Tightening environmental regulations, setting limits worldwide on shipping emissions have increased the attractiveness of gas as a marine fuel and LNG has emerged as the principal alternative fuel option being adopted today.

Up to now, the use of LNG as fuel has been limited to small and mid-size ships. It was originally adopted by LNG carriers for the simple reason that the Boil-Off Gas naturally generated by the normal warming up of the cryogenic cargo had to be managed to avoid the rise of pressure. It represents a competitive energy as well. With a few exceptions, for larger vessels, only “LNG ready” ships have been developed, such as for tankers, large container carriers and Very Large Ore Carriers. The main reasons being uncertainty of the LNG supply infrastructure, ensuring affordable LNG supply compared to other fuels, and extra CAPEX for dual fuel propulsion and auxiliaries. However, on the large container carrier market, the permanently moving economic and environmental pressure forces owners to innovate in order to comply and maintain profitably especially knowing that fuel cost can reach 50–60% of total OPEX.

In that perspective in mind, CMA CGM, one of the top three of the world’s largest container liners, has adopted a disruptive innovation by the use LNG as fuel for their largest new build container ships. This breakthrough project is crucial for the entire industry as it will demonstrate that compliance to stringent environmental constraint and increased economic advantage is possible.
The project includes nine LNG fueled Ultra Large Container Vessels of 22,000 TEU each, to be built in Shanghai at CSSC HZ and JN shipyards, featuring GTT’s Mark III containment system. The supply chain also includes an 18,600 m³ LNG bunker ship to deliver 0.3MTPA of LNG fuel.

The purpose of the paper is to review the existing LNG fueled fleet and available LNG bunkering infrastructure. In addition, an evaluation of the compliant options to meet with the new IMO emissions regulations will be presented as well as the rationale behind the choice of the LNG for large container liners which have fixed routes and are tightly scheduled.

The technical challenges of the world’s first ultra large LNG fuel container vessel, as well as the associated LNG bunkering ship will be explored. The paper will share the main technical features of Membrane LNG tanks and associated gas handling equipment for both the container vessels and the related bunkering ship. Some photos of the containers and bunker ship under construction here in China will also be presented.
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World’s largest LNG fuel supply chain for World’s largest box ship
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World’s largest LNG fuel supply chain for World’s largest box ship
1 Air emissions from ships

Shipping has been a cause of harmful air pollution due to the acceleration of world global growth and the increase of goods exchange. It is however the most ecological way of transportation of goods per carried ton compared to road air and even train transport.

Although much of the pollution emitted by international shipping gets deposited over the sea, it may be one of the largest sources of acidifying fallout on land in some countries. It may also contribute to raise levels of health damaging PM and ozone. This pollution should be reduced in order to protect health and the environment and to make shipping an even more sustainable form of transport. Technical measures exist that cut the level of pollution from ships and this paper will detail one case study in particular with the use of Liquid Natural Gas (LNG) as fuel.

Regarding the emission regulation, shipping being an international business, it largely obeys to the UN International Maritime Organization (IMO) in which a specific committee deals with pollution, i.e., the Marine Environment Protection Committee (MEPC) of the. In 1997 an agreement was reached on an air-pollution and was published as an annex to the IMO’s marine pollution “MARPOL” Convention – Annex VI, which came into force in 2005. It set at the date of the publication of this paper a global cap of 3.5 per cent on (up to 1st January 2020) the sulphur content of marine fuel oil, and established provisions allowing for the designation of special sulphur emission control areas (SECAs) with lower sulphur content and even more stringent control on sulphur emissions.

For these areas, a limit to the sulphur content of fuel used onboard ships is set at 0.1%. Alternatively, ships can use an exhaust gas cleaning system (e.g. scrubber) to cut their SO2 emissions. The Baltic Sea was the first SECA to enter into force in 2006, followed by the North Sea in 2007. Annex VI also set limits on the emissions of NOx from marine engines according to Tier III in Emissions Control Areas to be cut by 80%. The latter limit applies in the North American ECA since 2016 and to be entering into force in the North European ECA from 2021 onwards.

2 International environmental regulation on air emissions from shipping

2.1 General

As already exposed, most of the regulations concerning shipping and in particular regarding air emissions are developed at the global stage since shipping is inherently shipping International and as such needs a uniform and global regulation. However we will see that unilateral air emissions restrictions exist in North America, North European countries and recently in China.
The convention IMO MARPOL, and in particular MARPOL Annex VI imposes restriction on emissions of pollutants (NOx and SOx), GHG (CO2, VOC) and ozone depleting substances. The CO2, SOx and NOx are emitted by internal combustion engines or turbines used for propulsion or electric generation onboard. The rest of the other gases are related to crude oil cargo transportation and use of refrigerant gasses, there will not be discussed in this paper. However, the so called methane fugitives emissions, also named as methane slip, whilst not regulated, will be discussed as the GWP of methane when released to the atmosphere cannot be ignored.

