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LNG CONVERSION AND JUMBOISATION APPLIED TO VERY LARGE CONTAINER VESSELS

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CONVERSION AU GNL COMBINE A UN ALLONGEMENT DU NAVIRE
POUR LES TRES GRANDS PORTE-CONTENEURS

Afin de répondre aux exigences toujours plus strictes de l'Organisation maritime internationale (OMI), les armateurs devront trouver des solutions pour réduire les émissions de gaz à effet de serre (GES) de leurs navires, en particulier leurs émissions de CO2.

Une des solutions envisagées est de convertir une partie de la flotte existante à la propulsion au GNL. Ce type d'opération est long et coûteux, c'est pourquoi GTT, expert technologique des systèmes de confinement à membranes, Alwena Shipping, société de conseil et d'ingénierie navale, et le chantier naval COSCO Shipping Heavy Industry (Zhoushan) Co., Ltd (CHI Zhoushan), ont décidé de développer une solution alternative : la conversion au GNL combinée à un allongement du navire, également appelé " Jumboisation ".

L'allongement du navire combiné à l'opération de conversion au GNL du système de propulsion et de génération électrique à bord, permettent de réduire les coûts d'exploitation du navire, tout en limitant l'impact financier lié à la période d'immobilisation nécessaire pour la modification du navire.

La propulsion au GNL offre aux armateurs une solution conforme aux réglementations environnementales en cours d'adoption par l'OMI à l'horizon 2045. En comparaison avec un porte-conteneurs propulsé au fuel conventionnel, le navire converti permet de réduire les émissions de CO2 de l'ordre de 23 % sur un Aller / Retour Europe-Asie de 83 jours (escales comprises).

Le travail réalisé au sein du projet de développement commun (JDP) entre GTT, Alwena Shipping et CHI Zhoushan englobe la conception technique, opérationnelle et commerciale de l'opération de conversion et d'allongement, tout en proposant un schéma industriel compétitif.

Le résultat de ce travail conjoint indique la direction à suivre pour contribuer à décarboner une partie de la flotte de porte-conteneurs actuellement en opération. Assurance de la fiabilité de leur étude, GTT, Alwena Shipping et CHI Zhoushan ont reçu une approbation de principe (AiP) de la société de classification Bureau Veritas (BV).

SUMMARY

In order to meet the ever more stringent requirements from the International Maritime Organization (IMO), shipowners will have to find solutions to reduce Green House Gas (GHG) emissions of their ships, in particular their CO2 emissions.

One solution considered is to convert part of the existing fleet to LNG propulsion. This type of operation is timely and costly this is why GTT, a technological expert in membrane containment systems, Alwena Shipping, a naval consultancy and engineering firm, and COSCO Shipping Heavy

Industry (Zhoushan) Co., Ltd (CHI Zhoushan) shipyard, have decided to develop an alternative solution: conversion to LNG combined with a lengthening of the vessel, also called “Jumboisation”.

The length increase of the ship (or jumboisation), combined with the LNG conversion of the propulsion and electrical generation systems enables a reduction in the operating costs of the ship, which limits the financial impact of the immobilization period required for the retrofit operation.

LNG propulsion offers ship-owners a solution to comply with the environmental regulations being adopted by the IMO by 2045. In comparison with a conventional fuel-powered container ship, the converted vessel reduces CO2 emissions by around 23% over an 83-day Europe-Asia return trip (port calls included).

The work carried out within the Joint Development Program (JDP) between GTT, Alwena Shipping and CHI Zhoushan supports the technical, operational and commercial design of the conversion and jumboization operation, while also proposing a competitive industrial plan.

The result of this joint work shows the way to contribute to decarbonize part of the container ship fleet currently in operation. Assurance of reliability of their study, GTT, Alwena Shipping and CHI Zhoushan have received an Approval in Principle (AiP) from the classification society Bureau Veritas (BV).

1. INTRODUCTION

The objective of this study is to address the scope of work required to perform a conversion of propulsion from conventional fuel to dual fuel (LNG & Fuel Oil) for a Very Large Container Vessel.

The method selected and discussed in this document is a retrofit & jumboisation by which the large containership is lengthened by a vessel block combining a LNG membrane tank and a container cargo section.

GTT, ALWENA SHIPPING and COSCO HEAVY INDUSTRY ZHOUSHAN (CHI) have been working for half a year to build a comprehensive business case of the LNG conversion & jumboisation

- GTT acts as LNG fuel system designer, covering LNG membrane tank, Fuel Gas Supply System (FGHS), and bunker stations
- ALWENA SHIPPING acts as naval architecture expert, in charge of the LNG propulsion business case economic feasibility
- CHI acts as retrofit yard in charge of the whole conversion, sharing expertise on the duration and cost of retrofit operations

This study has been carried out on a 14,000 TEU class container ship with a 12,225m3 LNG fuel tank capacity.

The retrofit solution presented in this document can be applied in the same way for a wide range of VLCV, taking care of the increase of ship’s dimensions and LNG tank’s capacity.

The full study integrating engine architecture selection, LNG tank dimensions and weight definition will be conducted in detail at retrofit project stage.

Converting a conventional HFO container ship to a dual fuel ship able to function on LNG can be an important conversion. A cryogenic LNG tank is installed along with the surrounding system to manage tank pressure and fuel gas demand. It also includes retrofitting the main engine (with option for diesel generators) from single to dual fuel and the installation of the gas pipe network from LNG tank to gas consumers. This new fuel system will have an obvious impact on the ship.

