“Biogas upgrading: Membrane separation takes over”

- The success story of Poundbury continues -

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Abstract

Due to governmental incentives and growing environmental awareness, it becomes increasingly attractive to upgrade biogas to natural gas quality and inject it into the natural gas grid or to use it as transport fuel. In this way, the biomethane can be utilized with the highest energy efficiency. Progressively, effort is being put into the utilization of organic waste streams in anaerobic digesters, producing useful products such as fertilizers and biogas. DMT has been developing biogas treatment plants for over 25 years, closely following market developments.

To upgrade raw biogas to biomethane, it is required to remove unwanted and harmful gases, such as carbon dioxide (CO_2) and Hydrogen Sulphide (H_2S). Several biogas upgrading technologies are available for the upgrading of biogas. The choice and configuration for a biogas upgrading plant is a tailor-made fit between customer requirements, (local) energy demand and operational aspects. However, for most situations, especially for plants up to 1000 Nm^3/h, the Carborex® MS system (based on an ingenious, multi-stage, high selective membrane system) offers the best economics as well as several unique technical advantages. The DMT Carborex® MS is a compact modular and containerized unit, which applies high selective gas membranes for biogas upgrading. The upgraded gas has a methane concentration up to 98-99% CH_4, which greatly reduces the consumption and cost of propanisation. This system has the highest energy recovery available (96-98%), therefore, it maximises revenues. The CO_2 is recovered as >99,5% pure.

Recent market data shows that the number of biogas upgrading installations based on membrane technology is growing quickly. In this article, DMT will showcase last year’s operation data of the Carborex® MS plant at Poundbury, which is currently the largest commercial biogas upgrading plant in the UK. Furthermore, the prospects for membrane based biogas upgrading, especially with regards to the shift towards larger scale application, will be described.

Keywords: Carborex® MS, Biogas, Bio-methane, Gas separation, Green gas, highly selective gas membrane, Membrane separation, Upgrading

Figure 1 Biogas upgrading plant using high selective membranes

Introduction

In October 2012, HRM Prince Charles opened the first commercial Biomethane to Grid Plant in England (at Rainbarrow farm, near the town of Poundbury in the Duchy of Cornwall). The anaerobic digester at Rainborrow farm is fed with a feedstock consisting of maize, grass, potato waste, whey, and small amounts of food waste (chocolate and muesli) from local Poundbury factories. At full capacity, a biogas production of approximately 850 Sm^3 per hour can be achieved. The produced gas (containing ±53% methane) is divided between a generator (energy generation) and biogas upgrading system (gas grid injection). Roughly 200 Sm^3 per hour of biogas is used to fuel a 400 kW generator. Approximately fifty percent of the generated energy is used on site (amongst others to drive the upgrading installation), the rest is exported. Up to 650 Sm^3 per hour of biogas is led to the DMT Carborex® MS biogas upgrading plant, which uses a multistage system of membranes to clean out CO_2 and provide a gas stream containing 98.4% methane. Prior to entering the SGN net entry facility (NEF unit), approximately 4% propane is added to the biomethane to increase the energy content of the biogas. At the NEF unit, the distinct gas odour is added to the biomethane and the gas quality is confirmed to match that of natural gas. The biomethane flow going into to SGN Network is circa 400 Sm^3 per hour, enough gas for 4,000 houses in winter and 56,000 houses in summer. The design of Poundbury is based on recent developments in membrane separation, and uses highly selective membranes. The system is designed to obtain low methane losses (<0,5%), efficient and safe removal of carbon dioxide, water vapour, hydrogen sulphide and other trace pollutants with a fully automated compact modular plant. The Main components of the biogas upgrading installation are a booster system, a filter system, compressor and a multi stage membrane system. Moreover, the installation is equipped with propane injection and an odourization system. A general image of a typical DMT Carborex® MS system is displayed in Figure 2 (Langerak et al., 2013). Through the use of multiple stages of membranes, the gas is separated into a CH_4-rich stream and a CO_2-rich stream. The upgraded gas has a methane concentration of >98% CH_4, which greatly reduces the consumption and cost for propanisation. The CO_2 is recovered as >99,5% pure. It is the only upgrading technology that also removes significant amounts of oxygen (up to 70%).

