GTT
Technology for a Sustainable World

GTT Inside
The GTT newsletter - July 2022 - n° 25

# Message from Karim Chapot, VP Technical Division of GTT

I am pleased to be able to introduce the latest GTT inside with news on our more recent developments.

In this edition, GTT is presenting a new concept of LNG Carrier with three tanks. This evolution provides an improved guaranteed Boil Off Rate and a simplification of the construction process to further contribute to reductions in emissions. This evolution is possible thanks to recent research and development work, which relies strongly on data from ships in operation. With the development of digital solutions and the collection of information from hundreds of vessels, the design margins can be further fine-tuned and innovation thereby facilitated. On each special survey, ships are scrutinized and slight corrections are made when deemed necessary in order to maintain the outstanding LNGC industry track record. Accordingly, we explain how we monitor the position of the pumps at each special survey to keep the tank in normal operational conditions. The latest developments of GTT Next1 are also described with the construction of a large mock-up in France. Finally, the LNG as fuel team has introduced the development of Blocks with the membrane being fully prefabricated before installation in the vessel. This new way of building tanks has been applied successfully on container ships and is efficient for ship retrofit to LNG. This increased level of prefabrication will simplify LNGC shipbuilding and will certainly change the way ships can be built in the future.

Please enjoy this edition and I take this opportunity of wishing you an enjoyable Summer!

# TECHNOLOGIES

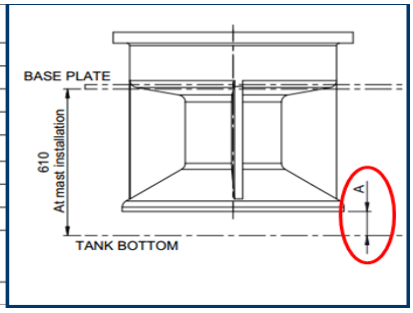
## Increased safety of LNG tank operations: control of the distance between cargo pumps and the Mark III primary membrane

Cargo pumps are positioned in the lower section of pump towers installed in the cargo tanks for unloading liquefied gas. As far as the operation of LNG cargo tanks is concerned, the position of cargo pumps has been designed to perform the following main functions:

- To optimize the duration of operations and maximize pumped volumes before switching to stripping operations.
- To provide for displacement of the pump tower due to inertia and particularly due to thermal expansion while the tank is warming up without inducing contact between pumps and the primary membrane.

For Mark III Tanks, the historical distance, defined between the flat part of the membrane and the lower part of the cargo pump, is 100 ± 5 mm. This value takes into account the height of a Mark III membrane knot (70 mm). Considering the minimum distance at the lowest installed position (100 - 5 = 95 mm) and the height of the membrane knot (70 mm), the remaining initial distance corresponds to 25 mm (95 – 70 = 25 mm) between the pump and the top of the membrane knot.

| DESIGNATION | DISTANCE to be check after mast installation and relaxing |
|---|---|
| CARGO PUMPS (Ref: A) | A = 100 ± 5 |
| SECONDARY LEVEL GAUGE (Ref: B) | B = 120 ± 15 |
| EMERGENCY PUMP WELL FOOT VALVE OPENED (Ref: C) | C = 120 ± 15 |
| FILLING PIPE (Ref: D) | D = 200 ± 15 |
| PRIMARY LEVEL GAUGE | THERMOWELLS E1 = 500 max E1* = 100 mini |
| | RADAR PIPE E2 = 70 ± 10 |
| | TEMPERATURE SENSOR E3 = 25 ± 1 |
| | BOTTOM BUCKET DEVICE E4 = 5 ± 1 |
| STRIPPING PUMP (Ref: F) | $F = 90^{+2}_{0}$ |
| FUEL GAS PUMP (Ref: F) | |
| TANK BOTTOM SAMPLING PIPE (Ref: H) | H = 210 ± 15 |

