. Reference vessel – MS NORD BUTTERFLY

The vessel chosen for this study is a 38,500 dwt product tanker. The vessel details have been provided by D/S NORDEN. The service speed at design draft including 15% sea margin is 14.0 knots. More details are provided in the tables 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

Table 1 Ship Main Particulars

Figure 2 MS NORD BUTTERFLY at anchor.

Installed Main Engine	
Supplier	MAN B&W
Model	6S50MC-C7.1 TI
Specified Maximum Continuous rating (SMCR)	9,480 kW @ 127.0 RPM
Normal Continuous rating (NCR)	8,058 kW @ 120.3 RPM

Table 2 Main engine data

Installed Auxiliary Engines	
Supplier	MAN B&W
Model	3 x 6L23/30H
Normal Continuous rating (NCR)	960kW @ 900 RPM
	910 KWe, 450V @ 60 Hz
SFOC (mechanical)	197 g/kWh +/- 5%
SFOC (electrical)	240 g/kWeh

Table 3 Auxiliary engines data

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 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 in 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 a fuel.

6. Operational assumptions

6.1 Ship operation and engine load profiles

Table 4 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.

It should be noted that the financial analyses have been carried out for a range of conditions varying from 0 to 100% operation in ECA.

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 4 Ship operation profile

Data from the reference vessels (based upon data from the ship owner) indicates an average operation of 13% in ECA (with a maximum of 17%).

The average daily fuel consumption of the main engine and auxiliary engines (based upon operational data provided by the ship owner) is provided below in Table 5 when running on HFO or MGO. 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	12.7	t/day
MGO	11.9	t/day

Table 5 Average Fuel consumption - base case

6.2 Operation in ECA, fuel options and global sulphur cap

All scenarios considered in this study are for 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 so as 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 6 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 6 Base case scenario

The scenario for alternative 1, which consists of installing a scrubber system, would entail running on HFO at all times for both the main engine and auxiliary engines as shown in Table 7.

Alternative 1: Scrubber operation				
	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 7 Alternative 1 Scrubber operation

The scenario for alternative 2, 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 m^3, externally placed on the main deck, see section 5 of this report), 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 route 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 done 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 8 below assuming the global sulphur cap as of 2020. In case of LNG used only inside ECA, MGO would be used for the main engine as of 2020 outside ECA.

Alternative 2: LNG operation				
	2015 - 2019		2020 - 2024	
	Non ECA	ECA	Non ECA	ECA
Consumption at sea (ME)	LNG/HFO*	LNG	LNG	LNG
Consumption at sea (AE)	HFO	MGO	MGO	MGO
Consumption at harbour, idling (AE)	HFO	MGO	MGO	MGO
Consumption at harbour, unloading (AE)	HFO	MGO	MGO	MGO

Table 8 Alternative 2 – LNG operation (Selection of LNG/HFO 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 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).

If the global sulphur cap enters into force in 2025 instead of in 2020, then the base case (shift to MGO) scenario is given in Table 9. In the case of the scrubber alternative, the scrubber installation would be used only in ECA throughout the whole period 2015-2024.

Base scenario: MGO, global cap in 2025				
	2015 - 2019		2020 - 2024	
	Non ECA	ECA	Non ECA	ECA
Consumption at sea (ME)	HFO	MGO	HFO	MGO
Consumption at sea (AE)	HFO	MGO	HFO	MGO
Consumption at port, idling (AE's)	HFO	MGO	HFO	MGO
Consumption at port, unloading (AE's)	HFO	MGO	HFO	MGO

Table 9 Base Scenario – MGO, Global cap in 2025

6.3 Fuel cost scenarios

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

HFO: 650 USD per tonne

MGO - HFO: 100 – 800 USD per tonne additional cost for MGO compared with HFO

LNG: 450 USD, 550 USD, 650 USD and 750 USD per tonne

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 also 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.

7. Technical Solutions

7.1 Solution A - Scrubber installation

7.1.1 Design Basis - Working principle PureSOx Scrubber

The exhaust gas scrubber system removes sulphur oxides and particulates from exhaust gas. The scrubber system is a hybrid system being capable of operation both on fresh water as well as sea water. The shift between these operation modes can be made as flying change-over while the scrubber is in operation controlled by a GPS signal informing about the position of the vessel.

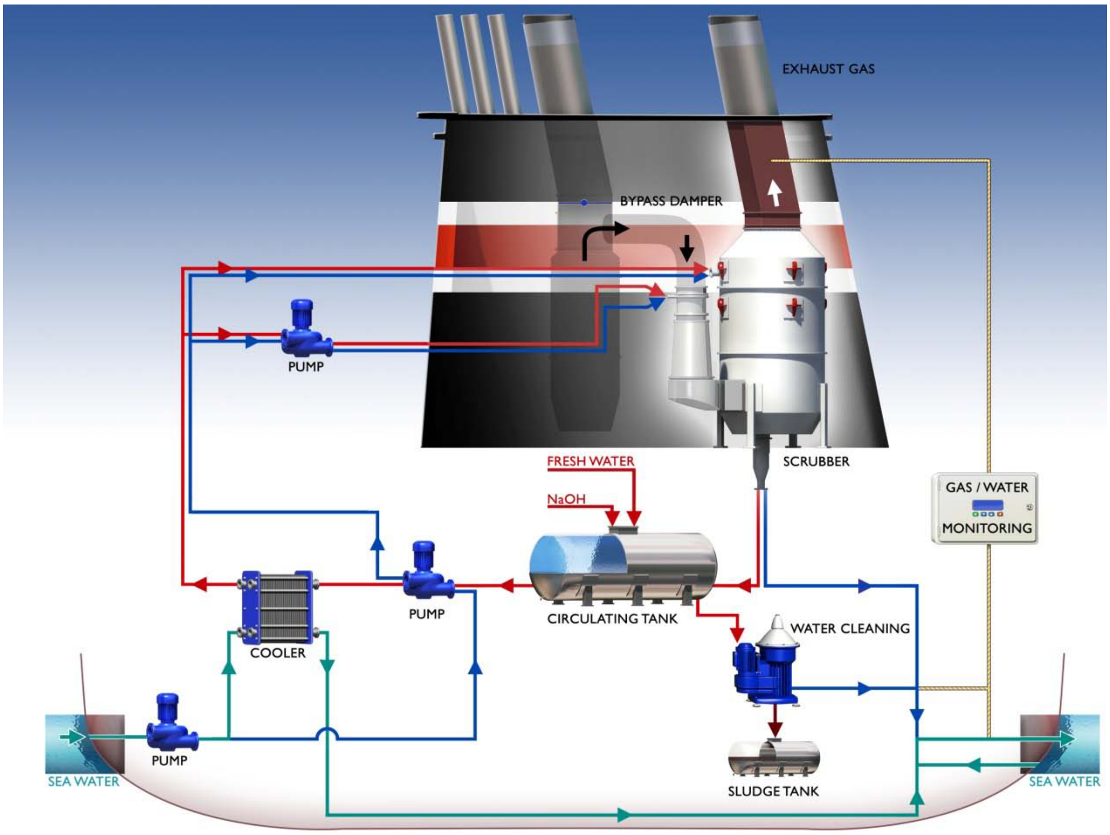

Figure 3 Scrubber installation principle

The scrubber consists of two sections – the jet scrubber and the packed tower. The jet scrubber is the inlet to the scrubber, and in this section of the scrubber the initial cooling and cleaning of the exhaust gas takes place before the exhaust gas enters the packed tower.

