World’s Largest LNG Fuel Supply Chain for World’s Largest Box Ships

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Diverse fleet – ocean going vessels emerging

Fleet in service (127):

Mainly covered regions are North Europe and North America, which is not a surprise due to ECA presences. Other emerging areas such as Asia, Australia and South America still with still a limited number of units.

New Orders (135):

Trend is to large ocean going vessels with stable trades routes such as containers carriers, or large cruise ships with fix operating areas.
BV involvement in gas fueled ships
38 ships in service and 54 ships on order

→ BV leading class for LNG fueled ship orderbook with strong references
Environmental regulation in shipping - Timeline 2019 – 2050

**EU MRV**
- First mandatory reporting period starts 1 Jan
- Verified annual emission report by 30 Apr

**IMO BWM**
- Certification existing ships by IOPPC renewal after 8 Sep

**IMO DCS**
- DoC for SEEMP Part II by 31 Dec

**IMO SOx**
- Global 0.5% sulphur cap enters into force on 1 Jan

**IMO NOx**
- North Sea & Baltic Sea ECA enters into force on 1 Jan (tier III)

**IMO EEDI**
- Phase 3 enters into force on 1 Jan (up to 30% reduction)

**IMO GHG**
- Reduction of the total annual GHG emissions by at least 50% by 2050 compared to 2008

**IMO CO2**
- Adoption of revised strategy (COP 23)
- Reduction of CO2 emissions per transport work by at least 40% compared to 2008
Local emissions regulations

MARPOL Annex VI on SOx emissions (regulation 14)

Until 31 December 2018

Since 1 January 2019
Different options for IMO 2020 compliance

1. Switch to low-sulphur fuel
   - Negligible CapEx
   - Available in main ports, (require some refinery upgrade)
   - Price, NOX & CO2 reduction?

2. Keep HFO - invest in scrubbers
   - Fuel price
   - HFO availability - further acceptance of scrubbers
   - Capex & Opex – increase CO2

3. Switch to LNG - invest in new equipment or retrofit
   - Global Emission compliance + Opex reduced
   - LNG availability for tramping
   - CapEx

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**Vehicle Type**
- VLCC
- MR Tanker
- Panamax
- Handymax
- Handysize
- 12-14,999 TEU
- 1-1,999 TEU

**Estimated Retrofit Cost**
- $4.0m - $8.0m
- $3.5m - $4.5m
- $5.0m - $6.0m
- $4.0m - $5.0m
- $3.0m - $3.5m
- $6.0m - $7.0m
- $1.0m - $2.0m

**Feasibility**
- LNG as fuel
- HFO + scrubber
- MGO or LSHFO

Illustrative FO prices FOB Rotterdam

Courtesy Clarkson's
Evolution of ship propulsion 1850 – 2020

From sail to gas

A clipper ship built in 1852 was a sailing vessel setting the 1854 world record for fastest sailing ship at 22 knots.

Built in 1865 to compete with tea clippers, *Agamemnon* could steam at 10 knots consuming only 20 tons of coal a day (half of previous steamships) thanks to compound steam engine.

*Selandia* was the largest and most advanced diesel-driven ship at the time of her maiden voyage from Aalborg to London in January 1912 (12 knots).

CMA CGM decides to equip its future nine 22,000+ teu ultra-large container ships (UCLS) to be delivered in 2020 with engines using liquefied natural gas.
Emissions advantages / Gas Only and Dual Fuel Engines

However some obstacles need to be addressed:

- Methane slip which aggregate unburned methane specifically in Otto cycle and possible limited gas vent after engine stop should be taken into account as it might reduce significantly the CO2 reduction advantage.

- NOx Tier III compliance with high-pressure gas engines (needs EGR)

- Knocking & misfiring
2 stroke DF for large cargo vessels

**MAN B&W MEGI**
- Operation according to the standard Diesel cycle, in gas mode and FO mode
- Gas is injected in the cylinder at high pressure (350 bar) close to TDC
- Pilot injection necessary to start the combustion process

**WinGD XDF**
- Operation in gas mode according to the Otto cycle, with premixed lean burn technology
- Gas admission in the cylinder at low pressure (18 bar max) at mid-stroke
- Ignition by pilot injection in pre-chamber, to ensure the ignition of gas
MN – Gas composition & knocking resistance

- The MN is a **calculated** value from a gas composition to determine the combustion properties of that gas composition.

- For the definition there are two boundaries:
  - Pure methane is defined as MN 100
  - Pure hydrogen is defined as MN 0

- Example:
  - A mixture from 80% methane and 20% hydrogen has the MN number of 80

- Gas compositions with other components which show the same combustion behavior than 80% methane and 20% hydrogen have the same MN (80).

