Gas Fuelled ships

*LNG-Fuelled Engines and Fuel Systems for Medium-Speed Engines in Maritime Applications*

Dag Stenersen, MARINTEK
Presentation outline

- Background
  - Environmental challenges and emission restrictions at sea
  - Need for alternative fuels (to replace HFO)
  - "Small scale LNG" and LNG fueled ships
- Natural Gas fueled marine engines
- Propulsion systems and onboard LNG fuel systems
- Bunkering - fuel supply infrastructure
- Safety - rules and regulations
- LNG in short sea shipping in Norway
- R&D Challenges
- Summary and conclusions
Global shipping – Regional and local challenges

Ship Traffic Pattern
- Low
- High
- Very Low
- Medium
- Very High

Derived from 1983-2002 ICOADS.
IMO MARPOL Annex VI - SOx /NOx emission limits in ECA from 2015/2016

- New stringent limits for SOx and NOx in Emission Control Area (ECA)
  - SOx for all ships after 2015.
  - NOx for new ships after 2016.

- Demand for reduction of Green House Gases (GHG) from shipping which mainly consists of CO₂

- Expecting new special limits for Particular Matter (PM)

Marpol 73/78 is the International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978
Emission Control Areas (ECA)
IMO MARPOL Annex VI - SOx emission limits

Stricter IMO limitation on SOx

Global sulphur limitations
- Global cap from 4,5% to 3,5% effective from 1. January 2012
- Global cap from 3,5% to 0,5% effective from 1. January 2020

SECA (Sulphur Emission Control Area) limitations*
- New sulphur limit from 1,5% to 1,0 % effective from 1. March 2010
- New sulphur limit from 1,0% to 0,1 % effective from 1. January 2015

PM (Particulate Matter) regulated indirectly by the sulphur reduction

*(SECA=ECA)
IMO requirements to prevent pollution from ships
IMO MARPOL Annex VI - NOx emission limits

Global NOx limitations
- Tier II ⇒ 20% reduction of Tier I limit for new ships after 1. January 2011

Emission Control Area (ECA)
From 1. January 2016
- NOx Tier III ⇒ 80% reduction from Tier I limit (new ships)
Need for alternative fuels

World’s Liquid Fuels Supply

- Non-Petroleum Unconventional Liquids
- Non-OPEC Unconventional Petroleum Projects
- Non-OPEC Unconventional Petroleum Liquids
- OPEC Unconventional Petroleum Liquids
- Non-OPEC Conventional Projects
- OPEC Conventional Projects
- Non-OPEC Existing Conventional
- OPEC Existing Conventional

Source: EIA, AEO2009

AEO2009 Reference Total Consumption

Unidentified Projects

43
Fuel cost development

Source: AIR-LNG SA elaborations, based on eia.doe & Platts statistics
"Small scale LNG" distribution system

Covering the long coast of Norway

- LNG source
  - Base load LNG to receiving terminals
  - Small scale LNG production plants (4)
    - 10,000-300,000 ton/year

- LNG distribution
  - Coastal tankers (1000 m³ – 7500 m³)
  - Trailers (50 m³), rail or local pipeline

- LNG terminals (~40)
  - 100 m³ - 6500 m³ LNG
Development of LNG fueled marine engines

- Started in 1980 to develop engines for LNG carriers utilizing boil-off gas as fuel
- Commercial engine development started 1984 - resulting in 3 engine concepts released 1988-1996:
  - Spark Ignited Lean Burn engine (Otto cycle)
  - Dual fuel engine (Combined Otto/Diesel cycle)
  - High pressure direct injection engine (Diesel cycle)
- Application – stationary power and heat generation (COGEN)
- First marine application in 2000 – The “prototype” LNG fuelled ship “MF Glutra”
- 2003: Commercial market growing from the Small scale LNG project
  - Engine and fuel system development continues to improve performance and safety for marine applications
- 2011: Fast growing interest in deep-sea shipping applications
  - Driven by emission control legislation and fuel cost
  - Large slow speed engines under development
  - New ships and retrofit installations in existing vessels
LNG fueled marine engine concepts

