LNG fuelled bulk carriers and tankers

INTERTANKO & INTERCARGO
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Martial CLAUDEPIERRE
LNG and Alternative Fuels
Business Development Manager
1. Environmental regulations
   Reduction of CO2, NOx, PM and SOx emissions

2. Why LNG as fuel?
   Economics CAPEX & OPEX, LNG vs scrubber or LSHFO

3. LNG as fuel and Safety

4. Gas propulsion design
   LNG as fuel tankers, large ships and challenges

5. Bunker vessels

6. LNG Bunkering
   SIMOPS, Safety distances, equipment & checklists
Environmental Regulations
Global environmental regulation fosters clean fuels

- **EEDI phase 1**
  - 2015
  - 0.1% Sulphur limit ECA

- **EUROPEAN CO2 MRV**
  - 2016
  - Nox Tier III for newbuildings in North America ECA

- **EEDI phase 2**
  - 2020
  - 0.5% global sulphur limit worldwide

- 2021
  - Nox Tier III for newbuildings in North Europe ECA

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- **World wide since 2011**
  - ECA from 1st January 2016

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To comply with the new requirements, vessels use fuel oil with a sulphur content of no more than 0.5% m/m, or other equivalent measures to reduce emissions including exhaust gas scrubbing, alternative clean fuels and shore power (cold ironing).
Ordering cargo or tanker today: which type of fuel?

**Three options**

- HFO fuel (3.5% sulphur) with exhaust gas treatment units switchable
- Using low-sulphur HFO (0.5%) and treatment units in EU ports and (S)ECAs for 0.1% compliance (or MGO)
- LNG as fuel

**Feasibility**

Feasibility of LNG as fuel is made credible thanks to recent global development in LNG fuel bunkering logistic.
Tier III NOx compliance alternatives

**Tier III**

- Gas only or dual fuel engines with Otto cycle
- External exhaust gas after treatment units such as SCR (Selective Catalyst Reactor). These units use urea or ammonia and work at high temperature
- Exhaust Gas Recirculation systems (EGR) enable compliance with Tier III, associated with dual fuel 2 stroke (MEGI) or liquid fuel engines
SOx compliance

**Possible solutions**

- Use of low sulfur fuels
- Use LNG
- Install scrubbers

- Operating cost of scrubber is about 45 USD/t of bunker scrubbed, including additional bunkers, sludge disposal, caustic soda used in closed loop mode as well added repair and maintenance and insurance

**Scrubbers**

- Air pollution: continuous measurement of effluents sulphur content
- Water pollution (washwater discharge)
- Caustic soda used in closed loop systems (7 % of fuel consumption)
- BV Guidelines on scrubbers
However some concerns are still to be considered:

- NOx Tier III compliance with high-pressure gas Diesel engines (needs EGR)
- Methane slip
- Knocking & misfiring

Note: However 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.
The concern of so called «methane slip»

The sources of methane releases in the atmosphere are:

- Slip during gas combustion
- Release when stopping gas operation
- Tanks designs and operation

Methane slip & GWP for a 2-stroke ME-GI engine:

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

For a WinGD XDF: 2 g/kWh.
TNO study on LNG supply in the Netherlands. Well-to-Wake (WtW) greenhouse gas savings by substituting conventional marine fuel by LNG.
Why LNG as fuel?
LNG by sea strong safety record

- 90,000 cargo voyages since early 60's
- Total number of launched LNGc over 500 / 25 FSRU + 13 New orders
- 88 LNG c / FSRUs + 2 FLNG built with a BV class since 1995
MSC Cruises reveals novel look of its LNG World-class newbuilds

One year after they were first announced, MSC Cruises confirmed the order for up to four LNG-powered cruise ships of 200,000gt at STX France and released the first rendering of their novel design.
LNG propulsion – number of ships on order is increasing

June 2017
LNG fuelled ships

**BV Market Leadership**

- Total fleet & order book as of March 2017 slightly over 200 ships.
- BV the class market leader in 2016 for new orders
- From small work units to large LNG fuelled ship in service

**#1 in LNG fuelled orders**

**DUX – Tug Boat**

**HONFLEUR – Brittany Ferries ferry to be built by Flensburger Shipyard**
Gas propulsion – Cargo ships & tankers – some examples

15,000 dwt oil/chemical tanker Ternsund, built at Avic Dingheng, China and delivered to Denmark’s Terntank Rederi at the end of June 2016

Container feeder Wes Amelie being retrofitted now to gas as fuel – 16 sister vessels to be retrofitted as well

Bergen Viking Oil Tanker

Transport Desgagnés Damia Asphalt Tanker
The challenges of LNG as Fuel

3 factors have hindered the development of LNG as fuel

- Uncertainty on dates of implementation of the environmental regulations, in particular for the global sulfur cap (01/01/2020 or later?). This is no more the case.

