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Liquefied Biomethane experiences

Draft version

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Executive Summary

The Blue Corridors project's aim is to establish liquefied natural gas (LNG) as a real alternative for medium & long distance transport - first as a complementary fuel and later as an adequate substitute for diesel.

LNG is a mixture of low-molecular-weight hydrocarbons with nitrogen as a principal inert impurity and methane as major component. Liquefied biogas (LBG) is basically the same as LNG but is produced from renewable sources. They can be mixed and used as a vehicle fuel.

This deliverable shown the experiences of the project partners and other companies around the world, these experiences are similar in many ways.

Also this deliverable is a summary of the topics related with the LBG. The building refueling stations, vehicle technology, different uses, distribution chain, etc.

The experiences shown the need to own the distribution chain in order to secure the deliverable all the way to the final customer and, also, describe the need to mix LNG with the renewable LBG to get a better environmental impact but still get a reasonable price.

Another similar important experience to secure the best way to use the LBG is the use reliable technical suppliers to minimize problems.

But there are also differences. For example, Some partners uses the synergies between compressed gas and liquefied biogas since they feel that the possibility to refuel CBG and LBG at the same station but in separate areas has been very important in the early stages.

There are also country specific differences. UK has a larger difference between gas and diesel price than Sweden has, which affects the business case for the truck owner. This means that in UK the driving force for the truck owner is both environmental and economical, but in Sweden the main driving force is environmental. The deliverable mentions the large interest from truck owners and transport buyers.

Contents

1 Introduction

1.1 LNG Blue Corridors project

The LNG Blue Corridors project's aim is to establish LNG as a real alternative for medium- and long-distance transport—first as a complementary fuel and later as an adequate substitute for diesel. Up to now the common use of gas as fuel has been for heavy vehicles running on natural gas (NG) only for municipal use, such as urban buses and garbage collection trucks. In both types of application, engine performance and autonomy are good with present technologies, as they are well adapted to this alternative cleaner fuel.

However, analyzing the consumption data, the equivalence in autonomy of 1 liter of diesel oil is 5 liters of CNG (Compressed Natural Gas), compressed to 200 bar. Five times more volume of fuel prevents the use of CNG in heavy road transport, because its volume and weight would be too great for a long-distance truck. This opens the way for LNG (Liquefied Natural Gas), which is the way natural gas is transported by ship to any point of the globe. NG liquefies at 162º C below zero, and the cost in energy is only 5% of the original gas. This state of NG gives LNG the advantage of very high energy content. Only 1,8 liters of LNG are needed to meet the equivalent autonomy of using 1 liter of diesel oil. A 40-ton road tractor in Europe needs a tank of 400 to 500 liters for a 1.000 km trip; its equivalent volume with liquid gas would be 700 to 900 liters of LNG, a tank dimension that could easily be fitted to the side of the truck chassis. LNG therefore opens the way to the use of NG for medium- and long-distance road transport.

LNG has huge potential for contributing to achieving Europe's policy objectives, such as the Commission's targets for greenhouse gas reduction, air quality targets, while at the same time reducing dependency on crude oil and guaranteeing supply security. Natural gas heavy-duty vehicles already comply with Euro V emission standards and have enormous potential to reach future Euro VI emission standards, some without complex exhaust gas after-treatment technologies, which have increased procurement and maintenance costs.

Figure 1-1. Impression of the LNG Blue Corridors

To meet the objectives, a series of LNG refueling points have been defined along the four corridors covering the Atlantic area (green line), the Mediterranean region (red line) and connecting Europe's South with the North (blue line) and its West and East (yellow line) accordingly. In order to implement a sustainable transport network for Europe, the project has set the goal to build approximately 14 new LNG stations, both permanent and mobile, on critical locations along the Blue Corridors whilst building up a fleet of approximately 100 Heavy-Duty Vehicles powered by LNG.

This European project is financed by the Seventh Framework Programme (FP7), with the amount of 7.96 M€ (total investments amounting to 14.33 M€), involving 27 partners from 11 countries.

This document corresponds to the 6st deliverable within work package 3. It is a document describing the principal issues related to the LBG about experiences observed by the partners and other companies and projects related with LBG fuel industry. This document will be available at the project website: http://www.lngbluecorridors.eu/.

1.2 Aim of this deliverable

The aim of this deliverable is to summarize the experiences from developing and building the LBM stations and use

Liquefied natural gas (LNG) is a mixture of low-molecular-weight hydrocarbons with nitrogen as a principal inert impurity and methane as the major component. Liquefied biogas (LBG), also called liquefied biomethane, is basically the same as LNG but is produced from biogas generated from the anaerobic decomposition of waste or crops rather than sequestrated carbon, therefore LBG can be considered as renewable (i.e. there is no additional carbon loading on the biosphere from the combustion of the fuel). The introduction of liquefied gas is an important measure in terms of achieving Europe's objective of reduced environmental impact from road traffic.

LBG tends to have higher methane content than LNG but its calorific value is often lower because the balance gas is inert nitrogen rather than heavy hydrocarbons such as ethane or butane. However LBG's principal advantage over LNG is its lower carbon intensity. The Renewable Energy Directive states that biomethane produced from AD of waste has a carbon intensity of 17g CO_2e/MJ compared to 60g CO_2e/MJ for LNG, making it one of the lowest carbon biofuels. Given their relative chemical proximities, LBG and LNG can be mixed either virtually or physically in any proportion to form Bio-LNG. These qualities mean that LBG and Bio-LNG is the only commercially viable option for reducing CO_2 emissions in Europe's heavy truck fleet.

In Sweden and in UK, two of the partners in the LNG Blue Corridor Project, sell Bio-LNG as a fuel for heavy duty vehicles. This report is about their experiences. First, the UK based company Gasrec, describes their experiences and other experiences of projects related to this issue. Gasrec is the largest producer of LBG produced from landfill gas. Then FordonsGas Sverige AB, from Sweden, describes their experiences with distributing and selling liquefied biogas produced from digestion of organic waste.

2 Production[1]

Biogas is the name of the gas produced when organic material is decomposed under anaerobic conditions. These processes take place naturally when the amount of organic material is sufficient and where oxygen does not enter.

Digestion processes has been used since 1960 but then the main goal was to stabilize and thicken sewage sludge at sewage treatment plants and to treat polluted organic process wastewater. After the energy crisis in the 1970s, the interest in recovering energy from renewable sources grew and the biogas production was expanded to include industrial waste and manure. In the beginning of the 1990s the first co-digestion plants for the joint digestion of different substrates, like organic farm- and household waste, were built. Landfill gas has been collected since the 1980s. At first it was collected because of safety reasons, but today the reduction of greenhouse gas emissions is an important argument.

The main constituents of biogas are methane, CH_4, and carbon dioxide, CO_2, with small amounts of hydrogen sulphide, H_2S and water vapor. The gas can be used directly for production of heat and/or electricity or it can be further processed to natural gas quality for use as vehicle fuel or for injection into the gas grid.

There are two sources of biogas and these are landfills and digester chambers. In landfills, gas is produced spontaneously as long as there is decomposition of organic material. Since the process is not controlled or optimized, it results in a lower CH_4 content, around 50 %, in comparison to digester gas. The landfill gas is collected with permeable tubes by applying a slight under-pressure. Since Jan 2005 it is prohibited to landfill organic material, which will result in a decreasing biogas production. However, the decomposition process in a landfill is slow, so they will probably give gas for another 30 – 50 years.