2.2 CO2 emissions regulation IMO DCS (Data Collection Scheme)

IMO DCS regulation requires all vessels above 5000 GT to monitor the fuel consumption during all voyages on worldwide bases. The vessel operators are required to update SEEMP and to include Data Collection Plan which with methods and measures for measurement and reporting of fuel consumption on yearly bases.

2.3 CO2 emissions regulation EU MRV (Monitoring Reporting & Verification)
The EU Regulation on the monitoring, reporting and verification of emissions of CO₂ from maritime transport (EU 2015/757) (hereafter: EU MRV Regulation) lays down rules for the accurate monitoring, reporting and verification of CO₂ emissions and other relevant information from ships above 5,000GT calling at EU ports.

Article 4 of the EU MRV contains the principles and Article 5 together with Annex I contain the methods for monitoring and reporting emissions of CO₂ emissions and other relevant information on maritime transport. Annex II contains rules on the monitoring of other relevant information including distance travelled, time spent at sea and cargo carried (for passenger, ro-ro and container ships).

Each year the company with responsibility on the ship's operations has to report the results of previous year's annual monitoring of aggregated CO₂ emissions emitted and other relevant information. In order to do so, companies shall apply the monitoring methodology incorporated in the monitoring plan (MP) as assessed by the verifier. The MP lays down the detailed monitoring rules to be followed when monitoring the CO₂ emissions and other relevant information data for a specific ship. It is therefore a fundamental document. Regular and at least annual checks of the MP by the company are required so as to ensure that the MP reflects the nature and functioning of the ship. Also, according to the regulation, some specific circumstances, as the change of the company or some findings by the verifiers, will trigger the modification of the MP by the company.
Main differences from IMO DCS are exposed below:

<table>
<thead>
<tr>
<th>DATA</th>
<th>REPORTED DATA</th>
<th>Verifier</th>
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</thead>
<tbody>
<tr>
<td>Per voyage to/from EU ports, within EU ports and yearly aggregated report</td>
<td>CO2 emissions calculated</td>
<td>Accredited by National Accreditation Body</td>
</tr>
<tr>
<td>Time at sea and in port</td>
<td>Actual cargo carried</td>
<td></td>
</tr>
<tr>
<td>Transport work</td>
<td>For berthing and voyage</td>
<td></td>
</tr>
<tr>
<td>Yearly reporting for all voyages worldwide</td>
<td>Hours underway</td>
<td>Administration or organisation duly authorised</td>
</tr>
<tr>
<td>DWT (as cargo proxy)</td>
<td>/</td>
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Normally at the date of publication of this paper the EU MRV regulation and IMO DCS Regulation would have been merged.

2.4 Energy efficiency design index EEDI (MARPOL Annex VI regulation 19)

The CO2 emission represents total CO2 emission from combustion of fuel, including propulsion and auxiliary engines and boilers, taking into account the carbon content of the fuels in question. If energy-efficient mechanical or electrical technologies are incorporated on board a ship, their effects are deducted from the total CO2 emission. The energy saved by the use of wind or solar energy is also deducted from the total CO2 emissions, based on actual efficiency of the systems.

The transport work is calculated by multiplying the ship’s capacity (dwt), as designed, with the ship’s design speed measured at the maximum design load condition and at 75 per cent of the rated installed shaft power.

The EEDI, in establishing a minimum energy efficiency requirement for new ships depending on ship type and size, provides a robust mechanism that may be used to increase the energy efficiency of ships, stepwise, to keep pace with technical developments for many decades to come. It is a non-prescriptive mechanism that leaves the choice of which technologies to use in a ship design to the stakeholders, as long as the required energy-efficiency level is attained, enabling the most cost-efficient solutions to be used.

2.5 MARPOL Annex VI on NOx emissions (regulation 13)

Environmental controlled areas so called ECA have been implemented in which Tier III requirements are to be fulfilled for any new construction after entry into forces.
Since January 2016, MARPOL Tier III requirement on NOx is in force for ships with keel-laying on or after 1 January 2016 and with engine output of 130kW and above in North American and US Caribbean ECA zones. Consequently, emissions of NOx are to be reduced by 80% compared to initial reduction level Tier I. Tier III requirement is not retroactive.

Available technological solutions for compliance with the IMO NOx Tier III limits are:

- Selective catalytic reduction (SCR) systems acting on eliminating NOx from exhaust gas on a catalyst bed,
- Exhaust gas recirculation (EGR),
- Alternative fuels such as liquefied natural gas (LNG), or liquefied ethane (LEG).

2.6 MARPOL Annex VI on SOx emissions (regulation 14)

Sulfur oxide emissions released by ships exhaust gas which was already limited to 1% since July 2010 must now be lower than 0.1% since January 2015 in Northern European waters (North Sea, Baltic Sea and English Channel), and along the United-States and Canadian coasts and parts of the Caribbean sea.

