WÄRTSILÄ RENEWABLE GAS/ PUREGAS SOLUTIONS

BIOGAS UPGRADING/ CAPURE TECHNOLOGY

November 19th, 2020
American Biogas Council
Biogas Upgrading Case Studies Webinar
Quick Notes

- You should be able to hear me talking now. If you can’t, use the questions module to describe your issue.

- Two Audio Options: Phone or Computer
  Choose one and connect

- Pro tip: Don’t call in on our phone if your audio is set to “Mic and Speakers”

- Ask questions using the Questions Panel on the right side of your screen at any time.

- The recording of the webinar and the slides will be available after the event. We will post them online and send you a link.
Who we are

The only US organization representing the entire biogas industry

All sectors represented

- Project developers/owners
- Equipment retailers and dealers
- Waste management companies
- Waste water companies
- Farms
- Utilities
- Municipalities
- Consultants and EPCs
- Financiers, accountants, lawyers and engineers
- Non-profits, universities and government agencies

200+ organizations
2,000+ individuals
The US Biogas Market

Current
- 255 on Farm
- 1,269 Water
- 66 Food Scrap
- 645 at Landfills

Potential
- 8,300 on Farm
- 4,000 Wastewater
- 1,000 Food Scrap
- 440 at Landfills

2,200+ Operational Biogas Systems
15,000+ Potential New Biogas Systems

Wait, Don’t Biogas Systems ONLY Work on LARGE Farms?

Breaking down 222 Dairy Biogas Systems…
1: > 20,000 cows
6: 10,000-20,000 head
16: 5,000-10,000 head.
Total LARGE farm digesters: 10%
Biogas Process

- Energy crop
- Manure
- Organic waste
- Bio fertilizer
- Bio CO₂
- Heat
- Biogas
- Anaerobic digester
- Capture plant
- Heat/Electricity
- Renewable heat & power
- Liquefaction BioLNG
- Gas to grid
- CNG
Biogas Process

Energy crop

Manure

Organic waste

Biogas

An aerobic digester

Heat / Electricity

Capture plant

Biomethane

Gas to grid

Liquefaction BioLNG

Renewable heat & power

Heat

Bio CO2

Bio fertilizer

CNG
CAPURE PROCESS

1. Biogas
2. H₂S Removal
3. Absorption
4. Stripping
5. Gas compression and drying

Bio CO₂

Liquefaction BioLNG

Biomethane

Gas to grid

CNG
99.9% of the CH₄ in the biogas can be sold
  • Always the highest revenue

CApure Technology
  • No affinity for CH₄ / high affinity for CO₂

Best In Class
  • No other single technology achieves this efficiency
Minimises GHG emissions
Helps achieve sustainability criteria
CO₂ can be used directly for crop propagation
No need for additional exhaust treatment
Easier to recover CO₂ for Food Grade applications
Biogas upgrading without heat integration
Biogas upgrading with heat integration
• < 0.06 kWh/Nm³ Biogas in electricity consumption
  • CApure process operates at low pressure (only the CH₄ is compressed)

• < 0.1 kWh/Nm³ Biogas in net heat consumption
  • 95% of the heat used can be recovered

• Low consumption of water and solvents
  • Long life, biodegradable organic solvents used in CApure process
    are part of a closed-loop system

• Low maintenance cost
  • Robust design, Easy access, 98% uptime guaranteed
# Extensive Product Range

5 core models - available in 2 versions
- Standard version
- Low pressure version (LP)

<table>
<thead>
<tr>
<th>Core model</th>
<th>Max Capacity (scfm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA30LP</td>
<td>567</td>
</tr>
<tr>
<td>CA50LP</td>
<td>800</td>
</tr>
<tr>
<td>CA60LP</td>
<td>1521</td>
</tr>
<tr>
<td>CA70LP</td>
<td>2276</td>
</tr>
<tr>
<td>CA80LP</td>
<td>3780</td>
</tr>
</tbody>
</table>
HIGHEST BUILD QUALITY AND DESIGN

