MOMENT

modern water management

Biogas production using sludge from small scale sewage plants

REPORT 4.2.3

Title	Biogas production using sludge from small scale sewage plants a feasibility study in Ronneby municipality
Author(s)	Catarina Welin
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MOMENT Partner(s)	Municipality of Ronneby
Editors	Tobias Facchini Stan Weyns

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ABOUT PROJECT MOMENT

In cooperation between seven regions in four countries around the South Baltic Sea area the project MOMENT aims at reducing the outflow of nutrients and hazardous substances by modern water management. This includes the establishment of Water User Partnerships allowing a “bottom up” approach starting at a local level and working within river basins letting the water set its own independent boarders. The project is co-financed by the South Baltic cross-border programme 2007-2013 and runs from September 2009 until August 2012.

Contact us

Projectleader: Tobias Facchini, tel +46 (0)480 44 83 83, tobias.facchini@rfkl.se
Financial Manager: Johan Lundbäck +46 (0)480 44 83 42, johan.lundback@rfkl.se
Editor and publisher: Tobias Facchini

ABSTRACT

This feasibility study is part of Ronneby municipality's participation in the project MOMENT - Modern Water Management in the South Baltic Sea area. The study is also funded in part with subsidy within LOVA, local water management projects. The objectives are to establish the status of private small scale sewage plants and carry out a feasibility study on the potential biogas production with sludge from these sewage plants. The study area is situated along the coast in the southwest part of Ronneby municipality. The study is conducted as a combined sewer inventory and literature study on biogas.

Biogas is produced by anaerobic (oxygen free) digestion of organic material. The process involves several steps and ends with methanogenesis where methane CH_4 and carbon dioxide CO_2 is formed. There are two main techniques for biogas production, wet digestion for pumpable substrates with <12 % TS (total solids) and dry digestion for stackable substrate with 20-35 % TS (total solids). How well the process works is partly due to the relationship between carbon and nitrogen (C/N-ratio) in the material that is digested. Too low ratio leads to toxic conditions for the micro organisms and too high ratio leads to less growth. Optimal ratio should be around 20. C/N-ratio of sludge in small scale sewage plants is low. As a suggestion, straw can be added to improve the process. After dewatering and possibly purification, the produced gas can be used in boilers for gaseous fuels, for cogeneration (CHP) or for production of vehicle gas.

To achieve a recycling of nutrients, they need to be returned to agriculture. Above all, it is the limited resource phosphorus that needs to be recycled. Spreading of the digested sewage sludge is surrounded by extensive regulations and restrictions, and despite an existing certification, REVAQ, there is a lot of resistance within the Swedish food industry for spreading on agricultural land.

The result of the sewer inventory shows that 44 % of the houses in the study area have an adequate sewage treatment and 53 % have an inadequate sewage treatment. The remaining 3 % have a sewage plant of dubious function.

Produced estimates are based on a biogas plant with wet digestion and a digestion chamber with the size of 700 m^3. The substrate used is 10 000 m^3 sewage sludge from septic tanks in the entire municipality and 56 tons of chopped straw. Estimated production is 178 000 Nm^3 biogas per year, or 20 Nm^3 biogas per hour. The compared alternatives are cogeneration (CHP) and upgrading to vehicle gas. The calculations show a deficit of 25 230 SEK for cogeneration (CHP) and a surplus of 125 826 SEK for vehicle gas production.

The feasibility study recommends an investment in biogas production with subsequent upgrading to vehicle gas. The gas should then be used primarily for municipal waste collection vehicles.

INTRODUCTION

This feasibility study is part of the EU-project Moment, where Ronneby municipality is one of several Swedish partners. Project partners are also situated in Lithuania, Poland and Kaliningrad. The project has been developed within Euroregion Baltic (ERB) and is part financed by the European Union (European Regional Development Fund) through the South Baltic Cross-border Cooperation Programme 2007 – 2013. The objectives of the MOMENT-project are to increase political awareness concerning the importance of water management for the development of the situation in the Baltic Sea, to develop and test methods for sustainable water management, with special focus on decreased outlets of nutrients and hazardous substances from small and diffuse sources, within pilot areas in the shape of river basins, and to spread the information of achieved results and experiences (Project MOMENT, 2011). To increase the study area the project is also financed through LOVA-subsidy (Ronneby municipality, 2009) managed by the county administrative board of Blekinge. LOVA (local water management projects) is a subsidy to reduce the outlet of phosphorus and nitrogen to the Baltic Sea (SEPA, 2011a).

In Sweden there is a comprehensive environmental legislation through the Environmental Code (MB) (SFS 1998:808). It defines domestic waste as waste that origins from households (MB Chapter 15. §2). Latrine, sewage and sludge from domestic septic tanks are classified as domestic waste if the facility is designed for single households (SEPA, 2008a). Furthermore, the Environmental Code says that wastewater must be discharged and treated or disposed of in such a way that it does not harm human health or the environment (MB Chapter 9. §7). Responsibility for the collection, management and treatment of domestic waste in the form of sewage fractions lies with the municipalities (SEPA, 2011b).

Creating a cycle of nutrients means that nutrients in sewage fractions are returned to the soil where the nutrients are needed, without risk to human health and the environment. This is particularly important for phosphorus, which is a limited resource in the form of exploitable phosphate minerals. Other nutrients in wastewater that should be utilized are sulphur, nitrogen and potassium. In the long run, it is important to recycle even more resources from sewage waste, such as humic substances and essential elements (SEPA, 2002; SEPA, 2009a).

One of the biggest environmental problems in the southern Baltic Sea is eutrophication. The problem arises when the surplus of plant nutrients phosphorus and nitrogen are added to our waters. The result is overgrowing of lakes, rivers and coastal waters and algal blooms. The increased growth generates more biodegradable materials that require oxygen and therefore causing anoxic bottoms. In time we will have a depletion of biodiversity

(Swedish River Basin District Authorities of Southern Baltic Sea, 2010). For the Baltic Sea it is estimated that 13 % of the added phosphorous and 2 % of the added nitrogen comes from private wastewater (SEPA, 2009b). Of the anthropogenic impact on transportation in Bräkneån river basin during 2006, it is estimated that 5 % of the nitrogen and 22 % of the phosphorus comes from private small scale sewage systems (County administrative board of Blekinge, 2008).

OBJECTIVES

The objectives of this study are to compile the status of small scale sewage plants in the defined area, compare and assess different technologies for biogas production with sludge from small scale sewage plants as a substrate, and for the defined area make an estimate of costs and make suggestions for an infrastructure solution and recycling of nutrients to agriculture.

METHOD

The study area

The study area is situated along the coast in the southwest part of the municipality of Ronneby. It extends from the municipal boundary in the west to the eastern boundary of Bräkneån river basin. In the north the area is bounded by the railway and highway E22 south of Bräkne Hoby (Figure 1). The area contains several sites with cohesive leisure cottage settlements. The coastline is varied with rocky hills and wetter lowland areas. In the inland there is an agricultural landscape characterized by alternating fields, pastures and woodland. The area is 24,8 km^2 and has a coastline of about 23 km.

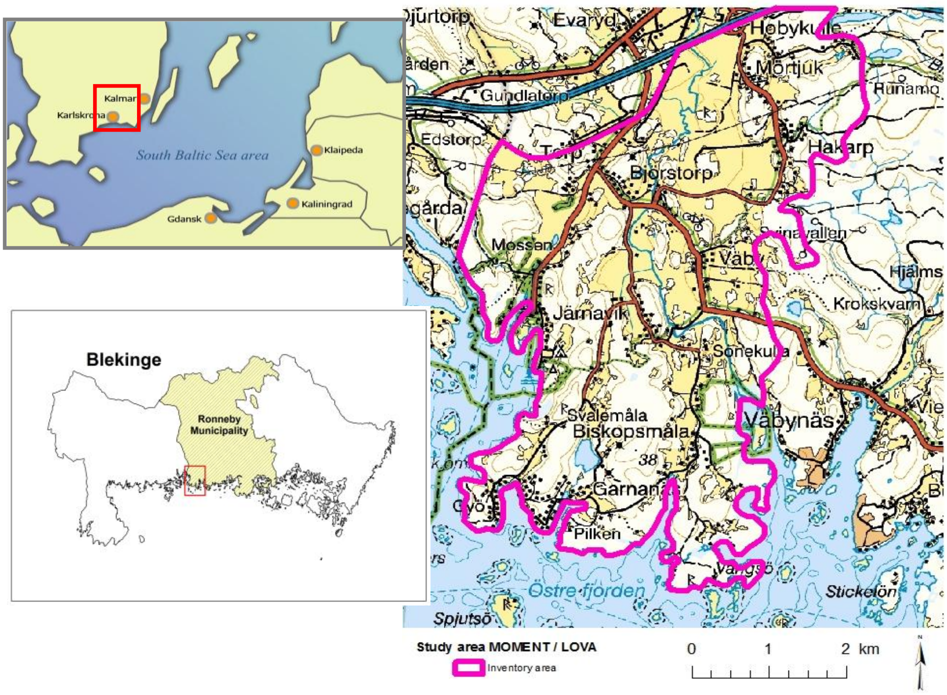

Figure 1: The project study area is located in the southwest part of Ronneby municipality.(Background Map © Lantmäteriet Gävle 2011, under contract M2005/3986 for resulting output)

Sewer inventory

The sewage inventory starts with a search in the Environmental Health Division's information systems and archives for the area's buildings and addresses. All found sewage plants are recorded by type and year of construction. Facilities are then sorted into groups:

1. Connected to municipal sewage – in private or municipal management
2. Green facilities - Adequate sewage treatment = facilities constructed in 1999 or later
3. Red facilities - sewage treatment that directly can be considered to be inadequate = facilities older than 1987 or only soakage pit. Including facilities where required actions have been deferred.
4. Sewage to be inventoried in the field - properties that lack information on sewage treatment or facilities constructed during 1987 - 1998. Exclude active cases.

