SEVENTH FRAMEWORK PROGRAMME
THEME ENERGY.2009.3.2.2

Biowaste as feedstock for 2nd generation

VALORGAS

Project acronym: **VALORGAS**
Project full title: **Valorisation of food waste to biogas**
Grant agreement no.: 241334

D5.3 - Case and feasibility studies of small-scale upgrading in Europe and India

Due date of deliverable: Month 28
Actual submission date: Month 28

Project start date: 01/03/2010 Duration: 42 months

Lead contractor for this deliverable

Jyväskylän Yliopisto (JyU)
University of Jyväskylä

Revision [0]

D5.3: Case and feasibility studies of small-scale upgrading in Europe and India

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Table of Contents

1 Introduction 4
2 Case and feasibility studies of small-scale biogas upgrading in Europe 4
2.1 Case study 1: Kalmari farm, Finland 4
2.2 Case Study 2: Zalaegerszeg, Hungary, Okoprotec 7
2.3 Case study 3: BioSling, Sweden 8
2.4 Case study 4: Bruck an der Leitha, Austria 10
2.5 Case study 5: Plucking, Austria 13
2.6 Case study 6: Schwaighofen biogas plant, Austria 13
2.7 Case study 7: Eugendorf/Salzburg plant, Austria 14
2.8 Case study 8: St. Margarethen am Moos plant, Austria 14
2.9 Case study 9: Plönninge biogas plant, Sweden 14
3 Economics of small-scale upgrading units in Europe 16
3.1 MT Biomethan GmbH, Germany 16
3.1.1 Economics of biogas upgrading 18
3.2 Motala Biogas upgrading unit, Motala, Sweden 19
4 Case and feasibility studies of small-scale upgrading in India 22
4.1 Biogas upgrading and bottling system developed at IIT Delhi 22
4.1.1 Economics of the biogas upgrading system developed by IIT Delhi 22
4.2 Rajasthan Go Seva Sangh Plant, Jaipur (Pilot scale plant) 23
4.3 Madhav Govigyan Anusandhan Sansthan, Nogaon, Bhilwara (Pilot-plant) 25
4.4 Biogas upgrading and bottling plant at Nasik, Maharashtra (1st Technolology demonstration plant) 26
4.5 Biogas Upgrading and Bottling Plant at Abhohar, Mukatsar, Punjab 27
5 Economics of a small-scale upgrading unit in India 29
5.1 Biogas production, purification & bottling and slurry utilisation system 29
References 30

D5.3: Case and feasibility studies of small-scale upgrading in Europe and India

1 Introduction

This report presents case and feasibility studies of small-scale biogas upgrading plants (<50 m^3 $hour^{-1}$) in Europe and India. As mentioned in D5.1, there are only 13 small-scale upgrading units in Europe (IEA Bioenergy 2012). Most of these units are located in Sweden, Austria and Switzerland. Each case study includes the technology of biogas upgrading, utilisation of the biomethane and the costs of biogas upgrading wherever applicable. In addition, economic data for a couple of small to medium biogas upgrading units are also included as a reference. In India, upgrading of biogas to biomethane has been very limited and confined mostly to pilot-scale and demonstration projects. Some of work projects involved and carried out at the Indian Institute of Technology are presented in this report. WP5 project partners have collected and/or shared the information from the their own data, literature as well as primary data through interviews and/or questionnaires.

2 Case and feasibility studies of small-scale biogas upgrading in Europe

2.1 Case study 1: Kalmari farm, Finland

(Source: Jussi Läntelä, Metener Ltd, Finland)

The small-scale biogas upgrading unit of one project partner and SME Metener Ltd at Kalmari farm in Finland is presented in Figure 1. This plant uses patented high pressure water scrubbing upgrading technology. The main difference with respect to traditional water scrubbing technology is the utilisation of high pressure water in batch absorption columns. During the compression or filling phase, raw biogas is compressed to buffer storage where it flows to fill the upgrading column. Once the column is completely filled, the gas flow is cut off and the column is filled with water by a high pressure water pump. Carbon dioxide and sulphurous compounds are absorbed into the water and simultaneously the gas is pressurised to ~150 bar. After the scrubbing cycle, washwater is recycled to the process after a regeneration step. Regeneration takes place in a flash tank and water regeneration tanks. Upon regeneration, the column is filled with raw biogas and cycle begins again. Two parallel columns operate in different phases, one filling (compression) and other emptying (regeneration). Product gas is collected in a pressure vessel and dehumidified by absorbent. The dehumidified product gas is ready to be stored in intermediate pressure bottle banks or boosted by hydraulic compressor to the high pressure bottle banks of the refuelling station.

The upgraded product gas is H-level biomethane with energy content 36-50 MJ kg^{-1} and 30-40 MJ Nm^{-3}. The Wobbe index is 45.6-54.7 MJ Nm^{-3}. During normal operation, the upgrading unit produces a product gas with 92-99% CH_4 depending on the raw gas quality. Product gas contains 1-5% CO_2, <2% inert gases and <1 ppmv H_2S. The upgraded product gas is dehumidified before entering the high pressure gas storage system (250-270 bar). Gas is dried using silica gel or alumina. The product gas after upgrading is completely odorless, and for safety it is odorised to allow leak detection.

a) Upgrading unit fitted into a container

b) View inside the container

c) High pressure columns with high pressure gas bottles in the background

d) Filling station

Figure 1. High pressure water scrubbing upgrading unit at Kalmari Farm, Finland (Source: Jussi Läntelä, Metener Ltd, Finland)

The advantages of the technology are simplicity, gained by combining the scrubbing and pressurisation phases, and the compact size of the plant. The technology is most suitable in the range of 30-100 Nm^3 $hour^{-1}$ raw biogas. Units are easily fitted and delivered in a container. The upgrading system is controlled completely by automated and touch screen computer system. The size of the upgrading system is well suited for farm as well as for small community. Raw gas intake can be selected from 30 to 100 Nm^3 $hour^{-1}$. In other words, the gas production is between 1000-4000 MWh $year^{-1}$. In 2011, a new card vehicle filling station with high pressure gas tanks (300 Nm^3, 270 bar) was installed. The card vehicle filling station replaced the old filling station which had too small capacity gas storage to meet increased demand. The gas demand at Kalmari's farm filling station has doubled each year. Currently, around 100 vehicles including two delivery lorries and one taxi use the upgraded biomethane as vehicle fuel.

Economics of upgrading. A breakdown of the upgrading costs is given in Table 1. The total cost of upgrading is estimated to be around € 0.32 kg^{-1} biomethane. Electricity and water consumption are the main components and account for 87% of the total upgrading cost. Other costs include maintenance and spare parts and are estimated to be around € 0.04 kg^{-1} biomethane. The average selling price of biomethane is estimated to be around € 1.2 kg^{-1} which is equivalent to around € 0.8 l^{-1} of petrol.

Table 1. Cost of upgrading at Kalmari farm, Finland (Source: Metener Ltd)

Parameter	Cost (€, euros)
Electricity consumption (kWh kg^{-1})	1.30
Price of electricity (€ kWh^{-1})	0.11
Electricity cost (€ kg^{-1} biomethane)	**0.14**
Water consumption (m^3 kg^{-1})	0.035
Prize of water (m^3)	3.90
Water cost (€ kg^{-1} biomethane)	**0.14**
Maintenance costs (€ kg^{-1} biomethane)	0.04
Total cost (€ kg^{-1} biomethane)	**0.32**

Note: Prices of electricity and water are based on average prices in central Finland.

Average electricity consumption of the upgrading unit is approximately 0.5-0.6 kWh Nm^{-3} of raw biogas and 1.2-1.4 kWh kg^{-1} of upgraded and pressurised product gas at 250 bar including the electricity needs of the filling station. Electricity consumption for upgrading is mainly affected by the raw biogas quality. If the CH_4 content in the raw gas is high, the energy required for CO_2 scrubbing is less. In a cold climate, the electricity consumption is lower due to reduced cooling needs. Heating is only needed if the upgrading system is not used and the weather is cold. Normally waste heat from the upgrading process is sufficient to keep the process temperature at suitable level (15-20 ^oC). It is worthwhile to consider using biogas to produce electricity for the upgrading process if there is surplus onsite biogas production: this will reduce the carbon footprint of the upgrading process.

Average water consumption of the upgrading unit is between 6-25 l Nm^{-3} of raw biogas and 15-60 l kg^{-1} of biomethane. Most of the process water is regenerated by a gas desorption unit and recycled back to the process. It is usually necessary to replace 5-20% of the process water flow to keep the pH of the water at an acceptable level. It is important to note that water recycling makes up a significant part of the upgrading costs and considerable savings can be achieved if washwater is recycled. Surface water sources can be used for upgrading when available which can also provide significant savings.

