DUAL FUEL ENGINES
LATEST DEVELOPMENTS

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HAMBURG, 27.9.2011
• Environmental and market drivers
• LNG as a marine fuel
• DF engines
• RoRo concept design
• Machinery and fuel comparison
• Conclusions
Factor trends: Environment

- **NO\textsubscript{x}**
  - Acid rains Tier II (2011)
  - Tier III (2016)

- **SO\textsubscript{x}**
  - Acid rains
  - Sulphur content in fuel

- **Particulate matter**
  - Direct impact on humans
  - Locally regulated

- **CO\textsubscript{2}**
  - Greenhouse effect
  - Under evaluation by IMO

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From now on....
NOx reduction – IMO requirements and methods

Tier I (present)
- Ships built 2000 onwards
- Engines > 130 kW
- Retrofit: Ships built 1990 – 2000
- Engines > 90 litres/cylinder and > 5000 kW
- Wärtsilä: RTA, W46, W64

Tier II (global 2011)
- Ships keel laid 2011 onwards
- Engines > 130 kW

Tier III (ECAs 2016)
- Ships in designated areas, keel laid 2016 onwards
- Engines > 130 kW

Specific NOx emissions (g/kWh)

Dry methods (engine optimization)
- Concepts are ready

SCR Catalyst
- Alternative pathways under investigation (Combined measures)
IMO Sulphur Limits

- 4.5% starting in 2008
- 3.5% starting in 2012
- 1.5% starting in 2015
- 1.0% starting in 2020
- 0.5% starting in 2021
- 0.1% starting in 2022

World

EU in ports

ECA
Main options for operations inside ECA

- MGO + SCR
- HFO + Scrubber + SCR
- LNG
The society is demanding lower CO$_2$ emissions from ships

IMO is trying to respond the demand by introducing guidelines for:
- Energy Efficiency Design Index (EEDI)
- Energy Efficiency Operational Index (EEOI)
- Market based instruments
- …
Fuel prices

Sources: www.lngoneworld.com, www.bunkerworld.com, LR Fairplay
Cleaner Exhaust Emissions with LNG

- 25-30% lower CO$_2$
  - Thanks to low carbon to hydrogen ratio of fuel
- 85% lower NO$_X$
  - Lean burn concept (high air-fuel ratio)
- No SO$_X$ emissions
  - Sulphur is removed from fuel when liquefied
- Very low particulate emissions
- No visible smoke
- No sludge deposits
DF ENGINES
Otto or Diesel cycles: effects on $\text{NO}_x$

Flame front propagation

Nikolaus August Otto

Fuel spray $\text{NO}_x$ formation

Rudolf Christian Karl Diesel
Otto or Diesel cycles: effects on NO\textsubscript{x}

Big temperature difference → NO\textsubscript{x} formation!

![Graph showing cylinder temperature vs. crank angle for Otto and Diesel cycles.]

- **Diesel**, max flame temp.
- **Otto**, max flame temp.
Select the right technology

**DUAL-FUEL (DF)**
Meets IMO Tier III

**SPARK-IGNITION GAS (SG)**
Meets IMO Tier III
No redundancy
No HFO flexibility

**GAS-DIESEL (GD)**
Does NOT meet IMO Tier III
High gas pressure
Gas burning technologies

- GAS-DIESEL (GD)
- DUAL-FUEL (DF)
- SPARK-IGNITION GAS (SG)

Timeline:
- 1987
- 1992
- 1995
The marine favourite technology?

**DUAL-FUEL (DF)**
Meets IMO Tier III

**SPARK-IGNITION GAS (SG)**
Meets IMO Tier III
No redundancy
No HFO flexibility

**GAS-DIESEL (GD)**
Does NOT meet IMO Tier III
High gas pressure
Wärtsilä’s choice

DUAL-FUEL (DF)
Meets IMO Tier III

1. IMO Tier III compliant
2. Low pressure gas
3. Fuel flexibility; GAS, MDO and HFO
Dual-fuel engine characteristics

- High efficiency
- Low gas pressure
- Low emissions, due to:
  - High efficiency
  - Clean fuel
  - Lean burn combustion
- Fuel flexibility
  - Gas mode
  - Diesel mode
- Three engine models
  - Wärtsilä 20DF
  - Wärtsilä 34DF
  - Wärtsilä 50DF
Dual-fuel engine range

