Efficient liquid biomethane production with cryogenic upgrading

by Benjamin Berg

Producing liquid biomethane is an attractive way of valorizing biogas, provided that the gas treatment technology is adapted to a project’s capacity and cost-effective. By combining cryogenic upgrading with biomethane liquefaction, Cryo Pur developed a new integrated system, with a lower energy consumption and adapted to a wider range of biogas projects than previous solutions. This process has been successfully demonstrated in operation within the "BioGNVal" project since mid-2015. This article presents the process operation and its benefits.

1. BIO-LNG, AN ATTRACTIVE FORM OF BIOENERGY

On top of being a locally-produced renewable fuel, liquid biomethane, or bio-LNG, owes its attractiveness to its compactness compared to gas (600 times less volume at 1 bar), a benefit both for downstream logistics, and for its final use.

When used as a road fuel, this allows for a short refueling time and a long range (up to 1,500 km on one tank), thus making bio-LNG relevant for the long-haul truck sector, where little renewable alternative is available. Only in liquid form can the biomethane bring its benefits to heavy goods transportation, that is, compared with diesel, a 90% decrease of GHG emissions, a 70% decrease of NOx emissions, and no emission of fine particles [1].

The compactness of bio-LNG also enables easy storage and off-grid transport, which is valuable even if the biomethane is to be used in gaseous form. This gives the opportunity to unlock a large number of potential biomethane production projects, which would otherwise be blocked by a lack of suitable gas grid within reach for injecting biomethane. Bio-LNG can be transported off-grid from production site to consumption sites at a much lower cost than under gaseous form [2].

2. CRYOGENIC UPGRADING AND LIQUEFACTION – THE PRINCIPLE

Until 2014, production of liquid biomethane had been limited to a few demonstration projects (two in Europe, one in Sweden and one in Norway) juxtaposing biomethane upgrading units with CO2 polishing units and liquefaction units initially more adapted to LNG applications. Such designs carried limitations in terms of investment costs and downscaling.

This led the Cryo Pur team to develop a new, integrated process for both biogas upgrading and biomethane liquefaction, leveraging the team’s expertise in cryogenic CO2 separation.

Cryogenic upgrading relies on low temperature to perform a physical separation of the CO2 present in the biogas. CO2 is actually frosted as the gas passes through a heat exchanger at temperatures between –90°C and –120°C. This allows to reach the methane purity level required for liquefaction. Since the process uses cryogenic temperature, combining it with biomethane liquefaction at –125°C (and 15 bar(a)) leverages synergies in the production of cold, thus minimizing the energy consumption of both steps. Likewise, the gas pretreatment, included before upgrading, also makes use of cold temperatures to frost and remove water, together with Volatile Organic Compounds and siloxanes.

The details of the process are described in section 4 below.
The Cryo Pur process results in a more scalable, robust and more energy-efficient integrated system for producing bio-LNG from biogas. As illustrated in Figure 1, another benefit is the production of liquid and pure bio-CO₂, which is another valuable product with a use in greenhouses, water treatment, truck refrigeration, dry ice and other industrial applications.

The Cryo Pur process is also well-suited to upgrading raw gas containing high levels of N₂ and O₂, as is the case with landfill gas, through the integration of a cryogenic distillation column for removal of air gases.

### 3. THE BIOGNVAL DEMONSTRATION PROJECT AND RESULTS

It is this innovative technology which was selected in 2013 for the “BioGNVal” project, which aimed at building a demonstration plant to turn raw biogas directly into liquid biomethane and liquid CO₂. The project, carried out in partnership with SUEZ and partly funded by ADEME (The French Environment and Energy Management Agency), is located on the SIAAP site in Valenton, the second largest Waste Water Treatment Plant in Paris area.

The unit (Figure 2) was designed and manufactured in 2014, and installed and commissioned in 2015. Dimensioned for treating a raw biogas flowrate of 120 Nm³/h, it successfully produces 1 ton per day of bio-LNG and 1.6 tons per day of liquid bio-CO₂.

The industrial demonstrator allowed to validate the design and dimensioning of the sub-systems, as well as the control protocol of the process, and to confirm that the expected performance was met in terms of energy consumption and product specifications. In particular, a fully automated control and safety system was developed to prepare the equipment for 24/7 unmanned operation, a requirement for the upcoming commercial versions.

The downstream use of the two products, bio-LNG and liquid bio-CO₂, was demonstrated by the three other project partners: ENGIE (with its subsidiary company GNVert), provider of a bio-LNG fueling station; IVECO, provider of a LNG-powered heavy-duty truck; and Thermo King, which developed a truck refrigeration system using liquid bio-CO₂ in replacement for diesel-powered cooling units.

The demonstration project in Valenton continues until April 2017, after which the unit will be installed at another location.

Following the success and lessons learned with the BioGNVal project, Cryo Pur was able to raise funds for industrializing and commercializing the product. The first commercial contract was signed in 2016, for a unit with a capacity of 3 tons of bio-LNG per day, to be started mid-2017 at a large farm in Northern Ireland.