SOx and particulate matter emission controls apply to all fuel oil combustion equipment and devices onboard and therefore include both main and all auxiliary engines together with items such as boilers and inert gas generators.

Alternatively, there are other means of compliance that are accepted, such as exhaust gas cleaning systems which operate by water washing the exhaust gas stream prior to discharge to the atmosphere. When using such arrangements there would be no constraint on the sulphur content of the fuel oils as bunkered provided the relevant after-treatment system is properly certified.

More and more regions are considering implementing similar Emission Control Areas, and eventually a cap on the sulfur emissions of ships will be implemented worldwide 1st January 2020.
2.7 Other local regulations on air emissions

Local regulations such as California, Europe and China are already in force, capping at different levels sulphur emissions. This is in particular the case on coastline of China since early 2019.

3 Compliance with sulphur cap local and international rules

3.1 Compliant fuels

The use of so called compliant fuel: desulphurised fuel refined from heavy fuel oil or produced by blending different type of fuels such as distillates is a straight forward way to comply with the cap of 0.5% of sulphur content in marine fuels. However, they poses some concern in terms of reliability, stability during storage, additive that might generate wears and tears of injection pumps and liners, and low lubricity characteristics compared to heavy fuel oil.

3.2 Scrubbers

A possible alternative option to low sulphur fuel is to install exhaust gas cleaning (scrubbers), which can reduce SO2 emissions by up to 99 per cent, and also cut PM emissions. There are still some concerns however, including the abatement efficiency of various technologies especially when coupled to a 2 stroke engine, use in harbor areas is somewhat more and more forbidden, and waste production and handling. In the other hand, due to differential predicted prices between low sulphur fuel oils and HFO, for retrofitting existing vessels, return on investment can be short term beneficial for open loop types.
4 LNG a fuel

Using Liquefied Natural Gas (LNG) as marine fuel means a full compliance to any environmental regulation ahead. This statement is however subject to specificities depending on technologies (2 or 4 stroke, low pressure or high pressure gas injection).

Analyzing 2 stroke dual fuel engines, it is interesting to see the differences between the two technologies proposed on the market place, one using high pressure (HP) gas injection (above 350 bar) as per Diesel thermodynamic cycle (MAN B&W), the other one fulfilling Otto thermodynamic cycle with gas injection at a lower pressure (LP), 16bar(g) (WinGD).

LNG is the marine fuel resulting in the least emissions. Beside a reduction in overall CO2 emission the main benefits are:

- NOx emissions below Tier III limits permanently
- Sulphur emissions disappear literally
- Particulate formation 90% lower than with liquid fuels
Applying LNG as fuel broadly for international shipping will reduce the harmful emissions from shipping and bring the international shipping into the forefront to combat global air pollution.
5 LNG as fuel market development

5.1 LNG as fuel vessels

Initially, the LNG as fuel initiative was limited to vessels operating all year in Emissions Control Areas (ECA) by fix routes where funds were encouraging the use of low NOx technologies. This was particularly the case for Norway where in the 2000’s the first fjord ferry gas only was put in service with a relatively small power propulsions system and small LNG storage onboard.

In parallel, the LNG carrier industry experimented in 2006 the first ever Dual Fuel engine to be installed onboard a vessel.

The LNG carrier “GdF Provalys” featured a DF electric propulsion system with three 12V50DF and one 6L50 DF Wartsila. These engines opened the new era of DF propulsion and electric generation onboard commercial vessel, either under IGC regulation for LNG carriers or under IGF code regulation for the other types of vessels.

During the years 2006-2014 the industry has seen a steady and slow evolution of the market of LNG fuel vessels, mainly composed of short sea shipping and ferries. The reason behind was mainly the presence of emissions control areas, as already mentioned in Baltic and North Sea in Europe and the second in North America, with allocated funding, the lack or limited LNG bunkering infrastructure, mainly composed of truck to ship bunkering convenient for short voyage ferries and shorts sea shipping embarking a limited amount of LNG, and in addition the relatively high cost of construction around +20 to 30% more compared to a liquid fuel version (CAPEX) and high fuel cost (OPEX) compared to HFO of MGO at equivalent energy basis. In addition to these costs, an extra price to pay is the waste of cargo space due to the poor integration of LNG storage tanks and the lower density and energy content of the LNG vs HFO or MGO.

There has been a sharp change of the LNG as fuel market in 2017 with the adoption of LNG as fuel by Ultra Large Container Carrier Ocean going vessels. The fleet in service is above 132 units (aggregate diverse fleets) when the new orders is building up to 140 units. Mainly covered regions are North Europe and North America, which is not surprising due to ECA regulation. Other emerging areas such as Asia, Australia and South America still own a limited number of units.
World’s largest LNG fuel supply chain for World’s largest box ship
To give one figure in order to understand and grasp the sudden acceleration of the LNG Fuel market development, one of the nine CMA CGM Vessel will have more LNG stored onboard than all the aggregate volume of LNG fuel existing vessels and under construction.