Digester gas is produced under controlled situations in a digester chamber. Most of the gas is produced in sewage sludge treatment plants, but the production from co-digestion is steadily rising. In co-digestion plant different substrates like manure, slaughterhouse and industrial waste and sorted food waste from food industry, restaurants and households are digested together.

The digester gas is produced in three main steps, by a number of different microorganisms:

1. Hydrolysis: In the hydrolysis, microorganisms use enzymes to break down complex organic material to more simple compounds like sugars and amino acids.
2. Fermentation Through fermentation organisms form intermediate products like fatty acids, alcohols and hydrogen.
3. Methane Production In this step a unique group of microorganisms, called methanogens, produces methane from acetic acid. These organisms have very specific requirements on their environment. They are sensitive to temperature fluctuations and pH, they grow slowly and they die when in contact with oxygen.

[1] *Production of liquid biogas, LBG, with cryogenic and conventional upgrading technology – Description of systems and evaluations of energy balances. Nina Johansson 2008*

The duration in the digester chamber is between 15-30 days, depending on substrate and temperature. The process is mesophilic (~37 °C) or thermophilic (50-55 °C), which is the temperature at which the CH_4 producing bacteria have growth rate peaks. This means that heat must be added to the process. A stirring device helps to keep a steady temperature, and at the same time it gives better contact between microorganisms and substrate and prevents stratification.

The gas is taken out from the top of the tank and the CH_4 content varies between 60-70 %, depending on substrate. After digestion, there is a rest of organic material, called digestate, which is pumped out to a storage tank. Depending on the substrate origin and pretreatment, this digestate can function as an excellent fertilizer. Further, it could be certified and used as an organic fertilizer.

If the substrate has an animalistic origin the material must be hygienized to eliminate pathogenic bacteria. The material is heated to 70°C for at least one hour before it is injected into the digester chamber.

Some substrates, like food waste from households and restaurants, needs to be sorted and grinded into a fine homogenous material, called *slurry*, before it is injected into the gas chamber. Metals are removed from the waste with a magnet.

3 Purification technologies[2][3]

Biogas used as vehicle fuel must first be purified and upgraded. Purification means that contaminants are removed from the gas stream while upgrading means that the energy content is raised through removal of CO_2. In the following chapter conventional purification and upgrading technologies will be briefly described.

3.1 Conventional technologies

The most common solutions for separation of CO_2 from CH_4 are:

- Adsorption: Pressure Swing Adsorption (PSA)
- Absorption: water scrubbing, physical absorption and chemical absorption
- Membrane separation: high pressure and low pressure

3.1.1 Adsorption

CO_2 is adsorbed from the biogas stream on a material like activated carbon or molecular sieves. The most common adsorption process is the Pressure Swing Adsorption (PSA)

- Pressure Swing Adsorption: A PSA plant consists of a series of vessels filled with adsorption material, working on 4 different phases: adsorption, depressuring, regeneration and pressure build-up. When the adsorption material is saturated in one column, the gas flow is led to the next, while reducing the pressure regenerates the saturated column, as it makes the adsorbed molecules to leave. The pressure is firstly reduced to atmospheric and then to a light vacuum. The vent from the first stage contains significant amounts of CH_4 and therefore it is sent back to the gas inlet, in order to keep the CH_4 losses low. In the second stage the vent mainly consists of CO_2 and is vented to the atmosphere.

Before entering the adsorption column the gas needs to be dry and free from H_2S, to avoid the irreversible adsorption of the same in the adsorption material.

3.1.2 Absorption

The pure physical absorption technology uses the differences in binding forces in different molecules to separate CO_2 and other compounds as H_2S from CH_4. CO_2 and H_2S are more polar and therefore more soluble in a polar absorption fluid than the non-polar CH_4. The adsorbent liquid can also react with the CO_2, driving the absorption toward completion. This process is called chemical absorption.

- Water scrubbing: CO_2, H_2S and NH_3 are physically dissolved in water under pressure in an absorption column. Water leaving the column is enriched with CO_2, but also with small amounts of dissolved CH_4. After the column the water passes through a flashing tank, were the pressure is reduced, which releases the CH_4. The vent from the flashing is then sent back to the gas injection, reducing the CH_4 losses in the process. The water can be used just one time

[2] *Production of liquid biogas, LBG, with cryogenic and conventional upgrading technology – Description of systems and evaluations of energy balances. Nina Johansson 2008*

[3] Report: Overview of biogas technologies for production of liquid transport fuels – Danish technological institute – Laura Bailón and Jorgen Hinge December 2012

(single pass adsorption) or it can be reused by treating it in a desorption column where the CO_2 and other contaminants are removed (regenerative adsorption).

In non-regenerating process, water use is approximately 150 l/Nm^3 raw biogas. A hundred times less water can be consumed by a plant reusing its water, although this depends on several factors of which H_2S concentration is the most important.

- Physical absorption: instead of water organic solvents are used as absorption fluid. Besides CO_2 also H_2S, NH_3 and H_2O can be separated. Solvents come in different forms and brands, including polyethylene glycol, Selexol · , Genosorb · . Smaller plants can be built compared to the water scrubbing because the solubility of CO_2 is higher in these liquids than in water. H_2S is also highly soluble in organic solvents, so the higher H_2S concentration the higher temperature process is required to regenerate the solvent. Due to absorber costs and the disposal of contaminated absorber, the absorber is always regenerated. Additional drying of the upgraded gas is not necessary due to absorption of water by the organic solvent.
- Chemical absorption: solvents as mono-ethanol amine (MEA) or di-methyl ethanol amine (DMEA) which react chemically with CO_2 are used. Amines are highly CO_2 selective, and result in minimal losses of CH_4, but they are toxic to humans and the environment and require significant energy consumption for regeneration. As in physical absorption, in chemical absorption regeneration always is carried out. The preliminary purification of the biogas is very demanding (< 6 ppm H_2S, low oxygen) to avoid corrosion, undesirable chemical reactions and higher temperatures for the regeneration.

3.1.3 Membrane technology

In a membrane separation system CO_2 and other components as H_2O, H_2S and NH_3 are transported through a thin membrane to higher or lesser extent while CH_4 is retained, due to difference in particle size and/or affinity. Two basic systems exist: gas-gas or dry membranes and gas-liquid membranes.

- Dry membranes: are membranes with a gas phase on both sides and the driving force is the differences in partial pressure. CO_2 permeates to the low-pressure side, while CH_4 stays under pressure. A major disadvantage of this technique is the low methane yield. Due to imperfect separation the raw gas can be purified to maximum 92% CH_4 in one step. When two or three steps are used, a gas with 96% or more CH_4 is achieved. Methane losses can be partly prevented by recirculation of a part of the permeated CO_2-enriched gas.

The membranes separate some H_2S but since H_2S is corrosive it is recommended to remove it before the process. Also, the gas needs to be compressed and dried.

- Gas-liquid membranes: Gas-liquid absorption membranes for upgrading biogas have been developed only recently and are still in research and development phase. A micro porous hydrophobic membrane separates the gaseous stream from a liquid phase. CO_2 from the gas stream diffuse through a membrane being absorbed by the liquid phase flowing in counter current. Liquid is prevented from flowing to the gas side due to slight pressurization of the gas. The removal of CO_2, carried out with an amine solution, is very efficient and biogas can be upgraded to more than 96% CH_4 in one step. The amine solution can be regenerated by heating, which releases a pure CO_2-flow which can be sold for industrial applications.