Figure 1: LNG tank conversion and Jumboisation

Figure 2: LNG tank conversion and Jumboisation

2. DESIGN CONCEPT OF THE LNG FUEL VESSEL

2.1. Generalities on the vessel

Length over all before retrofit	366.0m
Length over all after retrofit	394.9m
Length between perpendiculars before retrofit	350.0m
Length between perpendiculars after retrofit	394.9 m
Breadth moulded at waterline	48.2m
Depth moulded at waterline	30.2m
Design Draught moulded	13.5m
LNG tank capacity	12,230 m3

LNG fuel tank is designed in accordance with IGF code. Tank is positioned from frame 145 to frame A20 on centreline of the ship. The additional cargo bay from A20 to A36, which is followed by frame 146.

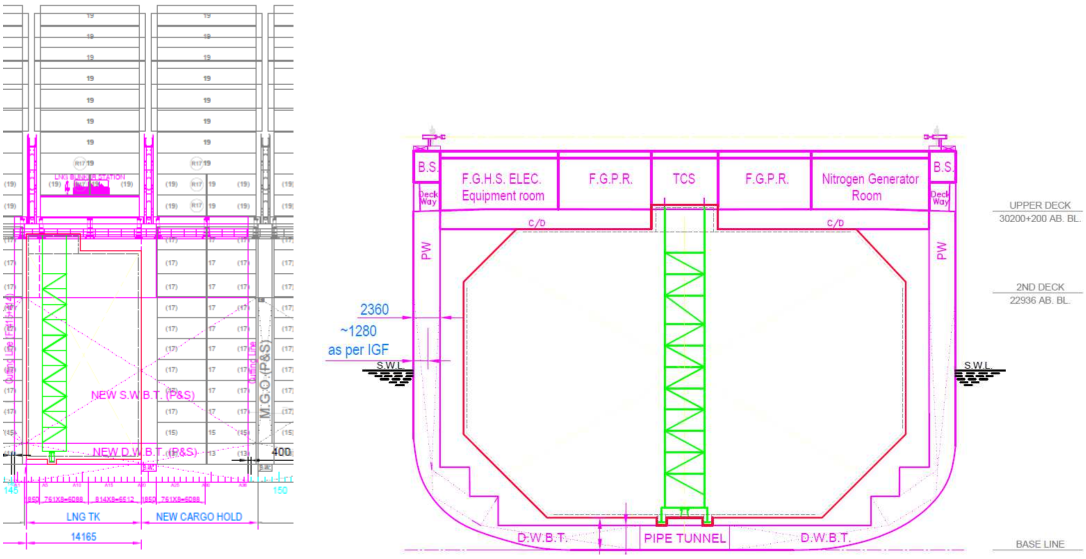

Figure 3: New block section

2.2. LNG fuel main systems

Main sub-systems of the LNG Fuel Gas System of the vessel are as follows:

- Dual fuel Main Engines for propulsion and option for pure gas or dual fuel Auxiliaries Engines for electrical power production
- Option for Dual fuel Auxiliary boiler used for heat production and gas disposal
- Fuel Gas Handling (or supply) System, which enables the feeding of required demand of fuel gas to engines. It includes LNG pumps, gas compressors and heat exchangers such as vaporizers.
- LNG Fuel Tank which enables to store the LNG fuel
- Bunkering stations which enable to load LNG as fuel inside the tank
- Fuel piping and venting system

3. GTT MARK III TECHNOLOGY

3.1. Mark III concept

Mark III technology is a cryogenic liner used to contain liquefied gas at low temperatures during shipping, onshore and offshore storage, at atmospheric pressure.

The Mark III membrane system is an insulating system, directly supported by the ship’s hull structure.

It is composed of a primary corrugated stainless steel membrane, positioned on top of a prefabricated insulation panel, including a complete secondary membrane made of composite material.

This modular system calls for standard prefabricated components that can accommodate any shapes and capacities of tanks. These are designed for mass production techniques and easy assembly.