5.2 LNG Bunkering infrastructure development

When we look back to the development of LNG as fuel vessel, it is pristine clear that the “vault key” for a wider development of LNG as fuel was the LNG bunker delivery logistic chain. The first age of LNG as fuel was satisfied with LNG bunkering from trucks, but rapidly it appeared not more bearable to multiply the number of trucks to deliver requested higher quantities of LNG as fuel. It became obvious that larger investment were necessary, involving many stakeholders internationally.

Shell and Total were the first LNG supplier to understand the new market development needs and to bring an appropriate answer in terms of large scale bunkering solution. The MOL owned bunker vessel, chartered by Total Fuel featuring 18,600 m³ of LNG bunker capacity, two GTT’s Mark III membrane tanks and the appropriate auxiliaries to transport, store, deliver the LNG and mange vapor return from client vessel is the top of its class new design LNG bunker vessel.

With this LBV in operation in Rotterdam and ARA region, from early 2020 onwards, the availability of LNG as fuel in a quantity in scale with the developed market is secured. The rest of the world is also moving quickly, North America sizing new LNG floating bunkering such as the 2,200m³ “Clean Jacksonville” in Port Fourchon USA.

In Canada the long date existing fleet of LNG as fuel vessels is of a paramount importance for an active development of LNG bunker solutions. Port Authorities and gas producers and distributors in West Coast as well as East Coast are seriously considering investments in LNG bunker vessels able to provide LNG fuel for the domestic fleet and the international trade vessels as well. Canada is a long lasting in LNG export and is able to turn its facilities to rapidly scale up a large LNG bunkering chain.

In Asia, whilst being a bit late on the market due to a traditional high price of LNG and absence of environmental regulations in place, rapid decisions making process and implementation of local emissions control areas such as in PRC induced by MSA, enabling the region to catch up with the demand of international and local LNG fuel markets.

Today, about a dozen of LNG bunker vessels of different sizes are in operations, mainly in North Europe, but also in North America. Asia has signed different sizes of LBV under construction mostly in China, when the second largest LBV owned by MOL and chattered by Pavilion and Total will be delivered by Singapore based shipyard.
SembCorp. BV is by far the main class for these vessels, independently of technologies and sizes, our expertise on LNG bunker vessel (first ever LNG bunker vessel Gas4Sea - ENGIE NYK as members of the alliance - Zeebrugges launched in 2015 is BV class) and strong involvement on LNG regulation has made preferred choice of class for such innovative vessels.

The LNG STS (ship to ship) is the way for developing the market, mimicking the HFO and MGO market, offering flexibility and opportunities to use the LBV as short sea LNG carriers to answer other demands. But there is a cost to pay, as a typical LNG bunker vessel will cost up to five times more than a basic HFO/MGO bunker barge. Investors are at stake, and many of them have taken action by facilitating local regulations, delivering financial supports and learning from other front runners.

6 ULCV LNG fuel 22,000 TEU Dual Fuel

6.1 Dual fuel project history of CMA CGM initiative

CMA CGM has a reputation to be in the front line of innovation and environmental care. This was again demonstrated by the bold decision, long matured willingness to endeavor the order of LNG fuel Ultra Large Container Carriers. The decision was taken to equip the 22000 TEUs nine vessels with a technology firmly focused on the protection of the environment. By choosing LNG, CMA CGM confirmed its ambition to be the leading force in the industry in environmental protection by being a pioneer in innovative and eco-responsible technologies.

The project is the conclusion of a long lasting investigation made since 2010 when the first JIP with DSME & CMA CGM was elaborated. Back that time, environmental regulation was already encouraging to find alternative way of being sustainable whilst maintaining profitability. However, due to the lack of LNG bunkering chain and the lack of visibility in terms of LNG fuel costs, it was not found relevant to derive the AIP to a real project. Type B tank and high pressure DF 2 stroke engine propulsion system were assessed; ship structure and LNG fuel storage, and economics were also studied.

In 2013 a 16000 TEU MARIC & Shanghai Jiangnan Changxing Heavy Industry was assessed. Membrane type fuel storage tank was considered. Meanwhile other AIP and JDP were achieved paving the way to a clear mutual understanding of such design.
In 2017, all planets were aligned for a groundbreaking decision by CMA CGM to request shipyards to propose an ultra large container ship with option for DF. HZ was finally selected and associated LNG bunker vessel came along rapidly, to be constructed in the same shipyard.