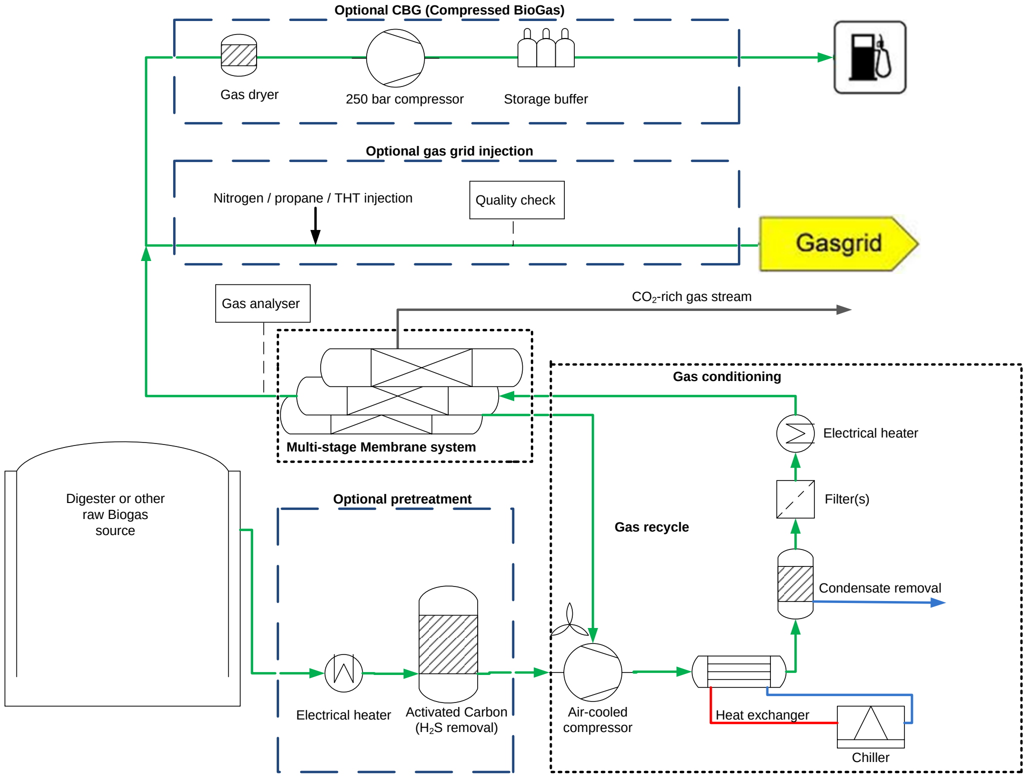

Figure 2 Configuration of a typical DMT Carborex® MS system

Performance data Poundbury

In this chapter, performance data of the first year of operation as well as milestone achievements, of the Poundbury upgrading installation, will be show cased. Main aspects to be evaluated are: gross gas flows, plant availability, quality control (Wobbe/calorific value, trace components), propane injection, methane slip energy consumption, time to grid (the time between start-up of the installation from standstill and the moment at which the gas is entering the gas grid) and the estimated lifespan of the membranes.

Gross gas flows

The average inlet gas flow during 2013 was approximately 600 Nm^3/h, with a methane content of 53%. Due to the almost perfect separation of methane (>96% purity) and CO_2 (>98.5% purity), an average product gas flow (output of biomethane) of 350 Nm^3/h on average could be obtained. This includes the addition of ±3-4% propane. The off gas glow, the gas stream in which the majority of the CO_2 is discharged, was on average 280 Nm^3/h. Roughly 214.000 Nm^3 of biomethane was injected into the gas grid each month. Consequently, a number of milestones have already been achieved. In April 2013, the 1.000.000 Nm^3 of biomethane into the grid mark was reached. Nowadays (October 2013), the installation at Poundbury has produced more than 2.500.000 Nm^3 of biomethane.

Propane injection

Due to the high removal efficiency of CO_2 (outlet concentration <1,8%) and O_2 (outlet concentration <0,1%), the membrane system only required an average propane addition of 3,3%. Compared to other technologies, for example, a pressurized water scrubbing system, which has a less effective CO_2 removal (general operational range 2-4% CO_2%), and no oxygen removal, approximately 1% less propane needs to be added. This represents an annual saving (reduced propane expenses) of roughly £74.000,-.

Plant availability

If we examine the availability of the DMT plant over the last year, we can conclude that not taken into account the first three months, which were used for fine tuning of the installation, an average availibility of 97.8% was obtained. For the following years it is expected that an uptime >98% can be ochieved.

Quality control

The Biomethane quality is controlled with two different parameters. The first is the general control based on CO_2 content done by the Carborex® MS unit, the second parameter is the fine control of the gas, which consist of the propane addition, based on calorific value (CV).