- Lack of LNG distribution infrastructure in major ports. The logistic chain has improved a lot.

- Uncertainty of the relative price between LNG as fuel, HFO 3.5% and LSHFO but:
  - Price gap between North Europe & Asia and Henry Hub (USA) is reduced by half
  - LNG production will increase significantly above crude oil expected production meaning that LNG price will presumably remain cheap and stable
  - LNG import countries pushing for LNG index not linked to oil crude prices

<table>
<thead>
<tr>
<th></th>
<th>Prices 6 June 2017</th>
<th>USD/t</th>
<th>RATIO</th>
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<tbody>
<tr>
<td>HFO 380 @3.5% S</td>
<td>306</td>
<td>1.00</td>
<td></td>
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<tr>
<td>MGO</td>
<td>577</td>
<td>1.89</td>
<td></td>
</tr>
<tr>
<td>LS 380 @ 1%S</td>
<td>511</td>
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<td></td>
</tr>
<tr>
<td>(ratio computed for</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Antwerp)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LNG-380e</td>
<td>269</td>
<td>0.88</td>
<td></td>
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</tbody>
</table>

Source: shipandbunker.com/prices/vancouver
Ample LNG supply in 2020?

Strong growth in gas supply led by US shale gas with possible oversupply of LNG in 2020:

Gas supply growth 2015-2035

LNG supply

Source: Wood Mackenzie

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Global development of the LNG bunkering infrastructure with the highest density in Europe is encouraged by state financial and regulatory support of LNG initiatives.

Launch of LNG infrastructure is planned in the key ports.
LNG as fuel competitiveness

LNG-380e is the price for an amount of LNG that delivers the energy equivalent of one metric tone of IFO380 bunker fuel.

LNG-MGOe is the price for an amount of LNG that delivers the energy equivalent of one metric tone of MGO

LNG tanks and cargo capacity
- **LSHFO price and volume availability are uncertain** (-15% compared to MGO?)
- **Complicated operation and maintenance of scrubber + sludge management and SCR ar low load**
- **Scrubber and LNG compete on price of bunker**

<table>
<thead>
<tr>
<th></th>
<th>HFO low sulphur</th>
<th>HFO 3,5% + SCRUBBER</th>
<th>LNG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product availability</strong></td>
<td>Caution</td>
<td>Neutral</td>
<td>Satisfactory</td>
</tr>
<tr>
<td><strong>Bunkering infrastructure</strong></td>
<td>Neutral</td>
<td>Caution</td>
<td>Neutral</td>
</tr>
<tr>
<td><strong>Environment: IMO and beyond</strong></td>
<td>Neutral</td>
<td>Satisfactory</td>
<td>Neutral</td>
</tr>
<tr>
<td><strong>Technological risk and impact on ship design</strong></td>
<td>Caution</td>
<td>Neutral</td>
<td>Satisfactory</td>
</tr>
<tr>
<td><strong>Operations, maintenance and OPEX</strong></td>
<td>Caution</td>
<td>Neutral</td>
<td>Satisfactory</td>
</tr>
<tr>
<td><strong>Price of fuel</strong></td>
<td>Satisfactory</td>
<td>Caution</td>
<td>Neutral</td>
</tr>
</tbody>
</table>
What is LNG?
Liquefied Natural Gas

1 Sm3 gas
(15 °C, 1.013 bara)
= 11 kWh
= 0.7 kg

→

1,6 litre LNG
(- 163 °C, 1.013 bara)
= 11 kWh
= 0.7 kg

Liquefying natural gas reduces the volume approximately 600 times
Why a risk assessment for LNG as fuel?

- Wind direction
  - Immediate ignition
    - pool fire
    - no vapour cloud

- Spill
  - Evaporation of pool
  - LNG pool
  - Heat flux from higher temperature water

- Spreading of pool:
  - waves, wind, composition and obstacles affect size/shape of pool. RPT may occur

- LFL concentration
  - Delayed ignition
    - vapour cloud fire

- UFL concentration
  - Fire burns back to pool
LNG safety

Â LNG is quite different from other transport fuels

Â All these fuels are flammable - LNG however is a boiling liquid

Â LNG creates vapour that can spread further and reach more places than traditional liquid fuels

Â The vapour is also potentially explosive

Â Unlike traditional liquid fuels which pollute the surroundings on spillage the evaporation of LNG leaves no trace

Â Methane is a greenhouse gas about 20 times more potent that carbon dioxide • LNG needs to be treated differently
Embrittlement of carbon steel structures
Need to protect adequately the structures near possible sources of spills and LNG jets (from flanges, small bore connections...).