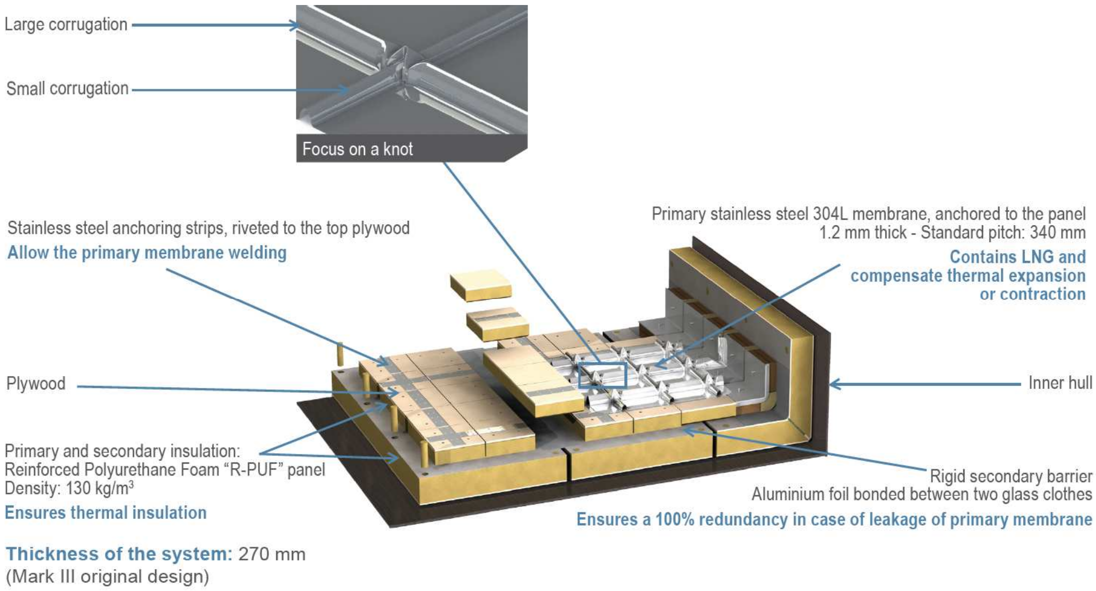

Figure 4: GTT Mark III technology

3.2. Mark III advantages

Mark III benefits from a strong position in the market and more than 200 LNG carriers are equipped with this technology and its evolutions.

The corrugated membrane technology has been constantly improved and takes advantage of more than 50 years of experience at sea. It is also compliant with the latest standards: IGC 2016 and IGF.

The low thermal conductivity of the foam results in a thin insulation; thus maximising the cargo capacity for any ship external constraints.

The two independent insulation spaces are continuously flushed with nitrogen gas. The integrity of both membranes is permanently monitored by detection of hydrocarbon in the nitrogen, making Mark III a very safe system.

3.3. LNG tank dimensions

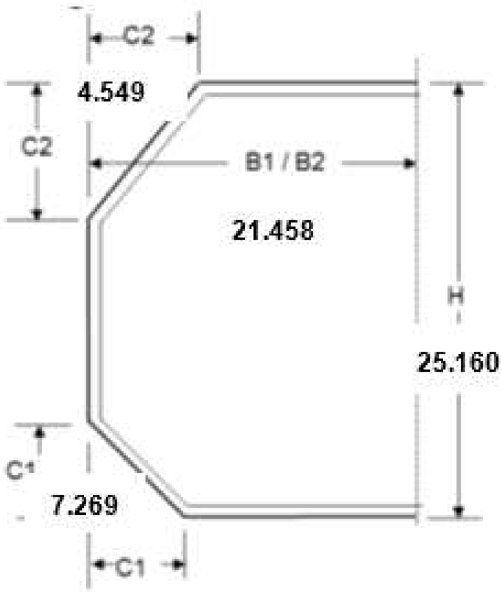

Figure 5: LNG tank dimension

LNG tank dimensions at primary membrane level are:

- L = 13.600 m
- B = 19.380 m
- H = 25.160 m
- C1 (lower chamfer) = 7.269 m
- C3 (upper chamfer) = 4.549 m

The internal tank volume is 12,230 m3 (at 100% filling ratio).

The internal tank surface at primary barrier is 3,354 m2

The tank is surrounded by cofferdams.

4. CONVERSION WORK

4.1. Prefabrication works

4.1.1. Structural work

Construction of the new block to be inserted at frame 145 from base line to upper deck

Installation of tank boundary structure

Installation of tank membrane system according to GTT documentations (such as: erection procedures/bonding procedures/welding procedures/testing procedures).

- Installation of the membrane system should be performed by a GTT licensed and trained company (shipyard and/or GTT outfitter)
- All procurement of membrane insulation element should be done to GTT homologated suppliers.

Pre-fabrication and erection of the fuel gas supply space (FGSS) room structure above the tank space

Pre-fabrication of bunker stations

Supervision of prefabrication

4.1.2. Hull outfitting work

Outfitting of new cargo hold above tank space and FGSS

Installation of fire insulation wherever necessary

Installation of air locks in FGSS

Prefabrication, pressure test and inspection of all ventilation ducts and pipes

4.1.3. Electrical outfitting work

Prefabrication of all electrical equipment

Installation of electrical equipment in FGSS

4.1.4. Machinery outfitting work

Installation of pipes and cable work in pipe duct

Installation of pipes and ventilation ducts in the FGSS

Factories acceptance tests of complete LNG fuel supply equipment

Installation of all LNG fuel equipment in the FGSS

Installation of nitrogen system for inner barrier space

Installation of piping and equipment for bunker stations

4.1.5. Erection preparation work

Preparation of the new block to be inserted at the cut location

Installation of the proper reinforcement for towing the block while floating in the dry dock after vessel is cut in two and separated

Preparation of the bunker stations new structures for erection on the upper part of the vessel. The estimated lifting weight of the new structure for bunker stations is in the range of 12.5t for each of them.

