GREEN SHIP
OF THE FUTURE

ECA retrofit study

Comparison of various abatement technologies
to meet emission levels for ECA's

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About Green Ship of the Future

Vision

Green Ship of the Future is an open private-public partnership in which the Danish maritime community joins forces in order to explore, develop and demonstrate ambitious technical solutions for cleaner, more energy-efficient and sustainable ships and maritime operations.

Approach

This is done by using technical developments and innovations for new and existing ships. As an integrated part of the initiative, we wish to implement and evaluate technical solutions in order to push green innovation and thinking within the maritime industry – and doing so with an eye on the commercial feasibility connected to the industry.

The main focus areas

Ship design, machinery, propulsion, operation and logistics.

Since its foundation in 2008, Green Ship of the Future has carried through three major studies:

- A low emission container carrier study
- A low emission bulk carrier study
- The ECA retrofit study

The next study, a low emission Ro/Pax study, is already in progress and will be finalised by the end of 2012. Alle the studies have been supported by the Danish Maritime Fund.

Problem, objective and partners

The International Maritime Organization (IMO) has decided that all vessels sailing in the Emission Controlled Areas (ECA) must reduce sulphur level in fuel oil to 0.1% or clean the exhaust gas to an equivalent level by 2015 and globally in 2020 (with a sulphur content in the fuel of 0.5%). As a response to this challenge, the private Danish industry initiative Green Ship of the Future has performed a study in which a group of companies has worked together on comparing various abatement technogies in order to fulfil the IMO decision.

The objective of the study was to set up practical solutions as well as uncovering the financial aspects regarding installation, operation and maintenance of the two most realistic alternatives:

- LNG as fuel
- Scrubber technology

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

The study is based on an existing 38,500 TDW tanker vessel, NORD BUTTERFLY, from D/S NORDEN which presently operates 13% in ECA.

Participants in the study

The group consists of Alfa Laval – Aalborg (formerly Aalborg Industries), D/S NORDEN, Danish Shipowners' Association, Elland Engineering, Lloyd's Register, Maersk Maritime Technology, Maersk Tankers, MAN Diesel & Turbo, Schmidt Maritime and with the Green Ship of the Future secretariat as coordinators. The study has been jointly funded by the Danish Maritime Fund and the participating companies. Furthermore, the study has received input and support from the shipyards Fayard A/S (Denmark), Motorenwerke Bremerhaven AG (Germany) and Guangzhou Shipyard International Co., Ltd. (China).

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. For simplicity reasons, all of these low sulphur fuels are referred to as 'MGO' (marine Gas Oil, i.e. distillates). In the study, it is assumed 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 for the particular vessel 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 a fuel.

Scrubber solution

Design basis

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

The scrubber is designed sufficiently large and designed with a pump capacity so it can operate in low alkalinity waters as in the northern part of the Baltic Sea with a sea water alkalinity as low as 1.3 mmol/l where the normal sea water alkalinity is approximately 2.3 mmol/l. This feature enables the scrubber to operate in longer periods of time on sea water instead of using the more expensive fresh water mode where it is necessary to add caustic soda to the process.

Operational issues

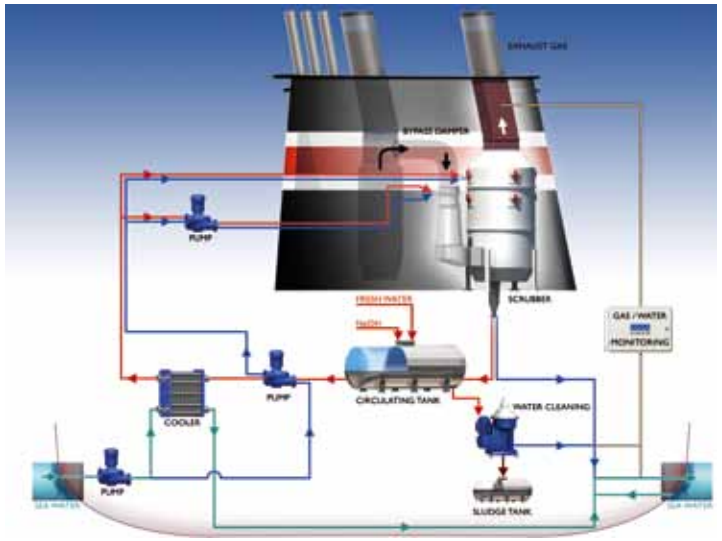
The presented scrubber installation is based upon the experience gained by Alfa Laval – Aalborg on the scrubber instal - lation onboard the Ro-Ro vessel FICARIA SEAWAYS (formerly TOR FICARIA), which is also a project developed within the Green Ship of the Future collaboration.

