EMISSION REGULATIONS
From now on....

Established Emissions Controlled Areas
Emissions Controlled Areas under consideration
Shipping critical points
How to fulfil emissions limits?

Several different alternatives are viable for emissions regulations fulfillment:

1. Change to low-sulphur distillate fuels
   - Does not fulfill NO\textsubscript{x} limits!

2. Apply exhaust gas treatment technologies

3. Switch to LNG
Environmental challenge

IMO NOx emissions regulations

- IMO Tier I - New ships 2000
- IMO Tier II - New ships 2011
- IMO Tier III - New ships 2016 in designated areas

NOx [g/kWh]

50DF Engine (in diesel mode)

50DF Engine (in gas mode)

Rated engine speed [rpm]
Natural Gas As Marine Fuel

-25% CO₂
-85% NOₓ
-100% SO₂
-100% Particulates

Dual-Fuel engine in gas mode
Diesel engine

Emission values [%]
100
90
80
70
60
50
40
30
20
10
0
Reducing local emission by switching to LNG
Natural Gas

Natural Gas is traded via seaborne transportation in its liquid form, adopting the name of Liquefied Natural Gas.

<table>
<thead>
<tr>
<th>Property</th>
<th>NG</th>
<th>LNG</th>
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</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Atmospheric</td>
<td>-161°C</td>
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<tr>
<td>Pressure</td>
<td>Atmospheric</td>
<td>Atmospheric</td>
</tr>
<tr>
<td>Density [kg/m³]</td>
<td>0.75</td>
<td>460</td>
</tr>
<tr>
<td>Low Heating Value [MJ/kg]</td>
<td>~ 50'000</td>
<td>~ 50'000</td>
</tr>
</tbody>
</table>

600 times more!
DUAL-FUEL ENGINES
APPLICATIONS AND REFERENCES
Dual-Fuel applications - References

- **Power Plants**
  - DF Power Plant
  - 51 installations
  - 186 engines
  - Online since 1997

- **Merchant**
  - LNGC
  - 108 vessels
  - 429 engines
  - 1'200'000 running hours
  - Conversion
  - 1 Chem. Tanker
  - 2 engines conv.
  - Complete gas train
  - Complete design

- **Offshore**
  - PSVs/FPSOs
  - 19 vessels
  - 93 engines
  - Online from 1994
  - New orders:
    - Harvey Gulf, the first 3 LNG-PSV to be operated in the Gulf of Mexico!

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

- **Navy**
  - Coastal Patrol
  - 4 segments
  - 177 installations
  - > 5’000’000 running hours

New orders: Harvey Gulf; the first 3 LNG-PSV to be operated in the Gulf of Mexico!
Wärtsilä is a system integrator
A complete and modularized solution for LNG fuelled ships

A. Storage tanks
B. Evaporators
C. Dual-Fuel Main engine
D. Dual-Fuel Aux engines
E. Bunkering station(s)
F. Integrated control system
Principle layout – Open Spaces/Deck

- Vents or opening to non-hazardous area
- Machinery or furnace exhaust

Zone 2 (R2 = R1 + 1.5m)
Zone 1 (R1 = 3m)

min. 10m from:
min. 6m from Working Deck

Gas Mast

Wärtsilä LNGPac

Bunkering Station

Single Wall Pipe
Double Wall Pipe

LNG Fuelled Ships
Gas fuel tanks not located below accommodation may be approved by the Society with a location closer than B/5 from the ship side.
Ship design in practice – Tankers (1)

LNG Fuelled Ships
Ship design in practice – Container Vessels (1)
Ship design in practice – RO-RO (1)

LNG Fuelled Ships
GVU Arrangement

LNG Fuelled Ships

max. 10m
DUAL-FUEL ENGINES

TECHNOLOGY
Engine characteristics - Operating modes

Gas mode:
- Otto principle
- Low-pressure gas admission
- Pilot diesel injection

Diesel mode:
- Diesel principle
- Diesel injection
Engine characteristics - Operating mode changes

Transfer from gas mode to diesel mode at 100% load

Transfer from diesel mode to gas mode at 80% load
Dual-fuel engine systems

- Gas fuel system
- Pilot fuel system
- Diesel fuel system
- Control system
Engine systems - Gas fuel system (1/7)

- Vent outlet
- Double-wall gas manifold
- Venting valve
Engine systems - Gas fuel system (3/7)

Gas admission valve
Double-wall gas piping is standard for Wärtsilä 50DF dual-fuel engines.