Manufactured and fully tested before delivered to site

High-Grade Stainless Steel used throughout

Built-in redundancy of key components such as compressors and blowers

Easy access for maintenance

US manufactured in Dubuque, Iowa
COMPREHENSIVE SERVICE SUPPORT

• Packages include remote operation, supervision, control, service, maintenance & 24/7 phone support

• Installation, Start-Up, Commissioning and Operator Training included as standard

• Extended warranty packages available

• Remote monitoring and call out available

• 98% uptime guarantee - further improved through optimisation program
• Over 40 operational sites
• Sites in USA, Sweden, UK, Denmark, Germany, Norway, Ireland, Switzerland
• Two new installations in US in 2019/2020
• Range of substrates including food waste, agricultural residues, green crops, WWTP
1.3. REFERENCES PLANTS

1. Borås, SWE, 2002, 450 Nm³/h, co-digestion **) FW, MSW
2. Göteborg, SWE, 2006, 1600 Nm³/h, WWTP *)
3. Kalmar, SWE, 2008, 200 Nm³/h, co-digestion **) FW
4. Falkenberg, SWE, 2009, 750 Nm³/h, co-digestion *) FW
5. Stockholm, SWE, 2009, 800 Nm³/h, co-digestion **) FW
6. Stavanger, NOR, 2009, 500 Nm³/h, co-digestion *) FW
7. Könnern, DEU, 2009, 3400 Nm³/h, green crops *)
8. Oslo, NOR, 2010, 750 Nm³/h, WWTP **)
9. Karlstad, SWE, 2010, 200 Nm³/h, WWTP **)
10. Linköping, SWE, 2010, 3400 Nm³/h, co-digestion **) FW, MSW
11. Sävsjö, SWE, 2012, 600 Nm³/h, manure co-digestion **) FW
12. Freiburg, DEU, 2012, 1000 Nm³/h, green crops *
13. Växjö, SWE, 2012, 500 Nm³/h, WWTP **) FW, MSW
14. Weissenborn, DEU 2013, 700 Nm³/h, green crops *)
15. Zürich, CHE, 2013, 1400 Nm³/h, WWTP *) MSW
16. Karlskoga, SWE, 2014, 900 Nm³/h **) FW, MSW
17. Crouchland, GBR, 2014, 2000 Nm³/h *)
18. Hemmet, DNK, 2015, 900 Nm³/h *)
19. Glenmore, IRL, 2016, 1800 Nm³/h
20. Lindum, NOR, 2015, 600 Nm³/h **) FW
21. Buchan, GBR, 2015, 1250 Nm³/h *)
22. Riverside, GBR, 2015, 2000 Nm³/h *)
23. Biokraft, NOR, 2017, 2200 Nm³/h with liquefaction **) FW
24. Rybjerg, DNK, Membrane plant, 2016,
25. Grøn Gas Vraa, DNK, 2016, 3000 Nm³/h
26. Sønderjysk, DNK, 2016, 5000 Nm³/h
27. Somerset, GBR, 2016, 1250 Nm³/h
28. Willand, GBR, 2016, 1250 Nm³/h
29. Granville, GBR, 2016, 3000 Nm³/h
30. Ekogas, SWE, 2017, 700 Nm³/h
31. Korskro, DNK, 2018, 5000 Nm³/h
32. Högbytorp, SWE, 2018, 2000 Nm³/h
33. Holsted, DNK, 2019, 3000 Nm³/h
34. Tekniska verken Linköping, LBG, SWE, 2019,
35. Bånlev, DNK, 2019, 3000 Nm³/h
36. GreenLab Skive Biogas, DNK, 2019, 5000 Nm³/h
37. VEAS, NOR, 2020, 2000 Nm³/h
38. Thorsø, DNK, 2020, 2000 Nm³/h
39. Three Mile Canyon Farms, USA, 2019, 6000 Nm³/h
40. Sønderjysk, DNK, 2020, 6000 Nm³/h
41. Junction City Expansion, USA 2020, 6000 Nm³/h

*) Grid injection to natural gas grid,
**) Vehicle fuel filling station or local bio methane grid
Food waste FW, Municipal solid waste MSW
The amine advantage

George Yavari
WHY AMINE?