The CH_4 content of the upgraded gas is a variable depending ot the CO_2 setpoint. By setting the CO_2 content at a certain setpoint, we indirectly control the methane content. Within the last year, the upgrading installation has been operating with a CO_2 content setpoint within the range 1,5-1.8%. Consequently the CH_4 concentration in the product gas lies within the range 98,2-98.5%. CH_4 values up to 99% can be obtained; this however, was not required at Poundbury. In Figure 3, an indication is given on the methane content of respectively the inlet biogas stream (average CH_4 content 53,98%, displayed in blue), the upgraded biogas stream before propane injection (average CH_4 content 98,45%, displayed in green), and the vent/waste gas stream(average CH_4 content 0,3% displayed in red). Through addition of propane, the volumertric percentage of methane in the biomethane, at the NEF unit, is lowered to a value of 94-95%.

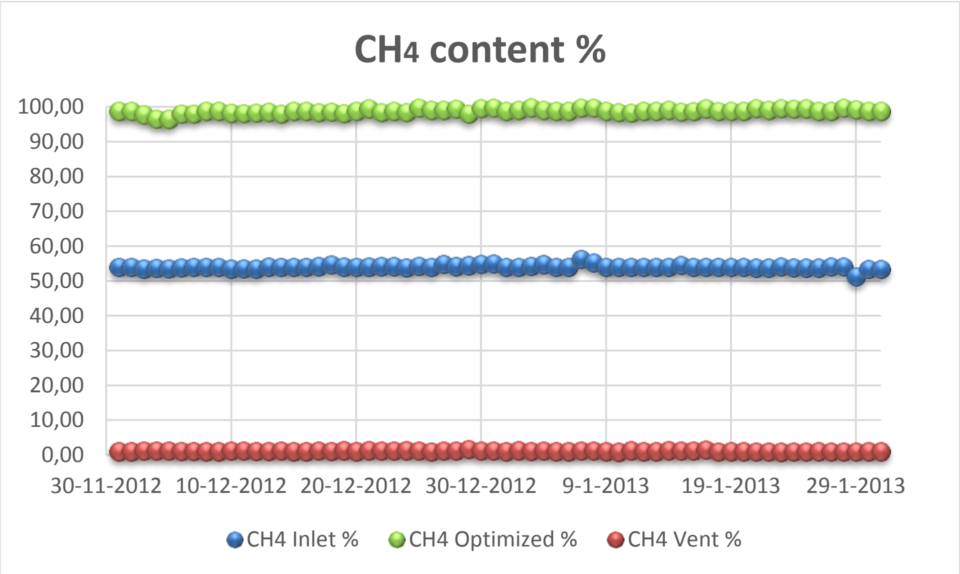

Figure 3 CH_4 levels in main gas stream (01-12-2012/31-01-2013)

The calorific value (interrelated to the Wobbe value) is a measure for the amount of heat produced by the complete combustion of a material or fuel, and in this case used to control the propane injection. Figure 4 shows a representation of the CV trend displayed at Poundbury installation during the last year, in which the CV value is adjusted on a daily basis by the grid operator to match the gas quality in the grid. The green flat line shows the target CV and the red line is the actual CV value. There is a 0,5 MJ/m^3 bandwith over and under the CV value set by the grid operator. Without any doubt, it could be said that, regardless the new CV target set, the system easily follows those changes with no bigger deviation from the set point than ±0.05 MJ/m^3. This is one of the key features for obtaining stable grid injection, and contributes significantly in the uptime of the upgrading installation.