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.

The performance of the scrubber is measured continuously, and the adjustment of the different operational parameters is controlled accordingly. Normally the engine's 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. 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 output, which is around 10% of the "normal" sludge. The sludge from the scrubber water will be 20% solid and 80% water.

Technical feasibility

The presented scrubber installation is expected to be technically feasible and should not present 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.



Principal sketch of the scrubber solution

LNG solution

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.

A further benefit of converting the MC-C engine to ME-B type engine includes improved 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.

Operational issues

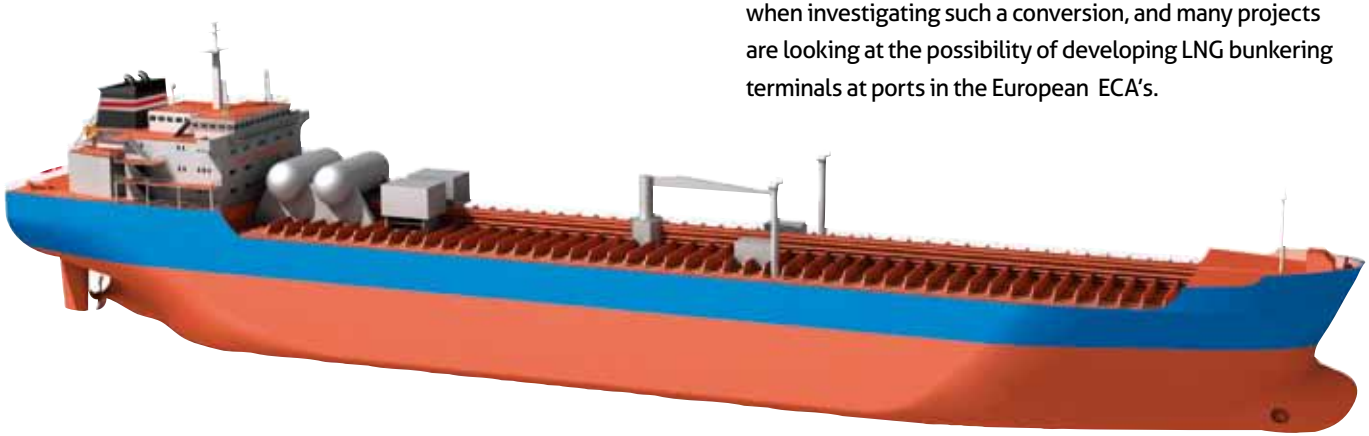
The most crucial aspect for the future success of LNG as a fuel is the implementation of, and adherence to, adequate safety standards. Both the technical and emotional aspects of safety must be fully addressed to ensure all persons involved in LNG handling are equipped with the correct information and 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 TC 67), and for LNG as a fuel (IMO IGF code), will ensure consistent safety standards for vessels operating with LNG.

Availability of LNG is also an important issue to consider when investigating such a conversion, and many projects are looking at the possibility of developing LNG bunkering terminals at ports in the European ECA's.

However, should LNG not be available, the conversion of the main engine to ME-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.

Technical feasibility

Operating LNG tankers on LNG is not new. For many years LNG tankers has been able to operate on the "boil off gas" using steam turbines and Dual Fuel Diesel Electric (DFDE) engines. In this case, the vessel will operate on LNG directly from a fuel tank. 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.



NORD BUTTERFLY equipped with the LNG solution

Financial analysis of retrofit options

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 the scrubber as well as the 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 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 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.

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

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

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

The scenario for alternative 1, installing a scrubber system, would entail running on HFO at all times for both the main engine and auxiliary engines is shown.

Alternative 2: LNG operation

	2015 - 2019		2020 - 2024	
	Non ECA	ECA	Non ECA	ECA
Consumption at sea (ME)	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

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

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.

Scrubber solution

Installing a scrubber system is feasible from a technical perspective as 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, storage and removal of the resulting sludge. Based on estimates provided by different 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.

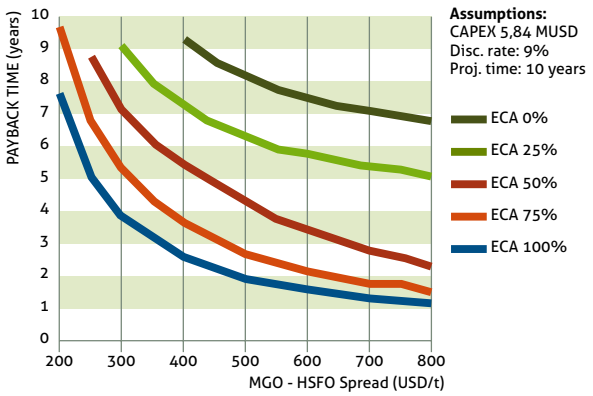
From a financial perspective, the scrubber alternative is potentially attractive when the vessel would trade a reasonable amount of time inside ECA. The NPV and payback time are quite sensitive to the spread in fuel cost between HFO and MGO. For a cost differential of around 350 USD/t, the payback time 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. 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.