A letter about the inventory is sent to property owners and then the inventory is executed in the field by using a protocol and a map. If there are unanswered questions concerning the sewage plant after the field inventory, a questionnaire is sent to the property owner. Sewer status is assessed according to established criteria (Table 1). Inventory records and information about the status of the sewage is then added into the computer system. The results are presented in an Excel file, as a compilation of sewer conditions, together with a summary chart with percentage distribution in different classes and status of existing sewers.

Table 1: Status of the inventoried sewage is assessed according to the following criteria. Different rules apply depending on whether the toilet (WC) is connected to the facility or not. (Greywater = water from sinks, showers and laundry)

	Status	**Description**
WC	Inadequate + nuisance	Overflows or direct discharge
	Inadequate	Wrong type or faulty septic tank, water-filled distribution chamber, soakage pit, unknown discharge point (documentation missing)
	Possibly Inadequate	Construction without a permit, too small drainage field area
	Adequate, OK	Sewer with a permit and no visible deficiencies (Three-chambered septic tank with subsequent drainage field area (Figure 2) or a cesspool (sealed tank) for only WC (Figure 3))
only greywater	Inadequate + nuisance	Discharge above ground which smells
	Inadequate	Wrong type or faulty septic tank, water-filled distribution chamber, drywell, soakage pit.
	Possibly Inadequate	Running water outdoors, two- or three-chambered septic tank with unknown discharge point, missing permits
	Adequate, OK	Sewer with a permit and no visible deficiencies (At least two-chambered septic tank with subsequent drainage field area)

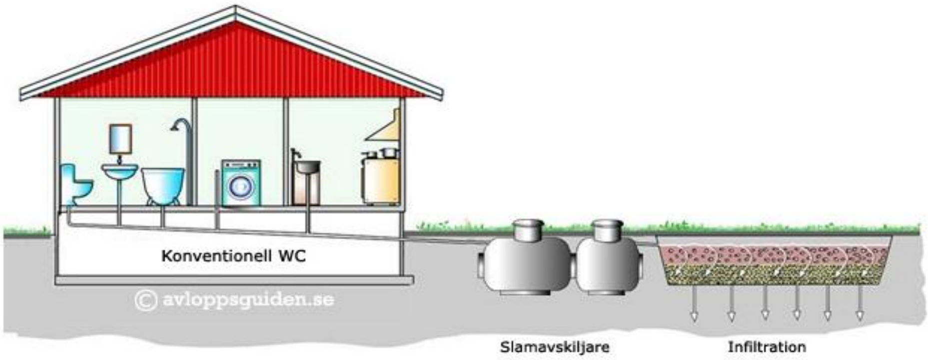

Figure 2: .A private small scale sewage plant for WC and greywater connected to a three-chambered septic tank with following infiltration. (Source: ©avloppsguiden.se)

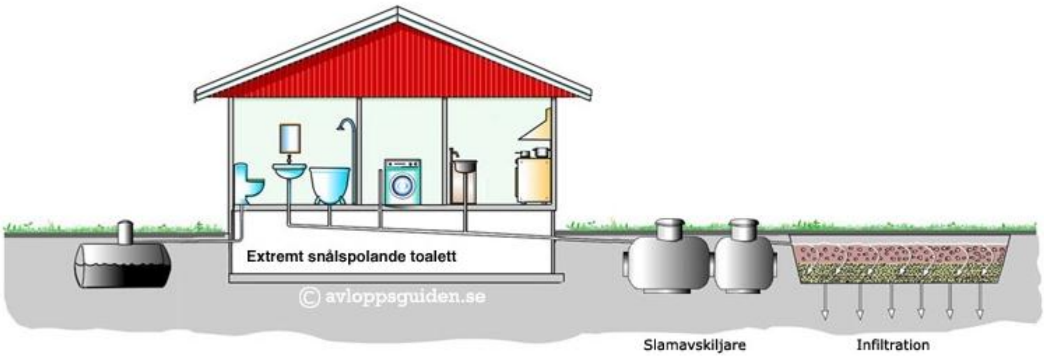

Figure 3: A private small scale sewage plant with WC connected to a cesspool (sealed tank) and greywater connected to a two-chambered septic tank with following infiltration. (Source: ©avloppsguiden.se)

FEASIBILITY STUDY ON BIOGAS

Background information on biogas and biogas production is obtained through a literature review and attendance at education day and workshops. Study visits are made at some sites in Scania; NSR in Helsingborg, Flinga Biogas AB in Tollarp, Wrams Gunnarstorp in Bjuv and Lund University's research station Anneberg in Billeberga.

For the suggestion on biogas production obtained background information is used as well as information from the sewer inventory. Furthermore information was gathered through a dialogue with Miljötekniks (Ronneby Miljö & Teknik AB ; Ronneby Environmental & Engineering Ltd) personnel and data withdrawal from Miljötekniks information system for sludge fetching.

Details of potential revenues and costs relating to biogas plants are gathered from companies in the line of business and previously conducted studies.

Anaerobic digestion - a microbiological process

Anaerobic digestion is the biological decomposition of organic material under anaerobic (oxygen free) conditions. Because an anaerobic digestion process releases small amounts of energy as heat, heat has to be added to assure that the micro organisms grow optimally (Schnürer & Jarvis, 2009). Various micro-organisms grow best at different temperature ranges. Organisms that thrive and grow best at temperatures between 20-45°C is called mesophilic while organisms that thrive and grow best at temperatures between 45-80°C are called thermophilic (Madigan & Martinko, 2006). A digestion process can be either thermophilic or mesophilic. The thermophilic process is usually kept around 55°C and the mesophilic around 37°C. Generally, a fewer number of species are active in thermophilic than in mesophilic digestion (Schnürer & Jarvis, 2009).

In the biogas process four stages can be distinguished hydrolysis, fermentation, anaerobic oxidation and methanogenesis (Madigan & Martinko, 2006; Schnürer & Jarvis, 2009; Persson et al., 2010). A schematic presentation of these steps is shown in figure 4. In order to quickly get a new biogas process going, it is advisable to start with a graft from a process that contains similar substrates, since these micro organisms already are adapted to the substrate to be digested (Schnürer & Jarvis, 2009). In order to maintain a good microbial activity the substrate should have a maximum of 35 % TS (total solids) (Schnürer & Jarvis, 2009). Water is needed both in the hydrolysis reaction (Persson et al., 2010) and the fermentation (Madigan & Martinko, 2006). The sewage sludge has been measured to produce 2/3 of the methane (CH4) by using acetate (CH3COO-) and 1/3 by using carbon dioxide (CO2) and hydrogen (H2) (Madigan & Martinko, 2006).

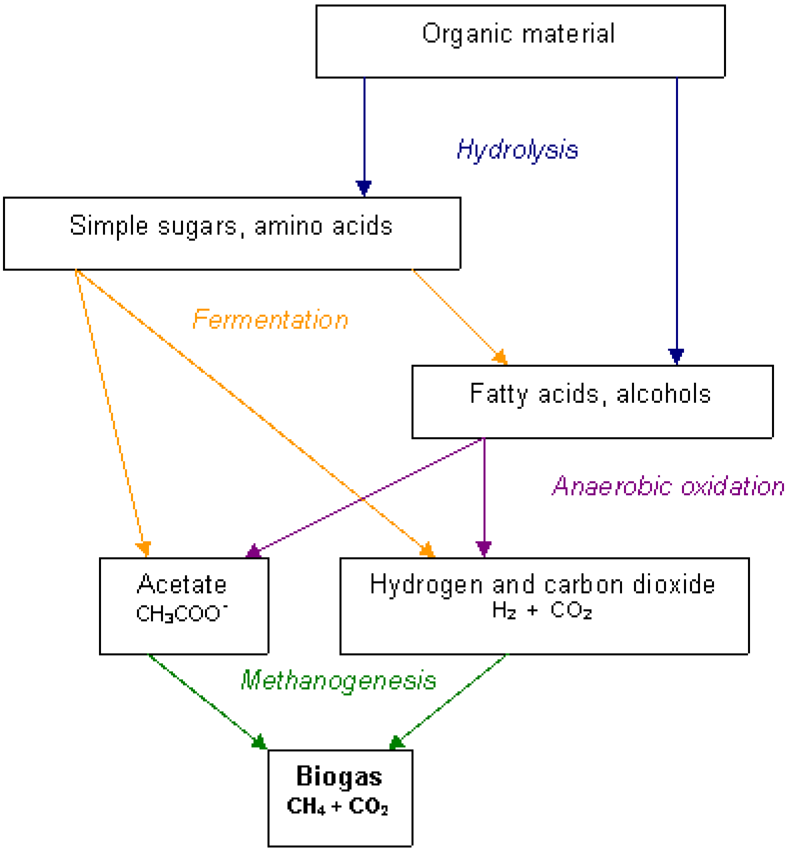

Figure 4: Schematic presentation of processes in a biogas reactor.

