ALTERNATIVE FUELS AND ENERGY EFFICIENCY FOR THE SHIPPING INDUSTRY:
An overview of LNG, LPG and Methanol Fuelled Ships
CONTENTS

- Introduction to Alternative Fuels
- LNG Fuelled Ships
- LPG Fuelled Ships
- MeOH Fuelled Ships
- IGF Code
- Activities of ClassNK
  - Publications
  - LNG Ready
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Background – Why Alternative Fuels?

Stricter Environmental Regulations
Background – Why Alternative Fuels?

High Potential of Alternative Fuels as Clean Energy

<table>
<thead>
<tr>
<th>Alt Fuels</th>
<th>NOx</th>
<th>Sox</th>
<th>PM</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG</td>
<td>Over 90 % (Pre-mixed)</td>
<td>90 – 97 %</td>
<td>90 %</td>
<td>23 %</td>
</tr>
<tr>
<td></td>
<td>20 – 30 % (Gas Injection)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LPG</td>
<td>30 – 50 % (Gas Injection)</td>
<td></td>
<td></td>
<td>20 %</td>
</tr>
<tr>
<td>MeOH</td>
<td>15 – 20 % (Gas Injection)</td>
<td></td>
<td></td>
<td>10 %</td>
</tr>
</tbody>
</table>

Reduction Exh Gas vs FO Diesel Engine (Tier II)
# Alternative Fuel Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>LNG</th>
<th>LPG</th>
<th>MeOH</th>
<th>Oil(ref)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling Point (@1 atm)</td>
<td>-161.5 °C</td>
<td>-42.2 °C</td>
<td>65 °C</td>
<td>≧150 °C</td>
</tr>
<tr>
<td>SG-Liq. (@BP, 1 atm)</td>
<td>0.425</td>
<td>0.580</td>
<td>0.80</td>
<td>0.83</td>
</tr>
<tr>
<td>SG-Vap. (@0°C, 1 atm)</td>
<td>0.554</td>
<td>1.522</td>
<td>1.1</td>
<td>-</td>
</tr>
<tr>
<td>Flash Point</td>
<td>-188 °C</td>
<td>-104 °C</td>
<td>11 °C</td>
<td>60-100 °C</td>
</tr>
<tr>
<td>Auto Ignition Temp.</td>
<td>537 °C</td>
<td>470 °C</td>
<td>455 °C</td>
<td>250-380 °C</td>
</tr>
<tr>
<td>LFL-UFL (Vol. in air)</td>
<td>5–15 %</td>
<td>2.2–9.5 %</td>
<td>5.5–44 %</td>
<td>-</td>
</tr>
<tr>
<td>Min. Ignition Energy</td>
<td>0.28 mJ</td>
<td>0.25 mJ</td>
<td>0.14 mJ</td>
<td>-</td>
</tr>
</tbody>
</table>

- Cryogenic T°
- Lower Specific Gravity
- Higher Min. Ignition Energy
- Heavier Vapour
- Lower LFL
- High Pressure
- Heavier Vapour
- Wide Flammable Limit
- Lower Min. Ignition Energy
- Toxic
- Invisible Fire
# Technical and Economical Comparison

<table>
<thead>
<tr>
<th>LNG</th>
<th>LPG</th>
<th>MeOH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shale Gas Revolution</strong></td>
<td><strong>Shale Gas Revolution</strong></td>
<td><strong>Large Production (over 70MTon / year)</strong></td>
</tr>
<tr>
<td><strong>Effective for all IMO Environment Regulations</strong></td>
<td><strong>Liquified by pressure at ambient T° (lower cost)</strong></td>
<td><strong>Renewable Energy (Biomass Fuel)</strong></td>
</tr>
<tr>
<td><strong>Records on LNG fuel ships</strong></td>
<td><strong>Possibility of existing LPG infrastructure</strong></td>
<td></td>
</tr>
<tr>
<td>- over 1,000 LPG terminals</td>
<td>- Over 1,000 LPGC</td>
<td><strong>Records on MeOH Fuel vehicles</strong></td>
</tr>
<tr>
<td><strong>Expected stable and lower Price</strong></td>
<td></td>
<td><strong>Liquified Fuel at ambient T° and Pressure (easier handling)</strong></td>
</tr>
</tbody>
</table>
Economic Potential of Alternative Fuels

- HFO (380 cSt)
- MGO/MDO
- Methanol
- LNG
- LPG

Fuel price ($/GJ on LHV basis)