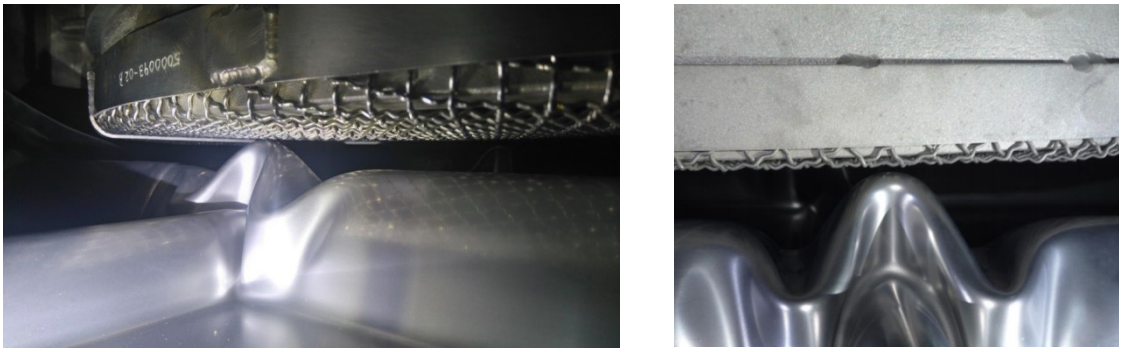



*Typical historical distance (100 ± 5 mm) defined between the lower part of the cargo pump and the flat part of the membrane*

By doing so, it is consistent with the maximum pump tower extension of 22 mm which may occur during extreme warming situations, where the tank temperature can reach 60 °C. Any damage to the primary membrane is avoided, even if the installation was performed to the lowest tolerances.

## Observations on vessels in operation

Following observations on vessels in operation, it has been noticed that the distance between the primary tank barrier and cargo pumps may have become smaller in comparison to the initial distance when the vessel was delivered. This has randomly affected vessels in the whole fleet to a greater or lesser degree. No pattern has been observed in relation to construction period, shipyard or vessel size.



*Example of critical distance reduction observed on few ships in operation*

In the most severe cases, concerning a very small number of Mark III vessels, contact between the cargo pump strainers and the primary membrane has been observed. Very recently, damage of the primary membrane, which remained in place, was observed for one vessel during warming up.

It has to be highlighted that during normal operations, cargo tanks are cold in the laden condition leading to contraction in the pump tower of more than 70 mm. This means that risks during operation are limited but consequences during tank decommissioning with forced heating have to be considered and new recommendations have to be implemented based on those observations.

Investigations have been performed to identify potential causes:

- Improper installation at the new-build stage is excluded. The initial distance has been measured and recorded in inspection sheets with the parties concerned.
- Impact of temperature with the external hull under colder conditions than the temperature of the tank was not demonstrated.
- Possible deformation of the pump tower under inertia has been assessed by a theoretical approach to be no more than 2 mm using a state-of-the-art methodology and available international standards.
- Potential failure of the pump tower connection to the inner hull at the tank ceiling has not been observed.
- Any potential deformation of the liquid dome cover has not been observed.

Based on our best understanding, the phenomenon is related to the relaxation of residual stresses in welded seams during operations at sea. Stabilization of the relaxation of the residual stresses in welded seams would be expected after the first few years of normal operation. Indeed, about 10 ships have benefited from measurement of the distance, without displaying any significant change in the remaining distance between two successive inspections.

This phenomenon is monitored continuously and measured at each special inspection to update our current level of understanding. New findings, if any, would be shared and implemented for the vessels concerned.

# Recommendations for delivered vessels and new-builds

## Recommendations for delivered vessels

The change in distance between the membrane and cargo pump that occurs after operations at sea cannot be predicted according to the best available knowledge and standards. To limit the risk of primary membrane damage, it is recommended that for Mark III vessels which have not yet been inspected after delivery or for which no information regarding the actual distance between pumps and the primary membrane is available, that the tank warming up temperature be limited to 30 °C.

Based on numerical simulations, limiting the temperature inside tanks to 30 °C would have a negligible effect on warming up time. From our available experience, some vessels in service have already implemented a reduction in the warming up temperature, with a limit reduced to 35 °C, and no particular problems have been reported during operation.

After the remaining distance has been measured during the next special inspection, new recommendations will be issued such as:

- No modification if the distance remains at its initial condition.
- Tank warming up temperature to be reduced if the remaining distance is not sufficient.
- Raising the cargo pumps in the event of a severe reduction in distance. To date, a limited number of vessels have had to raise their cargo pumps.