2.2 Case Study 2: Zalaegerszeg, Hungary, Okoprotec

(Source: http://www.okoprotec.hu/termekek)

The first biogas upgrading plant in Hungary was built at the wastewater treatment plant (WWTP) in Zalagearszeg by DMT environmental technology, Netherlands. This upgrading unit is a small-scale plant able to treat 50-100 Nm^3 $hour^{-1}$ of raw biogas coming from two anaerobic sludge digesters, and is used to optimise the energy utilisation of the WWTP.

The plant is designed first to desulphurise and dry the gas (Figure 2). After this preconditioning, the gas can be used directly in the local combined heat and power (CHP) plant to produce heat for the digester and electricity for the WWTP. The gas can also be upgraded to any desired methane quality. The upgrading results in high-quality gas at 9 bar, which can be injected in the gas grid, used for the CHP, or further compressed to be used as vehicle fuel. A small storage operating at 220 bar and a dispenser to facilitate direct fuelling of the company's car fleet are also available. Due to the flexibility of the system it is possible for the WWTP to utilise the biogas at its full potential and optimise the energy demand and supply in an economical and sustainable way for the complete WWTP (Figure 2).

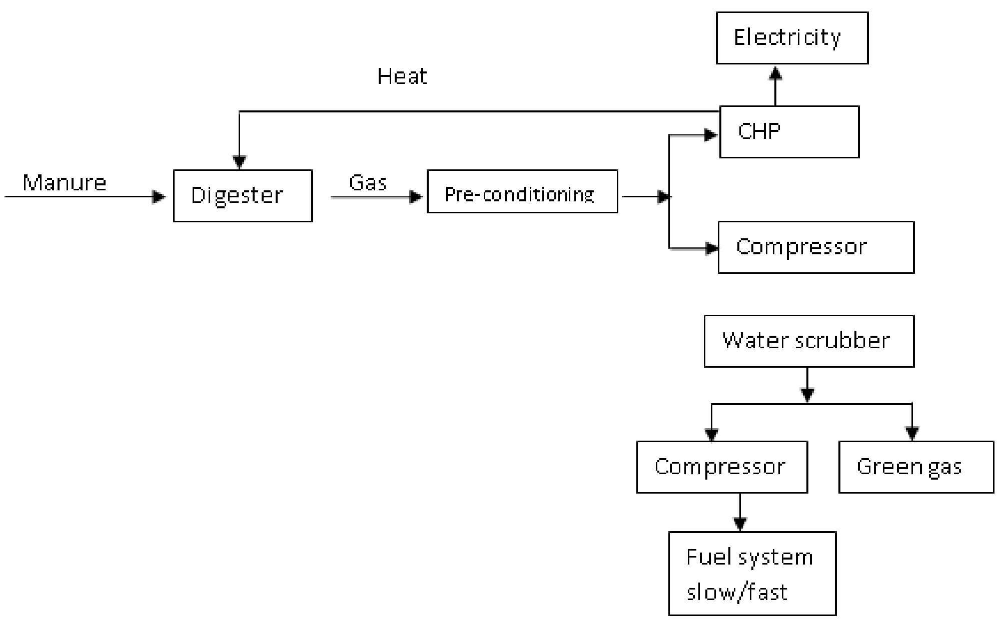

Figure 2. Process scheme biogas utilisation at Zalaergerzeg WWTP, Hungary (Courtesy, DMT Environmental Technology, The Netherlands)

The main advantage of this technology is the high flexibility combined with a simple process that can quickly adapt the gas quality to the specifications demanded. Within 20 minutes from the initial start of upgrading, it takes just a few seconds before the product gas has over 97% CH_4 concentration. Therefore, switching between CHP and upgrading and *vice versa* takes only a few minutes. In this way, the system has proven to be very reliable and robust (Haren, 2010). Preliminary results also showed that methane concentrations over 99.5% can easily be obtained. The energy efficiency of the installation is about 0.40 kWh Nm^{-3} biomethane including compression to 220 bars. Although this is slightly higher than for large-scale units, it is low given the operating conditions and flexibility. This energy consumption is achieved under the worst case conditions of a low flow rate, high outside temperature (and thus very intense system cooling) and with an on/off operated system running for a few hours every day.

Return on investment (ROI) is achieved at about 10,400 car fillings based on current diesel prices (year 2010). With 10 cars fuelling per day (as in 2010 data), the ROI is about 3 years. The maximum capacity for fuelling (at 24/7) would be about 70 cars, making it highly economically profitable.

Because of the small-scale nature of the installation, some components of the plant were simplified compared to large-scale systems. For instance, both the desulphurisation and the final drying of the gas are based on non-regenerative absorption technology. As the gas is mainly used locally, monitoring and control is simplified and the exact gas quality for fuel use is set at 96% or higher instead of controlling at 97±1%. In addition, the gas quality is controlled by an IR-analyzer instead of a gas chromatograph (GC). The plant is built in standard sea-containers, and is therefore easy to install (plug & play) – an essential feature for small-scale plant. To further optimise this idea of cheap but highly flexible units, DMT has recently been developing a small-scale system which uses membranes to separate the CO_2 from biogas.

2.3 Case study 3: BioSling, Sweden

Source: http://www.articnova.se/biosling_e.html

Artic Nova developed and manufactured a small-scale upgrade facility on behalf of BioSling AB, Sweden. BioSling is a unique design that allows small-scale biogas producers with cattle or energy crops to upgrade raw biogas for use as high-quality vehicle fuel or for gas grid injection in a cost-efficient way comparable to or even better than upgrading systems used with larger biogas operations. This technology also allows scaling of the biogas upgrading system in capital and operating costs, so that farms with as few as ~75 milk cows or up to about 900 cows can upgrade gas in an economically viable way for use as vehicle fuel or for gas grid injection. The BioSling system upgrading capacity provides up to 600 Nm^3 of vehicle-quality gas (97% methane) per day or the equivalent of about 650 litres of petrol per day.

The BioSling upgrading process consists of several steps (Figure 3). The rotating spirals or coils of hoses form the main components responsible for CO_2 scrubbing (Figure 4). The upgrading process starts with feeding biogas and water alternately into the outermost turn of the coil at a pressure of 2 bar. In the rotating coils, water and gas come into close contact with each other and thus the CO_2 is absorbed by water and scrubbed in proportion to exerted pressure. As the coil rotates, the water columns are forced inward and compress the gas between them. Gas compression results in absorption of the CO_2. By the end of each cycle, when the water and gas leave the rotating coil centre, most of the CO_2 is absorbed by the water and the methane content of the biogas has increased to 94%. Because of its low solubility, only a small amount of methane is dissolved in the water. The coil pump is turned slowly so that water and gas flow gently through the hoses. As the rotating coils replace pumps, compressors and gas-water mixers, mechanical maintenance is minimised when compared to traditional water scrubbing technology.

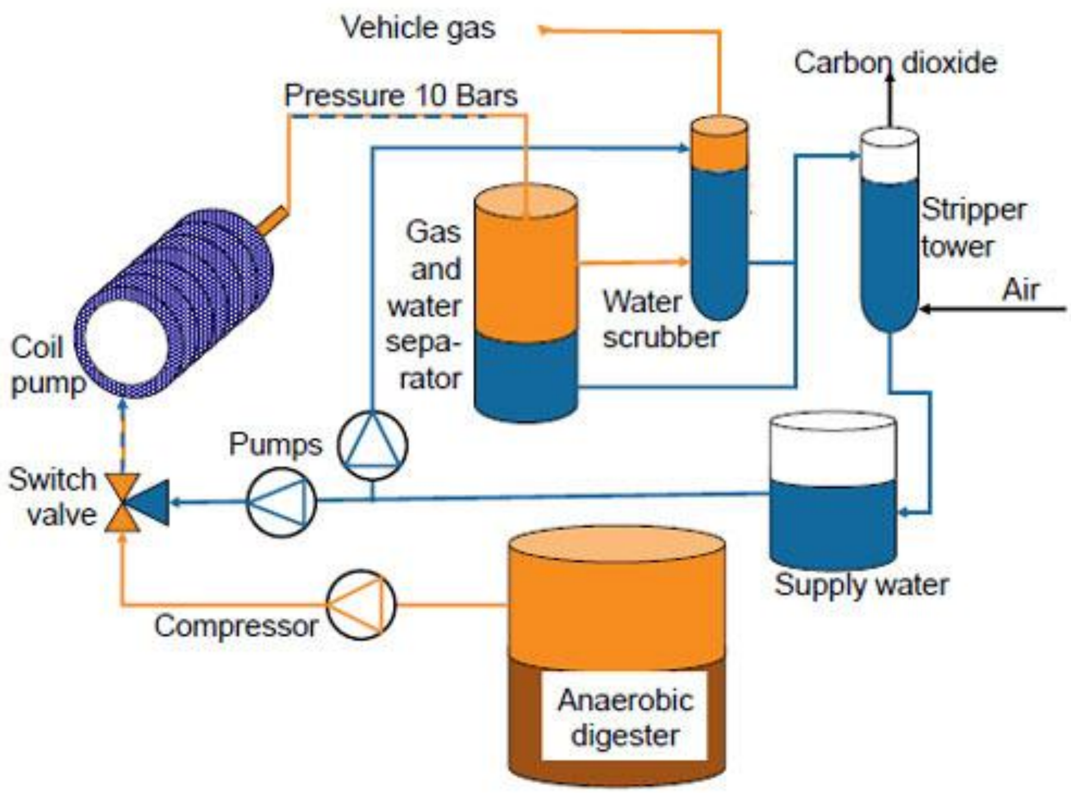

Figure 3. BioSling process flow diagram (Courtesy: Artic Nova, Sweden).

