Biogas in Sweden

Energigas Sverige – Swedish Gas Association

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1. From raw material to use

Biogas is formed when organic material is decomposed by microorganisms in an oxygen-free environment, so called anaerobic digestion. In a biogas process, many different microorganisms participate in a complex web of interacting processes which result in the decomposition of complex organic compounds such as carbohydrates, fats and proteins to the final products methane and carbon dioxide.

The main constituent of biogas, methane, is very energy-rich and can be used in several ways, for example, for production of electricity and heat. After purification, so-called upgrading, biogas can also be utilized as vehicle fuel, as a good alternative to petrol and diesel. In addition, biogas is a fuel in demand by industry, both as a fuel and as a raw material in different manufacturing processes. Biogas that is not used is flared off to avoid contributing to the greenhouse effect.

1. 1 What is biogas?

Biogas is formed when organic material is decomposed by microorganisms in an oxygen-free environment, so called anaerobic digestion. In a biogas process, many different microorganisms participate in a complex web of interacting processes which result in the decomposition of complex organic compounds such as carbohydrates, fats and proteins to the final products methane and carbon dioxide. This process occurs naturally in many environments with limited access to oxygen, for example in bogs and marshes, rice paddies and in the stomach of ruminants, such as cows.

This natural process is exploited in a biogas plant, where organic material such as sludge from wastewater treatment, manure, crops and food waste is placed or pumped into a completely air-tight container or digestion chamber (reactor). Raw biogas is formed, which mainly consists of methane and carbon dioxide, but also small amounts of nitrogen gas, ammonia and hydrogen sulphide. Biogas is often saturated with water vapour. In addition to biogas, a nutrient-rich digestion residue is also formed that may be used as a fertilizer.

1. 1. 1 Biogas data and facts - energy gas from biomass

Biogas is defined as a liquid or gaseous fuel produced from biomass with an energy content mainly originating from methane. Below some terms are explained that are sometimes used as synonyms for biogas.

Digestion gas
The biogas obtained from sewage sludge, manure, agricultural crops and food waste in a digester is sometimes called digestion gas. Digestion gas generally has a relatively high methane content (at least 55 %). Digestion gas obtained from co-digestion of different substrates is sometimes distinguished from that extracted solely from sewage sludge. Co-digestion means that many substrates are digested simultaneously in a biogas process, for example source-sorted food wastes or slaughterhouse wastes together with manure and sewage sludge. Compared with the digestion of sludge from sewage treatment plants, co-digestion usually results in biogas with a larger methane content.

Landfill gas
Gas extracted from landfills has the smallest methane content (45-55 %), because methane production from the landfill mass is not controlled and optimized in the same way as it is in a digester. Some air will also leak into the landfill as the methane is extracted by fans. Methane production in landfills is a slow process that can proceed for 30-50 years.

Liquid biogas
Liquid biogas (LBG - Liquefied BioGas) is, like liquefied natural gas, cooled, condensed methane. Biogas condenses at a temperature of c. -162°C and contains more energy per unit volume than biogas in its gaseous form. This enables biogas to be more effectively transported, which in turn helps to solve problems related to the logistics and distribution of biogas.

Bio-methane
Bio-methane is a generic name for gas that is mostly composed of methane that can be extracted from biological material, for example through anaerobic digestion or thermal gasification. The final product obtained from thermal gasification, in combination with methanation and conditioning, is called substitute or synthetic natural gas (SNG). It can be distributed and used in the same way as natural gas and upgraded biogas. SNG is produced by the decomposition of carbon-rich materials by heating. The gas that is produced undergoes several process steps before the final synthesis of methane, which is conditioned to a gas quality suitable for use as vehicle fuel or for injection into the gas grid. The technique has been demonstrated and is now being commercialized.

Biogas and natural gas of different origins
Both biogas and natural gas consist mainly of methane, although the methane molecules have different origins. Biogas is produced from the decomposition of organic material that is already in circulation in the biosphere above the earth´s crust, whereas natural gas originates from a similar anaerobic conversion of organic material that took place millions of years ago and from which the resulting gas is buried deep down in fossil layers.

1.1.2 Energy content in biogas and other fuels

A typical normal cubic metre of methane has a calorific value of 9.97 kWh, while carbon dioxide has none at all. The energy content of biogas is therefore directly related to the methane content.

Energy content in different fuels:

- 1 Nm3 biogas (97 % methane) 9.67 kWh
- 1 Nm3 natural gas 11.0 kWh
- 1 litre petrol 9.06 kWh
- 1 litre diesel 9.8 kWh
- 1 litre E85 (ethanol) 6.6 kWh

1.1.3 Clean and safe fuel - emissions negligible and lighter than air

When biogas is combusted, emissions of dust and particles into the environment are negligible. The exhaust from a biogas-driven vehicle smells less and the engine is quieter and vibrates less compared to a diesel engine. Emissions of carbon monoxide, hydrocarbons, sulphur compounds and nitrogen oxides are less than when petrol or diesel are used as fuels. The combustion of biogas gives no net release of greenhouse gases to the atmosphere, thus gives no contribution to the greenhouse effect.

Biogas is lighter than air. If a leakage should occur, methane rises through the surrounding air. Biogas has a higher temperature of ignition than petrol and diesel, which reduces the risk of fires and explosions at accidents. The gas tank has a robust construction which gives it a larger tolerance to stresses than conventional petrol tanks.

1.1.4 History of biogas

In Sweden, biogas has been produced at municipal wastewater treatment plants since the 1960´s. The primary incentive was to reduce sludge volumes. However, the oil crises of the 1970´s changed attitudes, leading to research and development into biogas techniques and the construction of new plants in order to reduce environmental problems and dependency on oil. Industry was first to act; sugar refineries and pulp mills started to use anaerobic digestion for waste water purification in the 1970´s and 1980´s. At this time, several smaller farm-sized plants were also constructed for anaerobic digestion of manure.

During the 1980´s, several landfill plants started to collect and utilize biogas produced in their treatment areas, an activity that expanded quickly during the 1990´s. Several new biogas plants have been constructed since the mid-1990´s to digest food industry and slaughterhouse wastes, and kitchen wastes from households and restaurants.

1.1. 5 Terminology

Biogas: Biogas is defined as a liquid or gaseous fuel produced from biomass with an energy content mainly originating from methane.

Bio-manure: digestion residue from biogas plants that digest relatively clean wastes such as manure, source-sorted food wastes, waste from the food industry, agricultural crops etc.

Gas yield: The amount of biogas in normal cubic metres that is produced per unit weight of organic substrate fed into the digester.

Hydraulic retention time: Average time for treatment of the material in the digester.

Digestion residue: The solid, liquid or sludge-like product that is formed after digestion, which contains water, undecomposed organic material, nutrients and microbial biomass.

Digested sludge: The residue obtained from digestion of sewage sludge.

Co-digestion: Simultaneous digestion of various substrates, which often produces more methane than when each substrate is digested separately.