Initially the project was targeting two bunkering operations in the sailing loop, as usually the case for HFO bunkering, one bunker stop in Malacca Strait-Singapore area, one in ARA region. Unfortunately, due to the uncertainty of the LNG bunker fuel back in 2017 and the differences of prices, it was decided to operate the vessel in the route North Asia to North Europe with one bunkering stop in Europe only, almost doubling the capacity of storage of LNG fuel onboard.
6.2 Design challenge

Designing such ULCV with LNG storage and Gas Fuel propulsion systems onboard pose different types of challenges. First of all, the large size of the vessel will bring some concern regarding stiffness of the structure, whipping and springing. Secondly, combining an LNG storage, a fuel gas handling system and a DF Main engine propulsion system will complicate the design of the ship due to additional ventilations duct routings, hazardous area arrangements, large membrane containment system to be accommodated in such a way to minimize the waste of cargo space, arrangement of vent masts, routing of double wall gas fuel piping with correspondent stress analysis consequence of long length of the double wall gas piping and localization and design of LNG bunker station. This non exhaustive list give an idea on how creative and proactive the stake holders, designer, shipyard, ship-owner, Class society and LNG fuel system main makers must be and cooperate positively at earliest stage for the success of the project.

On the 22kTEU DF, it was found necessarily rapidly that GTT, BV and MARIC to seat together to discuss on all relevant challenges. Later on the project, WGS was involved in the design of the FGHS.

Figure 13: 3D view of 22kTEU DF with location of GTT’s MarkIII LNG containment system

6.3 Sloshing

Due to partial filling, the wide only tank had to pass calculation for sloshing during normal operation of the ship, including navigation in North Atlantic condition; no partial filling can be excluded. Therefore calculation was made by Bureau Veritas and GTT, outputs concluded to reinforcement of the surrounding structure, change of foam density, and fine tune of the shape of the tank with adapted chamfrains.

Figure 14: Typical sloshing forces distribution
6.4 Operational issues

Rapidly after having cleared the main design issues, came the operational concerns, which might be even more critical that any design issue, since the subject was clearly new to all.

Amongst operational issue the most critical was how to secure permanently the bunkering of large quality of LNG in a container terminal, ships being alongside, during a limited period of time, with commercial simultaneous ongoing operations (SIMOPS) at relevant quality level and economic conditions.

Regulation on bunkering was and is still in progress, with SGMF LNG bunkering safety guidelines rev2 being republished with a much better understanding thanks to excellent IACS contribution, offering for the first time a frame for discussion with LNG fuel suppliers, ports authorities, container terminals, bunker operators and flag administration. BV has offered its expertise to accompany owner during several meetings, thanks to its active contribution on publishing SGMF Safety guidelines and BV NR620 LNG bunker ship. Other standards and regulations which have been taken into consideration are ISO 20519 and EMSA bunkering guidance.

![Figure 15: 3D artist view of SIMOPS LNG bunkering of a container carrier](image)

The main steps beforehand for the authorization of LNG bunkering to be delivered by the Port Authority are as follow:

6.5 Risk assessments

A bunkering operations risk assessment was undertaken in accordance with ISO 20519 (superseding the former ISO TS 18t683) which is specific to the supply of LNG as fuel to ships and refers to recognized standards that provide detailed guidance on the use and application of risk assessment. The objectives of the bunkering operations risk assessment are to:

- Demonstrate that risks to people and the environment have been eliminated where possible, and if not, mitigated as necessary and
- Provide insight and information to help set the required safety zone and monitoring and security area around the bunkering operation To meet these objectives, as a minimum, the bunkering operations risk assessment should cover the following operations:
  - Preparations before and on ship’s arrival, approach and mooring
  - Preparation, testing and connection of equipment
  - LNG transfer and boil-off gas (BOG) management
  - Completion of bunker transfer and disconnection of equipment
  - Simultaneous operations (SIMOPS).
The scale of risk assessment required for the bunkering process will depend on the bunkering method and equipment used with additional, more detailed, levels of risk assessment potentially required where novel procedures and/or equipment are selected. Risk assessment activities are generally broken into two main parts.

A higher level HAZID defines the scenarios that are possible. A HAZOP follows and this looks at more detailed scenarios and should provide mitigations for them. It is recommended that both of these activities are conducted with professional guidance, the Chairperson should be independent of all stakeholders to help ensure that an appropriately detailed and effective outcome is achieved.

Where designs or operational methods are modified after the risk assessment(s) have been conducted this may result in the risk assessments needing to be revised accordingly.

6.6 General description

The project is an ultra large container carrier (22 000 TEU), the larger in the world at the signature date of the contract. It features DF propulsion system, large membrane tank Mark III, gas handling preparation and gas fuel supply system. The vessel is an ocean going single screw dual fuel diesel engine driven fully cellular container vessel suitable for carrying dry cargo containers.

The vessel has a raked stem with straight bow, a transom stern and on continuous deck. Accommodation including Navigation Bridge is located semi-fore and an engine room is located semi-aft separately.