Gas plume dispersion simulation (case of the vent mast for DF tug)
Salvage of LNG fuel ships (SGMF)

3 On surface (grounded, collision, on fire, LNG leakage)
3 Semi submerged
3 Submerged
LNG as fuel design - Technical insight – Rules & Regulations
Rules for ships using LNG as fuel

- IMO regulations
  IGF Code 2016

- Bureau Veritas Rules
  Rule Note NR 529 (January 2017): Gas-Fuelled Ships

The objective of these regulations is to obtain an equivalent level of safety between the gas-fuelled ships and the conventional oil fuelled one see 3.2.1 of IGF Code:

The safety, reliability and dependability of the systems shall be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery.
LNG Fuel Tank technologies

IMO Classification of LNG Carriers (IGC Code)

Independent tanks
(separated from hull structure)

Type A
"simple" design
$P_0 \leq 0.7$ bar
Full secondary barrier

Type B
"refined" design
$P_0 \leq 0.7$ bar
Partial secondary barrier

Type C
$P_0 \geq 2$ bar
No secondary barrier

Integrated tanks
(part of hull structure)

Membrane
$P_0 \leq 0.7$ bar
Full secondary barrier

Cylinders

Spherical

Prismatic

Exoskeleton Tank:
LNG tanks design and location

**Location of LNG fuel tanks**

- To prevent damage to the LNG tanks in case of collision and grounding that can impact the tanks.

**Probabilistic approach**

*Flexibility and Strength*

**El Paso Paul Kayser in Gibraltar (June 1979)**

Severe grounding of the NO membrane “El Paso Paul Kayser” LNGC (125k) near Gibraltar.

*Very high deformations* on the outer hull and large warping of the inner hull (~30cm)

*Invar membranes withstood these high deformations without loss of tightness*
Conversion to LNG fuel - case studies

DF conversion – Parts which will be exchanged

DF conversion – Components added on the engine

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# Gas only and dual fuel engines

<table>
<thead>
<tr>
<th>Gas only Engines</th>
<th>Dual Fuel Engines</th>
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<tbody>
<tr>
<td>Low Pressure Gas</td>
<td>High Pressure Gas</td>
</tr>
<tr>
<td>Otto Cycle</td>
<td>Diesel Cycle</td>
</tr>
<tr>
<td>High &amp; Medium Speed (Bergen Rolls Royce)</td>
<td>Medium Speed (Wartsila, MAN, etc) 4 STROKE</td>
</tr>
<tr>
<td>Slow Speed (Wartsila X-DF) 2 STROKE</td>
<td>Slow Speed (MAN ME-GI) 2 STROKE</td>
</tr>
</tbody>
</table>

- Tier III in gas mode
- Low gas injection pressure
- Knocking Limitation of Methane Number
- Vulnerable to Rapid Load Change
- Sunsequent Methane Slip

- Not Tier III without SCR or EGR
- High Pressure injection
- No Knocking  • Negligible Methane Slip • High Efficiency

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2 stroke DF engines

**Win GD**

« Low pressure »

- Operation in gas mode according to the Otto cycle, with premixed lean burn technology
- Gas admission in the cylinder at low pressure (<16 bar) at mid-stroke
- Ignition by pilot injection in pre-chamber, to ensure the ignition of gas

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**MEGI**

« High pressure »

- Operation according to the standard Diesel cycle, in gas mode and FO mode.
- Gas is injected in the cylinder at high pressure (300 bar) close to TDC
- Pilot injection necessary to start the combustion process
NOx formation depends on the maximum flame temperature during the combustion process. Due to different air / gas mixing conditions, burning conditions, and pilot oil amount, the LP engine has lower NOx emissions. LP engine can fulfill Tier III emission level in gas mode. However, the limits may be exceeded during starting, stopping and transient conditions. HP engine needs an EGR or SCR to fulfill Tier III in gas mode. Obviously it also allows Tier III operation in FO mode.
Influence of the gas quality and so called MN

**Methane Number & gas quality as marine fuel**

- Minimum LHV: 28 MJ/Nm³
- Methane number: 70 (rated output)

► If the MN is too low, the DF engine may be affected by knocking. The control system of the engine will automatically:
  1. Limit the engine output to a safe level
  2. Trip the engine to liquid fuel to deliver 100% output.