LEAN BURN SPARK IGNITED ENGINE (LBSI)

DUAL FUEL GAS ENGINE (DF) – PILOT DIESEL IGNITION

High pressure gas injection - “Gas Diesel engine” –(GD)
Spark Ignited Lean Burn gas engine (LBSI)

- Single fuel LNG, low pressure gas supply (4-5 bar)
- High energy efficiency at high load, higher than the corresponding diesel engine
- Low emissions, meets IMO tire III
- GHG reduction potential in the range of 20-30% ref. to HFO (incl. methane)

- Challenge on methane slip, minimized by design and combustion process control
- Sensitive to gas quality (Methane Number)
- Not suitable for retrofit of existing engines
Engine control principles (LBSI)
Dual-Fuel engine (DF)

- Dual fuel capability (LNG-MDO)
- Low gas pressure supply (4-5 bar)
- High energy efficiency at high load
- Low emissions, meets IMO tire III
- Flexibility in fuel mix
- GHG reduction potential in the range of 20-30% ref. to HFO (reduction is dependant on level of methane slip)

- Challenge on methane slip, limited possibility to combustion process control
- Sensitive to gas quality (Methane Number)
- Possible for conversion of existing engines (extensive rebuilding)
"Micro Pilot" Dual Fuel concept (Wärtsilä 32)

DF - fuel injector

- Separate micro pilot injection - only 0,5 – 1,0% of fuel at full load
- Common rail - high injection pressure (>1000 bar)
- Central location of pilot sprays
## LNG fuel qualities – variable composition

### Worldwide LNG composition

<table>
<thead>
<tr>
<th>LNG export terminals</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5+</th>
<th>N2</th>
<th>LHV [MJ/kg]</th>
<th>MN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arun (Indonesia)</td>
<td>89.33</td>
<td>7.14</td>
<td>2.22</td>
<td>1.17</td>
<td>0.01</td>
<td>0.08</td>
<td>49.4</td>
<td>70.7</td>
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<tr>
<td>Arzew (Algeria)</td>
<td>87.4</td>
<td>8.6</td>
<td>2.4</td>
<td>0.05</td>
<td>0.02</td>
<td>0.35</td>
<td>49.1</td>
<td>72.3</td>
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<tr>
<td>Badak (Indonesia)</td>
<td>91.09</td>
<td>5.51</td>
<td>2.48</td>
<td>0.88</td>
<td>0</td>
<td>0.03</td>
<td>49.5</td>
<td>72.9</td>
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<td>Bintulu (Malaysia)</td>
<td>91.23</td>
<td>4.3</td>
<td>2.95</td>
<td>1.4</td>
<td>0</td>
<td>0.12</td>
<td>49.4</td>
<td>70.4</td>
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<tr>
<td>Bonny (Nigeria)</td>
<td>90.4</td>
<td>5.2</td>
<td>2.8</td>
<td>1.5</td>
<td>0.02</td>
<td>0.07</td>
<td>49.4</td>
<td>69.5</td>
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<td>Das Island (Emirates)</td>
<td>84.83</td>
<td>13.39</td>
<td>1.34</td>
<td>0.28</td>
<td>0</td>
<td>0.17</td>
<td>49.3</td>
<td>71.2</td>
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<tr>
<td>Lumut (Brunei)</td>
<td>89.4</td>
<td>6.3</td>
<td>2.8</td>
<td>1.3</td>
<td>0.05</td>
<td>0.05</td>
<td>49.4</td>
<td>69.5</td>
</tr>
<tr>
<td>Point Fortin (Trinidad)</td>
<td>96.2</td>
<td>3.26</td>
<td>0.42</td>
<td>0.07</td>
<td>0.01</td>
<td>0.01</td>
<td>49.9</td>
<td>87.4</td>
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<td>Ras Laffan (Qatar)</td>
<td>90.1</td>
<td>6.47</td>
<td>2.27</td>
<td>0.6</td>
<td>0.03</td>
<td>0.25</td>
<td>49.3</td>
<td>73.8</td>
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<tr>
<td>Skida (Algeria)</td>
<td>91.5</td>
<td>5.64</td>
<td>1.5</td>
<td>0.5</td>
<td>0.01</td>
<td>0.85</td>
<td>49.3</td>
<td>77.3</td>
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<td>Snøhvit (Norway)</td>
<td>91.9</td>
<td>5.3</td>
<td>1.9</td>
<td>0.2</td>
<td>0</td>
<td>0.6</td>
<td>49.2</td>
<td>78.3</td>
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<td>Withnell (Australia)</td>
<td>89.02</td>
<td>7.33</td>
<td>2.56</td>
<td>1.03</td>
<td>0</td>
<td>0.06</td>
<td>49.4</td>
<td>70.6</td>
</tr>
</tbody>
</table>