- HFO/LSFO: High price
- MGO: High price
- Methanol: High price
- LNG: High price
- LPG: High price

2012 - 2022
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Over 100 LNG fuelled ships have been built & operated. (Coastal ferry, PSV, Patrol vessel, RoPax, Tug, Product tanker, Gas Carrier etc.)
Promotion of LNG Fuelled Cargo Ships

- LNG fuelled containers, PCCs, dry cargo vessels are in operation / under construction.
Current Situation of LNG Fleet

**Owner Nationality**
- Europe: 63%
- Asia & Oceania: 18%
- North America: 15%
- Unknown: 4%

**Builder Nationality**
- Europe: 47%
- Asia & Oceania: 46%
- North America: 7%

Source: Clarksons Dec. 2017
Estimated Fleet of LNG Fuelled Ships by 2022
Typical System Configuration

- 4 stroke medium speed Gas Engine or DF Engine / Electric Propulsion
  - Track records of ferry, OSV etc.

- 4 stroke medium speed Gas Engine or DF Engine / coupling with propeller via R/G
  - Track records of chemical tanker, tugboat etc.

- 2 stroke slow speed DF engine / direct coupling with propeller
  - Track records of US coastal container carriers.
Typical System Configuration

<table>
<thead>
<tr>
<th>Type</th>
<th>4 stroke Gas engine</th>
<th>4 stroke DF engine</th>
<th>2 stroke DF engine (Low pressure type)</th>
<th>2 stroke DF engine (High pressure type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignition</td>
<td>Premixed combustion</td>
<td>Diffusing combustion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas supply pressure</td>
<td>4〜5 bar</td>
<td>&lt; 16 bar</td>
<td>300 bar</td>
<td></td>
</tr>
<tr>
<td>NOx Tier III (80% reduction)</td>
<td>Conformable</td>
<td>Conformable</td>
<td>SCR, EGR, etc.</td>
<td></td>
</tr>
<tr>
<td>SOx ECA</td>
<td>Conformable</td>
<td>Pilot oil : Low sulfur fuel oil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks</td>
<td>Methane slip, Knocking, Propulsion backup</td>
<td>Methane slip, Knocking</td>
<td>Methane slip, Knocking</td>
<td>Safety assessment for high pressure gas leak</td>
</tr>
</tbody>
</table>

• Methane slip
• Knocking
• Propulsion backup
## Types and Features of LNG Storage Tanks

<table>
<thead>
<tr>
<th>Type</th>
<th>Independent tank Type A</th>
<th>Independent tank Type B</th>
<th>Independent tank Type C</th>
<th>Membrane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shape</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Design Vapor Press.</strong></td>
<td>&lt;0.07MPa</td>
<td>&lt;0.07MPa</td>
<td>High pressure</td>
<td>≤0.025MPa</td>
</tr>
<tr>
<td><strong>Records of Gas carrier</strong></td>
<td>Medium to Large LPG ship</td>
<td>Large LNG ship</td>
<td>Small LPG ship</td>
<td>Large LNG ship</td>
</tr>
<tr>
<td><strong>Records of Gas fuelled ship</strong></td>
<td>Nil</td>
<td>Nil (under consideration)</td>
<td>Good</td>
<td>Nil</td>
</tr>
<tr>
<td><strong>Features</strong></td>
<td>• Good volume efficiency (Prismatic tank)</td>
<td>• Volume efficiency Spherical: Low Prismatic: Good</td>
<td>• Simple design &amp; construction</td>
<td>• Good volume efficiency</td>
</tr>
<tr>
<td></td>
<td>• Complete secondary barrier</td>
<td>• Detail fatigue analysis required</td>
<td>• Flexibility of work. pressure</td>
<td>• Complete secondary barrier</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Low volume efficiency</td>
<td>• Sloshing concern</td>
</tr>
</tbody>
</table>
Types of LNG Bunkering

- **Ship to Ship type**
- **Shore to Ship type**
- **Truck to Ship type**
- **Tank Container type**
Location of LNG Bunkering (Existing Projects)

Source: Galway Analysis
Location of LNG Bunkering (Proposed Projects)

Source: Galway Analysis
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Current status of LPG Fuelled Ships

- Several projects with Approval In Principle (AIP) from major classification societies currently on-going.