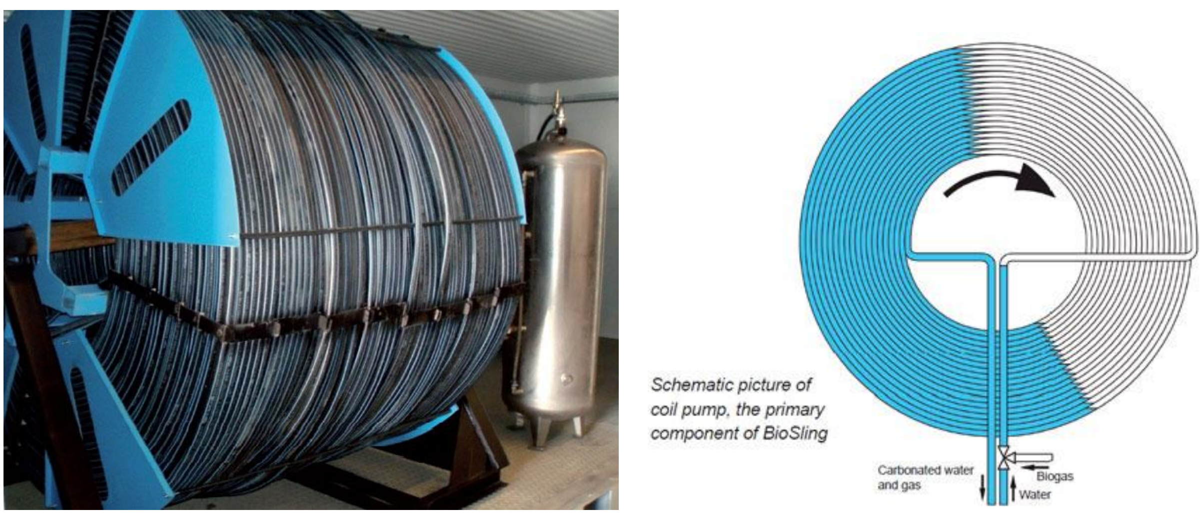

Figure 4. Biosling system. Coils of plastic hoses constitute the main component. The photo shows eight coils working in parallel. The vessel shown in the background accumulates the upgraded gas and separates it from water saturated by carbon dioxide (Courtesy: Artic Nova, Sweden).

The investment costs for the BioSling process are presented in Table 2. The cost of plant depends on the size and the complexity, interest rates and time of loan repayment. In some European countries, governmental subsidies are available to help farmers to invest in green technologies.

Table 2. Cost of investment of BioSling process (Courtsey: Arctinova, Sweden)

Number of coils	4	8	12	15	20
Daily yield of vehicle gas (Nm^3 at 9 bar pressure)	259	518	777	972	1296
Daily value of gas € (0.8 € /1.15)	180	360	540	676	900
Yearly value of gas €, (0.8 € /1.15)	65700	131400	197100	246900	328500
Corresponding amount of oil yearly (m^3)	82	164	246	308	410
Suitable to farms with number of cows	200	400	600	800	1000
Capacity of raw gas (Nm^3 $hour^{-1}$)	14.6	29.2	43.8	54.7	73.1
Yield of vehicle gas (Nm^3 $hour^{-1}$)	10.8	21.6	32.4	40.5	54.1
Corresponding amount of oil (l $hour^{-1}$)	9.4	18.8	28.2	35.2	47.0
Electric power consumption (0.32 kWh Nm^{-3})	3.45 kW	6.9 kW	10.4 kW	12.9 kW	17.2 kW

Estimation of income, based on 0.8 € l^{-1} of oil, which equals 1.15 Nm^3 vehicle gas

2.4 Case study 4: Bruck an der Leitha, Austria

Source: DENA, 2010; Virtual Biogas Project, www.virtuellesbiogas.at

The biogas plant in Bruck an der Leitha, 40 km to the east of Vienna, started operation in 2004. Biogas production is based on the combined fermentation of grass and maize together with residues from the food industry. In 2007 the Energy Park Bruck an der Leitha, the Technical University of Vienna and the plant manufacturer Axiom GmbH jointly undertook the re-development of this plant to upgrade the raw gas to natural gas quality using an innovative membrane technology. The upgrading plant has been designed to produce a biomethane volume flow of 100 Nm^3 $hour^{-1}$, corresponding to approximately 180 Nm^3 $hour^{-1}$ of raw biogas. The produced biomethane meets the applicable Austrian laws for grid injection and vehicle fuel standards (“Österreichische Vereinigung für das Gas- und Wasserfach" ÖVGW G31 (Erdgas in Österreich - Gasbeschaffenheit) and G33 (Regenerative Gase - Biogas). Therefore, the produced biomethane is a fully-fledged natural gas substitute and it is allowed to inject this gas into the public natural gas grid. The upgraded biogas is fed into the EVN grid and is transferred to the gas station operator OMV and Vienna Energy to be used as biofuel. Parallel to this grid injection two CHP-gas engines (830 kWel each) are operated at the biogas plant in Bruck an der Leitha producing electric power and district heat.

The biogas upgrading process consists of a two-stage membrane upgrading technology (Figure 5). The raw biogas is mixed with the permeate flow of the second membrane stage (recycle) and conjointly compressed and dried by cooling to gas temperatures of lower than 7 °C. Subsequently, the gas is reheated (using a part of the waste heat from the compressor) to the optimum temperature for the successive process steps. After a final desulphurisation by adsorption, the gas is transported to the two-stage gas permeation for final upgrading. The two-stage layout was implemented to ensure minimisation of the methane-slip of the upgrading plant.

Permeate of the second membrane stage (with significantly higher methane content compared to permeate of the first membrane stage) is recycled and recompressed. The permeate flow of the first membrane stage acts as a sink for CO_2 and leaves the upgrading plant as off-gas. As with any other separation technique, it is not possible to transfer all of the methane contained in the raw biogas to the product gas flow. A certain part of the methane is also separated from the product gas and ends up in the CO_2-rich off-gas, giving this gas stream a low methane content (usually 2 to 3% of the produced biomethane flow). In order to achieve a zero-emission-operation regarding methane, the off-gas flow is not released to the atmosphere but is transported to the existing gas engines (CHPs). Thus, the remaining chemical energy content of this gas flow is used to produce heat and power.

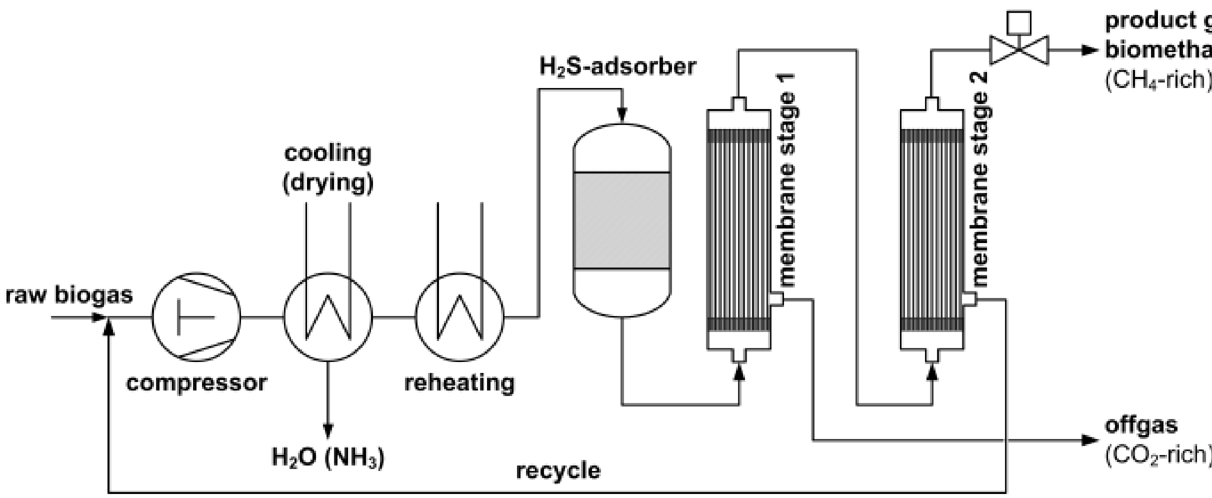

Figure 5. Flow sheet of the biogas upgrading plant applying gas permeation in Bruck an der Leitha (Source: Virtual Biogas Project, www.virtuellesbiogas.at)

The methane content of the product gas flow is controlled using a proportional valve in the piping of the second-stage retentate. This control strategy allows for a wide range of methane content in the product gas (from almost raw biogas composition with 70% methane up to 99% methane or more). During standard operation in Bruck an der Leitha, the methane content of the product gas is adjusted to 98% and the CO_2 content is adjusted to 1.8%. Oxygen, nitrogen, hydrogen sulphide, ammonia and humidity are also reduced to values well below the legal limits. The volume flow of the produced biomethane is controlled via an enhanced PID-controller affecting the frequency converter (and therefore the rotational speed) of the piston compressor.