Note the variation of Methane Number (MN) 87.4 – 69.5
Lean Burn combustion (LBSI and DF)

- Knocking
- Misfiring
- Optimum performance for all cylinders
- Efficiency
- Operating window
- NOx emissions [g/kWh]
- Thermal efficiency [%]

Mean effective pressure [bar]

Air / Fuel ratio

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Exhaust emission - Natural gas vs. MDO

- Sulphur emission is eliminated
- Particulate matters is close to zero
- CO₂ is reduced by up to 30%
  (Due to unburned methane the net reduction of GHG are in the range of 0% - 15%)
- NOx is reduced by 80-90%

Source: Rolls-Royce Marine
Performance – lean burn vs. diesel

- Rolls-Royce C26:33L9

**Otto-Cycle** (LBSI/DF)
- **Diesel-Cycle** (GD)

Specific fuel consumption [MJ/kWh] vs. Engine load [%]

**Otto Cycle**
- PHASES:
  1. Ignition delay
  2. Premixed combustion
  3. Controlled combustion
  4. Late combustion

**Diesel Cycle**
- PHASES:
  1. Ignition delay
  2. Premixed combustion
  3. Controlled combustion
  4. Late combustion

Rate of heat release vs. Crank angle

SOI, EOI, Lean burn, Diesel
Direct injection high pressure engine

- Multi-fuel capability (LNG-MDO-HFO)
- High pressure gas injection (300 -350 bar) 4-stoke and 2-stroke
- Maintain diesel engine performance
- No methane slip, GHG reduction in the range of 30% ref. to HFO
- Need NOx reduction techniques to meet IMO tier III
- Not sensitive to gas quality
- Pumping LNG to 350 bar and evaporate is simple and with low energy requirement
- Flexibility in fuel mix
- Suitable for conversion of existing engines (simple rebuilding)
High Pressure Fuel Gas Supply System

Process flow diagram

Cryogenic LNG tank
HP Pump
LNG Vaporizer
NG Accumulator
ME-GI Engine

LNG Storage Tank
FGS System
Power plant

Source: B&W / Cryostar
LNG powered ship design

26 LNG propelled ships in operation:
- Ferries (15)
- Offshore support vessels (5)
- Coast guard vessels (3)
- Product tanker (1)
- LNG tanker (2)

15 LNG propelled ships under construction

More than 40 LNG fuelled ships by 2012
Propulsion system arrangements and fuel systems
Gas consumption & NOx for variable versus fixed RPM

- MJ/kWh propellercurve
- MJ/kWh 1000 rpm
- g/kWh NOx propellercurve
- NOx 1000 rpm

Rolls-Royce K-engine
LNG fuel system

The challenges are handling and storing LNG onboard:

- Volume/space
- Safety
- Infrastructure

Vacuum isolated pressure storage tanks – a volume factor 4-5 times of MDO/HFO
Fuel capacity vs. installed power
Rules and regulations - Gas fuelled ships

