Biogas Liquefaction Technology Workshop

6 tons/day LBM Plant

13th of June 2017

Samsø Energy Academy, Denmark

Anders Siggberg
Wärtsilä is a global leader in complete lifecycle power solutions for the marine and energy markets. By emphasizing technological innovation and total efficiency, Wärtsilä maximizes the environmental and economic performance of its customers.

In 2016, Wärtsilä's net sales totalled EUR 4.8 billion with approximately 18,000 employees. The company has operations in more than 200 locations in nearly 70 countries around the world. Wärtsilä is listed on the NASDAQ OMX Helsinki, Finland.
A Comprehensive product portfolio
Wärtsilä Gas Solutions – Competence Center for Gas Technologies

Wärtsilä Gas Solutions has:

- 50 years of delivery references of gas handling systems
- More than 300 employees dedicated to the satisfactory delivery of high technology cryogenic solutions
- Commitment to innovation and new technology
- Focused on continuous improvements
- International operation

Our customers will benefit from highly skilled process engineers with operational experience:

- Extensive process understanding
- Extensive equipment understanding
- Extensive control & automation understanding
Wärtsilä LNG History: 2003 - 2015

**ONSHORE**

2003
Snurrevarden liquefaction plant, Norway. 22,000 TPA.

2007
Kollsnes II liquefaction plant, Norway. 84,000 TPA.

2008
Dual and Triple Brayton high-efficiency liquefaction processes launched.

2010
Kilpilahti liquefaction plant, Finland. 20,000 TPA.

2012
MiniMR liquefaction process launched with pilot liquefaction plant.

2013
EGE Biogas mini liquefaction plant, Norway. 4,000 TPA.

2015
ÆTornio Manga LNG terminal, Finland. 50,000 m³ tank.

2006 - 2008
31 LNG BOG reliquefaction systems delivered for Q-Flex LNG carrier fleet. 58,000 TPA each.

2007
Open & closed loop LNG regasification processes launched with pilot re-gas plant.

2009
Golar Winter FSRU with seawater/ propane LNG regasification system.

2010
GDF Suez Neptune and Cape Ann SRVs with steam/water-glycol LNG regasification systems.

2011
LNG fuel systems installed in multiple coastal ships and ferries.

2012
LNG regasification systems delivered as turnkey single-lift modules to Golar Khannur FSRU, PETRONAS JRU project and HHI Hoegh Generic FSRU.

**OFFSHORE**
In Denmark, there is three Wärtsilä entities:

- **Wärtsilä Danmark A/S** is a Service unit which main activities are the sales and services of engines and equipment for the Marine market and Power plants. Number of employees: 78

- **Wärtsilä Svanehøj A/S** produces hydraulically driven portable pumps, which are widely used in oil product and chemical tanker applications. Number of employees: 130

- **Wärtsilä Lyngsø Marine A/S** specializes in automation, navigation and communication products for the maritime industry. Number of employees: 60
**40 power plants with 60 engines producing 201 MW**

<table>
<thead>
<tr>
<th>Largest Plants</th>
<th>Location</th>
<th>Power</th>
<th>Engines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Svendborg</td>
<td>Svendborg, Denmark</td>
<td>17.0 MW</td>
<td>3x18V34SG</td>
</tr>
<tr>
<td>Grinsted</td>
<td>Grinsted, Denmark</td>
<td>13.3 MW</td>
<td>2x18V32GD</td>
</tr>
<tr>
<td>Skagen</td>
<td>Skagen, Denmark</td>
<td>12.9 MW</td>
<td>3x18V28SG</td>
</tr>
<tr>
<td>Danish Malting Group</td>
<td>Vordingborg, Denmark</td>
<td>11.0 MW</td>
<td>2x18V34SG</td>
</tr>
<tr>
<td>Frederikssund</td>
<td>Frederikssund, Denmark</td>
<td>11.0 MW</td>
<td>2x18V34SG</td>
</tr>
<tr>
<td>Ringsted Kraftvarmevaerk</td>
<td>Ringsted, Denmark</td>
<td>10.4 MW</td>
<td>2x18V34SG</td>
</tr>
<tr>
<td>Stövring</td>
<td>Stövring, Denmark</td>
<td>8.1 MW</td>
<td>3x16V35SG</td>
</tr>
<tr>
<td>Ringkøbing</td>
<td>Ringkøbing, Denmark</td>
<td>8.0 MW</td>
<td>1xW20V34SG</td>
</tr>
<tr>
<td>Grinsted El Wärmeverk</td>
<td>Grinsted, Denmark</td>
<td>6.8 MW</td>
<td>1x18V32DF</td>
</tr>
<tr>
<td>Jelling</td>
<td>Jelling, Denmark</td>
<td>6.1 MW</td>
<td>1x18V34SG</td>
</tr>
</tbody>
</table>

