BIOGAS AS VEHICLE FUEL

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Abstract

There is growing interest in the use of biogas as a fuel for transport applications. Some of the drivers behind this are the increasing regulation and taxes on waste disposal, an increasing need for renewable fuel sources, the EC's Biofuels Directive, the proposed Renewable Transport Fuel Obligation (RTFO), measures to improve local air quality and the need for clean transport fuels in urban areas. The aim of this paper is to present the potential role of biogas as a transport fuel. Biogas is produced from the process of anaerobic digestion of wet organic waste, such as cattle and pig slurries, food wastes and grown wet biomass. To be used as a transport fuel biogas has to be upgraded to at least 95% methane by volume and it can then be used in vehicles originally modified to operate on natural gas. Biogas fuelled vehicles can reduce CO2 emissions by between 75% and 200% compared with fossil fuels.

The higher figure is for liquid manure as a feedstock and shows a negative carbon dioxide contribution which arises because liquid manure left untreated generates methane emissions, which are 21 times more powerful as a greenhouse gas than CO2. Hence there is a double benefit by reducing fossil emissions from burning diesel and reducing methane emissions from waste manure; Biogas will give lower exhaust emissions than fossil fuels, and so help to improve local air quality. The paper sets out the resource that is available for producing biogas, together with the basic details of production technology. It goes on to explore how this gas can be used in vehicles, describing the basic technology requirements. The energy data and the costs of producing on biogas as a transport fuel are presented.

***Keywords**: biogas, transport, road transport, air pollution*

1. Introduction

The biogas is a non-fossil gas which is produced from sewage, manure, landfills or food industry waste. With those numerous and abundant origins, the potential of the European biogas production is so large that it could replace 12 to 20 % of the natural gas consumption. This renewable energy is already used for heat and electricity production, but the best upgrading solution of this clean energy should be the production of vehicle fuel. Biogas is worth using rather than natural gas because of its renewable sources. The fossil resources of oil, gas and coal are not unlimited. The environmental problems caused by waste and wastewater have to be repaired and to be avoided in the future. One effective way to avoid these problems is the biogas, which is produced by the fermentation of animal dungs, human sewage or agricultural residues, is rich in methane and has the same characteristics as the natural gas. The use of biogas as a clean fuel answers to current concerns dealing with economics, ecology and energetics:

- search on renewable energies while the fossil deposits are draining,
- reduction of the energetic dependence,
- limitation of the atmospheric pollution linked to the gas emissions,
- decrease of the smell and noise annoyances
- reduction of the green house effects.

Biogas fuels usually cause low pollution to the atmosphere and because they come from renewable energy resources, they have a great potential for future use. This vehicle fuel is the best way to upgrade waste.

2. Composition of biogas

During anaerobic digestion (i.e. digestion in the absence of oxygen) organic material is broken down in several steps by different types of microorganisms. The end-products are a gas containing mainly methane and carbon dioxide, referred to as biogas; and a slurry or solid fraction consisting of what is left of the treated substrate, referred to as digestate. Biogas can be produced from most types of organic raw material, except for lignin, which is not anaerobically degraded. The substrate composition will affect the yield of biogas and its content of methane. Landfill gas is produced during anaerobic digestion of organic materials in landfills and is very similar to biogas. Its methane content is generally lower than that of biogas, and landfill gas usually also contains nitrogen from air that seeps into the landfill gas during recovery. Landfill gas can also, in contrast to e.g. biogas from farms, contain a great number of trace gases.

There are different technologies for the biogas production, e.g. one stage, two stage and dry digestion [1]. The substrate, the production technology and the collection of the gas, all affect the composition of the gas (Tab. 1).

Tab. 1. Composition of biogas, landfill gas and natural gas

Parameter	**Biogas**	**Landfill gas**	**Natural gas (Danish)***	**Natural gas (Dutch)**
Methane (vol-%)	60 –70	35–65	89	81
Other hydro carbons (vol-%)	0	0	9.4	3.5
Hydrogen (vol-%)	0	0-3	0	–
Carbon dioxide (vol-%)	30– 40	15–50	0.67	1
Nitrogen (vol-%)	~0.2	5– 40	0.28	14
Oxygen (vol-%)	0	0-5	0	0
Hydrogen sulphide (ppm)	0–4000	0 –100 2.9 –		
Ammonia (ppm)	~100	~ 5	0	–
Lower heating value (kWh/Nm^3)	6.5	4.4	11.0	8.8

Tab. 2. Selected standard requirements for grid injection or for utilization as vehicle fuel [3]

Compound	**Unit**	**France**		**Germany**		**Sweden**	**Switzerland**		**Austria**	**The Netherlands**
		L gas	H gas	L gas grid	H gas grid		Lim. inject.	Unlim. Inject		
Higher Wobbe index	MJ/Nm^3	42.48–46.8	48.24–56.52	37.8–46.8 46.1–56.5		95–99			47.7–56.5	43.46–44.41
Methane content	Vol-%					95–99	> 50	> 96		> 80
Carbon dioxide	Vol-%	<2		<6			<6		< 26	
Oxygene	Vol-%			<3			<0.5		< 0.56	
	ppmV	<100								
	Mol%									<0.5
Hydrogen	Vol-%	<6		<5			<5		< 46	<12
CO2+O2+N2	Vol-%					<5				
Water dew point	°C	<-5[1]		<t[4]		<t[5]-5			<-8[7]	-10[8]
Relative humidity	ρ						<60 %			
Sulphur	mg/Nm3	<100[2] <75[3]		<30		<23	<30		<5	<45

To increase the quality of the raw biogas, the gas is usually cleaned of unwanted substances such as hydrogen sulphide, oxygen, nitrogen, water and particulates. The main reason for doing this is to prevent corrosion and mechanical wear of the equipment in which the biogas is used. The main difference in the composition between biogas and natural gas relates to the carbon dioxide content. Carbon dioxide is one of the main components of biogas, while natural gas contains very low amounts. In addition, natural gas also contains higher levels of hydrocarbons other than methane. These differences result in a lower energy content of biogas per unit volume compared to natural gas (Tab. 1). By separating carbon dioxide from the biogas in an upgrading process, the energy content of upgraded biogas becomes comparable to natural gas. Several countries have defined standards for grid injection of upgraded biogas or for utilization as vehicle fuel (Tab. 2). France, Germany and Switzerland have two levels of requirements for the upgraded biogas with different restrictions applied for the injection of low and high quality gas. Sweden has one standard that has Been defined for biogas utilized as vehicle fuel.

2. Cleaning of biogas

Apart from methane and carbon dioxide, biogas can also contain water, hydrogen sulphide, nitrogen, oxygen, ammonia, siloxanes and particles. The concentrations of these impurities are dependent on the composition of the substrate from which the gas was produced. In those upgrading technologies where carbon dioxide is separated from the biogas, some of the other unwanted compounds are also separated. However, to prevent corrosion and mechanical wear of the upgrading equipment itself, it can be advantageous to clean the gas before the upgrading.

Removal of water

When leaving the digester, biogas is saturated with water vapour, and this water may condensate in gas pipelines and cause corrosion. Water can be removed by cooling, compression, absorption or adsorption. By increasing the pressure or decreasing the temperature, water will condensate from the biogas and can thereby be removed. Cooling can be simply achieved by burying the gas line equipped with a condensate trap in the soil. Water can also be removed by adsorption using e.g. SiO_2, activated carbon or molecular sieves. These materials are usually regenerated by e.g heating or a decrease in pressure. Other technologies for water removal are absorption in glycol solutions or the use of hygroscopic salts.

Removal of hydrogen sulphide

Hydrogen sulphide is formed during microbiological reduction of sulphur containing compounds (sulphates, peptides, amino acids). The concentrations of hydrogen sulphide in the biogas can be decreased either by precipitation in the digester liquid or by treating the gas either in a stand alone vessel or while removing carbon dioxide.

Addition of Fe_2+ ions or Fe_3+ ions in the form of e.g. $FeCl_2$, $FeCl_3$ or $FeSO_4$, to the digester precipitates the almost insoluble iron sulphide that is removed together with the digestate. The method is primarily used in digesters with high sulphur concentration as a first measure or in cases where H_2S in the biogas is allowed to be high (e.g. higher than 1.000 ppm). For the removal of H_2S from biogas, several technologies have been developed that will be described below.

Adsorption on activated carbon

Hydrogen sulphide is adsorbed on the inner surfaces of engineered activated carbon with defined pore sizes. Addition of oxygen (in the presence of water) oxidizes H_2S to plane sulphur that binds to the surface. In order to increase the speed of the reaction and the total load, the activated carbon is either impregnated or doped (by addition of a reactive species before formation of the activated carbon) with permanganate or potassium iodide (KI), potassium carbonate (K_2CO_3) or zinc oxide (ZnO) as catalysers. For grid injection or utilisation as vehicle fuel, only marginal amounts of O_2 are allowed in the gas. Hence oxidation of the sulphur is not suitable. In those cases mostly KI-doped carbon or permanganate impregnated carbon is used because addition of oxygen is not required in the case of KI under reduced loading. While ZnO impregnated carbon is rather expensive, H_2S removal is extremely efficient with resulting concentrations of less than 1ppm.

Chemical Absorption

One of the oldest methods of H_2S removal involves sodium hydroxide (NaOH) washing. Because of the high technical requirement to deal with the caustic solution, it's application is hardly applied anymore except when very large gas volumes are treated or high concentrations of H_2S are present. Hydrogen sulphide can also be adsorbed using iron oxide-coated ($Fe(OH)_3$ or Fe_2O_3) support material (mostly pressed minerals, sometimes wood chips). In this treatment biogas is passed through iron oxide-coated material. Regeneration is possible for a limited number of times (until the surface is covered with natural sulphur), after which the tower filling has to be renewed. The process operates with two columns, one is absorbing, while the other is re-oxidized. If a small amount of air is present in the biogas, the system can operate with one column but loading is limited when compared to the two-column system. This method has been used worldwide in sewage sludge treatment plants, before Fe3+ addition became standard for the simultaneous removal of phosphate. Iron oxide is also the desulphurizing agent in SOXSIA® (Sulphur Oxidation and Siloxanes Adsorption), a catalyst developed by Gastreatment Services B.V. SOXSIA® that adsorbs siloxanes and removes H_2S from the raw gas. Up to 2000 ppm of H_2S can be removed from the gas at 40°C, atmospheric pressure and with a capacity of 1000 Nm^3 raw gas/hour. Another example of a product commercially available for adsorption of hydrogen sulphide from biogas is Sulfa Treat®.

Hydrogen sulphide can be absorbed in e.g. a ferric chelate solution in which Fe_3+ ions are reduced to Fe_2+ ions while hydrogen sulphide is oxidized to elementary sulphur. The ferric chelate solution is regenerated in a second vessel by addition of oxygen and water. Chelate technologies are designed for high loads and are usually not applied in biogas plants. In a process recently developed by Procede, a Dutch company, hydrogen sulphide removal is based on the precipitation reaction between hydrogen sulphide and a metal ion in an aqueous solution. The metal sulphide that is formed precipitates almost immediately. The metal ion is regenerated by using oxygen which converts the bound sulphur to sulphur dioxide that can be used to produce sulphuric acid or gypsum. The process is able to clean biogas down to less than 1 ppm hydrogen sulphide. It has so far been tested in a pilot plant (5 Nm^3/h), and will be available for biogas plants up to 1500 Nm^3/h. Acrion Technologies Inc. has developed a system called CO_2 Wash® for the cleaning of landfill gas. The CO_2 Wash® removes siloxanes, sulphur compounds, halogenated compounds and NMHC (non-methane hydrocarbons) from landfill gas [2]. The unwanted compounds are separated by liquid carbon dioxide originating from the landfill gas. The removed compounds dissolved in the liquid carbon dioxide can be incinerated together with landfill gas. Other streams from the CO_2 Wash® are a pure liquid carbon dioxide stream and a gas stream containing methane and carbon dioxide. The liquid carbon dioxide is 99.99% pure and the concentrations of siloxanes, chlorinated hydrocarbons and sulphur compounds in the methane and carbon dioxide stream are all below the detection limits of 5 ppb, 10 ppb and 100 ppm.

Biological treatment

Hydrogen sulphide can be oxidized by microorganisms of the species Thiobacillus and Sulfolobus. The degradation requires oxygen and therefore a small amount of air (or pure oxygen if levels of nitrogen should be minimized) is added for biological desulphurization to take place. The degradation can occur inside the digester and can be facilitated by immobilizing the microorganisms occurring naturally in the digestate. An alternative is to use a trickling filter which the biogas passes through when leaving the digester. In the trickling filter the microorganisms grow on a packing material. Biogas with added air meets a counter flow of water containing nutrients. The sulphur containing solution is removed and replaced when the pH drops below a certain level. Both methods are widely applied, however they are not suitable when the biogas is used as vehicle fuel or for grid injection due to the remaining traces of oxygen. An alternative system has been developed by Profactor, where the absorption of the H_2S is separated from the biological oxidation to sulphur. Hence, the biogas flow remains free of oxygen.