## Recommendations for new-build vessels

For new-build projects, it is recommended that the distance between the lower section of cargo pumps and the flat part of the membrane is increased from 100 ± 5 mm to 140 ± 5 mm, providing a minimum distance of 65 mm between pump and the top of membrane knot at the reference temperature. This increase in distance by 40 mm has been defined to cover the worst cases observed in more than 400 tanks measured during special inspections. Such an increase can be achieved, as far as practicable, in two ways:

- Raising the cargo pumps by 40 mm for vessels currently under construction.
- Modifying the primary membrane layout below the cargo pumps for vessels still in the design phase.

For a typical 174,000 m3 LNGC, raising up the cargo pumps would lead to an increase of 160 m3 in the LNG volume remaining to be pumped out of the vessel. Considering the typical stripping pump capacity, the stripping operation will be very close to 3 hours. Furthermore, the overall duration of unloading operations with the cargo pumps will remain unchanged. Dedicated analyses have to be performed for each project concerned taking into account its specific characteristics.

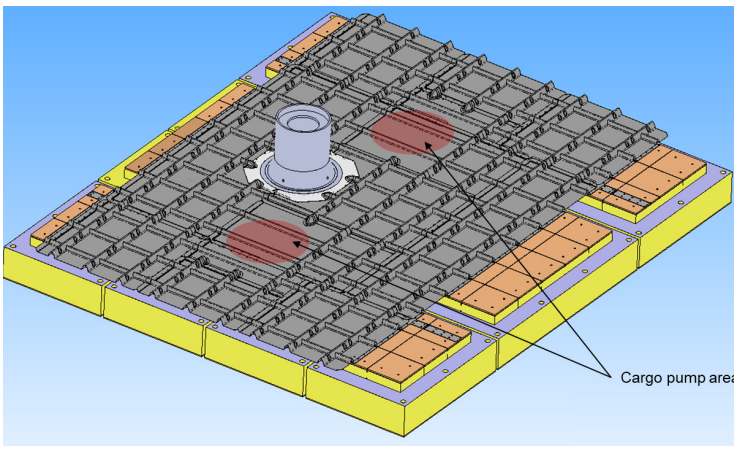



*Illustration of the optimized primary membrane arrangement under cargo pumps.*

The special membrane layout under cargo pumps consists of removing the knots and large corrugations that are in the way of the cargo pumps. The small corrugation height is typically 34 mm lower than the knot height which provides an increased distance between the cargo pumps and the top of the primary membrane. The layout has also been developed to be applied to projects where a sump has been used in the bottom area.

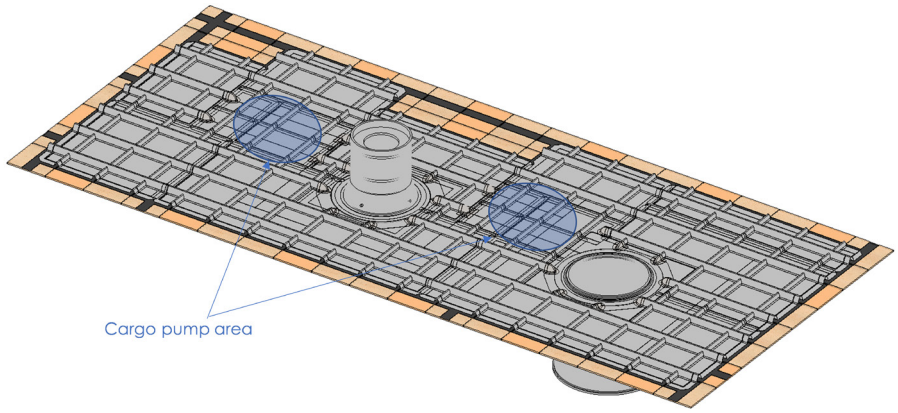



*Illustration of the optimized primary membrane arrangement under cargo pumps in case of sump application.*