The cooled exhaust gas will be cleaned in a packed tower filled with high-efficient/low-resistance packing material. This packing material has an open structure which prevents flooding under all loading conditions. On the other hand, the open structure has a large, wet surface ensuring a high efficiency in SO_2 and particulate removal.

The water used for scrubbing is supplied via spray pipes to guarantee a perfect distribution under all conditions including the ship's motions.

The exhaust gas leaves the scrubber with 100% R.H. Before leaving the scrubber, water droplets in the exhaust gas are separated by a demister. The demister efficiency is important to ensure a minimum of water loss, especially during fresh water operation, and to limit the content of water in the plume after the funnel. The demister will be cleaned regularly to avoid soot build-up and excessive pressure drop. Inspection openings are installed for reasons of maintenance and inspection.

Dimensions / weights of the scrubber		
Length	6.8	m
Width	5.3	m
Height	8.7	m
Weight operational	15	ton

Table 10 Dimensions/weight of scrubber

The system includes a circulation tank for freshwater mode. This tank is needed for degassing the water and acts as a buffer tank for fresh water to fill up the water piping with fresh water after operation on sea water. Furthermore, NaOH is added in this tank.

While in fresh water mode, the cleaning water will be circulated in the system in a closed loop. In this mode, the cleaning water will be cooled in a plate heat exchanger. The reason for cooling the water is to limit the loss of water as cold water in the scrubber will ensure that water from the combustion of the oil will condensate in the scrubber. The water in the fresh water operation mode will be cleaned in a separator, and sludge and clean water are generated. The separated sludge from the water cleaning unit can go to the ship's sludge tank for delivery to shore. A part of the cleaned water will be fed back to the circulation tank, and the other part will be discharged directly overboard as its quality is within the MEPC guidelines.

As more engines are connected to the scrubber, precautions are made to avoid exhaust gas in standby engines. If an engine is not in operation, the exhaust gas supply to the jet scrubber is blocked by a double valve with a compressed air sealing system. Then the standby engine is effectively protected from exhaust gasses from the engines in operation.

The control panel contains all the equipment for controlling and adjusting the exhaust gas scrubber unit. All failure messages/communication etc. are integrated in a touch screen PLC installed on the front door of the control panel. In case of a failure, the direct cause of the failure will be made visible by changing colour or by an alarm sign on the screen. In case of failure or if an emergency bottom is activated, the exhaust gas scrubber will shut down automatically, and the by-pass damper will open without stopping the engine. After elimination of the failure, the exhaust gas scrubber can be restarted while the relevant failure extinguishes of the screen.

The exhaust gas scrubber monitoring and data logging system complies with the MEPC regulations. As the rules require, the system logs SO_2, CO_2, pH, PAH and turbidity data as well as stamping the GPS position. All this data will be logged every 30 sec/1 min.
The logged data is recorded on a PC and a sent by email once a day to various recipients.

Operational information		
Max amount exhaust gas	92,000	kg/h
Exhaust gas pressure drop	100	mmWc
SOx Removal efficiency	Equivalent to 0.1% S in fuel oil	
Salinity of sea water	1300	µmol/l

Table 11 Operational information

7.1.2 Conversion

The retrofitting of a scrubber system includes the following work on board the ship:

Removal of the following equipment and structures:
- Funnel structure from D-deck and upwards
- B-deck platform aft of funnel (4.7m symmetrical about CL), incl. ladders
- C-deck platform aft of funnel (4.7m symmetrical about CL), incl. ladders
- D-deck platform aft of funnel (4.7m symmetrical about CL), incl. ladders
- Exhaust gas pipes from D-deck and upwards (excluded the pipe for oil fired boiler)
- Exhaust gas pipes for A/E from C-deck to D-deck
- Free fall life boat

Installation of the following equipment and structures:
- B-deck extension, pillars, ladder and platforms
- Sludge tank (internal structure tank)
- FW circulation tank
- NaOH compartment and tank
- C-deck extension, pillars, ladder and platforms
- Scrubber
- D-deck extension, ladder and platforms
- Free fall life boat
- Exhaust gas pipes, scrubber water pipes etc
- Funnel top structure
- Scrubber auxiliary machinery and pipe connections
- 440 V, 220 V, 24 V Electrical and automation installation

Figure 4 Aftship as originally built

A design package [1] sufficient to obtain prices for the conversion has been developed. The design is based on input from the ship owner, scrubber manufacturer, engine manufacturer and various other vendors.

The design package contains a breakdown of steel, outfitting, components, pipes etc. necessary for the conversion.

Figure 5 Aftship with scrubber installed (notice the enlarged funnel)

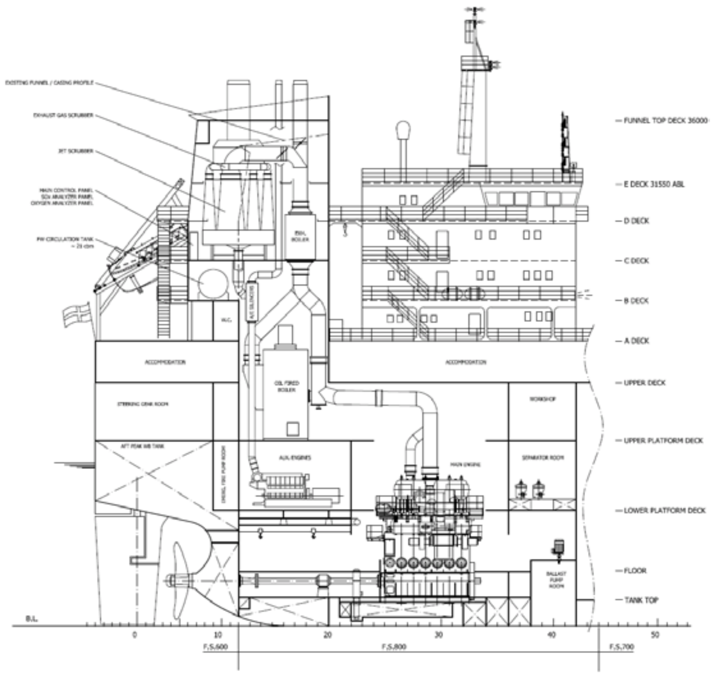

Figure 6 Scrubber installation

7.1.3 Operational issues

The additional fuel consumption of the auxiliary engines for operation of the scrubber including pumps, respectively, is shown in Table 12. In case of ECA operation, the auxiliaries will run on MGO.