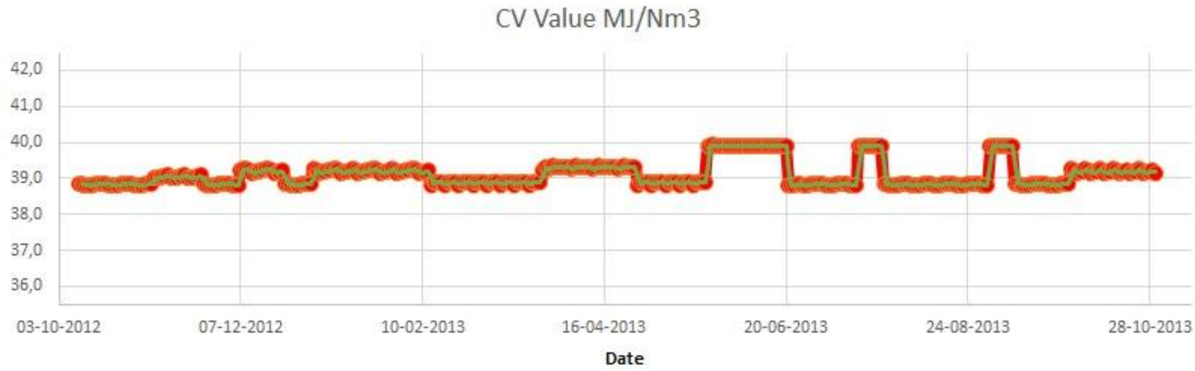

Figure 4 Representation of CV over time of a Carborex® MS system

The gas quality at Poundbury has to comply with a Wobbe value ranging between 47.2 and 51.4 MJ/Nm^3). The Wobbe parameter (influenced by both the CO_2 and the propane control) is one of the most important parameters when it comes to gas quality. It is an indicator of the interchangeability of fuel, and specifies the energetic content of the gas in relation to its density. It is important to remark that since the opening of the installtion the Wobbe was easily controlled within its boundary limits and displays a deviation which is not higher than ±0.02 MJ/m^3. This is mainly due to the good CO_2 control of the DMT installation and the propane dosing system.

Besides a strict range for energetic content on grid gas, limitations are set on a wide range of trace components. The most important trace components are oxygen and H_2S. Low values of H_2S and oxygen are required to protect the downstream equipment (gas grid) from corrosion. Even though the outlet oxygen level is largely depending on the raw biogas quality (oxygen concentration), the Carborex® MS offers a significant advantage compared to other technologies in obtaining the required oxygen level, through the removal of up to 70% of the oxygen. It is shown that the oxygen content at Poundbury did not reach values higher than 0,1%. This value is far below the maximum tolerable range for oxygen, which lies at 0,15-0,25%.

The H_2S in the biogas is removed in a pre-treatment (gas conditioning) step based on absorption in an activated carbon filter and is measured with an Infra red analyser. Through adequate monitoring, and timely changing of the absorption media in the AC-filters, the H_2S content in the biomethane can be easily kept below its limit value (< 5 ppm).

The membrane system displays a special feature when it comes to water removal. After removing the bulk of the water through condensation (cooling and compression), the membranes themselves facilitate additional separation of H_2O up to a dewpoint of ±-80°C.

Consequently, the required dewpoint of the product gas is obtained without the need for further drying(equipment).

Methane slip

One of the crucial points of biogas upgrading is the methane emission (often called methane slip). Methane is a 23 times stronger greenhouse gas than CO_2. Consequently, if methane slip is higher than 2%, it can reverse the positive environmental effect of a biomethane installation (Wellinger, 2009). Compared to technologies such as water scrubbing and pressure swing adsorption, the high selective membrane technology has a significant lower methane slip. In addition to providing an environmental technical benefit, this means that less methane is lost, and therefore, more product gas is made. Each percent of methane slip at Poundbury represents a value of roughly £16.000. During last year operation it was shown that the CH_4 content in the vent line is controlled at an average (low) value of ±0,3%.

Energy consumption

The energy consumption of the upgrading installation is depending on many variables, such as the raw gas quality, product gas & off gas requirements, loading rate and status of the membranes. For example, if an installation is operated at only a fraction of the design capacity the upgraded gas will be of high quality, this results in a high methane loss at the first separation step, which needs to be compensated with an increased recyle to recovery the methane. Consequently, the energy consumption of the upgrading system is increased. The energy consumption of the Poundbury installation has been tested under multiple conditions. Figure 5 shows the energy consumption at various levels of CO_2 removal (X-axe displays the CO_2 concent in the product gas). On average, the energy consumption of the installation varies between the range 0.22-0.25KWh/Nm^3. The red circle indicates the range in which the installation is normally operating. Under normal conditions (1,5-1,8% CO_2 concentration in the product gas), energy consumption will be within the range 0,22-0,24 KWh/Nm^3.