Hydrolysis

In the hydrolysis enzymes (produced by bacteria), in reaction with water, breaks down complex organic compounds into simple sugars, amino acids, fatty acids and alcohols (Persson et al., 2010). The rate of hydrolysis depends on the input substrate (Schnürer & Jarvis, 2009). But pH and temperature are also important (Persson et al., 2010).

Fermentation

During the fermentation bacteria break down simple sugars and amino acids to acetate, hydrogen and carbon dioxide. It also forms fatty acids and some alcohols in this process (Schnürer & Jarvis, 2009). Like the hydrolysis, fermentation also requires water in the reaction (Madigan & Martinko, 2006). The acid-forming bacteria grow quickly because the process generates a lot of energy. Therefore, this step is considered to be the fastest in the biogas process (Persson et al., 2010).

Anaerobic oxidation

During the anaerobic oxidation, bacteria (acetogens) convert fatty acids and alcohols to acetate, hydrogen and carbon dioxide (Persson et al., 2010). The process is inhibited by high concentrations of hydrogen. Acetogens perform such reactions in close cooperation with methanogens, which constantly consume the excess hydrogen and thus keep the hydrogen concentration at a low level (Schnürer & Jarvis, 2009).

Methanogenesis

In the final methanogenesis methanogens use acetate or hydrogen and carbon dioxide to produce methane (Schnürer & Jarvis, 2009). Methanogens are not bacteria, but belong to a group of organisms known as Archaea. Most methanogens are mesophilic and also obligate anaerobic, that is, requiring oxygen-free environments in order to live. They occur naturally in anaerobic environments such as wetlands, down in lake and ocean sediments and in the rumen of ruminants (Madigan & Martinko, 2006). The dominant methanogens in the biogas process has a doubling time of up to 12 days. The low growth rate means that the methanogenesis step is restricting the input rate of organic matter. Methanogens need a neutral pH (pH 7-8) to remain active and are therefore particularly sensitive to pH interference in the process. Because these organisms are important also in the anaerobic oxidation, interference in the methanogenesis may have serious consequences for the entire process (Schnürer & Jarvis, 2009).

Sewage sludge as a substrate

Small sewage plants

In this project, we look at the use of sludge from small sewage systems. These are not defined in Swedish law, but are considered to be small facilities for sewage treatment, for one or a few households. Most small plants in Sweden have either a septic tank where solid waste fractions, faeces and toilet paper, are separated from urine and water which continues through the facility, or a cesspool (sealed tank) to collect all toilet waste. The cesspool is usually associated with a low flush toilet. In some cases, the urine is sorted into a special tank (SEPA, 2008b).

Waste quantities and nutrient contents

Several studies have been conducted regarding the quantities of produced sewage and its nutrient content (Almquist et al., 2007, Jönsson et al., 2005; SEPA, 1995). Nutritional values in Table 2 are measured in the residential area Gebers, in Stockholm (Almquist et al., 2007). These values correspond well with the Swedish Environmental Protection Agency (1995) standard values and values developed by Jönsson et al. (2005) and can therefore be considered to represent an approximate average value for the swedes. Nutritional values may vary between regions and countries, as the nutrient content of urine and faeces mainly depend on the diet (SEPA, 1995), the same applies of course also to the composition of the organic household waste. The amount of phosphorus in greywater should have been significantly reduced after the introduction of the regulation on phosphates in laundry detergent on the 1 of March 2008 (Ministry of the Environment, 2008), and will decline further after the regulation on phosphates in dishwashing detergents has been introduced on the 1 of July 2011 (Ministry of the Environment, 2010). TS (total solids) content of the total sewage sludge varies depending on the amount of water per toilet flush and if the toilet waste is collected in a septic tank or a cesspool.

Table 2: In their study, Almquist et al. (2007) measured the content of the wastewater fractions and organic household waste from the residential area Gebers in Stockholm. Values are reported as grams per person and day (pd) (100% of daily output) or as grams per resident day (rd) (63% of daily output, average time spent at home). As a total 196,7 g of faeces, 24,3 g of toilet paper, 1,39 l of urine and 182 g of organic household waste is produced daily. VS (organic matter) and C/N-ratio (carbon/nitrogen-ratio) is the author's calculations.

	Faeces + Toilet paper (g/pd)	**Urine (g/pd)**	**Total Faeces + Toilet paper and Urine (g/pd)**	**Greywater (g/rd)**	**Organic household waste (g/rd)**
Total solids, TS	50,9	19,1	70,0	40,0	45,1
Ignition residue, G	6,4	12,0	18,5	0,004	5,18
Organic matter, VS (TS-G, own calculation)	44,5	7,1	51,6	40,0	39,9
Total organic carbon, TOC	24,0	3,5	27,5	9,0	23,8
Nitrogen, Tot-N	1,95	10,50	12,45	1,4	0,89
Phosphorus, Tot-P	0,69	0,69	1,37	0,6	0,16
Potassium, K	0,76	2,25	3,01	0,95	0,50
Sulphur, S	0,22	0,64	0,85	1,6	0,09
pH	7,6	9,2	-	6,7	5,5
C/N-ratio (own calculation)	12,3	0,3	2,2	6,4	26,8

Qualifications as a substrate

The availability of carbon (C) and nitrogen (N) are the parameters that are limiting for the micro organisms in the anaerobic digestion process. The carbon is energy source and nitrogen affects the growth rate. To be able to predict how successful and effective the biogas process will become, one can calculate the C/N-ratio. It describes the relationship between carbon and nitrogen in the organic matter. The ratio is not always accurate because the carbon may have different availability in different materials, but in sewage fractions and organic household waste the majority of carbon is easily accessed. A ratio around 20 is favourable for the micro organisms. Surplus nitrogen (ratio over 10-15) might lead to ammonium accumulation and be toxic. At the deficit of nitrogen (ratio above 30), it takes longer time to break down the material (Carlsson & Uldal, 2009).

By using values for TOC (total organic carbon) and total nitrogen in Almquist et al. (2007) report, the C/N-ratio of wastewater and organic household waste fractions can be calculated (table 1). The calculations show that faeces and toilet paper has a C/N-ratio of

12 which can function in the biogas process while the urine has a ratio of only 0,3. The high nitrogen content of urine gives the sludge from cesspools a lower C/N-ratio than sludge from septic tanks. As the digestion process progresses the C/N-ratio drops in the sludge, as carbon is released as methane (CH4) and carbon dioxide (CO2). To keep the biogas process in shape either carbon need to be added or nitrogen need to be removed.

Deficiencies in the nutrient ratio of different substrates can be remedied by co-digestion, which means that different substrates are mixed and digested together (Carlsson & Uldal, 2009). For example, food waste disposers for organic household waste, where waste is ground down and flushed into the sewer system, can be used to mix the sewage waste with more carbon-rich material (Karlsson et al., 2008).

Methane yield

Biogas is primarily composed by methane and carbon dioxide, but can also contain for example sulphur compounds. Warm, newly produced biogas also contains a lot of water vapour. The energy-carrying component of biogas is methane. Biogas and methane is measured in units Nm^3, standard cubic meters, which means value at 0°C and 1 atm pressure. Standardization is done because the volume of gas varies with temperature and pressure (Christensson et al., 2009).

Digestion experiments have shown that sewage sludge on average provides a biogas with 65 % methane content and a total of about 270 Nm^3 CH4 / ton VS (organic matter). By co-digestion with for example organic household waste synergy effects has been registered (Davidsson et al., 2007). A summary of the anaerobic digestion of sewage sludge at Scanian wastewater treatment plants shows similar results in methane yield. Despite that, 40-50 % of the organic material remains after completed digestion. An explanation for these quantities is that the main task of digestion at sewage plants has been to reduce sludge volumes. Biogas has been a by-product (Linné, 2007). This means that an increase in methane yield can be obtained at increased retention of organic material in the digester and/or a better optimized process.

Different techniques for the digestion process

Dry digestion

Dry digestion is a process where the substrate contains 20-35 % TS (total solids). The process is mainly used for stackable substrates such as organic waste, solid manure and crop residues. In a continuous process the material is fed into the digestion chamber, little by little, throughout the process. A batch process means that for every round of digestion all the material is loaded in and out at the same time. Sequential batch digestion means that multiple substrate chambers are linked in series and can be filled up and emptied at various times to get a steady gas production (Nordberg & Nordberg, 2007).

A batch process can be designed as a percolation bed or a soaked bed. One can also imagine a combination between these two techniques. In a percolation bed liquid is sprayed over the material and allowed to flow down to the bottom of the chamber. The liquid is then passed on for recycling (Figure 5). Multiple beds can be linked in series within the same fluid system. The circulating liquid has an inoculating effect to new beds. One problem that can occur is channel formation. This means that all the material will not be filtered through and methane production is lessened. A soaked bed means that the entire bed is soaked in liquid during substrate degradation. The liquid is drained off before the material is loaded out. The advantage of an evenly distributed liquid in the substrate is that a steady temperature and a good contact with all the material are achieved. The liquid is reused for the next round of substrate to be digested, providing a good inoculating effect (Nordberg & Nordberg, 2007).

