Fuel Flexibility and Engine Types
Utilisation of sidestreams (LNG, O&G)
Moscow 02-03-2016

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Wärtsilä Corporation

Power Solutions for
Power Generation
Marine/offshore

Total: 59.5 GW
Plants: 4769
Engines: 10930
Countries: 176

Russia
Output: 1.4 GW
Plants: 75
Engines: 229

• Listed in Helsinki
• 5 billion € turnover (2015)
• 18,500 Professionals

800 persons, Development budget 130 Million €/year
Agenda

Fuels sources
• Developments -> Engine types and fuels
• Sidestreams

Engines
• Engine portfolio
  • Diesel process
  • Otto process

Examples
  Sidestreams as fuels
  • LNG Blow-off, Boil-off gas
  • Sidestream liquids from LNG Liqufaction
Wärtsilä Diesel engine fuel path

- Diesel Oil (LFO)
- Heavy Fuel Oil (HFO)
- Natural Gas (NG)
- Crude Oil (CRO)
- Liquid Biofuels (LBF)
- Emulsified Fuels
- High Viscosity HFO
- ULV Liquids

Timeline:
- 1970
- 1980
- 1990
- 2000
- 2010
- 2015
Wärtsilä gas engines development

- GD = Gas Diesel engine
- SG = Spark ignited Gas engine
- DF = Dual Fuel engine
**SG = Spark Ignited**
- Otto process
- Fuel: gas
- 6 bar pressure gas

**DF = Dual Fuel**
- Otto process + pilot
- Diesel process
- Fuel: gas + liquid fuels
- Low pressure gas

**GD = Gas Diesel**
- Diesel process + pilot
- Fuel: gas + liquid fuels
- High pressure gas
- Large fuel mixture ratio

**LG = Liquid Gas**
- Diesel process + pilot
- Ultra low viscosity fuels
- LFO Pilot + back-up

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**C1**  | **C2**  | **C3**  | **C4**  | **C5**  | **C6**  | **C7**  | **C8**  | **C9**  | **C10** | **C11** | **C12** | **C13** | **C14** | **C15** | **C16** | **C17** | **C18** | **C22** | **C25** | **C50** | **C70 +**
Pipe line gas | LPG | Light Naphta | Heavy Naphta | Kerosene | Inter Gas Oil | HFO | Bitumen Asphalt

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**Octane rating = 100**

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**Cetane number = 100**
Octane rating = -30

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**Fraction**

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**Otto**  | **DieSEL**
The Wärtsilä Engine Portfolio

Three frame sizes of turbocharged, inter-cooled, heavy duty medium speed engines.

Wärtsilä 20
6 – 9 cylinders
Max. 1,6 MW
Liquid Fuel

Wärtsilä 32, 34
6 – 20 cylinders
Max. 10 MW
Liquid, Gas, Dual-Fuel

Wärtsilä 46, 50
12 – 20 cylinders
Max. 23 MW
Liquid, Gas, Dual-Fuel

Engine number indicates the cylinder diameter in cm: i.e. Wärtsilä 32 engine has 320 mm cylinder bore (about 13”)
- Modular design
- Convertible between engine types Diesel/SG/DF (34, 50)
### Wärtsilä Dual-Fuel Application References

#### Merchant
- **LNG Carrier**: 168 vessels
- **Multigas Carrier**: 8 vessels
- **Product tanker**: 2 vessels
- **Bulk tanker**: 1 vessel
- **CNG carrier**: 1 vessel

**732 engines**

#### Offshore
- **Offshore supply**: 24 vessels
- **FPSO**: 5 vessels
- **FSRU**: 4 vessels
- **Platform**: 2 vessels
- **FSO**: 1 vessel

**123 engines**

#### Specials
- **Ferries**: 9 vessels
- **Tugs**: 6 vessels
- **ROPAX**: 3 vessels
- **Navy**: 1 vessel
- **Icebreaker**: 1 vessel
- **IWW**: 1 vessel
- **Guide ship**: 1 vessel

