Västerås (Växtkraft) Biogas Plant

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Part funded by

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CASE STUDY – SOURCE SEGREGATED BIOWASTES

Västerås (Växtkraft) Biogas Plant

INTRODUCTION

The Växtkraft biogas plant is situated adjacent to the other installations at the waste treatment plant at Gryta, in the northern outskirts of Västerås (Figure 3 and Figure 4). Västerås (in Västmanland county), is Sweden's sixth biggest city and has around 140,000 inhabitants in the extended area. The Växtkraft biogas plant has a total throughput of 23,000 tpa, comprising of 14,000 tpa of source separated municipal kitchen waste, 4,000 tpa of grease trap removal sludge and 5,000 tpa of specially grown energy crops. The plant was planned and built, and is operated by Svensk Växtkraft, which was a company set up specifically to oversee the project. Svensk Växtkraft is owned by a consortium made up of Vafab-Miljö (the Solid-Waste Company owned by the municipalities in Västmanland), LRF (the National Federation of Swedish Farmers), Mälarenergi (the local energy company) and seventeen individual farmers close to the city of Västerås. The arrangement is shown in Figure 1.

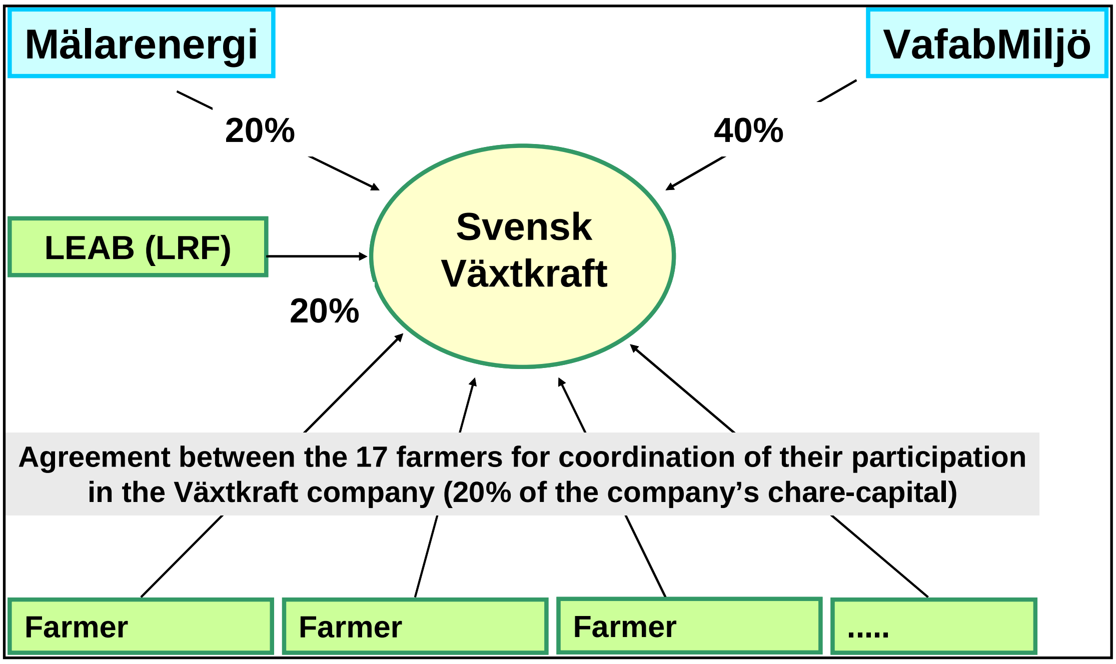

Figure 1 Chart showing ownership of the Växtkraft Biogas Plant (Persson, 2006)

The concept of the system (as presented by Per-Erik Persson, Chief Executive of Svensk Växtkraft AB, at the Agropti Gas workshop, May 2006) is shown in Figure 2.

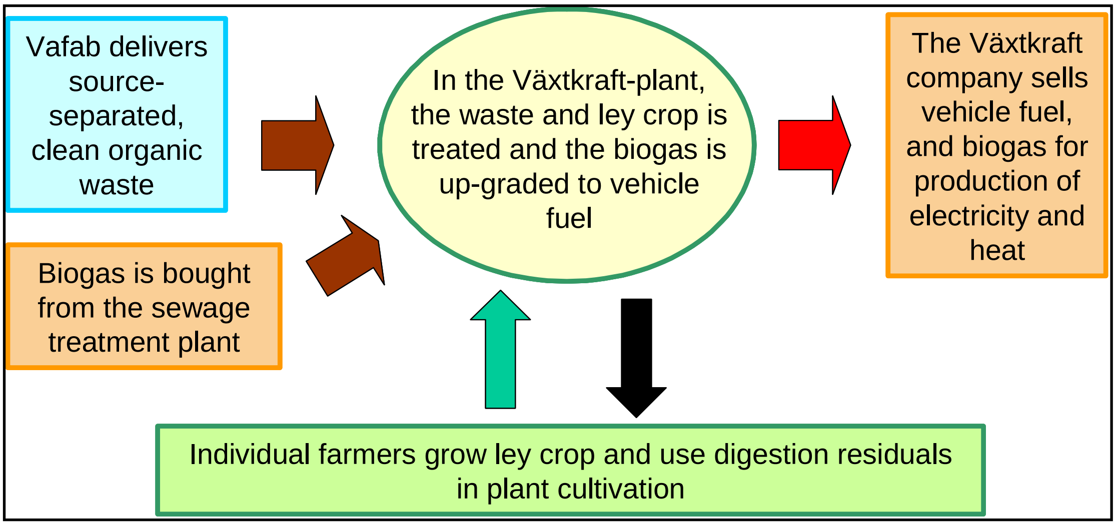

Figure 2 Overall simplification of system (Persson, 2006)

Figure 3 shows the location of Växtkraft plant in relation to the city of Västerås and the fields belonging to the participating farmers, on which the ley crop on which the digester is co-fed is grown.

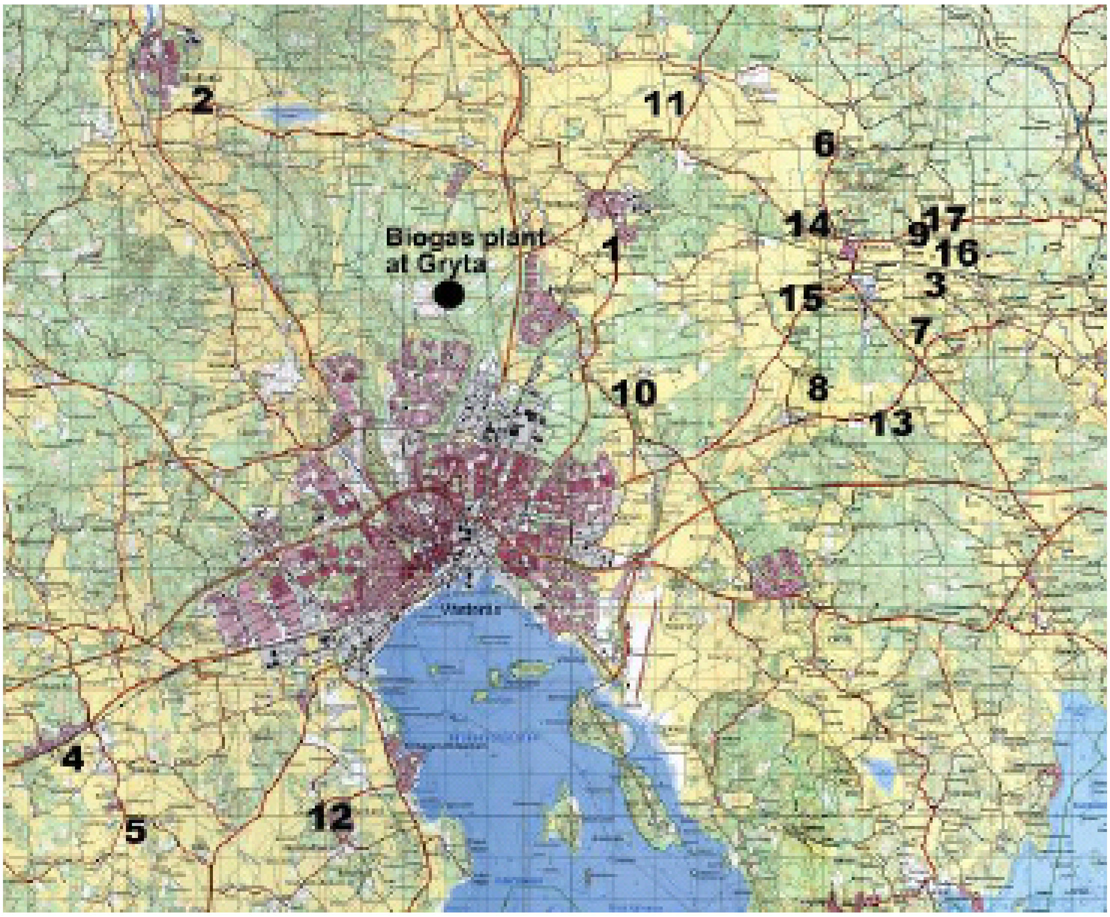

Figure 3 Location of Växtkraft Biogas Plant in relation to the city of Västerås and the participating farmers (Agropti Gas Promotional Information)

It can be seen that the plant is approximately 8 km from the city centre. As can be seen, all of the participating farmers contracted to grow ley have their fields located within 15 km of the site, with most being closer. The average distance from farm to plant is around 8 km. Figure 4 shows the location of the plant in relation to the sewage treatment works (from which biogas is also collected and upgraded), and the bus depot. The biogas from the centrally located sewage treatment works is piped up to Gryta, where it is added to the biogas produced from the Växtkraft plant and upgraded. The upgraded biogas is the piped (under a 4 bar pressure) back to the centrally located bus depot, where it is stored and used to re-fuel the city's bus fleet.