4.1.6. Paint work

Painting of all steelwork of the prefabricated hull block

Supervision of pain work

4.1.7. Material and construction quality requirement during prefabrication work

The selected steel material for the new block

- shall meet the GTT membrane hull scantling criteria associated with loads from the tank on the hull
- shall be compatible with the existing material of the ship at the cut location
- shall comply with technical specification of the existing vessel and provide sufficient strength to the whole new structure

The structure arrangement of the new block shall provide structural continuity of the hull girder structure in compliance with the class requirement

Tank boundary structure shall be well aligned and supported by the existing vessel structure for avoiding local deformation and stress concentration points

The applied steel materials for the ceiling of the FGSS room shall be designed to withstand potential dropped object on the LNG tank

4.1.8. Dry dock activities

Vessel arrival at quayside

Vessel towing into the dry dock

Vessel alignment and mooring

Measurement of the cutting line

Measurement of the vessel straightening

Hull and cargo hold cutting (control vessel bending)

Cutting frame 145 +414mm

Watertight test (cable & pipe end fittings protections)

Float out of aft section (S1)

Float in of new block (S2) and aft section (S3)

Alignment of the three (3) sections S1, S2 and S3

Scaffolding erection

Bevelling and cleaning

Welding & gridding

- During welding special studies should be done to avoid extra stress on membrane system resulting from hull welding.
- Gap and welding specification at the vicinity of tank should be established with GTT prior starting the project.

NDT

Watertight test & air test

Painting

Connecting block structural stiffeners and inserts with aft and forward part of the vessel

4.1.9. Hull outfitting works

Erection of pipe trunk space in cargo hold

Installation of ventilation ducts beside the funnel

Connecting CO2 system to FGSS

Connection of water spray system for bunker stations

Testing and commissioning of all systems

4.1.10. Electric outfitting work

Cutting of cables in the pipe duct, passage way and space above passage way

Installation of cable outfitting from FGSS to ECR

Installation of gas detecting and monitoring system

Installation of automation & control system for fuel gas plant

Testing and commissioning of all systems

4.1.11. Machinery outfitting work

Installation of LNG bunker pipes from FGSS to gas valve units

Installation of air supply system for gas line venting

Installation of gas valve units for M/E, A/E and Boiler in the engine room

Installation of ventilation ducts and fans for FGSS , air locks and gas valve units

Installation of air supply system for gas line venting

Installation of Steam / Condensate pipes for heating and pumping unit of war glycol unit in E/R

Rearranging of piping in E/R in order to accommodate LNG, NG and ventilation pipes where required

Testing and commissioning of all systems

4.2. CAPEX estimation

Together with the shipuard CHI Zoushan, a thorough cost analysis has been carried out and let to the conclusion that the whole retrofit operation was in the range of $41 million

The CAPEX breakdown is the following:

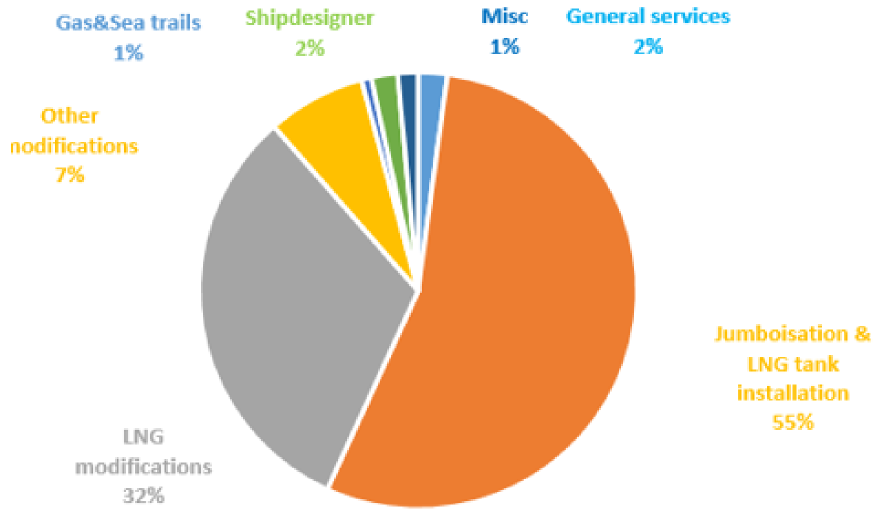

Figure 6: Retrofit CAPEX breakdown

4.3. Conversion planning

The shipyard expertise in “conventional” Jumboisation allowed to build a comprehensive operation schedule.

Overall retrofit project from vessel candidate selection to vessel delivery is 24months

Block construction and membrane outfitting + FGHS integration is 10 months

Vessel immobilisation at retrofit shipyard is 126 days

Vessel in dry dock 42 days

The 126 days of vessel off hire will generate a cost of $6 million, which will be compensated by the cargo capacity increase.

5. VESSEL OPERATIONAL PROFILE

For our study, validated by an Approval In Principle (AiP) from Bureau Veritas, we considered the case of a 147,000t deadweight container ship with a capacity of 14,000 TEU converted to a 163,000t deadweight container ship with a capacity of 15,000 TEU.

The main engine is converted to a dual fuel LNG engine and two out of the four auxiliary engines are replaced by dual fuel gensets.

5.1. Engine architecture

5.1.1. Main Engine selection

The existing Main Engine MAN B&W11S90ME-C10.5-Tier II is retrofitted to a MAN B&W11S90ME-C10.5-GI-LPSCR Tier III, with SCR system for Tier III areas.

5.1.2. Auxiliary Engine Selection

Two of the four gensets already onboard are kept : 1x Wärtsilä 8L32 + 1 x Wärtsilä 6L32. SCR systems for existing Diesel gensets are also installed to comply with Tier III regulation.

Two new Pure gas Bergen 36:45 gensets are installed : 1 x 3MW + 1x 5MW.