The high sensitivity of financial benefit to spread in fuel cost is illustrated in the figure below. 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 8 to 10 years for the 50% ECA case.

Assuming a spread of 350 USD/t between MGO and HFO the payback time is around 3 years at 100% ECA operation. At 50% ECA operation: payback time is approx 6 years. If a 3 year payback time is desired, then the MGO-HFO spread would have to be 650 USD/t.

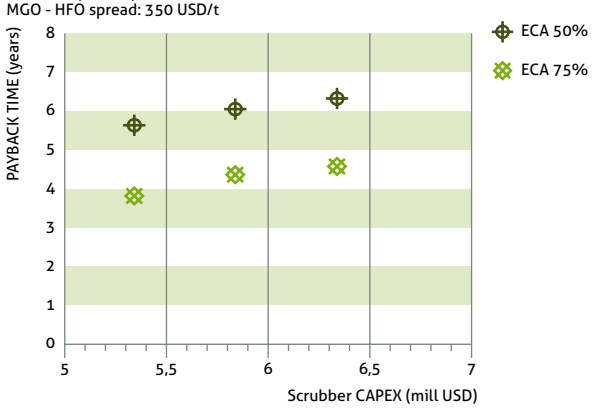
For NORD BUTTERFLY with 13% ECA operation the payback time is approx. 9 years with a spread of 350 USD/t between MGO and HFO.

Payback time - Scrubber vs MGO Scenario



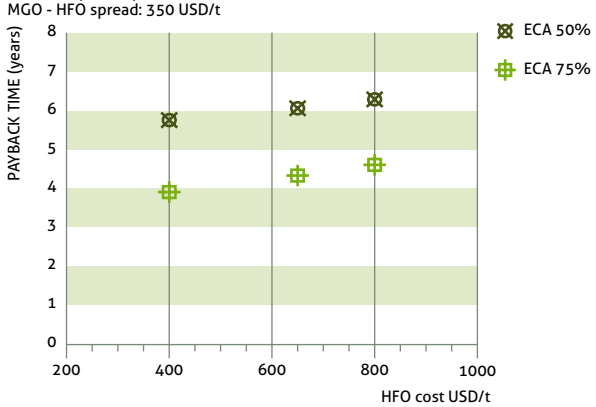
Payback time for scrubber for HFO at USD 650/t, global sulphur cap in 2020.

Payback time - Scrubber vs MGO
Global sulphur cap. in 2020
MGO - HFO spread: 350 USD/t



Sensitivity of payback time to variation in CAPEX by ±500,000 USD assuming MGO-HFO.

Payback time - Scrubber vs MGO
Global sulphur cap. in 2020
MGO - HFO spread: 350 USD/t



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

LNG solution

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. 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 and maintenance of system components.

Another main driver for selecting the LNG alternative will be the cost of LNG. The payback time is very sensitive to the LNG price under the assumed conditions. If LNG can be purchased at a cost of USD 100 or 200 less than HFO, 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.

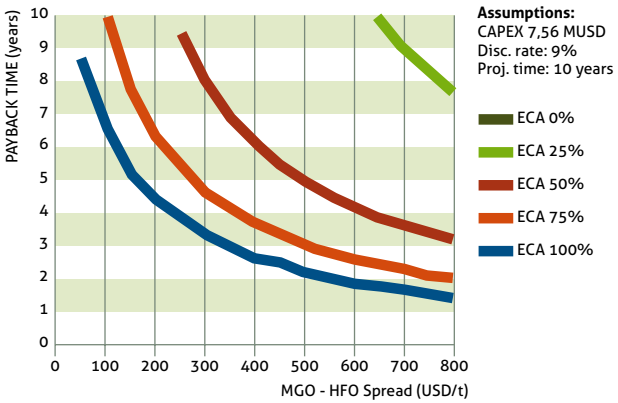
LNG only ECA:

For a spread of 350 USD/t between MGO and HFO and a LNG price of 100 USD/t less than HFO, the payback time is around 3 years for 100% ECA operation.

At 50% ECA operation: Payback time is approximately 7 years. If a 5 year payback time is desired, then the MGO-HFO spread would have to be 500 USD/t.

For NORD BUTTERFLY with 13% ECA operation, the payback time would exceed 10 years.