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

Table 12 Additional fuel consumption – scrubber solution

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 using 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' signals starts the scrubber, and the signals from the ship's Global Positioning System (GPS) determines 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 NaOH 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 are 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

Caustic Soda or sodium hydroxide solution is a highly alkaline liquid, thus making it very important to follow the health and safety guidelines. Alkalis have a decomposing effect on proteins which 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 should be required to observe the operating standard for safe operations. For this, it is necessary to provide education and training concerning:

- The characteristics, level of hazard, and methods of handling of sodium hydroxide.
- The location of protectors, showers, eye washers, water taps, cleaning hoses, and first aid facilities
- Proper method for the use of protectors and first aid facilities
- First aid measures to be taken in case of an emergency
- Proper usage of the first aid facilities
- Measures to be taken in the case of a chemical injury.

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.

Sludge generated during water cleaning

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 on board the vessel. If the "normal" sludge is not incinerated on board, 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 output which is around 10% of the "normal" sludge. The sludge from the scrubber water will be 20% solid and 80% water.

7.1.4 Technical feasibility of the Scrubber installation

The presented scrubber installation is based upon the experience gained by Alfa Laval – Aalborg on the scrubber installation on board the Ro-Ro vessel FICARIA SEAWAYS (formerly TOR FICARIA) (a project which also is a part of the Green Ship of the Future collaboration). FICARIA SEAWAYS has today logged more than 4,000 hours of operation with the scrubber installation and it is today working as designed and installed. The operation has mainly been on open loop operation with limited closed loop operation. There have been some modifications made based upon observations during the initial operation of the scrubber system.

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

7.1.5 Class review of scrubber solution

Partner in the project Lloyd's Register has prepared a preliminary review (3) of the proposed installation and has given the following feedback to the designers:

Based on the above, it is our opinion that the described scrubber retrofit would be feasible and technically sound. However, there are several points which require consideration for a final design:

- IMO Resolution MEPC.184(59) Scheme B compliance shall be demonstrated by continuous monitoring of the exhaust gas by means of a monitoring system approved by the Administration. Where wash water from the EGC is discharged the condition of the discharged water shall be monitored for pH, polycyclic aromatic hydrocarbons (PAH) and turbidity, and remain within stated limits. The values shall be logged.
- Lloyd's Register will issue "Exhaust Gas Abatement Rules" with specific requirements for scrubbers next year. A draft of these new rules will be available 03.2012.
- A common scrubber for several engines is a new design. This needs to be tested in order to demonstrate that the different back pressures can be correctly balanced in all power ratings and engine configurations.
- The proposed integral NaOH tank on the B-Deck needs to be carefully considered with respect to overflow protection, containment and handling of any chemical leakage.
- Material used for ship's piping systems to be specially considered
- It is assumed that the scrubber sea water intake has no negative effect on the ships cooling system performance and that it is accepted by the engine manufacturer.
- Power supply and power management necessary for operation of the scrubber to be separately considered.
- Final approval of the proposed scrubber is subject to a risk assessment of the complete system being approved and when all systems have been installed and tested to the satisfaction of the attending Surveyor.
- For the vessel in question the influence on the stability aspects (intact and damage) have not been evaluated in details. It is assumed that the impact of the conversion will not have a significant impact on the stability compliance thus operability of the vessel. On other ship types/sizes a conversion with a scrubber this may have some more impact on the stability aspects and would therefore have to be addressed in details on an early stage of the project.

7.2 Solution B – LNG propulsion

7.2.1 Design basis

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 the more detailed report (ref 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 is also required to fully convert the engine to ME-B-GI type engine.

7.2.2 Conversion into LNG propulsion

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

Removal of the following equipment and structures:

- Deck pipes and electrical cable pipes in an 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:

General

- 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
- Foundations for new LNG pipe system

MAN Diesel Turbo (based upon detailed report [(4)])

- 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

TGE (based upon detailed report [(5)])

- LNG tank
- Fuel gas supply system
- LNG piping system and valves
- Auxiliary systems
- Safety equipment
- Instrumentation and control system

A design package (2) sufficient to obtain prices for the conversion has been developed. The design is based upon input from the ship owner, engine manufacturer, LNG equipment and various other vendors.

The design package contains a breakdown of steel, outfitting, components, pipes etc. necessary for the conversion.

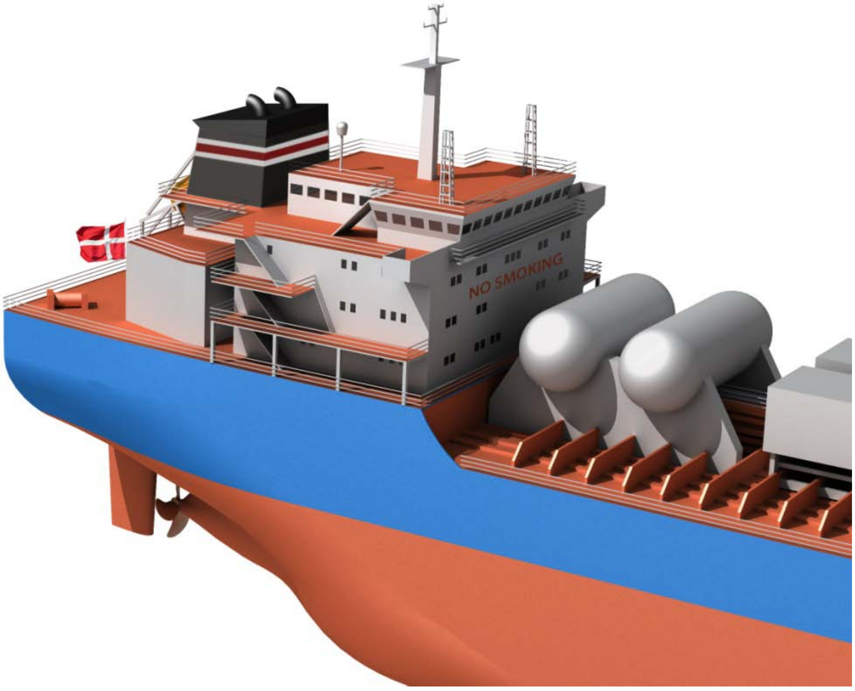

Figure 7 Aftship with LNG tanks seen from the side

Figure 8 Aftship with LNG tanks seen from the stern

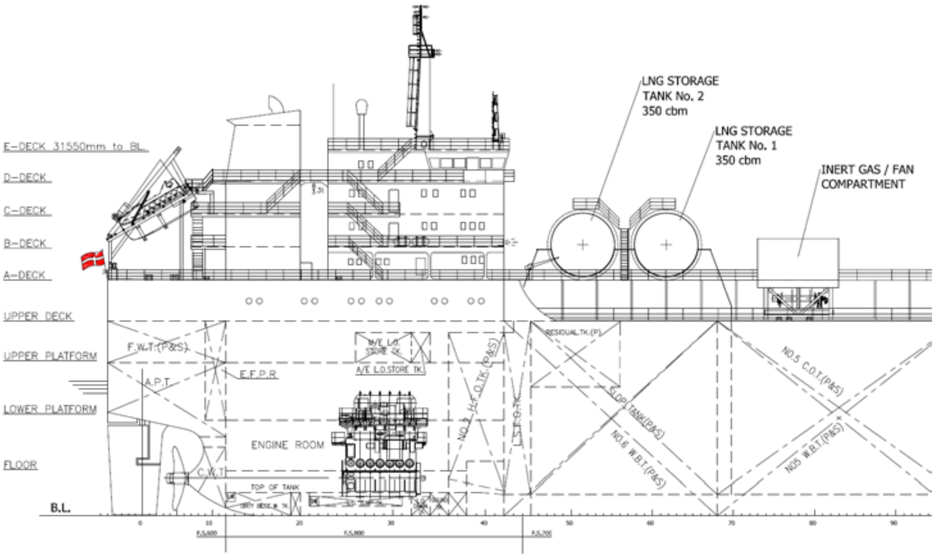

Figure 9 LNG tank arrangement and engine room

7.2.3 Operational issues

The fuel consumption in case of LNG application is provided in Table 13 and Table 14 below for the main and auxiliary engines, respectively.