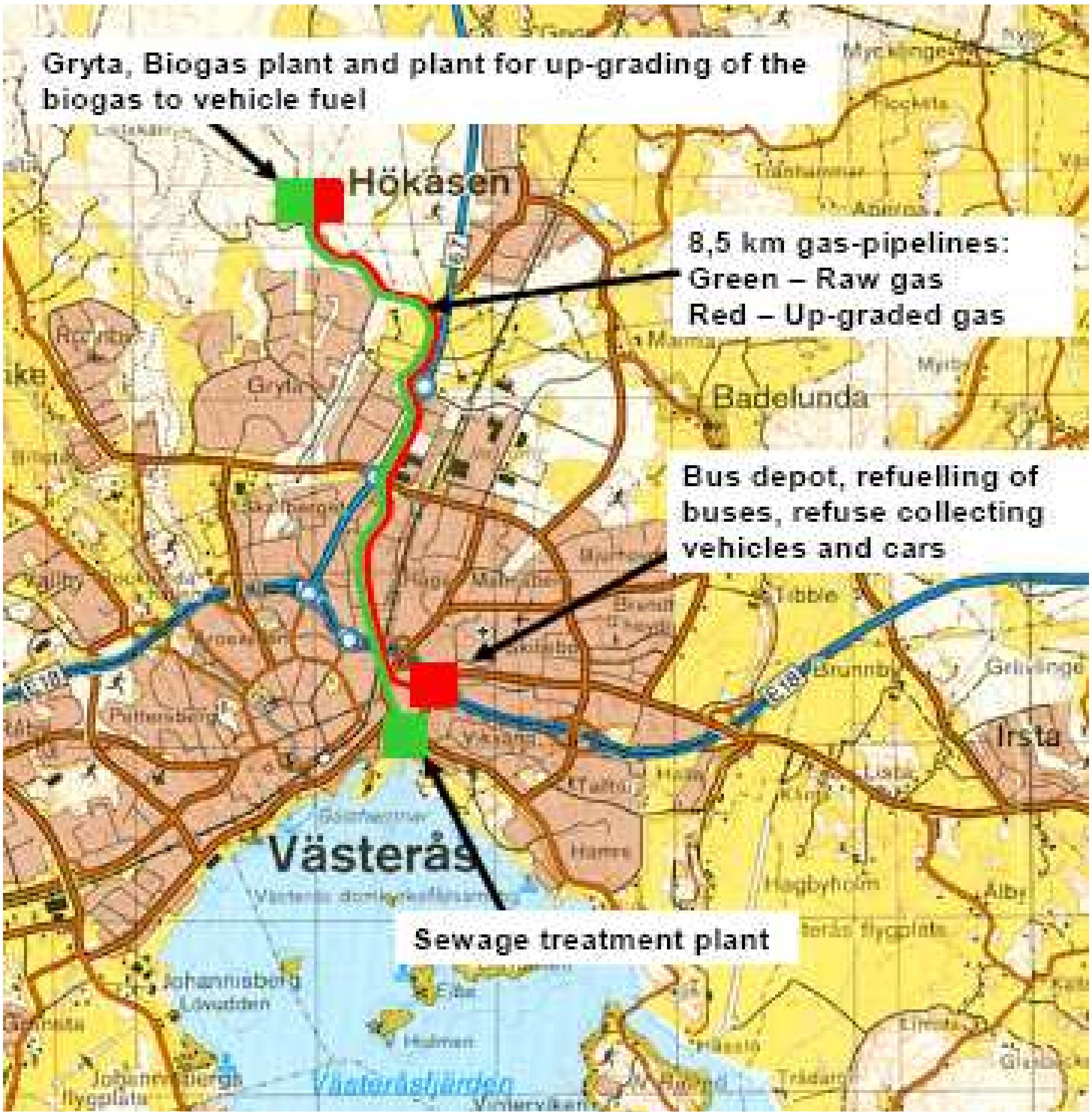

Figure 4 Location of the production sites for biogas and filling stations for vehicles in Västerås (Agropti Gas Promotional Information)

As with many other sewage sludge digesters in Sweden, it is possible to harvest all of the biogas produced, as most processes are heated by district heating schemes. In the UK, the biogas produced in most sewage sludge digesters is converted to electricity and heat, which is then used (almost completely) on site. The land requirement for the whole plant (including the biogas plant, the gas upgrading plant, the silage storage area and internal roads) is 22,411 m^2 (Persson, Personal Communication, 2006). The land requirement for the biogas plant is 12,000 m^2, which breaks down to include 2320 m^2 for the main building, and 5,915 m^2 for internal roads and driving areas (Persson, Personal Communication, 2006).

AGROPTI–GAS RESEARCH SCHEME

In 2003, the Växtkraft project became a central part of the Agropti-Gas Research Scheme (www.agroptigas.com) which is an EU demonstration project within the 5th framework program (FP5). Aside from receiving extra European Funding, becoming part of the Agropti-Gas Research Scheme involved incorporating national and international partners into the project. The partners co-operate in demonstration, evaluation and dissemination of the project. Agropti-Gas is divided into the following parts:

- Demonstration part including purchasing, building and start up the systems described in this publication.
- Analyses of the socio-economic effects.
- Analyses of the handling systems for ley crop and digestion residuals.
- Evaluation of the technical and biological processes.
- Dissemination of results.

Partners in the Agropti-Gas project and their responsibilities are:

- **Svensk Växtkraft** is responsible for the practical demonstration part of the project.
- **JTI** (Swedish institute of Agricultural Engineering) is responsible for the socio-economic analyses and the analyses of the handling of ley crop and digestion residuals.
- **SDU** (University of Southern Denmark) responsible for the dissemination of the results.
- **FAL** (Federal Agricultural Research Centre, Germany) is responsible for the technical and biological evaluation of the processes.
- **BAI** (Bulgarian Association of Investors) is responsible for the information about the project in the eastern European countries.
- **LRF** (The National Federation of Swedish Farmers).
- **Municipality of Växjö** is responsible for project coordination.
- **VLAB** (The Public Bus Company), contracted to buy biogas and provide and maintain vehicles that use it.

As noted above, the owners of Svensk Växtkraft are key players in the project, and their responsibilities are shown in Table 1.

Table 1 Owners of Svensk Växtkraft and their responsibilities

Company	Responsibility
Vafab Miljö AB (The Public Waste Company)	Environmentally sound handling of biowaste Sustainable utilisation of the biowaste (plant nutrients, humus and energy).
Mälarenergi AB (The Public Energy Company)	Efficient energy utilization of biogas from the sewage treatment plant. Establishment of energy efficient systems.
Local Farmers	Cultivation of ley crops. Organic farming. Additional incomes – contracting.
LRF (The Swedish Farmers Association)	Support of important development projects.

The results from the different parts of the project will be published in full, to enable interested parties across Europe to benefit from the results. The main aims of the Agropti-Gas project are:

1. To demonstrate a process technique with new components to enable co-digestion of easy degradable solid biomasses (waste) with agricultural feedstock.

2. To prove that biogas is competitive as a vehicle fuel, and AD is competitive as a waste management system.

3. To prove that re-circulation of bio-waste as a high quality fertiliser in conventional and organic farming is possible, and to demonstrate the advantages for the farmer to be part of the system.

Pre-conditions to the Agropti-Gas Project included:

- All necessary permits for the erection and operation of the plants needed to be obtained.
- The disposal of digestates needed to be guaranteed in terms of;
    - Agreements with farmers, and
    - Written approvals from the food industry.
- The use of biogas as vehicle fuel needed to be guaranteed.
- The technical and economical risks must needed to be limited to a 'reasonable' level.
- The company owners (of Svensk Växtkraft) needed to approve of all the Agropti Gas Project aims and objectives.