**61 engines**

#### DF Conversion
- **FPSO**: 4 vessels
- **RORO**: 2 vessels
- **Chemical tanker**: 1 vessel
- **Ferries**: 1 vessel
- **IWW**: 1 vessel

**28 engines**

#### DF Power Plant
- **Plants**: 75
- **Output**: 4877 MW
- **Online since**: 1997

**352 engines**

<table>
<thead>
<tr>
<th>Category</th>
<th>Vessels</th>
<th>Engines</th>
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<tbody>
<tr>
<td>LNG Carrier</td>
<td>168</td>
<td>732</td>
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<tr>
<td>Multigas Carrier</td>
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<tr>
<td>Product tanker</td>
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<td>CNG carrier</td>
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<td>123</td>
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</tbody>
</table>

>1,300 engines ➔ >12,000,000 running hours
SAVINGS POTENTIAL
EXISTING SOLUTION VS ENGINES
N2/CH4 RATIO = 45/55% LOW BTU GAS
OMAN LNG
## Fuel Properties Used in the Study

### Main Fuel

<table>
<thead>
<tr>
<th>Flash Gas</th>
<th>mol-%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (C1)</td>
<td>55%</td>
</tr>
<tr>
<td>Nitrogen (N2)</td>
<td>45%</td>
</tr>
<tr>
<td><strong>LHV (MJ/Nm3)</strong></td>
<td><strong>19,8</strong></td>
</tr>
<tr>
<td>0°C, 101,325 kPA</td>
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</tr>
<tr>
<td><strong>HHV (BTU/ft3)</strong></td>
<td><strong>555,5</strong></td>
</tr>
<tr>
<td>60°F, 101,325 kPA</td>
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</tr>
<tr>
<td><strong>Density (kg/m3) @0C</strong></td>
<td><strong>0,9574</strong></td>
</tr>
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</table>

### Back-Up Fuel

<table>
<thead>
<tr>
<th>Feed Gas Composition</th>
<th>mol-%</th>
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<tbody>
<tr>
<td>Methane (C1)</td>
<td>87</td>
</tr>
<tr>
<td>Ethane (C2)</td>
<td>4,9</td>
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<tr>
<td>Propane (C3)</td>
<td>1,7</td>
</tr>
<tr>
<td>Heavier</td>
<td>1,6</td>
</tr>
<tr>
<td>Nitrogen (N2)</td>
<td>3,9</td>
</tr>
<tr>
<td>Carbon Dioxide (CO2)</td>
<td>0,8</td>
</tr>
<tr>
<td><strong>LHV (MJ/Nm3)</strong></td>
<td><strong>38,1</strong></td>
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<tr>
<td>0°C, 101,325 kPA</td>
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</tr>
<tr>
<td><strong>HHV (BTU/ft3)</strong></td>
<td><strong>1067,9</strong></td>
</tr>
<tr>
<td>60°F, 101,325 kPA</td>
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<tr>
<td><strong>Density (kg/m3) @0C</strong></td>
<td><strong>0,8360</strong></td>
</tr>
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</table>
## Power Unit Characteristics Utilized in the Calculations

<table>
<thead>
<tr>
<th>Duty</th>
<th>Average Power Needed</th>
<th>Average Load from ISO Power-%</th>
<th>100% ISO Power Efficiency</th>
<th>Lifetime Average Net Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT for Power Duty</td>
<td>85 MW</td>
<td>50%</td>
<td>30%</td>
<td>23%</td>
</tr>
<tr>
<td>GT for Drive Duty</td>
<td>300 MW</td>
<td>70-75%</td>
<td>32%</td>
<td>27%</td>
</tr>
<tr>
<td>ICE for Power SC</td>
<td>85 MW</td>
<td>80-90%</td>
<td>45%</td>
<td>44%</td>
</tr>
</tbody>
</table>