### Table 1: Biogas composition at the inlet of the Bio-LNG plant in Valenton

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Nominal</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry biogas flow rate</td>
<td>50</td>
<td>100</td>
<td>120</td>
<td>Nm³/h</td>
</tr>
<tr>
<td>Drew point</td>
<td>10</td>
<td>20</td>
<td>37</td>
<td>°C</td>
</tr>
<tr>
<td>Dry biogas composition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td>60</td>
<td>63</td>
<td>70</td>
<td>mol %</td>
</tr>
<tr>
<td>CO₂</td>
<td>30</td>
<td>35</td>
<td>40</td>
<td>mol %</td>
</tr>
<tr>
<td>N₂</td>
<td>–</td>
<td>2 ± 0.1</td>
<td>–</td>
<td>mol %</td>
</tr>
<tr>
<td>O₂</td>
<td>–</td>
<td>0.43 ± 0.05</td>
<td>–</td>
<td>mol %</td>
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<tr>
<td>H₂S</td>
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<td>30</td>
<td>150</td>
<td>ppm vol</td>
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<tr>
<td>VOC</td>
<td>–</td>
<td>4.8</td>
<td>–</td>
<td>mg/m³</td>
</tr>
<tr>
<td>Siloxanes</td>
<td>–</td>
<td>7</td>
<td>–</td>
<td>mg/m³</td>
</tr>
</tbody>
</table>

### 4. DETAILED FUNCTIONING OF THE INSTALLATION

The Cryo Pur system is a cryogenic biogas upgrading process combined with a liquefaction one, developed since 2001 by Dr. Denis Clodic and his team [3,4]. The raw biogas entering the plant is typically composed of ~60% methane and ~40% carbon dioxide, water vapor and...
The Cryo Pur process transforms this raw gas into liquid biomethane and liquid bio-CO\(_2\) using 5 steps, as illustrated by the process diagram in Figure 3:

Pretreatment
1. Incoming biogas is treated with activated carbon filters to remove H\(_2\)S in the SS-210 sub-system;
2. The biogas is cooled to –40°C in the SS-240 sub-system, so that water vapor is alternately frosted and defrosted on two heat exchangers; as water is frosted, the Volatile Organic Compounds and Siloxanes present in the raw gas are captured with it.
3. In the same way, the biogas is then cooled to –75°C in the SS-250 sub-system, and residual water vapor is alternately frosted and defrosted on two heat exchangers. As shown in Figure 4, the follow-up of the temperatures allows to control the water’s phase changes in the subsystems.

CO\(_2\) capture
4. The biogas is then cooled to –120°C in the SS-300 sub-system, and the CO\(_2\) is alternately frosted and defrosted on two heat exchangers in swing configuration, to ensure that the CO\(_2\) content in the gas falls below 0.3 % prior to liquefaction. The swing between frost mode and defrost mode is performed through pressure control, as illustrated in Figure 5. At this stage, pure liquid CO\(_2\) is recovered from the vessel in defrost mode.

Liquefaction
5. The biomethane is compressed to 14 barg and liquefied at –120°C in the SS-400 sub-system. To produce bio-LNG at 2 bar(a), the liquid biomethane is then expanded after polishing, and finally transferred to the cryogenic storage vessel; the boil-off is recycled and liquefied again in the SS-400 unit.

5. BENEFITS OF THE PROCESS FOR PRODUCTION OF LIQUID BIOMETHANE

The integration of upgrading and liquefaction leads to cost savings, a simplified management of interfaces and a better energy efficiency: for both upgrading and liquefaction, the electricity consumption is 0.6 kWh/Nm\(^3\) raw biogas to produce bio-LNG at 15 bar(a)/-120°C, or 0.7 kWh/Nm\(^3\) raw biogas for bio-LNG at 2 bar(a)/-160°C.

The system being easily scalable, it can be adapted to various project sizes: the capacity of commercial units range from 100 Nm\(^3\)/h to 2,000 Nm\(^3\)/h raw gas. During operation, the process is also flexible enough to treat between 50% and 120% of the nominal flow with equal performance.
The process includes the removal of VOCs and Siloxanes, and since it is a physical separation process, it does not use consumables except activated carbon.

There is no methane slip in the process, which means that revenues from bio-LNG are maximized. Heat can be recovered from the process to cover the needs of the Anaerobic Digesters producing the raw biogas upstream. And finally, the sales of liquid bio-CO₂ to industrial consumers or distributors can be an attractive complement to biomethane revenues.

All these benefits contribute to making bio-LNG production technically and economically feasible at a smaller scale, while offering to improve the efficiency of bio-LNG production for larger scale projects. The design of commercial units is illustrated in Figure 6.

6. CONCLUSION

Biomethane liquefaction is an attractive way of valorizing biogas, as it enables biogas projects to get past limitations of the grid, and produces a renewable fuel for LNG-powered heavy vehicles.

However, before the BioGNVal project, the production of bio-LNG was limited to larger biogas projects, due to the high costs of liquefaction technologies, and only a very small number of installations were built in Europe.

In 2015, following years of R&D, Cryo Pur was able to successfully demonstrate, through the BioGNVal project, the operation of an innovative integrated process for cryogenic upgrading and liquefaction. Industrialized as an energy-efficient and scalable system with the potential to reduce investment and operating costs, while also producing liquid CO₂, this technology opens a wider range of possibilities for realizing bio-LNG production projects.

REFERENCES:


