Upgraded Biogas as Renewable Energy

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EXECUTIVE SUMMARY

Biogas is generated from the decomposition of a wide range of wet organic materials to produce a methane-rich gas. Commercial production across the 27 EU member states in 2007 totalled 5.9 ktOE (62TWhrs) renewable energy and is increasing annually. The two largest biogas producers in the EU are Germany and the UK; together these countries produce around 2/3 of EU biogas utilised as energy. In total around 60% of EU produced biogas originates from landfill with 25% from sewage sludge treatment and 15% from other sources. By late 2007, around 90% of the biogas captured for utilisation was converted into heat & electricity via combined heat and power (CHP) gas engines. However, in the last 15 years the upgrading technology that converts biogas to biomethane has developed significantly and by October 2008 there were a total of 79 biogas upgrading plants in the EU.

The EU biomethane sector is expanding in response to emerging policy and economic drivers (e.g. feed-in tariffs, renewable heat incentives, fuel tax exemptions and renewable transport fuel obligations). Most countries now pay renewable energy producers a commodity amount per kWh of electricity and/or heat produced and these incentives are being extended to also cover vehicle fuels and direct injection of gas to the grid network. In particular, Sweden has pioneered the use of biogas as vehicle fuel and is probably the best example of an EU member where biogas generated from sewage sludge, household organic wastes and commercial organic wastes is being upgraded and utilised as fuel for vehicles and also injected into the natural gas network. Initially the main driver was the low electricity prices in the country; however this is now supported by several government incentives, such as fuel tax exemption, government investment programmes and free parking in several cities. In Sweden there are now over a 100 biomethane filling stations and more than 53 million Nm$^3$ was sold, equating to 61 million litres of petrol.

The introduction of incentives in Germany has led to a marked increase in the installation of biogas upgrading plants since 2006, with a total of 15 plants in 2008, generating biomethane primarily for injection into the natural gas grid. This option appears to be particularly favourable for the country due to the well developed natural gas network and the excellent existing infrastructure for natural gas filling stations throughout Germany. The UK’s first biogas upgrading project is due to come on line in 2001, producing biomethane for use at vehicle fuel and also for grid injection. The development of this industry will support compliance with EU policy targets on renewable energy, carbon dioxide emissions and renewable transport fuel from 2010 onwards.
INTRODUCTION

The production of biogas is a result of a natural biological process that occurs where wet organic matter decomposes in the absence of oxygen. Biogas consists mainly of 30-60% vol carbon dioxide and 45-70% vol of high calorific methane (which is also the main component of natural gas). Trace gases present in biogas include hydrogen sulphide (1-2%), oxygen (0-2%), ammonia, halogenated hydrocarbons, and dust particles (all <1%).

The total biogas production in the 27 European member states in 2007 was 5.9 kilo tonnes raw oil equivalent (ktOE), which equals around 62TWh of energy from biogas [Beil et al., 2008]. This is an increase of 13.6% from 2005, with a further increase projected for 2008. The two largest biogas producers in the EU are the UK and Germany; together these countries produce around 2/3 of EU biogas utilised as energy. UK biogas is predominantly generated by landfills, in contrast to Germany where the bulk of biogas is generated from agriculture and biological waste treatment plants. Anaerobic digestion (AD), is widely used in Germany to stabilise sewage sludge and farm wastes and it is increasingly being used to treat the organic fraction of household and commercial wastes.

In total around 60% of the produced biogas in the EU originates from landfill, 25% from sewage sludge treatment and 15% from other sources, such as co-fermentation and waste treatment (Figure 1). By the end of 2007 around 90% of the biogas captured for utilisation was converted into heat & electricity via combined heat and power (CHP) gas engines. However, in the last 15 years the upgrading technology required to convert biogas into biomethane has developed significantly and by October 2008 there were a total of 79 biogas upgrading plants in the EU, nearly half of which are located in Sweden.

Currently, there are several biogas upgrading technologies on the market, all capable of producing a clean, high methane biofuel, thus enabling direct injection into the gas grid or use as vehicle fuel.
Biogas is considered as a renewable energy source, since the carbon originates from carbon dioxide taken up by plants during photosynthesis. It does therefore not contribute to the greenhouse effect, unlike the combustion of fossil fuels. Biomethane may be used as a vehicle fuel in exactly the same way as natural gas and has lower emissions than other vehicle fuels. This paper focuses on the development of biogas upgrading technologies to produce biomethane, both as a vehicle fuel and for injection into the gas grid, with examples of current activity in Sweden, Germany and the UK.

**Political Drivers**

EU policy targets require the use of 20% of renewable energy by 2020 and a cut in carbon dioxide emissions by 2050 of up to 60%. Biogas can provide renewable energy in the form of electricity, heat, and transport fuel. The generation of renewable electricity from biogas is well established, but the enhancement of biogas to biomethane for use as a vehicle fuel or for injection into the gas grid is increasingly being promoted.

Member states are obliged to ensure that biomethane has the same access to the gas grid as natural gas, provided that it meets the quality and safety requirements and that a continuous supply can be guaranteed. However, only some countries have currently adopted safety standards for the injection of biomethane into the gas grid. At the same time EU Directive 2003/30/EC obliges member states to develop and implement policies to promote the use of biofuel in the transport sector. The goal is to replace 5.75% of transport energy use with biofuel by 2010. Considering the total biogas production in the EU (Figure 1), the bulk of this renewable fuel could be provided by upgraded biogas.

**Economic Drivers**

There are two main economic drivers that may promote the utilisation of biogas as renewable energy: government incentives and operational profit. To date the renewable energy market in Europe is clearly dominated by the use of CHP engines to produce heat and electricity. This is encouraged by government incentives, such as financial benefits and grant support. Most countries pay the renewable energy producer a commodity amount per kWh of electricity and/ or heat produced. For example in the UK, this is currently two times one “ROC” (Renewable Obligation Certificate), with each valued at 3.7p/kWh plus a small payment associated with the Climate Change Levy, which together totals 7.8p/kWhr (8.7ct/kWhr), for renewable electricity produced. In Germany, the equivalent incentive is 11.67ct/kWh. This payment is in addition to the electricity and heat sales price, thus allowing the operators to realise considerable revenue from energy production.

Compared to the CHP sector, the conversion of biogas to biomethane is still a novelty in many EU countries, and economic incentives are not widespread. Sweden is pioneering the use of biogas as vehicle fuel and has introduced a range of incentives, including tax benefits, free parking, and the exemption of congestion charges for biomethane fuelled vehicles. Additionally, it was proposed in 2007 to have at least one renewable fuel pump at every petrol station in the country. Other countries, particularly Germany and Switzerland, recently also started putting increased efforts into the development and use of biomethane as a fuel, being encouraged by fuel incentives, tax exemptions and European legislation, but also by rising energy prices. The German government pays the operators a baseline bonus of 8ct/kWh for the utilisation of energy from biomass, a technology bonus of 2ct/kWh for biogas upgrading (both as vehicle fuel or for injection into the gas grid) and also offers grants of 30% of the capital investment for a biogas upgrading plant. Additionally, biogas fuelled vehicles are tax exempt until at least 2015. Similar tax incentives are now being introduced.
by the UK government. From April 2011 there will be feed-in tariffs for heat under the renewable heat incentive (RHI), which will also apply to biomethane injected into the gas grid. A similar incentive for vehicle fuel, the renewable transport fuel obligation (RTFO), will come into effect for biogas upgraded as vehicle fuel, although the rate of this incentive has not yet been set by the UK government.

**Biomethane requirements**

In order to guarantee that a gas product can safely and efficiently be used in vehicles as a biomass bio-fuel or to be injected into the natural gas network the biomethane must meet a gas quality specification. To date there is no European Standard for upgraded biogas and reference is made to the Swedish specification in the following section.

Upgraded biogas (biomethane) has similar properties to natural gas, which has been used as a vehicle fuel for decades. To utilise biomethane as a fuel for vehicles, the same engine and vehicle configuration that is used for natural gas can be used. In 1999 Sweden developed a national standard for the use of biogas as a vehicle fuel upon request of the Swedish motor industry. The parameters are summarised in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
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<tbody>
<tr>
<td>Lower Wobbe Index</td>
<td>43.9 – 47.3 MJ/Nm³</td>
</tr>
<tr>
<td>Methane concentration</td>
<td>97±2% by volume</td>
</tr>
<tr>
<td>Motor Octane Number</td>
<td>&gt;130</td>
</tr>
<tr>
<td>Water dew point</td>
<td>t-5, where t = ambient temperature</td>
</tr>
<tr>
<td>CO₂+O₂+N₂</td>
<td>&lt;5% by volume</td>
</tr>
<tr>
<td>O₂</td>
<td>&lt;1% by volume</td>
</tr>
<tr>
<td>Total sulphur</td>
<td>&lt;23 mg/Nm³</td>
</tr>
<tr>
<td>NH₃</td>
<td>&lt;20 mg/Nm³</td>
</tr>
</tbody>
</table>

This standard is similar to that applied when injecting biomethane into the natural gas network. However, many countries in Europe such as Sweden and Switzerland have national standards for injecting biomethane into the natural gas network. The requirements may therefore vary slightly. Additional quality requirements can be posed by the gas grid operator. In the UK for example, the gas grid operator (National Grid) requires a maximum oxygen concentration of 2%, odourisation of the gas and mixing the biomethane with propane to further increase its calorific value. The percentage of propane to be added depends upon the calorific value of the produced biomethane compared to the CV of the gas in the pipeline.

**Vehicle engine requirements**

The technical design of vehicles using biomethane fuel is the same as for vehicles fuelled with natural gas. They are usually equipped with two separate fuel tanks – one for petrol or diesel and one for biogas (dual fuel). The biogas is stored in the tank at a pressure of around 200 bars. The same motor may be used for both fuels, allowing switching between fuels, if one tank runs empty. Figure 2 shows the configuration of a typical dual fuel engine as supplied by Volvo.
Most biogas-powered lightweight cars use petrol for the ignition and then switch to gas after a few seconds. Heavy vehicles such as buses are constructed to use gas alone. Diesel fuelled HGVs however can be converted to dual-fuel engines, designed to operate interchangeably on natural gas with a diesel pilot, or 100% on diesel fuel. Biomethane is around 20% less efficient than diesel.

**Biogas upgrading technologies**

In order to use biogas as a vehicle fuel or for injection into the natural gas network the biogas must be cleaned (the CO\(_2\) and H\(_2\)S removed) and upgraded (>95% methane) to produce biomethane, which has a higher calorific value, to provide longer driving distances, or an energy content corresponding with the gas distributed via the natural gas grid. The quality standards ensure that the biomethane does not aggravate corrosion, does not contain mechanically damaging particles, and has a declared and assured quality.

Commercial scale biogas upgrading plants in Europe (2008) can be split into five different technology types – pressurised water wash, pressure swing adsorption (PSA), physical absorption, chemical absorption, and membrane filtration. Of the 79 biogas upgrading plants in the EU, 63 are based on either pressurised water wash (32) or on PSA (31).

The principle of the pressurised water wash process uses the fact that gases like carbon dioxide and hydrogen sulphide are more readily dissolved in water than methane. The biogas upgrading plant consists of a scrubber vessel for water scrubbing (absorption of CO\(_2\) and H\(_2\)S into water), a flash tank for methane gas recovery, and a de-sorption tower for the regeneration of the process water as shown in Figure 3. The principal steps of biogas upgrading by water scrubbing are:

1. Compressing the crude biogas
2. CO\(_2\) and H\(_2\)S removal by absorption in water
3. Water removal from the gas using an adsorption drier
4. Gas analysis for carbon dioxide and dew point
5. Odourising the gas

Initially, the biogas is compressed and it is then cooled with water from the cooling system in order to maximise the absorption efficiency. The compressed gas enters the absorption tower at the bottom and it flows upwards counter-current to the scrubbing water. The CO\(_2\) and H\(_2\)S
are absorbed into the scrubbing water. The scrubbing column is filled with a packing material to increase the surface area for effective absorption. The gas leaving the absorption tower at the top has a methane concentration of 97±1% by volume. Finally, before the upgraded gas is transported to the storage tank it is odourised and dried to remove water.

The wash water may be re-circulated and used again by stripping out the CO₂ and H₂S by passing the wash water through a de-sorption column where it is “degassed” with air under negative pressure. Some systems also include a flash tank to recover small amounts of methane that were absorbed in the water together with the CO₂. The methane can then be recirculated to the inlet compressors to minimise methane losses.

A typical product gas composition (pots-upgrading) is shown in Table 3.

Table 3 Typical product gas composition (biomethane)

<table>
<thead>
<tr>
<th>Product gas composition</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>&gt;97%</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>&lt;2.5%</td>
</tr>
<tr>
<td>Hydrogen Sulphide</td>
<td>&lt;5mg/Nm³</td>
</tr>
<tr>
<td>Dew point</td>
<td>-60°C at 4bar</td>
</tr>
</tbody>
</table>

Note: based upon an average methane concentration of 63% and H₂S 200-500ppm

Another biogas upgrading process commonly used is Pressure Swing Adsorption (PSA). It is in many ways similar to the wash water process, but separates out CO₂, H₂S, oxygen and nitrogen by adsorption and desorption on activated carbon at different pressures in four stages - adsorption, depressurising, desorption and pressure build up. Other processes include: adsorption using Selexol or absorption by means of chemical reaction.
The biogas upgrading plant is connected directly to a compressor and two types of refuelling can be chosen—“fast fill” (minutes) or “slow fill” (6-8 hours). At a fast fill refuelling station the biomethane is usually compressed to 200-300 bar and stored in banks of buffer storage cylinders from where the compressed gas is filled into the vehicles. At slow fill stations the biomethane is filled directly from a compact compressor into the vehicle. This method is often used for fleets that return to a central depot overnight. This type of refuelling station is considerably cheaper than the fast fill option, since no buffer storage cylinders are required.

**Examples of biogas upgrading in Europe**

Although the biogas upgrading technology has been available for several decades, its use across European member states varies significantly. The 79 European plants are spread over 9 countries, of which 35 are in Sweden, 15 in Germany, and 11 in Switzerland [Beil et al., 2008]. Examples from Sweden, Germany, and the UK are described in the following to show the varying status of biogas upgrading by European member states to date.

**Sweden**

Sweden is probably the best example of a country in Europe where biogas generated from the AD of sewage sludge, household organic wastes and commercial organic wastes is being upgraded and utilised as fuel for vehicles and also injected into the natural gas network. The country has become a world leader in biogas utilisation, using 55% of the 1.2TWh produced in 2006 for heat, 19% as vehicle fuel, 8% for electricity and 4% for biogas injection to the gas grid [Petersson, 2008]. Initially the main driver was the low electricity prices in the country that made biogas upgrading a more attractive option. This is now supported by several government incentives, such as fuel tax exemption, government investment programmes and free parking in several cities. In Sweden there are now over a 100 biomethane filling stations and more than 53 million Nm³ was sold, equating to 61 million litres of petrol. Biogas upgrading for injection to the grid was less attractive due to the patchy gas network in Sweden, although some targeted development is now taking place in the west of the country.

**Hendriksdal Biogas upgrading plant, Stockholm, Sweden**

This biogas upgrading plant improves the quality of biogas generated from the anaerobic digestion of sewage sludge produced at the Hendriksdal sewage treatment plant. The biogas upgrading plant was initially built with a capacity of 600Nm³/h and was later extended to increase the capacity to treat a total of 1,400Nm³/h of raw biogas. The plant was designed and built by Malmberg Water and the process is based upon water scrubbing, removing both CO₂ and H₂S sufficiently to comply with the relevant Swedish vehicle fuel standards, providing a minimum methane content of 97%.

Initially Stockholm Water, the operators of the plant, signed a contract for providing upgraded biogas for use in 120 buses owned by the City Council. Now the upgraded biogas is also used in lightweight vehicles and some of the gas is injected into the city’s natural gas network at Hammarby Sjöstad. This plant can produce a total of 7.7 million Nm³ of biomethane (upgraded biogas) per year. Figures 4 and 5 show the process plant and the building in which it is housed.
The total investment costs for the upgrading plant was 2.5 million Euro and this price included both the upgrading plant and a high pressure compressor system.

**Germany**

Germany’s goal is to replace 6% of its natural gas demand by biomethane in 2020, rising to 10% in 2030. In order to achieve this, the government already changed the gas grid connection ordinance in March 2008. Furthermore, a technology bonus within the Renewable Energy Feed-In Tariff law will be introduced for upgrading biogas to biomethane from 2009. These incentives led to a sudden increase in the installation of biogas upgrading plants since 2006. In October 2008 there were a total of 15 biogas upgrading plants in Germany, treating nearly 100 million tonnes of biogas per year. Up to 2006 the upgraded biogas was mainly utilised as heat and electricity but this has increasingly shifted towards injection into the natural gas grid, either as pure biomethane or as biomethane/natural gas mix. This option appears to be particularly favourable for the country due to the well developed natural gas network and the excellent existing infrastructure for natural gas filling stations throughout Germany.