Gas drying is done in two different steps in this upgrading plant. Firstly, the major amount of water is condensed and discharged by cooling the gas to temperatures below 7 °C. Secondly, the final drying of the gas is accomplished with membrane separation, because of the high drying-potential of the applied polyimide membranes. As a result, the product gas reaches extremely low pressure dew points, significantly lower than prescribed by law.

Another important upgrading step at the site Bruck an der Leitha is the separation of H_2S. A three-step desulphurisation process is currently employed. The first step involves in situ desulphurisation by addition of chemicals (liquid mixtures of various metal salts) directly into the digester. This results in a reduction of H_2S and ammonia by chemical bonding as well as improving the environmental conditions for the microorganisms involved, thus reducing the generation of these toxic substances and increasing the methane yield. The produced raw biogas at the exit of the gas storage tanks typically contains between 100 and 150 ppmv of H_2S (without dosing up to 3000 ppmv is possible). The second step involves biological desulphurisation by application of the chemoautotrophic bacteria thiobacillus in the form of a immobilised slime mould within a packed column. These microorganisms oxidise H_2S with molecular oxygen and convert the unwanted gas compound to water and elemental sulphur or sulphurous acid which is discharged together with the column's wastewater stream. At the end of this step, the gas usually contains up to 50 ppmv of H_2S. The third step of desulphurisation is the final adsorptive desulphurisation using iron-oxide pellets, usually reducing the H_2S content to values of lower than 1 ppmv.

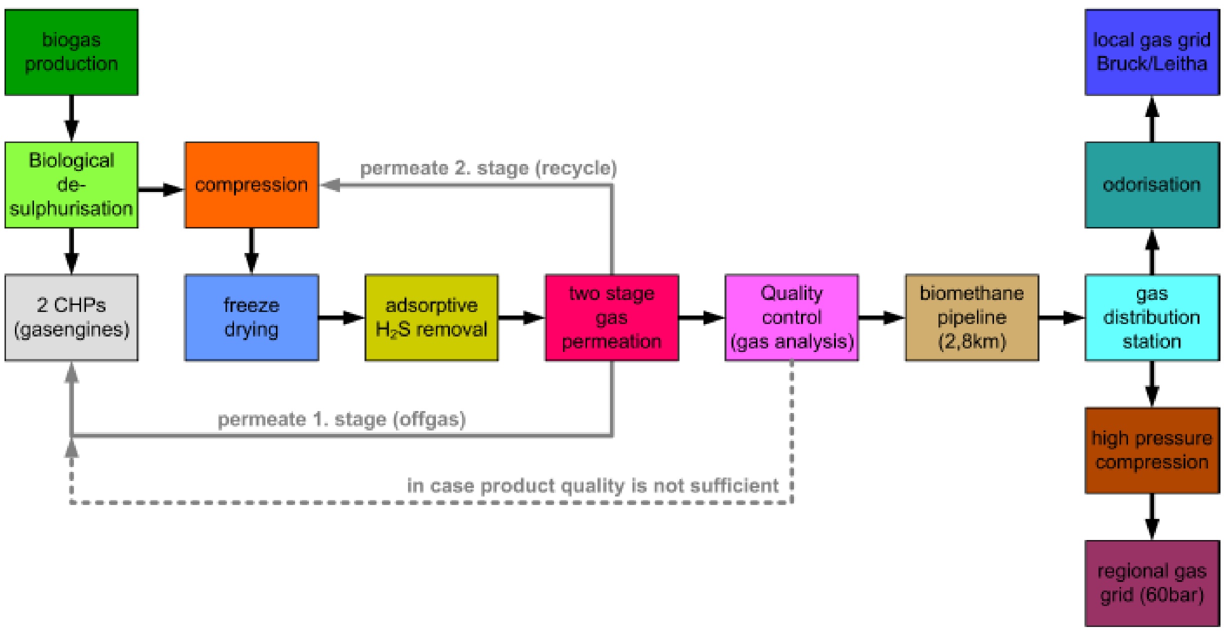

Figure 6. Process integration of the biogas upgrading plant Bruck an der Leitha (Source: Virtual Biogas Project, www.virtuellesbiogas.at)

The produced biomethane is transported to the gas distribution station via a 2.8 km pipeline (Figure 6). Depending upon the gas quality (complying with the Austrian standards), the biomethane is injected into grid or used for electricity generation in the gas engines of the biogas plant. The supplied biomethane is transported via the local natural gas grid at up to 3 bar to the nearby city of Bruck an der Leitha (population about 7600). The total produced biomethane is consumed in the city during the winter months; additional fossil natural gas is needed to supply the city to 100%. During the summer months the local consumption of Bruck an der Leitha is significantly lower than the produced biomethane; therefore, the surplus biomethane is compressed to 60 bar and fed to the regional gas grid (grid level 2). As a result constant operation of the biogas upgrading plant over the whole year is possible, ensuring optimum plant utilisation and cost structure.

2.5 Case study 5: Plucking, Austria

(Source: Baumgartner et al., 2010; IEA Bioenergy, 2011)

Austria's first biogas upgrading plant was built in Upper Austria in June 2005. The biogas pilot feeding plant was built at an existing biogas plant of the Linsbod family in Pucking. This plant is operated by Erdgas OÖ (http://erdgasooe.ooegw.at) and OÖ Ferngas AG (http://www.ooeferngas.at). The biogas is upgraded to natural gas quality and is injected into the existing natural gas grid. An existing biogas plant that used biogas for generation of electricity serves as a gas production plant.

The upgrading plant capacity is 10 Nm^3 $hour^{-1}$ of raw gas. The technology applied is pressure swing adsorption (PSA). The substrate consists of a mixture of manure from 10,500 hens and 50 breeding pigs. This substrate yields a raw biogas production of about 10 Nm^3 $hour^{-1}$, which was previously used in a combined heat and power plant.

The plant produces about 6 Nm^3 $hour^{-1}$ of biomethane. This is an annual energy production of 400,000 kWh, equivalent to the average annual requirement of 40 household apartments. This represents a CO_2 reduction of 108 000 kg $year^{-1}$ when compared to commonly-used oil heating. The refined biogas fulfils the quality requirements of the ÖVGW directive G31. Refined biogas can also be used as vehicle fuel or for cogeneration (for example stationary fuel cells), and is not dependent on the location of gas injection.

The biogas to be refined is taken out of the pipeline via a valve between the biogas plant (including the storage tank) and the CHP unit. During the first gas quality check, raw biogas is analysed for various components. In the desulphurisation stage, H_2S is converted to sulphate by a biological process. The system is designed to reduce the concentration of H_2S in the raw biogas from 2000 ppmv down to a maximum of 200 ppmv. During the second quality check, the biogas is analysed again and enters the CO_2 separation and drying stage, based on pressure-swing adsorption. When entering the system, the biogas is completely purified from any remaining H_2S by activated carbon. CO_2 is removed by an adsorption material (activated carbon, molecular sieves). Methane, which has less affinity to the adsorbent, leaves the plant at a concentration of 97%. After desulphurisation, CO_2 separation and drying, the biomethane is injected into the OÖ Ferngas AG gas grid via a transfer station.

From 100% energy, 81% is sold to the gas grid, 9% is used to cover the electricity demand for biogas and upgrading plant, and the remaining 10% is used to cover the heat demand of the biogas plant.

2.6 Case study 6: Schwaighofen biogas plant, Austria

(Source: Baumgartner et al., 2010)

The biogas upgrading plant in Schwaighofen was established in 2008. The main substrate used for biogas production is grass. The upgrading plant capacity is 18 Nm^3 $hour^{-1}$ of raw gas and the upgraded biogas is fed into the natural gas distribution network and offered for sale at separate gas stations as "Bio-natural-gas". CNG cars can be refilled using the biogas from the gas station. The biogas produced from one hectare of grass is sufficient to drive 40,000 km (once around the globe).

2.7 Case study 7: Eugendorf/Salzburg plant, Austria

(Source: Baumgartner et al., 2010)

In 2007, two biogas projects have been realised in Eugendorf (Salzburg) and Margarethen am Moos (Lower Austria). In contrast to the previous examples, these involve direct use of the upgraded biogas at a biogas filling station installed at the biogas plants.