ME consumption at sea		
LNG	21.9	t/day
MGO pilot fuel for LNG operation	1.4	t/day

Table 13 ME LNG & MGO consumption at sea (Data has been corrected due to less burn value)

AE additional consumption, LNG equipment		
MGO	0.3	t/day

Table 14 AE MGO consumption at sea

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 ther case of LNG bunkering, 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.

7.2.4 Technical feasibility of the LNG solution

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, a concept 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 shipyards and will smoothly facilitate vessel conversion.

7.2.5 Class review of LNG solution

Partner in the project Lloyd's Rister has prepared a preliminary review (3) of the proposed LNG installation and has given the following feedback to the ship owner and designers:

In case that the Owner wishes to proceed with the design of the LNG retrofit installation, a number of subjects need to be addressed and a much more detailed design and documentation work including risk analysis is to be carried out.

However, based on the above conceptual design review, no major and unsolvable problems has been identified at this stage and therefore, it is concluded that the project is feasible from a regulative point of view.

New rules and regulations from IMO as well as Lloyd's Register are underway and are expected to be implemented in the coming years, i.e. the IMO rules and regulations (the new IGF Code) are expected to enter into force in 2015/16 and the Lloyd's Register Rules for the Classification of Natural Gas Fuelled Ships are expected to enter into force in 2012.

The IMO IGF Code will be much more detailed than the current IMO interim guidelines and will therefore be addressing more topics to be considered. Consequently, further pending issues may arise during the detailed design. But it is not foreseen to give major problem for the present design proposal.

For the vessel in question the influence on the stability aspects (intact and damage) have not been evaluated in details. It is assumed that the impact of the conversion will not have a significant impact on the stability compliance thus operability of the vessel. On other ship types/sizes a conversion with a LNG as fuel this may have some more impact on the stability aspects and would therefore have to be addressed in details on an early stage of the project.

8. Financial analysis of retrofit options

8.1 General comment

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.

8.2 Scrubber alternative

The investment cost is shown in Table 15 below:

CAPEX SCRUBBER Installation								
Scrubber machinery and equipment							2,600,000	USD
Steel (150t) / pipe / electrical installations and modifications							2,400,000	USD
Design cost & Classification costs							500,000	USD
Off-Hire Cost (Installation time)	Off-Hire:	20	days	Rate:	17,000	USD	340,000	USD
Total							**5,840,000**	**USD**

Table 15 CAPEX Scrubber installation

Conversion prices were obtained from three shipyards (FAYARD (Denmark), MWB (Germany) and GSI (China)) and quite interestingly the spread in cost was minimal.

Based on the given CAPEX and OPEX values, the NPV and payback period have been calculated.

Figure 10 and Figure 11 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 will be reduced as HFO can continue to be burned throughout the whole period 2015 – 2024 outside ECA. For comparison purposes, the payback time is shown in Figure 12, which illustrates the longer payback time in case of the 2025 date.