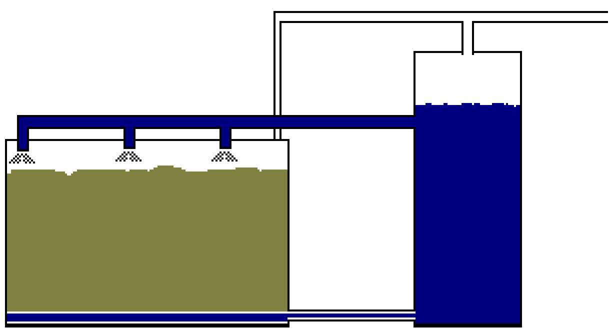

Figure 5: A simplified schematic diagram of a dry digesting facility with batch loading of substrate and circulating percolation liquid.

In a continuous dry digestion process material is fed into one end of the reactor and to the same extent out in the other. The material is pushed forward by screw-like devices in the form of rotating arms or paddles. A continuous process can also be complemented by a percolating liquid flow (Nordberg & Nordberg, 2007).

Technology with liquid flow can be divided into two steps, with the main step for methane formation in a tank where the drained liquid is led, after having passed through the substrate. In that case the digester is fitted with a carrier material for microbial colonies (Nordberg & Nordberg, 2007) or designed as an UASB (Upflow Anaerobic Sludge Blanket). In an UASB micro organisms form so-called anaerobic filters. This is achieved by continuous accumulation of colonies in the bottom of the reactor. The liquid circulates with an upstream flow, meaning from bottom to top of the reactor (Lundberg, verbally 2010). In this type of facility biogas is collected from both the substrate bed and the fluid tank. One advantage of a two-step system is that the multiplication of methanogens does not become a limiting factor (Nordberg & Nordberg, 2007).

In Germany, batch percolation bed is most common. The material is loaded into and out of big garage-like buildings with a tractor or wheel loader. In Sweden dry digestion is not widespread (Nordberg & Nordberg, 2007) but Västblekinge Miljö AB (VMAB) in Karlshamn is planning to build a dry digestion facility with continuous process for organic household waste (Sternsén, verbally 2010) and in Anderslöv, Flinga Biogas AB is building a dry digestion plant with sequential batch for manure from 50 horses (Lundberg, verbally 2010).

Wet digestion

Wet digestion means a process where the substrate contains less than 12 % TS and is possible to pump (Björnsson, verbally 2010). Wet digestion facilities are almost exclusively continuous plants (figure 6). Digestion takes place in a stirred tank. Stirring is required to maintain an even temperature and prevent foaming and sedimentation. To avoid problems with mixing, the material needs to be fine. In drier substrates liquid might need to be added in order to obtain a pumpable consistency (Christensson et al., 2009). Various types of stirring in the digestion tank occur. The most common method is the propeller stirring (mechanical). In the past gas stirring, where biogas is compressed and fed into the bottom of the tank again, was common but is increasingly being replaced by propeller stirring (Starberg et al., 2005).

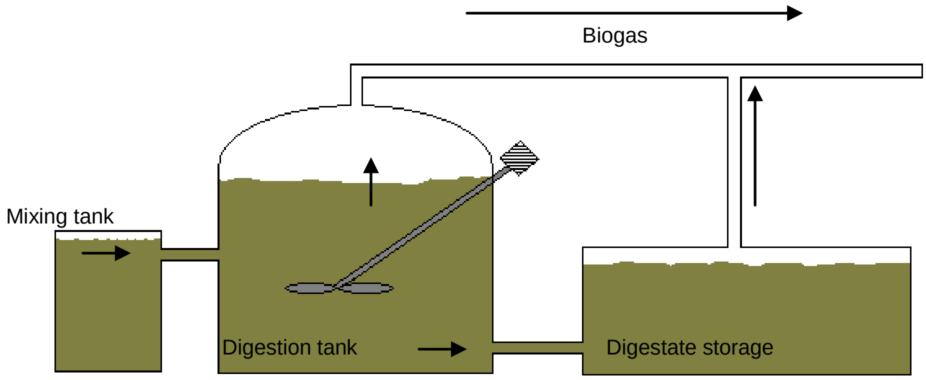

Figure 6: Concept of a wet digestion facility with propeller agitation and continuous operation.

The continuous process can be designed as a single-step or a two-step digestion. At two-step digestion there are two reactors connected in succession (Starberg et al., 2005). Another variation is to have an initial step with hydrolysis at higher temperatures. This may increase the degree of digestion and methane yield (Persson et al., 2010). For wet digestion in continuous operation, it is important to have a steady supply of raw material in terms of both quantity and type. It is also important that the residence time (time the substrate is in the digester) is long enough, at least 15 days. If the material passes too quickly a hydraulic overload is obtained and methanogens do not have time to grow but is washed out with the material leaving the digestion tank. This means that methane production is absent and undigested material leaves the tank. If the substrate has a high concentration of organic matter or the material is fed into the digester at high rate, you can get an organic overload. The process can handle a maximum of 1-4 kg of organic matter per m^3 tank and day. At higher loads the methanogens can not keep up with methane production and intermediates accumulates. Lower loads and longer dwell time gives a higher methane yield. This must be weighed against the construction cost (Björnsson, verbally 2010).

There are wet digestion facilities in many sewage treatment plants in Sweden. Plants for other materials like organic household wastes are amongst other places situated in Wrams Gunnarstorp, in Kristianstad and in Helsingborg.

Other solutions

In developing countries work is being done to improve living conditions for rural people by implementing biogas plants for individual households and small farms. SNV (Netherlands Development Organisation), which is an international development organization of Dutch origin, supports the national biogas program in for example Asia and Africa (Nguyen & Watts, 2009). SNV is to a significant part financed by the Dutch State (SNV, 2011).

Biogas plants are built for one household, and treat both sewage, organic household waste, livestock manure and crop residues (figure 7). The plants can be down to a size of 1 m^3. The concept is based on the motto easy and cheap. The substrate is fed manually into one end and the processed material, due to the pressure from the produced gas, out at the other end (Singh & Sooch, 2004, NBP, 2009; PDBP, 2009). The residence time can be up to 50 days (PDBP, 2009). The plants can be designed a little differently but the basic principle remains the same. No stirring is done. The gas is collected in the upper part of the container and led through a pipe with a dehumidification point directly to the use in for example lamps and stoves in surrounding buildings (Singh & Sooch, 2004, NBP, 2009; PDBP, 2009).

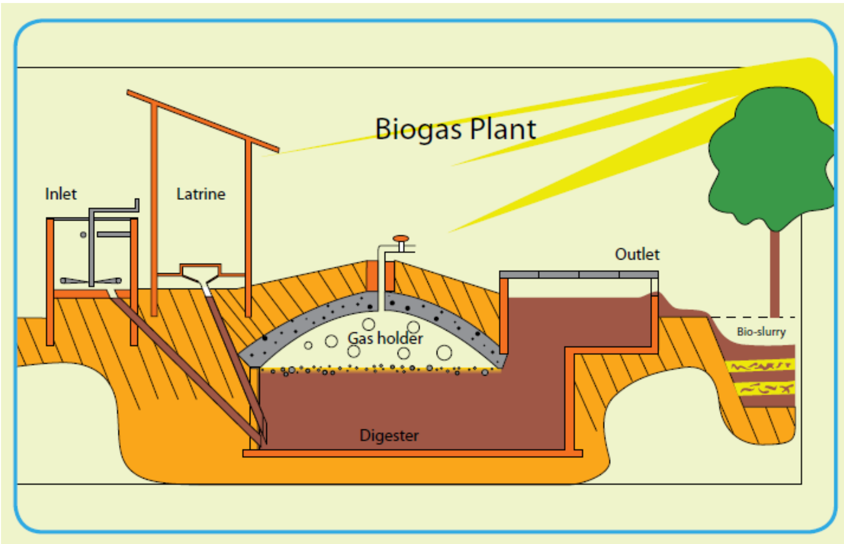

Figure 7: Sketch of how a simple biogas plant for one household can be designed. (Source: Nguyen & Watts, 2009)

VARIOUS USES OF BIOGAS

Simple purification of biogas

Newly produced and warm biogas contains some water vapour. In order to use gas in an engine or gas burner it needs to be dewatered. Water vapour condenses when the biogas is cooled. If the gas is cooled in the gas pipe the condensate need to be drained without letting the biogas out. The gas can also be dried by being brought through a drying material. If the sulphur content in the biogas is high it needs to be desulphurised (Christensson et al., 2009).

Boilers for gas fuel

After simple purification biogas can be used directly in a boiler for gas (Christensson et al., 2009). Boilers connected to storage tanks for hot water can be used for residential heating or hot tap water.

Cogeneration (CHP) - electricity and heat

Cogeneration is a process that generates electricity and where surplus heat is utilized. In this type of process approximately 1/3 of the energy content is converted to electricity and 2/3 is converted to heat (Lantz, 2010).