**Wärtsilä 20DF**
- 6L20DF: 1.0 MW
- 8L20DF: 1.4 MW
- 9L20DF: 1.5 MW

**Wärtsilä 34DF**
- 6L34DF: 2.7 MW
- 9L34DF: 4.0 MW
- 12V34DF: 5.4 MW
- 16V34DF: 7.2 MW
- 20V34DF: 9.0 MW

**Wärtsilä 50DF**
- 6L50DF: 5.85 MW
- 8L50DF: 7.8 MW
- 9L50DF: 8.8 MW
- 12V50DF: 11.7 MW
- 16V50DF: 15.6 MW
- 18V50DF: 17.55 MW

Electrical & Mechanical applications

Higher output for 60Hz / Main engines
Wärtsilä successfully tests new 2-stroke dual-fuel gas engine technology

Wärtsilä Corporation, Trade & Technical press release, 23 September 2011:

“Wärtsilä successfully tests new 2-stroke dual-fuel gas engine technology to comply with IMO Tier III emission limits“

“The on-going tests show that the Wärtsilä 2-stroke gas engine performance is in compliance with the upcoming IMO Tier III NOx emission limits, thereby setting a new benchmark for low-speed engines running on gas.”
Main advantages of the Dual-Fuel 4-stroke engine compared to SG:

- Redundancy, backup without interruptions in power or speed.
- Able to operate on liquid fuel outside ECA-area (incl HFO)
- Simple system, no PTI/”take me home” or double gas system needed.
- Vessel re-routing possible, gas supply not a limitation
Dual-Fuel applications – References

Power Plants
- DF Power Plant
  - 49 installations
  - 155 engines
  - Online since 1997

Merchant
- LNGC
  - 68 vessels
  - 254 engines
  - 950,000 rh
- Conversion
  - 1 Chem. Tanker
  - 2 engines conv.
  - Complete gas train
  - Complete design

Offshore
- PSVs/FPSOs
  - 22 vessels
  - 78 engines
  - Online from 1994

Cruise and Ferry
- LNG ferries
  - 1+1 vessels
  - 4 engines per vessel
  - Complete gas train
  - 2800 passengers
  - In service in 2013

Navy
- Costal Patrol
  - Coming…

→ 4 segments → 140 installations → > 3,000,000 running hours
The industry's most environmentally sound and energy efficient large passenger vessel to date.

**Main particulars:**
- **Overall length:** 214.0 m
- **Breadth, moulded:** 31.8 m
- **Cruising speed:** 22 knots
- **Passengers:** 2800
- **Class:** LR
- **Ice class:** 1A
- **In service:** 2013
- **Shipyard:** STX Finland Oy
- **Ship Owner:** Viking Line

**Machinery:**
- **Main Engines:** 4 x Wärtsilä 8L50DF
- **Output:** 4 x 7600 kW
- **LNGPac 200:** 2 x 200 m³
- **Integrated tank – and aux. rooms**
- **Bunkering system, Safety systems**
- **GVU in enclosure**
- **Cold recovery for HVAC**
LNGpac Main Components

Main Engine Room

Gas Valve

GVU

Pressure build up evaporator

Tank room

Bunkering line, insulated pipes

Bunkering Station

Water/Glycol system

Bottom tank filling

LNG – gas evaporator

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Gas Valve Unit in enclosure

Main features

• Can be located in the same engine room, dedicated compartment not needed

• Compact design and easy installation (plug-and-play concept)

• Integrated ventilation system when combined with LNGPac
LNGPac: A turn key solution

Auxiliary equipment room

Tank room – All cryogenic valves

Length minimized
Storage volume (Relative)

Volume relative to MDO in DE

- Diesel
- LNG (10bar)

Fuel - Tank - Tank Room

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Conventional tank location
The LNG tanks can be located outside

- Does not take up space inside ship
- Good ventilation
- No ventilation casing needed trough accommodation
- Visible location for good PR
LNG storage in trailers
LNG logistics is a key question for introduction of LNG as a marine fuel.