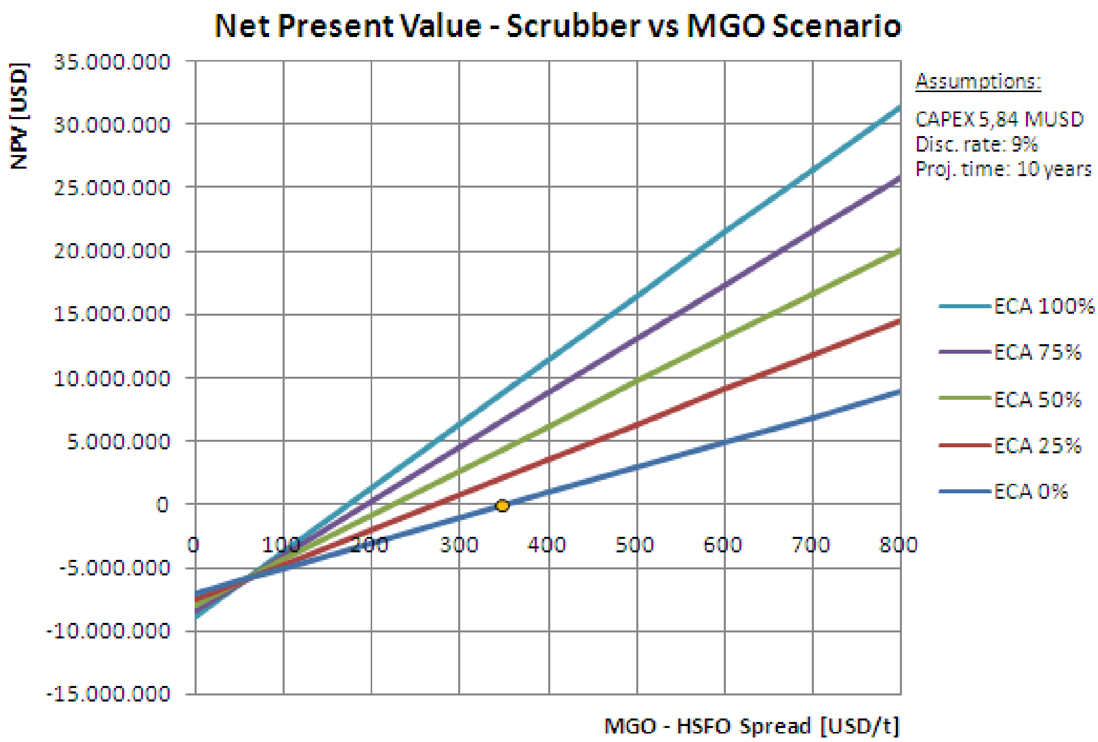

Figure 10 NPV for scrubber for HFO at USD 650/t, global sulphur cap in 2020

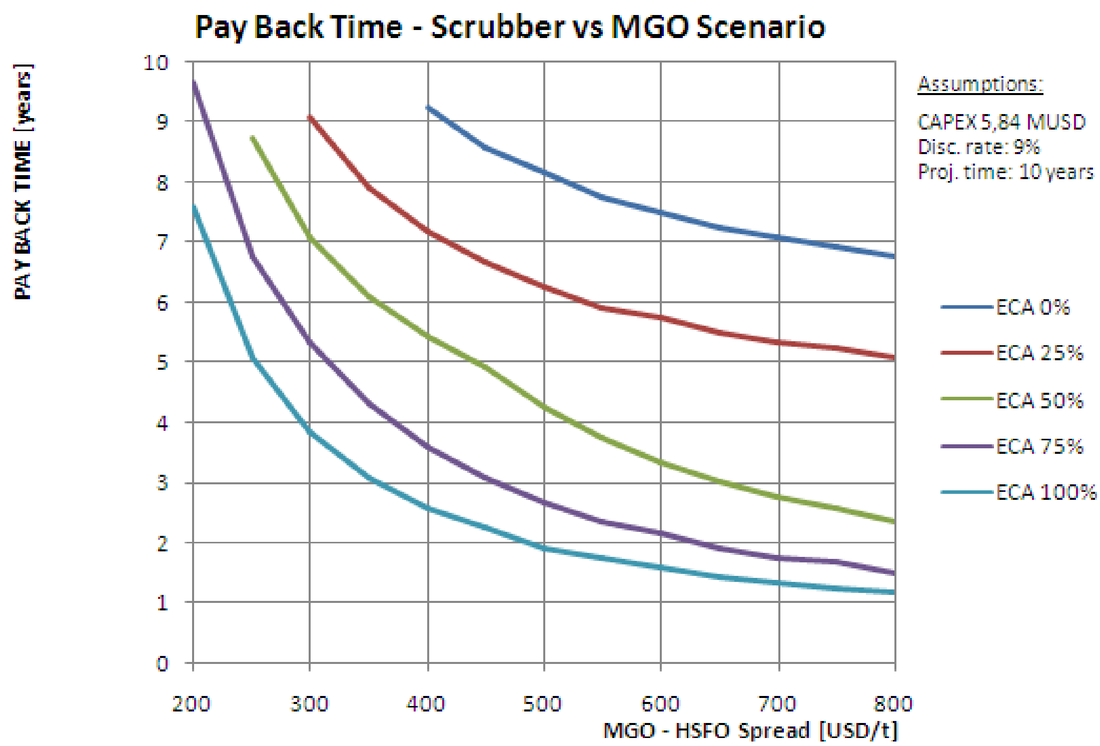

Figure 11 Payback time for scrubber for HFO at USD 650/t, global sulphur cap in 2020

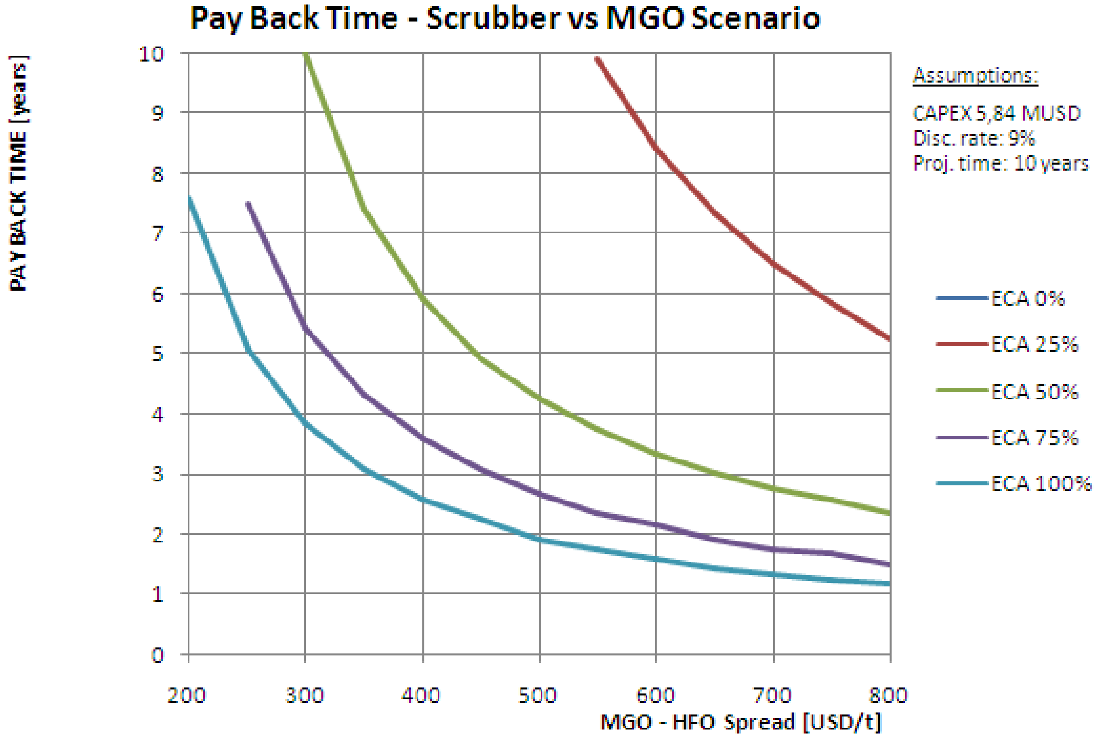

Figure 12 Payback for scrubber for HFO at USD 650/t, global sulphur cap in 2025

It is clear that the spread between MGO and HFO costs has an important effect on the financial values. It should be noted that the preceding figures apply to an assumed HFO cost of USD 650 per tonne. As one might expect the absolute HFO cost to have an influence on NPV and payback time, Figure 13 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.

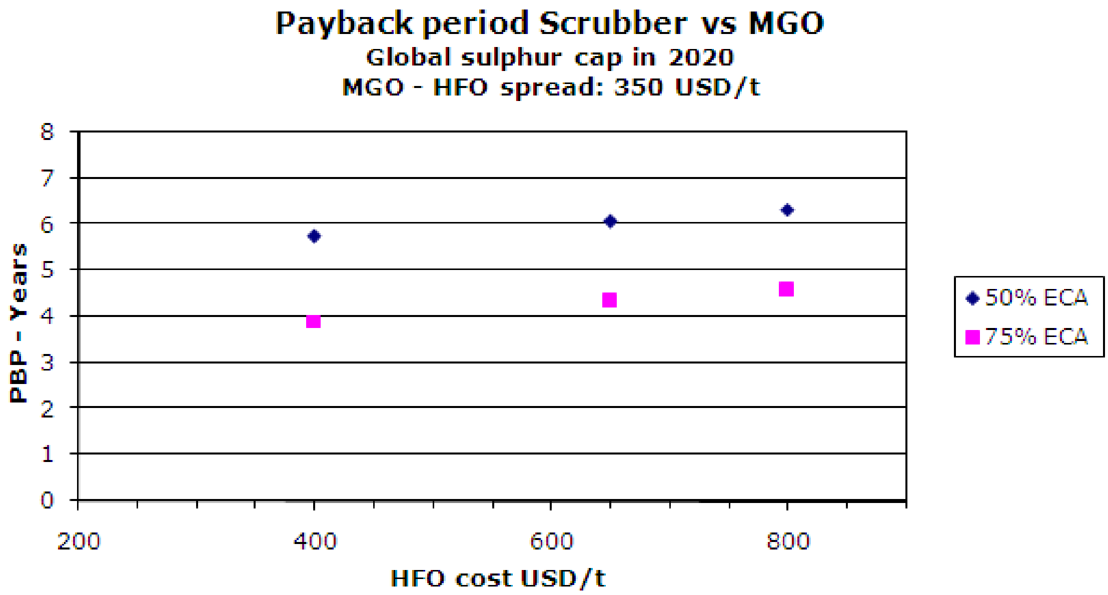

Figure 13 Payback time as a function of HFO cost, global sulphur cap in 2020

Figure 14 shows the same information as Figure 13, except that here the global sulphur cap would apply as of 2025. Whereas the payback time for 75% ECA operation happens to be the same for both dates, the corresponding NPV is lower in the case of the 2025 sulphur cap.