5.2. Hypothesis

For the sake of this study, the following assumptions have been made:

Main Engine	MAN B&W11S90ME-C10.5-GI-LPSCR Tier III (Retrofitted)
MCR	46.000 kW x 76.0 rpm
CSR (62% MCR)	28.700 kW x 72.0 rpm with active PTO
SFGC (at CSR)	~137.9 g/kWh +5% (without engine driven pumps) guarantee refers to ISO 3046/1 at CSR shop test ambient condition and lower calorific value for the LNG of 50000 kJ/kg
PTO	2000 kW (installed during the retrofit)
Gensets	1x Wärtsilä 8L32 + 1x Wärtsilä 6L32 + 2x Pure gas Bergen 36:45
Power of Gensets	Bergen : 3350 kWe x 720 rpm + 5020 kWe x 720 rpm
	Wärtsilä: 3690 kWe x 720 rpm + 2760 kWe x 720 rpm
Reefer Plugs	1000 pcs
Consumption	5.5kW/ reefer

Hotel load at seagoing	2000 kW
Hotel load at berth with operations	2500 kW
Hotel load during manoeuvring	3150 kW
Additional equipment for FHGS	330 kW
Additional equipment for SCR System	26kW
Bow thruster	3000 kW

Service speed abt. 17 knots (with 2000 kW of PTO with 15% sea margin) on design draught.

Maximum speed abt. 20.2 knots (without PTO with 15% sea margin) on design draught.

5.3. Operational profile

At sea:

- 1x Main Engine running with active PTO, fuelled by gas
- 2 x pure gas gensets running.

During Manoeuvring:

- 1x Main Engine running without PTO, fuelled by gas
- 2 x pure gas engine running and 2 x diesel gensets running

At berth in operations:

- No Main Engine
- 2 x fuel gas engine running, 1 diesel engine running

5.4. Consumption figures

Designed fuel gas consumption (for propulsion only), at CSR (62% MCR) of main engine, on the basis of LNG of which net calorific value of 50,000 kJ/kg and SFOC is 137.9 g/kWh : abt. 95.2 t/d (+5%).

The cruising range at service speed (17 knots) is abt. 21.000 nm.

This cruising range is calculated with these assumptions :

- Service speed at design draft with 15% SM
- LNG tanks at 95% full at departure and 5% remaining in the bottom of the tank
- No reefer container – only hotel load for seagoing

6. COMPLIANCE WITH COMING OMI REGULATIONS

As part of its greenhouse gas strategy, IMO has set a target of reducing carbon intensity by 40% by 2030 and 70% by 2050. The overall ambition of the greenhouse gas strategy is to reduce greenhouse gas emissions by at least 50% by 2050 compared to 2008 levels.

This means a significant reduction in the carbon dioxide output of the fleet.

While long-term changes are needed, IMO recognizes the need for short-term measures to reduce the carbon intensity of shipping, while preparing for a future of increasing reliance on alternative fuels and zero-carbon ships.

The objectives formulated for the period 2023 - 2030 are therefore "More work, less fuel", and for the period 2030 -> 2050 objectives are for their part "More work, much less fossil fuel". After 2030, the aim is to increase the efficiency of ships considerably and to switch from fossil fuels to alternative fuels and zero carbon emission ships.

To achieve this goal, several tools have been and will be put in place to guide and monitor shipowners' operations. One such tool is the EEDI (Energy Efficiency Design Index), which came into force in 2020 in its phase 2 and this year in its phase 3 for container ships (April 1, 2022). It calculates "theoretical" CO2 equivalent emissions per ton-mile, based on the maximum capacity of the vessel and the fuel consumption data of the engines.

EEDI is applied to new ships and its counterpart EEXI (Energy Efficiency Index for eXisting vessels) will be applied to existing ships.

In the short term, that is from next year, ship owners and operators will have to take into account the entry into force of the EEXI and reduce the carbon intensity of shipping. The EEXI formula is now identical to the EEDI formula, but is applied to existing vessels.

The easiest way to comply with the EEXI will be to reduce the power of the propulsion engine and therefore the speed of the vessel. For long-term compliance with EEXI, switching to LNG is an effective solution.

With our concept of converting to a low-carbon fuel and increasing the capacity of the vessel, we have an impact on both the CO2 factor of the fuel and the capacity of the cargo carried : switching to LNG will reduce CO2 emissions while jumboization will increase the transport work.

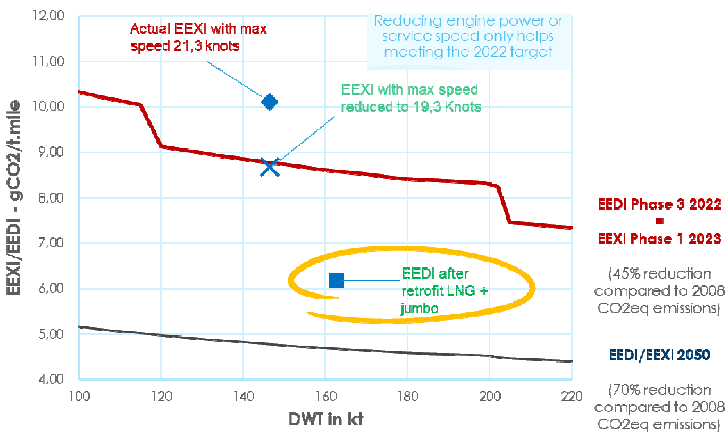

Figure 7: EEXI/EEDI evolution per deadweight tonnage

As explained above, the main engine is converted to a dual fuel LNG engine and two of the four auxiliary engines are replaced by dual fuel gensets.