The upgrading plant in Eugendorf has been in operation since 2008. Biogas is produced from energy crops and upgraded to biomethane. The upgrading plant capacity is 22 Nm^3 $hour^{-1}$ of raw gas. The produced biomethane is used for feed-in into the gas grid and also as vehicle fuel. The technology applied is PSA.

2.8 Case study 8: St. Margarethen am Moos plant, Austria

(Source: Baumgartner et al., 2010)

The biogas plant at Margarethan am Moss began operation in 2007. The substrates used for gas production are energy crops and manure. This was the first upgrading unit located near Vienna, Austria. A biogas processing train and a biogenic CNG filling station were added in 2008. The biogas is purified through one-step membrane technology developed in Austria. The plant capacity is 70 Nm^3 $hour^{-1}$ of raw biogas. For the first time upgraded biogas, which has the quality of natural gas, was sold at a gas station in Austria.

This project showed that in Austria biogas upgrading is realisable based on the current state of the art. Prior to use of the biogas for upgrading, the biogas plant produced electricity and heat for 120 households in the region. Since 2008, CNG vehicles can refuel at the biogas station with upgraded biogas under the brand name of "methaPUR". The production output is about 25 kg $hour^{-1}$. The produced biomethane is stored in a high pressure (300 bar) accumulator with a capacity of 140 kg (25 kg of biomethane equates to a tank full with an operating distance of ~500 kilometres). A second accumulator is planned.

2.9 Case study 9: Plönninge biogas plant, Sweden

(Source: Bioprocess Control Sweden AB, 2011)

The Plönninge biogas plant was constructed in 2004 at Plönninge Agricultural High School, and serves as a demonstration and research site. It was constructed by Läckeby Water AB, Sweden and is operated in collaboration with the Region of Halland and Bioenergicentrum Halland.

The aim of the project was to promote regional development in renewable energy, and especially to promote small-scale biogas production in agricultural enterprises. The plant also serves as a demonstration plant for future farm-based biogas plants in the region and around the world.

The feedstocks for the biogas plant are remnant silage and cow manure from farms and other available waste products in the area. The volume of the digester is 300 m^3 with an expected gas production of 250-300 Nm^3 day^{-1}. The average retention time of the digester is around 30 days, depending on the availability of manure. Manure from around 80 cows is collected in a manure tank, which is then pumped into a larger mixing tank. This is further mixed in the same tank with more solid substrates (e.g. silage or potatoes). Iron chloride is also added to reduce the amount of H_2S in the produced biogas, by precipitation of FeS from sulphur-containing compounds. The mixed material is then pumped into a buffer tank where it spends around one day before it is fed into the digester. The digester is top mixed with two sets of impellers, and is kept at an average temperature of 37 ºC. As the material is fed into the digester, digested slurry or digestate is removed into two serial connected storage units, where it is stored for around half a year before it is used as a fertiliser to cultivate crops at the farm.

The produced gas is consumed in three different ways using the following systems: i) in a gas burner for producing heat; ii) in a Stirling engine for producing electricity and heat; and iii) in an upgrading unit for producing biomethane as a vehicle fuel. Originally only the gas burner was installed at the plant but in order to promote the production of higher value products, the Stirling engine and the biogas upgrading unit were installed in 2008; the Stirling engine began operation in 2011.

Table 3. Cost of biogas upgrading at Plönninge biogas plant (Source: Peter Karlsson, Biogas Öst seminarium 2011-04-01)

	SEK/year	€/year
Investment loan (15 years)	167 000	19 785
Interest (6%)	75 000	8 886
Maintenance, approx (4%)	100 000	11 848
Electricity (10% average production)	42 000	
Personnel salary (0.5 h/day)	45 000	5 331
Total	430 000	50 947

The biogas upgrading plant has a raw biogas capacity of 17 Nm^3 $hour^{-1}$. Biogas is upgraded to biomethane by a water scrubbing process (Figure 7). The upgrading unit itself is estimated to cost between SEK 400,000 and 700,000 (Table 3), depending on the specifications demanded by the customer. The aim is that the finished product will enable medium to large-scale farmers to become self-sufficient in fuel production. This, however, requires that more private farmers invest in small-scale digesters on their farms. Given this development the production of biogas poses no problems. It is estimated that in southern Sweden alone biogas equivalent to 400,000 m^3 of petrol could be produced per year by digesting organic material including waste products and crops. This would provide enough fuel to run 200000 to 300000 cars.

Figure 7. Biogas upgrading unit (water scrubber) at Plönninge biogas plant, Sweden. (Source: Courtsey: BioRega, Sweden; Peter Karlsson, Biogas Öst seminarium 2011-04-01)

3 Economics of small-scale upgrading units in Europe

3.1 MT Biomethan GmbH, Germany

(Source: http://www.mt-biomethan.com)

MT-Biomethan GmbH is based in the town of Zeven in Lower Saxony, Germany. The company offers a complete range of biogas processing and feeding technology. The processing plants work according to the unpressurised amine scrubbing process (Figure 8). The biogas is refined to natural gas quality and then fed into the general natural gas grid. The processing procedure is characterised by extremely low methane losses of less than 0.1% while yielding very high methane purity levels of at least 99%.

Amine washing. A process flowchart for the amine washing gas upgrading method is presented in Figure 8.

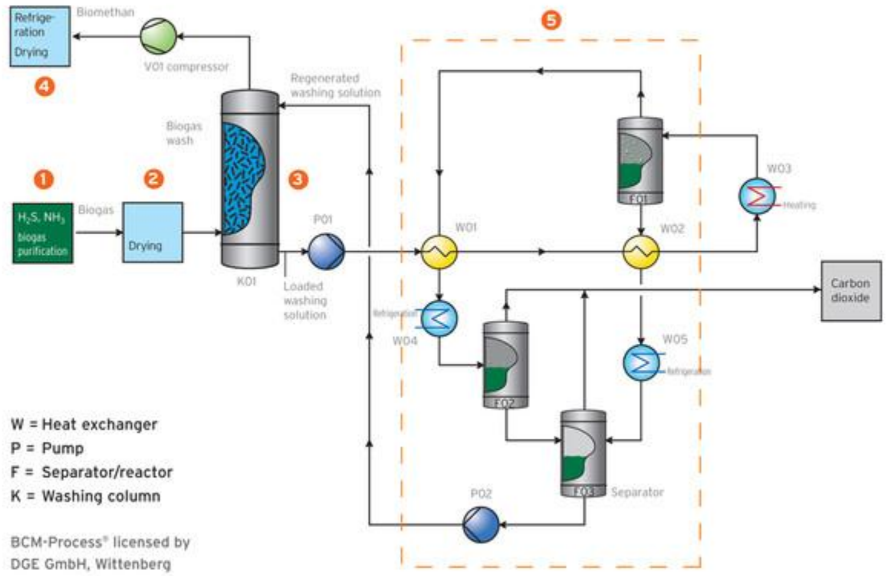

Figure 8. Flowchart of the amine washing process. BCM-Process® licensed by DGE GmbH, Wittenberg (Courtesy: www.mt-biomethan.com)

Desulphurisation. Any residual sulphur in the crude biogas needs to be removed before the actual amine wash. The biogas flows through an activated carbon filter system with a special coating; the system has a very high capacity for hydrogen sulphide, which is converted into elemental sulphur and held within the system. The spent activated carbon can be spread on the fields along with the fermentation residues from the biogas plant; thus, the separated sulphur rejoins the natural circulation.

Drying. Crude biogas saturated with water vapour is dried in this step. This process ensures that the concentrations in the amine washing solution do not change.

Non-pressurised amine wash – separating CO_2 from biogas. The non-pressurised amine washing process sends previously desulphurised and dried biogas into a washing column packed with fillings. The washing solution is an aqueous amine solution that flows from top to bottom, counter-current to the biogas flow. The washing process takes place at a temperature of 40 °C. The filling media in the column increase the surface area, ensuring more intensive exchange between the gas and liquid phases. Due to its chemical composition, the amine solution is highly effective at absorbing the carbon dioxide in the biogas. Methane, on the other hand, does not react with the washing solution, and arrives as high-purity methane for extraction at the head of the column. The selectiveness of the washing solution ensures minimal methane losses of less than 0.1%.

Biomethane cooling and drying. After washing, the biomethane needs to be cooled down and dried again. The gas is led into a heat exchanger, where steam and amine-charged steam condense onto cooling surfaces before being led back into the washing system. The biomethane is transferred from there to a feeding facility for the natural gas supply system.

Regenerating the washing solution. Used amine solution containing carbon dioxide is extracted at the bottom of the column for regeneration. The aim is to expel the carbon dioxide absorbed from the solution by heating. This step in the process completely restores the amine solution's capacity to absorb carbon dioxide, and the regenerated washing solution can be reused.