What makes this project unique is that grass and organic municipal waste is co-digested and that the farmers and the municipality have joined and formed a company to undertake the project. The Agropti-Gas Scheme adds to this by further formalising the information dissemination, to the benefit of all interested parties. More information is available on the Agropti-Gas website (www.agroptigas.com).

OBJECTIVES OF THE VÄXTKRAFT PROJECT

The objectives of the Växtkraft project are as follows;

The Waste Perspective

- To handle high quality biowaste and crops in an environmentally sound way.
- To establish a sustainable circulation of plant nutrients and energy between the city and the agricultural sector.

The Agricultural Perspective

- To demonstrate a cost effective system for production of an eco-labelled fertilizer from organic household waste and agricultural feedstock and spread the knowledge to other regions in Europe.
- To contribute to an environmentally sound and sustainable form of farming and to promote employment within the region.
- To extract biogas and plant nutrients from ley crops.
- To reduce the use of biocides and chemical fertilizers and promote organic farming.

The Energy and Transportation Perspective

- To extract and utilize high-grade bioenergy from biowaste and energy crops with no net-contribution of carbon dioxide to the atmosphere.
- To demonstrate a cost effective system for production of biogas vehicle fuel.
- To establish a sustainable market for biogas as vehicle fuel within the region.

The Research and Development (R & D) Perspective

- To constitute a basis for R & D activities.
- To provide opportunities for studies on cultivation systems based on ley crops and organic fertilizers.
- To demonstrate the overall system.

WASTES COLLECTION AND DELIVERY

Kitchen waste has been source separated in the Västerås region since 1999. In the Västerås area households have two main options for their wastes collection.

- Source separation.
- Mixed waste collection.

Another option for kitchen and garden waste is home composting. The source separation option is 'optional' in name, but in reality the pricing of each option leaves little choice, with the mixed waste collection being significantly more expensive. Importantly, it remains a 'choice' rather than an 'instruction', which results in a much higher level of public participation. Because it is voluntary, the risk for mistakes made by unmotivated households is minimized.

The choice of alternative made by a single household is confirmed by a written agreement between the municipality and the household. According to the agreement the households within the source separation scheme commit themselves to source separate the organic household waste in accordance to instructions from the municipality. The agreement also gives the municipality the right to control the quality of the source separated organic waste from the single household. Among the 144,000 households in the region, approximately 90% participate in the source separation scheme, 7% home-compost the biowaste while approximately 3% produce a mixed household waste that is treated by incineration.

In addition to the cleverly worked collection 'options' there is a very high level of public education in Sweden. This public education is ongoing. Two full time campaigners tour the regions schools, and annually visit and educate 10,000 school children aged 9 – 11. These school children are seen as key players in 'taking the message home'. Prior to the implementation of source separation Växtkraft aimed for an 85% personal contact rate. The actual percentage of the population directly visited, and informed face to face of the plans for their kitchen waste was 90%. To ensure that the public do participate, and keep contaminants to a minimum, there are a team of two full-time 'rubbish inspectors'. These inspectors actually check citizens source separation bins. Rather than fining (or otherwise punishing) offenders, offenders are 're-educated', and the reasons behind the source separation are re-explained to them. Another offence will then result in the offending household being 'banned' from the source separation scheme, resulting in the necessary payment of the higher charges for mixed wastes collection. The source separation quality is also controlled by waste hauler, who is able to point the 'inspectors' in the direction of offenders. There are also basic quality monitoring procedures when the waste arrives at the biowastes treatment site. This combination of measures serves to keep the level of contaminants exceptionally low, at less than 0.5%. This level of contamination is much lower than in other organic waste source separation schemes in other countries, and is one of the major reasons why the Växtkraft project has been successful to date. Such was the success of the source separation in the area that, initially, more of a contamination problem was caused by spillages between the various sections of the collection trucks. This technical problem was easily solved at an early stage.

The importance of this public education expenditure was continuously re-iterated. Public participation is key to a quality product, which is fundamental to the survival of the whole project. It was judged that all money spent on public education was worth it in the long run. The extra effort and expenditure at the start were money very well spent. 'If they don't get it right from the start you will need to go back and talk to them again anyway, once your process has already experienced problems due to contamination'. The council provided the households with all of the necessary collection gear for free (or included in their annual fee). This included the ventilated wheelie bin, paper bags and the wire container to hold paper bags. Other points on the collection and public education schemes are;

- It is essential to provide clear and simple rules of source separation.
- To keep the public informed as to 'why' they are source separating, based on the (correct) belief that they are much more likely to participate if they understand reasons behind it.

- Source separation results are reported back to the citizens quarterly, so they can take pride in the results. Citizens who are told they are doing well are more likely to keep doing well.

The collection system for the organic household waste, is an open, ventilated system based on collecting kitchen waste in the kitchen in paper bags placed in a wire rack (Figure 5). The paper used to make the paper bags is water resistant, and so does not go soggy when filled with wet wastes. The paper bags are almost impermeable to odours (Pettersson, Personal Communication, 2006). The use of paper bags permanently remind the households that nothing but biodegradable organic waste should be placed into the bag. To guide households in the source separation, sorting instructions are printed on the bags. The instructions state that: only food leftovers, garden waste, wilted flowers, pot plants and household paper should be placed in the paper bags. Full paper bags are deposited in ventilated plastic bins (Figure 6) until collection.

Figure 5 Paper kitchen wastes collection bag (Växtkraft Promotional Information)

Waste from institutional kitchens is handled in the same way as household wastes. Sludge from grease separators in institutional kitchens and restaurants is collected with slurry tankers and is delivered directly to the plant (Växtkraft Promotional Information).

Farmers who are partners in the company Svensk Växtkraft are also contracted for the cultivation of ley crops to be used for biogas production. Cultivation of ley crop in rotation with food crops helps improve the balance of the soil. Clover ley crop in particular helps to fix nitrogen in the soil and makes soils more fertile. According to the contract the leys shall lie for two or three years and have a high percentage of clover (25% of the seed) due to the intended improvement of the soil structure and the intended value of ley as a preceding crop. The leys shall be part of the normal crop rotation of the farms. According to the present rules for EU subsidies the ley may be cultivated on land that is set aside. The ley is under-sown, either in a cereal crop, or in spring oil-plants. Under-sowing, fertilizing and management are done in accordance with the guidelines given by Svensk Växtkraft. Harvesting is done at the same time of the year as for “normal”, large-scale ensiling of ley crop for cattle. At harvest, the crop is wilted and finely chopped with a precision chopper. In order to achieve high efficiency, minimize costs and to obtain a substrate that has the intended properties for digestion, the harvesting is organized by Svensk Växtkraft. However, the practical work of harvesting and ensiling is performed by hired contractors. The crop is preserved as silage in plastic bags. The silage is taken out from the bags by a wheel loader and is transported to the biogas plant continuously throughout the year (Växtkraft Promotional Information). Some photographs of the harvesting and storage of the ley crop are shown below. These photographs were sourced from Växtkraft Promotional Information.

Figure 6 Ventilated kitchen wastes collection bin (Växtkraft Promotional Information)

Figure 7 Harvesting ley-crop (Växtkraft Promotional Information)

Figure 8 Harvesting ley-crop (Växtkraft Promotional Information)

Figure 9 Storing ley-crop on-site (Vaxkraft Promotional Information)

Figure 10 Storing ley-crop on-site (Vaxkraft Promotional Information)

PLANT DESCRIPTION

The Västerås project, which was started up in 2005 is a full scale biowastes treatment plant. Biogas is upgraded and used as a vehicle fuel to fuel the city's bus and municipal refuse fleets. The plant treats approximately 23,000 tpa of the following wastes. The quantity and total solids content of the incoming waste is shown in Table 2.

Table 2 Wastes treated at Västerås

Waste/crop	Throughput in 2005 (tpa)	Total Solids Content (%)
Source separated kitchen waste	14,000	30
Grease trap removal sludge	4,000	4
Ley crop	5,000	35

The source separated kitchen is from households and from institutional kitchens. It is ‘clean’, with an average contaminant percentage less than 0.5%. The grease trap removal sludge is from grease separators in institutional kitchens and restaurants. The ley crop is ensilaged and is harvested from a contracted ley acreage of 300 hectares cultivated by farmers who are also part-owners in the plant. The anaerobic digestion and pre-treatment system was provided by Ros Roca. More details about Ros Roca are available on the Ros Roca website (www.rosroca.de). A process flow diagram of the Västerås plant is shown in Figure 11.