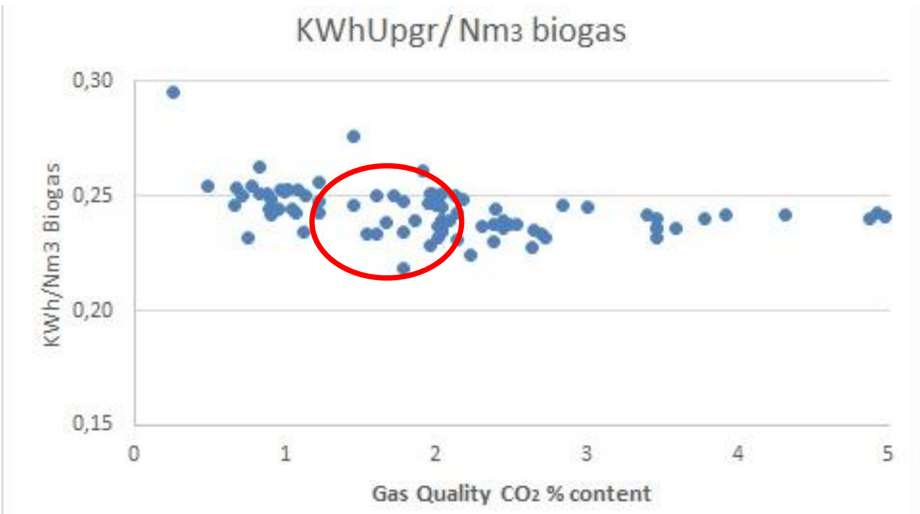

Figure 5 Energy consumption versus CO_2 content in product gas

Time to grid

When the biogas upgrading installation is starting up from a complete standstill situation, the gas quality will be automatically controlled on specification within two to five minutes. During this time the pressure and flow (which can be ramped up and down to practically any flow required within minutes) are set at the required values and the CO_2 and CH_4 content is brought within range. Injection of Propane (CV control) is started as soon as the gas is on specification. After 3-4 on spec measurements (9-12 minutes analysing time) the NEF unit opens up the grid. The total time required (at a normal start-up) is consequently approximately 20 minutes, and is displayed in Figure 6. Due to this short time to grid, the biogas upgrading unit can be operated in a very flexible way.

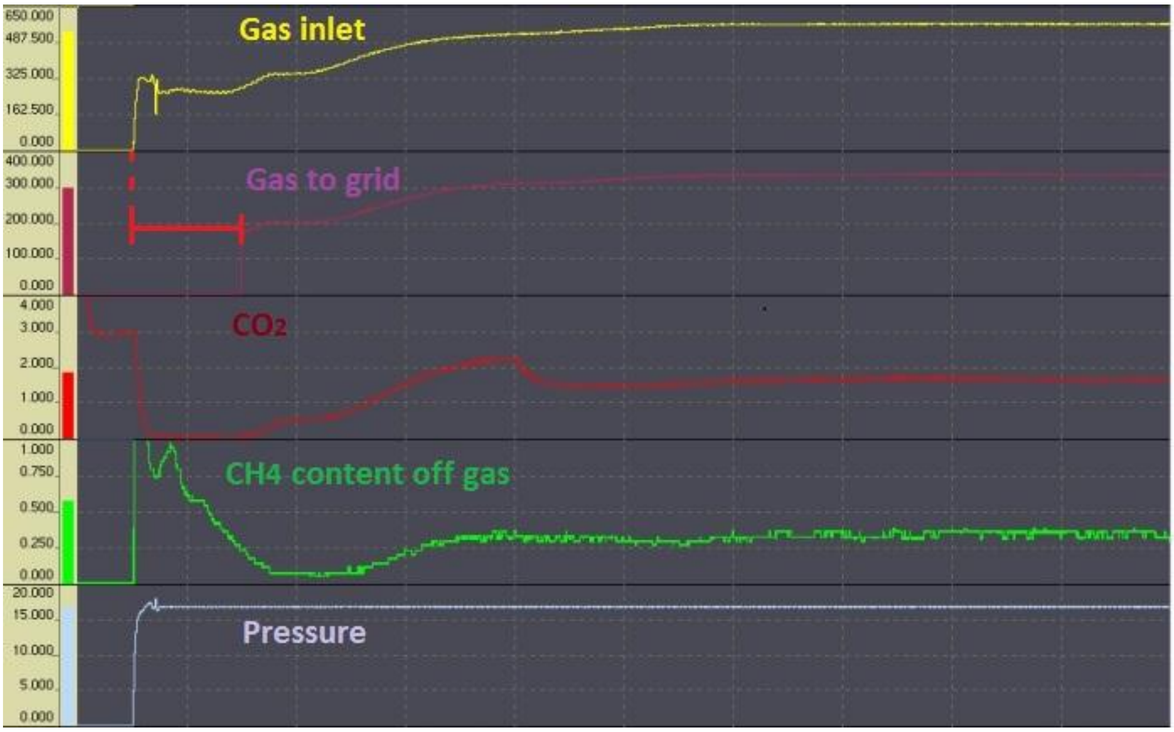

Figure 6 Impression of time to grid of a Carborex® MS system

Expected membrane lifespan

Based on the operational data from Poundbury, and our current knowledge of the degradation speed of high selective membranes, our best indication with respect to the membrane lifespan is a period of approximately 6-7 years.