In practice local conditions are very different (water supply, available heat, emission limits, etc.), therefore there is not a best technical solution available on the market; all of them have their advantages and disadvantages.

Investment cost, operation costs and maintenance costs are always taken into consideration as well as plant capacity. The operational costs are determined by the use of chemicals and by the use of energetic or physical aid streams, like heat or water, while other techniques might require electricity (pressure and/or cooling). When the installation is located near an entity that has an excess of heat, a technique that requires heat as the amine gas cleaning can be an economical relevant choice. A lot of the choices are determined by the presence or the absence of suppliers for the technology in the particular country. In Sweden, water scrubbers are used mostly. In Germany they prefer PSA and chemical scrubbing units and in The Netherlands they rather chose water scrubbers, PSA-units as well as membrane technology.

Table 3-1 Comparison of different commercial technologies. Values are dependent on the size of the plant and the specific commercial technology.

	PSA	Water scrubbing	Physical scrubbing	Amine scrubber	Membrane separation
Electricity consumption (kWh/Nm^3)	*kWh/Nm^3 raw biogas:* • 0.23[1] • < 0.3[5] • 0.25[6] *kWh/Nm^3 clean biogas:* • 0.29 – 0.43[9] • 0.3 – 1.0 suppliers data[4] • 0.5 – 0.6 Swedish plants data[4]	*kWh/Nm^3 raw biogas:* • 0.3[1] • <0.25[5] *kWh/Nm^3 clean biogas:* • 0.4 (0.3 – 0.6)[2] • 0.3[7] • 0.4 – 0.5[7] With regeneration[4]: • 0.45 – 0.9 suppliers data • 0.3 Swedish plants data No regeneration[4]: • 0.45 – 0.9 suppliers data • 0.4 – 0.6 Swedish plants data	*kWh/Nm^3 raw biogas:* • 0.2 – 0.3[1] *kWh/Nm^3 clean biogas:* • 0.4 (Selexol) Swedish plants data[4]	*kWh/Nm^3 raw biogas:* • 0.1 – 0.15[1] • 0.05 – 0.12[6] (Cirmac) • 0.2 – 0.25[6] (DMT) *kWh/Nm^3 clean biogas:* • 0.12 (LP Cooab)[2] • 0.15 suppliers data[4] • 0.18[7]	*kWh/Nm^3 raw biogas:* • 0.18[1] • 0.20[6] *kWh/Nm^3 clean biogas:* • 0.14[2] • 0.26[7]
Heat consumption (kWh/Nm3) and Heat demand (°C)	None	None	*kWh/Nm^3 raw biogas:* • < 0.2[1] 55 – 80 °C[8]	*kWh/Nm^3 raw biogas:* • 0.5 – 0.75[1] *kWh/Nm^3 clean biogas:* • 0.2[7] 100 – 180 °C[8]	None

	PSA	Water scrubbing	Physical scrubbing	Amine scrubber	Membrane separation
CH_4 losses (%)	2 – 4[1] 2 – 10[2,8] 1 – 3[6] 2 – 5[5] 2[7]	1 – 2[1,8] < 1[5]	< 2[1] 2 – 4[5] 1 – 4[8]	< 0.1[1,5,8] 0.1 – 0.2[6]	~ 2[1,7] 3 – 5[8] 15 – 20[6] (without using residue gas)
CH_4 recovery (%)	83 – 99[1,3] < 96[5] > 96[8] Max. 98[6] VPSA = 97[2]	< 97[1,5] > 97[2,8] 98.5[5] 96 – 98[9]	93 – 97[1] > 97[8] > 99[5]	97.5 – 99.5[1] 99.9[2] >99[3,5,8] > 99.5[7] 95 – 98[7]	90 – 98[1] 82[2] 90[3,5] 90 – 93.5[7] 98[1] 96 – 98[8]
Pre-purification	Yes	Recommended roughly	Recommended roughly	Yes	Recommended
H_2S co-removal	Possible	Yes	Possible	Contaminant	Possible
N_2 and O_2 co-removal	Possible	No	No	No	Partial
Operation pressure (bar)	3 – 5[1] 4 – 7[5] 6 – 8[6] 4 – 10[8]	4 – 7[1,5] 4 – 10[8]	4 – 7[1,5] 4 – 8[8]	Atmosferic[1,5]	5 – 7[1] 6 – 8[5,8]
Pressure at outlet (bar)	4 – 5[1]	7 – 10[1]	1.3 – 7.5[1]	4 – 5[1]	4 – 6[1]

3.2 Cleaning technologies

In the purification step damaging compounds like H_2O, H_2S and particles and, if present, siloxanes and halogenated compounds are removed. This could otherwise cause problems with corrosion, deposits and mechanical wear on the downstream equipment and engines. This problems with siloxanes are explained in more detail in the Deliverable 3.2 Gas Quality.

Below follows a description of the most commonly used technologies for the removal of each component.

3.2.1 Hydrogen sulphide - H_2S

H_2S is formed when organic material containing sulphur is decomposed under anaerobic conditions. It is very corrosive on most metals and the reactivity increase with concentration and pressure, elevated temperature and in presence of water. Also, H_2S can cause problems with bad smell from the upgrading plant. H_2S can be removed in a catalytic oxidation reaction on activated carbon, forming elementary sulphur, S, and H_2O. By impregnating the carbon with potassium iodide or sulphuric acid the reaction rate can be increased. When saturated the activated carbon can be regenerated or replaced with new carbon. The technology is commonly used when a PSA system is used for the upgrading.

Another alternative for H_2S removal is chemical absorption on a solid material containing a metal oxide. Commonly used metal oxides are iron hydroxide and oxide. Some materials can be regenerated while others need to be replaced when saturated.

3.2.2 Water vapor – H_2O

Digester gas and landfill gas are usually saturated with water vapour. The concentration is increased with elevated temperature and at a temperature of 35°C the water content is around 5 %. Water forms corrosive acids in reaction with CO_2 and H_2S that can damage equipment if it is not removed.

The most common technology for water removal is adsorption on the surface of a drying agent. This drying agent can be zeolites, silica gel, aluminum oxide or magnesium oxide. The drying agent is packed in two vessels and while one is in operating mode the other one is regenerated.

3.2.3 Other components

3.2.3.1 Siloxanes

Siloxanes are organic silica compounds that occasionally occurs in landfill gas and digester gas produced from sewage sludge. During combustion it is converted to inorganic siliceous compounds, forming a white powder. Deposits of this powder in the downstream equipment

cause extensive damage by erosion and blockage. Siloxanes can be removed from the gas stream through absorption in a liquid mixture of hydrocarbons or with activated carbon. Spent activated carbon cannot be regenerated.

3.2.3.2 Halogenated compounds

Halogenated compounds are often present in landfill gas. During combustion it forms a corrosive product and, under certain conditions, dioxins and furans are formed. Halogenated compounds can be removed through adsorption on impregnated activated carbon.

3.2.3.3 Dust and particles

Dust and particles are removed with filters with different mesh size. These filters also remove droplets of water and oil.

3.3 Liquefaction

The most common liquefaction techniques used are closed closed-loop or opened-loop cycles. In opened-loop cycles the refrigerant is a part of the feed gas and in closed-loop cycles the biogas cooling and liquefaction is attained by an external refrigerant that flows continuously in a separated circuit. These liquefaction techniques are well known and have been in use for several years in the technical gas industry, for example for the liquefaction of natural gas, but in a much larger scale than in biogas plants

3.3.1 Closed-loop systems

This system operate using a single cryogenic refrigerant as methane or nitrogen (Nitrogen/Brayton cycle) or a mixture of these with other hydrocarbons (Mixed-refrigerant cycle). The biogas enters the process and is first cooled by the separate refrigeration process to a low temperature and thereafter expanded through either a valve or a turboexpander. This decreases both the pressure and the temperature with results in condensation of the methane (Figure 2).