LNG storage tank, membrane type, GTT’s Mark III, is installed below accommodation under deck in accordance with IGF code. The double bottom and side area around the LNG storage tank are arranged as void space. Double hull construction is provided from N°1 to N°11 cargo hold including engine room. Double bottom shall be extended from aft peak bulkhead to as far forward as practicable subject to strength consideration. Double bottom shall be about 2650mm. Ballast overboard is arranged in way of engine room.

6.7 Principal dimensions

- Length overall: 399.90 m
- Length between perpendiculars: 393.9.00 m
- Breadth (moulded): 61.30 m
- Depth (moulded): 33.50 m
- Design draught (moulded): 14.50 m
- Scantling draught (moulded): 16.00 m
- Freeboard Type B

6.8 Cargo capacity

Capacities maximized 20ft container (ISO standard 8ft 6inches high container). Lashing for 5 tiers lashing bridges.

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<tr>
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<th>20 ft</th>
<th>40 ft</th>
<th>Total (equivalent TEUS)</th>
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<tbody>
<tr>
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<td>308</td>
<td>13324</td>
</tr>
<tr>
<td>In hold</td>
<td>9696</td>
<td>-</td>
<td>9696</td>
</tr>
<tr>
<td>total</td>
<td>22404</td>
<td>308</td>
<td>23020</td>
</tr>
</tbody>
</table>

6.9 Main fuel and lube oil tank capacities

- The LNG fuel is stored in one cargo tank with total maximum capacity of 18,600 m³
• HFO/LSHO total volume including service tanks (100% full) abt. 2500 m³
• MGO/MDO total volume including service tanks (100% full) abt. 1500 m³
• Fresh Water Tank (100 % full) abt. 550 m³
• L.O. (100 % full) abt. 500 m³
• Ballast Water tanks (100% full) abt. 51,000 m³

6.10 Deadweight
Design draught (moulded) 14.50 (m)  
Deadweight abt. 184 900 (t)
Scantling draught (moulded) 16.00 (m)  
Deadweight abt. 216 900 (t)

6.11 Powering
The vessel is capable of continuous operation at the maximum propulsion shaft power (MPP).

• Propulsion System :
  o One Main Engine type WinGD 12X92DF
• Dual-Fuel Generator Engines
  o Number of Engines: 6
  o Type: 9L34DF - 4320kW x 2 + 8L34DF - 3840kW x 4
• Dual Fuel Auxiliary Boiler
  • It can be used as GCU
  • Steam capacity: 14t/h
  • Maker: ALFA LAVAL

The predicted speed is 22.0 knots at the scantling draught and at main engine output of 90%MCR.

7 Description of the LNG fuel storage tank and the fuel gas handling system (FGHS)

7.1 General
The main advantage of membrane tanks is that they make efficient use of the space available on board. The Mark III membrane system chosen for this large container vessel concept consists of a cryogenic liner directly supported by the ship’s inner hull. The liner is composed of a primary metallic membrane with an insulation layer and a secondary membrane underneath. The max pressure allowable of this tank design is 700 mbarg.

One key challenge is the management of boil-off gas. The pressure slightly increase inside the membrane tank due to heat ingress and must kept well below MARVS to prevent releasing gas to the atmosphere. This is achieved by using the boil-off gas to power the auxiliary engines and the boiler for hotel load supply.

During navigation, the power demand from main propulsion engine DF WinGD is much higher than the natural boil-off, thus ensuring a low operating pressure inside the tanks. However, the inside pressure above saturated pressure will still be monitored in order to prevent extra boil off gas during navigation at nominal speed.

7.2 Fuel Gas Handling System
The main function of the Fuel Gas Handling System (FGHS) is feeding gas consumers. Gas consumers are separated into medium and low pressure classes. Inlet gas pressure of the auxiliary engines and boiler are around 6 barg; whereas, inlet gas pressure main engine is around 16 bars.
The FGHS is directly located on the top cofferdam of the LNG fuel tanks. This configuration enables shortest distance between fuel storage and FGHS.

In parallel of gas supply, the FGHS has been designed to keep tanks’ pressure within their design range at all times, in accordance with IGF Code. As design gas consumption is twenty times greater than maximal boil-off gas, tank pressure will be easily managed along the ship operational profile. Furthermore, thanks to an auxiliary boiler, idle condition following IGF approach is covered.
The main role of Fuel Gas Handling System is to supply to engines and boiler necessary amount of fuel gas. As mentioned above, Natural Boil Off rate will be too low compared to Main Engine consumption need. That’s why on top of NBOG, Forced Boil Off will be created through vaporizers.