SNG: Substitute natural gas, a gas equivalent to natural gas which is produced from gasification of coal, biomass or other materials consisting of carbohydrates.

Upgraded biogas: Biogas that has been purified (upgraded) to vehicle fuel quality, with a methane content of c. 97 %.

Degree of digestion: Indicates, as a percentage, how much of the organic material has been converted into biogas during a certain period of time. This can be used to estimate effective digestion periods for a given material.

Units

- Nm3 — Normal cubic metre, volume of gas at atmospheric pressure (1,013 bars) and 0°C
- KWh — Kilowatt hour
- MWh — Megawatt hour (1 MWh = 1 000 kWh)
- GWh — Gigawatt hour (1 GWh = 1 000 MWh)
- TWh — Terawatt hour (1 TWh = 1 000 GWh)

- DW (%) Dry weight
- VS (%) Volatile solids. Organic content, i.e. dry weight minus ash, in, for example, a substrate

1.2 Production of biogas

Many different organic materials are suitable as substrates in a biogas process, such as sludge from wastewater treatment plants, food waste, manure, plant material and process waters from food industries. In some cases, pre-treatment is necessary for optimal function of storage systems, pumping, stirring/agitation and microbial decomposition.

The biogas process can be divided into three main steps; hydrolysis, fermentation and methane formation. In the first step, microorganisms, aided by enzymes, decompose the complex organic compounds to simpler compounds such as sugar and amino acids. A number of intermediate products are formed in the next step (fermentation), including alcohols, fatty acids and hydrogen gas. Methane is formed in the last step by a unique group of microorganisms. The raw biogas that is produced consists of mainly methane and carbon dioxide.

In order to use biogas as a vehicle fuel, its energy content must first be increased by removing carbon dioxide, so-called upgrading. Water and contaminants such as hydrogen sulphide and particulate matter must also be removed. This is done in a so-called upgrading plant.

Methane may also be produced through thermal gasification and methanation. This technique has been demonstrated and is now being commercialized.

1.2.1 Substrate - the raw material for biogas production

Many different organic materials are suitable as substrates in a biogas process, such as sludge from wastewater treatment plants, food wastes from households and restaurants, manure, different plant materials and process waters from food industries. Co-digestion of various materials often gives a higher methane yield, that is the produced amount of biogas per unit of organic matter fed into the digester is larger than when each substrate is digested separately.

1.2.2 Pre-treatment - for purity, and the proper consistency and water content

Some substrates need to be pre-treated for optimal function of storage systems, pumping, stirring/agitation and microbial decomposition, as well as to eliminate contamination. Dry materials may need wetting, while highly liquid substrates, for example wastewater and sludge from sewage treatment plants, must be de-watered to prevent them from occupying too much of the digester volume. Foreign objects (e.g. plastic, metals) must be removed from source-sorted food wastes originating from households and shops etc.

Techniques used in practice include mincing and disruption using mills or cutting tools. Substrates that are particularly difficult to decompose may need some kind of chemical or thermal pre-treatment to increase their availability to the microorganisms.

1.2.3 Anaerobic digestion - a microbial process in which methane is formed

The biogas process can be divided into three main steps. In the first step (hydrolysis), microorganisms, aided by enzymes, decompose the complex organic compounds to simpler compounds such as sugar and amino acids. A number of intermediate products are formed in the next step (fermentation), including alcohols, fatty acids and hydrogen gas. Methane is formed in the last step by a unique group of microorganisms that have very specific environmental requirements.

Methane producing microorganisms grow slowly and die if they come into contact with oxygen. They also need access to certain vitamins and trace elements and are sensitive to rapid changes in temperature, acidity (pH) etc.

The digester
The biogas process can be designed in different ways. The biogas is collected from the top of the container, while the substrate is usually pumped in. The residue is removed by pumping or through an overflow for later storage or recirculation to the process. The one-step digester, which uses a single reactor for the complete microbiological process, is the simplest and commonest design. All decomposition steps take place simultaneously and in the same container.

The two-step digester is another variant, in which the process takes place in two consecutive steps. Hydrolysis and fermentation take place in the first reactor, although some methane is also produced. The residue or leachate from the first chamber is then fed into the second reactor, which is specially adapted for methane production. For example, it can be designed as an anaerobic filter with inbuilt carrier materials to which the microorganisms can attach, so that they grow better. This often results in a fast and effective production of biogas with methane contents of up to 85%.

Supply of substrate
Continuous digesters treating liquid substrates (e.g. municipal and industrial wastewaters) continuously pump new material into the digester, giving a constant inflow of substrate throughout the day. Sludge-like materials such as manure and sewage sludge can also be fed into the reactor more or less continuously, in a process called semi-continuous digestion. Solid materials such as crop residues and food wastes are normally fed to the process less frequently and in larger portions.

Temperature
Temperature is an important factor to consider in anaerobic digestion. Biogas processes are generally run at one of two different temperatures: 37oC (mesophilic) or 55oC (thermophilic). Mesophilic and thermophilic microorganisms grow best at these temperatures. Heat must be supplied to the biogas process since, in contrast to an aerobic compost, it is not self-heating.

1.2.4 Raw biogas - equivalent to not cleaned biogas

Methane constitutes the energy-rich part of biogas. Biogas is composed of 45-85% methane and 15-45% carbon dioxide, depending on the conditions during production. Biogas also includes small amounts of hydrogen sulphide, ammonia and nitrogen. Biogas is often saturated with water vapour.

1.2.5 Upgrading - various techniques for purifying biogas

In order to use biogas as vehicle fuel, its energy content must first be increased by removing carbon dioxide, so-called upgrading. Water and contaminants such as hydrogen sulphide and particulate matter must also be removed. Upgraded biogas is 'odourised' with a scented additive to enable the detection of any gas leaks. Finally, the gas must be compressed under a pressure of c. 200 bars before it can be used. Upgraded biogas has a methane content of about 97% and can therefore be used in the same way as natural gas.

Common techniques
Physical absorption (water wash) is the commonest technique for upgrading biogas. The method is based on the fact that carbon dioxide is more soluble in water than methane. A variant of this method is to use a solvent that absorbs carbon dioxide more efficiently than water. Other methods include absorption with a solution of dimethylether derivative (trade names Genosorb and Seloxol) or absorption by a chemical reaction with a solvent (trade name Cooab). Pressure swing adsorption (PSA), which separates different substances on the basis of their molecular size, is another common technique employed to upgrade biogas.

Liquid biogas by cryogenic upgrading
Carbon dioxide can also be separated from methane using cryogenic technology. This method is based on the fact that the two gases have different boiling points, which means that carbon dioxide can be removed by cooling the biogas to a liquid form. Gaseous methane will be converted into a liquid form at -162 oC. Liquefied biogas (LBG) has advantages concerning transportation, as it is three times denser than the corresponding gaseous compressed biogas (CBG). The liquefied carbon dioxide can be used as a coolant in the food industry or in refrigerated transport.