- Amine has been used since the 1960s by the oil and gas industry for processing and sweetening of natural gas.

- More recently small-scale versions have been developed for the removal of CO$_2$ from biogas and CO$_2$ removal (carbon capture) from flu gas.

- Amine is the most energy efficient media for CO2 removal providing the highest CH4 recovery, the highest CH4 purity and the lowest OPEX.

- The use of Amine reduces the methane slip to less than 0.1% which is more than a 500% reduction compared to other technologies.

- Methane is a harmful GHG - approx 28 times more harmful than CO2. Thereby biogas upgrading by Amine emits much less GHG than other upgrading technologies.
IS AMINE DANGEROUS OR POLLUTING?

- Dimethylamine is a BIODEGRADABLE organic solvent with the formula \((\text{CH}_3)_2\text{NH}\)

- A Puregas CA50 will be filled with only 1.8 m³ of amine and 1.8 m³ of water

- The solution is in a CLOSED-LOOP SYSTEM and the amine is recycled back into the process. None is consumed in the upgrading process.

- In biogas upgrading plants, handling of the amine needs to follow the same precautions as other liquids such as compressor oils, glycol, condensate etc i.e. wear protective gloves/protective clothing/eye protection etc. Avoid breathing dust/fume/gas/mist/vapours/spray.
### How does amine process compare with other upgrading technologies?

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Amine process</th>
<th>Membrane</th>
<th>Water scrubbers</th>
<th>PSA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology - process steps</strong></td>
<td>Pre-treatment needed: VOCs and siloxanes are removed before the membranes</td>
<td>Pre-treatment needed: H2S &amp; VOC removal + Gas cooler/Chiller</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Performance values (electricity consumption)</strong></td>
<td>0,06 kWh/Nm³</td>
<td>0,28 kWh/Nm³ (3-stage)</td>
<td>0,25 kWh/Nm³ (have not met the performance tests on 0,21)</td>
<td>0,3 kWh/Nm³</td>
</tr>
<tr>
<td><strong>Operational conditions</strong></td>
<td>Higher temperature than others = The hot streams allow heat integration &amp; heating of substrates.</td>
<td>Low temperatures (excess heat cannot be utilised without a heat pump)</td>
<td>Microbiological growth in the water – capacity decrease &amp; cleaning (fatty substrates), Low Temp (see previous)</td>
<td>Swinging is managed with buffer tanks (continuous process), Low Temp (see previous)</td>
</tr>
<tr>
<td><strong>Methane slip</strong></td>
<td>&lt; 0.1% of inlet CH4</td>
<td>&lt; 2.5% of inlet CH4</td>
<td>&lt; 5% of inlet CH4</td>
<td>&lt; 4% of inlet CH4</td>
</tr>
<tr>
<td><strong>Product quality (remaining CO2)</strong></td>
<td>&lt; 1 vol% CO2 in product</td>
<td>~1 vol% CO2 in product (3-stage), 1-stage has higher CO2 in product</td>
<td>~2 vol% CO2 in product</td>
<td>~2 vol% CO2 in product</td>
</tr>
<tr>
<td><strong>Health, environment, safety (HSE): Raw gas impurities are removed in each technology but by different means and the sidestreams need to be treated differently</strong></td>
<td>Solvent: amine, Leakages to environment are minimised with process safety, Amine traces go out only with off-gas (&lt; 150 micrograms/Nm³ CO2)</td>
<td>A dry system, Gas cooler with chiller as pretreatment collecting the impurities (water, VOC, impurities) &amp; AC (VOC, H2S)</td>
<td>Water treatment – impurities end up in water streams</td>
<td>Gas-cooler will knock-out water and VOC, Traces of VOC in the offgas</td>
</tr>
<tr>
<td><strong>Utilities &amp; efficiency (cooling water consumption) – heat integration reduces the total low energy consumption for the upgrading)</strong></td>
<td>Efficient heat integration possible and with heat integration no cooling water needed, Less water consumption</td>
<td>No water consumption but high electrical consumption</td>
<td>Water consumption and high electrical consumption</td>
<td>No water consumption but high electrical consumption</td>
</tr>
<tr>
<td><strong>CAPEX &amp; footprint (large plants, &gt; 500 Nm³/h)</strong></td>
<td>Amine CAPEX attractive, less footprint</td>
<td>Higher footprint and CAPEX, Same footprint as amine</td>
<td>Higher footprint</td>
<td>Higher footprint</td>
</tr>
<tr>
<td><strong>CAPEX &amp; footprint (small plants, &lt; 500 Nm³/h)</strong></td>
<td>Higher footprint and CAPEX</td>
<td>Lower footprint and CAPEX, 1000-2500 Nm³/h mid range</td>
<td>1000-2500 Nm³/h mid range</td>
<td></td>
</tr>
</tbody>
</table>
Electricity Consumption Comparison