Good service coverage!
SAMSØ LBM – 6 TPD
LBM PLANT

Wärtsilä Solution
General Information – Biogas Cleaning Plant

Feed Biogas Requirements:
- CH$_4$ content 55 – 70 %vol
- CO$_2$ content 29 – 44 %vol
- H$_2$S content 300 ppm max
- NH$_3$ content 300 mg/Nm3 max
- O$_2$ + N$_2$ content 0.5%vol max
- H$_2$O is saturated
- Pressure = 5 – 60 mbarg
- Temperature = 5 - 40°C

Clean Biogas Specification:
- CH$_4$ content 99.9%vol
- CO$_2$ content 50 ppm max
- H$_2$S content 4 ppm max
- H$_2$O content 1 ppm max
- Pressure = 20 barg
- Temperature ≤ 40°C

CO$_2$ Specification:
- CO$_2$ content 97.6 – 98.6 %vol
- CH$_4$ content 0.05 – 0.15 %vol
- H$_2$S content < 3 ppm
- O$_2$ + N$_2$ content < 0.1 %vol
- H$_2$O content 1.2 – 1.8 %vol (saturated)
- Pressure = 10 – 20 mbarg
- Temperature = 38 – 50 °C

Biogas cleaning to reach **Liquefaction specification** in one single plant.
Heat Integration Concept for biogas production plants

- **Feed XX m3/h**
- **Substrate**
  - 10°C → HEX1
  - 20°C → HEX2
  - 52°C → AD 1
  - 55°C → HEX4
  - Building heating
  - Heat Integration >90%

- **HEX1**
- **HEX2**
- **AD 1**
- **HEX3**
- **HEX4**

- **Amine Biogas cleaner**
  - 55/35°C → A
  - 85/65°C → B

- **Heat source**
  - Pellet boiler
  - YY MW
  - B/C (200-1000 kW)
  - 0,12 kWh/Nm³
  - 0,57 kWh/Nm³

- **B/C (250-1000 kW)**
How does the Wärtsilä MR Liquefaction Plant work?

A pre-cooling system is used to cool (-10°C) both the clean gas (upstream the Cryogenic Heat Exchanger), and the MR (upstream the separator). By doing this, the liquefaction system will have constant and stable operation conditions independent of ambient variations. Furthermore, it also contributes to energy saving.

The pre-cooling is performed by a chiller. The cooling demand of the pre-cooling plant will vary with required liquefaction capacity and ambient temperature. The capacity of the chiller is controlled by a variable frequency drive, giving efficient operation also at part load.

The mixed refrigerant (MR) side works according to the following principles: Compressed MR is cooled to partially liquefied state, and split in a liquid fraction and a vapor fraction in a separator. In the Liquefier, part of the MR stream is used for cooling the MR itself.

The MR compressor is also equipped with VFD to maintain flexibility and efficiency in adapting different modes of liquefaction.
### Parts in Biogas Liquefaction Project

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>DESCRIPTION</th>
<th>QTY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas Precooler</td>
<td>Brazed steel plate heat exchanger. Cooling the Clean Biogas to -10°C prior to entering the Cold Box.</td>
<td>1</td>
</tr>
<tr>
<td>MR Precooler</td>
<td>Brazed steel plate heat exchanger. Cooling the MR to -10°C prior to entering the MR Separator.</td>
<td>1</td>
</tr>
<tr>
<td>MR Separator</td>
<td>A vessel separating vapor and liquid phase of the cooled MR before entering the Cold Box.</td>
<td>1</td>
</tr>
<tr>
<td>Cold Box</td>
<td>Alumunium plate fin multiple pass heat exchanger. The clean precooled biogas transfers its heat to the precooled MR (gas and liquid phases) in a counter flow until it condenses and exit as Liquid Biogas (LBG) from the bottom part of the Cold Box (between -150°C to -160°C).</td>
<td>1</td>
</tr>
<tr>
<td>Control Valves</td>
<td>Regulating the flow and pressure of the LBG, liquid MR, and vapor MR. Before flowing to the storage tank, LBG must be depressurized from 29 Barg to storage tank pressure.</td>
<td>3</td>
</tr>
</tbody>
</table>
MR Compressor