The Brayton cycle is simple and robust but has a low efficiency since the cooling curve for N_2 does not correspond to the one for CH_4. The mixed-refrigerant cycle is designed to match the cooling curve for CH_4 resulting in a continually cooled gas stream and thereby a lower energy demand. However, this process is much more complex than using a single refrigerant.

3.3.2 Open-loop systems

These systems are based mainly on a successive compression-cooling-expansion process of the biogas. The last expansion stage is usually carried out in a turbo expander (TEX) to obtain LBG.

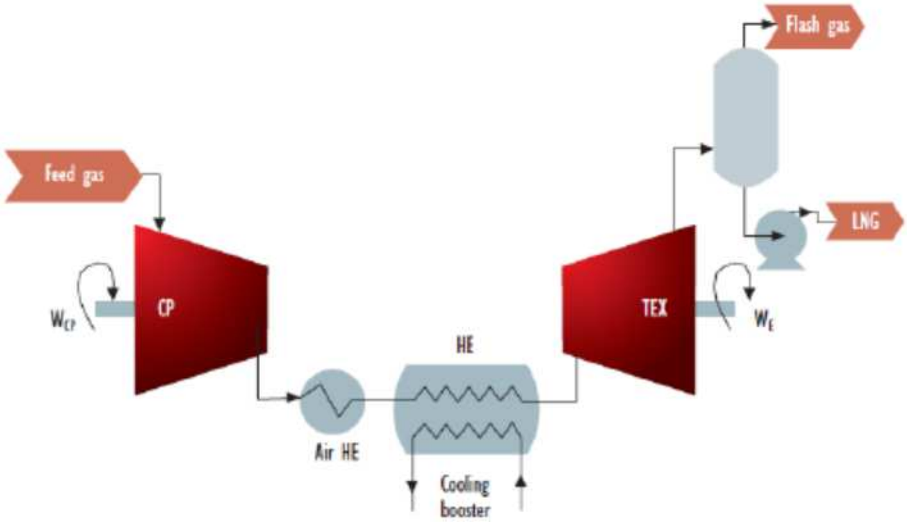

Figure 3-1 General scheme of an open-loop cycle (Begazo, 2007)

If the upgrading plant is situated close to the gas network one option could be to inject upgraded biogas into the gas grid and then produce LBG at a pressure letdown station in the gas grid with an open-loop cycle. These stations are situated were the distribution network accesses the transmission pipeline and have the function to reduce the pressure to match the requested commercial distribution pressure. Here the expansion of the gas can take place through a turbo expander. A fraction of the gas stream can then be liquefied with little or no power investment since the work taken out in the turbo expander drives the compressor. One of these letdown systems has been developed by Idaho National Engineering and Environmental Laboratory (Begazo, 2007). This technology is in use in a demonstration plant in Sacramento, California.

4 Refuelling

This chapter is a brief summary about the fuel station technology based on the experience of some companies of the sector. These experiences have been that the refueling station has developed to the actual technology gaining the better performances and quality to get refuels the vehicles today, with the LBG.

There are three different types of fuel station available, using LBG as a feed stock:

- LBG refueling station
- LCBG refueling station
- Multi-purpose refueling station

LBG stations fuel LBG to vehicles equipped with a cryogenic tank. LCBG stands for *liquid to compressed biogas* and LBG is transformed to CBG at the refueling station. Multi-purpose refueling stations are able to fuel both LBG and CBG, and consist of one LBG part and one LCBG part. There are a number of companies in the LNG business working with the development of fuel stations using LBG as a feedstock.

The reason why the multi-purpose station is chosen is because LBG could be a good alternative for heavier vehicles. Here it is assumed that these vehicles already are available and in use on a large extent. The refueling station assumes to be situated in conjunction with one of the frequent roads in Sweden, not in vicinity with the gas network. The following requirements lie as a background for the design:

- Possibility to fuel both LBG and CBG
- One double dispenser for CBG; one nozzle for vehicles (NGV-1) and one nozzle for busses (NGV-2)
- One single nozzle for LBG
- Expected volume of sale: 3000 Nm3/day
- Pressure on CBG: up to 230 bar (200 bar at 15°C)

The standard equipment on the multi-purpose station consists of a storage tank for LBG, cryogenic pumps, ambient vaporizer, odorant injection system and dispensers.

There are three types of cryogenic pumps:

- Reciprocating
- Centrifugal
- Submerged

Reciprocating pumps are able to function at very high pressures and are therefore used for the filling of buffer tanks and gas cylinders. Centrifugal pumps are able to produce high flow rates and are used for the transfer of cryogenic liquids between reservoir tanks or road tankers. A submerged pump is a centrifugal pump installed inside a v insulated cryogenic tank. This tank is totally submerged in the cryogenic liquid, which makes it stay in permanently cold conditions.

LBG is stored in a vacuum insulated cryogenic vessel and LBG is delivered with semi-trailers. The volume of the storage tank is usually designed to match refilling on a weekly basis. The transfer from trailer is either done by gravity or by transfer pumps, the latter significantly reducing transfer time. From the LBG storage tank the station is divided into two; the LBG part and the LCBG part.

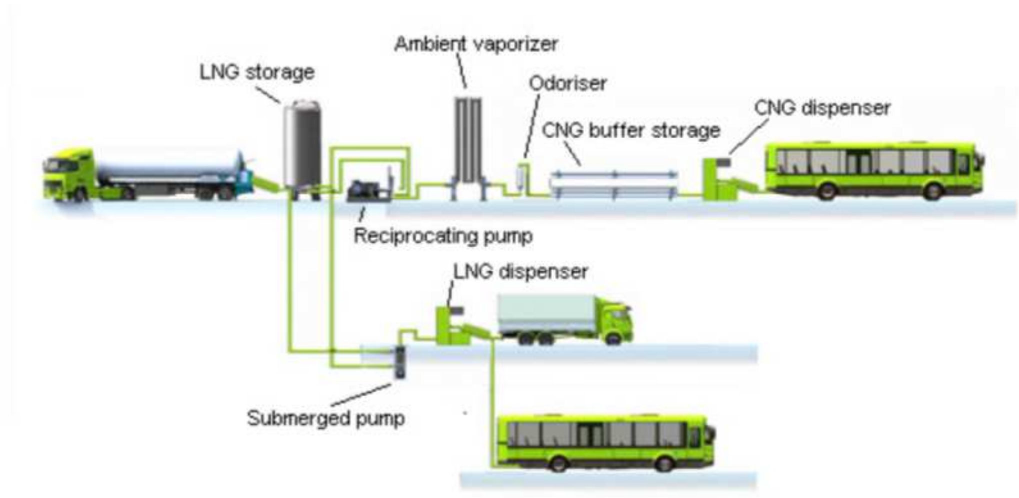

Figure 4-1 Sketch over a multi – purpose refueling station (Vanzetti Engineering, 2008)

The LCBG part consists of a reciprocating pump, an ambient vaporizer and buffer storage. The reciprocating pump sucks LBG from the storage tank and raises the pressure to around 300 bar, before sending it to the ambient high pressure vaporizer. CBG is then odorized before going to the CBG storage and the dispenser. The buffer unit is gas vessel storage, with a maximum working pressure of 300 bar, enabling fast filling of vehicles.