**Requirements for gas quality as marine fuel**

- Minimum LHV: 28 MJ/Nm³
- Methane number: 70 (rated output)

3 If the MN is too low, the DF engine may be affected by knocking. The control system of the engine will automatically:
  1. Limit the engine output to a safe level
  2. Trip the engine to liquid fuel to deliver 100% output.
Main technical concerns for gas installations

- **Design**
  - Bunkering principles including bunkering vessel characteristics
  - Bunkering stations position
  - Design pressure definition
  - Volume optimization in the tank hold space

- **Maintenance & operations**
  - BOG management various solutions (Boilers, reliquefaction, engines, ...)
  - BOG and heat exchange calculation

- **Machinery system**
  - Nitrogen system
  - Gas detection system
  - Automation
Typical designs snapshot – tankers – bulkers LNG as fuel

VLOC with SPB type tank

VLOC with membrane tank + 2 buffer type C tanks on deck

Tanker with Type C tanks on deck
LNG Bunker vessels
### Small Scale LNGc (<40k)

<table>
<thead>
<tr>
<th></th>
<th>BV</th>
<th>World</th>
<th>BV share</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG carrier fleet in service</td>
<td>8</td>
<td>29</td>
<td>27.6%</td>
</tr>
</tbody>
</table>
LNG Bunkering – Increase of Required Volumes

2002
Truck to Ship / Bunkering station
Shore to Ship
Typically less than 200 cbm

2012
Small scale terminal
Terminal to Ship
Typically less than 1000 cbm

On purpose new builds
5,000-8,000 m³
Ship to Ship
LBV today ~ 6000 cbm
Tomorrow > 12000 cbm

2017 onward
**Minimum performance requirements**

- Equipped with an effective transfer system able to reach any type of LNG fuel vessels (open deck or enclosed bunker station)
- High maneuverability (operation in ports)
- Able to load cargo from any LNG terminal
- Efficient BOG handling system
- Able to deliver nitrogen to client vessel and to manage her BOG via vapor return line
LNG Bunkering in practice

LNG BUNKERING IN PROGRESS!
NO ACCESS TO DECKS 2 & 3
VIA THIS STAIRWELL
Please use STARFISH Stairwell (STBD AFT) if you need to depart the ship
**LNG bunkering principle**

**General principle of LNG bunkering**

To OCU, Boiler, Reliquefaction Plant

- Type C Tank
- LNG Pump
- Bunkering Ship
- Atmospheric Tank
- LNG-Fuelled Ship
- Compressor

Vapour, Venting, Inerting

**Required safety equipment**

- Emergency Release Couplings (ERC)

**LNG leak during Truck to Ship bunkering**
A safety zone and a security zone should be established around the bunkering operation in accordance with ISO 20519. These zones are in addition to the established practice of setting hazardous area classification zones that will be required around areas with potential for explosive atmospheres such as the bunkering connections.
**Methodology**


LFL contour

*Full bore release, Jet -X, Wind -Y*

**Definition**

A **safety zone** is the area around the bunkering station where only dedicated and essential personnel and activities are allowed during bunkering.

Its purpose are:

- to control ignition sources in order to reduce the likelihood of igniting a flammable gas cloud due to an accidental release of LNG or natural gas during bunkering,

- to limit the exposure to non-essential personnel in the event of potential hazardous effects (fire) during an incident when bunkering.
A QRA can be developed for two situations, where the risk is calculated:

A The LNG operation *without* taking into account SIMOPS

A The LNG operation *with* SIMOPS and defined mitigating measures

A SIMOPS is allowed in case it is demonstrated that the relative increase in risk is not significant provided that the overall project risk criteria can be met.

A Furthermore, it should be demonstrated that the proposed mitigating measures are effective in reducing the risk.
Other LNG fuel ISO standards under preparation

ISO/WD 21593
Marine LNG Fuel Bunkering QCDC

3 **Arrangement:** Presentation flange arrangement, end flange, connection.

3 **Requirements for nozzle and receptacle:** Venting depressurization, internal check valve, protective cap, storage, handle or hand-wheel.

3 **Marking:** Manufacturer and International Standard information.

3 **Testing:** General requirements, prototype testing, production testing.

ISO/TC 28/SC4/WG17
Marine LNG fuel specification

LNG transfer there is a small quantity of LNG which is taken and vaporised (few grammes) and the composition of the gas is analysed in a chromatograph. The average value is sent to the data center (which received also the volumetric values). On the basis of the average value of the transferred LNG, the calorific value of the LNG is calculated and the BDN, with the quantity of energy transferred is immediately generated and transmitted to the PIC of the receiving ship.

ISO/TC 8/SC3 on Gas and DF engines qualification