EEDI Phase 3 and EEXI Phase 1, which will come into effect in 2022 and 2023 respectively, require the same CO2 emission reduction (compared to 2008) for container ships of this capacity: 45%.

In its current configuration, the 14,000 TEU container ship will exceed this limit.

As mentioned earlier, the easiest way to comply with the regulations will be to reduce the power of the propulsion engine (Engine Power Limitation), and consequently to reduce the speed. The EEXI obtained by reducing the maximum speed to 19.3 knots is then slightly lower than the value required by the EEXI regulation in 2023.

In comparison, our modernization and jumboization concept significantly reduces CO2 emissions per ton transported and mile traveled. Switching to 100% LNG reduces the vessel's EEDI by one third.

It is important to note that after retrofitting and jumboization of the vessel, we will no longer speak of EEXI but EEDI, because the transformation of the vessel will be considered as major by the classification societies.

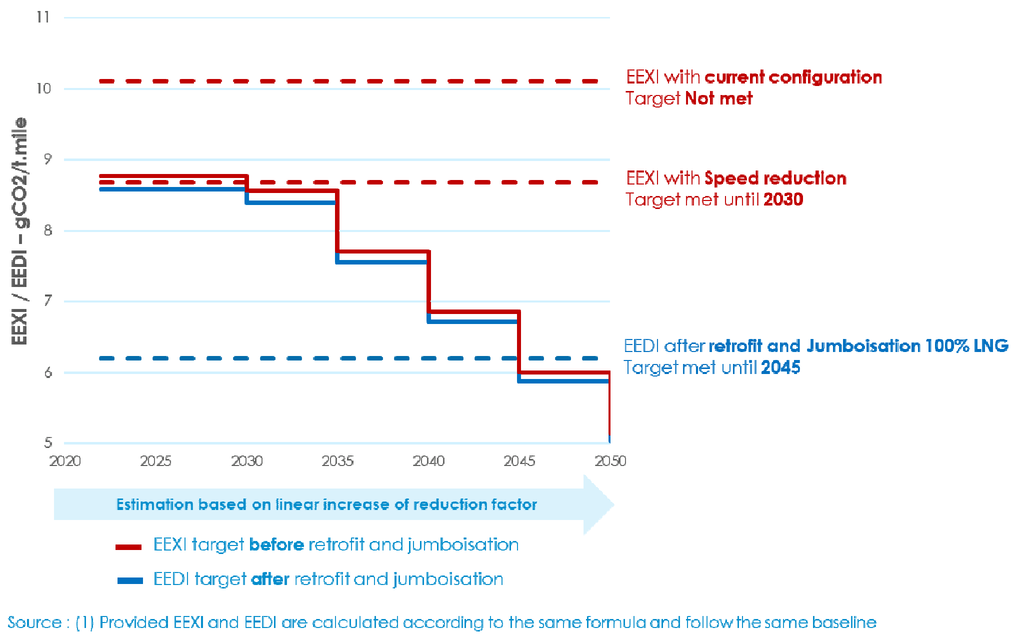

Figure 8: Estimate EEDI/EEXI requirement evolution

As the capacity of the vessel has increased (DWT + 16000t) and the installed power of the propulsion engine has slightly decreased following the conversion (-2.6MW), the admissible CO2eq emissions of the vessel will not be the same.

This is what we wanted to highlight on the above chart: solid line in red for the EEXI limit values and in blue for the EEDI limit values.

We assume here that the emission reduction target will decrease linearly until 2050, when the target is a 70% reduction.

By doing so, the EEDI of the converted vessel will be lower than the EEDI target until 2045.

7. RETURN ON INVESTMENT

A question may naturally arise: what will be my return on investment from an economic point of view?

To answer this question, we have taken the data from the case study submitted to Bureau Veritas.

The operational profile of our candidate is still as follows: a 14,000 TEU container ship making a round trip between Europe and Asia in 80 days, **at an average speed of 17 knots**, to get conservative results.