The LBG part only consists of a centrifugal pump that transfers LBG from the storage tank, through vacuum insulated lines, to the LBG dispenser that dispense LBG at a pressure of 5-8 bar. (Nexgen Fueling, 2008) Some LBG dispensers are supplied with a system for the recovery of the vehicle boil of gas.

To reduce methane losses all venting lines are collected and sent back to the higher parts of the storage tank, to be reliquefied by the cold LBG.

5 Open infrastructure for LNG/LBG[4]

After years of experience it is able to know the keys to open infrastructure for LNG/LBG, and these keys are explained below in this chapter.

There are some items taking into account that have influenced to technical aspects related to refueling stations. The LBM stations are built to serve all kinds of LBM trucks from different manufacturers and potential after-market conversion systems.

5.1 Technical isssues due to a new technology and development of a new market.

Today there are no decided standard defining the criteria for LNG / LBG filling stations. Due to this fact a lot of focus has been to secure that the filling station is fulfilling all relevant regulations, as well as, all relevant technical design criteria to be able to serve all possible trucks. This is a relevant issue since technology suppliers for LNG/LBG vehicles and refueling systems are suing different solutions.

Another relevant aspect is the gas quality. This issue is most important to take into account as the functionality of the vehicle systems is dependent on the fuel quality. The most important factors identified are listed in the table below with comments and clarifications.

Issue	Clarification of issue	Potential problem	Solution
Hot or cold gas	Depending on the technology provider (Hardstaff, Westport, etc.) the gas must be delivered with the right temperature/pressure ranging from 1 to 8 bars.	If gas with low temperature is delivered to vehicles designed for higher pressure the vehicles will not run or run on diesel only until working pressure has been reached.	As vehicles for lower working pressure are also running on higher pressure the gas will be delivered at a pressure above 5 bars. Therefore, the filling station is equipped with a gas conditioning system securing the proper temperature and pressure of the fuel.
Gas quality and LBG vs. LNG	The fuel quality differs depending on the source. LNG properties are different if the fuel comes from Africa or Norway. LBG has typically a higher content of methane compared to LNG	Depending on the sensitivity of the technology the vehicles will have functional problems if the quality of the gas is differing too much.	Secure that the fuel supplied are compatible with the suppliers of the vehicle systems.

[4] Reporto n experiences from Liquefied and compressed methane gas (LCMG) filling station demonstration – Tula Ekengren, FordonsGas Sverige AB, November 2010

Supply of fuel to the filling sation	The supply of fuel to the filling station must match the estimated demand of fuel.	The fuel must med conditioned if the pressure/temperatures too low at the delivery to the filling station causing down time when the station cannot deliver fuel to vehicles. Also vaporizing due to too little demand of LNG might occur.	Optimization of the fuel supply chain.
Receptables and nozzles	There are two main manufacturers of nozzles (at the filling station) and receptacles (on the vehicle tank). The compatibility is not ensured to 100% due to lack of standardization.	If nozzle and receptacles are not compatible the vehicles might not be able to refuel. Note: the identified potential issues. All safety aspects are fully secured at all times.	Vehicles should be equipped with Kodiak receptacles. If so, no geometrical conflict casing problems to attach the nozzle to the receptacle will occur. The chosen manufacturer secures no methane leakage by transporting it back to the tank.
Need of separate ventilation hose	Present solution for refueling is using a separate venting hose to secure the vehicle tank pressure is not too high to start the refueling process	The market evaluation shows that all extra handling compared to diesel refueling might be used as a reason not switching to LNG instead of diesel. It is also an issue of increased investment cost and a source for potential problems.	The filling station will have a separate hose at the time for opening. The work continues to develop technology tht is venting back to the gas to the storage tank through the feeder hose.
The variation of CMG/LMG outtake	In the beginning there will be mostly CMG filling. As market of LMG heavy duty vehicles increases this will change.	With to low CMG consumption there might be a problem with boil off	The placement of the CMG dispenser in a good environment for public filling.

5.2 Selection location

5.2.1 Market criteria

Market based criteria for location of the station has been:

- LMG refueling close to the truck operators local hubs.
- Access to traditional truck-stop services.
- Close to highway to support long haulage transit traffic.
- Surfaces must be able to handle the weight og the vehicles.
- Good location for the CNMG station to complement existing CMG infrastructure.

5.2.2 Requirements from administrative authorities

Local and national authorities are setting up requirement based on the different scope of theiur activity. In the table below the most relevant authorities, their scope and the given remarks during the process are listed below.

Authority / Administration	Scope	Potential remarks	Solution
MSB – Swedish Civil Contingencies Agency	National administration with responsibility to approve the filling station facility	Focus on risk avoidance based on placement, design and the technology used.	A good and open dialogue during the process
Local fire brigade	Securing plans for safe and fast rescue efforts	Remarks mainly based on the fact that the chosen location is a place for many trucks and connected services, i.e. potential lack of accessibility.	Dialogue. The formal decision is taken by MSB
Department of housing and urban development	Secure good city planning and urban environment and development. Approve building permits.	Hight of the LNG storage tank. Road signage.	Dialogue. LNG storage tank lower than originally planned.

5.3 Selection of technology and supplier

There are a few providers of LCNG filling stations. The partner Fordonsgas has the criteria to use as modern and user friendly technology as possible. This is due to ensure correct and exact functionality at all conditions. An example of this is that the filling station is using a pump to pump the LMG fuel over to the vehicle. A more inexpensive solution is to use self-pressure. However, self-pressure is causing variances in filling times and will increase the potential to get rid a separate venting hose, etc. Therefore, the solution using a pump to get the fuel from the storage to the vehicle was chosen.

Price is naturally one of the most important criteria, but in order to also secure low life cycle costs other important criteria when choosing technology providers have been:

- Knowledge of both technical issues and market issues
- Reliability
- Environment
- Availability of spare parts
- Local representation and support.

5.4 Design and lay-out of the filling station

The design of the filling station is done by the supplier of the equipment according to the criteria given by Fordonsgas regarding capacity etc. The lay-out of the filling station in terms of where the different components (storage tank, payment pillar, dispenser etc.) are placed depended mostly on safety distances according to the regulations. Experiences from the supplier together with the specific conditions at the facility and experiences from Fordonsgas' heavy duty CNG refueling business gave the final result as shown in the drawing below.