After simple purification biogas can be used for engines with some kind of generator. The motors can be of several types; spark-ignition engine, diesel engine and gas turbine. In spark-ignition engines gas is used directly and ignited by spark plugs. Diesel engines need igniters, such as diesel or RME, to ignite the gas as the compression pressure in the cylinders is not sufficient for spontaneous combustion. Although gas turbines can be used, they are not common in small plants (Christensson et al., 2009). The amount of electricity produced depends on engine efficiency and methane content in the biogas. The heat will be utilized by engine cooling, oil cooling and fumes (Lantz, 2010). Carbon dioxide produced during combustion of biogas can be directed to greenhouses as air fertilization (Christensson et al., 2009).

The cost to distribute power on the grid will vary depending on conditions at the site and who owns the power net (Andersson & Holmgren 2010; Lantz, 2010). According to the Electricity Act (SFS 1997:857) electricity distributors are always obligated to connect electricity producers to their grid. The power net owner is also required to compensate the plant owner for the so-called network benefit, which the plant gives in terms of reduced transmission losses. A production facility that can produce a maximum power of 1500 kW need only to pay an annual cost for measurement, calculation and reporting of transmitted electricity and a connection fee. Facilities approved for production of renewable electricity are eligible for certificates under the Electricity Certificates Act (SFS 2003:113). Measurements must then be done every hour and regularly be reported to the swedish national grid (Andersson & Holmgren 2010; Lantz, 2010). The network owner is not required to measure anywhere else than at the access point and report net measurements. If instead the power production is measured at the generator, the plant obtains certificates for its own consumption as well. Anyone who sells electricity to end users is required to purchase a number of certificates, known as quotas. Therefore there is a market for selling certificates (Lantz, 2010). A CHP plant primarily supplies electricity for its own consumption, and then the surplus to the grid. Therefore it is of interest for economic calculations to know both what the plant can sell electricity for and what it costs to buy from the grid for their own consumption (Lantz, 2010).

Vehicle gas

To use biogas as vehicle gas it needs to be upgraded. The upgrade means that the methane content is increased by the removal of other components in the gas. Above all, it is carbon dioxide which is separated from the gas (Persson, 2003; Sällvik et al., 2010). Carbon dioxide separated from biogas can be used for sale (Christensson et al., 2009). There is a Swedish standard "SS 15 54 38 - Biogas as fuel for fast ignition engines" which, among other matters, regulate energy and water content in vehicle gas. Among other things it stakes that the methane content should be 97 % ± 1 and that the sulphur content is not allowed to exceed 23 mg/Nm^3. If biogas should be fed on the natural gas grid the energy content need to be increased and often 7-9 volume percentage propane is added (Sällvik et al., 2010). The upgrade can be done using several techniques such as water wash, PSA and chemical absorption (Persson, 2003). Some newer techniques include cryogenics, membrane technology and small-scale water wash (Benjaminsson, 2006). The techniques are briefly described below.

Water wash and small-scale water wash

The technique is based on the fact that carbon dioxide has higher solubility in water than methane has. Lower temperatures and higher pressures increase the solubility. In a traditional water wash the gas face a counter current of water that dissolves carbon dioxide. The water may be flowing through or recirculating (Persson, 2003). Small-scale water wash is a stripped-down version of the larger facilities specially adapted for lower gas flows. For example, one supplier used active water cooling to increase the solubility of carbon dioxide in the water (Benjaminsson, 2006).

PSA - Pressure Swing Adsorption

PSA technology is based on that the carbon dioxide under high pressure are adsorbed on activated carbon or zeolites. When the material becomes saturated it is regenerated by a gradual drop in pressure. Often, the plant has several columns working in parallel (Persson, 2003; Sällvik et al., 2010).

Cryogenics

Cryogenic technology is based the fact that methane and carbon dioxide have different boiling points. Carbon dioxide sublimates, goes from solid directly to gas, at 1 atm (atmospheric) pressure. Therefore, the carbon dioxide is separated by condensation at a pressure of 5,2 atm and a temperature below -85°C (Benjamin's son, 2006).

Membrane Technology

Membrane technology is based on the separation of substances with different molecular size. Pressurized biogas flows through the membrane and carbon dioxide is seeping out through the membrane wall, which is permeable to carbon dioxide but not methane (Benjaminsson, 2006).

Chemical absorption

Chemical absorption is similar to water wash technique as the gas meets a fluid stream. The difference is that the liquid consists of a chemical that chemically binds the carbon dioxide (Persson, 2003; Sällvik et al., 2010).

THE USE OF DIGESTATE

Sanitation

In the EU Regulation (EC) No 1774/2002 laying down health rules concerning animal by-products not intended for human consumption, there are regulations for the handling of digestion residue from biogas production. It defines how the sampling must be performed and the levels of indicator organisms that may be present in the residue.
If sewage sludge from wastewater treatment plants should be used as fertilizer, the material shall be subjected to sanitation to kill pathogenic micro organisms. These can be for example bacteria, viruses or fungi (Schnürer & Jarvis, 2009). Micro organisms that are pathogenic to humans usually have a growth optimum at 35-40°C and have problems at temperatures above 45-50°C (Norin, 2007). The default method of sanitation today is pasteurization, which involves heating to 70°C for one hour. An alternative method is heating to about 55°C for 10 hours minimum (Schnur & Jarvis, 2009). Thermophilic digestion at 53-57°C can be used as sanitation if you can achieve the requirements for exposure. This can be achieved with semi-continuous operation where the output is closed for several hours when new material is fed into the process (Norin, 2007). In existing facilities sanitation is often performed as a batch before feeding the substrate into the biogas process (Christensson et al., 2009). Some organisms can survive pasteurization. It is spore-forming fungi and spore-forming bacteria of the genus Clostridium, which survives as spores (Schnur & Jarvis, 2009).

Spreading restrictions and storage of the digestate

Digestate is included in the term "organic fertilizers" and its use is governed by SJVFS 2004:62, regulations and guidelines on environmental concerns in agriculture with regard to plant nutrition. When the digestate originates from sewage fractions SNFS 1994:2, public notice of the regulations on the protection of the environment, especially the soil, when sewage sludge is used in agriculture, also applies. Digestate from waste fractions is not allowed to be spread:

- on pasture
- on agricultural land where grazing or forage crops is to be harvested within 10 months
- to cultivation of potatoes, root crops, vegetables or berries and not on arable land where such a crop is to be harvested within 10 months

Furthermore, the ground has to be analyzed for the content of metals, so no limits are exceeded during spreading. Limits also exist for the amount of total phosphorus and ammonium nitrogen that can be spread per hectare of arable land (SNFS 1994:2).

Blekinge is a sensitive area for water pollution by nitrates, according to the regulation SFS 1998:915 about environmental concerns in agriculture. In these sensitive areas fertilizers may not be spread between 1 November and 28 February. Nor is spreading on water-saturated, flooded, snow covered or frozen ground allowed (SJVFS 2004:62).

As long as the residue is warm and there is organic material left, the methane production continues (Christensson et al., 2009). In order to prevent the release of methane into the air and to comply with the above rules storage possibilities are required for the digestate.

Certification

Sewage sludge can be certified according to REVAQ. This means that operations are carried out in a documented structured and systematic way, that traceability and high quality is achieved in the practical handling, that a systematic improvement work is conducted, that the sludge meets the specified requirements for sanitation and metal content and that a presentation of the sludge composition is given (Svenskt Vatten, 2011).

What is Sweden’s view on sludge use?

The Swedish Environmental Protection Agency (2002 & 2009a) believes it is important to recycle nutrients from sewage fractions. Nutrients should be returned to the soil, where nutrients are needed, without risk to human health and the environment. Of particular importance is the recycling of phosphorus, which is a limited resource in the form of exploitable phosphate minerals. Other nutrients that should be utilized are sulphur, nitrogen and potassium. In the long run, it is also important to recycle other resources from wastewater, such as humic substances and essential elements.

LRF (2010), the Farmers Federation, do not discourage their members from using the sludge, but is restrictive in its approach and recommends that only sludge from REVAQ-certified plants is used. Based on current scientific research, LRF (2010) estimate that the risk in spreading is small. However, the levels of the undesirable substances must be reduced. Several industry associations in food production, for example, Svenskt Sigill (2011) and the Swedish Dairy Association (2010), do not allow the spreading of sludge on agricultural land, whether the sludge is REVAQ-certified or not.

In experimental cultivation digested sewage sludge has been used in two places in Scania since 1981. While the harvest has increased by 7 %, one has not seen any negative impact on plant uptake of heavy metals. Soil microbiology has been improved. Values for heavy metals in the soil have increased for copper and mercury, while other values are unchanged. Today, the sludge content of mercury is 10 times lower than it was during the 1980s and 1990s (Andersson, 2009).

Other ways to extract phosphorus from the sludge

At SEPA's mission, Balmer et al. (2002) have investigated various systems for recycling of phosphorus from sewage. Six systems were evaluated:

- direct use of sludge in agriculture, 95 % recirculation
- collection of urine, 40 % recirculation
- collection of toilet waste, 75 % recirculation
- extraction of phosphorus from sewage water, 60 % recirculation
- extraction of phosphorus from sludge, 70 % recirculation
- extraction of phosphorus from ashes of incinerated sludge, 60 % recirculation

Balmer et al. (2002) points out that in an endurance perspective nutrients other than phosphorus should also be considered. These are mainly nitrogen, potassium and sulfur. In regard of all these nutrients, the best recycling is recived if blackwater (urine and faeces) are sorted and processed separately and not mixed with other wastewater. By this form of management an average of 74 % of phosphorus, nitrogen, potassium and sulpfur can be recycled while only 15-18 % can be recycled in the phosphorus extraction processes above.