Removal of oxygen and nitrogen

Oxygen is not normally present in biogas since it should be consumed by the facultative aerobic microorganisms in the digester. However, if there is air present in the digester nitrogen will still be present in the gas when leaving the digester. Oxygen and nitrogen can be present in landfill gas if the gas is collected using an under pressure. These gases can be removed by adsorption with activated carbon, molecular sieves or membranes. They can also to some extent be removed in desulphurisation processes or in some of the biogas upgrading processes. Both compounds are difficult (i.e. expensive) to remove hence, their presence should be avoided unless the biogas is used for CHPs or boilers.

Removal of ammonia

Ammonia is formed during the degradation of proteins. The amounts that are present in the gas are dependent upon the substrate composition and the pH in the digester. Ammonia is usually separated when the gas is dried or when it is upgraded. A separate cleaning step is therefore usually not necessary.

Removal of siloxanes

Siloxanes are compounds containing a silicon-oxygen bond. They are used in products such as deodorants and shampoos, and can therefore be found in biogas from sewage sludge treatment plants and in landfill gas. When siloxanes are burned, silicon oxide, a white powder, is formed which can create a problem in gas engines. Siloxanes can be removed by cooling the gas, by adsorption on activated carbon (spent after use), activated aluminium or silica gel, or by absorption in liquid mixtures of hydrocarbons. Siloxanes can also be removed whilst separating hydrogen sulphide, as described under "Removal of hydrogen sulphide".

Removal of particulates

Particulates can be present in biogas and landfill gas and can cause mechanical wear in gas engines and gas turbines. Particulates that are present in the biogas are separated by mechanical filters.

Full scale technology for biogas upgrading

Upgrading of biogas or landfill gas is defined as removal of carbon dioxide from the gas. This will result in an increased energy density since the concentration of methane is increased. Several technologies for biogas upgrading are commercially available and others are at the pilot or demonstration plant level. Some of these technologies are:

- Pressure Swing Adsorption (PSA);
- Water scrubbing;
- Organic physical scrubbing;
- Chemical scrubbing;
- Membranes.

3. Comparison of different upgrading techniques

The most widely used technologies for biogas upgrading are pressure swing adsorption, water scrubbing, organic physical scrubbing and chemical scrubbing. Their characteristics as given by the technology providers are summarized in Tab. 3. However, it is important to remember that the best technology to choose is based on specific parameters at the plant, such as the availability of cheap heat and the electricity price. It should also be noted that it is often possible to lower the methane loss, but at the expense of a higher energy consumption [3].

Methane that is lost in the upgrading process can be prevented from causing a methane slip to the atmosphere. Today, technological developments have led to cheaper and more efficient plants thanks to the increasing interest in upgrading biogas. The demand for more plants has also led to the development of standardized upgrading units which also decreases the costs. The upgrading costs of established techniques are dependent on the specific technology, but most importantly on the size of the plant (fig. 1). However, the field of biogas upgrading is developing rapidly and thus the cost development would also be expected to change. Today, there are commercially available plants for capacities lower than 250 Nm^3/h, while also plants larger than 2000 Nm^3/h are being built. These developments and also the fact that more plants are being built will likely lead to lower prices.

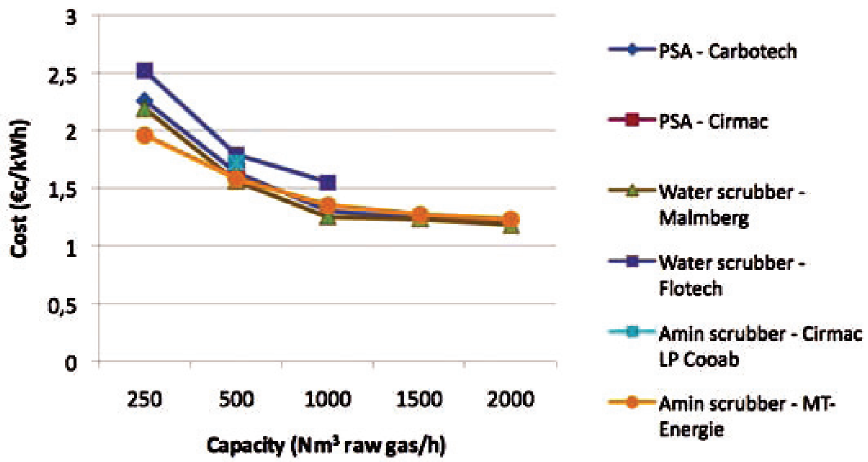

Fig. 1. Estimated cost of biogas upgrading plants using different technologies [3]