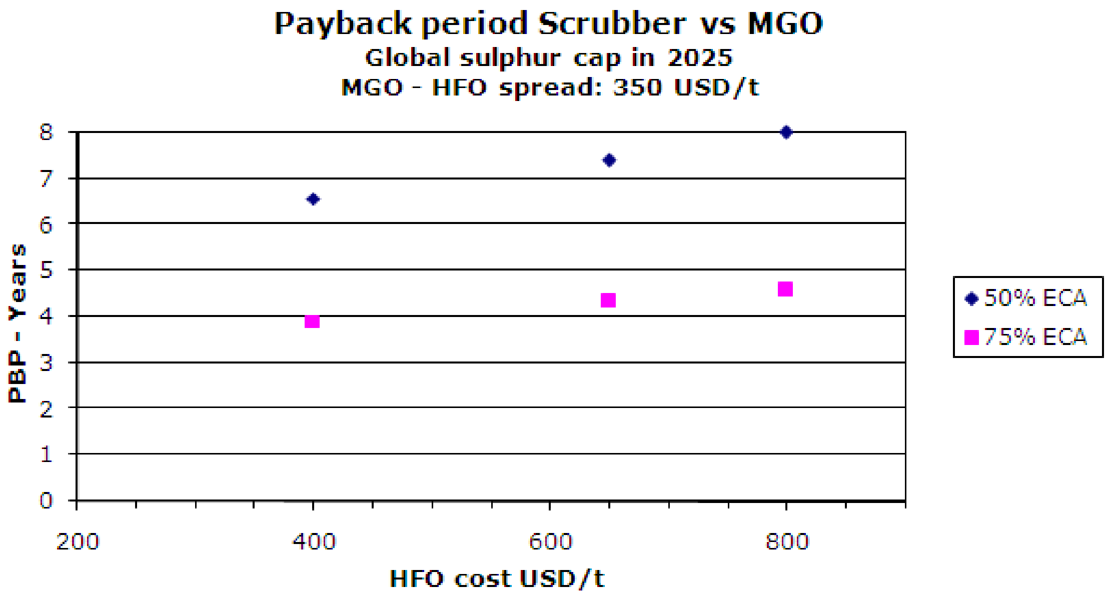

Figure 14 Payback time as a function of HFO cost, global sulphur cap in 2025

The sensitivity of the payback time to changes in CAPEX of the scrubber installation is illustrated in Figure 15.

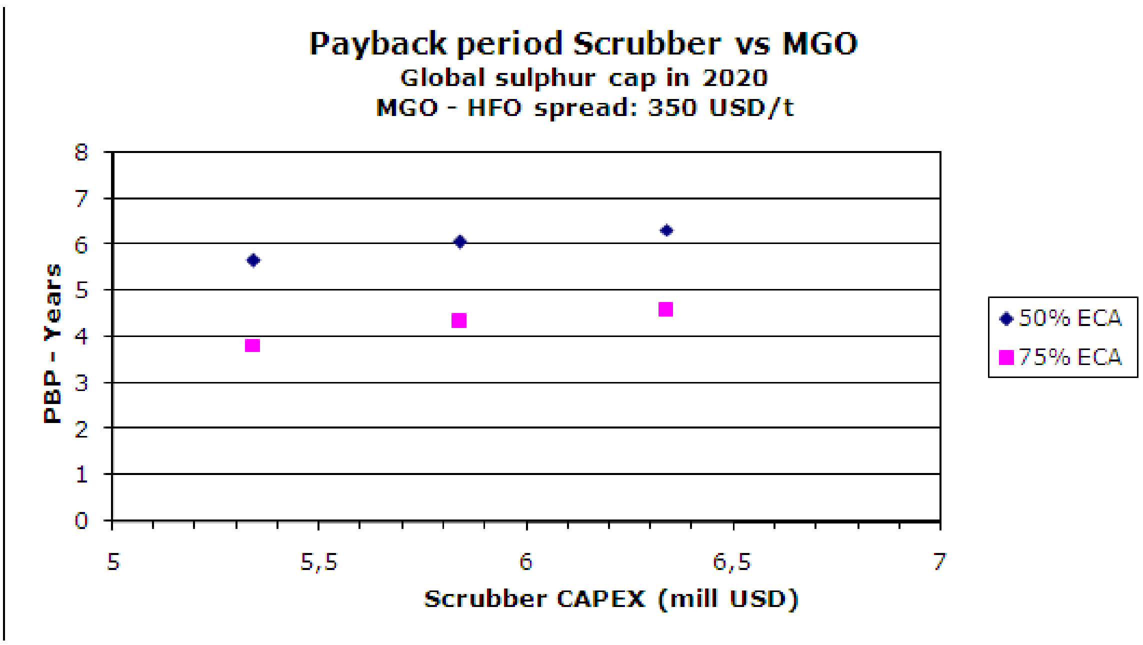

Figure 15 Payback time as a function of CAPEX

8.3 LNG alternative

The following table (Table 16) shows the investment cost of the LNG conversion.

CAPEX LNG Installation								
LNG machinery and equipment, main engine conversion							4,380,000	USD
Steel (300t)							2,000,000	USD
Design & classification costs							500,000	USD
Off-Hire Cost (Installation time)	Off-Hire:	40	days	Rate:	17,000	USD	680,000	USD
Total							**7,560,000**	**USD**

Table 16 CAPEX LNG installation

The cost is estimated by the design team based upon equipment costs as steel weight.

Based on the resulting CAPEX and OPEX values, the NPV and payback period have been calculated for different scenarios. Figure 16 and Figure 17 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 purposes, Figure 18 shows the payback time values for the same conditions, except that here it is assumed that LNG is burned only inside ECA.