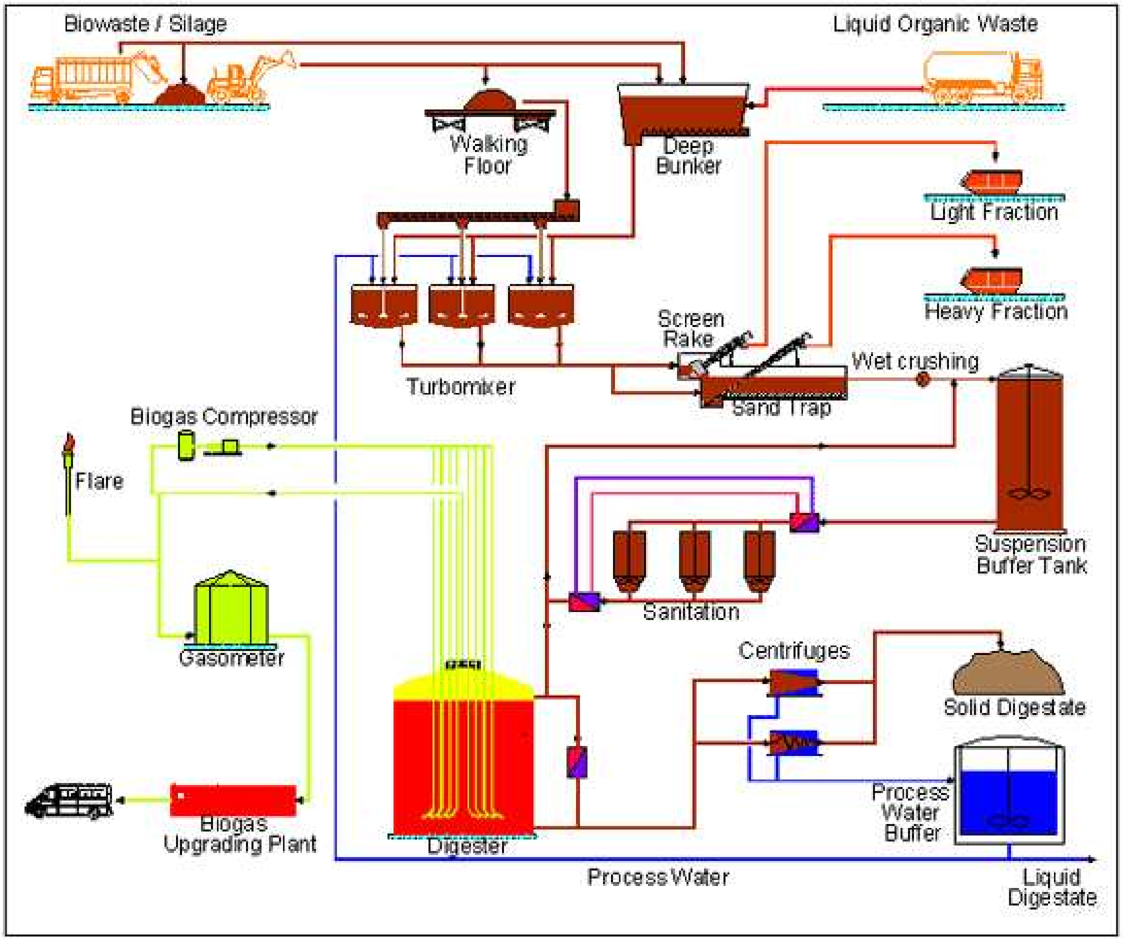

Figure 11 Process flow diagram (Ros Roca website, accessed July 2006)

PRE-TREATMENT

Waste is delivered to a covered wastes reception area, where source separated kitchen waste and ley crop are unloaded directly on to the floor (Figure 12 and Figure 13).

Liquid wastes, such as the grease trap sludge is unloaded directly into a liquid wastes reception bunker (Figure 14). The bunker is discharged automatically with screws and a pump and can be cleaned afterwards.

The first step in the process is a wet pre-treatment. All of the organic waste is mixed with process water in a turbomixer (Figure 15) and a suspension with a solid concentration of up to 15% is produced. It is possible to separate out of the turbomixer impurities like glass, stones, bones by means of a grit system. The turbomixer is then discharged by hydraulic flow to a screening unit which separates floating material like plastic, wood and other non biodegradable structural material.

Figure 12 Waste being unloaded in wastes reception area (Pettersson 2006)

Figure 13 Wastes reception area

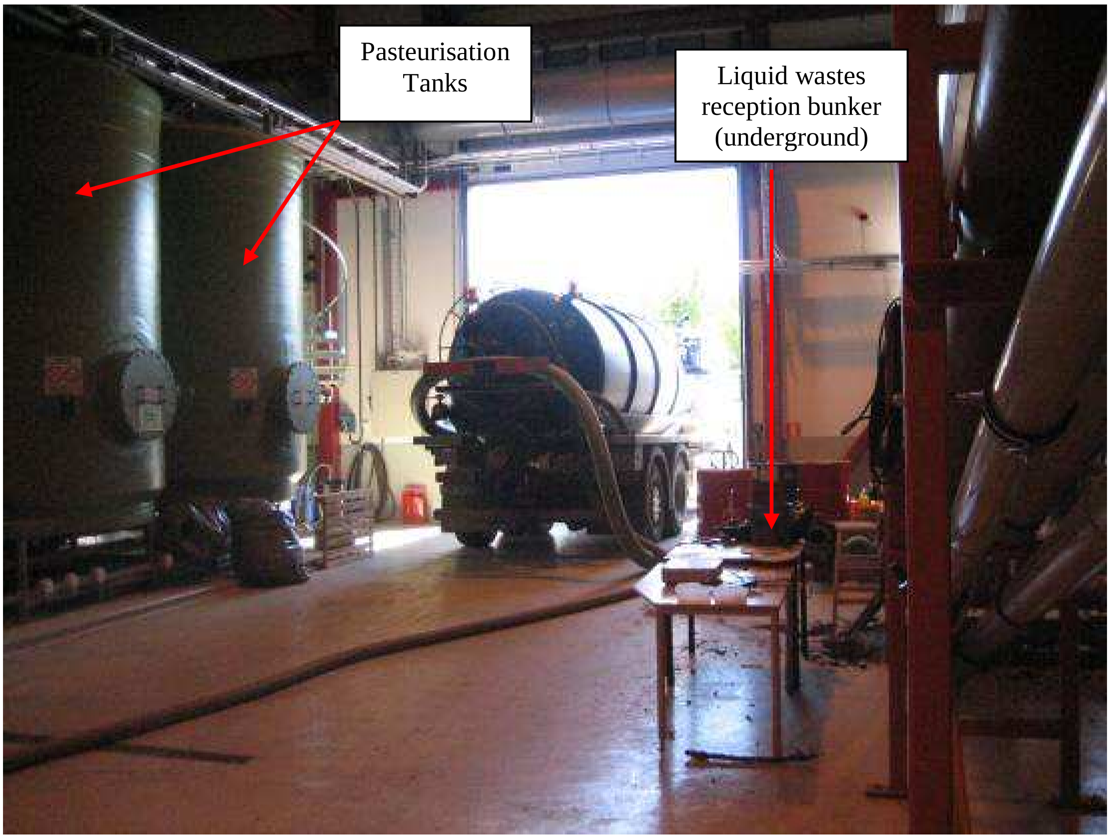

Figure 14 Liquid wastes reception area

Figure 15 Turbomixers

The suspension having passed the screen flows through an aerated sand trap where small inert particles like sand, glass, stones are separated. The result of a very efficient wet pre-treatment is a suspension strongly enriched with biodegradable material and almost free of impurities. The suspension then passes a crushing unit to ensure that only particles with a size of less than 12 mm are charged via a suspension buffer tank to the sanitation process. The sanitation process (70° C for one hour) takes place immediately before the anaerobic digestion. Figure 16 shows the three pasteurisation tanks.

Figure 16 Pasteurisation tanks

The design of the sanitation process makes possible to lead back suspension which was not correctly sanitized to the suspension buffer tank and the suspension can pass the sanitation process again. The sanitation process works under batch conditions in mixed tanks, in such a way as to ensure no short circuiting. The retention time as well as the sanitation temperature are controlled and monitored continuously. The exhaust heat from the co-generation unit is usually used for the sanitation process. After successful sanitation the suspension is charged continuously to the pre-digestion mixing/buffer tank, which is the tall tank narrow in Figure 17, where it is held prior to anaerobic digestion. The concrete structure in the foreground of Figure 17 is the biofilter, while the building on the left is the reception and mechanical treatment building. The shorter, wider tank to the right (just visible over the biofilter) is the digestate storage tank, where digestate is stored after digestion prior to being de-watered and transported to the farms. The anaerobic digester is the large tank at the back.