- Lifetime values for GTs include: starts/stops and idling stand-by unit
- Average weighted lifetime efficiency for Turbines: 26.1
- ICE values given for simple cycle (SC) and combined cycle (CC)
Existing Fuel Feed System for Gas Turbines – 45/55%

- Gas Mixing Ratio: 55% C1 – 45% N2
  - GT electrical efficiency: 23%
  - GT mech. efficiency: 27%

Flash Gas (55% methane, 45% nitrogen)
3000 Ton/Day, 58.570 mmBTU/Day

Feed Gas (87% methane, 4% nitrogen)
1453 Ton/Day, 62.680 mmBTU/Day

GT Power Plant: 85 MW
30.260 mmBTU/Day
370 MW fuel input

GT mechanical Drives: 300 MW
90.990 mmBTU/Day
1110 MW Fuel Input

Mixed Fuel Gas:
4.453 Ton/Day
121.250 mmBTU/Day
1480 MW fuel Input
30% N2 (vol.-%)
Proposed Fuel Feed - Engines Power Plant with Simple Cycle

- Gas Mixing Ratio: 55% C1 – 45 N2
  - GT mech. efficiency: 27%
  - ICE-SC electrical efficiency: 44%

Flash Gas (55% methane, 45% nitrogen)
3000 Ton/Day, 58.570 mmBTU/Day

Feed Gas (87% methane, 4% nitrogen)
1118 Ton/Day, 48.238 mmBTU/Day

*ICE Engines Power Plant: 85 MW
15.820 mmBTU/Day
193 MW fuel input

*ICE Internal Combustion Engine

GT mechanical Drives: 300 MW
90.990 mmBTU/Day
1110 MW Fuel Input

Mixed Fuel Gas:
3.308 Ton/Day
90.990 mmBTU/Day
1110 MW fuel Input
30% N2 (vol.-%)

GT for Liquefaction
- average load: 300 MW
- average el. Efficiency: 27%

GT for Liquefaction
- average load: 85 MW
- average el. Efficiency: 44%
# Feed Gas Saving per - Engine vs. GT Existing Solution

ICE as Single Cycle: 44% as average efficiency,

<table>
<thead>
<tr>
<th>Total Flow</th>
<th>Unit</th>
<th>Existing Situation</th>
<th>Solution with ICE Power Plant Single Cycle</th>
<th>Difference mmBTU/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash Gas Usage</td>
<td>mmBTU/D</td>
<td>58.570</td>
<td>58.570</td>
<td>0</td>
</tr>
<tr>
<td>Feed Gas Usage</td>
<td>mmBTU/D</td>
<td>62.680</td>
<td>48.239</td>
<td>-14.440</td>
</tr>
<tr>
<td><strong>Total Fuel Usage</strong></td>
<td><strong>mmBTU</strong></td>
<td><strong>121.260</strong></td>
<td><strong>106.809</strong></td>
<td><strong>14.440</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Saving Potential*</th>
<th>Saving Potential ~110 Euro/1000 m^3 4 USD/mmBTU</th>
<th>Saving Potential ~150 Euro/1000 m^3 5 USD/mmBTU</th>
<th>Saving Potential ~180 Euro/1000 m^3 6 USD/mmBTU</th>
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</thead>
<tbody>
<tr>
<td>Lifetime Savings mmBTU</td>
<td>105.443.000 mmBTU</td>
<td>105.443.000 mmBTU</td>
<td>105.443.000 mmBTU</td>
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<tr>
<td>Annual Savings MUSD</td>
<td>21,1 MUSD</td>
<td>26,4 MUSD</td>
<td>31,6 MUSD</td>
</tr>
<tr>
<td>Lifetime Savings MUSD</td>
<td>421,8 MUSD</td>
<td>527,2 MUSD</td>
<td>632,7 MUSD</td>
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</tbody>
</table>

*Savings Potential Assumptions: 365 days per year, 20 years
Case 2. LNG Value Chain for a 5 MTPA