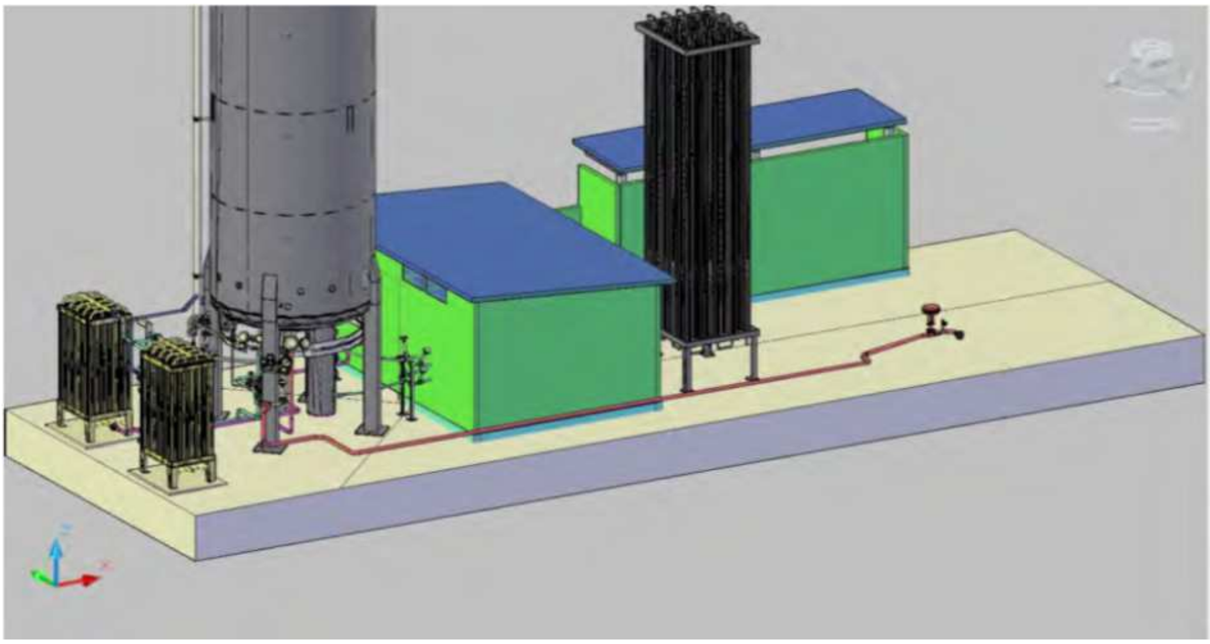

Figure 5-1 the lay-out of the filling stations

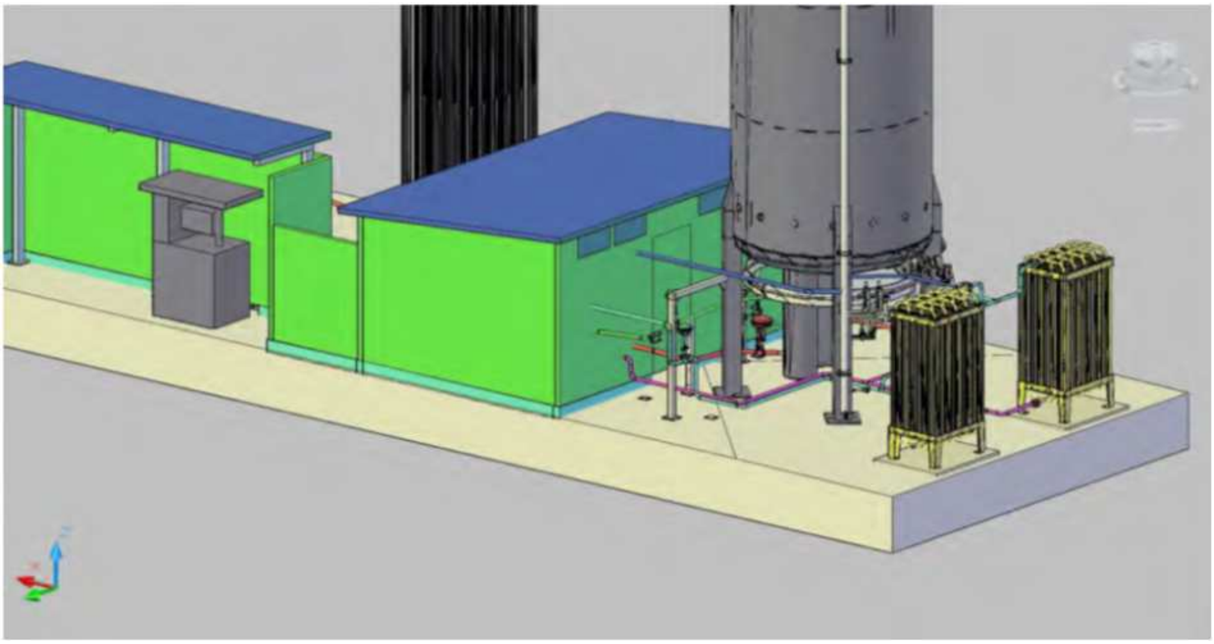

Figure 5-2 The lay-out of the filling stations

5.5 Fuel supply for the filling stations

Sweden has today no domestic LNG production plant, neither a LBG production plant. A LNG-terminal is under construction and it will support the Stockholm area.

The Linkoping facility will supply the filling station with LBG as from 2011. The biogas will be produced mainly from food processing waste and the facility is planned to deliver 60 GWh annually. As the filling station will open before liquefied biogas is delivered from the new plant the station will be provided with LNG produced in Norway and transported by trailer to the filling station. If the station is using its maximum capacity it will require one LMG trailer every second day, i.e. a capacity of 50 heavy duty vehicles and in addition to this a good capacity for CMG filling.

6 Incentives[5]

6.1 Farmers incentives

The farmers were facing the obligation to ensure storage capacity for liquid manure, initially for 6 months, which was later increased to 9 months.

Restrictions on the livestock production in terms of maximum stock density per acreage where the manure is being spread: originally 1.7 livestock units (LU) for pigs and 2.3 LU for cattle (1 LU equals 100 kg of nitrogen in the manure), now further strengthened to 1.4 and 1.7 respectively.

Obligatory minimum utilization percentages for the nitrogen in the manure and fixed maximum total application of nitrogen in manure and fertilisers for each crop.

For the farmers there were advantages in using biogas plants to fulfil these obligations as the joint biogas –plants efficiently redistributes manure from livestock producers to plant producers and from stables to decentralized storage tanks near the fields where the digested manure is used as fertilizer improves the nutrient value of the manure due to mineralization of the nitrogen and hence optimizes the application of manure to the crops compared to raw manure.

In the coming years the Danish farmers will be facing further challenges such as reduction of bad smells from application of manure and reductions in leaching of phosphorous. Digestion of the manure in a biogas plant reduces the content of organic matter and the manure becomes thinner. Therefore the digested biomass disperses much quicker into the soil which effectively reduces the bad odors.

The digestion makes it technically easier to separate the liquid manure. By simple mechanical separation technology such as a decanter centrifuge the digested manure can be split up into two fractions: a liquid fraction comprising 80-85 per cent of the volume containing 80 per cent of the nitrogen of which almost all is ammonium which can be utilized right away by the crops a fiber fraction comprising 15-20 per cent of the volume but containing more than 75 per cent of the phosphorous content and almost all the organic bound nitrogen.

Environmentally friendly liquid manure, which can be utilised by the local farmers as a high value fertilizer with low impact on the environment, though, minimum risk of leaching and highly reduced smell. The fibre fraction contains all the environmental and societal problems (leaching of nutrients and smell). It can, due to the reduced volume, be transported to more distant places, which need organic soil improvers. The Danish Parliament has in 2006 passed a new act which makes it legal to use the fibre fraction as a biofuel to produce electricity and heat and hence totally eliminate the environmental impact. The phosphorous can be recovered from the ash. By investing in biogas plants with separation technology the Danish livestock farmers have the option to keep up or even further increase the production. In many parts of Denmark the alternative to use this kind of proven environmental technology is to reduce the livestock production up to 40 per cent. This would have very serious impact on not only the farmers' economy but also the socio-economy of the rural areas and the Danish society at large.