Compared to single-wall gas piping, engine-room requirements regarding gas detection, ventilation, etc., become less stringent, making the engine room less complex and thus cheaper to build.
Gas admission valve (Closed)
Gas admission valve (Open)
Engine systems - Pilot fuel system (1/2)
For optimum pilot and diesel fuel distribution

- Pilot solenoid valve
- Pilot needle
- Main needle
Engine systems - Diesel fuel system

- Pilot-fuel common rail 900bar
- Main fuel injection pipe
- Main fuel injection pump
- Main fuel quill pipe
- Twin-nozzle injection valve
Engine control and cylinder load balancing based on cylinder pressure sensors

- **First target:**
  - Increased safety
    - More reliable knock detection
    - Real misfire detection
    - Maximum cylinder pressure control

- **Future targets:**
  - Automatic engine power control
    - “Real” derating control
  - Improved fault detection/diagnostics for preventive maintenance
  - Increase of load due to better engine control and possibility to run closer to maximum cylinder pressure and knock limits
LNGPAC
Thermodynamic basics

- LNG (Methane) at -161°C is in equilibrium with gas at 1 bar (g)
- LNG (Methane) at -134°C is in equilibrium with gas at 5 bar (g)

- If gas temperature is above equilibrium temperature/pressure, gas will condensate on the liquid surface, heating the liquid

23 April 2012
Bunkering procedure

1. Collapse the gas pressure
2. Open the main filling line
3. Close the filling line valves
4. Inert the piping with Nitrogen (not shown)
Tank pressure increase

1. Open pressure control valve
2. LNG flow by the hydrostatic pressure into the vaporizer
3. LNG is vaporized and gas is returned to the tank

Glycol/water mixture

Bar(g)

Time

© Wärtsilä 23 April 2012 LNGPac process presentation / S. Karlsson
Normal operation

1. Double block valves are opened
2. LNG is forced by the tank pressure through the evaporator and instantly evaporated
• PLC cabinet placed in a safe area near the “cold - box”
• Valves controlled by solenoids placed in safe area near the “cold box” and bunkering station
• LNGPac HMI and network can be part of WIAS or WAMS system or can be a separate system with monitor on bridge and ECR
• All operating procedures / sequences, alarm procedures are part of a software developed by Wärtsilä. Procedures and modes are described in the LNGPac operating manual
GAS-POWERED VESSELS
ONBOARD INSTALLATION
"Old" arrangement

- Forced ventilation
- Single wall fuel gas pipe
- Double wall fuel gas pipe

Gas safe area

Gas hazardous area
Installation with GVU enclosure

- Forced ventilation
- Double wall fuel gas pipe
- Gas safe area
- Enclosure
- Engine room
- Saved space!
Start-up performance

- **Backup start**
- **Diesel start**
- **Gas start**

### Key Stages:
- **Starting air**
- **Combustion check, only pilot fuel**
- **Pilot fuel & back-up fuel**
- **Pilot fuel & gas**
- **Speed acceleration**
- **Synchronisation**

### Timeline:
- **Gas leak test**
- **Starting & speed acceleration**
- **Synchronisation**

Engine speed (rpm) vs. Time (sec)
LNG storage location

Gas storage below deck

LNG tank

Min. B/15 or 2 m (the lesser)

Never less than 760 mm
THE TARBIT PROJECT

...COMING ONLINE SEPTEMBER 2011...
Vessel delivery date 17.09.2007
Vessel typology 25'000 dwt Chemical tanker
Owner Tarbit Shipping AB
Ship Builder Shanghai Edward Shipbuilding Co Ltd
Flag Sweden
Class Germanischer Lloyd

DWT 24783 ton
GT 17757 ton
Displacement 33788 ton
Length p.p. 166.99 m
Length o.a. 177.02 m
Keel to Mast Height 44.85 m
Draught 9.7 m
Breadth Extreme 26.3 m
Breadth Moulded 26 m
Speed 16 kn
Main facts