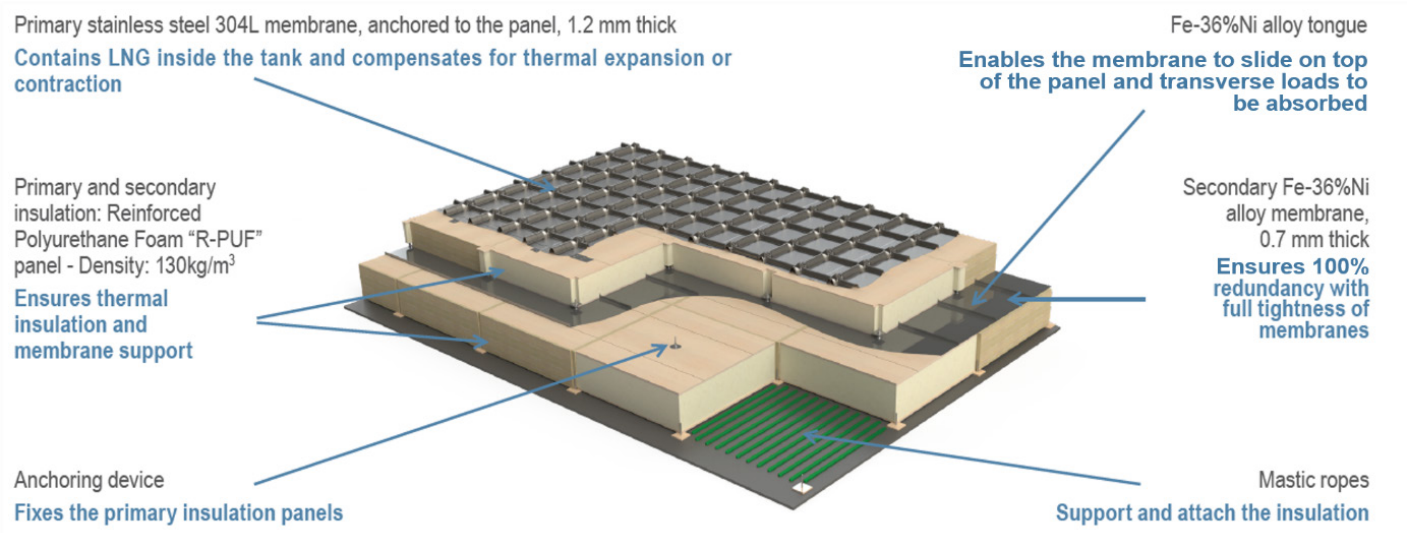
The layout has been designed and verified to provide enough flexibility in the primary membrane to provide an acceptable safety margin as far as cyclical pressure and thermal and hull extension loads are concerned. This solution optimizes the LNG volume remaining in the tank prior to stripping operations and, in the meantime, provides additional margin to cover the reduced distance observed on ships in operation. This solution is currently being implemented on some initial projects that are in the design phase.

GTT has contacted the builders to modify the ships under construction as far as practicable and will provide ship-owners with a service letter detailing the recommendation about tank warming-up for vessels which are in service.

# INNOVATION

## GTT Next1: the latest development in GTT's technologies

*GTT has received an Approval in Principle (AiP) from the classification society Lloyd's Register EMEA, for its future Cargo Containment System applicable to LNG carriers, "GTT NEXT1".*



GTT NEXT1 technology is the latest development under GTT's program of continuous innovation. It is made up of two independent metallic membranes, both supported by a layer of insulating foam material. It includes new concepts for anchoring components as dihedral parts, providing a further increase in thermal performance and ensuring a guaranted Boil-off Rate of less than 0.07%V/d (*).

The AiP from Lloyd's Register EMEA confirms that "the proposed system is capable of being developed into a safe and viable containment system without any major changes to the basic arrangements". GTT and Lloyd's Register EMEA have studied, in particular, the detailed arrangement of the Flat Wall area, considering all applicable loads from the ship or cargo.

A large mock-up of the GTT NEXT1 system is currently under construction at GTT's facilities to qualify the technology under thermal and ballast deformation conditions of the hull. This representative proof test, scheduled for Q4 2022, should complete the technical documentation and enable a General Approval for Ship Application to be issued at the end 2022 or in early 2023.

(*) BOR is project dependent due to vessel size, tank layout and reinforcements.