7.3 FGHS components

- 2 BOG compressors.  
  Screw compressor oil free non-cryogenic
- 2 BOG heaters
- 2 LNG vaporizers
- LNG tank is fitted with 4 pumps submerged pumps.  
  2 fixed pumps with a rate of 16m3/h, one fixed pump with a capacity of 32m3/h and one retractable pump of 32m3/h. The drum of 32 m3/h retractable pump will be able to receive one emergency pump of 230 m3/h in case of de-bunkering necessity.
- Vent Mast  
  One FWD vent mast is arranged for LNG fuel tank, primary insulation space and for FGHS safety valves respectively. Height and dimensions are designed according to BV and IGC requirements. A second venting mast is installed in E/R funnel for maintenance routing operation of GCU, Main Engine and Auxiliary Engines.
7.4 FGHS capacity

- NBOG: up to 830Kg/h
- FBOG: up to 14 t/h

![Figure 16: Typical Fuel Gas Supply System Process flow diagram](image)

7.5 LNG Bunker station

The LNG bunkering station is located on hull recess at same level than accommodation ladder. One bunker station is arranged on starboard side, one bunker station is arranged on port side. Each station is arranged with two liquid transfer manifolds and one vapor connection transfer manifolds.

The LNG liquid lines are used for both is possible using the submerged LNG supply pumps. Two liquid manifolds and one vapor manifold shall be arranged on each port and starboard side. The following connections are provided:

- LNG max bunkering rate: (including slow starting & topping-off): 1600 m3/h
- Maximum back pressure at liquids manifolds: before strainers during loading: 2.3 barg
- Number of liquids manifolds used during loading: 2 (per side), size: 8”
- Number of gas manifolds used during loading: 1 (per side), size: 8”

World’s largest LNG fuel supply chain for World’s largest box ship
7.6 Main engine Dual Fuel WinGD

WinGD 12X92DF

- Type: Two stroke, single acting, direct reversible, crosshead, electronically controlled
- Number of cylinder: Twelve
- Cylinder bore / Stroke: 920mm / 3,468mm
- SMCR: 63,840 kW x 80 RPM
- NCR: 57,456 kW (90% SMCR) x 77.2 RPM
- Starting method: Compressed air (max. pressure of 3 MPa)
- Type: Low Pressure (Otto cycle)

8 World’s largest LNG bunker vessel

8.1 General

The LNG bunker vessel is driven by a Dual-Fuel Diesel Electric system for propulsion and power generation with twin Azimuth thrusters, vertical-shaped bow and transom stern designed for the bunkering of Liquefied Natural Gas (LNG) to LNG fueled vessel. The vessel is of 2G type. The cargo containment system is a membrane Mark III Flex type as developed by GTT. The cargo area is of double hull, and cofferdams which are located at forward and aft end of the cargo area and between cargo tanks with double bottom construction, and consist of two center cargo tanks with GTT’s Mark III Flex.

The vessel has a continuous main deck with a transom stern and a raked stem with bulbous bow, two Azimuth thrusters driven by a Dual-Fuel Diesel Electric system. She is designed to meet for LNG bunkering operation to the CMA-CGM 22,000 TEU LNG-Fueled Container vessel. The requirements of specific berths have been fully considered, with particular regard to details, such as the working envelopes of cargo arms, bunkering facilities, ballast tank arrangement, fenders, flat of side, shore gangways, and storing pickup points.

![Figure 17: Rendering view MOL LBV 18,600m³ with main auxiliaries](image-url)
8.2 Principal dimensions
- Length overall 135.00 m
- Length between perpendiculars 131.00 m
- Design draught 6.50 m
- Cargo Tank 100% full
- NO.1 Cargo Tank abt. 9,300 m³
- NO.2 Cargo Tank abt. 9,300 m³
- Total capacity : abt. 18,600m³

8.3 BV Class notations
+HULL, +MACH, LNG Bunkering Ship, BOG, RE, Initial-CD, IG- Supply, DualFuel, Unrestricted Navigation, +AUT-UMS, AVM-APS, +AUT-PORT, VeriSTAR-HULL CM FAT, SYS - NEQ, MONSHAFT, INWATER SURVEY, CLEANSHIP (C), GREEN PASSPORT, ERS-S, BWE, BWT.

8.4 SIMOPS

The main challenge offered by LNG as fuel is to maintain same profitability as for an usual fuel such as HFO or MGO. We have been through all technical details and highlighted the design differences and the safety assessment to be done in order to ensure at least same level of safety compare to a liquid fuel vessel version.

![Figure 18: Various cases of bunkering operation with pressurized/atmospheric LNG fuel tanks](image)

Same approach is expected when dealing with LNG bunkering. In particular, it is requested by end user the authorization to bunker LNG as fuel during commercial operations, inducing that the bunkering operation will not take place in a dedicated remote area but will take place in the container terminal, ships side by side, container loading and unloading by cranes, “business as usual”.

This require a specific risk approach, named SIMOPS, where not only the bunkering operation will be analyzed, but also the environment around the ship, its possible interaction, and other activities of the port around that would be impacted or would impact on the bunkering operation itself.