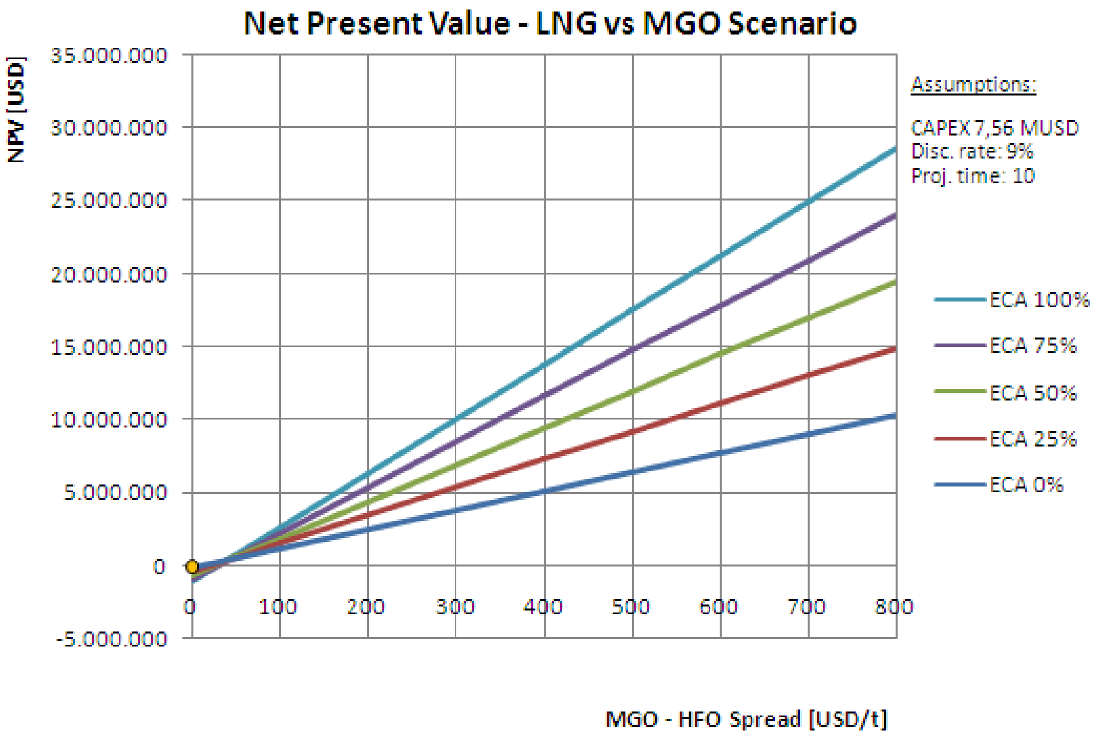

Figure 16 NPV for LNG alternative, operation on LNG inside and outside ECA; HFO cost USD 650/t, LNG cost USD 550/t, global sulphur cap in 2020

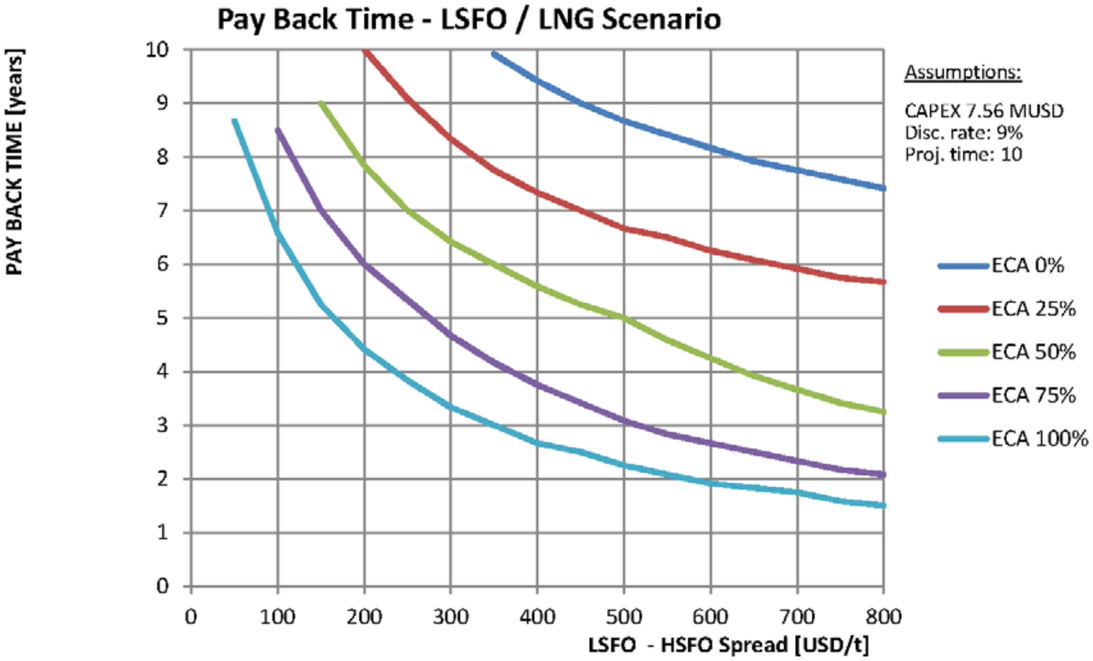

*Figure 17 Payback period for LNG alternative, **operation on LNG inside and outside ECA**; HFO cost USD 650/t, LNG cost USD 550/t, global sulphur cap in 2020*

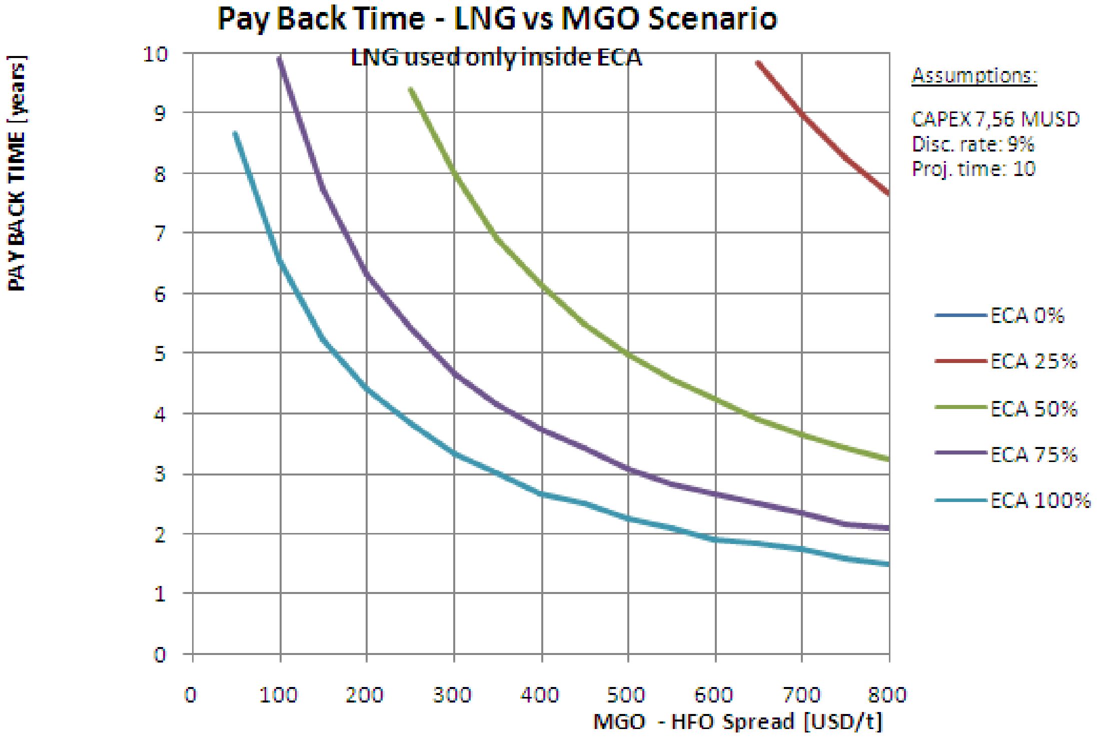

*Figure 18 Payback period for LNG alternative, **operation on LNG only inside ECA**; HFO cost USD 650/t, LNG cost USD 550/t, global sulphur cap in 2020*

To illustrate the sensitivity of the LNG alternative to the purchasing cost of LNG, Figure 19 shows the payback values as a function of LNG cost varying from USD 450 to 750/t for two selected operational percentages inside ECA's. Similary, the effect on payback periods for different LNG-HFO spreads are investigated in
Figure 20.