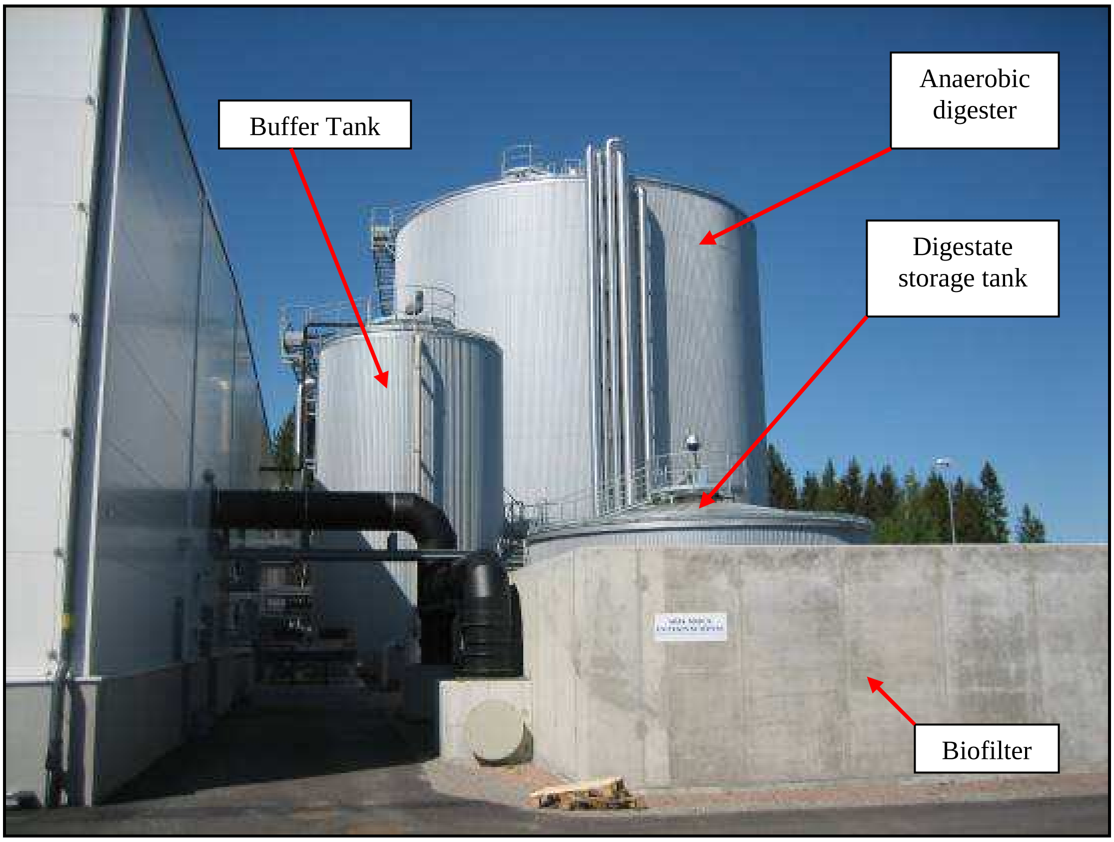

Figure 17 Digestate storage tank, buffer tank, and anaerobic digester at Växtkraft plant

ANAEROBIC DIGESTION

The anaerobic digester, shown in Figure 18, has a volume of 4,000 m^3. The retention time of the digester is 20 days (Persson, Personal Communication, 2006). Digestion is mesophilic, and carried out around 37°C. There are no moving parts in the digester, and mixing is provided by compressed biogas injection.

The digester is fed 6 days per week. Technically, the plant could be fed for seven days per week, but the plant is deliberately not fed on the seventh day so that it 'can clear the backlog' of process intermediates such as volatile fatty acids (Ahrens, 2006). There is some debate about whether this feeding regime is better than a continuously stable pattern, or a system that periodically 'shocks' or pushes the bacterial culture in order to strengthen it and encourage its development. It is assumed that lab scale tests have proven that this system is the optimum for this particular feedstock mixture in this particular digester. Ros Roca state that the digestion process is characterized by a low electricity consumption and a high surplus of electricity which is very important for the economy of the plant. No details of the monitoring regime or the operating pH range were given.

Figure 18 Anaerobic digester at Växtkraft plant

DIGESTATE

Because there is no post-AD treatment other than de-watering the throughput time of the plant is approximately 21 days (excluding the ley crop storage). The digested suspension is de-watered with centrifuges**.** No polymers are used to enhance the de-watering of the digestate. This is a requirement of the Swedish Organic Farming Quality regulations. As the solid digestate is nearly free of impurities, it needs no further treatment. It can be used directly in agriculture or can easily be upgraded to other products (for example, potting soil). The solid digestion residue from the process is of high quality directly after the digestion and certified from the Bundesgütegemeinschaft Kompost e.V. (BGK). The company transports the digestion residuals to the storage facilities on the fields of the participating farmers. The fertilizing potential of the digestion residuals is utilized by using modern spreading techniques. It is up to the farmer how the digestion residuals are used, although he receives guidelines from Växtkraft.

From the biogas plant one liquid and one solid phase of digestion residuals is obtained. The solid phase is handled as "normal" farm manure and is spread with conventional manure spreaders, *i.e.* the residuals must be dry enough to allow stacking. The liquid phase is pumpable and possible to spread with conventional slurry-spreaders. By the separation of the residuals into two phases the plant nutrients are divided too, so that the solid phase can be considered as a phosphorus fertilizer and the liquid phase as a nitrogen fertilizer. Pending the spreading, digestion residuals are mainly stored adjacent to the cultivated acreage. Liquid residuals are stored in covered tanks in order to minimize the ammonia losses during storage. The basic principle for the design and placing of the stores is to minimize the transport distances in connection with spreading. Solid and liquid residuals are distributed between the farmers in proportion to their contracted acreage of ley. The digestion residuals can replace mineral fertilizer on 1,200 – 1,600 hectares of cereals. The plant produces 4000 tpa of solid digestate (with a dry matter content of 25%) and 13,000 tpa of liquid fertiliser (dry matter content 2%). Liquid digestate (Figure 19) is re-circulated and excess tankered direct to on-farm storage tanks (Figure 21and Figure 22). Each farm has enough storage capacity for one years worth of liquid fertiliser storage. This is so that the liquid fertiliser can be stored and used at peak growing times (spring and early summer), when its addition will have the most positive impact on plant nutrient uptake and growth rates. There is also less rain in spring and early summer so there will be less nutrient leaching.

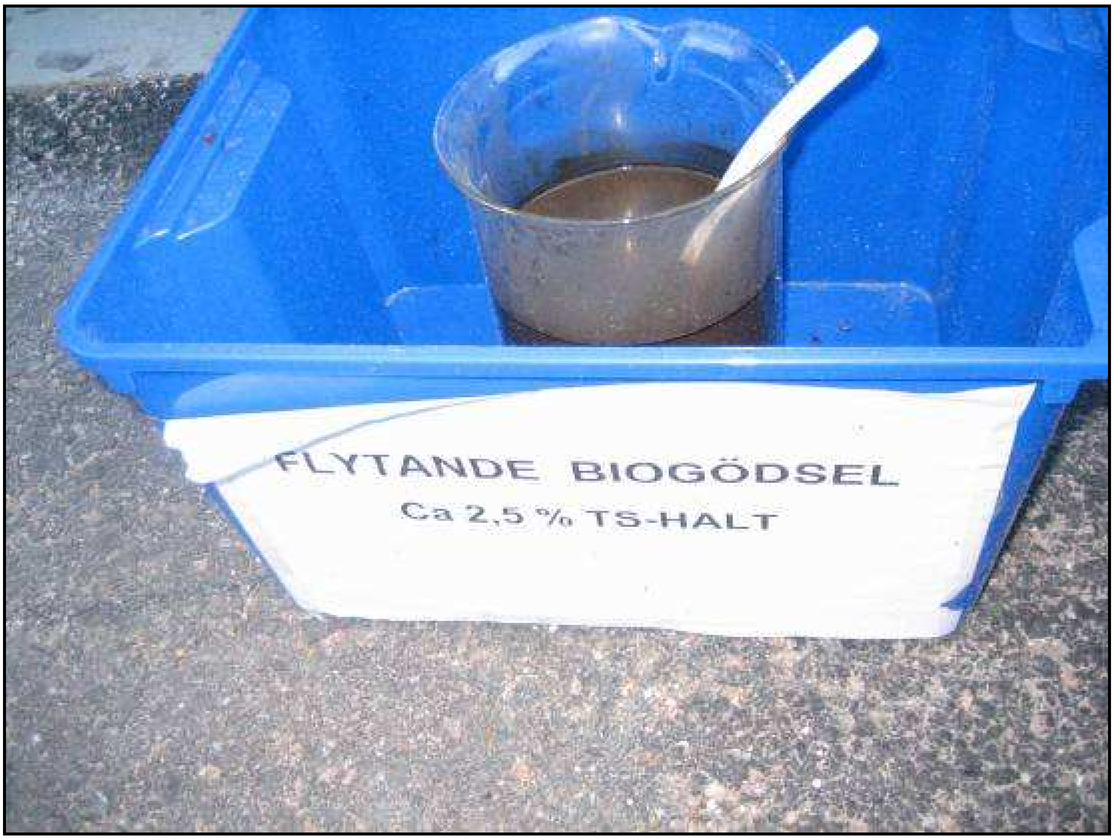

Figure 19 Liquid digestate

Figure 20 Liquid digestate transport from site (Pettersson, 2006)