In their report Fransson et al. (2010) show that phosphorus and some nitrogen can be precipitated as struvite if magnesium is added to the digestate at high pH. The precipitate is then separated from the digestate and can be used for refining or as fertilizer directly. It was noted that it is difficult to provide the right amount of chemicals for optimum precipitation and that the precipitate is not free from heavy metals.

RESULTS OF THE SEWER INVENTORY

After the search in computer systems and archives, it turns out that there are 481 residential addresses in the area. Some properties have multiple addresses. Of the addresses 11 are undeveloped sites, 15 of them have municipal community facility, 29 of them have ongoing sewage issues (counted as green), for 10 of them required actions have been deferred (counted as red), 110 of them are adequate (green), 144 of them are inadequate (red) and 162 of them have to be inventoried in the field. Of those to be inventoried 63 have sewage plants constructed between 1987 and 1998, and for 99 the information is missing. Distributed in percentage there is 29 % adequate (green), 32 % inadequate (red), 2 % undeveloped, 3 % municipal and 34 % in need of inventory (Figure 8).

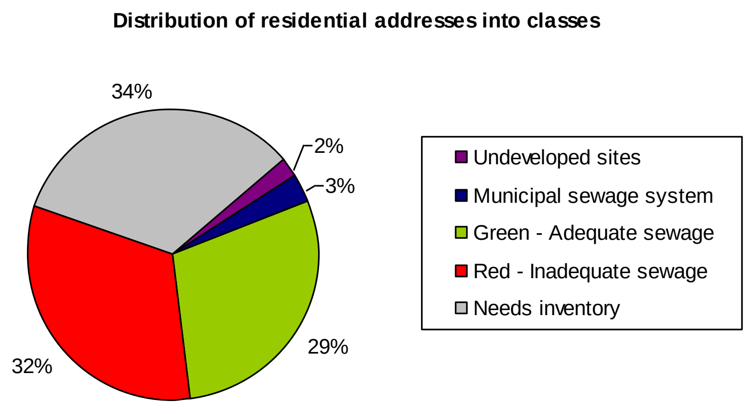

Figure 8: Distribution of residential addresses in classes after archive inventory.

After the field inventory, one can summarize the overall status of small sewage plants in the area. Of the plants 39 % are adequate (green), 5 % are residences that lack running water and sewage, these are counted as adequate (green). 3 % of the plants are possibly inadequate. 52 % of the plants are inadequate (red) and 1 % are inadequate and a nuisance (red) (Figure 9).

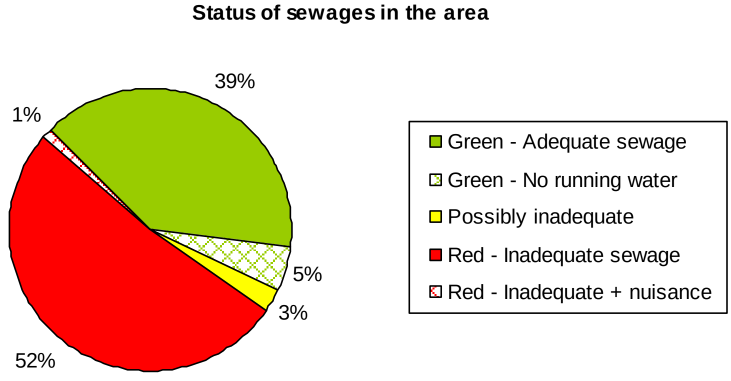

Figure 9: Percentage distribution in different status for sewages in the area, after inventory in the field.

RESULTS OF THE BIOGAS STUDY

Substrates for anaerobic digestion

A person produces an average of 51,6 g VS (organic matter) toilet waste per day. Of this, 63 % is expected to end up in the own drain, the remaining time is spent outside the home (Almquist et al., 2007). It makes 51,6 x 0,63 ≈ 33 g VS/day. A household of four persons then produce 33 grams x 4 persons x 365 days = 48 180 g (about 48 kg) VS (organic matter) a year. The greywater is on average 40 g VS per person and day, which means that a family of four produces 40 grams x 4 persons x 365 days = 58 400 grams (about 58 kg) VS a year. Since the figures are average figures, one can generalize and round off and say that a four-person household produces about 100 kg VS (organic matter) per year in their private sewers.

In order to get an idea of how well the biogas process will work C/N-ratio is calculated for the substrate.

C/N-ratio = amount of TOC (total organic carbon) / amount of Tot-N (total nitrogen)
E.g. In a given amount of substrate there is 22 g TOC and 2 g Tot-N
22 / 2 = C/N-ratio 11

In a cesspool (sealed tank) only toilet waste is collected. In a septic tank for WC, a so-called three-chambered septic tank (here after simply called septic tank), organic matter from both toilets, bathing, washing and laundry are collected. Nitrogen in urine is highly soluble in water and does not stay in the septic tank. This gives a higher C/N-ratio of sludge in septic tanks compared to the sludge in cesspools. From values in table 2 C/N-ratio of sludge in septic tanks is estimated. If one expects that the nitrogen in urine does not stay in the septic tank the sludge contains 63 % (the proportion of the day spent at home) of 1,95 grams of Tot-N from the faeces and 1,4 grams of Tot-N from the greywater, as a total (1,95 x 0,63) + 1,4 ≈ 2,6 g Tot-N. The sludge also contains 63 % of 27,5 grams of TOC from faeces and urine, and 9 grams of TOC from the greywater, as a total (27,5 x 0,63) + 9 ≈ 26,3 grams of TOC. Together it gives a C/N-ratio of 26,3 / 2,6 ≈ 10. C/N-ratio in a septic tank is 2,2 according to table 2.

Sludge from small scale sewage plants has a low C/N-ratio. To obtain an efficient process one needs to add carbon up to the optimum ratio of around 20. Input of carbon-rich organic household waste could provide a substrate mixture with better C/N-ratio. One could, with the help of food waste disposers, be able to bring household organic waste to the private sewage plant, but it means increased number of retrievals and an increased cost for the property owner. Given that each facility is located in the countryside, chances are that most people compost their organic waste at home and therefore have no costs for it today. Other collected organic household waste can be hard to come by because there is competition for raw materials when large plants like NSR in Helsingborg, Karpalund in Kristianstad and VMAB in Mörrum are in operation. As a suggestion, digestion can instead be done together with chopped straw. Straw has a C/N-ratio of 90 and total solids (TS) of 78 %. Of TS 91 % is VS (organic matter) (Carlsson & Uldal, 2009). To calculate the amount of VS (organic matter) in straw the following formula can be used:

Quantity VS straw =	amount of straw x 0,78 (% TS) x 0,91 (% VS of TS)
	E.g. 1,4 kg straw gives 1,4 x 0,78 x 0,91 = 1 kg VS straw.

To calculate the amount of straw that needs to be put into the mixture, C/N-ratio is calculated from this formula:

The mixture C/N-ratio =	(the added amount of VS, substrate 1 x C/N-ratio, substrate 1 + the added amount of VS, substrate 2 x C/N-ratio, substrate 2) / (the added amount of VS, substrate 1 + the added amount of VS, substrate 2)
	E.g. (2 kg VS straw x 90 + 10 kg VS from septic tanks x 10) / (2 + 10) = (180 + 100) / 12 ≈ C/N-ratio 23

As the digestion process progresses C/N-ratio of the substrate drops as the carbon is released as methane and carbon dioxide. To keep a batch process running smoothly, while at the same time wishing to use the organic material at a maximum, one has to either input carbon or remove nitrogen. Liquid may be filtered to keep the organic particles, while highly soluble nitrogen (and phosphorus) is removed from the system. If you have a continuous process C/N-ratio in the digester will, because of the carbon usage, be slightly lower than the value calculated for the added substrate. During the accumulation and storage time some degradation of the organic matter occurs and some nitrogen escapes into the air, both from a septic tank and from a cesspool. This implies some uncertainty in the calculation of C/N-ratio of the substrate.

Biogas from sewage sludge has about 65 % methane content. Of one ton VS (organic matter) sewage sludge one can produce 270 Nm^3 CH4 (Davidsson et al., 2007), which means around 415 Nm^3 of biogas. Biogas from straw has a methane content of approximately 70 %. Of one ton VS (organic matter) of straw one can produce 207 Nm^3 CH4, which means around 294 Nm^3 of biogas (Carlsson & Uldal, 2009).

An example of outcome calculation from a biogas process could look like this:
If 180 septic tanks containing 100 kg VS is emptied once a year, it provides 18 ton VS annually. With this one could produce 415 x 18 = 7 470 Nm^3 biogas (270 x 18 = 4 860 Nm^3 CH4) per year. If adding 3,8 ton straw it gives 3,8 x 0,78 x 0,91 ≈ 2,7 ton VS straw. Together with the sludge it provides a C/N-ratio of (2,7 x 90 + 18 x 10) / (2,7 + 18) ≈ 20,4, and an additional production of 2,7 x 294 ≈ 790 Nm^3 biogas (207 x 2,7 ≈ 560 Nm^3 CH4) per year. As a total it makes 8 260 Nm^3 biogas per year or nearly 1 Nm^3 biogas per hour.