**Biogas upgrading plant Darmstadt, Germany**

The biogas upgrading plant in Darmstadt (Figure 6) was designed for the annual treatment of more than 2.5 million Nm³ of raw biogas produced from big slurry and energy crops. The plant commenced operation in spring 2008 and the upgraded biogas is fed into the regional natural gas network.

The total investment costs for this plant was 3.5 million Euro in 2007. The scope included the biogas upgrading plant, an injection station and a compression system to allow injection into the natural gas network.

**United Kingdom (UK)**

The UK is the largest biogas producer (per head) in Europe; however renewable energy production in the UK in 2008 was less than 2% of the total energy consumption. Despite the
overall target of 15% to come from renewable sources by 2030 there is currently limited activity in the renewable energy sector focussing on biogas as a renewable source. However a pilot project to upgrade biogas from sewage sludge is currently being developed by United Utilities in Manchester that will process 250 Nm³/hour of biogas into biomethane for subsequent injection to the gas grid and use a transport for the company’s sludge tankers. The expected date for implementation of this first UK biomethane project is early 2011.

**Economics**

Commercial viability depends upon the required capital investment and the revenue or fuel savings that can be made. According to literature [Beil 2008; Persson, 2003; Trendsetter, 2003] the investment costs for a biogas upgrading plant range between 0.5 and 0.8 million Euros for a plant treating 250Nm³/h and 1.2-1.5 million Euros for a biogas upgrading plant with 1,000Nm³/h capacity, depending upon technology and supplier. The operational costs are generally quoted to be between 1-2% of the capital investment depending upon the technology. Together these costs provide the biogas upgrading costs per Nm³ produced. A typical split of the production costs is shown in table 1; also included in the price is the current fuel duty for the UK. The fuel duty is for the production of vehicle fuel only and may have to be adjusted to reflect individual national legislation.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Average costs stated in literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upgrade to vehicle fuel with compression &amp; refuelling station¹</td>
<td>€/Nm³</td>
<td>0.30-0.39</td>
</tr>
<tr>
<td>Additional costs for infrastructure²</td>
<td>€/Nm³</td>
<td>0.03-0.06</td>
</tr>
<tr>
<td>Fuel duty³⁴</td>
<td>€/Nm³</td>
<td>0.127</td>
</tr>
<tr>
<td>Total estimated costs, (excl. VAT), excl. electricity demand</td>
<td>€/Nm³</td>
<td>0.46-0.58</td>
</tr>
</tbody>
</table>

Notes:
1) Based on 300m³/h raw gas flow; upgraded to requirements shown in Table 2
2) connection to the gas grid; guidance only; varies widely depending upon i.e. size and location
3) 1litre of fuel equals 1Nm³ of upgraded methane gas
4) From UK National Budget published April 2009

With an estimated maximum cost of 0.58€ per Nm³ (including duty) the biogas fuel price is competitive with diesel fuel in most European countries, which ranges from 0.5€/Nm³ (or per litre) to 1.2 €/Nm³. The total upgrading costs are mainly affected by the investment costs, and to a lesser extent the utilisation of the design capacity. Generally, operating and upgrading costs decrease with increasing treatment capacity.

Generic costs for injecting biomethane into the gas grid cannot be accurately projected since these depend on a range of site-specific parameters, including ground conditions, general civil works, monitoring equipment and telemetry to be installed. The most expensive part of the gas grid injection however is the connecting pipe to the gas main and the distance required; this is likely to cost around 150,000€/km [Trendsetter, 2003] depending on material and the pipe diameter being laid, the operating pressure and the compression required respectively.
CONCLUSION

Biogas is widely produced across the EU, from a wide range of organic materials and has historically been converted to energy (heat and power) largely through CHP. However the technology for upgrading the biogas to high-methane biomethane is well established and increasingly being implemented in some EU member states, particularly Sweden and Germany, with some interest also being shown in the UK. Renewable energy uses for the biomethane include direct injection to the gas grid network and/or use as a vehicle fuel (natural gas substitute). These alternative end uses are likely to be more attractive than CHP in some circumstances and the developing policy and economic drivers in some EU countries (e.g. feed-in tariffs, renewable heat incentives, fuel tax exemptions and renewable transport fuel obligations) are acting to support the development of this technology and end-use for biogas and ensure it is commercially viable. This in turn will support compliance with EU policy targets on renewable energy, carbon dioxide emissions and renewable transport fuel from 2010 onwards.

ACKNOWLEDGEMENTS

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