LNG Terminal

LNG Feeder

LNG Container feeder
LNG Ferry
LNG Ro-Lo
LNG Tug
Marine LNG terminals

- Existing or under construction
- Proposed

As per September 2009
Bunkering from LNG truck
LNG bunker barge/tanker
LNG barge carrier – operation principle
LNG barge carrier – operation principle
LNG distribution

- NG pipe line
- Local LNG liquefaction plant
- Large scale LNG liquefaction plant / LNG import terminal
- Local distribution LNG terminal
- LNG tank in port
- LNG tank on barge
- Small ships
- Small & large ships

PORT DISTRIBUTION
Total Concept Optimization

Wärtsilä engineers solutions for LNG delivery, storage, transportation and utilization onboard.
RORO CONCEPT FOR ECA
RoRo trends
RoRo trends

- Growing capacity
  - Efficiency of scale
- Slowing down
  - Reducing fuel costs
- Flexible cargo intake
- Designed for operation inside ECA areas
RoRo concept

RoRo vessel for European routes in ECA
- Operation area: European SECA area
- RoRo cargos
  - Double stack containers on main deck
  - Trailers and mafis on upper deck and in lower hold
  - Containers on upper deck
- Focus on environmental and economical performance
  - Operation inside SECA area
  - IMO tier III NOx compliant
RoRo main particulars

- Size: 22 000 GT
- Length: 190.0 m
- Length, bp: 180.0 m
- Beam, wl: 26.6 m
- Draft (design): 6.5 m
- Depth, main deck: 8.3 m
- Speed, service: ~19 knots (incl. 15% SM)
- Lane meters: 2 800 m
- Deadweight (design): 10 500 tons
- Propulsion power: 10 800 – 11 400 kW (installed)
- Aux power: ~2 100 kW (installed)
- Drivers: 12 pax
Propulsion

- Single screw
  - Simple and well proven
  - Good ice performance
  - Low cost

- Energopac rudder
Machinery alternatives for comparison

1. **MGO**
   - Operates on MGO
   - SCR to reduce NOx to tier III limit

2. **HFO + Scrubber**
   - Operates on HFO
   - Scrubber removes SOx
   - SCR to reduce NOx to tier III limit

3. **DF - LNG**
   - Operates on LNG
   - No exhaust cleaning needed
Installed propulsion power: 10.8 MW
Installed aux power: 2.1 MW

SCR needed for IMO tier III compliance

EnergoPac rudder

GEAR

9L46F 10 800 kW

Auxpac 1 050 kW

Auxpac 1 050 kW

1 MW

2 x 1 MW
Installed propulsion power: 10.8 MW
Installed aux power: 2.1 MW

SCR needed for IMO tier III compliance
Closed loop works with freshwater, to which NaOH is added for the neutralization of SOx.

CLOSED LOOP = Zero discharge in enclosed area
Containerships VII - scrubber installation
Installed propulsion power: 11.4 MW
Installed aux power: 2.1 MW
LNG storage in trailers

3 x LNG trailers = 150 m3 of LNG
LNG tank capacity (LNG trucks on deck)

- Target for autonomy: 2 days
- Daily consumption (acc. to profile): 19 tons
- Total consumption: 38 tons, 84 m³
- + 15% Margin: + 13 m³
- Total tank capacity demand: 97 m³
- Volume capacity of one truck: 50 m³

→ Two LNG trucks loaded every second day
LNG storage in trailer
### Assumed fuel prices

<table>
<thead>
<tr>
<th></th>
<th>USD/ton</th>
<th>EUR/ton</th>
<th>USD/MBtu</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFO</td>
<td>635</td>
<td>455</td>
<td>16.5</td>
</tr>
<tr>
<td>MGO</td>
<td>950</td>
<td>680</td>
<td>23.4</td>
</tr>
<tr>
<td>LNG</td>
<td>740</td>
<td>530</td>
<td>16.0</td>
</tr>
</tbody>
</table>

For reference: NG market price in US: <5 $/MBTU

Source: [www.bunkerworld.com](http://www.bunkerworld.com) (September 2011), LNG price estimated