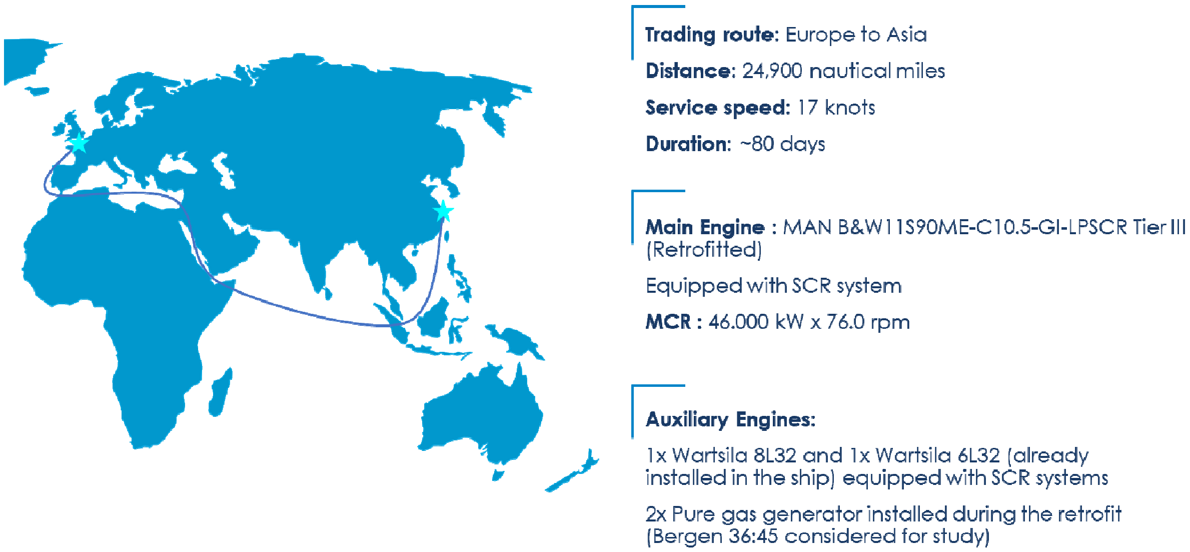

Figure 9: Operational profile assumptions

The main engine for this specific case is a conventional MAN propulsion engine converted to a 46000 kW MEGI LNG engine.

As for the architecture of the auxiliary engines, the philosophy is to keep two conventional engines out of the 4 initially present, and to replace the two others by two pure gas engines, allowing to limit methane emissions (methane slips). After discussions with the various suppliers of auxiliary units, it turned out that converting this type of gensets would be as expensive as replacing it.

Considering the operating costs of the LNG converted vessel and the unmodified vessel running on conventional fuel (and without speed reduction due to the implementation of EEXI), it appears that the reduction in operating costs could reach **$1.4 million per year.**

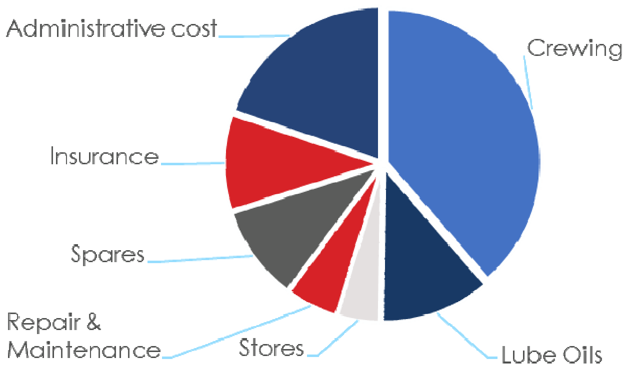

Figure 10 : OPEX estimation

These operating costs include crew costs, insurance, administration costs, and maintenance.

OPEX per day for LNG ship is estimated conservatively at $16,000

The costs of fuels and consumables considered for the comparison are presented here.

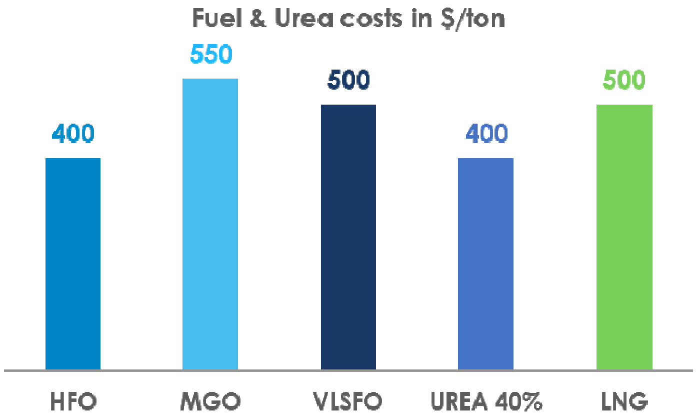

Figure 11 : Fuel cost savings

Fuel prices considered for the study are average prices before the latest conjectural events

For both conventional and LNG fuel costs, we have used mid-2021 prices.

Nowadays, the spot cost of LNG has been boosted by the post-covid economic recovery, particularly in Asia, a cold winter in Europe and more recently the war in Ukraine (TTF based price).

To assess the impact of the rising LNG price on the pay back of our concept, we performed a sensitivity study based on the LNG price and the Asia-Europe freight rate, which also increased.

For this sensitivity study, we did not vary the cost of conventional fuels, nor the cost of freight between Europe and Asia, which are less impactful, even if given the current trends they would be favourable for the payback of the investment.

In the current context, the Asia-Europe freight cost is around $8,000 per FEU and the LNG price in Asia is around $25/MMBTU in spot contract.

Below other assumptions are considered :

- MGO : 550 $/mt;
- HFO : 400 $/mt;
- North Europe to China/East Asia FEU freight price : 900$;
- Filling rate EB : 60%;
- Filling rate WB : 85%.

With these different costs, **the payback period for our operation is around 7 years**. With a long-term contract on LNG supply or a return to spot LNG prices from early 2021, the payback could be as short as 2 years.