- Wärtsilä developed refrigerant composition
- Very reliable "standard" screw compressor
- Cooling in a MR (Mixed Refrigerant) cooling loop
- Closed system with zero refrigerant loss
- Fully automated cool down
- Fully automated selfregulating capacity control from 0 to 100% load

Typically supplied by Sabroe, Denmark!
Pre-Cooling and Glycol System

- Two independent glycol-water systems for process pre-cooling and general cooling purposes
- Air cooled circuit
- Pre-cooled circuit with integrated ammonia chiller unit
- Fully automated – self regulating systems

Typically supplied by Sabroe, Denmark!
**LBG Storage and export**

- Standard vacuum insulated pressure tank
- Very limited heat ingress
- Reliable, tested design
- Standard solutions for pump and filling station
- Local operation by truck driver without intervention from plant control
Process Control

- Automatic
- Robust
- Easy to operate
- Capacity is automatically adjusted to the incoming gas flow, with maintained process stability
Typical Plant Layout

1. Gas pretreatment
2. Liquefaction
3. LNG storage
4. Electrical and control system
5. Truck loading
Preliminary Performance Figures

- Turn-down: down to 40% of max production
- Start up from warm condition: approximately 4 hours
- Start up from cold condition: approximately 3 hours
- Maximum methane slip: 0.1% CH₄

<table>
<thead>
<tr>
<th>Utility</th>
<th>Unit</th>
<th>Value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specific electricity consumption</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biogas Upgrading</td>
<td>kWh/Nm³ Raw Biogas</td>
<td>0,15</td>
<td></td>
</tr>
<tr>
<td>Biogas Liquefaction</td>
<td>kWh/kg LBG</td>
<td>0,70</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous (auxiliary pumps, lightings, sensors, etc.)</td>
<td>kWh/kg LBG</td>
<td>0,10</td>
<td></td>
</tr>
<tr>
<td>LBG Export Pump rated Power</td>
<td>kWe</td>
<td>6,2</td>
<td></td>
</tr>
<tr>
<td><strong>Specific heat consumption for biogas upgrading</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat carrier: Water, Steam, Hot Oil, etc.</td>
<td>kWh/Nm³ Raw Biogas</td>
<td>0,63</td>
<td>Heat Recovery: up to 0,49 kWh/Nm³ will be available for the Digestors/Biogas Production</td>
</tr>
<tr>
<td>feed/return temp: 130°C / 115°C; or steam &gt;3 barg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Consumables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument Air, 6 barg dewpoint -40°C</td>
<td>Nm³/hour</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Chemicals for Biogas Upgrading</td>
<td>kg/year</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>Active Carbon for Biogas Upgrading</td>
<td>kg/year</td>
<td>1540</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>litre/1000 Nm³ Raw Biogas</td>
<td>&lt;60</td>
<td></td>
</tr>
<tr>
<td>Waste water from Biogas Upgrading</td>
<td>litre/1000 Nm³ Raw Biogas</td>
<td>&lt;20</td>
<td></td>
</tr>
</tbody>
</table>

LBG Wärtsilä
Methane Number (WMN): ~100
→ The gas can be used as fuel for the Wärtsilä 20DF engines on the Samsø ferry!
### Scope of Work

<table>
<thead>
<tr>
<th></th>
<th>Equipment Supply</th>
<th>Process EPC</th>
<th>EPC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Procurement</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Construction of Skids</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Transport</td>
<td>Either: FOB, CIF, CIP, DAT or DAP</td>
<td>DAP to project site</td>
<td>DAP to project site</td>
</tr>
<tr>
<td>Installation Works</td>
<td>Provide Supervision</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Commissioning &amp; Gas Trial</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Civil Works</td>
<td>NO</td>
<td>NO</td>
<td>✓</td>
</tr>
</tbody>
</table>

We can supply according to your preference.
Experience and recent success
Experience and Recent Success

### Snurrevarden

<table>
<thead>
<tr>
<th>Customer</th>
<th>Gasnor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Small scale liquefaction plant</td>
</tr>
<tr>
<td>Tank net volume</td>
<td>2 x 250 m³</td>
</tr>
<tr>
<td>Capacity</td>
<td>60 TPD / 22,000 TPA</td>
</tr>
<tr>
<td>Size of liquefaction unit</td>
<td>16 m x 18 m</td>
</tr>
<tr>
<td>Gas source</td>
<td>Pipeline gas. Inlet pressure 120-150 bar.</td>
</tr>
<tr>
<td>Details</td>
<td>• LNG transported to customers by tanker truck</td>
</tr>
<tr>
<td>Scope of supply</td>
<td>Complete plant, incl.</td>
</tr>
<tr>
<td>Delivery method</td>
<td>EPCIC</td>
</tr>
<tr>
<td>Delivered</td>
<td>2003</td>
</tr>
</tbody>
</table>