Don’t confound MN with methane content!
The challenge of methane slip

The sources of methane releases in the atmosphere are:

- Slip during gas combustion – poor combustion process
- Poor combustion chamber design
- Release when stopping gas operation
- Tanks designs and operation

Methane slip & GWP for a 2-stroke DF Diesel cycle engine:

- 0.2 g/kWh (E3 cycle)
- 25-100% load

For a 4 stroke DF Otto cycle: <2g/kWh.
## LNG fuel tanks & volume ratio

<table>
<thead>
<tr>
<th>Tank type</th>
<th>Membrane</th>
<th>Type B</th>
<th>Type C single cylinders (x3)</th>
<th>Type C multi lobe (up to 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume useful for the LNG for a volume available of 2000 m³ in the tank hold space</td>
<td>1620 m³</td>
<td>1335 m³</td>
<td>970 m³</td>
<td>1230 m³</td>
</tr>
<tr>
<td>Volume ratio</td>
<td>75%</td>
<td>63%</td>
<td>45%</td>
<td>62%</td>
</tr>
</tbody>
</table>
It did not come overnight…

**Several JIP with CMA CGM**
- **2010 – DSME BV JIP with type B tanks and MEGI main engine**

- **2012/2013 – 16000 TEU MARIC & Shanghai Jiangnan Changxing Heavy Industry**

**Progress made – lessons learnt**
- Venting and gas purging system (in particular optimised vent mast location)
- DF Otto cycle and HP Gas Diesel for Main Engine comparison
- Fuel gas systems
- LNG fuel tank arrangement
Main parameters for design

- For LNG mode (with MDO as pilot fuel):
  - When running on LNG mode only, cruising range shall give ability to perform **one round trip**. The reason behind this requirement is that bunkering facilities will most probably be available only in Europe at first. In other words, the vessel should be able to leave Europe, go to Asia, and come back to Europe while burning LNG only (expect MDO as pilot fuel).
- LNG will not be limited to ECA areas only.
- LNG should be bunkered during **commercial operations**, to keep bunkering time as blank.
- Minimize **cargo capacity loss**.
Main safety issues to be addressed for LNG as fuel propulsion

**Location of gas fuel tanks**

- To prevent explosion in case of collision and grounding leading to penetration of the tanks and to segregate tanks from accommodations and cargo spaces

**Bunkering**

- The majority of LNG carriers incidents happened during LNG transfer. The risk of casualties may increase during transfer operations.

**Machinery safety**

- Risks of gas-related hazards are to be minimized through arrangement (required double piping), detection, ventilation and safety actions
Tank and fuel gas preparation system design

- Engineering for **optimized** Fuel Gas Handling System and Bunker Station
- **Compact** System thanks to **membrane** Fuel Tank - 18 600 m³ LNG - location underneath accommodations,
- One tank
- Limited impact on cargo bays next to accommodations
GTT Mark III containment system is a sea proven technology.

The corrugated stainless steel primary barrier:
- Thickness: 1.2mm
- Material: Stainless Steel 304L

The insulation panel:
- It is a prefabricated component integrating the two insulation layers and the secondary barrier and on top of which the primary barrier is welded.
Sloshing: excessive loads identified through CFD analysis

Tank modified with *chamfered* upper plane to deflect sloshing loads

18,600 cbm Mark III membrane system
1. Seakeeping analysis - to calculate the motions of the ship and, consequently, tank motions,

2. Sloshing model tests (carried out by the designer) and computational fluid dynamics (CFD) calculations (both using calculated tank motions) are carried out in order to determine sloshing loads,

3. Sloshing loads applied to entire containment system.

3-step sloshing assessment and calculation process
Some progress
Tight schedule: 9 vessels, 2 shipyards: Hudong & Jiangnang, First vessel to be delivered first quarter 2020.

Many Large-Scale LNG sources with potential future development (Oman, Suez, Jebel Ali, Fujairah). Total & Shell bunkering hubs.

LNG Bunker in Singapore soon

LNG offers under development with Yokohama intended to be an LNG bunkering hub.
LNG Bunker vessel – MOL Total – 18600 cbm – GTT CCS

- GCU
- Elevated manifold for loading at terminal
- Lower manifold for bunkering
- Mark III CCS
- Sub cooling unit
- Brayton type
- Compressor
The main risk assessment is to be developed for the LNG operation with SIMOPS (commercial operation during bunkering).
Wrap up & conclusion

This project is by far the largest LNG fuel vessel today. It has drastically boomed the total LNG fuel volume contract and transformed the LNG as fuel market. As a world first in a nascent LNG fuel industry, the nine Ultra Large Container Vessels and the dedicated LNG bunker ship have been a key factor of the development for the LNG fuel industry. We are seeing more and more vessels LNG fueled in the near future thanks to the large development of the LNG bunker fleet all over the world. CMA CGM, BUREAU VERITAS and GTT have pioneered this new era of ocean going vessels LNG fueled and worldwide bunkering operations along the international trade routes opeing the way for the entire shipping industry to replicate at lower industrial and logistic risks.

At the writing of this paper, another order of LNG powered ULCV classed by BV and fitted with GTT membranes has been placed in China, as well as a new order of a large Japanese owned LNG bunker vessel classed by BV and fitted with GTT membranes in Singapore, confirming the trend for disruptive innovative clean ships accompanied with larger LNG bunker vessels and economic advantage of LNG fuel.

CMA CGM, MOL, Total, Bureau Veritas & GTT, have proven not only the technical feasibility of disruptive designed LNG as fuel clean ships but more importantly the viability of the logistic and economic model.
Thank you for your attention!

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