Vessel owned by Tarbit Shipping AB (Sweden)

On time charter to Statoil

Sailing in Norwegian waters

Conversion partially financed by Norwegian “Næringslivets Hovedorganisasjon” (Confederation of Norwegian Business and Industry)

Designed by Wärtsilä Ship Design (former Skipskonsulent)

Built by Edward Shipbuilding Co Ltd (Hudong-Zhong JV)
Main engine conversion

TODAY
2 x W6L46B
5850 kW each

PTO 1500 kW

PTO 1500 kW

WÄRTSILÄ 8L20 1200 kW

WÄRTSILÄ 8L20 1200 kW

TOMORROW
2 x 6LW50DF
5700 kW each

April 2012- V. Potapov, Wärtsilä
Many “firsts”

- First LNGPac delivered by Wärtsilä
- First Dual-Fuel engine in mechanical-drive application
- First Gas Valve Unit in enclosure
- First Dual-Fuel engine marine conversion
- First Dual-Fuel “single main engine” approval
Gas Valve Unit in enclosure

Main features

- Can be located in the same engine room and still comply with IGC and (future) IGF codes.
- Integrated ventilation system when combined with LNGPac
- Compact design, easy installation
- Delivered in containerized form (“plug-and-play” concept)
**SCOPE OF SUPPLY:**

- Ship Design
- Engine conversion
- LNGPac system (2 x 500m³)
- Gas supply units
- Torque meter for power measurement
- Bunkering system
- Gas piping (single and double walled)
- Exhaust system
- Fire-fighting upgrade
- Gas detection system
- Electrical system

**ADDITIONAL**

- NOₓ measurement during sea trial DF and
- LNGPac training for personnel
VESSEL CONVERSION
Equipment placement

LNG tanks
Equipment placement

- LNG pipes
- Water/Glycol
- Cold Box
- LNG tanks
Equipment placement

2ND PLATFORM DECK

1ST PLATFORM DECK
ENGINE UPGRADE
DF conversion – parts to be exchanged

- Cylinder heads
- Cylinder liner & anti-polishing ring
- Pistons & piston rings
- Connecting rods (upper part)
- Dual-needle injection valve
- Turbochargers modified for DF operation
- Camshaft pieces for DF Miller-valve timing
- UNIC control system

April 2012 - V. Potapov, Wärtsilä
DF conversion – Components added to the engine

- Exhaust gas waste gate
- Gas rail pipe
- Gas admission valves
- Pilot-fuel system:
  - Pilot-fuel oil filter
  - Common rail piping
  - Pilot-fuel oil pump

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## References

**Sold engine conversions worldwide**

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Country</th>
<th>Year</th>
<th>Conversion type</th>
<th>Status</th>
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<tbody>
<tr>
<td>Tintrofa</td>
<td>Portugal</td>
<td>2004</td>
<td>1 x 12V32 HFO ⇒ 12V34SG</td>
<td>Finalized</td>
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<tr>
<td>Almeida</td>
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<td>2004</td>
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<tr>
<td>Century Power</td>
<td>Pakistan</td>
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<td>Denizil</td>
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<tr>
<td>Gera</td>
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<td>Christino Roha</td>
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<td>Ongoing</td>
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INSTALLATION IN PRACTICE
Applications - Container feeder (option 1)
Possibility of top-up LNG ISO containers for increasing vessel's endurance
Applications – Offshore supply vessel

LNG Fuelled Ships
Applications – Passenger vessel

LNG Fuelled Ships
**MARLIN Green**

**MAIN PARTICULARS**
- Length over all: 180.0 m
- Gross Tonnage: 22,050 GT
- Net Tonnage: 7,760 NT
- Design Speed: 18 knots
- Container capacity, max.: 2,554 TEU
- Reefer plugs up to: 586
- LNG Cargo tank (100%): 945 m³
- LNG capacity increase by top-up LNG ISO containers

**MACHINERY**
- Main engine 4-stroke Wärtsilä 2 x 8,775 kW W9L50DF
- Aux. engines 4-stroke Wärtsilä 3 x 1,521 kWe W9L20DF
- Shaft generator 1 x 1,100 kWe