1.2.6 Digested residue - contains microorganisms and nutrients

The organic material is rarely completely decomposed during the process. A digestion residue is formed, which apart from water and organic material, also contains microorganisms and various nutrients. The digested material removed from the reactor is usually covered during storage, for example with chopped straw or a gas-tight membrane, to prevent losses of methane, nitrous oxide and ammonia.

1.2.7 Biogas from landfills forms spontaneously

Landfill gas may be extracted from landfills that contain a large amount of organic materials, mostly household waste. This gas forms spontaneously and may be extracted with the help of perforated pipes (so-called gas wells) that are drilled or pressed into the landfill. The composition of landfill gas differs from other biogas, since it often contains a fairly high amount of nitrogen gas, which originates from air leaking into the landfill when the biogas is extracted. The amount of nitrogen gas depends on the pressure used to extract the gas as well as on the compactness of the landfill. Landfill gas also contains a variety of different trace elements. Some of these may have a negative effect on the environment or may be corrosive. The composition of landfill gas changes over time due to changes in the decomposition environment in the landfill.

1.2.8 Thermal gasification - a hot topic for development

Thermal gasification is performed by a controlled heating of different woody raw materials and carbon-rich waste products. The carbohydrates are broken down to mainly carbon dioxide and hydrogen gas (synthetic gas). This gas can then be used to produce a variety of different fuels, for example bio-methane that is made by methanation of the synthetic gas. Provided it has the right quality, bio-methane can be used as a substitute for natural gas in practically all applications. The technique has been demonstrated and is beginning commercial operations. For example, there is a research plant in Gothenburg, which is a collaboration between Chalmers Technical University and the municipality-owned company Göteborg Energy AB.

Read more about thermal gasification under Research/Development.

1.3 Use of biogas

The energy in biogas can be exploited in different ways. For example, it can be used for local heating or remote heating (via district heating networks). Biogas can also be used to generate electricity, thus contributing to an increased proportion of ‘green electricity’ distributed through the grid.

Biogas as vehicle fuel is the area of application increasing the most rapidly. Biogas that has been purified and upgraded to contain a high proportion of methane may with advantage be used as a vehicle fuel. Methane can also be used as a raw material in various manufacturing processes, with diverse final products such as paints, plastics, furniture, animal feeds and lubricant oils.

In addition, the biogas process generates a nutrient-rich digestion residue, that can be used as a fertilizer.

1.3.1 Heat - the most common use

Biogas can be used for local heating or remote heating (via district heating networks). For heat production, only water vapour needs to be removed from the gas prior to combustion.

Boilers are found at most biogas plants, where the gas is often used to heat nearby buildings. Excess heat can be distributed to more distant premises, either directly through gas pipes or indirectly through district heating networks.

1.3.2 Combined power and heat - green electricity in the grid

Biogas can be used to produce both power and heat in the same plant. About 30-40 percent of the energy can be extracted as electricity and the remainder as heat. As in the case when only heat is produced, the gas must be dried before combustion. In addition, particulate matter and, if necessary, any corrosive substances (e.g. hydrogen sulphide) must also be removed.

Diesel and gas engines (e.g. the Otto engine) are well suited to small-scale power plants. One kind of diesel engine, the so-called dual-fuel engine, found, for example, at some German biogas plants can be driven on both diesel and gas. Gas turbines can be used at larger plants. Micro-turbines in the range between 25 and 100 kilowatts have been introduced in recent years for the combined production of power and heat from biogas.

1.3.3 Vehicle fuel - the best bio-fuel

Biogas that has been upgraded, i.e. when the carbon dioxide has been removed, to a methane content of c. 97 % may be used as vehicle fuel, presenting a good alternative to petrol and diesel. The use of biogas as a vehicle fuel is continuously growing. Most filling stations to date are found in south and west Sweden, but the number is also increasing in other parts of the country. Both biogas and natural gas are called vehicle gas when they are used as fuel.

Cars that run on vehicle gas are often called bi-fuel cars because they have separate tanks for petrol and gas. The same engine is used for both fuels and the car automatically switches to petrol if the gas runs out.

On the other hand, gas-driven heavy vehicles such as buses and trucks are built to run only on gas. The Otto engine is normally used, which means that fuel consumption is somewhat higher than for diesel engines. The dual-fuel engine, which can run on both vehicle gas and diesel, is now being introduced onto the market. Up to 90% of the diesel can be replaced by gas. This engine is an environmentally-friendly alternative that is suitable for heavy vehicles, because of the low fuel consumption and low emissions of nitrogen oxides, particulate matter etc.

1.3.4 Industry - biogas as raw material

Methane burns with a clean and pure flame, which means that boilers and other equipment are not clogged by soot and cinders. This leads to a cleaner workplace environment and less wear and tear on the plant. The methane molecule can also be used as a raw material in many different manufacturing processes, with diverse final products such as paints, plastics, furniture, animal feeds and lubricant oils. By using their own biogas, for example from digestion of various wastes and industrial process waters, enterprises can become self-sufficient in heat and electricity.

1.3.5 Digestion residue - bio-manure and digested sewage sludge

The residue from the biogas process may be used as fertilizer providing that it does not contain contaminants (e.g. heavy metals, infectious microorganisms or residues of medicines or pesticides etc.). Visible contaminants such as plastic and glass objects are also unacceptable.

Digestion residues can be classified as bio-manure or digested sewage sludge, according to their origin (i.e. the substrate used). In general, we can say that a contaminated raw material will give a contaminated final product. Careful source-sorting is therefore critical for a successful outcome. The residue produced at biogas plants that digest relatively uncontaminated organic wastes such as manure, source-sorted food wastes, crop residues, process water from the food industry etc. is usually termed bio-manure. It has a similar consistency to liquid cattle or pig manure and is rich in nutrients. There are usually no problems with contamination and the bio-manure is therefore well suited for use as a fertilizer in agriculture.

Digested sewage sludge originating from water treatment plants usually has a high water content, so that de-watering is required before spreading. The sludge often has a high phosphorous content, which is valuable from the point of view of plant nutrition. However, the content of heavy metals can limit its use in agriculture. After mixing with structural materials such as sawdust and sand, the digested sludge is typically used as a filler material in the construction of roads, golf courses etc. or as a cover material in landfills.

1.4 Distribution

Biogas can be distributed in separate pipes or through the existing gas grid. It can also be transported as compressed gas or in liquid form. New systems for storage and distribution of biogas are being developed, now that it is increasingly used as a vehicle fuel.

1.4.1 Gas pipelines - biogas can be co-distributed with natural gas

Local consumption of biogas in the vicinity of the plant is still commonest. A pipe is laid from the production plant to one or more users. Gas up to pressures of 4 bars can be distributed in pipes constructed of plastic (polyethylene).

The sale and marketing of biogas is considerably helped by the possibility of connecting biogas production plants to the general gas grid, which stretches along the west coast from Malmö to Stenungsund. Temporary peaks in production can then be effectively regulated, for example in the summer when heating requirements are lower and locally produced biogas is often 'flared off'. Before the gases are mixed in the grid, a long-chain hydrocarbon (usually propane) is added to the upgraded biogas to attain the same energy content as natural gas and thus to ensure a fair debiting of customers.