[5] *EUROPEAN & DANISH BIOGAS EXPERIENCE Bruno s nielsen*

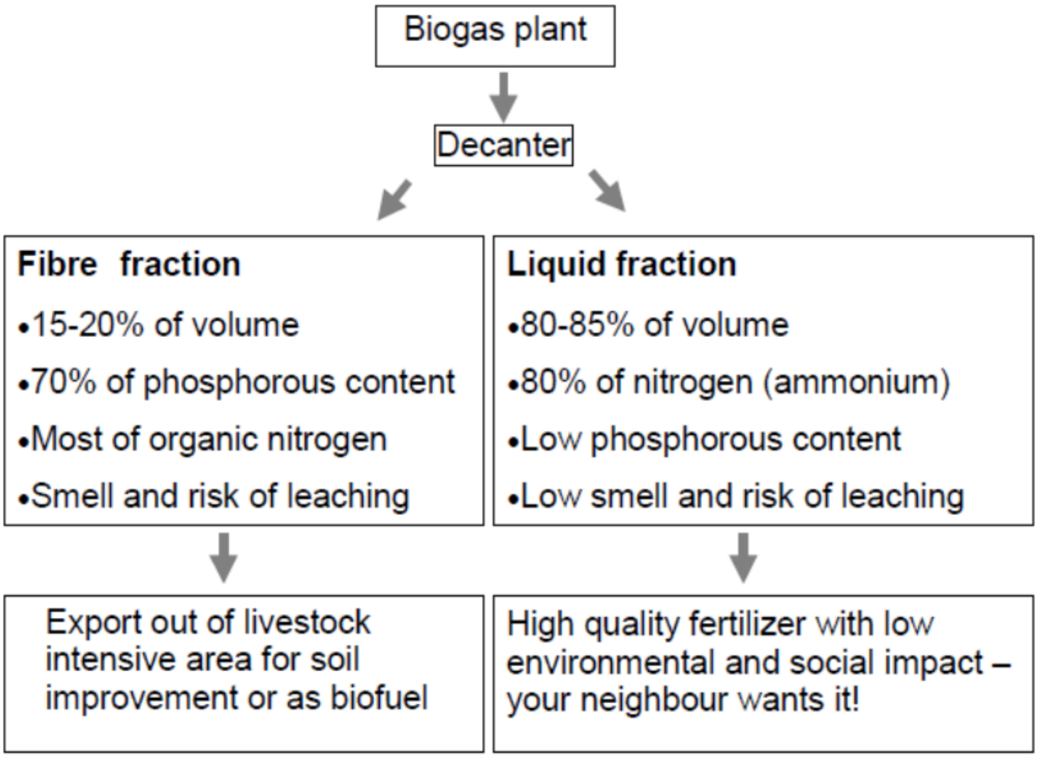

Figure 6-1. Combined and mechanical biogas separation plant.

6.2 Societal Incentives

An anaerobic digester is not only environmental equipment treating the manure in the interest of the farmer. It is indeed also a technology that gives many advantages for society in general:

- Reduces emission of greenhouse gases by substituting fossil fuel and by reducing emission of methane from manure storage facilities and N_2O from the fields, which are respectively 21 and 320 times as serious greenhouse gases as CO_2.
- Protects ground water and aquatic environment against leaching through increased utilization of the nutrients by the crops.
- Increases life quality in rural areas by reducing obnoxious smells
- Reduces zoonoses and other pathogens in manure.
- Renewable energy and nutrient recovery from waste.
- Continued and perhaps increased agricultural and food production.
- Utilises biomass from energy crops and natural habitats that need thinning to prevent overgrowth.

Due to these, and other, societal benefits there is a willingness in many countries to support the installation of biogas plants. In Denmark a socioeconomic analyses was done in 2002 stating that Danish society earns money by establishment of new joint biogas plants. This is primarily due to the simultaneous solution of many problems, which reduces investment of public and private money in solving the problems one by one, which will be much more expensive.

Unfortunately the current Danish government that came into office in 2001 for many years didn't want to promote biogas. There are, however, indications that the policy is shifting as the government has realized that environmental issues and especially climate change has a very high priority in the Danish public. The political interest is also promoted by the fact that climate change and protection of water and environment is a priority issue all over the world, which might promote markets for industry within these key technologies. Therefore the Danish farmers – and the biogas industry – are looking forward to a change in the Danish policy which might not only open up for the national market but also internationally.

6.3 Development in other European Countries

Biogas is also being promoted in other European countries. The traditional frontrunners in addition to Denmark are Austria and Germany. But also in Sweden, Netherlands, France, Spain, United Kingdom etc. there is a growing acknowledgement of the multifunctional advantages in biogas. Especially in Germany the government has been promoting the development of biogas through very favourable framework conditions. To compare the situation the Danish biogas plants are being paid $122 CAD per MWh electricity (which will be reduced to $81 CAD after 10 years in new plants). German plants are paid $145 CAD per MWh on large joint biogas plants and up to $300 CAD in small farm-scale biogas plants using energy crops. Further development for biogas in Denmark and most other countries is as a tool to solve the problems related to livestock production whereas the future in Germany is also in biogas plants with energy crops as main raw material.

7 Current barriers and incentives[6]

7.1 Barriers to commercialization and deployment

There are a lot of studies relating to the stakeholders interviewed about the main barriers of the LBG. In this chapter it is explain the main found in the report of feasibility study of road vehicle biomethane by AEA (AEA Feasibility Study for a Road Vehicle Biomethane Demonstration Project 2010).

The main barriers to widespread deployment of biomethane to power heavy duty vehicles are these:

- The lack of refueling infrastructure, and the capital costs of refueling stations.
- The limited number of suppliers of biomethane.
- The lack of certainty with regard to government incentives and fuel duties.
- The (assumed) low residual value of gas powered vehicles.

Overcoming the capital costs of establishing a refueling infrastructure is the single biggest barrier to deployment. While a strong business case can be made for vehicle purchase in many fleets, the cost of one or more permanent refueling stations is much harder to justify without significant economies of scale, especially since it is up front expenditure that has to be made before any fuel savings are achieved. Without government support, only a very few operators at this stage are likely to be convinced enough to invest in the 10-20 vehicles that might make this investment worthwhile.

There is only one current supplier of biomethane in the UK, GasRec. This is less of a problem than it might first appear – GasRec could supply a lot more vehicles in the UK than it does at the moment (more than half of its gas is exported), and if its supply was exhausted, fleet operators could use natural gas instead. However, for many fleet operators, the main driver for switching to gas is customer pressure for carbon savings, which are much higher when using biomethane. Many of the operators we spoke to were concerned about the lack of choice and depth of supply, and also expressed concerns that a lack of competition probably meant they would pay monopoly prices for their gas.

Both fleet operators and gas producers expressed concern that the government had not provided enough reassurance regarding the continuity of incentives and duties. Given the up-front investment required to make use of biomethane in vehicles, and the importance of incentives and duties to the expected payback, confidence that those incentives will remain fixed until the investment has paid off is as important as the level at which they are set.

Some fleet operators expressed concern that they would not be able to roll out the use of gas powered vehicles because they could not guarantee a strong residual value at the end of the vehicle lease. For many operators, vehicles are procured under an operating lease based on the difference between purchase price and the residual. A gas powered vehicle will typically have a price premium of around £25,000, but in the current market it is assumed that this adds nothing to the residual value, meaning that the operating lease is too expensive.

7.2 Market incentives and legislation

[6] *AEA Feasibility Study for a Road Vehicle Biomethane Demonstration Project 2010*

Since biomethane production and use touches not just on transport but also on waste management and energy generation, a wide range of incentives and legislation influence its uptake.