**CLASS**
DNV + 1A1 ICE-1A Container Carrier, NAUTICUS (Newbuilding) E0, DG-P, BIS, TMON, NAUT-OC, BWM-T, CLEAN, COMF-V(2), GAS FUELED

LNG Fuelled Ships
25,000dwt PRODUCT TANKER “Bit Viking”

MAIN PARTICULARS
- Length o.a. abt. 177.10 m
- Breadth mld. 26.00 m
- Depth moulded 12.80 m
- Design draught 9.20 m
- LNG tank abt. 2 x 520 m3
- Service speed abt. 17.0 knots
- LNG Cargo tank (100%) 972 m3

MACHINERY
- Main engines, medium speed 2 x Wärtsilä 6L50DF, 5,850 kW MCR
- Generator sets 2 x Wärtsilä 8L20, 1,200 kW
- Shaft generator x 2
- Propulsion units 2 x CP propeller, 5.2 m diameter

CLASS
GL (+) A5 E3 NAV-OC ESP INERT IW RP2 50% “OIL TANKER & CHEMICAL TANKER TYPE 2” + MC E3 AUT

LNG Fuelled Ships

April 2012, V. Potapov
LNG feeder

MAIN PARTICULARS
- Length o.a. abt. 41.55 m
- Breadth mld. 10.00 m
- Depth moulded 4.00 m
- Design draught 2.50 m
- LNG Cargo tank (100%) abt. 350 m³
- Service speed abt. 6.0 knots

MACHINERY
- Main engines, medium speed 1 x 800 kW MCR
- Main engine fuel LNG, MDO and Boil-off LNG
- Shaft generator 1 x 300 kW MCR
- Generator sets 2 x 100 kW MCR
- Propulsion units 1 x CP propeller, 3 or 4 blades
- Bow thruster 1 x el.driven CP, 200 kW

CLASS
DNV + 1A1, Tanker for Liquefi ed Gas (LNG), GAS FUELLED, TMON, E0. Or equivalent IACS.
Vessel type 2G.

LNG Fuelled Ships
MAIN PARTICULARS

- Length over all: 92.20 m
- Breath: 210.0 m
- Speed: 15.5 knots
- Deck cargo area: 945 m²
- LNG capacity: 1 x 234 m³

MACHINERY

- Main engines: 4 x Wärtsilä 6R32DF 2,010 kW
- Main azimuth thruster: 2 x 2,300 kW
- Tunnel thrusters: 2 x 1,200 kW
- Azimuth thruster: 1 x 880 kW
- Emergency diesel generator: 160 kW
VS 493 PSV

MAIN PARTICULARS
• Length over all: 94.90 m
• Breath: 20.40 m
• Speed: 16.0 knots
• Deck cargo area: 1030 m²
• Cargo: 5,000 m³
• LNG capacity 1 x 120 m³

MACHINERY
• Dual-Fuel Generator sets: 4 x 2,010 kW
• Azimuth Thr. for prop.: 2 x 3,000 kW
• Tunnel Thr. Fwd 2 x 1,000 kW
• Azimuth Thr. Fwd 1 x 800 kW

CLASS
• DNV +1A1, SUPPLY VESSEL, SF, E0, DP AUTR, GAS FUELED, LFL*, OIL REC, CLEAN DESIGN, COMF-(V3), NAUT-OSV(A), ICE C. FiFi-1, dk (+) and HL(p)

LNG Fuelled Ships
**MAIN PARTICULARS**
- Length over all: 85.00 m
- Length between perp.: 75.00 m
- Breath: 19.00 m
- Speed: 15.5 knots
- Deadweight @ 7.5 m: 5000 t
- LNG capacity: 1 x 180 m³

**MACHINERY**
- Gen sets: 4 x Wärtsilä 8L20 DF 1,408 kWe
- Azimuth thr for Prop: 2 x 1,500 kW
- Tunnel thr fwd: 3 x 1,000 kW

LNG Fuelled Ships
**MAIN PARTICULARS**

- Length over all: 80.60 m
- Breath: 19.00 m
- Speed: 16.5 knots
- Deck Cargo Area: 820 m²
- LNG capacity: 1 x 180 m³