1.4.2 Road transport - less volume with liquid methane

Upgraded and compressed biogas can be distributed on a trailer in a mobile container system. This is the commonest way of transporting biogas by road today. A new technique under development is to cool the biogas to liquid form (Liquefied BioGas, LBG) by cryogenic upgrading.

Compared with gas at atmospheric pressure, the energy per litre is concentrated 600 times by converting methane to liquid form. A big advantage with the cryogenic technology is that it makes it possible to transport the gas longer distances even in the absence of pipelines, for example on ships or with trailers.

1.4.3 Spreading bio-manure - with trailing hose spreader or in pipeline

Bio-manure is usually spread using a tractor equipped with a manure container and trailing hose spreader. Another method is being employed in Helsingborg, in which bio-manure is pumped out to farms in buried pipelines. This avoids the need to transport the bio-manure to the fields by truck, thus saving energy. It also ensures that the bio-manure does not come into contact with substrates that have not yet been pasteurized. This can otherwise be a risk if the same trucks are used to transport both the raw substrate and the final bio-manure to and from the plant.

1.5 Environment and society

One of the most important tasks we are faced with today is to reduce our exploitation of the earth's finite resources and to develop systems for re-cycling nutrients and energy that are sustainable in the long-term. In the biogas process, waste is converted into energy and hence, the exploitation of finite resources is reduced.

1.5.1 Environmental goals - national goals for a better environment

The Swedish government has defined 16 national environmental goals for environmental quality. Most of these are to be fulfilled by the year 2020. Biogas can make a positive contribution to meeting many of these targets including, for example, 'only natural acidification', 'limited climate change', 'no eutrophication', and 'high-quality urban environments'.

Under the heading of 'high-quality urban environments' there is a goal set such that at least 35% of food wastes from households, restaurants and shops should be recycled through biological treatment by 2010. In 2009, c. 21% of food wastes was treated biologically in various compost and biogas plants. In addition, deposition of organic waste in landfills was banned in Sweden in 2005.

Another target under 'high-quality urban environments' states that by 2015, at least 60% of the phosphorous in sewage should be recycled to productive land, with at least half

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being returned to arable land. Application of the nutrient-rich residue from the biogas process on agricultural land should help to meet these targets.

1.5.2 Benefits to society - increased employment and a thriving countryside

Production of biogas offers many benefits to society. For example, new jobs are created, we help rural areas to thrive and we get a clean fuel for industry.

Increased employment
Promoting biogas implies an investment in job creation and regional development. The involvement of many interested parties in planning, construction, cost estimation, production, control and distribution is needed to ensure the successful development of biogas as a fuel.

Sustainable energy resource
The development of biogas represents a strategically important step away from oil dependence which will contribute to a sustainable energy supply in the long-term.

A thriving countryside
One of the advantages of biogas technology is that it can be established locally without the need for long-distance transportation or import of raw materials. Small or medium-sized companies and local authorities can establish biogas plants anywhere (i.e. they need not be sited in any particular location, for example, in or close to large cities).

Sustainable waste management
Utilizing organic wastes reduces the amount that must be taken care of in some other way, for example by combustion.

Clean fuel for industry
Methane is a fuel in demand by industry, partly because it is a gas, which gives a high-quality combustion that can be precisely controlled. Methane burns with a clean and pure flame, which means that boilers and other equipment are not clogged by soot and cinders. This leads to a cleaner workplace environment and less wear and tear on the plant.

1.5.3 Environmental benefits - biogas is the most environmentally-friendly vehicle fuel

The biogas process has many advantages from the point of view of the environment, especially since it results in two environmentally-friendly final products, biogas and bio-manure. Biogas is the most environmentally-friendly vehicle fuel on the market today, and can also be used to generate electricity, produce heat and as a raw material in industry.

A renewable source of energy
Biogas is a renewable source of energy. The carbon dioxide that is released when biogas is combusted and mixed with the oxygen in the air does not contribute to the greenhouse effect. The carbon in the methane molecule produced by the biogas process originates from the carbon dioxide in the air that growing plants have previously taken up by photosynthesis.

Environmentally-friendly fuel
Biogas gives the smallest emissions of carbon dioxide and particulate matter of all vehicle fuels on the market today. A gas engine is quieter and vibrates less than a diesel engine, which means a better working environment for professional drivers. Calculations

show that replacing fossil vehicle fuels by biogas reduces the carbon dioxide emission per unit of energy by 90%. The benefits can be doubled if biogas is produced from manure, since this decreases emissions of both methane and fossil carbon dioxide. The reduction, measured in carbon dioxide equivalents, can then be as large as 180% per unit of energy.

A valuable fertilizer

All the nutrients in the original substrate (e.g. nitrogen, phosphorous, potassium, calcium and magnesium) are retained in soluble and plant-available forms in the residue, and cannot be lost by leaching, since the digestion takes place in closed containers. Using digestion residues reduces the need for mineral fertilizers.

Reduced methane emissions

Methane is a greenhouse gas. In a 100-year period, its contribution to the greenhouse effect is c. 20 times greater than that of carbon dioxide. One problem with conventional methods of handling and storing manure is that spontaneous emissions of methane can occur. These methane emissions can be avoided by digesting the manure in closed chambers (reactors) where all the methane is collected as biogas for later combustion.

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2. Biogas in Sweden and world-wide

Sweden has come a long way when it comes to utilization of biogas and has pioneered the purification of biogas to vehicle fuel quality. Although the building of biogas plants has been promoted for several years, demand for biogas is still greater than the supply in many regions.

Below you can read about biogas statistics, research and development, and about some successful biogas projects.

2.1 Swedish case studies

Download at: www.energigas.se/Publikationer/Rapporter.aspx

2.2 Biogas in figures

In 2009, 1.4 TWh of biogas was produced at 230 Swedish digestion plants. A greater proportion of this biogas was used in 2009 compared with previous years: 49% was used for heating, 5% for producing electricity, 36% was upgraded, and only 10% was flared off. Different kinds of waste constituted the main substrates for biogas production, including sewage sludge, source-sorted food wastes and wastes from the food industry.

2.2.1 Production - sewage treatment plants produce most biogas

1363 GWh of biogas was produced in Sweden in 2009. Sewage treatment plants were the largest source (c. 44%, 605 GWh), while 25% (335 GWh) originated from landfills, 22% (299 GWh) from co-digestion plants and 8% (106 GWh) from industrial plants. Small-scale on-farm biogas production contributed 1% (18 GWh) to the total production.

Total biogas production in 2009 was similar to 2008, but the contributions from the different types of plant had changed. Production from co-digestion and farm-scale plants increased, while it remained unchanged at sewage treatment plants. Biogas production from landfills and industrial plants decreased between 2008 and 2009.