Figure 21 Liquid digestate transport to storage tanks (Pettersson, 2006)

Figure 22 On-farm liquid digestate storage tank (Pettersson, 2006)

Figure 23 Spreading the liquid digestate (Pettersson, 2006)

The solid digestate (Figure 24) is transported by truck direct to the fields on which it will be applied (Figure 25 and Figure 26). The application of the solid digestate to the land provides NPK and other nutrients, as well as organic matter. Guidelines are provided by the company to each of the participating farmers on the amount of digestate that they can spread on each hectare of their land. The digestate is much better defined, much more regulated and better for the land than manure, which is used throughout Europe anyway (Wahlberg, 2006). All experiences with the soil improver and liquid fertiliser from the full scale process and from the lab and pilot scale projects have been overwhelmingly positive so far (Wahlberg, 2006).

Figure 24 Solid digestate

Figure 25 Truck removing solid digestate container from plant (Pettersson, 2006)

Figure 26 Truck unloading solid digestate container on farmland (Pettersson, 2006)

QUALITY CONTROL OF THE DIGESTATE

Liquid and solid digestates from the biogas plant are accepted as fertilizers in organic farming according to EC regulations. One of the preconditions for the decision to build the plant was that the digestates should be accepted for use in conventional cereal production, according to the rules of Svenskt Sigill and Cerealia and in organic farming according to the rules of the KRAV organisation. The quality control of the digestates is performed according to the rules for certification of compost and digestates, developed by the Swedish Environmental Protection Agency and the Swedish Association of Waste Management. The quality control is carried out in several steps, partly by inspections in connection with the collection and the reception at the plant and partly by analyses of the substrate within the biogas process and the digestates on delivery to the farm. Spot checks are carried out in connection to the collection of the waste in order to ensure that the given sorting instructions are followed. If impurities are found in the biowaste, the household/business is informed. If subsequent spot checks show that the given instructions are still not followed, the household/business in question will be suspended from the source-separation system. At delivery at the biogas plant, impurities (like wrongly sorted bags) are sorted out mechanically in the receiving hall. Furthermore, remaining impurities are separated in the wet pre-treatment step of the biogas plant in which light residuals are separated in a wet screen and heavy residuals in a sand grit trap. The grease trap removal sludge is controlled by checking that the sludge is collected at accepted grease traps and by chemical analyses. Sludge accepted to be charged into the biogas plant undergoes the wet pre-treatment process, mentioned above.

BIOGAS PRODUCTION AND UTILISATION

In lab tests the ley crop silage was shown to produce around 80 m^3 of biogas/tonne. In lab tests the grease waste was shown to produce around 45 m^3 of biogas/tonne. The kitchen waste produces approximately 100 m^3 of biogas/tonne (Ahrens, 2006). This corresponds to an expected biogas production of 550 m^3/hour at full loading capacity, or an average biogas production of 86 m^3/tonne of waste input under the current feeding regime. Average methane content is expected to be 60% (Ahrens, 2006). Figure 27 shows a process flow diagram for the biogas produced.

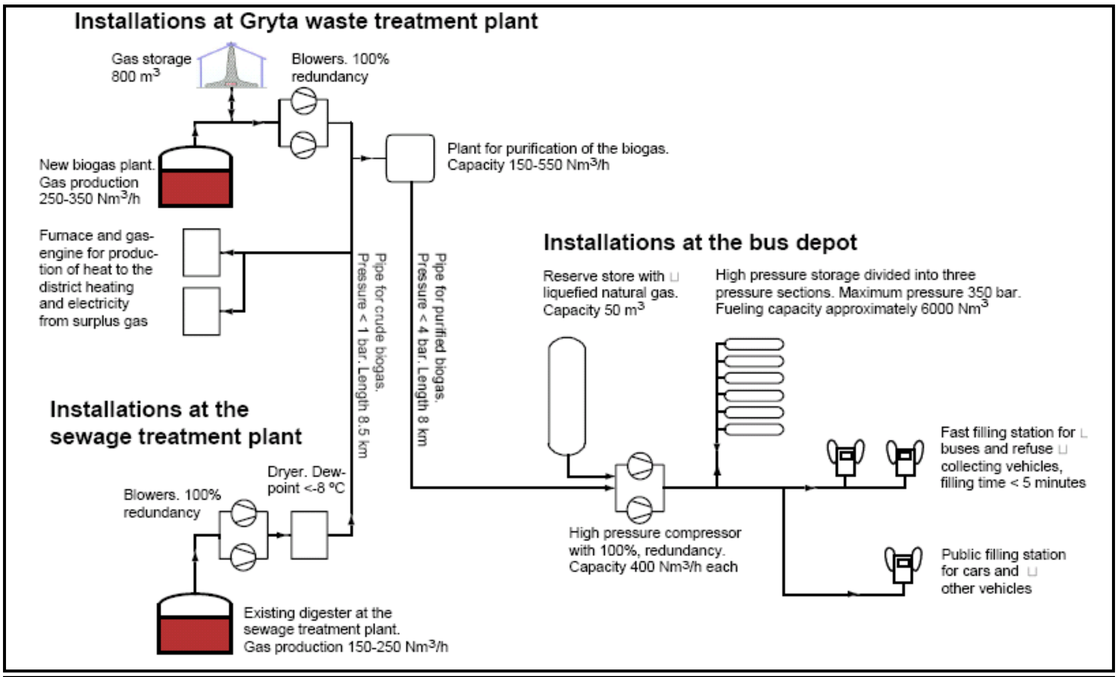

Figure 27 Overall biogas flow diagram (Växtkraft Promotional Information)

As mentioned above, the biogas is upgraded to natural gas quality (97 - 98% methane) and used as vehicle fuel for city buses and refuse collection vehicles. The biogas upgrading procedure will be described below. Prior to upgrading, the biogas must be compressed, and is added to the biogas pumped up from the sewage treatment works and compressed to 10 bar in the compressors shown in Figure 28.

Figure 28 Compressor units (Ahrens, 2006)

After compression, biogas is passed to the gas upgrading building (Figure 29), where a biogas scrubber uses 1,560 m^3 of water per day to upgrade 6,300 m^3/day of biogas from 65% methane to 97 - 98% methane. The scrubber operates at a pressure of 10 bar. Figure 29 shows the gas upgrading building (in the background), with the pre-digestion mixing/buffer tank on the right. The low concrete structure in front of the biogas upgrading building is the biofilter. Figure 30 shows the inside of the biogas upgrading building. The three columns are the biogas scrubbers, in which the biogas is mixed with water under pressure. The hydrogen sulphide concentration in the biogas before upgrading is around 1,000 ppm, and is 0 ppm after. A small amount of hydrogen sulphide is later added to give the upgraded gas an odour. The carbon dioxide percentage in the biogas was 30 – 35% before upgrading, and 2% after.