Simultaneous Operations can add additional hazards, particularly ignition sources outside of those associated with the bunkering operation itself. SIMOPS are inevitable in many ship operations however; this must not significantly impact the safety of the LNG transfer process. Procedures and rules can be designed to successfully allow SIMOPS through co-ordination between the port authority, terminal operator, bunker infrastructure owner and gas fueled ship. SIMOPS should not in general be permitted inside the safety zone.
The safety zone is defined as an area where special precautions are taken to limit access, ignition sources and other hazardous events. Special precautions and extensive risk assessment should be required to justify allowance of non-standard operations only within the safety zone. SIMOPS is to be at an acceptable level and all parties involved are in agreement. The risk assessment should take into account as a minimum, but not be limited to, the following:

- Size of the safety zone
- Failure/impact scenarios
- Access and escape / evacuation routes
- The largest credible spill
- The transfer flow rate
- Access, including evacuation routes and times
- The type of cargo operation
- Safeguards to control passenger/cargo movements
- dropped objects
- vent mast positions and air intakes and
- Hazardous cargo handling or restrictions

A safety zone and a monitoring and security area may be established around the bunkering operation in accordance with ISO 20519. These zones are in addition to the established practice of setting the hazardous zone that will be required around areas with potential for explosive atmospheres such as the bunkering connections, valve stems, flanges and vent stacks. The safety zone is the 3-dimensional envelope where natural gas/LNG may be present as the result of a leak/incident during bunkering. There is a recognized potential to harm life or damage equipment/infrastructure as the result of a leak of gas/LNG. The zone is temporary in nature it only being present during bunkering. This zone may extend beyond the gas fueled ship/bunker vessel. In the safety zone, the following restrictions normally apply during the bunkering operations, except if otherwise justified by the safety analysis or agreed by the National Regulator:

- Naked lights are not permitted
- Naked lights, mobile phones, hand held radios, cameras and other non-certified portable electrical equipment are strictly prohibited
- Cranes and other lifting appliances not essential to the bunkering operation are not to be operated
- No vehicle (except the tank truck) should be present in the safety zone
- No ship or craft should normally enter the safety zone, except if duly authorized by the Port Authorities
- Other possible sources of ignition should be eliminated
- Access to the safety zone is restricted to the authorized staff, provided they are fitted with personal protective equipment (PPE) with antistatic properties and portable gas detector
9 Technical challenges and lesson learned

Contrary to conventional LNG carrier, the LNG fuel tank for this project has such features:

- All filling level, as it is a fuel tank,
- Large and single fuel tank

In order to design a proper solution, specific design shall be considered in order cope with the requirement. The key changes are:

- Insulation reinforcement: The insulation panels needs to withstand the load coming from the LNG sloshing. Heavier densities on foam panel up to 210Kg/m³ need to be produced in some parts of the tanks. GTT already implemented similar reinforcement on Very Large Ethane Carrier (VLEC) which are designed to carry heavier cargoes such as Ethane and LPG
- Primary Membrane reinforcement below corrugation: like the insulating panel, the primary Membrane is facing the sloshing loads of the cargo, and needs to have proper reinforcement underneath the corrugations with so called “wedges”. While wedges are usually in plywood, for this particular project the material used is aluminum that is stronger than plywood in order to avoid major deformations of the primary membrane.

![Figure 20: Artiste view of the aluminum wedges below primary membrane corrugations](image)

- Inner hull reinforcement: As the membrane tank is non self-supported and used load bearing material, the inner hull shall be also designed to withstand the hydrodynamic pressures from fuel tank. Therefore specific assessments combined to sloshing tests have been carried out to define a minimum thickness for the hull. In these conditions, the deformation of the hull against sloshing stays similar as observed on LNGC.
- Protection of pump tower: Due to the high sloshing load and because only fuel gas pumps are applied, GTT has revisited the design of the pump tower in order the limit the exposition of the equipment to the sloshing.

10 Conclusions

This project is by far the largest LNG fuel supply chain up today, and has doubled the total LNG fuel volume contract. As a world first in a nascent LNG fuel industry, the nine Ultra Large Container Vessels and the dedicated LNG bunker ship has been a key factor of the development for the LNG fuel industry. We will see more and more vessels LNG fueled in the near future thanks to the large development of the LNG bunker fleet all over the world. Supply and economics of LNG will play a significant role in that development, and container transported by such clean and efficient ships will remain more than ever the cleanest and cost effective mode of transport thanks to LNG as fuel.
At the writing of this paper, another order of LNG powered ULCV has been placed, a retrofit of an existing ULCV as well as a new order of a large LNG bunker vessel in Singapore, confirming the trend for innovation and economic advantage with the adoption of LNG fuel.

GTT, Bureau Veritas, CMA CGM, MOL, and Total have proven not only the technical feasibility of LNG as fuel but more importantly the viability of the economic model thanks to this disruptive innovation for a cleaner future.