2.2.2 Use - the importance of biogas as a vehicle fuel is increasing

The primary use of biogas today is for heating, either for the producer's own buildings or processes or for their customers. In 2009, 49% (667 GWh) of the total biogas production (1363 GWh) was used for heating, 5% (64 GWh) for producing electricity, 36% (488 GWh) was upgraded, and 10% was flared off (no information is available for the remaining 1% of total production). The proportion of biogas that was upgraded increased by 37% between 2008 and 2009, which was proportionally the largest increase of any area of use. Most of the upgraded biogas is used as vehicle fuel.

Of the upgraded biogas, 151 GWh was injected into the existing natural gas network in south-west Sweden, at stations located at Laholm, Falkenberg, Helsingborg, Malmö, Bjuv, Göteborg and Lund.

2.2.3 Production plants - most biogas plants are located in Skåne

In 2009, biogas was produced at 230 digestion plants in Sweden (136 sewage treatment plants, 4 industrial plants, 21 co-digesters, 57 landfills and 12 farm-based plants).

The total digester volume was slightly less than 500 000 m3. Sewage treatment plants contribute the greatest total digester volume, but individual digesters are generally largest at the industrial plants. There is a large range of digester volumes, from the smallest at c. 100 m3 to the largest with a total volume of 30 000 m3.

Biogas is upgraded to natural gas quality at c. 40 plants in Sweden.

2.2.4 Prognoses for biogas production - the target is 3 TWh by 2012

Based on c. 50 planned and ongoing biogas projects across the country, production in 2012 is expected to reach c. 3 TWh. However, some of the planned projects are not yet fully financed.

2.3 The potential of biogas - almost fully meets the needs of the transport sector in Sweden

A study was carried out in 2008 on the potential biogas production from natural waste products in Sweden. These included all available organic wastes from households, restaurants and large kitchens, shops, parks and gardens, as well as all sewage sludge, manure, crop residues and various industrial wastes. The study considered the potential for digestion and that for thermal gasification of forest raw materials separately.

It is neither practicable nor economically viable to collect all available substrate for digestion. For example, manure cannot be collected in the summer from cows that graze outdoors. Not all local authorities have separate collection systems for organic wastes. Furthermore, there are other competing uses for organic wastes, such as animal feeds derived from waste products from crop production and the food industry or the use of straw for animal bedding.

The total biogas potential from domestic waste products, excluding forest raw materials, was calculated to be 10-15 TWh per year. Forest waste products represent a significant potential for future biogas production. The total energy potential in waste products from forestry and the forest industry was calculated to be 59 TWh per year. Methane is produced from woody raw materials by thermal gasification, a method which has not yet been tested at full-scale. It is therefore difficult to assess when the technique will become commercially available.

Thus, the biogas and energy potential of natural waste products in Sweden amounts to c. 74 TWh per year. Forest waste products represent c. 80% of this total.

2.4 Research and development

Research and development projects are ongoing on many sub-topics within the broad subject of biogas. Biogas and bio-methane can be produced in many different ways, including anaerobic digestion, production of SNG by thermal gasification and methanation and production of landfill gas.

Research is being carried out on all these different production methods to increase and optimize gas production to achieve high yields whilst minimizing energy consumption and environmental impacts. Research and development work is also focused on the distribution and use of biogas. Some information on R & D work on biogas in Sweden is given below.

2.4.1 Digestion - improved techniques to increase production and use of biogas

One main objective of R & D work on biogas is to increase the production and use of biogas by developing improved techniques. The biogas system is complex and therefore requires that many interested parties co-operate to ensure that all parts of system interact properly. R&D work is being carried out on several different sub-topics of the biogas system:

- increasing the degree of exploitation of the biogas potential in Sweden
- improving the efficiency of biogas production
- increasing the possibilities for the sale and marketing of biogas
- reducing environmental, health and climate impacts

2.4.2 Thermal gasification - gasification of biomass

The objective of R & D work in thermal gasification is to find techniques, materials, systems, and methods of quality control that will lead to the development of sustainable systems for the production of renewable energy gases. Special emphasis is placed on building knowledge and capacity related to the sustainable domestic production of energy gas from bio-fuels and other renewable energy sources. The technique of gasification of biomass is in the development stage and has still not been demonstrated at commercial scale plants.

Production of biogas by gasification of biomass has been demonstrated at the mega-watt scale in Güssing in Austria. The first commercial plant is being planned in Gothenburg, as part of the GoBiGas project, where the goal is to begin operations in 2012.

The following research reports may be consulted for more information on gasification:

- Gas Cleaning, downstream biomass gasification, Status Report -2009
- Substitute natural gas from biomass gasification -2008
- International Seminar on Gasification – 2008
- International seminar on gasification and methanation -2007
- Country Report Sweden, IEA Task 33 Thermal Gasification of Biomass -2008
- High efficiency power production from biomass and waste -2008
- Production of Synthetic Natural Gas(SNG) from Biomass -Development and operation of an integrated bio-SNG system - 2006

Download the reports at:
www.biogasportalen.se/BiogasISverigeOchVarlden/FoU/Termiskforgasning.aspx

2.4.3 Biogas from landfills - for more efficient extraction and reduced emissions

R&D work on landfill gas is focused on the development of methods and techniques to improve understanding of the internal structure of a landfill and the movement of gas and water, in order to better exploit the energy potential in the gas and reduce emissions to the atmosphere and water resources. R&D work is being carried out on several different topics related to landfill systems:

- more efficient gas extraction from landfills
- quantifying gas emissions from landfills in Sweden
- reducing emissions of landfill gas to the atmosphere and climate impacts
- new ways to use landfill gas

2.4.4 Distribution - for lower costs and reliable delivery

The objective of R& D work on distribution is to find techniques, materials, systems, and methods of quality control that will lead to lower investment, running and maintenance costs, improved reliability of delivery and a high degree of safety in the distribution of energy gases.

Currently, energy gas is distributed in either plastic or steel pipes. Research is being carried out on the resistance of plastic pipes to mechanical and corrosive forces. For steel pipes, corrosion is the main topic of interest, which can be caused by unfavourable soil conditions, electrical or electromagnetic forces or the effects of new gases and gas mixtures.

2.4.5 Use - focus on industrial applications

Landfill gas and biogas that is not upgraded is used primarily to produce heat and/or electricity. Upgraded biogas and bio-methane from gasification can be used as vehicle fuel or in industrial processes. Research on industrial applications includes, for example, optimizing engine performance, the development of gas turbines and use in power stations, process chemistry, heating and cooking. Research is also being carried out on the influence of gas quality and impurities in the gas on the performance of vehicle engines and gas turbines.

The following research reports may be consulted for more information.

Industrial use

- Catalytic burners in larger boiler appliances - 2009.
- Hydrogen Production for Refuelling Applications - 2009.
- The potentials for integration of black liqour gasification with gas fired paper drying processes - A study from the energy cost perspective - 2006.

Power and heat production

- An improved reactor system for small-scale fuel processing - the Optiformer concept-2008.
- Microturbine Energy Systems - The OMES Project-2004.