3.1.1 Economics of biogas upgrading

(Source: Mr Emanuel Bregulla, MT-Biomethan GmbH**)**

The detailed cost breakdown of upgrading using the amine washing process at MT Biomethan GmbH is presented in Table 4. As can be seen, the investment cost of a 600 Nm^3 $hour^{-1}$ raw biogas upgrading unit is approx. € 1,952,850. Of which, upgrading equipment cost is approximately € 1,226,685. In the scrubbing column, normal tap water is sprinkled and is re-circulated in the scrubbing column. Only a small amount of make-up water is used. There is a need to reduce electricity consumption in the system. The cost shown is approximate and may vary depending on the site conditions, variations in plant and machinery costs etc.

Table 4. Costs of small-scale biogas upgrading in Europe (source: MT Biomethan GmhH)

Parameter		Amount (€)
Raw biogas flow (Nm^3 $hour^{-1}$)		600
1. Capital cost (€)		
Upgrading equipment		1 226 685
H_2S scrubber, cleaning		126 155
Installation & odour		200 000
Feed compressor		200 000
Injection		200 000
Sub-total		***1 952 840***
2. Operating cost/year)		
Maintenance		53 000
Energy		61 000
H_2S scrubber		3 410
Personnel		21 500
Other		
Sub-total		***138 910***
Methane recovery (%)	99	
Input methane (%)	> 40	
Availability	>95	
Methane output (m^3 $year^{-1}$)	1 091 638	
Energy output (GJ $year^{-1}$)	12 059 593	
Loan (€)		1 464 630
Interest rate (%)	5	
Amortisation (years)	10	
Expenses	Year 1	
Principal		85 910
Interest		73 282
O & M		53 000
Total		***212 192***
Production cost (€ GJ^{-1})		0.017
Production cost € Nm^{-3} upgraded gas		0.40

3.2 Motala Biogas upgrading unit, Motala, Sweden

(Source: Motala Kommune & Svensk Biogas AB, 2011)

The biogas upgrading unit at Motala was started in 2009 at Karshults wastewater treatment plant. Biogas is produced from municipal and industrial sewage. In 2012, the collection of food waste from households in Motala is planned to start. The collected organic waste will be used as feedstock for biogas production. The digester is operated at about 35 ° C with a residence time of about one month. In 2011, 320,000 m^3 of biogas per year was produced, or enough for about 260 cars or seven urban buses. The digestate is dewatered and sanitised for at least 6 months before being transported to nearby farms and used as fertiliser.

The biogas for upgrading at Motala unit mainly comes from Karshults sewage treatment plant. Motala also receives some biogas from Swedish Biogas plant in Linköping, which produces biogas from food waste and residues from abattoirs. The gas is transported to Motala by gas trailer. At Motala, biogas is upgraded to vehicle fuel quality (97% CH_4). The upgrading unit capacity is 80 Nm^3 $hour^{-1}$ of raw biogas. High pressure water scrubbing technology is used for biogas cleaning and upgrading (Figure 9). The unit is supplied by Greenlane Biogas systems, who offer a standard range of biogas upgrading plants with unit capacity from 80 to 2500 Nm^3 $hour^{-1}$ or more with customised designs.

Figure 9. Biogas upgrading unit at Motala (unit supplied by Greenlane® Manuka - 80 Nm3 $hour^{-1}$ capacity; Source:www.flotech.com)

In 2009, 45000 m^3 of compressed natural gas was produced. In full operation, it is planned to produce 450000 m^3 of biomethane. The biomethane is distributed to the filling station through underground conduits or on a gas trailer from Motala gas station. Motala has been working to replace all of the municipality's 100 vehicles with biogas-fuelled vehicles. At year end 2010/2011, there were 89 registered biogas-powered passenger cars, 4 garbage trucks, crane truck, 7 minivans / vans (Figure 10).

In addition to municipal vehicles, there are more than 40 other companies and individuals who have fuel cards for biogas in Swedish Biogas stations in Motala. It is envisaged that by taking the advantage of the existing gas produced at the wastewater plant and upgrading it to vehicle fuel quality, Motala city can become self-sufficient in biogas. After an agreement with Östgötatrafiken (July 2011), a total of 21 biogas buses are in operation in and around Motala. Further, Östgötatrafiken has a goal to run all buses on renewable fuel by 2015. This means that the 32 buses that are stationed in Motala will be biogas buses.

Figure 10. Biogas bus (above) and municipal car (below) in Motala. (Photographer: Margaret Hagman & Roy Rudin; Source:www.motala.se)

The detailed energy consumption and operating costs of biogas upgrading at Motala unit is presented in Table 5. The total energy consumption was 80.7 kW of which compression accounts for 50% followed by water pumping and cooling. The total operating cost of an 80 Nm^3 $hour^{-1}$ upgrading unit is 54159 € $year^{-1}$. Electricity alone accounts for 99.5% of the operating costs. As water from the wastewater treatment plant is used, only a small amount of make-up water is required. To reduce the costs, however, there is need to reduce electricity consumption in the system. The cost of unit of raw biogas upgraded is approximately 22 € $year^{-1}$ and may vary depending on biogas quality etc.

Table 5. Total energy consumption and operating costs of biogas upgrading at Motala biogas upgrading unit (Information provided by Mr Sven Larsen, Project Leader, Motala biogas plant, Sweden)

Design case – Kanuka 300	
1.Installed capacity	300 $Nm^3\ hour^{-1}$
a. Inlet gas condition, 50 mbar & 30 °C	
b. ($Nm^3\ hour^{-1}$) Normal conditions are defined as 0 °C and 1.013 bar	
2.Cost	
a. Price of 1 kWh of electricity	0.08 €
b. Price of 1 m^3 of water	1.0 €
c. Price of 1 l of biodegradable oil	N/A
d. Operating hours per year	8350
3.Energy consumption	
a. Compressor power draw	40.6 kW
b. Water pump power draw	13.9 kW
c. Chiller power draw	17.9 kW
d. Chilled water recirculation pump	3 kW
e. Stripping air blower draw	3 kW
f. Drier/purifier heater – average over 24 hrs	2 kW
g. Ancillaries	0.2 kW
Total energy consumed	**80.7 kW**
4.Estimated operating cost	
a. Electricity cost	53908 € $year^{-1}$
b. Electricity energy per unit raw gas	269 W Nm^{-3}
c. Water cost	251 € $year^{-1}$
d. Biodegradable lubrication oil cost	0 € $year^{-1}$
Total operating cost	**54159 € $year^{-1}$**
Total cost per unit raw gas	**21.62 € $year^{-1}$**
5.Utilities consumption	
a. Biodegradable lubrication oil for compressor	0 l day^{-1}
b. Compressed air (5-7 bar)	2 $Nm^3\ hour^{-1}$
c. Make-up water (< 25 °C)	30 l $hour^{-1}$
6.Effluent streams	
a. Separated gas: typical composition 56% N_2, 29% CO_2, 14% O_2, 1% H_2O+H_2S, etc	351 $Nm^3\ hour^{-1}$
7.Optional items	
a. Air compressor	0.9 kW
b. Odourising unit	23.2 kg $year^{-1}$
8.Heat recovery	
a. Heat recovery	Nil

4 Case and feasibility studies of small-scale upgrading in India

As mentioned in D5.1, biogas production in India is increasing, but upgrading of biogas to biomethane has been very limited. Most of the work has been carried out at the Indian Institute of Technology (e.g. Kapdi et al., 2005; Vijay et al., 2006). This report will present the some case studies on small-scale upgrading of biogas, and bottling the biomethane for use in vehicles. Most of these case studies are either pilot-scale or demonstration plants.

4.1 Biogas upgrading and bottling system developed at IIT Delhi

(Source: Prof. V.K. Vijay, IIT Delhi)

Biogas upgrading system using water scrubbing. The biogas upgrading system developed at IIT Delhi is based on water scrubbing. The set-up consists of a packed tower as shown in Figure 11. Raw biogas is first compressed in a raw biogas compressor and fed to the bottom of the packed bed. Water is pressurised through a rotor pump and then fed to the top of the packed bed. In the packed bed gas and water comes into contact and the water physically absorbs the CO_2 of the biogas. Water sealing is maintained in the bottom section of tower in order to prevent the escape of gas from the water outlet. Due to high turbulence inside the tower, the purified gas contains water droplets with it; a mist eliminator is used to remove this. Water coming from the packed tower goes in to a flash tower, which is a hollow vessel at near atmospheric pressure. At the normal pressure water releases the absorbed CO_2 and H_2S into another tower, where after further upgrading the CO_2 can be used for other purposes. After releasing the absorbed gases, the same water is recycled for further upgrading. An H_2S concentration of up to 2000 ppmv can be purified satisfactorily along with CO_2 in the water scrubbing method.