Tab.3. Comparison between selected parameters for common upgrading processes [5]

Parameter	PSA	Water scrubbing	Organic physical scrubbing	Chemical scrubbing
Pre-cleaning needed a	Yes	No	No	Yes
Working pressure (bar)	4–7	4–7	4–7	No pressure
Methane loss b	< 3 % / 6 –10%f	< 1 % / < 2%g	2– 4%	< 0.1%
Methane content in upgraded gas c	> 96%	> 97%	> 96 %	> 99%
Electricity consumption d ($kWh/N·m^3$)	0.25	< 0.25	0.24–0.33	< 0.15
Heat requirement (°C)	No	No	55–80	160
Controllability compared to nominal load	+/- 10–15%	50 –100%	10 –100%	50 –100%
References	> 20	> 20	2	3

Since the quality of biomethane is similar to that of natural gas, the incorporation of biomethane in NGV, in any proportions, is possible with no modification either of the vehicles running on natural gas or of the associated distribution infrastructure. These two fuels are perfectly complementary, insofar as biomethane constitutes a renewable input to NGV, but it will be able to grow only if the NGV approach itself is well established. Investments in NGV (engine technology, larger number of stations) therefore contribute to the gradual development of biomethane vehicle fuel.

4. Gas vehicles

Biogas can be upgraded to natural gas quality and used in the same vehicles that use natural gas (NGVs). At the end of 2005 there were more than 5 million NGVs in the world. Public transport vehicles driven on gas such as buses and waste trucks are increasing considerably. In total 210’000 heavy duty vehicles are operated, there of 70’000 buses and 140’000 trucks. A number of European cities are exchanging their buses with biogas driven engines. Six of them teamed in the BiogasMax EC project to share and document their experience. Most of the gas driven personal cars are converted vehicles that have been retro-fitted with a gas tank in the luggage compartment and a gas supply system in addition to the normal liquid fuel system.

Dedicated gas vehicles can be optimized for better efficiency and also allow for more convenient placement of the gas cylinders without losing luggage space. Gas is stored at 200 to 250 bars in pressure vessels made from steel or aluminium composite materials. Today more than 50 manufacturers worldwide offer a range of 250 models of commuter, light and heavy duty vehicles. Gas vehicles have substantial advantages over vehicles equipped with petrol or diesel engines. Carbon dioxide emission is reduced by more than 95%. Depending on how the electricity for upgrading and compressing of the gas is produced, the reduction might be as high as 99%. In both leading biogas fuel countries, Sweden and Switzerland, electricity is almost free of CO_2 because it is produced by hydro or nuclear power. Emissions of particles and soot are also drastically reduced, even compared with modern diesel engines equipped with particle filters. The emissions of NOx and Non Methane Hydrocarbons (NMHC) are also drastically reduced.

Heavy duty vehicles are normally converted to run on methane gas only but in some cases also dual fuel engines have been used. The dual fuel engine still has the original diesel injection system and gas is ignited by injection of a small amount of diesel oil. The engine normally idles on diesel oil. Dual fuel engines normally require less engine development and maintain the same driveability as a diesel vehicle. However emission values are not as good as for the corresponding between spark ignition and diesel engine.

The energy content of biogas and landfill gas is dependent on its content of methane. The energy content for biogas with a methane content of 65 %, and for biogas upgraded to 97 % methane can be seen in the Table no 4, as well as the energy content of some other fuels.

Tab. 4. Energy content of biogas and some other fuels [6]

Fuel	Energy content [kWh]
1 Nm^3 biogas (65 % methane)	6.5
1 Nm^3 biogas (97 % methane)	9.7
1 litre petrol	9.1
1 litre diesel	9.8

5. Recapitulation

Biogas can be used in a number of applications including fuel for natural gas vehicles. The main environmental benefit is that fossil fuels like petrol and diesel can be replaced. Natural gas used as a vehicle fuel gives 20-30 % lower CO_2 emissions. For biogas the reduction of green house gas emissions can be as much as 100 %. In fact, a reduction above 100 % can be achieved when biogas produced from manure is utilized as a vehicle fuel. Methane, which is a strong green house gas, is released into the atmosphere from manure in traditional manure storage. Biogas as a vehicle fuel can thus both decrease the leakage of methane from manure and decrease the emissions of fossil carbon dioxide. Another advantage is that vehicles running on upgraded biogas or natural gas have lower emissions of particles, NO_x and SO_x.

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