Comparison of typical Biogas upgrading plant using Membrane and Chemical absorption technology

Membrane System

<table>
<thead>
<tr>
<th>Raw Biogas</th>
<th>Blower</th>
<th>Fan Cooler</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2S removal</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Membrane System</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2 Absorber</td>
</tr>
<tr>
<td>CO2 Stripper</td>
</tr>
<tr>
<td>Hot Water Supply</td>
</tr>
<tr>
<td>Hot Water return</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical Absorption System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow</th>
<th>$3500$ scfm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>50%</td>
</tr>
<tr>
<td>CO2</td>
<td>33%</td>
</tr>
<tr>
<td>H2S</td>
<td>500ppm</td>
</tr>
<tr>
<td>H2O &amp; others</td>
<td>4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electricity Consumption:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical kWh/Nm3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electricity Consumption:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical kWh/Nm3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biogas</th>
<th>99%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH4 recovery</td>
<td>97.00%</td>
</tr>
</tbody>
</table>
Electricity Yearly Consumption

Basis: 3500 scfm of inlet raw biogas flow
Using membrane system increase the electricity cost by 1,260,000 dollars /year.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Absorption</td>
<td>0.06</td>
<td>kwh/Nm3</td>
</tr>
<tr>
<td>Membrane</td>
<td>0.28</td>
<td>kwh/Nm3</td>
</tr>
<tr>
<td>Difference</td>
<td>0.22</td>
<td>kwh/Nm3</td>
</tr>
<tr>
<td>Yearly Electricity usage difference</td>
<td>12,578,834</td>
<td>kw/year</td>
</tr>
<tr>
<td>Electricity cost</td>
<td>0.10</td>
<td>dollar / kwh</td>
</tr>
<tr>
<td>Total Energy Cost Difference</td>
<td>1,257,883.40</td>
<td>dollars / year</td>
</tr>
</tbody>
</table>
# Methane Recovery and Revenue Comparison

**Basis:** 3500 scfm of inlet raw biogas

<table>
<thead>
<tr>
<th></th>
<th>Methane Recovery</th>
<th>Product biomethane in scfm</th>
<th>Product gas Caloric value btu/ft³</th>
<th>Production Million btu / year</th>
</tr>
</thead>
<tbody>
<tr>
<td>CApure amine process</td>
<td>99.90%</td>
<td>2028</td>
<td>1000</td>
<td>1,065,901</td>
</tr>
<tr>
<td>Membrane System</td>
<td>97.0%</td>
<td>1969</td>
<td>1000</td>
<td>1,034,959</td>
</tr>
<tr>
<td>Difference</td>
<td>2.90%</td>
<td>59</td>
<td></td>
<td>33,942</td>
</tr>
</tbody>
</table>

**Biomethane price** $35 per million btu

**More Revenue in a Year**

*By utilizing Wartsila Puregas CApure amine process technology*

$ 1,082,972.52
Integration of heat recovered from biogas upgrader into the digestion process
Operation & Automation

Fredrik Vigertsson
Uptime and Reliability

• Facility is going through a Factory Acceptance Test before being shipped to site
• Well tested PLC program with a long history
• All analog signals are trended
• Easy to use HMI panel with user friendly interface
• 24/7 helpdesk with online support with a skilled Wärtsilä engineer receiving the calls
Plant settings

