

Demonstration of Integrated Cryogenic Biogas Upgrading and Liquefaction for Bio-LNG Production

Benjamin Berg¹ and Denis Clodic²

1. *Cryo Pur; Ecole Centrale Paris, Wissous 91320, France*

2. *Mines ParisTech, Wissous 91320, France*

Abstract: Liquid biomethane, or bio-LNG, offers a renewable and clean alternative to diesel for powering long-haul trucks. Cryo Pur demonstrated the successful operation of an innovative system for transforming raw biogas into bio-LNG. The integrated system combines cryogenic CO₂ separation, including recovery of liquid CO₂, with the subsequent liquefaction of biomethane, in order to efficiently produce bio-LNG and to adapt to a wide range of biogas sources and flowrates. The “BioGNVal” demonstration project took place at a waste water treatment plant in France between 2015 and 2017. It resulted in the production of fuel-quality bio-LNG, used to refuel LNG trucks. The project led to the industrialization of the solution, with the aim of increasing the availability of bio-LNG fuel.

Key words: Clean fuel, bio-LNG, biomethane, Renewable Natural Gas, circular economy.

1. Introduction

1.1 *Bio-LNG as a Fuel for Trucks*

The production of biogas, and its upgrading into biomethane (also known as Renewable Natural Gas), as a way to extract value from organic waste, is following an upward trend, according to the IEA’s count of biogas upgrading plants [1]. In the USA alone, there were 50 upgrading plants in operation in 2015.

Biomethane is particularly valuable as a renewable road fuel: in comparison with diesel, its use produces 90% less GHG emissions, 70% less NO_x emissions, and 95% less emission of fine particles [2].

To be used as a fuel for long-haul trucks, which require a long range and a short refueling time, biomethane must be liquefied to gain the adequate compactness. Liquefied biomethane, or bio-LNG, can then be used in any truck with a natural gas engine and a LNG tank, and can offer a range of 1,500 km.

Worldwide, the number of vehicles powered by natural gas or biomethane has increased at an average

rate of 19% per year since 2000, to reach more than 24 million in 2017 [3].

In the USA, there were 165 000 NGVs in 2015, of which nearly 8 700 port and regional haul trucks [4], for which liquefied gas is required. The country now has 131 operational LNG fueling stations, with another 55 planned [5].

The ongoing expansion of LNG refueling stations paves the way for an easy adoption of bio-LNG, which can be blended with fossil LNG.

1.2 *Challenges with bio-LNG production*

One issue limiting the availability of bio-LNG had been the complexity of upgrading and liquefying biomethane. Liquefaction units initially developed for LNG applications carry limitations in terms of investment costs and downscaling, and are sensitive to the CO₂ content in the methane. A polishing step was therefore needed between the upgrading unit and liquefaction unit. Juxtaposing different technology bricks has proven difficult in operation [6], while it

Corresponding author: Benjamin Berg, M.Sc., research fields: cryogenic gas separation, biogas upgrading, biomethane liquefaction, CO₂ capture and recovery.

does not optimize the energy efficiency of the whole process.

1.3 Cryo Pur Demonstration Targets

Following 15 years of research and development in the field of cryogenic CO₂ separation [7, 8], Cryo Pur developed a dedicated and integrated system for biogas upgrading and biomethane liquefaction, aiming at reducing the energy consumption of the process, while offering enough flexibility to address a wider range of project sizes.

This process has been successfully demonstrated in operation from end 2015 within the “BioGNVal” project in France. This paper presents the project results and the benefits of the technology.

2. Technology Description

2.1 Working Principle

Cryogenic upgrading uses low temperature to perform a physical separation of the CO₂ present in the biogas. CO₂ is in fact frosted as the gas flows 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 14 barg) uses synergies in the cooling process, and, in this way, minimizes the total energy consumption. In the same manner, the gas pretreatment included before upgrading also uses cold temperatures to frost and remove water, together with Volatile Organic Compounds and siloxanes.

Another benefit is the production of liquid and pure bio-CO₂, recovered through melting the CO₂ frosted in the upgrading step, as a by-product which can be used in greenhouses, water treatment, truck refrigeration, dry ice and other industrial applications.

