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**Micro-scale biogas liquefaction – The Samsø case, the technology and market aspects**

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1. **Introduction**

The Renewable Energy island of Samsø, Denmark, with 3700 inhabitants, has a vision to become free of fossil fuels by 2030. For this to be realized, the transport sector needs focus and for an island community, the ferries are very obvious targets. Samsø municipality started their own shipping company in 2013 and ordered a new LNG fuelled ferry, inaugurated in 2015. The intention behind this was to develop the value chain ‘back’ to own island biogas production and local farmers.

Alongside with the environmental planning for the biogas production, which was completed successfully in December 2017, we have through the work of two Interreg projects Biogas 2020 and GO-LNG been working on the technical and financial aspects of the biogas handling and liquefaction. However, it was found that biogas liquefaction is globally very rare and the very small scale needed on Samsø has proved a major challenge.

In the following, we will summarize the aspects of micro-scale treatment and liquefaction of biogas for inspiration. The work is published in the report Biogas Liquefaction and use of Liquid Biomethane (Tybirk et al. 2018)

1. **The Samsø value chain**

The ferry Prinsesse Isabella uses around 30 GWh of energy annually. It is a dual fuel ferry using LNG and Marine Diesel Oil (MDO). The mixture depends on the prices obtained on the open market, although the ferry needs a small proportion of MDO for flexible harbour manoeuvrings as the engines react faster on this fuel.

When the ferry was ordered the prospects for LNG prices were estimated to be lower than MDO. In addition, the SECA regulations of emissions pointed to LNG and later replaced by Liquified Bio Methane (LBM) to be the future fuel.

This could enable a value chain back to the farming community creating approximately 13 local jobs, and a feasibility study (Mikkelsen, 2015) showed that the potential to fuel the ferry with local biogas was present on the island. This was the basis for a unique value chain named *From Field to Ferry* attracting much international attention.

1. **Biogas liquefaction technologies**

On the biogas upgrading and liquefaction technologies no manual was available. Samsø Municipality consulted a lot of companies and challenged them to present their solution for the Samsø case at an international workshop held at Samsø in 2017.

Liquefaction of fossil methane is usually done in large scale (> 1000 metric tonnes per day or 365.000 tonnes annually) at larger refineries. The promotion of Liquid biomethane (LBM) as marine fuel require the development of small-scale liquefaction facilities at the biogas plants i.e. with a capacity (much) below 100.000 tonnes annually per unit and corresponding bunkering facilities in harbours (Nguyen et al. 2017).

*Info Box. Characteristics of LBM*

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| --- |
| Compared to most hydrocarbon-based fuels, LNG has higher energy content, of about 45 to 50 MJ per kg higher heating value (HHV).  Compared to compressed natural gas (CNG), LNG has an energy density greater by factor 2.5, which reaches approx. 22 MJ/litre.  At atmospheric pressure, LNG occupies a volume 600 times less than conventional natural gas (Nguyen et al. 2017).  Liquefied Biomethane (LBM) has approximately the same characteristics as LNG. |

Based on a Samsø ‘Field to Ferry’ concept the companies below have given their potential solutions for this ‘nano-scale’ gas treatment solution from raw biogas to LBM. The plant is (in phase 1) expected to produce some 6 mio. Nm3 of biogas (some 685 Nm3/hour) or 3,5 mio Nm3 biomethane (400 Nm3/hour). The resulting LBM production would be around 7 tonnes daily or 2500 tons annually, fulfilling the energy need of the ferry Prinsesse Isabella. Table 1 shows the companies on the market with technologies for nano- or micro- scale biogas liquefaction. Around a handful of liquefaction plants from Wärtsila, Cryo Pur and Air Liquide with different technologies are running in Europe today.

*Table 1. The LBM technologies in operation according to Tybirk et al. (2018)*

|  |  |
| --- | --- |
|  | Short technology description |
| **Cryo Pur** | Integrated upgrading and liquefaction system based on cryogenic upgrading (with Mixed Refrigerant Integrated Cascade). |
| **Wärtsilä** | Amine upgrading and further dried in a pressure swing adsorption process. Liquefaction: Wärtsilä’s MR (Mixed Refrigerant) process is based on a simple screw compressor and a proprietary mix of refrigerants |
| **Air Liquide** | Biogas upgading: membrane filtration; CO2 polishing: Pressure and swing adsorbtion; Liquefaction: reverse turbo brayton |
| **NærEnergi and Galileo** | Cryobox technology based on high pressure gascompressor. The gas is cooled under high pressure (250-300bar), and then condensated by reducing the pressure to the desired level (typically 2-3 bar). |
| **Kosan**  **Crisplant** | Based on the multi-refrigerant principle in a new more energy efficient process. The scalable system makes it very easy for the customer to increase their supply as the demand rises. |
| **Pentair Haffmans/ Stirling Tech.** | Membrane separation + cryogenic separation CH4 / CO2, stirling cooling generator |
| **Biofrigas AB** | CryoSep is the unique system that upgrades and liquefies raw gas to BIO-LNG in the same plant. The technique used is cryogenic, cooling the raw gas in steps to -165C in these steps, the gas is purified to pure methane 99%. |

Some technologies can readily be scaled, others not and more details about the technologies can be found in Tybirk et al. (2018). However, only few plants are in production mode and the capacity and prices are very site specific.

1. **Barriers and opportunities for LBM**

A major barrier for LBM production in small scale is the economy.

*Investment and running costs*

Investment costs are relatively high and the operation cost should be kept minimal in automatized procedures. When only few scattered operators are yet in production, the service is often not right at hand.

Much technology adaptation and optimization would be expected in the future and this will probably influence the costs significantly.

*Few customers*

Another barrier for LBM is to find appropriate costumers with a LBM need that fits the production over the week, month and year. The number of potential customers is growing as more vessels on LNG have been ordered. However, the match of consumption to the production delimits the costumers to a regular traffic pattern, such as ferries.

In small scale – depending on the liquefaction technology chosen – it can be costly also to produce Compressed Bio Methane, where more customers are available (gas grid, busses, trucks, tractors). Some of the liquefaction technology providers can readily deliver upgraded and compressed CBM.

Trucks are now available on CNG, LNG or both, so the market is opening.

This is a typical egg and hen problem: we need technology providers, we need customers for the gas, but with the present interest from technology providers (table 1) we have a growing interest.

*Opportunities for LBM*

The ongoing negotiations on the Renewable Energy Directive can create a new green and international market for biogas – and LBM. Purchasing ‘offset’ or biotickets can become a very interesting option to reduce carbon footprint – especially if the directive will increase the mandatory blending of advanced biofuels (such as waste based biogas) the LBM market could take off.

A small market is already present, but could be further strengthened through the revised Renewable Energy Directive.

1. **Future prospects**

If the value chain from fields to marine vessels should grow in the future, the coming legislation should either

* require mandatory biofuel blend in marine and aviation sectors (creating a large market due to environmental regulation and a business via bioticktets) or
* adequate subsidies for this specialized and still expensive technology due to innovativeness and scale, but very promising in terms of climate gas reduction.

If the global heavy-duty transport (marine, trucks, trains, aviation) is to become low-emission in the future, the societal demand for finding the technical solutions will pave the way for research and innovation. Some market regulation has to follow, to make good show-cases of this promising concept.

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