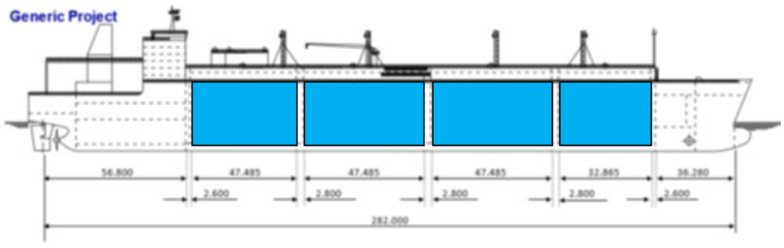
# INNOVATION

## Objective: to improve the overall performance of LNG Carriers while reducing construction cost

One of our missions at GTT is to conceive cutting-edge technological solutions for an improved energy efficiency. Over the last decades, GTT has made continuous efforts to improve its containment systems focusing on two areas in order to meet our clients' expectations:

- Improvement of the thermal performance which has enabled GTT to divide by more than 2 the daily guaranteed LNG Boil Off Rate,
- Improvement of containment system capability to sustain higher dynamic loads.

At the same time, in-house studies and research have allowed us to consider all partial fillings in tanks, which are currently requirements for the application of our containment systems in the offshore and the LNG as a fuel market (fuel tanks for commercial vessels). These technical advances are beneficial for all our technologies as their applications provide significant performance improvements. They have permitted GTT's innovation and basic design teams to challenge the status quo of the standard 174k LNG carrier design.



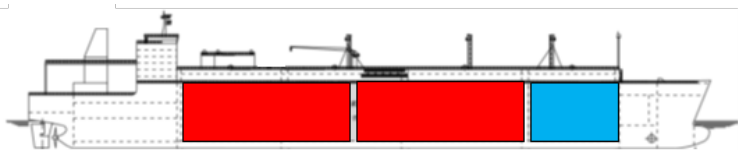

*Current design of LNG Carrier with four tanks*

While performance increase and cost reduction are usually evolving in opposite directions, the innovation detailed hereafter can meet both requirements.

In the past, large LNGC have been developed with 5 cargo tanks. More recently, 200k LNGC designs are available with only 4 cargo tanks. GTT has decided to take this idea one step further, and has developed a new concept of 174k LNG carrier with an innovative design which proposes a configuration with three tanks compared to the standard arrangement with four tanks.

## The aim is to improve the cost efficiency as well as the overall performance of the ship.

Reduction of construction cost beneficial to shipyards and their customers is obtained thanks to the suppression of one cofferdam, one pump tower together with all the associated cryogenic equipment (liquid & gas domes, valves, piping, radars…). The cargo containment system (CCS) overall surface area will be also reduced by around 2.000 m², generating lower costs for the materials and for the installation, as well as allowing a reduction in the construction schedule.



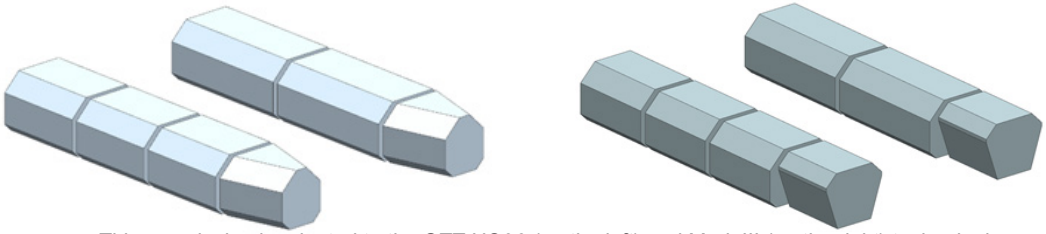
*New design of LNG Carrier with three tanks*

In parallel, the ratio of shipped LNG volume compared to the insulation surface will be also improved. The direct consequence will be a reduction of the generated boil off. As an example, one could target a boil off rate as low as 0.080% of the volume per day for a Mark III Flex depending on the level of reinforcements. This significant reduction will generate benefits for ship-owner and charterer thanks to a lower consumption of gas during laden voyages.

Thanks to its expertise in naval hydrodynamics, GTT developed the global three tank LNGC concept ship design including dedicated sea-keeping studies.

Extensive sloshing model test campaigns were performed in the GTT laboratory on our hexapods – a ship motion simulation platform - in order to evaluate the loads on the containment system resulting from the tank designs envisaged for this innovative LNGC.

The effect of an increase in tank length has been specifically investigated by the GTT hydrodynamic experts in order to thoroughly investigate the specific challenges of this new concept (tank length increased by up to 55%). These tests have shown that the concept is feasible with both Mark III and NO96 technologies thanks to the large range of insulation reinforcements already available and possible tank design optimizations or further CCS improvements, as required.
Calculations of ship stability under normal and damaged conditions have also been performed and have been confirmed as being fully in line with Class rules.