2.2 Process Detail

Raw biogas is typically composed of about 55-60% CH₄, 40-45% CO₂ and impurities. The Cryo Pur system uses low temperatures to treat the gas in three steps and transform it into pure liquid CO₂ and liquid CH₄:

Pretreatment: After H₂S removal (with activated carbon filters), water is frosted/defrosted and removed, together with Volatile Organic Compounds and siloxanes. A swing process is used: the biogas flows continuously through a vessel put “online” (in “frost mode”), while another vessel in parallel, in which ice has accumulated on the fin surfaces, is put “offline” (in “defrost mode”) for melting ice and extracting water in liquid form.

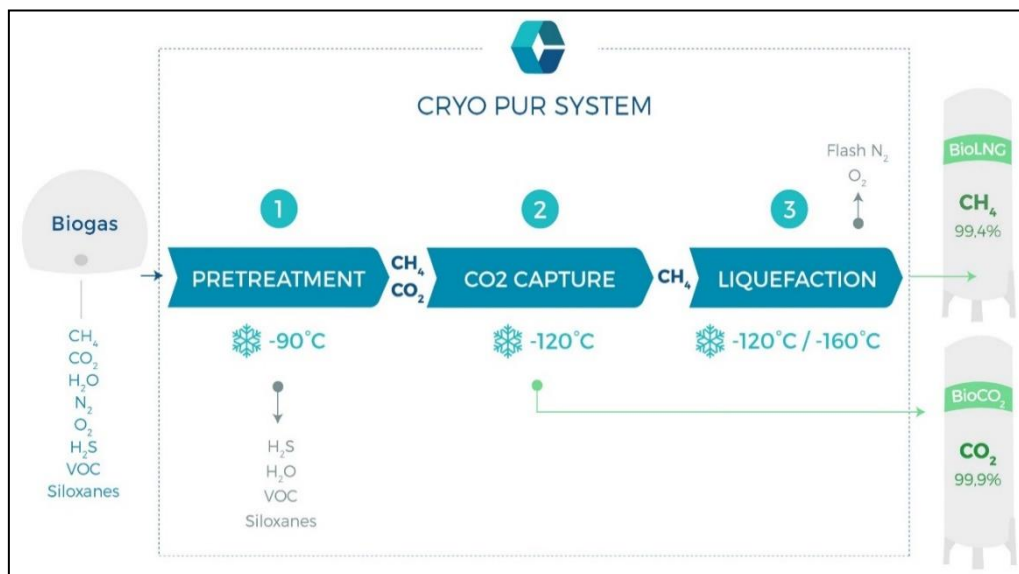


Fig. 1 Schematic representation of the Cryo Pur process.