Vehicle gas

- Refuelling stations for hydrogen or reformate gas-2006.

Download the reports at:
www.biogasportalen.se/BiogasISverigeOchVarlden/FoU/Anvandning.aspx

2.4.6. Links - R&D organizations

Sweden:

- Elforsk - www.elforsk.se/In-English1/
- JTI – Swedish Institute of Agricultural and Environmental Engineering - www.jti.se/index.php?page=english

- SGC, Swedish Gas Centre - www.sgc.se/uk/index.asp
- SP - www.sp.se/en/Sidor/default.aspx
- Swedish Energy Agency - www.energimyndigheten.se/en/
- Swedish Environmental Proctection Agency - www.naturvardsverket.se/en/
- Swedish Waste management - www.avfallsverige.se/topmenu/in-english/
- The Swedish Research Council Formas - www.formas.se/default____529.aspx
- The Swedish Water and Wastewater Association - www.svensktvatten.se/web/english.aspx
- Värmeforsk - www.varmeforsk.se/eng-start
- Vetenskapsrådet - www.vr.se/inenglish/aboutus.4.69f66a93108e85f68d48000123.html
- Vinnova - www.vinnova.se/en/
- Waste Refinery - www.wasterefinery.se/sv/Sidor/default.aspx

International:

- VTT is an independent expert organization with R&D on technical and technical/economical issues - www.vtt.fi/?lang=en
- Energy Research Centre of the Netherlands - www.ecn.nl/home/

2.5 International

The situation with respect to biogas production differs greatly between different countries. In some countries, biogas is produced for household needs in small plants, while others produce biogas in large industrial plants. In many countries, including many in Europe, most biogas is produced in landfills. The use of biogas also varies greatly among countries and different parts of the world. In Sweden, some of the biogas produced is upgraded and can therefore be used as a vehicle fuel or as a replacement for natural gas by injecting it into the gas network.

The European bio-fuels organization AEBIOM has produced a road map for biogas in Europe, which can be downloaded here:

www.aebiom.org/IMG/pdf/Brochure_BiogasRoadmap_WEB.pdf

2.5.1 Statistics - from EurObserver and Eurostat

It is difficult to estimate global biogas production. There is, however, better information for Europe, thanks to the statistics on biogas production and use published by EurObserver and Eurostat.

EurObserver publishes so-called barometers for several different types of renewable energy. They also produce an annual summary of all the barometers published during the year. These publications contain information from the previous year, so that some of the data are estimates.

- Summary of barometers. Statistics here: www.biogasportalen.se/BiogasISverigeOchVarlden/Internationellt/Statistik.aspx

Eurostat is the EU's statistical office. They summarize statistics at the EU level to support political decision-making. Information on, for example, biogas production in EU member states can be found on the Eurostat home page.

2.5.2 Links - links to networks and organizations

International organizations
National networks and organizations

2.5.3 International biogas projects - examples

GasHighWay - the objective is to encourage production of biogas and its upgrading for use as vehicle fuel in a number of countries with small markets for methane-driven vehicles (Finland, Estonia, Poland, Czech Republic, and to a certain degree, Austria).

MaDeGasCar - this is an EU project with the objective to increase the number of vehicles driven by alternative fuels in European countries, with an emphasis on light vehicles.

Bio-SNG - this EU project (Demonstration of the production and utilization of synthetic natural gas (SNG) from solid bio-fuels) demonstrates the production of bio-methane via gasification and methanation of wood chips. The bio-methane is intended to be used as a vehicle fuel.

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3. Become a producer of biogas

There is a great potential for biogas production in Sweden. If you, as a farmer or a civil servant working for a local authority, are considering whether biogas could be produced on your farm or in your municipality, this section is intended for you. It is divided into three main sub-sections: i.) Getting started, ii.) Economic support and incentives, and iii.) Lessons learned. You will find information on various support and incentive systems, regulations and regulatory bodies, and decision-support tools to help you plan.

3.1 Getting started

A number of factors determine which kind of plant is most suitable. It is important to consider the availability of different kinds of substrate, both now and in the future, the quantities of substrate to be digested, and what the gas will be used for. Certain substrates, for example, slaughterhouse wastes, must be pasteurized before it can be digested.

Basic questions

- What are the conditions and factors that might affect production?
- What and how much can be digested?
- Is the substrate available all year around, also in the future?
- How to design the biogas plant?
- What permits are needed?
- What is the cost of building the plant and what is the depreciation?
- How many employees will be needed to run the plant?
- What will the biogas be used for?
- Will the biogas be upgraded, and if so, with what technique?
- Who is the customer?
- What will be the costs of distribution?

The suitability of a substrate as raw material for biogas production

- Dry weight (DW %). A low dry weight means that the substrate is easier to pump, but it might need more stabilization
- Organic content (VS %)
- Nutrients
- Risk for mechanical problems
- Influence on the quality of digestion residue
- Digestibility
- Biogas yield
- Need for pre-treatment
- Risk for microbiological problems
- Odour problems

3.1.1 Advice and decision-support - consult an expert or simulate a market. Can your local authority produce biogas?

The Falköping model is an EXCEL-based decision-support tool for biogas production. The idea behind the tool is to simulate a biogas market based on known production conditions. The Falköping model is part of Biogasmax and was developed in a collaboration between SWECO, the local authority at Falköping and Transport and Travel Research Ltd. Contact FKModel for more information.

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3.1.2 Permits and inspections - regulations and regulatory authorities

Planning permission and permits are required to build and run a biogas plant in Sweden to satisfy various laws and regulations. This is the case for the complete biogas plant, including storage facilities for gas and digestion residues, and equipment and pipelines for gas.

Different authorities are responsible for different regulations, and no single authority can make an overall assessment. It is always the case that the person planning the biogas plant is responsible for making sure that all necessary permits are obtained and that inspections are carried out.

Obtaining permits
Environmental regulations specify whether a business which potentially poses environmental risks requires a permit, and how an assessment should be carried out. In some cases, a permit will be required, but in others, it may be sufficient to notify the local authority.

Regulations on animal by-products
Substrates of animal origins (e.g. manure, food wastes, slaughterhouse wastes) must be pasteurized (heated to 70oC for one hour) before it can be digested in a biogas plant. Exceptions can be made for on-farm digestion of manure if the residue is applied on-farm and not transported to other farms.

Insurance
Before they will insure a biogas plant, insurance companies usually stipulate that:

- an expert classifies the plant into risk zones etc.
- the plant is built according to the 'Energy Gas norm' and instructions published by Swedish Gas Association
- the person responsible for running the plant has attended the 'Gas plant' training course
- the County Council, local authority and emergency authorities are contacted to check whether permits are needed
- an authorized surveyor checks the plant and any building it may be located in

3.1.3 Challenges - avoiding problems and limitations

Biogas and bio-manure benefit both the environment and society in many ways. As such, biogas will surely play a significant role in the future, with respect to energy supply and waste management in Sweden. However, some potential problems and challenges need to be addressed and resolved if biogas production in Sweden is to continue to increase.