IMO Interim guidelines for gas fuelled ships - 2009

Different engine room arrangements

- ESD (Emergency Shut Down) protected engine room
  - Minimum two separate engine rooms
  - Redundant systems
  - Increased ventilation
  - Gas detection
  - Minimum of ignition sources

- Inherently safe engine room
  - Ventilated double piping to engine
  - No other special requirements for the engine room

**IMO code in progress:**
International code for gas fuelled ships – IGF - 2014
Inherently safe engine room

- Ventilated double wall piping
- Gas dangerous area
LNG in short sea shipping in Norway

Covering the long coast of Norway

- **LNG source**
  - Base load LNG to receiving terminals
  - Small scale LNG production plants (4) 10,000-300,000 ton / year

- **LNG distribution**
  - Coastal tankers
  - Trucks

- Regional terminals (~40) 100m³ - 6500m³ LNG

Source: Gasnor
LNG in short sea shipping in Norway

Production- Infrastructure – bunkering- use

Skangass – Risavika
300,000 ton/year
Storage capacity 30,000 m³
In operation Q4 2010

Small scale LNG production

Source: Skangass

Source: Gasnor
LNG in short sea shipping – bunkering alternatives

- Bunkering from trailer
- Ship bunkering terminal, supply vessel
- Ship bunkering terminal, ferry
LNG bunkering logistics, future

Ship to ship
Necessary for large capacities
Flexible
(as today’s MDO and HFO bunkering systems)
## Capital cost related to LNG fuel

<table>
<thead>
<tr>
<th>Additional cost factor</th>
<th>Car ferry (5 MW/250m³LNG)</th>
<th>Platform supply vessel (PSV) (8 MW / 200 m³LNG)</th>
<th>Ro-Ro (5 MW / 450m³LNG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engines</td>
<td>~3%</td>
<td>~3%</td>
<td>~2%</td>
</tr>
<tr>
<td>Fuel system</td>
<td>~4-5%</td>
<td>~2-3%</td>
<td>~5-8%</td>
</tr>
<tr>
<td>Arrangement and structure</td>
<td>~2-3%</td>
<td>~3-6%</td>
<td>~2-5%</td>
</tr>
<tr>
<td>Total</td>
<td>~10%</td>
<td>~8-12%</td>
<td>~9-15%</td>
</tr>
</tbody>
</table>
R&D challenges

- Engines and systems
  - Part load efficiency optimization
  - Methane slip reduction
  - Fuel gas quality
  - Cost reduction

- Fuel handling and storage
  - Better storage tank solutions (space and cost)
  - Improved fuel handling systems – bunkering logistics
  - Simpler and more robust fuel system design without reducing safety (space and cost)

Commercial challenge:
Cost elements – need more actors in the market…
Summary and conclusions

- LNG is considered to be the most promising alternative marine fuel
- Using LNG as ship fuel, harmful exhaust emissions are reduced significantly
- LNG is available worldwide in large scale, and can be further distributed to small scale fuel market. Norway has demonstrated that small scale LNG production and distribution is competitive as marine fuel
- Proven engine technologies are available for medium speed natural gas engines, and under development for slow speed 2-stroke engines
- Energy efficiency is equal and even better using LNG compared to MDO/HFO
- LNG fuelled engines are environmentally friendly, and meet all the known emission requirements (IMO tier III), without exhaust gas cleaning
- Engine R&D challenges are related to part load efficiency, methane slip and variable gas composition (Methane number)
- The main challenges using LNG are availability and on-board fuel storage and handling systems. LNG storage and handling technology for ships are under further development to reduce space requirement and cost
- LNG fuelled ships require significant higher capital investment in fuel system – typical 8-15% additional cost, which can be justified by lower operating costs (emissions and fuel)
Thank you for your attention!

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NOx < 2 g/kWh
SOx ~ 0
PM ~ 0