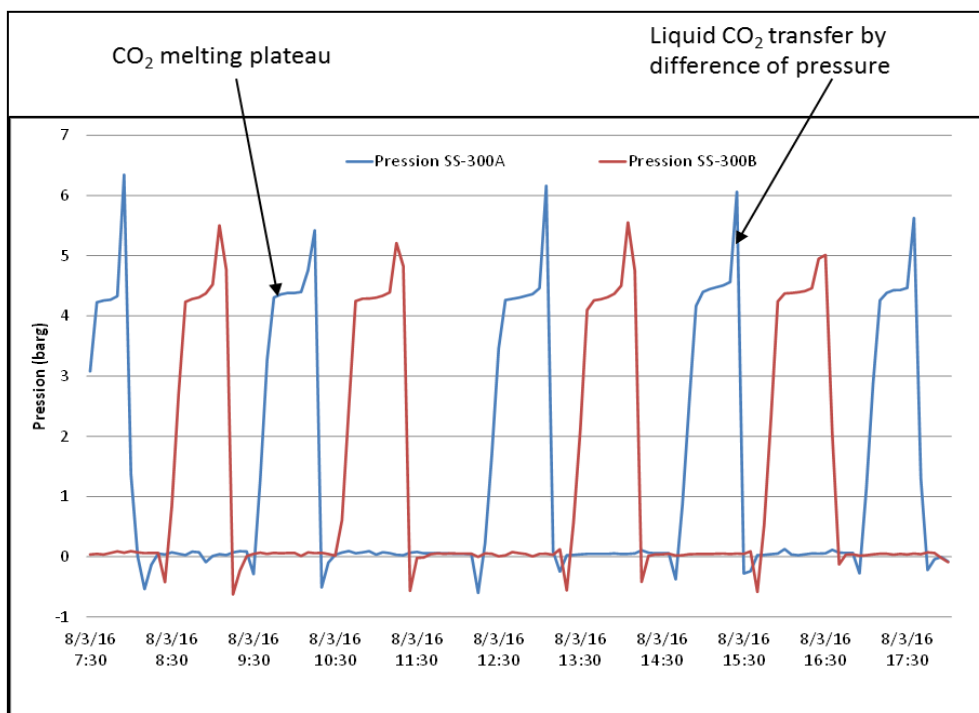


Fig. 2 Pressure in the CO₂ frosting/defrosting vessels.

CO₂ separation: in a similar swing process, CO₂ is frosted/defrosted as the gas passes through heat exchangers at temperatures between -90°C and -120°C. Fig. 2 shows the variations of pressure in the online and offline vessels, which is used to control the swing process. At this stage, pure liquid CO₂ is recovered. The upgraded biomethane continuously flows through the vessels, and is then pure enough to be subsequently liquefied.

CH₄ liquefaction: The biomethane is compressed to 14 barg and liquefied at -125°C. The bio-LNG produced is finally stored in a cryogenic vessel. To produce bio-LNG at 1 barg and -160°C, which is often required for supplying bio-LNG as a fuel to the road transport market, a boil-off/re-liquefaction loop allows to lower the temperature and pressure of the product, at the expense of a small additional electricity consumption.

3. BioGNVal Demonstration Project

3.1 Project Description

Initiated in 2013, the “BioGNVal” project aimed at

demonstrating the production, supply chain and use of bio-LNG as a fuel.

The project, coordinated by SUEZ and partly funded by ADEME (The French Environment and Energy Management Agency), was located on the SIAAP site in Valenton, the second largest Waste Water Treatment Plant in Paris area. Project partners included:

SUEZ: designer of Anaerobic Digesters and operator of the WWTP belonging to the SIAAP.

Cryo Pur: equipment supplier of the plant for biogas upgrading, biomethane liquefaction and liquid CO₂ production (see industrial demonstrator in Fig.3).

GNVert (Engie group): LNG/bio-LNG distributor.

Iveco: producer of LNG-powered trucks, using bio-LNG.

Thermo King provided a truck-mounted system for demonstrating the refrigeration of trailers using the liquid CO₂ produced by the demonstration plant.

The Cryo Pur pilot and demonstration unit was designed and manufactured in 2014, installed and commissioned in 2015, and in operation until end of April 2017. The BioGNVal project was officially inaugurated on May 9th, 2016.



Fig. 3 Cryo Pur bio-LNG demonstration plant at Valenton Waste Water Treatment Plant.

3.2 Biogas Specifications

The raw biogas, containing 60% methane, comes from anaerobic digestion of sewage sludge.

The unit was designed for treating a raw biogas flowrate of 120 Nm³/h, corresponding to a production capacity of 1 ton per day of bio-LNG and 1.6 tons per day of liquid bio- CO₂.

The specifications of the gas in Valenton can be seen in Table 1.

3.2.1 Pilot phase

The pilot phase took place from October 2015 until April 2016, and consisted in daily operation for 10-12h, 5 days per week. It demonstrated the safe operation of the system and validated the upgrading and liquefaction processes.

The pilot enabled to reach the following performance for each sub-system:

Desulfurization: H₂S content below 1 ppm after the pre-treatment unit.

Dehumidification: H₂O content below 1 ppm prior to CO₂ removal.

Gas Cleaning: removal of VOCs and Siloxanes.

CO₂ removal: CO₂ content below 0.3% in bio-LNG and liquid CO₂ with 99.99% purity.

Liquefaction: production of bio-LNG with 99.7% methane.

The production of liquid biomethane is evidenced by the increase of the mass of bio-LNG in the storage tank at the outlet of the Cryo Pur plant, as shown in Fig. 4.

Measurements of the liquid biomethane composition were performed by third party and the results are shown in Table 2, with the French standard for vehicle gas as a reference [9].