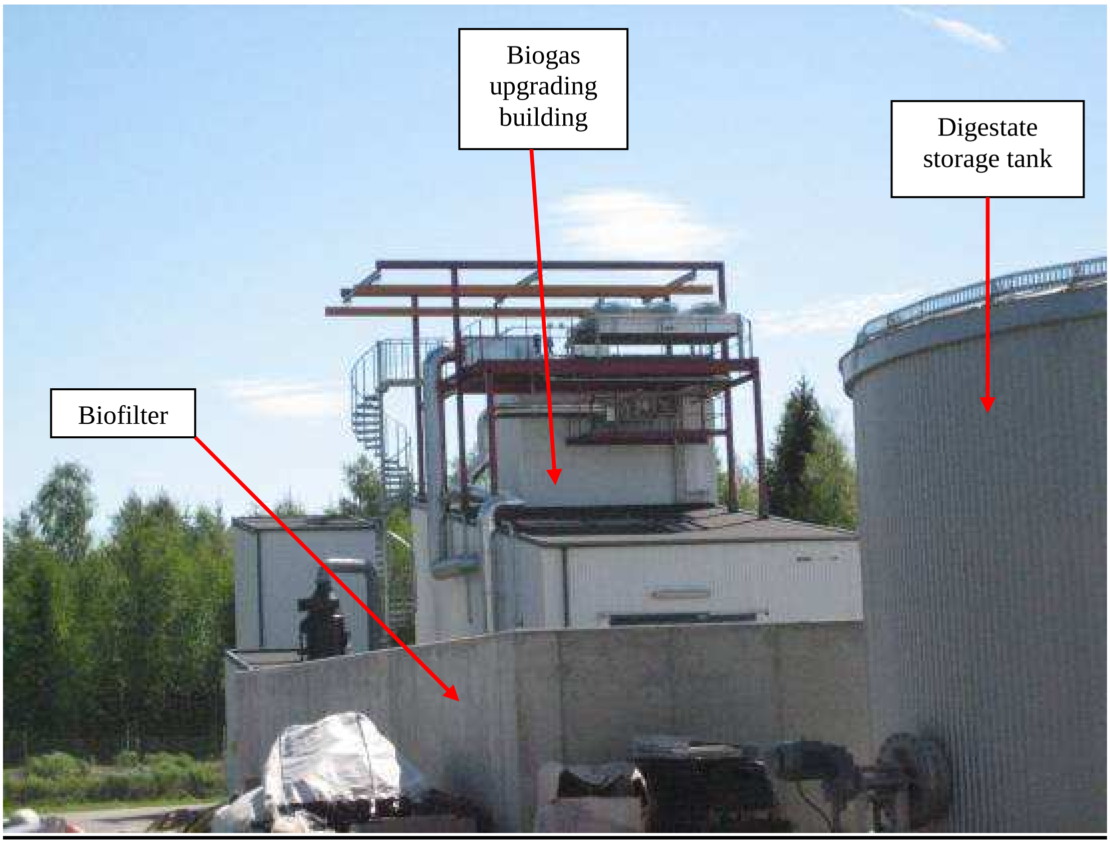

Figure 29 Biogas upgrading building

Figure 30 Inside of biogas upgrading building

After the carbon dioxide and hydrogen sulphide have been removed by scrubbing, the upgraded gas is dried in adsorption driers to remove water vapour, and re-odorised as a safety precaution. A flow diagram of the biogas upgrading system is available in Figure 31.

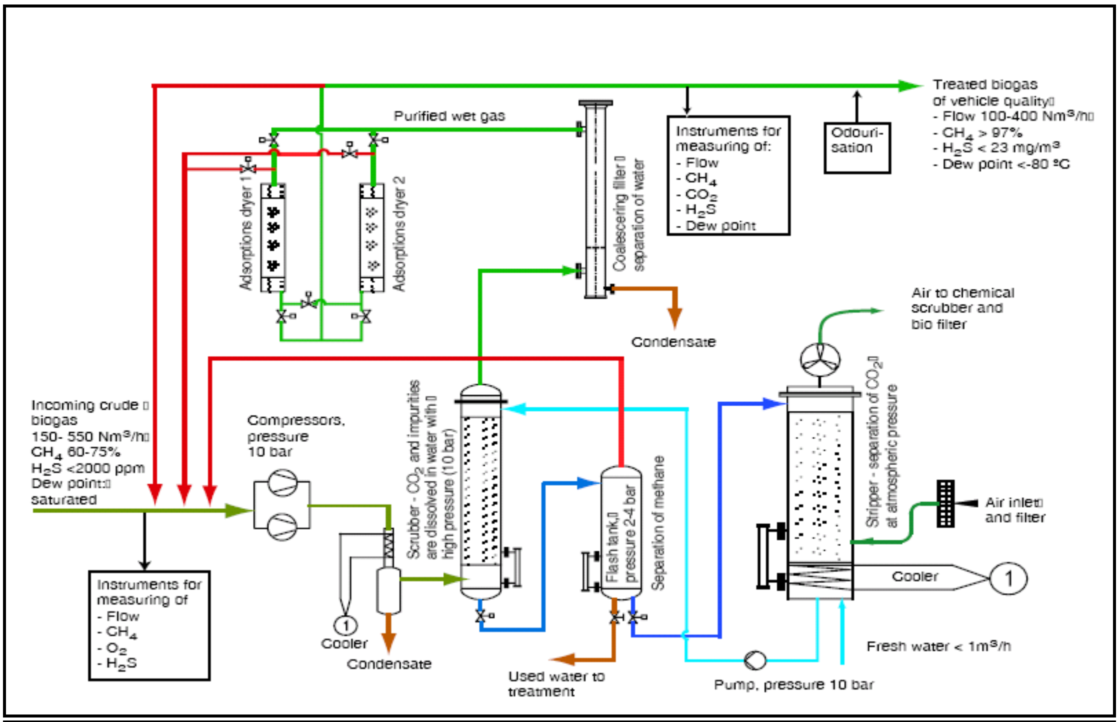

Figure 31 Flow diagram of biogas upgrading (Ahrens, 2006)

As can be seen from Figure 31 the core technology of the gas scrubbing system is the bubbling of biogas through a contra-flow of water at a high pressure (10 bar). The carbon dioxide and hydrogen sulphide, being much more soluble than the methane, dissolve into the water stream and are removed from the gas. Approximately 2% of the methane is also lost in the upgrading system. Trace gases such as Toluene, 1H-pyrazol, tromethamine and butanedinitril are also removed. A full list of the trace gases removed is available in Ahrens (2006). Upgraded biogas is then piped 8.5 km to the bus station in the centre of town (Figure 33 and Figure 34). At the bus station the biogas is further compressed to 330 bar (Figure 32) for storage efficiency and stored on-site (Figure 33). Buses are filled overnight, and one fill-up exceeds their maximum daily range they will not need to be filled again until the end of their working day.

Figure 32 Compressors at Västerås Bus Depot

Figure 33 Biogas storage at Västerås Bus Depot

The biogas pumps from which the buses re-fill are shown in Figure 34.

Figure 34 Biogas fuel pumps

There is also a public biogas filling station served by the same system, located just the other side of the bus station perimeter fence. At the bus depot, a reserve store with liquid natural gas is installed as a back-up in case of a decline in the gas supply. This reserve capacity is necessary, since buses that have been adapted for biogas fuel, can run only on gas, and are therefore totally dependent on daily deliveries of gas. The gas from the two production sites is sufficient to supply all of the city buses (at least 40 buses), 10 refuse collection vehicles and some 500 cars and other light transport vehicles. Only biogas that is needed is upgraded and piped to the bus station. The excess is sold back to the energy company (Mälarenergi), who utilise it in an existing CHP plant for electricity and heat production. The heat produced is led into the district heating system in Västerås. It is anticipated that about 75% of the gas production will be used for vehicle fuel while the rest will be used for CHP production. There is also a biogas flare for emergency maintenance situations, but obviously the flare will be used as seldom as possible.

ENERGY BALANCE

Around 2.9 MWh is input into the plant every day, of which 1.2 MWh is used by the compressors. The plant produces an average of 6,290 m^3 of upgraded methane per day. If the biogas was used directly in the CHP plant, rather than upgraded and used as a transport fuel, approximately 24 MWh/day of electricity would be produced, and 44 MWh/day of heat. This means that on balance the plant would produce and excess of electricity of approximately 21 MWh/day (based on the authors calculations). This would correspond to 7,665 MWh/a. The plant has a total electrical efficiency rate of 93.4% (Ahrens, 2006).

WATER AND WASTEWATER TREATMENT

The process minimises its water requirements by re-circulating process water for the dilution of the solid waste and the ley crop. No wastewater treatment is required (from the digestion process) as all liquid digestate not re-circulated is used on the farms. The biogas upgrading plant uses 65 m^3 of fresh water/hour to upgrade biogas from 65% methane to 97 – 98% (Ahrens, 2006). This water is treated before being released. No information was available on how or where this wastewater was treated.

EXHAUST AIR TREATMENT

The process is ‘closed’, with collection and treatment of all exhaust gases in a scrubber and a biofilter, to avoid any odour problems around the plant. The air is pre-heated before it enters the bio filter in order to ensure the intended function of the biofilter in the cold winter conditions.

VISUAL AND LOCAL IMPACT

The biogas-plant is situated adjacent to the other installations at the waste treatment plant at Gryta, in the northern outskirts of Västerås. The whole plant is surrounded by woodland, and can not be seen from outside the complex. With regards to odours, the plant smelt of silage rather than wastes, and therefore portrayed an agricultural image (rather than a wastes treatment image) to visitors. There was no odour nuisance to neighbours due to the siting of the plant on an existing wastes treatment complex. All exhaust air was collected and treated in a scrubber and biofilter in order to avoid any odour problems in the surroundings of the plant.