Infrastructure

In the study area, which represents about 1/6 of the coastal area in the municipality of Ronneby, there are 185 septic tanks for toilets and 142 cesspools (sealed tanks), many of them belonging to leisure houses. Today sludge trucks drive out to empty the private sewers. A septic tank for toilet by permanent accommodation is emptied once a year, by leisure houses it is emptied every two years. Cesspools and two-chambered septic tanks for greywater are emptied after ordering. The collected sludge is driven to the wastewater treatment plant by Rustorp in Ronneby. In the entire municipality about 10 000 m^3 are collected per year. It is not possible to distinguish what is coming from which area of the municipality. The volume includes both water and actual sludge. With an average of 2,5 m^3 per emptying approximately 4000 emptyings is done per year. If each emptying contains 100 kg VS (organic matter) it would result in 4000 x 100 = 400 000 kg = 400 tons VS per year.

Today's infrastructure solution works well with the planned emptyings over the year and orders which are picked up when needed. Ordered emptying of cesspools can be irrational, but is coordinated as well as possible. Miljöteknik (Ronneby Miljö & Teknik AB ; Ronneby Environmental & Engineering Ltd) has two sludge trucks which can transport 12,5 m^3 and 13 m^3 sludge. Together the trucks drive 55 000 km annually and consume about 24 800 litres of diesel. The trucks are old and should be replaced in 2012. Biogas-powered vehicles may be an option as a possible collaboration with VMAB in Karlshamn, around a gas filling station for waste collection vehicles in Ronneby, is discussed. On average waste collection vehicles (garbage trucks) consume from 0,76 to 0,91 Nm^3 vehicle gas/km (Rehnlund, 2010). Calculated on that the fuel consumption for biogas sludge trucks in Ronneby municipality would be approximately 46 000 Nm 3 vehicle gas per year.

Systems with cesspools (sealed tanks) are a good option along the rocky coast of Blekinge, both from a health standpoint, to reduce the risk of impact on nearby drinking water wells and to reduce emissions to the Baltic Sea. Since this type of facility is emptied on demand, it is difficult to get a rational infrastructure. Therefore, it is urgent that these transports can be performed in a way that is as environmental friendly as possible. Environmental impact of transport with today's fossil fuels can not be considered negligible, but by changing the transport vehicles to biogas-powered vehicles the environmental impact can be reduced even if the number of cesspools along the coast is increased. The option to fetching the sludge from septic tanks and cesspools by car is to expand the municipal sewage network of pipes and pumping stations all the way to the coast, and connect those who currently have private sewers. This is very expensive and hardly feasible except in some dense settlements.

The fetching of the sludge is already well organized and must be performed regardless of whether one produces biogas from it or not. This means that no additional cost for transportation will occur. If sludge trucks are switched to biogas-powered trucks that run on locally produced biogas an environmental benefit occurs instead.

Environmental benefits

Environmental benefits are very difficult to value in money and will therefore not be included as an item in the report's calculations. It is easier to determine if an environmental benefit arises or not. In a comparison between two alternatives, where the conditions otherwise are equal but one option means an environmental benefit, the option with an environmental gain should definitely be selected. If the alternative with environmental benefit would be more expensive, one will have to try to give the environmental benefit a value. Being able to achieve environmental goals must in this context be of high value, or even very high. Environmental benefits can also be calculated as lower costs for future environmental problems, which would have occurred if another option was selected.

Ronneby municipality (2007) has adopted a vision of a fossil fuel free municipality, where one of the goals is the reduction of carbon dioxide from transports. By switching to biogas-powered waste collection vehicles one will be much closer to that goal. In addition, biogas is produced from a substrate that already exists and is handled (sewage sludge) which means a major environmental gain.

In order to achieve sustainability in the community, it is important to recycle nutrients. On properties with urine separating dry toilets, there is already a functioning recycling through composting of faeces and the distribution of urine and compost in their own garden. Sewage sludge from municipal treatment plants has a difficulty to meet the requirements on content of heavy metals. There is a greater opportunity to obtain a cleaner product if not industrial wastewater and storm water are mixed with the sewage. In a comparison of values for heavy metals in sewage sludge from Eriksson's (2001) study and in toilet waste by Almquist et al. (2007), it turns out, using values for faeces which has the highest metal values of the fractions collected in a septic tank, that household sewage contains 2-22 % of the quantities that conventional sewage sludge contains of cadmium, lead, copper, chromium, mercury, nickel, silver and aluminium. Considering zinc, faeces contains almost 65 % more than the sewage sludge does. Despite the higher zinc content in sludge from septic tanks, this is a cleaner alternative than traditional treatment plant sludge. This means that an environmental benefit arises from the use of digestate, based on sludge from septic tanks, as a fertilizer.

Digestate

Since the disposal of the digestate on the Swedish market is very uncertain, it will not be included as an income item in the report's calculations. But to close the nutrient cycle nutrients in the sludge/digestate need to be returned to agriculture. The best option for the treatment and recycling adaptation of digestate usage is to ensure that the material that is digested is free of unwanted substances. If the digestate is spread on arable land it is also required that the substrate is sanitized. Levels of bacteria and nutrient values can be measured after sanitation or on the digestate.

In order to gain acceptance for spreading of digestate as fertilizer on farmland, it requires at least REVAQ certification and a clear declaration of contents. It also requires that the digestate has reasonable nutrition content in relation to transport costs, as it is expensive to transport water. Water in the digestate when spreading helps nutrients to get down into the soil to plant roots, which is good when spreading in growing crops. When there is too much water and light permeable soils, leaching can occur instead. Digestate can also be dewatered and composted, and then used as soil improvers in for instance parks. If you can produce a good product, both in terms of nutrient and heavy metal contents, it will gain a value on the fertilizer market.

Choice of technology

Principal options

In order to produce biogas with sludge from septic tanks, one could consider different alternatives. Either everyone can have their own facility and consume the gas themselves or one can collect the sludge to a larger facility. Since the basic investments are large and running your own biogas plant requires time and commitment the most appropriate option in the study area would be to collect the sludge to a larger facility. The amount of sludge within the study area is too small (only gives about 1 Nm^3 of biogas per hour) for it to be economically viable to build a biogas plant for this alone. Another option that can pay off financially is if a biogas plant is being built for the sludge from all small scale sewage plants in the municipality. Such a facility should preferably be placed at the sewage treatment plant in Rustorp (on the outskirts of Ronneby) where the sludge is already driven today.

Reactor type and volume

Sewage sludge has a low total solid. One could consider dewatering the sludge and use the dry fraction in a dry digestion facility. The problem is how to deal with excess water. Much of plant nutrients, especially nitrogen, are found in this fraction. If you want to recycle the nutrient content, it is easier to keep the flow intact. Traditionally wet digestion technique is used for sewage sludge, which in this case would be the preferred option from a process point of view.

Digester chamber size is calculated on the volume of material to be processed and residence time in the digester. 10 000 m^3 sludge per year gives about 27 m^3/day. If one adds 40 tons VS (organic matter) of straw to the sludge it gives a C/N-ratio of 17,3, which should be good enough. It means approximately 56 tons of straw (375 large round bales). This increases the volume of the added substrate to the digester by about 1 m^3/day. Giving a total of 28 m^3/day. At 25 days retention time it requires a reactor chamber of 700 m^3, which can be counted as a small-scale reactor. In order to accommodate a portion of the produced gas there also needs to be margins on the size.

Is sulphur treatment required?

Sulphur is mainly found in proteins (Lantz, 2008). The sewage sludge is relatively low in sulphur concentrations, 0-50 ppm. 1 ppm is equivalent to approximately 1,5 mg of sulphur/Nm^3 biogas (Gasföreningen, 2005 se Lantz, 2008). To engines for cogeneration, the amounts need to be less than 250 mg/Nm^3 biogas to avoid increased abrasion and maintenance. In vehicle gas the sulphur content may not exceed 23 mg/Nm^3 (Lantz, 2008). Depending on what the gas will be used for desulphurisation may be required. If a water wash is used for the upgrading of the gas, a purification of sulphur is also obtained as hydrogen sulphide dissolves in water. Analysis of sulphur values in the produced gas will determine whether additional sulphur treatment is needed.

Construction proposal

The proposed facility is a wet digester. The proposal is based on 10 000 m^3 sludge from septic tanks, combined with straw. It takes fairly large quantities of straw, 56 tons. It can be hard to come by these amounts in the immediate area, but if booked in advance, it can be delivered from areas with more frequent cropping. Sanitation is done at 70°C for one hour. There is an advantage to have the straw within the sanitation as the pre-treatment facilitates further degradation of the straw.

Gas volumes

Assuming that private sewers provide 400 tons of VS (organic matter) per year one can produce 415 x 400 = 166 000 Nm^3 of biogas per year. When mixing with 40 tons VS (organic matter) of straw another 40 x 294 ≈ 12 000 Nm^3 of biogas is obtained per year. Overall, it makes an annual production of 178 000 Nm^3 of biogas (table 3) or about 20 Nm^3 per hour. Some of the produced gas is spent on the operation of the facility. This is deducted in the calculations as a part of the operating cost. Calculation of the quantity produced vehicle gas is based on the fact that vehicle gas contains 97 % methane and has an energy content of 9,67 kWh / Nm^3, and that methane has an energy content of 9,97 kWh / Nm^3 (Svenskt Gastekniskt Center, 2006). Percentages for the calculation of outcome in the production of combined heat and power (cogeneration) is taken from Lantz (2010) report about local farm production of CHP. A summary of the produced gas and outcomes at different production orientation is shown in Table 3.