*This new design is adapted to the GTT NO96 (on the left) and Mark III (on the right) technologies*

The applicability of this solution is considered for all the most recent GTT containment systems, (Mark III Flex & Flex+ and NO96 Super+ in order to propose the most efficient solutions, both in terms of construction cost and thermal performance, in order to further contribute to emissions reduction.

An AiP (Approval in Principle) process for the three-tank concept is on-going with DNV.

Our objective is to have validated this concept for all our systems by the end of 2022.

# LNG AS A FUEL

## LNG Retrofit & Jumboïsation


*LNG retrofit and Jumboïsation applied to a 14,000TEU container vessel*

The International Maritime Organization (IMO) has set new targets to reduce CO2 emissions (from transport): a decrease of 40% by 2030 and 70% by 2050, compared to 2008 levels. Annual greenhouse gas (GHG) emissions from international shipping are also regulated, stipulating a reduction of 50% by 2050. Two associated IMO indices - EEXI and CII - have been established to provide ship-owners with a benchmark to reduce their levels and get on track to meet the objectives.

Facing these new requirements, ship-owners and maritime stakeholders have to take measures in order to make their existing fleet compliant with the new regulations. LNG retrofit offers a solution to this challenge.

Among challenging segments for LNG retrofit is that of container vessels, as they require smart and compact solutions for the LNG tank due to space constraints. This is where the use of GTT membrane technology is perfectly adapted. In this context, GTT has decided to build upon the first large scale LNG retrofit of the HAPAG LLOYD Brussel Express (ex Sajir) and improve the business case by proposing a solution combining LNG retrofit and cargo capacity increase in order to reduce the payback time of the whole conversion operation.

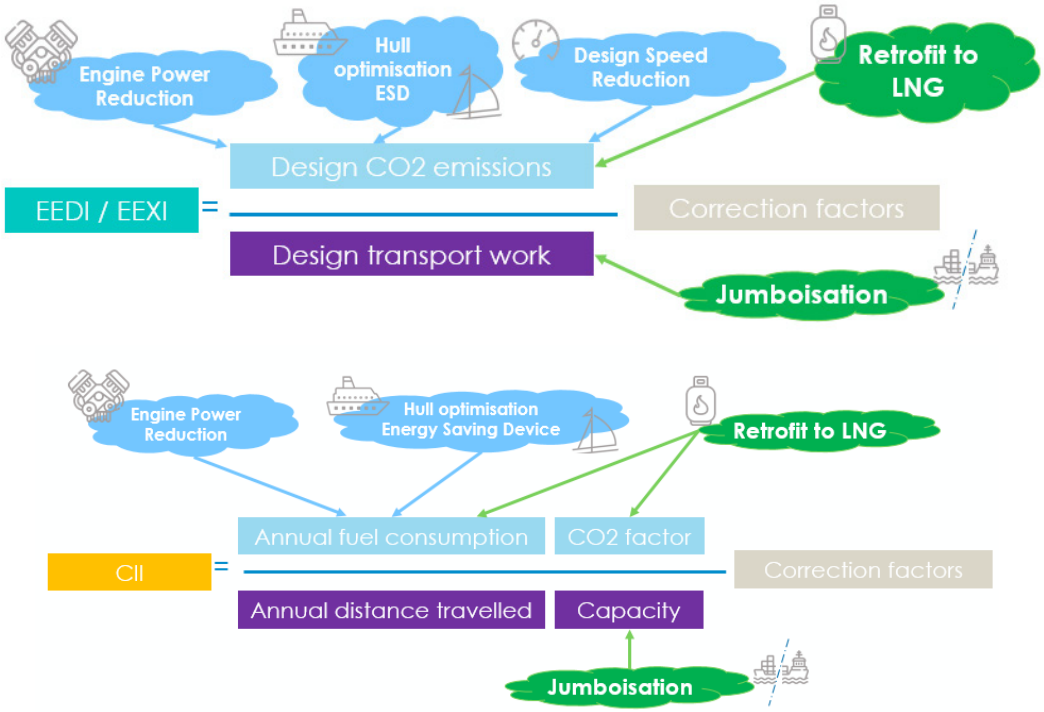
A new section, composed of the LNG tank, LNG fuel gas handling system (FGHS) and a cargo bay to load containers, is integrated towards the aft of the vessel. This lengthening operation is called Jumboïsation.