Activate recirculation
- QC46.05 LL, low methane concentration biomethane delivery
- QHL66.05 HH, high dew point biomethane delivery
- QHS62.05 H, high hydrogen sulfide concentration
- QCQS65 HH high carbon dioxide concentration biomethane delivery
- QHS66.05 HH, high hydrogen sulfide concentration
- PT66.11 High delivery pressure
- LG68.01 Low gas storage level
- LG66.01 Low incoming biogas pressure

Manual capacity limit:
- QC46.05 LL, low methane concentration biomethane delivery
- QHL66.05 HH, high dew point biomethane delivery
- QHS62.05 H, high hydrogen sulfide concentration
- QCQS65 HH high carbon dioxide concentration biomethane delivery
- QHS66.05 HH, high hydrogen sulfide concentration
- PT66.11 High delivery pressure

Automatic capacity limit:
- QC46.05 LL, low methane concentration biomethane delivery
- QHL66.05 HH, high dew point biomethane delivery
- QHS62.05 H, high hydrogen sulfide concentration
- QCQS65 HH high carbon dioxide concentration biomethane delivery
- QHS66.05 HH, high hydrogen sulfide concentration
- PT66.11 High delivery pressure
Case Studies
Fredrik Vigertsson
More Biogas – Kalmar, Sweden

- 750 Nm³/h raw biogas (65% methane)
- 99.95% methane efficiency
- 30,000 tons pa of food waste, manure and crop residues
- Heat supplied from biomass boiler
- Two high pressure compressors, each compress the biomethane to 250 Barg
- Four trailer filling stations
- Local CNG fueling
Karlskoga Biogas – Sweden

- 900 Nm³/h raw biogas (65% methane)
- Food and agricultural waste
- 10% landfill gas with 45% methane added
- Two high pressure compressors, each compress the biomethane to 250 Barg
- 10 trailer filling stations
- Local CNG fueling
Riverside Biogas – Glenfiddich Distillery

- 2000 Nm³/h biogas from spent malt.
- 99.9% methane efficiency
- Heat supplied from CHP
- Back up biogas boiler.
- Injects 1,200 Nm³/h biomethane direct to the gas grid
- Propane enrichment and gas network entry facility.
Buchan Biogas – Peterhead (SGN)

- 1200 Nm³/h biogas from agricultural waste
- 99.9% methane efficiency
- Heat supplied from biogas boiler
- Injects 720 Nm³/h biomethane direct to the gas grid
- Propane enrichment and gas network entry facility.
Biogas Zurich, Switzerland

- Wastewater treatment facility
- 1400 Nm$^3$/h biogas from sewage sludge
- Heat supplied from biogas boiler
- Injects 840Nm$^3$/h biomethane direct to the gas grid
- Propane enrichment and gas network entry facility.
Sønderjysk Biogas, Denmark

- 5,000 Nm$^3$/h biogas from agricultural waste
- 540,000 tons of manure, straw and agricultural residues
- Injects c. 2,000 Nm$^3$/h biomethane to the gas grid
- Produces enough energy to heat 15,000 homes or fuel 570 city busses.
Castle Eaton Farm, UK

- 750 Nm³/h biogas from agricultural waste
- 99.9% methane efficiency
- Chopped straw & agricultural residues
- Virtual Pipeline
- Biomethane injected to the gas grid at high pressure.
- Multiple sites feed into the same injection point.
Three Mile Canyon Farms, Oregon USA

- 6,000 Nm³/h biogas from dairy waste
- 99.9% methane efficiency
- Feedstock: Cow manure
- Pipeline injection for California market
- Biomethane injected to the gas grid at 900 psig
- Plant operating uptime over 99%
- Largest manure-to-RNG operations in the United States
Junction City Expansion Project, Oregon USA

• 6,000 Nm³/h biogas from agricultural and dairy waste
• 99.9% methane efficiency
• Feedstock: Hay, straw and cow manure
• Injecting on Northwest Natural Pipeline gas for California market
• Biomethane injected to the gas grid at 400 psig.
• Plant to be commissioned this year
Questions?