Table 3: Produced biogas and expected outcomes for cogeneration and upgrading to vehicle gas.

	Biogas with cogeneration		**Biogas with upgrading**	
Production	Nm^3 gas	kWh	Nm^3 gas	kWh
Produced biogas	178 000	1 160 000	178 000	1 160 000
Produced vehicle gas, after 2 % production losses			117 000	1 136 000
Produced electricity, 30 % of the gas production		348 000		
Produced hot water, 55 % of the gas production		638 000		

Revenues from gas

According to the Electricity Certificates Act (SFS 2003:113) you get one certificate per MWh of renewable electricity produced. Svenska Kraftnät (2011) is dealing with electricity certificates and presents market statistics on production and sales. The average price per certificate the last year was 260 SEK and in May 2011 it was 205 SEK. Miljöteknik's (2011) price for transmission, according to tariff 2 (households with annual consumption <20 000 kWh), is 0,23 SEK / kWh including VAT, and for district heating 0,7025 SEK / kWh including VAT. The average price for electricity during 2010-2011 is by Nordpol (2011) just over 0,54 SEK / kWh in Sweden. Ronneby municipality currently has a fixed-price contract at 0,45 SEK / kWh, excluding VAT and can most likely use the power generated internally at the plant in Rustorp. Taking into account the heat loss and switching costs, the price is set to

0,50 SEK / kWh excluding VAT for district heating. Biogas 100 (vehicle gas containing 100 % biogas) costs according to E.ON (2011) 12,40 SEK / Nm^3 including VAT.

Given the above, the following pricing revenues are used in the calculation (all incomes excluding VAT), electric current 0,45 SEK / kWh, reduced transmitting costs 0,18 SEK / kWh, electricity certificates 260 SEK each, district heating 0,50 SEK / kWh and vehicle gas 9,92 SEK / Nm^3.

Costs

The calculations should be viewed as estimates of delivered turnkey systems and not as regular offers. Investment cost varies with ones own input of work and choice of equipment. For all investments a 5 % interest and an amortization of 20 years are calculated. The calculations are designed for comparing the options cogeneration and upgrading to vehicle gas. A summary of investments and costs for different parts of the biogas plant and its alternative approaches is found in Table 4.

The basic version of the biogas plant contains sanitation tank, mixing tank, digestion reactor, technology/surveillance equipment, digestate storage, gas storage and gas torch. According to Christensen et al. (2009) the investment cost for a biogas plant with a digester volume of 700 m^3 is about 5 000 SEK / m^3 or a total of 3 500 000 SEK. After the calculations by Lantz (2010), the maintenance cost is set to 2,5 % and operating and labour costs to 4 % of the investment cost.

For straw management one needs a straw chopper, a screw conveyor and a straw storage. A four meter high warehouse building of 10x15 meter holds about 450 big round bales. Possibly, the straw can be stored underneath a tarpaulin. The cost for straw and straw handling is an approximate average of prices in advertisements on the internet. The cost for the straw warehouse is 125 000 SEK of the total investment. If the straw is stored outside under a tarpaulin that part of the cost disappears. Straw management, maintenance, operating and labour costs together are estimated to 2,5 % of the investment. The cost for purchasing and transporting straw is calculated, after pricing in internet ads, to 1 SEK/kg.

The cogeneration plant needs an engine with a generator, hot water pipes and transmission equipment for electricity. The cogeneration plant is calculated for a gas engine with an output of 40 kW. Calculation and percentages are taken from Lantz (2010) report about local farm production of cogeneration. Investment cost is set to 730 000 SEK and maintenance, operating and labour costs are set to a total of 4 % of the investment. The cogeneration plant's electricity generating gas engine can be connected to the municipally owned grid at the sewage treatment plant in Rustorp without significant cost. However, a minor cost occurs for the measurement of electricity. To find a market for all the hot water produced from cooling the engine and the heat exchanger on the flue gases, the plant may be connected to Ronneby municipality's district heating network. The water temperature in district heating is at a maximum 120°C and in summer it is around 85°C. Today the district heating network reaches as far out as to Ronneby Brunn. There are thoughts on expanding the network to Ronneby harbour, which means that the network passes Rustorp and a connection will be possible there.

Vehicle gas production requires an upgrading plant and a gas filling station. The cost is for an upgrading plant in the form of a small-scale water wash for a biogas production of 20 N m^3 per hour. The information comes from Peter Karlsson of Biorega AB. The plant is delivered as a container installation. Upgrading plant, high pressure storage and gas filling station are included. Investment cost for a completely new plant is 3 million SEK but can be a bit cheaper if one can get hold of a used gas filling station. Life expectancy is about 20 years. 10 % of the produced vehicle gas energy is spent on operating costs, which mainly consists of heating and operation of high pressure compressors. Maintenance is estimated to 4 % of the investment.

Table 4: Statement of investments and costs for different parts of the biogas plant and the alternative branches.

	Biogasplant, 700 m3	**Straw management**	**Cogeneration plant, gas engine of 40 kW**	**Upgrading plant for vehicle gas**
Investment cost	3 500 000 SEK	170 000 SEK	730 000 SEK	3 000 000 SEK
Annual cost of capital	268 000 SEK	13 000 SEK	56 000 SEK	230 000 SEK
Maintenance cost	87 500 SEK	4 250 SEK	29 200 SEK	120 000 SEK
Operating cost	140 000 SEK			10 % of vehicle gas energy

Calculations

A summary (Table 5) and comparison of the calculations, for biogas production with cogeneration and upgrading to vehicle gas, show that the biogas with cogeneration has significantly lower costs while revenues are lower than for upgrading. Cogeneration calculation results in a small loss but if the electricity price will increase 0,08 SEK / kWh or heating compensation will increase by 0,04 SEK / kWh, the calculation breaks even. The estimate for the upgrade of vehicle gas shows a positive result. The compensation for the vehicle gas may drop down to 8,85 SEK / Nm^3 before the calculation shows a loss. Investments and costs for upgrading vehicle gas are much higher than those for the cogeneration, which means a higher financial risk. The risk is well compensated by the higher income as well as the great environmental benefits that can be achieved by replacing fossil fuels with renewable vehicle gas.

Biogas with cogeneration		Biogas with upgrading to vehicle gas	
Revenues		**Revenues**	
Electric current 0,45 SEK/kWh	156 600	Vehicle gas 9,92 SEK/Nm^3	1 160 640
Electric transmission 0,18 SEK/kWh	62 640	**Total revenues**	**1 160 640**
Electricity certificates 348 pc à 260 SEK	90 480		
District heating 0,50 SEK/kWh	319 000	**Costs**	
Total revenues	**628 720**	Investment	6 670 000
		Annual cost of capital	511 000
Costs		Maintenance and operating cost	351 750
Investment	4 400 000	Operating cost for upgrading plant, 10 % of the vehicle gas energy	116 064
Annual cost of capital	337 000	Purchase of straw incl. transport 1 SEK/kg	56 000
Maintenance and operating cost	260 950	**Total costs**	**1 034 814**
Purchase of straw incl. transport 1 SEK/kg	56 000		
Total costs	**653 950**		
Profit before valuation of environmental benefits and digestate	**-25 230**	Profit before valuation of environmental benefits and digestate	**125 826**

Table 5: Comparative calculations for biogas production with cogeneration and upgrading to vehicle gas. All amounts in SEK.

CONCLUDING REMARKS

Production of biogas from sewage sludge is a good way to produce energy. It is environmentally friendly, renewable and resource efficient. If we then process the biogas to vehicle gas, we can at the same time reduce our dependence on fossil fuels that significantly contribute to global climate change. Sewage sludge from households is less burdened with heavy metals than conventional sewage sludge. A separate collection and treatment of this sludge provides better conditions for the return of nutrients to soils and recycling systems. This is particularly important for phosphorus that is a finite resource.

The defined study area is too small for an economically sustainable development of biogas production from these households sewage sludge. The recommendation from this study is therefore to invest in digestion and biogas production with sludge from all private sewers in the municipality of Ronneby. From biogas one should produce vehicle gas which is primarily used as fuel for municipal waste collection vehicles. Any surplus can be sold or used by local car pools, buses or the like. With this procedure, Ronneby municipality get closer to two of their environmental targets, reduced carbon emissions from transport and increased self-sufficiency in energy. In addition, disposal of household sewage sludge in the modified way described above is an important step towards a sustainable society.

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In cooperation between seven regions in four countries around the South Baltic Sea area the project MOMENT aims at reducing the outflow of nutrients and hazardous substances by modern water man-agement. This includes the establishment of Water User Partnerships allowing a “bottom up” approach starting at a local level and working within river basins letting the water set its own independent boarders. The project is co-financed by the South Baltic cross-border programme 2007-2013 and runs from September 2009 until August 2012.

CONTACT US

Author: Catarina Welin, tel +46 (0)457 61 81 73, catarina.welin@ronneby.se

Project manager: Tobias Facchini, tel +46 (0)480 44 83 83, tobias.facchini@rfkl.se

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