COSTS AND ECONOMICS

The total capital cost for the biogas plant was in the region of €8.4 million. The contract was a ‘turn-key’ contract, which means that everything from the initial ground work to the plant running at the levels stated in the contract (Persson, Personal Communication, 2006). The total capital cost for the gas upgrading plant was €1.7 million. The contract was similar to that for the biogas plant, meaning that everything was included, and the contract was not complete until the plant had been running successfully to pre-stipulated performance levels for a stated period of time. The total capital cost for the facilities at the bus depot (high pressure compressors, high pressure gas storage, LNG storage, tank stations for buses and cars, including buildings and internal gas piping *etc*.) cost a total of €1.4 million (Persson, Personal Communication, 2006). The plant was co-funded by EU FP5 program for research and demonstration, by the Swedish government and by the conglomerate of investors described above. The funding was as follows:

- 30% by EU.
- 30% by Swedish Government.
- 40% by the Conglomerate of investors who own the plant.

The 40% share provided by the owning partnership was based on finance from financial institutions, whose reactions to the application varied greatly. The risk perceived by the banks was reduced greatly by the size of the participating companies for example, the energy company (Mälarenergi), wastes and water companies (Vafab-Miljö).

As part of the Agropti Gas project a socio-economic analysis report was carried out (JTI, 2006). To summarise the findings of the socio-economic analysis, the system as it stands is a win-win situation. The results for the annual benefits are summarised below:

- Benefit to the environment was estimated at €91,930.
- Benefit to society was estimated at €275,781.
- Benefit to agriculture was estimated at €72,000.
- **Total Benefit = €439,970**.

Other benefits not factored into these figures include;

- Increased opportunities for rural employment.
- Positive impact on working environments.
- Increased levels of health (as emissions of ammonia and VOCs are reduced, as well as particulates, CO_2 and NO_x reductions from the substituting of diesel as a transport fuel).

A negative impact is the compaction of the soil when spreading the solid digestate or liquid fertiliser. Another area that needs more work was the storage facilities for digestate (solid and liquid), which currently lead to ammonia loss. Conclusions of the socio economic analysis were;

- Project was beneficial on all levels considered.
- Income from biowaste is the largest income.
- Replacement of mineral fertiliser is positive for the agricultural system.
- Substituting diesel with biogas for city buses is environmentally positive.

The full presentation, including how these estimations were calculated is available in JTI (2006).

DISCUSSION AND CONCLUSIONS

The conclusions observed so far have been overwhelmingly positive. There have been benefits observed on all levels considered - agriculturally, energetically, in terms of wastes treatment, in terms of transport and most importantly financially. The positive financial results are a direct consequence of the Swedish Government's taxation and development policies, aimed at promoting renewable energy provision. Government support was key in Sweden. Without top-level Government support, Sweden would not have any biogas plants. Competitiveness depends on the taxation system in your particular country (Nilsson, 2006). It is unknown if similar positive economics would be possible in a similar UK based system. This would require further study based on more detailed economic information than was made available.

The information contained in the Agropti-Gas Workshop presentation by Carl Magnus Pettersson (Production Manager of the Växtkraft Project), titled 'Lessons Learned' should be studied and taken on board by any decision maker who is considering embarking on a similar project. Key points were extracted and are discussed below.

- **'Identify the important key organisations and involve them in the project in an early planning phase'.**

This is a fundamental key to success. All of the project partners are key to its success in different ways, because of what they can bring to the project.

- '**A company should be formed to make key decisions and manage/realize the project'.**

The key stakeholders should be part owners of the company, so they have active roles. That said, it is important that responsibilities, boundaries and aims are clearly defined.

- '**Make the partners (key organisations) owners of the company**', and
- '**Give the owners active roles in the operation with focus on their specific fields of competence'**. Within this**:**
    - **'it is key that the company does not compete with any of the owning companies'**.

Potential conflicts could arise if these pre-conditions are not met.

It has been said that the farmers are the most important partners in the conglomerate. Indeed the farmers, and their wish to improve their soil was one of the main drivers for the project. The farmers in the region are mainly crop producers, with very little intensive agriculture. As such the soil quality had been observed to be gradually decreasing over a number of years. The farmers wanted to increase the organic and nutrients content in the soil, but with not enough manure to go around they began to search for other alternatives to increase the productivity of the region's stiff clay soil. They looked at the cultivation, cropping, anaerobic digestion (and re-application of the digestate) of ley as a serious soil improvement option. Early studies showed that this would not be economic, therefore they investigated the possibility of taking in municipal biowaste. If the farmers were not on board, the project would simply not be viable. There would be no disposal route for the solid digestate, and therefore the plant would need to pay to have it disposed of. Also, the liquid digestate would need to be treated as wastewater, significantly adding to the capital and running costs of the plant. It was stated that farmers do not benefit greatly financially (at least directly), but their benefit is that they improve their soil quality.

Despite the importance of the farmers, without the wastes and energy companies on-board the project would not have been viable either. Aside from the gate fee from the municipal biowastes being a critical financial input, the sheer size of the energy and waste companies (and their financial clout) meant that the banks took the project seriously and provided the initial finance. These points serve to underline the key concept that a solid partnership between many stakeholders is required.

- '**Get one main contractor for each plant, co-ordinating sub-contractors. This makes life easier for the purchaser'**.

This is an important point that has been re-iterated in personal communications with numerous sources throughout Europe. Co-ordinating contractors for such a diverse plant can be extremely problematic and time consuming.

- '**Reduce the amount of tenderers to a few reliable suppliers, capable of successfully finalising the project. They must have sufficient experience, competence, size and financial strength**'.

Only get tenders from four or five 'major players'. Do not ask for applications from anyone and everyone. Tenders for full plants (or parts of plants) represent huge amounts of work (for those who will submit them, and for those who must evaluate them). The use of suppliers with existing reference plants and a proven track record in the field is highly recommended. It was stated (as it has been referred throughout in this project) that 'corners should never be cut' for short term financial gains. Also extreme care should be taken if considering awarding contracts to an un-proven supplier. The financial strength of the suppliers should always be analysed, as there have been problems in the past of projects running into major difficulties because the suppliers (or some sub-contractors) have gone bust.

A high quality biowaste is essential for the realization of digestate quality standards, which are key to project goals and finances.

- '**A source separated high quality biowaste is achievable but calls for massive efforts, for example information and education activities towards the households**'.

The source separation of biowastes should be established well before the AD plant is scheduled to come online. This provides two main benefits:

1) The population gets used to source separation, and the percentage of contaminants decreases.
2) The exact characterisation in terms of quantity, content and contaminants of the waste stream can be established.

In this case, the source separated biowaste was treated by IVC, purely as an intermediate measure, while the AD process was being planned. In this way there was a viable 'product' to show the public from the start. This also meant that the public did not lose interest in source separation, and let their standards slip, as may have happened had they realised that their source separated biowaste was being incinerated with the residual waste anyway.

- '**Focus on the quality of biowaste, rather than quantity. Restrict the biowaste to food waste**'.

The achievement of a high quality source separation and therefore a high quality biowaste is fundamental for the success of the whole project. In fact, the Swedish lack of contaminants in the waste source separated by the Swedish population provide the primary reason why the project has been successful, as compared to similar schemes in other countries where the quality of source separation was not so good (Denmark, Finland and Germany).

Doubt has been expressed over the possibility that the digestate could possibly meet Swedish Organic Farming Quality Standards, as it is wastes-based. The plant owners (including the farmers) insist it does. If the pre-agreed and contracted quality standards are not met, the farmers are within their rights to refuse to accept the digestate or fertiliser. It may well be that the Organic Farming Regulations differ greatly between Sweden and other European countries. This has not been verified by the authors. The farmers would lose the markets for the crops they produce if they were to apply contaminated digestate. As such, if the quality standards are not met, the digestate will need to be landfilled, as the farmers will not be obliged to accept it.

In summary, the key data is shown in Figure 35.

Key data:

Incoming substrates to the biogas plant per year

• Source-separated organic waste from households and institutional kitchens with a dry matter content of 30 %	14 000 tonnes
• Liquid waste (grease trap removal sludge), with a dry matter content of 4 %	4 000 tonnes
• Ley crop from a contracted acreage of 300 hectares with a dry matter contents of 35%	5 000 tonnes

Production per year

• Biogas from the biogas plant	15 000 MWh
• Biogas from the sewage treatment plant	8 000 MWh
• Up-graded biogas to fuel quality	
Energy	23 000 MWh
Equivalent to petrol	2.3 Million litres
• Digestion residuals	
solid part with a dry matter content of 25-30%	6 500 tones
liquid part with a dry matter content of 2-3%	15 000 tonnes

Figure 35 Key data from Växtkraft Project (Växtkraft Promotional Information)

A key concept is the integrated thinking between farmers, the agriculture sector, the waste sector and the energy sector. The political framework must be in place to encourage development. Pettersson (2006) suggested that they would '**do it again, in almost the same way**'. Although the Växtkraft/Västerås project has been successful to date, it was only started up in 2005. Therefore, as yet, there is a lack of an operational track record. The track record over time is the only real way to judge the success of such a project.

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