Compression and bottling unit. The bottling part of the plant consists of a high pressure compressor, a cascade of storage cylinders and a dispensing nozzle for filling vehicles with the compressed purified gas. Dried and purified gas goes into the suction of a high pressure compressor, which compresses the gas to desired working pressure (~20 MPa) and fills it into the storage cylinder cascade. A CNG dispensing cable with a nozzle is used for filling of gas in the vehicles. In the system a multi-stage compressor is used for the compression of methane-enriched biogas at 20 MPa pressure in CNG cylinder. Filters are used for the moisture removal. The storage cylinders used are high pressure, seamless steel cylinders of the type already used for CNG applications.

4.1.1 Economics of the biogas upgrading system developed by IIT Delhi

The developed system consists of raw biogas processing capacity, biogas upgrading and a bottling system. The cost of a unit of 20 Nm^3 $hour^{-1}$ capacity is approximately € 53,000 and of a high pressure gas storage cylinder cascade is approximately € 14,600. Water used in the scrubbing column is normal tap water which is re-circulated in the scrubbing column so that only make-up water is required. Electricity consumption in the system could potentially be reduced. As with the previous studies, the cost is approximate and may vary depending on the site conditions, variations in plant and machinery costs etc.

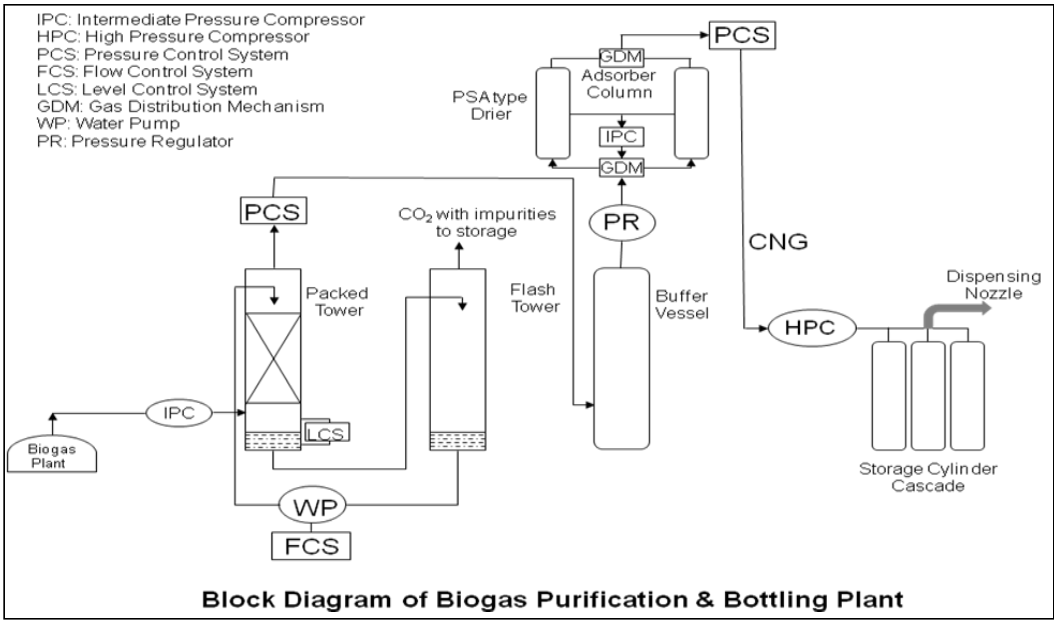

Figure 11. Block diagram of the biogas upgradation & bottling plant designed and setup at IIT Delhi campus (source: Prof. V. K. Vijay, IIT Delhi)

The end users of the small-scale system will most likely have a limited knowledge of process technology when compared to larger companies / industries. Furthermore, there may be limited working hours available to operate the installation and for maintenance. Therefore, the unit needs to be simple to operate with uncomplicated systems and preferably automatic with less need for human interaction. The water scrubbing system developed is simple without any complex operations and little manpower is required for the operation. The water scrubbing system is based on water as a stripping agent, which is easily available in rural as well as in urban areas.

It is a moderate simple, robust technology which can easily be regulated to handle variations in flow and gas quality. Water scrubbing gives high methane efficiency and high overall process efficiency. The operation and the maintenance should take minimum effort, especially for small-scale sites. For small-scale plants in developing economies, however, it is more important to have a cheap and simple unit without much sophisticated instrumentation.

4.2 Rajasthan Go Seva Sangh Plant, Jaipur (Pilot scale plant)

(Source: Prof. V. K. Vijay, IIT Delhi, India)

After successful development of a water scrubbing based biogas upgrading and bottling system at laboratory scale at IIT Delhi, a pilot level plant was set up in 2006 at Rajasthan Go Seva Sangh, Durgapura, Jaipur (an NGO operating a common cattle shed having around 300 cows), as shown in Figure 12. It was a unit with a capacity of 20 Nm^3 $hour^{-1}$ and sufficient biogas was available for testing and making the technology popular in the field. It was a simple system, having manual control of gas and water flow so that flooding does not occur. A high pressure diaphragm compressor was used to bottle upgraded biogas at 20 MPa and dispense it to a vehicle. The plant is regularly operated for around 2 hours every alternate day to run a vehicle on biomethane.

Figure 12. Biogas plant (left) and upgrading unit (right) (Source: Prof. V.K.Vijay, IIT Delhi, India)

There are three biogas plants at Rajasthan Go Sewa Sangh, having capacities of 80 m^3, 60 m^3 and 30 m^3 respectively. The raw biogas produced was evaluated by IIT Delhi and has a CH_4 content of 58% and CO_2 of 40%. After enrichment of gas, the CH_4 content was 80% and CO_2 was 8%, with the remaining percentage being moisture and air. Theoretically the water scrubbing unit is able to purify the biogas beyond this level. The lower quality of purification is due to only partial fulfilment of the desired parameters for proper purification. After enrichment of biogas, it needs to be bottled into CNG cylinders at very high pressure (recommended 200 bar) for various applications. At Rajasthan Go Sewa Sangh, the biogas is being used to run a three-wheeler Auto Rickshaw and operating a 100% biogas engine for generating the electricity.

Economics
Existing Biogas plants = 80 m^3 + 60 m^3 + 30 m^3 = 170 m^3
Assuming 80% efficiency of biogas plants, daily production of gas: 136 m^3
The gas is used for preparing medicines, in the canteen for cooking the food, boiling milk and for preparation of butter etc. Therefore, saving of LPG is:
1 m^3 of biogas = 0.4284 kg of Methane (assuming 60% of methane by volume).
Calorific Value of 1 m^3 of biogas = 23.562 MJ
Calorific value of LPG: 50 MJ kg^{-1}
Therefore, equivalent daily saving of LPG: 136 m^3 *23.56 MJ/50 MJ ≈ 64 kg
Annual Saving of LPG = 64 kg x 365 d = 23,360 kg.
Annual Saving in terms of money = 23,360 kg x Rs 45 = **Rs. 7,00,800/-**
The gas is used to run a three wheeler, therefore, petrol/diesel saving is:
1 m^3 of biogas = 0.6 m^3 of methane (assuming 60% methane by volume)
= 0.4 kg of methane (density of methane = 0.67 m^3 kg^{-1})
Since 1 kg of methane is equivalent to 1 litre of petrol/diesel
Equivalent daily saving of petrol/diesel: 136 m^3 * 0.4 kg ≈ 55 l of petrol/diesel
Annual saving of petrol/diesel = 55 l x 365 d = 20,075 l $year^{-1}$
Annual saving in terms of money = 20,075 l $year^{-1}$ x Rs 45 = **Rs. 9,03,375/-**

4.3 Madhav Govigyan Anusandhan Sansthan, Nogaon, Bhilwara (Pilot-plant)

(Source: Prof. V.K. Vijay, IIT Delhi, India)

Madhav Govigyan Anusandhan Sansthan, Nogaon, Bhilwara is a registered society (non-governmental organisation) under the Society Registration Act of the Government of Rajasthan. It has five large cattle sheds (500 cows), two biogas plants, a biogas engine generator (20 kW), warehouses, worm-compost pits, chaff cutting system, a grazing field, a bull house, veterinary care unit, central office, a panchgavya products laboratory etc. The Sansthan has a dedicated team of volunteers and people working to improve the rural economy through cows, organic agriculture and decentralised energy systems. It is approximately 500 km from Delhi and there is no grid supply; only biogas-based captive power.

a) Biogas plant

b) Upgrading unit

c) Dispenser unit

d) Biogas vehicle

Figure 13. Bhilwara biogas plant. (Source: Prof. V. K. Vijay, IIT Delhi, India)

There are two biogas production plants with capacities of 65 and 45 Nm^3 day^{-1} (Figure 13). Hence the total production plant capacity is 110 Nm^3 day^{-1} and at 80% plant efficiency the total biogas production is about 88 Nm^3 day^{-1}. About 13 Nm^3 day^{-1} of raw biogas is utilised for cooking, medicine preparation in the laboratory and water heating. Raw biogas available for upgrading is about 75 Nm^3 day^{-1} and the volume of upgraded biogas obtained is about 37 Nm^3 day^{-1}.