1 EUR = 1.4 USD
Annual fuel consumption and cost (relative)

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Energy Consumption %</th>
<th>Fuel Cost %</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGO</td>
<td>100,0 %</td>
<td>100,0 %</td>
</tr>
<tr>
<td>HFO + Scrubber</td>
<td>105,4 %</td>
<td>77,1 %</td>
</tr>
<tr>
<td>LNG</td>
<td>100,6 %</td>
<td>68,8 %</td>
</tr>
</tbody>
</table>
Annual fuel, lube oil and consumables cost (k€)

10 years
6% interest

- MGO
- HFO + Scrubber
- LNG

Senitec chemicals
Fresh Water
NaOH
Urea
Lube oil
Fuel

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Annual machinery cost

- Scrubber operating costs (NaOH + FW + Senitec Chem)
- SCR operating costs
- Maintenance costs
- Lubrication oil costs
- Fuel costs
- Annual capital costs

Graph showing annual machinery related costs for MGO, HFO + Scrubber, and LNG.
Concept payback time (compared to MGO)

Payback Time [Years]

MGO  HFO + Scrubber  LNG

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Net present value (NPV) – 10 years of operation

- MGO
- HFO + Scrubber
- LNG

Net Present Value [kEUR]

27 September 2011
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Exhaust emissions

- HFO - IMO tier II
- MGO
- HFO + Scrubber
- LNG

REF. outside ECA
Inside ECA, IMO tier III compliant
IMO Energy Efficiency Design Index (EEDI)

\[
\text{EEDI} = \frac{\text{CO}_2 \text{ from propn} + \text{CO}_2 \text{ from Auxiliaries} \cdot \text{Efficient use of energy}}{f_i \cdot \text{Capacity} \cdot V_{ref} \cdot f_w}
\]

\[
\text{EEDI} = \left( \prod_{j=1}^{M} f_i \right) \left( \sum_{k=1}^{n_M} P_{MEn} \cdot CF_{MEn} \cdot SF_{CMe} \right) + \left( \sum_{j=1}^{M} f_i \cdot \sum_{k=1}^{n_{PI}} P_{PI} - \sum_{k=1}^{n_{eff}} P_{AEff} \cdot CF_{AE} \cdot SF_{Cae} \right) - \left( \sum_{k=1}^{n_{eff}} P_{eff} \cdot CF_{ME} \cdot SF_{CMe} \right)
\]

\[
\frac{f_i \cdot \text{Capacity} \cdot V_{ref} \cdot f_w}{f_i \cdot \text{Capacity} \cdot V_{ref} \cdot f_w}
\]
The graph compares EEDI ratings for different types of fuel: MGO, HFO + Scrubber, and LNG. The EEDI values are as follows:

- MGO: 23
- HFO + Scrubber: 22
- LNG: 18
Operating part time in SECA
1. **MGO - HFO**
   - Operates on **MGO** inside SECA
   - and **HFO** outside SECA
   - SCR used only in port and inside NECA

2. **HFO + Scrubber**
   - Operates on **HFO**
   - Scrubber only used inside SECA
   - SCR used only in port and inside NECA

3. **DF - LNG**
   - Operates on LNG all the time
   - No exhaust cleaning needed
Annual fuel costs – part time in ECA

<table>
<thead>
<tr>
<th></th>
<th>Inside ECA</th>
<th>Outside ECA</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFO - MGO</td>
<td>33%</td>
<td>100%</td>
</tr>
<tr>
<td>HFO + Scrubber</td>
<td>67%</td>
<td>33%</td>
</tr>
<tr>
<td>DF-LNG</td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

Annual costs [k€]

- HFO - MGO
- HFO + Scrubber
- DF-LNG

27 September 2011
Annual costs – part time in ECA

Inside ECA
Outside ECA

Annual costs [k€]

HFO - MGO HFO + Scrubber DF-LNG

HFO - MGO HFO + Scrubber DF-LNG

HFO - MGO HFO + Scrubber DF-LNG

HFO - MGO HFO + Scrubber DF-LNG

SCR operating costs
Scrubber operating costs
Maintenance costs
Lubrication oil costs
Fuel costs
Annual capital costs
Conclusions

DF engines – a well proven technology

DF engines running on LNG has great potential
- Best NPV
- Lowest emissions
- Short payback time