Price mechanisms

As a vehicle fuel, natural gas is currently taxed at 35p less than diesel, a differential that the government has currently fixed until 2014. At present, diesel is taxed 57.19p/litre and gas at 22.16p/litre. This derogation applies equally to natural gas and biomethane, and is vital to the cost effectiveness of gas powered vehicles. Although gas powered vehicles are more efficient than diesel vehicles, until they are manufactured in large quantities their price premium will require this subsidy for them to be economic.

Since gas powered vehicles can use natural gas or biomethane, the wholesale price of natural gas sets an effective upper bound on the price of biomethane. Users will pay some premium for the extra carbon savings biomethane provides, but this is limited. (It would of course increase if carbon was directly priced in some way in the transport sector.)

Smaller electricity generation plants, under 5 MW, can now claim Feed In Tariffs (FITS) meaning they will receive 9p/kWh, fixed for 15-20 years.

If a biogas producer chooses to invest in upgrading their gas to biomethane, they can sell it as transport fuel, but will soon also be able to inject it into the gas grid. „Biomethane to Grid" (BtG) will be eligible for the Renewable Heat Incentive (RHI), amounting to 4p/kWh. However, this will probably only be attractive to larger plants, as there will be significant investment required in equipment to prevent accidental contamination of the gas grid.

If a biomethane producer does decide to sell their gas as transport fuel, they will be able to claim Renewable Transport Fuel Certificates (RTFCs). Like ROCs, RTFCs are traded on the open market, with a „buy-out" price at which a company that cannot source enough RTFCs would have to pay to the government in order to make up any shortfall in the number of RTFCs it submits at the end of the year. The buy-out price is currently set at 30p/liter, and although RTFCs are currently trading at well below this price, the rising percentage of biofuels required under the Renewable Transport Fuel Obligation is anticipated to push the price up towards this level.

As mentioned above, a recent report by the Carbon Trust13 compared the income that gas producers could earn from generating electricity, selling the gas as transport fuel and injecting it into the grid. They concluded that in the absence of incentives transport provided the highest return, and that this

was still the case with incentives (FITS, RTFCs and RHI) albeit with a much smaller margin between the three. It seems likely therefore that the capital cost of gas clean-up, combined with the small and uncertain market for biomethane transport fuel, may be dissuading many investors that might otherwise get good returns from providing gas to the transport sector.

Currently there is only one producer of biomethane in the UK, and the price they can charge is closely bounded by the upper and lower limits described above. However, if the prices of oil and gas rises, the price that could be charged for biomethane for transport may go up and should stimulate more producers to enter the market. Since the cost of producing biomethane is linked to the waste management industry rather than oil and gas production, it is likely that increased production of biomethane would create a widening price gap between biomethane and diesel.

8 Relevant experiences[7]

Studding the situation of the LBG infrastructure and technology around the world, it is believed it important share this experiences of US. To learn what are the difficulties and how this issues has been resolved to growth technical and knowledge in the world of liquefied biomethane fuel.

Rising oil prices in the 1970's triggered an interest in developing "commercial farm-scale" biogas systems in the United States. During this developmental period (1975-1990) approximately 140 biogas systems were installed in the United States, of which about 71 were installed at commercial swine, dairy, and caged layer farms.

Many of these initial biogas systems failed. However, learning from failures is part of the technology development process. Examining past failures and success led to improvements and refinements in existing technologies and newer, more practical systems. The main reasons for the success and failure of biogas recovery projects follow.

8.1 Reason for success

Biogas recovery projects succeeded because:

- The owner/operator realized the benefits biogas technology had to offer and wanted to make it work.
- The owner/operator had some mechanical knowledge and ability and had access to technical support.
- The designer/builder built systems that were compatible with farm operation.
- The owner/operator increased the profitability of biogas systems through the utilization and sale of manure by products. Some facilities generate more revenues from the sale of electricity and other manure by products than from the sale of milk.

8.2 Reasons for failure

Biogas recovery projects failed because:

- Operators did not have the skills or the time required to keep a marginal system operating
- Producers selected digester systems that were not compatible with their manure handling methods.
- Some digester/builders sold "cookie cutter" designs to farms. For example, of the 30 plug flow digesters built, 19 were built by one designer and 90 % failed.
- The designer/builders installed the wrong type of equipment, such as incorrectly sized engine-generators, gas transmission equipment, and electrical relays.
- The systems became too expensive to maintain and repair because of poor system design.
- Farmers did not receive adequate training and technical support for their systems.
- There were no financial returns of the system or returns diminished over time.
- Farms went of business due to non-digester factors.

8.3 Today's experiences

[7] Chapter 1 – Overview of biogás technology

The development of anaerobic digesters for livestock manure treatment and energy production has accelerated at a very face pace over the past few years. Factors influencing this market demand include: increased technical reliability of anaerobic digesters through the deployment of successful operating systems over the past decade; growing concern of farm owners about environmental quality; an increasing number of states and federal programs designed to cost share in the development of these systems; and the emergence of new state energy policies designed to expand growth in reliable renewable energy and green power markets.

9 LNG Blue Corridors conclusions and recommendations

The experiences so far within this project are that the technology is known. Standardization and development of user is friendly and the cost efficient solutions are obvious improvement areas.

Taking into account the collective opinions of stakeholders, and the barriers discussed, we recommend that to encourage biomethane as a transport fuel in the Europe, the development of the infrastructure for own-depot fuelling and in public refueling stations should be prioritized. The short term advantages would be to reduce the effective price seen by all operators.

A more streamlined approach is to put in place incentives that encourage use of gas (and therefore interest in refueling stations).

Production of LBM out of biogas is technically possible and proven in practice. LBM is most likely produced from co-digestion or industrial digestion of biomass. Industrial digestion is on average 23 % cheaper than co-digestion.

The cost of upgrading biogas goes up at a smaller scale. At a larger scale, cost and supply of biomass becomes a problem.

Given that LBM can only replace LNG as a fuel up to a certain percentage, the infrastructure must be organized in such a way that LBM can be integrated directly with LNG. At a larger scale, LBM can possibly be mixed with LNG in storage terminals. These storage terminals can fuel LNG ships when located near inland waterways. At a smaller scale, refilling station can be alternately supplied with LNG or LBM.

The pump price of LBM is thus the same as LNG. This price must be lower than diesel, if transport companies are to switch to LNG trucks. LNG currently is about 50 % cheaper than diesel. Investments in LNG trucks pay themselves back in 3 to 5 years at this price. The tax policy for vehicles on natural- or biogas currently favors the compressed from instead of the liquid form, because the government distinguishes between the phase of the gas.

For the longer term there are environmental advantages for introducing LBM in conjunction with LNG.

The most important topics to ensure the evolution of LBG as vehicle fuel are:

- Simultaneously stimulate developments in the LNG sector and wait until this market has matured more, before integrating LBM into it. It is unwise to create an entirely separate infrastructure for the distribution of LBM.

- Try to create the conditions in which transport companies automatically switch to LNG, by ensuring a low vehicle payback time and providing enough refilling locations).

- Begin production of LBM on a small scale (i.e. starting with low risk and manageable projects). To stimulate the introduction of LNG fuel use in the transport sector, the following things should happen.

- The excise tax on LNG must be separated from the excise tax on LPG.

- Agreements with the industry must be made on how to cope with different fuel qualities.

References

List of Tables

List of figures

Partners (only for public deliverables)