In January 2021, GTT, maritime advisory ALWENA SHIPPING and Chinese repair shipyard COSCO Shipping Zhoushan decided to launch a Joint Development Program to study all the technical and economic aspects of such a retrofit operation.

As a result of this collaboration, in January 2022, the study received an Approval in Principle from the French classification society Bureau Veritas.

A market analysis has shown that the ideally targeted container family size was between 9,000TEU and 14,000TEU, less than 10 years old, and having to stop in the coming years for their second special survey. For the sake of the study, the focus was put on a 14,000TEU container vessel.

LNG retrofit and Jumboïsation may extend the lifetime of the asset until 2045 as each operation acts on the numerator and denominator of the EEXI and CII formula, the tools put in place by the IMO to monitor and control vessel CO2 emissions.

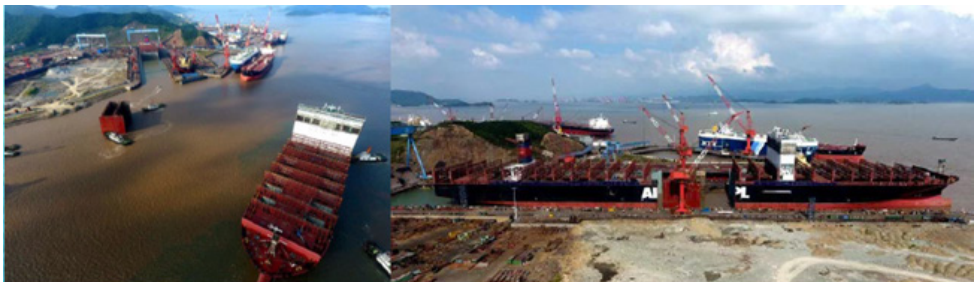



The Jumboïsation consists in cutting the container vessel in two and inserting a new section in between the two parts. This new section is almost 30m long and has the same breath as that of the ship.
It comprises room for more than 1100TEUs and an LNG tank of 12,200m3. This LNG capacity allows this size of ship to make the return voyage from Asia to Europe.

The tank is equipped with GTT Mark III membrane technology, which guarantees the Boil-Off performance, and is adapted to the lowest consumption level of the vessel.

The new block made of the LNG tank and the new container bay is built at the retrofit yard or at a GTT qualified block manufacturer prior to vessel arrival. It is equipped with the FGHS on top in order to reduce interfaces and the retrofit duration. The vessel arrives in the dry dock at the shipyard, she is cut in two, the fore part of the ship is floated out and the new section is floated in followed by the fore part. All three sections are aligned, the dry dock is emptied and the three sections are welded back together.

The vessel will stay 42 days in the dry-dock, and 4 months at the shipyard. The overall project requires a total of two years from early engineering to commissioning.



*Picture courtesy of COSCO Shipping Zhoushan*

*Picture courtesy of COSCO Shipping Zhoushan*

Based on market prices of Q1 2022, the cost of the whole operation is estimated at around $41 million while the additional revenue generated by the cargo capacity increase will generate an additional revenue of $6M per year. Also considered in the business case is the loss during off-hire and the saving generated by switching from conventional fuel to LNG. The business case has been built considering average historical prices for fuel costs, freight and charter rates on a return trip Europe to Asia at a speed of 17 knots lasting around 80 days.

It has been considered that only the main engine was retrofitted. 2 out of the 4 auxiliary engines will be replaced from conventional to pure gas engines, as it is easier to replace rather than to retrofit a 4 stroke engine from conventional to dual fuel.

OPEX savings by running on LNG have been estimated to $1.4 million per year, using again average historical prices for the fuel comparison calculation.

Overall, this study has shown that the initial investment of $41 million would pay back in less than 7 years, quite rapidly compared to the extend lifetime of the asset until 2045.

A sensibility analysis on the LNG price and freight price was also conducted and has shown that very interesting paybacks can be achieved when considering lower LNG prices.

While the newbuilding market clearly becomes saturated, LNG conversion is a proven and available solution that allows ship-owners to meet the IMO regulations currently in place and coming into force soon. Jumboïsation will offer an additional source of revenue contributing to improving the payback of the operation.