Classical LNG Value Chain – Up-Stream

Raw Gas Source:
- Dry gas fields
- Wet gas fields
- Associated Gases

Gas Processing:
- At source
- Pipeline quality
- High send-out pressure

LNG Production:
- LNG production
- NGL handling
- Condensate handling

Logistics:
- On-site storage
- Carrier loading and transportation
LNG Production and Power Needs

**LNG Production**
- Gas Reception
- Acids removal
- De-hydration
- Liquefaction Process
- Heavies removal
- Nitrogen removal End Flash
- LNG Storage

**Fractionation - NGL Handling**
- Condensate Stabilization
- Condensate: C5+
- Fractionation - NGL Handling
- Ethane
- Propane
- Butane
- NGL Storage

**Power Plant**

**LNG Carrier**

**LPG Carrier**

**Condensate Carrier**

**Power for Cooling Compressor**

**General Power Generation**
Fuel Feed for Power Generation

LNG Production

Gas Reception → Acids removal → De-hydration → Liquefaction Process → Nitrogen removal → End Flash → LNG Storage

Fuel Feed Alternatives:
- Feed Gas: -85% methane
- Sweet/Dry Gas: -90% methane
- Lean Feed Gas: -92% methane
- Flash Gas: -60% methane -40% nitrogen
- Boil-Off Gas: -92% methane -2% nitrogen

Fuel Feed Compressor Drive

Fuel → 200 MW mech.

Combustion → Compressor → Turbine → Liquefaction Compressor

Gas Turbine based mechanical drive

Fuel Feed Power Generation

Fuel → 70 MWe

Combustion → Compressor → Turbine → Generator

Gas Turbine based power generation

Feed Gas: -85% methane
Sweet/Dry Gas: -90% methane
Lean Feed Gas: -92% methane
Flash Gas: -60% methane -40% nitrogen
Boil-Off Gas: -92% methane -2% nitrogen
## Typical Power Generation Strategy

<table>
<thead>
<tr>
<th>Duty</th>
<th>Duty Power Need MW</th>
<th>Efficiency % (ISO)*</th>
<th>Fuel Power MWth*</th>
<th>Annual Fuel Gas Input Ton/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Production</td>
<td>70</td>
<td>32</td>
<td>218</td>
<td>132,300 (0,132 MTPA)</td>
</tr>
<tr>
<td>Mechanical Drives</td>
<td>200</td>
<td>34</td>
<td>588</td>
<td>355,000 (0,36 MTPA)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>270 MW</strong></td>
<td><strong>33,6%</strong></td>
<td><strong>776 MW</strong></td>
<td><strong>488,070 (0,488 MTPA)</strong></td>
</tr>
</tbody>
</table>

*single cycle industrial GT

### Power Generation Solution

- **Gas Turbine based mechanical drive**
- **Gas Turbine based power generation**

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Annual LNG/Fuel Gas Flow Rate

Annual Gas Value as Fuel

- Gas Price 4 USD/mmBTU: 96 MUSD
- Gas Price 6 USD/mmBTU: 144 MUSD
- Gas Price 10 USD/mmBTU: 240 MUSD

Annual LNG Volume MTPA
- 5 MTPA

9.8% of Annual production

Liquefaction Plant Annual Capacity
- 0.49 MTPA

Annual Fuel Consumption - Power Units

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Side Streams as Power Generation Fuel
New Power Strategy:

- ICE allows usage of side-streams as fuel
- High Electrical efficiency (heat rate): 45%
- Question of fully electrified production
Wärtsilä Power Plant with Multi Unit Principle

Wärtsilä multi-unit Power Plant for base load and intermittent power generation:
- CMPP, 200 MW, Brazil,
- Fuel: Natural Gas
Alternative Power Generation Strategy

Power Generation by ICE* Power Plant

- **Multiunit Power Plant:**
  - Based on 10 or 20 MW engine frame size
  - Constructed with 6 unit blocks
  - Typically N+1 or N+2 configuration