Methane leakage
Methane is a greenhouse gas, so that leakages during handling and treatment of biogas and digestion residues should be avoided. The organization for waste management and recycling, 'Avfall Sverige' (Swedish Waste Management), has initiated a voluntary scheme whereby biogas producers regularly perform an inventory of emissions. Any leaks that are discovered during the inventory must be dealt with.

Prior to spreading, bio-manure should be stored and transported in closed containers. In this respect, it is important to note that methane losses from bio-manure are much less than when fresh manure is handled.

Odours
Problems caused by odours are sometimes experienced at biogas plants, usually in

connection with waste deliveries prior to digestion. New technologies are being developed to address these problems. For example, some plants have installed compost filters that reduce odours during handling and pasteurization of fresh wastes.

Contaminants in digested sludge
The digestion residue produced by anaerobic decomposition of the sludge from sewage treatment plants can contain undesirable substances, such as residues of pesticides, medicines and relatively high concentrations of heavy metals. These digestion residues are not comparable to the bio-manure produced at plants that digest cleaner organic wastes, such as manure, crops, source-sorted food waste and clean process liquids from the food industry. Bio-manure is uncontaminated, and its quality is assured by certification (SPCR 120).

Work is ongoing at sewage treatment plants to improve the quality of the digestion residue and therefore extend its uses. In this context, it is important to work 'upstream', that is to detect and eliminate undesirable substances in the wastewater before it reaches the treatment plant.

Competition for agricultural land
No direct competition with food production will occur if the land that is today in set-aside in Sweden (10-15% of the cultivated area) is instead used to grow crops for bio-energy. Thus, growing crops for biogas is an effective way of utilizing the land, maintaining its capacity for future crop production. Marginal land that would otherwise become re-forested can be advantageously exploited for biogas production. Furthermore, arable land is most effectively utilized when the by-products of food production such as tops and other crop residues are used to produce biogas. However, even if there is no real conflict with food production, competition could arise if land was used to grow crops for alternative means of producing energy (e.g. ethanol).

3.2 Economic support and incentives - to achieve energy and climate political targets

A number of economic incentives and measures have been introduced in Sweden to meet the political targets that have been set up in relation to energy and climate policy within the EU. The most important of these is energy taxation, which encompasses energy, carbon dioxide and sulphur taxes. Other important measures include the electricity certificate system, the climate investment and energy efficiency programs, and trading in emission allowance units. These are described below.

Energy taxation
The tax system today mainly aims to promote energy efficiency and encourage the development and use of renewable energy resources in Sweden. It includes energy, sulphur and carbon dioxide taxes. Different fuels are taxed at different rates, depending on the pollutant emissions they give rise to and how they are used. All taxes are subject to VAT, which means that reported taxes and tax advantages for end-users increase by 25 %.

A new proposal for fuel excises was presented to Parliament on 22nd October 2010, that specifies energy and carbon dioxide taxes for 2011, 2013 and 2015.

Vehicle fuel
Carbon dioxide neutral vehicle fuels have been tax-fee since 2004, and will continue to be so until 2013 according to current Parliamentary decisions. However, the law on energy taxes changed on 1st January 2011, such that biogas is now subject to tax, but that this cost is tax-deductible for the plant owner.

In 2010, biogas has a competitive tax advantage equivalent to c. 0.1 Swedish Crowns/kWh compared with natural gas. This will increase successively to c. 0.22 Swedish Crowns/kWh by 2015 due to tax increases on natural gas. Compared with petrol, biogas has a competitive tax advantage of c. 0.6 Swedish Crowns/kWh in 2010, which will increase to 0.64 Swedish Crowns/kWh by 2015. Compared with diesel, the equivalent figures are 0.44 and 0.52 Swedish Crowns/kWh respectively.

Heat
Heat production is liable for energy and carbon dioxide taxation and in certain cases charges are also levied for sulphur and nitrogen emissions. On the other hand, consumers are not charged. No energy taxes are charged when biogas is used for heat production. Biogas is also exempt from the carbon dioxide tax, which is not the case for fossil fuels.

Electricity
Energy and carbon dioxide taxes are not levied on electricity generation. Instead, the consumer is charged a combined electricity tax. In some cases, electricity producers are liable for taxes charged for nitrogen and sulphur emissions. A special system has been introduced (electricity certificates) to encourage the generation of electricity from renewable resources, since the use of tax exemptions on production is not a viable option.

Electricity certificates
A support system based on electricity certificates was introduced in May 2003 to encourage the production of electricity from renewable sources (including biogas). Producers receive one certificate for each MWh of electricity generated from renewable resources. The certificate can be sold, which generates additional income for the producer. At the same time, all electricity consumers (with the exception of some heavy industrial consumers) are required to buy a certain proportion of renewable electricity by purchasing certificates. The cost of the certificates is distributed among the consumers. The certificate system has been extended to 2030. New plants receive electricity certificates for 15 years.

Investment support - agricultural program
An investment support for farm-based biogas production was introduced in 2009, whereby farms and other rural businesses investing in biogas production or refinement receive 30% of the investment costs. The maximum amount of support for a single business is 1.8 million Swedish Crowns during a three-year period. This investment support is included in the rural development program and comprises 200 million Crowns for the period 2009-2013. The conditions imposed by the program are that manure represents at least half of the substrate digested, and that the digestion residues are stored leak-free.

Super-environmentally-friendly car premium
The Government has announced a 'Super-environmentally-friendly car premium' worth 40 000 Swedish Crowns. It can be paid out for cars with carbon dioxide emissions of less than 50 grams/km, which will mostly be relevant for electric cars and the best gas-driven cars. It has been estimated that 5000 cars in the next four years will be covered by this program, which will cost the Treasury 200 million Swedish Crowns.

Dispensation from traffic tolls for environmentally-friendly cars
Environmentally-friendly cars have been given dispensation from traffic tolls in Stockholm in order to promote their use. This dispensation has been withdrawn for cars bought after 1st January 2009, and will cease completely for all environmentally-friendly cars from 1st August 2012.

Local traffic regulations
Some local authorities have introduced dispensation from parking fees for cars classified as environmentally-friendly according to the Swedish definition.

Reduced vehicle taxes
The vehicle tax for cars manufactured in 2006 or later, as well as older cars that fulfill Euro 4 requirements, consists of a carbon dioxide-based fee added to a base rate. A reduced factor for carbon dioxide emissions is applied in the case of electric and gas-driven cars.

Reduced tax on company cars
For tax purposes, the value of a gas-driven company car is 40% lower (a maximum reduction is set, however, at 16 000 Crowns). If the employer pays for fuel, the value of the tax benefit is set at 1.2 times the cost of fuel. Access to free parking is not taxed.

Gas station grants
To improve accessibility to renewable fuels, Government subsidies were available until December 2009 to support the establishment of filling stations for fuels other than ethanol, especially vehicle gas. The Government paid 1/3 of the cost of installing a vehicle gas pump.