It is a 7 years payback to be considered during to lifetime extension of the vessel until 2025

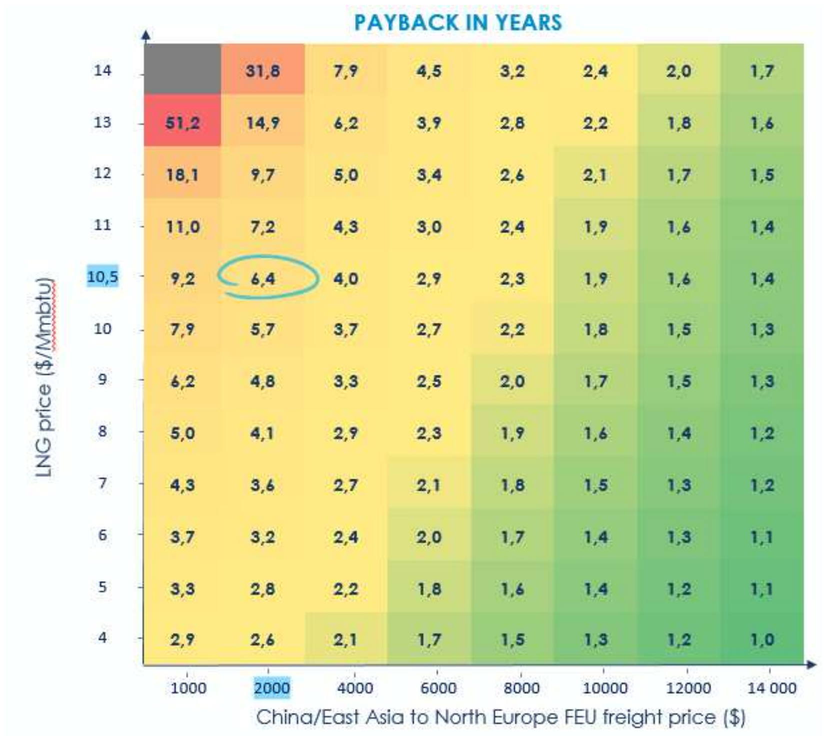

Figure 12: Sensitivity analysis for the payback

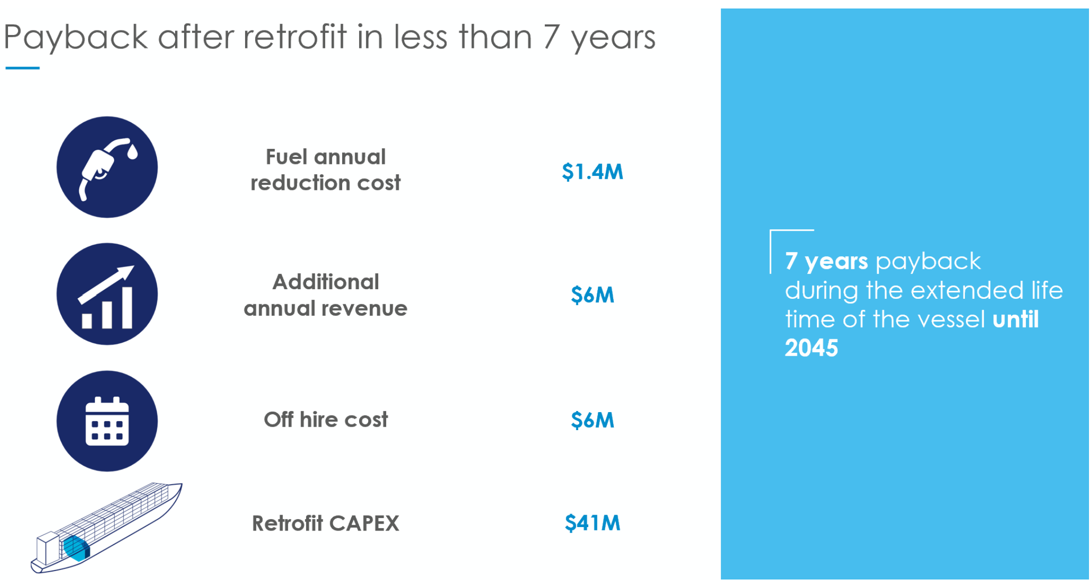

Figure 13: Return on investment summary

8. CONCLUSION

The conversion to LNG combined with a lengthening of the vessel described in this report not only reduces the ship's fuel-related operating costs or increases the ship's loading capacity, it also brings the ship into compliance with international regulations and ensures consistent operating conditions for the next twenty years.

The operation will ensure compliance with IMO's new EEXI (Energy Efficiency Design Index) and CII (Carbone Index Intensity) regulations, thanks to the choice of a more economical fuel with a lower carbon index compared to HFO (Heavy Fuel Oil) and MGO (Marine Gas Oil), as well as the increasing of the ship's cargo capacity, thus meeting the strong demand for maritime transport.

It contributes to extend the lifetime of the asset and adds cargo capacity. The cargo capacity increase of 1,100TEU will generate additional revenues, combined with the OPEX reduction provided by the LNG fuel selection, and the vessel will be compliant with IMO regulation until 2045.

The LNG retrofit & jumboisation is a 2 years process with only 4 month off hire. The initial $41million investment may be substantial, but the return on investment should be less than 7 years, which can be shortened depending on the economic context.

It should also be noted that today LNG is available along the main shipping routes, with the supply chain in place and proven infrastructure.

BioLNG, which is a practically carbon neutral biofuel, is now developing. Tomorrow renewable synthetic LNG will be available, produced via electrolysis using a renewable source of electricity, for instance solar or wind. BioLNG and synthetic LNG could be used interchangeably with existing LNG bulk infrastructure, supply chains, bunkering vessels, dual fuel engines, and the fuel storage and supply systems on board vessels