- **Plant Performance:**
  - 60 MW - 8+2 20V32GD
  - 275 MW – 17 + 2 18V46GD
  - Multi-Fuel Units
  - Net Electrical Efficiency: 43%

---

*ICE Internal Combustion Engine*
Alternative Power Generation Strategy

Proposed Fuel Feed Alternatives for ICE based Power Plant

- Ethane
- Propane
- Butane
- Pentane+

Fractionation - NGL Handling

NGL + Heavier

- Nitrogen removal
- End Flash

Flash Gas

Fuel Feed Alternatives:
- Sweet/Dry Gas: 90% methane

If ICE Technology uses the same fuel as GT solution, the saving is only the gas flow difference between 43% to 33% electrical efficiency – being about 25% less fuel consumed

Side Streams as Power Generation Fuel – Kari Punnonen
Case Study - Hydrocarbon Balance

**Feed Gas Composition**

<table>
<thead>
<tr>
<th>Component</th>
<th>mol-%</th>
<th>Flow Rate: MTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (C1)</td>
<td>86,3</td>
<td></td>
</tr>
<tr>
<td>Ethane (C2)</td>
<td>5,4</td>
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<tr>
<td>Propane (C3)</td>
<td>1,9</td>
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<tr>
<td>Heavier</td>
<td>6,15</td>
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<tr>
<td>Nitrogen (N2)</td>
<td>0,25</td>
<td></td>
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**LNG Composition**

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<th>Component</th>
<th>mol-%</th>
<th>Flow Rate: MTPA</th>
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<tbody>
<tr>
<td>Methane (C1)</td>
<td>92,2</td>
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</tr>
<tr>
<td>Ethane (C2)</td>
<td>5,9</td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N2)</td>
<td>1,9</td>
<td></td>
</tr>
</tbody>
</table>

**Flash Gas**

<table>
<thead>
<tr>
<th>Component</th>
<th>mol-%</th>
<th>Flow Rate: MTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane (C1)</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N2)</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

**Side Streams as Power Generation Fuel**

- Condensates: C5+
  - Thermal Power MW: 226
  - *Flow Rate: MTPA: 0,15

- Butane: C4
  - Thermal Power MW: 375
  - *Flow Rate: MTPA: 0,25

- Propane: C3
  - Thermal Power MW: 400
  - *Flow Rate: MTPA: 0,26

- Ethane: C2
  - Thermal Power MW: 461
  - *Flow Rate: MTPA: 0,29

*350 days per year, Hysys Model
# Hydrocarbon Summary at LNG Plant

<table>
<thead>
<tr>
<th>Hydrocarbon Fraction</th>
<th>Flow Rate MTPA</th>
<th>Thermal Power MWth</th>
<th>Potential Electrical Power MW with ICE*</th>
<th>Wärtsilä Engine type</th>
</tr>
</thead>
<tbody>
<tr>
<td>LNG</td>
<td>4,99 MTPA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash Gas</td>
<td>0,115 MTPA</td>
<td>84,7 MWth</td>
<td>36 MWe</td>
<td>SG</td>
</tr>
<tr>
<td>Ethane (now blended into LNG)</td>
<td>0,29 MTPA</td>
<td>461 MWth</td>
<td>198 MWe</td>
<td>SG/LG</td>
</tr>
<tr>
<td>Propane + Butane</td>
<td>0,25 &amp; 0,26</td>
<td>400, 375 MWth</td>
<td>172, 161 MWe</td>
<td>LG</td>
</tr>
<tr>
<td>Condensates</td>
<td>0,15 MTPA</td>
<td>226 MWth</td>
<td>97 MWe</td>
<td>LG</td>
</tr>
</tbody>
</table>

* ICE Internal Combustion Engine, net electrical efficiency: 43%
Thank you for your attention!

or visit www.wartsila.com