Regulations relating to filling stations
By law, any filling station that sells more than 2500 m3 of fuel must offer at least one alternative renewable fuel. From 2010, this law covers all filling stations in Sweden. Renewable vehicle gas has the disadvantage of higher investment and distribution costs compared with liquid alternatives such as petrol, diesel and ethanol.

3.3 Lessons learned

This section gives a brief summary of some lessons learned and experiences gained from biogas production at Swedish co-digestion plants, sewage treatment plants, farm-based facilities and industrial plants. First, some general conclusions are listed.

- It is very important to secure long-term access to raw materials before starting operations. Contracts with suppliers should be drawn up.

- The objective should be to utilize all of the biogas produced. Local and regional markets for biogas should be carefully investigated before starting operations.

- With current Swedish market prices, combined power and heat production from biogas is most profitable if the heat and electricity can be used on-site (i.e. within the company). Upgrading biogas to vehicle fuel quality requires relatively large investments. On the other hand, the demand for upgraded biogas is continually increasing, so that such investments can be profitable in the long-term.

- It is important that the digestion residues and bio-manure find suitable markets. Contracts with buyers may be necessary. The Swedish certification system for bio-manure is an excellent means of 'quality assurance', increasing its application in agriculture.

- A strong commitment and broad political support from local authorities, for example by encouraging the purchase of biogas vehicles, promotes the wider development of biogas. Close collaboration between various partner organizations and individuals is required to ensure that the entire system functions properly, from the supply of substrate to the distribution of biogas and bio-manure.

- There is a great deal of international interest in biogas technology. Strong support to develop the domestic market would help Swedish biogas companies expand and become successful on the international market.

3.3.1 Co-digestion - successful co-operation

An important aspect which affects project success is whether the bio-manure that is produced finds a suitable market. Certification is an important tool in this context, since it emphasizes the quality of the final product and also focuses attention on environmental questions in the whole process from waste management to food production.

The profitability of co-digestion plants depends on a number of factors, many of which are difficult for the plant to control. For example, one important factor is the availability of substrate. Certain substrates, for example, slaughterhouse waste, have a high energy content and are therefore in demand in a competitive market. The price of petrol is an important factor for producers of vehicle gas. Another important factor affecting profitability is whether there is a market for the bio-manure that is produced.

Close collaboration between various partner organizations and individuals is required to ensure that the entire system functions properly, from the supply of substrate to the distribution of biogas and bio-manure. It would be difficult to construct and operate a biogas plant without this co-operation.

3.3.2 Sewage treatment plants - unexploited capacity

An increasing number of sewage treatment plants are becoming interested in upgrading their biogas to vehicle fuel as a consequence of the increasing demand for biogas as an environmentally-friendly alternative to fossil fuels.

In general, there is an unexploited capacity for increased biogas production at sewage treatment plants in Sweden. In many cases, more biogas per reactor volume can be produced by optimizing process conditions. In addition, many local authorities are planning to increase biogas production by co-digesting sewage sludge with, for example, source-sorted food wastes or organic wastes from the food industry.

The quality of the sludge residue is determined by the degree of contamination of the substrate. If the wastewater contains contaminants (e.g. heavy metals, residues of medicines or pesticides), then there is a risk that these will be found in the residue, which will restrict its use.

3.3.3 Farm-based plants - few today, more tomorrow

On-farm anaerobic digestion of manure, crops and food wastes etc. can be carried out with relatively simple technology, making use of existing storage facilities and spreader equipment etc. Farmers have extensive experience of crop production and manure handling, which helps in the planning and operation of the plant.

One important reason why farmers are interested in producing biogas is that the process also results in a bio-manure with many favourable properties. Compared with fresh manure, digestion allows the farmer to achieve better control over the nitrogen content of the final product, which enables improved precision in fertilization, as well as reducing emissions of methane, ammonia and nitrous oxide. There is also less need to buy mineral fertilizers. Liquid bio-manure smells less than fresh manure and generally flows more easily, which makes it easy to spread with existing equipment.
Several cooperative projects on the construction of upgrading plants to purify biogas to

vehicle fuel quality are in the planning stages. This requires cooperation between farmers within a region and the construction of pipeline networks for both the raw and upgraded gas. This results in economies of scale and should also reduce the investment costs related to the construction of pipelines and plants for gas production and purification.

3.3.4 Industrial plants - clean workplace, less wear and tear

Both the environment and the company in question can benefit from treating process water and wastewater in a biogas plant. This is exemplified by the case studies from the bio-refinery in Örnsköldsvik and Norrmejerier´s dairy in Umeå. Apart from the purification of wastewater and process water, energy is produced in the form of biogas. The work carried out in such factories is often energy-intensive. Biogas is therefore an environmentally-friendly and cost-effective alternative to oil, both for heating and electricity generation. Combustion of methane does not produce soot or cinders, which contributes to a cleaner, healthier workplace and minimal wear and tear on boilers and other equipment.

Energy self-sufficiency also improves the competitiveness of industry, given uncertainty and rising prices in the oil market.

3.4 More literature

There is a variety of literature dealing with biogas. A selection is listed below. They can all be found and downloaded at:
www.biogasportalen.se/BliProducentAvBiogas/MerLitteratur.aspx

3.4.1 Reports

- Berglund M. 2006 Biogas production from a systems analytical perspective. Dissertation, Environmental and Energy systems, Lund Technical University.
- Brandin J, Hulteberg C and Liljegren Nilsson A. 2008 Bio-Propane from glycerol for biogas addition. SGC Report 198.
- Cook K. 2008 Demonstration of software application biogas optimizerTM at the Händerlö biogas site. SGC report 188.
- Håkansson A. 2006 Preventing microbial growth on pall-rings when upgrading biogas using absorption with water wash. SGC report 166.
- Johansson J. 2008 Production of liquid biogas, LBG, with cryogenic and conventional upgrading technology - Descriptions of systems and evaluations of energy balances. Report, Environmental and Energy systems, Lund Technical University.
- Ljungberg SÅ, Meijer JE, Rosqvist H and Mårtensson SG. 2009 Detection and quantification of methane leakage from landfills. SGC report 204

3.4.2 Brochures

Basic data on biogas - Sweden 2007. SGC

3.4.3 Standards and guidelines

Swedish Gas Association produces standards and guidelines for safe production and handling of energy gases. These are written in Swedish and can be ordered from the Association's homepage: www.energigas.se/Publikationer/NormerAnvisningar.aspx

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3.5 Industry contacts

Industry contacts including distributors, consultants, business partners and organizations are listed here: www.biogasportalen.se/BliProducentAvBiogas/Kontakter.aspx

4. About us

Swedish Gas Association is a branch organization financed by membership fees, whose work has the aim of increasing the use of energy gases. We play a broad role as spokesman in the field of energy gases, where safety, technology, and advocacy are important components. We aim to promote sustainable long-term energy policies in Sweden through the safe, environmentally-conscious and efficient use of gas.