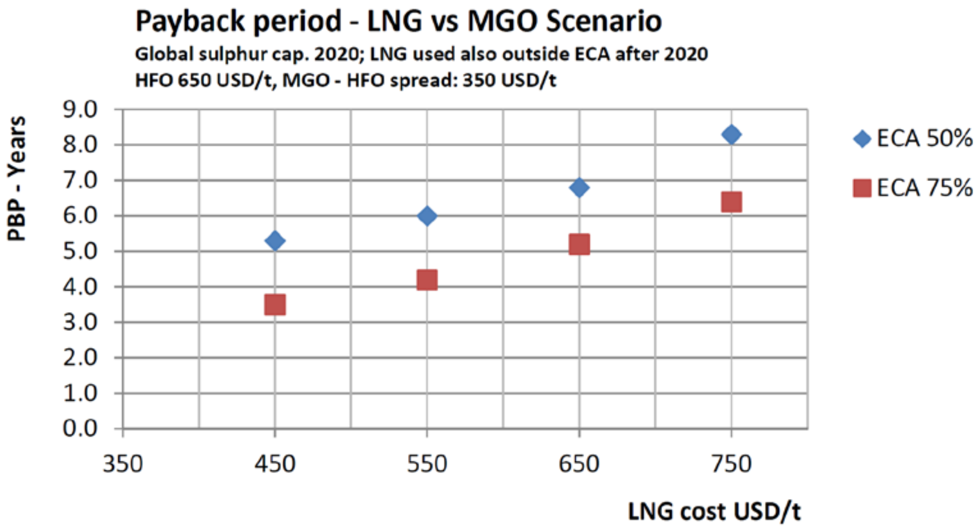

Figure 19 Payback time as a function of LNG cost

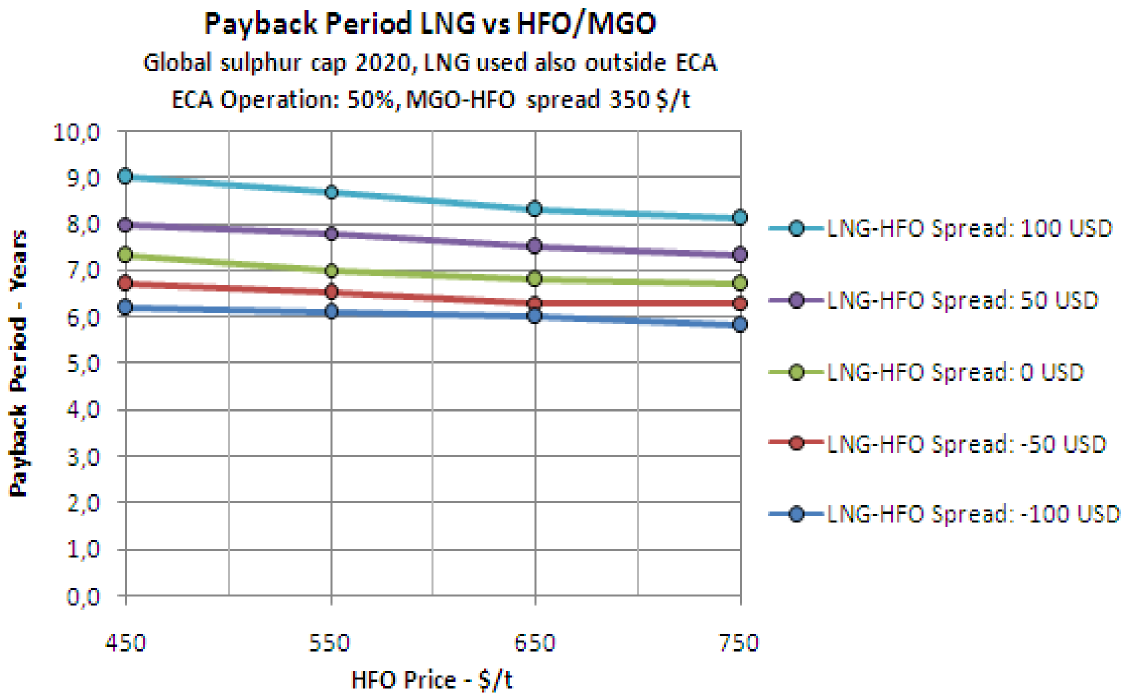

Figure 20 Payback time LNG vs. HFO/MGO

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 due 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 long time between overhauls.

From a financial perspective, the scrubber alternative is potentially attractive when the vessel would operate 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 differential of around USD 350 per tonne, 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 11). 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.

As shown in Figure 12, 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.

The high sensitivity of financial benefit to spread in fuel cost is illustrated in Figure 12 if the spread between HFO and MGO is USD 300 instead of USD 350 per tonne, the payback period increases from 3 to 4 years for the 100% ECA case and from 8 to 10 years for the 50% ECA case.

Figure 13 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 14. A change in CAPEX of half a million dollars (around 10% of original amount) has a limited influence (around 10% change) on the payback period, as illustrated in Figure 15.

Concerning the option of converting to LNG as a fuel, there are a number of factors that will influence the decision to select this option. From a technical perspective, the installation is feasible but quite complex, see section 7 of this report. 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.

Another main driver for selecting the LNG alternative will be the cost of LNG. As illustrated in Figure 19 and Figure 20, the payback time is highly sensitive to the LNG price under the assumed conditions: if LNG can be purchased at a cost that is USD 100 or USD 200 less than HFO, then the LNG alternative is financially attractive for ECA operation of at least 50%, assuming that a payback time of not more than 5 years is acceptable; if the LNG cost is comparable to HFO at USD 650/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.

In addition, 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, then the payback time would be of such long duration that this option would be of interest only in case of a high percentage ECA operation (exceeding 75%), see Figure 18. For a cost spread of USD 350 between MGO and HFO and for a cost of USD 550/t for LNG, the NPV and payback time are of the same order as for the scrubber alternative.

With regard 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.

10. Conclusions

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 USD 1.7mio. more expensive than the scrubber solution. If LNG is only used only inside ECA, the payback periods are long except for 100% ECA operation. If LNG is also used outside ECA after 2020, the business case becomes 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 is 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 become more attractive if the main engine was originally an ME-engine, hence the MC to ME conversion of USD 800,000 could be saved. The LNG solution could also be more attractive as a new building.

11. Future Work

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 on board conversion of methanol might become 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.

12. Acknowledgement

Green ship of the Future wishes to thank the Danish Maritime Fund for financial support to partly fund this project. Furthermore, Green Ship of the Future wants to thank the Maritime industry in Denmark for the encouragement and support in both the present project and in all our work towards greener shipping.

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