The experience gained during the pilot phase led to improvements being implemented on the unit and validated in operation. In particular: the use of activated carbon filters, instead of soda scrubbing, for H₂S removal; the use of more efficient polymer-protected aluminum / copper finned tubes heat exchangers for corrosion protection; the installation of a two-stage biomethane compression unit and low temperature chiller providing water-glycol solution at -14°C to all low temperature units, ensuring a better energy efficiency and redundancy.

From April to November 2016 the pilot unit underwent a revamping work to integrate the key learnings from the pilot phase and to start the demonstration phase.

3.2.2 Demonstration phase

From December 2016, the demonstration unit was authorized to operate 24/7 including with liquefaction.

Table 1 Inlet gas specifications.

	Nominal value	Unit
Dry biogas flow	100	Nm ³ /h
Dew point	20	°C
CH ₄	63	mol%
CO ₂	35	mol%
N ₂	2+/-0.1	mol%
O ₂	0.4	mol%
H ₂ S	30	ppm vol
VOC	4.8	mg/m ³
Siloxanes	7	mg/m ³

Table 2 Biomethane product composition.

	Valenton	Vehicle gas standard 2H
CH ₄ [%-vol]	> 99.7	> 93
CO ₂ [%-vol]	< 0.3	< 2.5
O ₂ [%-vol]	0	< 1
N ₂ [%-vol]	0	< 7.5
Siloxanes [μg/Nm ³]	10	< 300

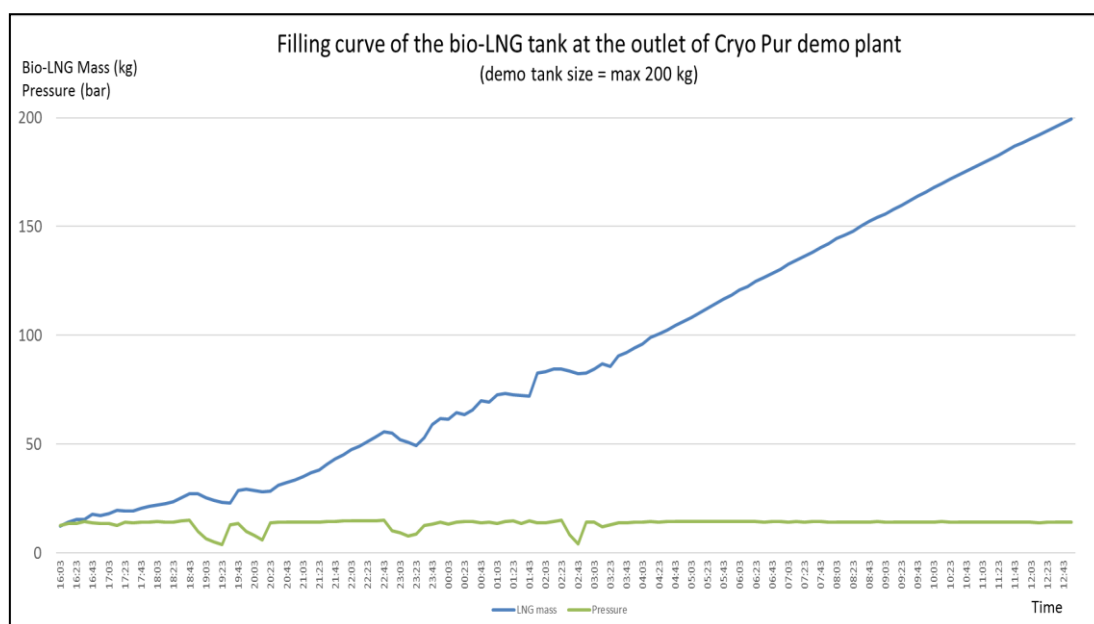


Fig. 4 Bio-LNG mass produced when starting the unit.

The demonstration unit was fitted with a remote monitoring system, transmitting operation data, alarms and access to control screens to Cryo Pur.

Continuous operation ran during 17 weeks until the end of the operation permit on April 30th, 2017.

CO₂ purity and bio-LNG purity were in line with the results of the pilot phase (more than 99.9% and more than 99% respectively).