- Rules and regulations are being developed by several regulatory bodies for this type of fuel.
LPG Fuel Supply System

Source: MAN Presentation Material
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Current status of MeOH Fuelled Ships

Ro-Pax “STENA GERMANICA”
(2015: Conversion to MeOH Fuel)

50K DWT M/T “MANCHAC SUN”
(2016: New Building delivered)
MeOH Fuel Supply System

Fuel valve train (GVU) -> Methanol supply system -> Methanol service tank

- Double-walled pipes
- Single-walled pipes

ME-LGI Engine

Fuel Booster Injection Valve (FBIV)

- MeOH flow: 8 bar MeOH supply pressure, 550 bar MeOH suction

Source: MAN Presentation Material

Source: FCBI energy report 2015
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International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels (IGF Code)

- Adoption of IGF code (MSC.391(95)) at MSC 95 in June 2015
- Mandatory code for ships using low-flashpoint (below 60 °C in general) fuels under SOLAS convention
- Application: All passenger ships, and cargo ships whose Gross Tonnage is over 500 ton (except Liquefied Gas Carriers)

| Newly built ships | • The building contract is placed on or after **1 Jan. 2017**
|                   | • The keels of which are laid or which are at a similar stage of construction on or after **1 July 2017**, or
|                   | • The delivery of which is on or after **1 Jan. 2021**.
| Ships in service  | • Converts to using low-flashpoint fuels on or after **1 Jan. 2017**
<p>|                   | • Undertakes to use low-flashpoint fuels different from those which it was originally approved to use before <strong>1 Jan. 2017</strong> |</p>
<table>
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<tr>
<th>Ch.</th>
<th>Title</th>
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<td>GENERAL</td>
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<td>GOAL AND FUNCTIONAL REQUIREMENTS</td>
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<tr>
<td>4</td>
<td>GENERAL REQUIREMENTS</td>
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<tr>
<td>Part A-1</td>
<td>SPECIFIC REQUIREMENTS FOR SHIPS USING NATURAL GAS AS FUEL</td>
</tr>
<tr>
<td>5</td>
<td>SHIP DESIGN AND ARRANGEMENT</td>
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<td>FUEL CONTAINMENT SYSTEM</td>
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<td>BUNKERING</td>
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<td>FUEL SUPPLY TO CONSUMERS</td>
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<td>Ch.</td>
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<td>EXPLOSION PREVENTION</td>
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<td>VENTILATION</td>
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<td>ELECTRICAL INSTALLATIONS</td>
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<td>Part B-1</td>
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<tr>
<td>16</td>
<td>MANUFACTURE, WORKMANSHIP AND TESTING</td>
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<tr>
<td>Part C-1</td>
<td></td>
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<tr>
<td>17</td>
<td>DRILLS AND EMERGENCY EXERCISES</td>
</tr>
<tr>
<td>18</td>
<td>OPERATION</td>
</tr>
<tr>
<td>Part D</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>TRAINING</td>
</tr>
</tbody>
</table>
Risk Assessment (Ch. 4)

- Risks arising from the use of low-flashpoint fuel affecting persons, environment, or integrity of the ship to be examined.
- In LNG fuelled ship, address only when the code requires

- Risk assessment for LNG fuelled ships required in IGF Code
  - Maximum amount of spill to be handled in drip tray (5.10.5)
  - Critical events in the gas dangerous space separated by airlock (5.12.3)
  - Evaluation of the liquefied gas fuel containment system (6.4.1.1)
  - Additional accidental scenario in designing membrane type tank (6.4.15.4.7.2)
  - Closed / Semi-enclosed bunkering stations (8.3.1.1, 13.7)
  - Decreased number of ventilation of tank connection spaces (13.4.1)
  - Gas detector at ventilation inlets to accommodation and machinery space (15.8.1)
Arrangement of Fuel Tank (Ch. 5)

(1) $V \leq 1,000 \text{ m}^3$ :
   $d = 0.80 \text{ m}$;

(2) $1,000 \text{ m}^3 \leq V \leq 5,000 \text{ m}^3$ :
   $d = 0.75 + \frac{V}{4,000}$;

(3) $5,000 \text{ m}^3 \leq V \leq 30,000 \text{ m}^3$ :
   $d = 0.8 + \frac{V}{25,000}$;

(4) $30,000 \text{ m}^3 \leq V$ :
   $d = 2 \text{ m}$

$V$: Cap. of fuel tank, $d$: dist. from outer plate

Deterministic approach

- Minimum value of $B/5$ or $11.5\text{ m}$
- (B: Ship’s maximum mold breadth)

or

Probabilistic approach

- Considering the damage probability of fuel tank occurred by collision
  
  $f_{CN} = f_l \cdot f_t \cdot f_v \leq 0.02$ (Passenger Ship)
  $\leq 0.04$ (Cargo Ship)