Payback time - LNG vs MGO Scenario



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

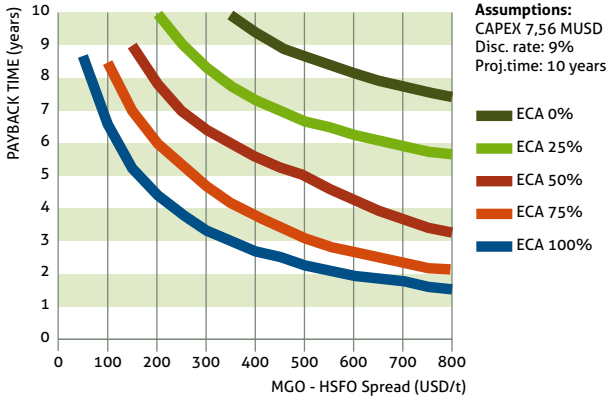
LNG both ECA and outside:

For a spread of 350 USD/t between MGO and HFO price of 100 USD/t less than HFO, the payback time is around 3 years for 100% ECA operation.

For 50% ECA operation and 350 USD/t spread between MGO and HFO: Payback time is approx 6.0 years.

For NORD BUTTERFLY with 13% ECA operation, the payback time would be approx 8.8 years with 350 USD/t spread between MGO and HFO.

Payback time - LNG vs MGO Scenario

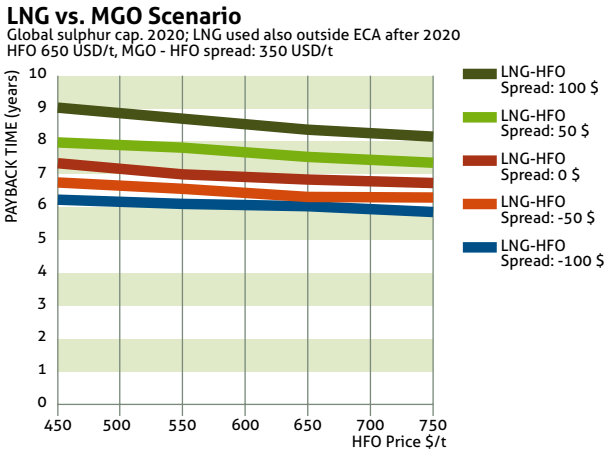


*Payback time for LNG alternative, operation on LNG **inside ECA and outside ECA after 2020**; HFO cost USD 650/t, LNG cost USD 550/t, global sulphur cap in 2020.*

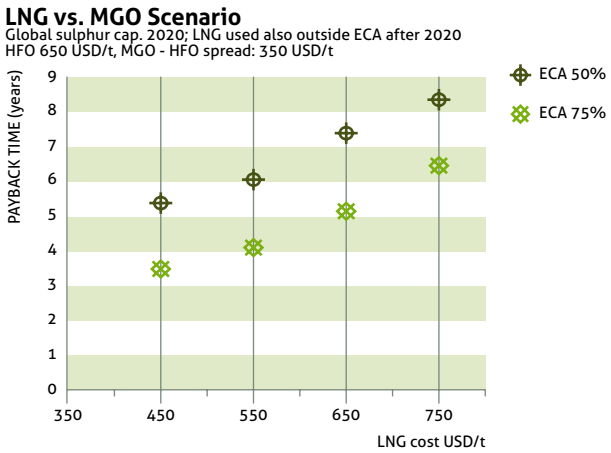
LNG solution continued

In addition the financial benefit of the LNG alternative will depend on the spread between HFO and MGO. If LNG was to be used only as a fuel inside ECA, then the payback time would be of such length that this option would be of interest only in case of a high percentage of ECA operation (exceeding 75%). 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, thereby reducing the CAPEX and shortening the payback period.



LNG payback time as a function of HFO cost.



LNG cost has been varied assuming a fixed HFO cost and spread with MGO:

- *If LNG cost would be the same as MGO (1,000 USD/t) the payback time will be around 10 years at 75% ECA operation.*
- *If LNG would be half of MGO (i.e. 500 USD/t) payback time is around 3-4 years at 75% ECA operation.*

Conclusion and future work

Conclusion

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

For NORD BUTTERFLY with 13 % 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 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 used only inside ECA, the payback periods are long, except for 100% ECA operation. If LNG is also used outside ECA, the business case become more interesting with a payback period of 3 years and 4.5 years for 100% and 50% ECA operation respectively, 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 800,000USD could be saved. The LNG solution could also be more attractive as a new building.

Future Activities

Since the start of the ECA project, new technology has arrived, 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 works 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.

Acknowledgements

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For further information, please visit our website www.greenship.org.

The Danish Maritime Fund

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