"The first stand-alone small scale LNG plant in Northern Europe.”
**Experience and Recent Success**

**EGE Biogas**

<table>
<thead>
<tr>
<th>Customer</th>
<th>Cambi AS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Mini liquefaction plant</td>
</tr>
<tr>
<td>Tank net volume</td>
<td>180 m³</td>
</tr>
<tr>
<td>Capacity</td>
<td>11 TPD / 4,000 TPA</td>
</tr>
<tr>
<td>Size of liquefaction unit</td>
<td>8 m x 14 m</td>
</tr>
<tr>
<td>Gas source</td>
<td>Biogas from 50,000 TPA of food waste</td>
</tr>
<tr>
<td>Details</td>
<td>Fuel production for 135 buses in the city of Oslo</td>
</tr>
</tbody>
</table>
| Scope of supply | Complete plant, incl.  
• Gas pre-treatment  
• Cooling system (Ambient air)  
• MR liquefaction process  
• Storage tank  
• Electrical and control systems  
• Service agreement  
Excl. Civil works and installation |
| Delivery method | EPC |
| Delivered      | 2013 |

“135 Oslo region buses will be able to run on biogas which means 10,000 tonnes emission reduction per year.”
On Going Project

**Biokraft LBG**

- **Owner**: Biokraft AS
- **Type**: Mini liquefaction plant
- **Tank net volume**: 350 m³
- **Capacity**: 25 TPD / 9,125 TPA
- **Size of liquefaction unit**: 12 m x 20 m
- **Gas source**: Biogas from fish industry and paper mill waste
- **Details**: Biogas to be used on city buses in Trondheim
- **Scope of supply**: Liquefaction plant, incl.
  - Cooling system (Ambient air)
  - MR liquefaction process
  - Storage tank
  - Electrical and control systems
  - Service agreement
  - Installation of plant
  Excl. Civil works
- **Delivery method**: EPC
- **Delivered**: 2017

“We expect strong demand for liquefied biogas as fuel. Wärtsilä’s biogas liquefaction solution represents an important step forward in realising this potential.”
### On Going Project

**bioHybrid Hahnennest**

<table>
<thead>
<tr>
<th><strong>Owner</strong></th>
<th>Erdgas Südwest GmbH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>MR liquefaction plant</td>
</tr>
<tr>
<td><strong>Tank net volume</strong></td>
<td>105 m³</td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td>10 TPD / 3500 TPA</td>
</tr>
<tr>
<td><strong>Size of liquefaction unit</strong></td>
<td>30 m x 40 m</td>
</tr>
<tr>
<td><strong>Gas source</strong></td>
<td>Biogas from bio-waste and/or pipeline gas</td>
</tr>
<tr>
<td><strong>Details</strong></td>
<td>The plant will produce both bioLNG and LNG</td>
</tr>
<tr>
<td><strong>Scope of supply</strong></td>
<td>Liquefaction plant, incl.</td>
</tr>
<tr>
<td></td>
<td>• Gas Cleaning</td>
</tr>
<tr>
<td></td>
<td>• MR liquefaction process</td>
</tr>
<tr>
<td></td>
<td>• Storage tank</td>
</tr>
<tr>
<td></td>
<td>• Export system</td>
</tr>
<tr>
<td></td>
<td>• Electrical and control systems</td>
</tr>
<tr>
<td></td>
<td>• Installation of plant</td>
</tr>
<tr>
<td></td>
<td>Excl. Civil works</td>
</tr>
<tr>
<td><strong>Delivery method</strong></td>
<td>EPC</td>
</tr>
<tr>
<td><strong>Delivered</strong></td>
<td>2018</td>
</tr>
</tbody>
</table>

“Biogas and pipeline gas compositions can vary substantially, and Wärtsilä’s advanced technology can handle both.”
VALUE PROPOSITION

plants are operating and maintained easily. Plant owner can focus resources on making profit from the commercial activity.

thanks to the good design the plant requires minimum footprint and able to handle load variation easily while maintaining efficiency

state of the art control system will automate the plant. This minimizes OPEX which is essential for a small scale LNG business.

Standard off the shelves equipment will ensure high availability throughout years of operation, thus maximizing plant owners’ earnings.

Simple Operation and Maintenance

Designed for Unmanned

High Flexibility

Robust Parts