Flexible fuel tank arrangement possible
Arrangement of Fuel Tank (Ch. 5)

- **Tank connection space:**
  - Space surrounding tank connections and valves
  - Safely contain leakage (gas tightness, low temperature material)
  - Thermal isolation from hull structure

[Diagram]
- Direct access from open deck
- Exh. air fan
- Fire damper
- Gas detector
- Fire detector
- LNG fuel tank
- Engine room
- Cofferdam* ≧900mm
  - (*Optional in Type C tank)
- A-60 class fire protection

*Note: LNG fuel tank, Engine room, Gas detector, Fire detector, Fire damper.*
Fuel Supply to Consumers (Ch. 9)

Gas fuel piping outside the machinery space:
To be located in dedicated spaces (Located directly in accommodation, service space, control space, etc. not allowed.)

Inside the machinery space:
“Gas-safe machinery space” or “ESD-protected machinery space”
Standards / Guidelines for LNG Bunkering

LNG BUNKERING GUIDELINE:

✔ ISO TS18683 “Guidelines for systems and installations for supply of LNG as fuel to ships”
✔ ISO 20519 “Ships and marine technology – Specification for bunkering of liquefied natural gas fuelled vessels”
✔ SGMF “Gas as a marine fuel safety guidelines”
✔ IACS “LNG Bunkering Guidelines (IACS Rec 142)

Etc.
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Activities of NK - Publications

- Rules for low-flashpoint fuelled ship “Part GF” of ClassNK Rules
  (Entry into force on January 2017)

- “Guidelines For Gas Fuelled Ships Ver.4” (April 2016)
  • Guidelines for the design of LNG fuelled ship
  • Annex 3 “Guidelines for the safety of ships using methyl / ethyl alcohol as fuel”
  • Annex 4 “LNG Ready”
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Activities of NK – LNG Ready

<Background>
- Enhanced air pollution prevention regulation (NOx / SOx regulation)
- LNG fuelled ship draws attention as a countermeasure for such regulations
- Challenges; LNG bunkering infrastructure, cost competition with oil fuel and other countermeasures

<Trend in maritime industry>
Seeking ship which can be converted to LNG fuelled ship in future with an expectation of future LNG fuel expansion
- New building ships: installing some part of systems in advance
- Delivered ships: feasibility assessment of the conversion to LNG fuelled ship

<Demand to classification society>
Certification of design or installation stage (LNG Ready)
Activities of NK – LNG Ready

**ClassNK LNG Ready Objective**
- Identify items that are already designed and installed
- Class Notation “LNG Ready”

**LNG Ready Notation Line up**

<table>
<thead>
<tr>
<th>Basic Notation</th>
<th>Additional Notation (Installation/Construction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“S”</td>
<td>Hull Structural Readiness</td>
</tr>
<tr>
<td>“T”</td>
<td>Fuel Containment System Readiness</td>
</tr>
<tr>
<td>“F”</td>
<td>Fuel Gas Supply Systems Readiness</td>
</tr>
<tr>
<td>“B”</td>
<td>Bunker Stations Readiness</td>
</tr>
<tr>
<td>“H”</td>
<td>Boil off Gas Handling System Readiness</td>
</tr>
<tr>
<td>“G”</td>
<td>Gas Consumers Readiness</td>
</tr>
</tbody>
</table>
Activities of NK – LNG Ready

1. Design Review
   ✓ Hull Structural rein. for LNG Storage Tank
   ✓ LNG fuel storage tank structure and arrang’t
   ✓ Fuel Gas Bunkering system and arrang’t
   ✓ Fuel Gas Supply System
   ✓ Gas Handling System
   ✓ Gas Consumers

2. FAT & SAT
   ✓ Fabrication insp.
   ✓ Hyd. test
   ✓ Leak test
   ✓ Performance test
   ✓ Gas trial

3. Class Certificate
   “LNG Ready” Notation affixed
Conclusions

- Alternative fuels are necessary to meet the stricter environmental regulations set out by the IMO.

- Currently, LNG is the alternative fuel mostly used in the shipping industry. However, LPG and MeOH fuels are expected to be widely adopted in the short term in the shipping industry.

- There is a regulatory framework already established for the adoption of alternative fuels.
THANK YOU

for your kind attention

March 2018