**MACHINERY**

- Gen sets: 2 x Wärtsilä 6L32 DF 2,510 ekW
- Azimuth thr for Prop: 2 x 2,450 kW
- Tunnel thr fwd: 2 x 1,000 kW
- Azimuth thr fwd: 1 x 830 kW
MAIN PARTICULARS
- Length over all: 89.60 m
- Breath: 21.00 m
- Speed: 17.0 knots
- Dead weight: 6500 tonnes
- Deck cargo area: 1050 m²
- LNG capacity: 1 x 180 m³

MACHINERY
- Gen sets: 2 x Wärtsilä 6L32 DF 2,510 ekW
- Gen sets: 2 x Wärtsilä 6L20 DF 1,014 ekW
- Azimuth thr for prop: 2 x 2,450 kW
- Tunnel thr fwd: 2 x 1,000 kW
- Azimuth thr fwd: 1 x 830 kW
MAIN PARTICULARS
- Length over all: 89.60m
- Length between p.p: 86.40m
- Breath moulded: 21.00m
- Speed: 16.4knots
- Deck Area: 1050m²

MACHINERY
- 4 x Wärtsilä 6R32DF
- Tunnel thruster
- Retractable azimuth thr.
- Steerprop
- 2 x 2,700kW
- 2 x 1,000kW
- 1 x 880kW
- 2 x 2,450kW

LNG Fuelled Ships
KV BARENTSHAV

MAIN PARTICULARS

• Length over all: 93.20 m
• Breath: 16.60 m
• Depth: 8.60 m
• Speed: 16.5 knots
• LNG capacity: 1 x 220 m³

CLASS

DNV +1A1, ICE C, Tug, E0, Fi-Fi-1, Oil recovery, Clean Class, Dynpos Aut, Gas Fuelled

MACHINERY

• Dual Fuel main engines: 1 x 4,000 kW
• Generating sets.: 3 x 865 kW + 1 x 642 kW
• Bow Thr.: 1 x 736 kW
• Azimuth Thr. Fwd: 1 x 736 kW
• Main engine: 4000 kW
• Generator sets (gas): 3x865 kW + 1x642 kW
• Shaft generator: 2,500 kW
• Bow thruster: 736 kW
• Stern thruster: 736 kW
**DESCRIPTION**

- Power supply for vessels while in harbour. The power supply is ensured by three (3) dual fuel diesel generators, which fulfil the IMO Tier III emission requirements and provide up to 8MW.

**MAIN PARTICULARS**

- Main engine 3x Wärtsilä 6L34DF MCR 2,510 kWe
- LNG capacity 2 x 145 m³
- MDO 120.8 m³
- LNG Endurance (at 85%MCR) approx. 104 hours
- MGO Endurance (at 85%MCR) approx. 86 hours
CLdN: LNG Conversion of Ro-Ro vessels
CLdN Contract Structure

- **Contracting Parties:** CLdN Shipping S.A. (Owner) and Wärtsilä Norway AS
- **Wärtsilä Scope of Supply, timetable and contract price:**
  - **Phase I** – first 16 weeks
    - Basic design of the Vessel gas conversion, detailed design of LNG docking station
    - Tendering package for Yards, firm offers from Yards
  - **Phase II** – Conversion of M/V Valentine by Q1/2013
    - Wärtsilä subcontracts conversion yard (Yard selection by W and C jointly)
    - Supply of 2 x 12V34DF engines, gearboxes, gas valve unit
    - Yard to make detailed design
    - Wärtsilä is turn key contractor with overall responsibility
  - **Phase III** – up to five sister vessels of Kawasaki series
    - Likely solution: Equipment from Wärtsilä as Owners supply to CLdN, who will make direct conversion contract with Yard.
- **Contract** based on Wärtsilä Combined Contract and BIMCO repair contract, with negotiated adjustments. CLdN will receive extensive user rights on the LNG gas docking station and basic conversion design on their fleet.
• Successfully signed in Luxemburg on 17 April 2012.
Go For Gas!

WÄRTSILÄ
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www.wartsila.com

vladimir.potapov@wartsila.com