About 31 Nm^3 day^{-1} of upgraded biogas is utilised without bottling, in a natural gas engine for electric power generation and battery charging for inverter operation. About 6 Nm^3 day^{-1} of upgraded biogas is bottled for running a CNG auto luggage carrier, as shown in Figure 13d, which is used to transport milk, milk products, and cattle feed in the nearby villages.

4.4 Biogas upgrading and bottling plant at Nasik, Maharashtra (1st Technolology demonstration plant)

This plant was installed under a new initiative by the Ministry of New and Renewable Energy (MNRE) for bottling of biogas to demonstrate an integrated technology package in entrepreneurial mode on medium-size mixed feed biogas-fertiliser plants (BGFP) including generation, upgrading/enrichment, bottling and piped distribution of biogas. Installation of such plants aims at meeting stationary and motive power, cooling, refrigeration and electricity needs in addition to cooking and heating requirements. Under the demonstration phase, the Ministry had a provision for a central financial assistance of 30 to 50% of the cost (excluding cost of land) for implementation of a limited number of such projects following an entrepreneurial mode on a build, own and operate basis.

Figure 14. Biogas upgrading and bottling plant at Nasik, Maharashtra (Source: Prof. V. K. Vijay, IIT Delhi, India)

A 500 Nm^3 biogas day^{-1} capacity BGFP project for generation, upgrading/enrichment, bottling of biogas was sanctioned by MNRE with €74,000 central financial assistance during the year 2009-10 to Ashoka Biogreen Pvt Ltd at village Talwade, District Nasik, Maharashtra, as shown in

Figure 14. The biogas bottling plant was commissioned on 16 March 2011 after obtaining a license for filling and storage of compressed biogas in CNG cylinders.

The biogas generated from the plant has achieved a purity of 98.4% as confirmed through tests conducted by an accredited lab. The purity of the enriched biogas is continuously monitored by an online analysis system. A schematic diagram of the BGFP project is given in Figure 15.

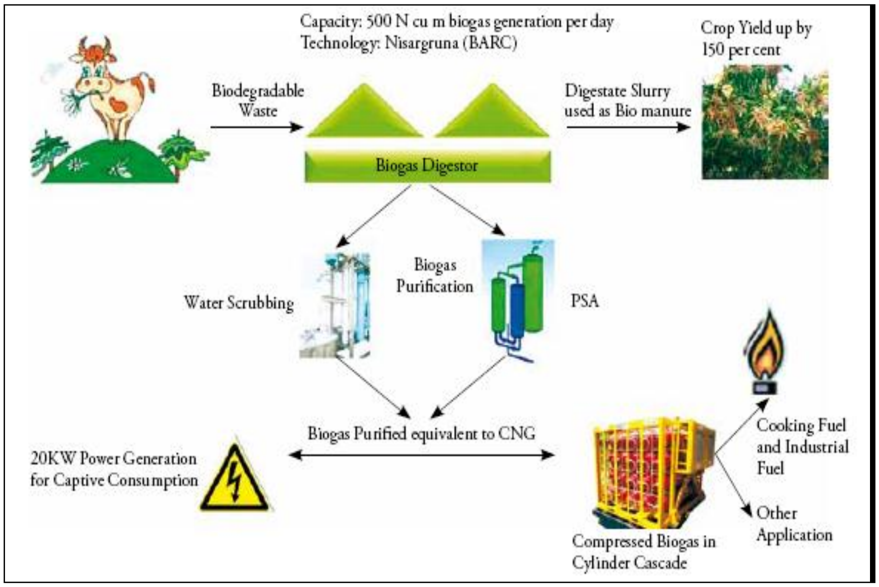

Figure 15. Schematic diagram of biogas upgrading and bottling plant at Nasik, Maharashtra (Source: Prof. V. K. Vijay, IIT Delhi, India)

Ashoka Biogreen has installed two independent set-ups for biogas upgrading, namely water scrubbing and pressure swing adsorption. Gas composition monitoring has been installed to continuously monitor the performance of both set-ups. The upgraded gas is filled in t cylinder cascades of 20 cylinders each (80 l capacity) using a high pressure compressor of 5 Nm^3 $hour^{-1}$. Upgraded biogas is primarily used to generate electricity to provide power for the entire plant. A 5 kW CNG Kirloskar generator is installed for this purpose. The cylinders are filled up to 150 bar only, as per the license conditions. For experimental purposes, Ashoka Biogreen runs a CNG vehicle (TATA Magic) within its premises from the gas generated at the site.

4.5 Biogas Upgrading and Bottling Plant at Abhohar, Mukatsar, Punjab

(Source: Prof. V.K. Vijay, IIT Delhi, India)

Anand Energy promoted a 600 Nm^3 day^{-1} biogas generation capacity BGFP project for generation, upgrading/enrichment and bottling of biogas. This was the second project of its kind to have been commissioned and was sanctioned by the MNRE with € 67,000 CFA during the year 2009-10. The plant is located at Abohar, Mukatsar (Punjab) and has started operation after having received the consent to operate from the Punjab Pollution Control Board and a licence for filling and storage of compressed biogas in CNG cylinders.

Figure 16. Biogas plant (left) and upgrading unit (right)

The biogas is produced by upflow anaerobic sludge blanket (UASB) digesters and the biogas upgrading technology used is water scrubbing. Cylinder cascade is used for compressed biogas filling and stored at 15 MPa.

*Commercial Activities***:** The plant is producing upgraded biogas with a methane composition of around 95%. The purified gas is filled in cylinder cascades using a high pressure compressor, and is being sold to meet the heating/cooking demand of the hotel industry nearby. With upgraded biogas, the promoter is able to replace commercial Liquefied Petroleum Gas (LPG) and hence is able to sell the gas at the commercially attractive price of Rs 50 per kg. At this selling price, the overall project is an attractive investment.

5 Economics of a small-scale upgrading unit in India

5.1 Biogas production, purification & bottling and slurry utilisation system

(Source: Prof. V.K. Vijay, IIT Delhi, India)

Cost components	
1.Biogas Plant:	
Waste required	~20 t Cattle Dung per day
Water requirement in biogas plant:	~ 20 t/day
Biogas production	1000 Nm^3/day
Cost	Rs 60 lakhs
2.**Biogas Purification & Bottling System**	
Raw biogas quantity	1000 Nm^3/day
Purified gas quantity	~ 375 kg
Purified gas composition	CH_4: 95%, H_2S: < 25 ppm, Moisture: < 20 ppm
Cost	Rs. 55 Lakhs (excluding the cost of cylinders for gas storage)
3. **Slurry Management System:**	
Slurry production	~ 6 t/day
Cost	Rs. 20 Lakhs
4.Other Cost	
Land preparation, Civil work, High pressure gas storage cylinders Taxes, Logistic etc.	~ Rs. 15 Lakhs
Total Initial Cost of Project	Rs.15 million
5.Revenue	
Purified Gas	Rs. 11250/d (@ Rs. 30/kg * 375 kg)
Slurry	Rs. 12000/d (@Rs. 2/kg * 6000 Kg)
Total Revenue	Rs. 23250/d
Annual Revenue	Rs. 81.375 Lakhs (@ Rs. 23250/d * 350 days)
Cost of Dung	Rs. 5000/d (@ Rs. 250/t * 20 t)
Annual cost of dung	Rs. 18.25 Lakhs (@ Rs. 5000/d * 365 d)
Cost of Water & Electricity	Rs. 15 Lakhs (Annual)
Manpower Cost: Rs. 6 Lakhs (Annual)	Rs. 6 Lakhs (Annual)
Annual Maintenance cost: Rs. 8 Lakhs	Rs. 8 Lakhs
Total Recurring cost: Rs. 47.25 Lakhs	Rs. 47.25 Lakhs

* Above calculations provide only a very rough idea for the complete project, while the actual figures vary on a case-by-case basis and are for discussion purposes only.

Conclusions

The report indicates that small-scale biogas upgrading (<50m3 hour-1 of raw biogas) is mainly developed in Sweden, Austria and Switzerland. As we have already reported in D5.1, that the number of units are around 13 in Europe. Most of the case studies reported indicate that the upgrading units are developed and operated by an individual farmer, community or technology provider for own use, demonstration or pilot-scale testing of the upgrading technology respectively. The cost of small-scale upgrading is highly dependent on the biogas production, and the technology used. The main costs of biogas upgrading are the costs for electricity and water consumption. The range of applications for biomethane includes from own vehicle use, grid injection to use in municipal fleet vehicles and city buses. In India, biogas upgrading is mostly confined to demonstration and pilot-scale studies. Thus, there is a considerable interest in the expansion on biogas upgrading and utilisation of the biomethane.

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