Increasing market share for membrane plants

When it comes to economics, energy efficiency, methane loss, flexibility and reliability/up-time, the Carborex® MS is the best available technology on the market for small scale biogas upgrading. The trend from old-fashioned upgrading techniques such as PSA and water scrubbing towards membrane based systems can also be seen in the number of operational biogas upgrading plants within the market, which is displayed in Figure 7. For the period 2013-2014, DMT expects that approximately 30-40% of all new projects will be based on membrane technology. Even higher percentages might be obtained for installation with a capacity of less than 1000Nm^3/h. With the first plants for 1.000-2.000 Nm^3 per hour in production, the future looks green and prosperous for high selective membrane based upgrading.

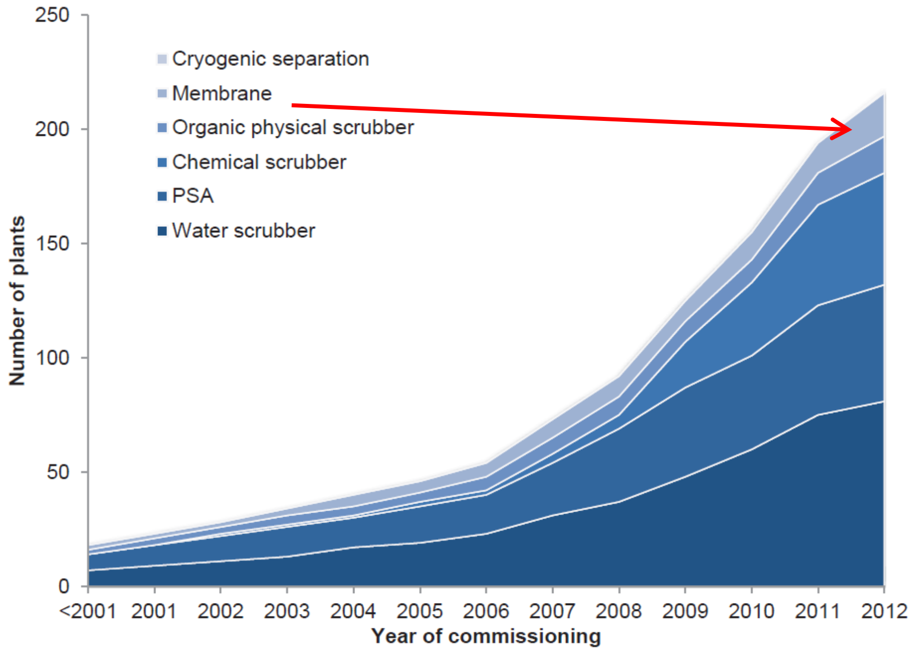

Figure 7 Visualisation of technology used in biogas upgrading plants. Only plants that are in operation today are included. Data from Bauer et al., 2013.

Conclusions

Since the opening of the biogas upgrading installation at Poundbury in October 2012, more than 2.500.000 Nm^3 of biomethane has been injected into the gas grid (±214000 Nm^3 per month).

By efficient and safe removal of carbon dioxide, water vapour, hydrogen sulphide and other trace pollutants, a high quality of upgraded gas is provided (±98.45% CH_4 and ±,1,55% $CO)_2$. Due to this high quality of upgraded gas, on average, only 3,3% of propane addition was required, thereby facilitating significant savings on propanisation.

With its excellent control on CO_2 and accurate propane dosing, the gas quality was easily kept within its boundary limits (±0.05 MJ/m^3 deviation on setpoint CV). This contributed greatly to the achievement of 97.8% uptime within the first year of operation.

With an energy consumption between 0.22-0.25 kWh per Nm^3 biogas (at normal condition), a methane slip of approximately 0.3-0.5% (facilitating high methane recovery and low environmental impact), robust design (little hardware, no additional drying or polishing steps etc.), flexibility to operate at almost any gas flow, ease and speed of control, and short time to grid (<20 minutes), the Carborex® MS demonstrates to be an outstanding installation for upgrading of biogas, which can significantly contribute to the realization of a greener future.

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