The energy consumption for a biogas flow of 85 Nm³/h was 0.7 kWh/Nm³.

The sub-systems for dehumidification and CO₂ removal reached an availability of 92%, with some stops due to issues with the sealing of cryogenic valves.

Availability for the liquefaction sub-system was 76%, due to adaptations being made on the CO₂ filtering system for being able to store bio-LNG at 6 barg. Once a new system regulation had been put in place, the operation was continuous.

While the plant was dimensioned for the regular production of bio-LNG at 14 barg and -120°C, it was also tested for producing bio-LNG and performing truck refills at lower pressures, down to 4 barg.

Learnings from the demonstration phase enabled further improvements of the unit, which would also be integrated in the commercial units to come:

Use of a cryogenic polymer foam for insulation, instead of perlite, reducing thermal losses by 30% on the modified subsystem.

Use of valves with body welded to pipe, instead of flange valves, for perfect sealing.

Improvements in the welding of heat exchanger vessels.

4. Industrialization

4.1 Design of the First Industrial Unit

Key learnings from the BioGNVal project were taken into account for designing the first industrial unit. In order to ensure a level of availability above 90%, all sub-systems have built-in redundancy for rotating machines. The remote monitoring system is fitted with deviation detection modules enabling preventive maintenance.

4.2 Commercial Reference

The first contract for a Cryo Pur biogas upgrading and biomethane liquefaction unit was signed in 2016 for treating a capacity 300 Nm³/h biogas at a large farm in Northern Ireland. The unit has been delivered in September 2017 and is due to start operations in Q4 of the same year.

4.3 Commercial Potential

The flexibility and benefits associated with cryogenic biogas upgrading and liquefaction open the way for many more bio-LNG projects. The BioGNVal demonstration plant in Valenton received more than 50 visits from many European countries and raised interest from various industries such as household, industrial or agricultural waste management, waste water treatment, landfills, as well as CO₂-consuming industries. Cryo Pur developed a product range for units between 100 and 2,000 Nm³/h raw gas. In particular, Cryo Pur is working on several projects for the production of bio-LNG to be used as a fuel in the road transport sector, in particular in Italy or in Northern Europe where this market is expected to grow fast.

5. Technology Benefits

The system developed by Cryo Pur for biogas upgrading, CO₂ liquefaction and biomethane liquefaction has multiple benefits compared with previously available technologies.

As demonstrated with the Valenton plant, Cryo Pur's design makes bio-LNG production feasible for smaller projects (under 1,000 Nm³/h of biogas), for which there were previously no affordable solution. The technology can also be scaled up to suit larger projects.

The integration of pre-treatment, upgrading and liquefaction in one system leads to costs savings and simplifies the management of interfaces, which can be delicate in ramping-up operations, by reducing the number of independent technology bricks.

It also results in a better energy efficiency, since the system takes advantage of synergies in the use of cold temperatures for dewatering, CO₂ frosting, and CH₄ liquefaction. The total electricity consumption is below 0.6 kWh/Nm³ raw biogas (to produce bio-LNG at 14 barg/-120°C), or 0.7 kWh/Nm³ raw biogas (for bio-LNG at 1 barg/-160°C).

Since it is based on a physical separation process, the system does not use consumables, other than activated carbon for removing H₂S.

Other benefits contribute to improving further the environmental profile of bio-LNG production projects, while having a positive impact on project economics:

There is no methane slip in the process, maximizing the bio-LNG sales.

Heat can be recovered from the refrigeration systems to cover the needs of the site (typically for producing the raw biogas through Anaerobic Digestion upstream).

Pure, liquid bio-CO₂ recovered from the cryogenic upgrading stage can be sold as a product to industrial consumers or distributors, in addition to biomethane revenues.

These benefits have the potential to make bio-LNG production more attractive for a wider range of biogas projects.

6. Conclusion

The BioGNVal pilot and demonstration project enabled to validate an innovative technology for producing bio-LNG, based on cryogenic upgrading of biogas. While demonstrating the feasibility of the system for small-scale biogas plants, the project provided valuable learnings for designing a range of commercial units for bio-LNG production. The technology benefits contribute to making bio-LNG a more available and more affordable fuel for the transport sector.

Acknowledgments

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