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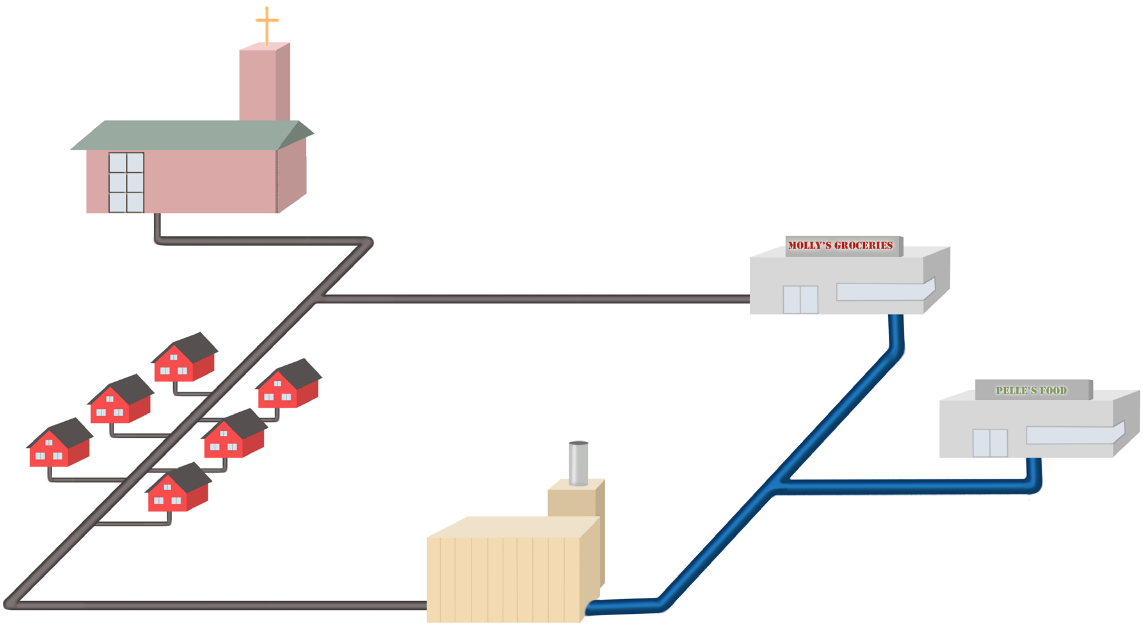

Development of a waste management service based on small-scale biogas

Master's thesis in Design and Human Factors

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Gothenburg, Sweden 2015

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Abstract

The aim of this project was to evaluate the market possibilities for FOV's textile based biogas digester in Sweden, and to develop a concept of how to approach this market. The source of biological waste to approach was chosen to be grocery stores. Grocery stores threw away 70,000 tonnes food waste in 2012.

The conclusion was that there is a possibility for a future market for small scale biogas in Sweden. It is however important to separate the biogas digester from the grocery store. The reason for this is the outspoken need from the stores to only focus on their core business.

The final concept therefore contained a pretreatment facility in the grocery store, pipelines for the pretreated slurry to the biogas digestion plant and a combined site for the biogas digester and heat plant, which is in turn connected to a district heating system,

Keywords: Biogas, small-scale biogas, digestion, food waste, grocery stores, service development.

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Helena Almegius

Göteborg, 2015

Contents

1. Introduction

In this chapter an introduction to the project will be given, including background, a presentation of FOV Biogas and the purpose of this master thesis.

1.1 Background

In 2010, 1,010,000 tonnes of food waste was generated in Sweden, from which 39,000 tonnes was generated in grocery stores. [1] Out of the total amount of food waste, 9,7 % was digested, 13 % composted, and 77,3 % incinerated. The aim from the Swedish Environmental Protection Agency *(Naturvårdsverket)* is that 50 % of all food waste should be digested or composted in 2018. (Naturvårdsverket, 2012a)

The large part of biogas production in Sweden today is in large scale. As much as 95 % of the production of biogas in 2013 was performed at large scale biogas plants. (Statens energimyndighet, 2014) FOV Biogas has developed a small scale biogas digester based on textile material. The textile makes it cost-efficient and easy to transport and install. In this project the aim is to evaluate the market possibilities for FOV's textile based biogas digester in Sweden.

1.2 FOV Biogas

FOV Biogas is a cutting edge-technology company focusing on cost-efficient biogas production through textile biogas digesters. One of FOV's digesters can be seen in figure 1. The company origins from FOV Fabrics, which was founded in 1962. (FOV Fabrics, 2015) FOV Biogas' mission is "to make biogas technology an accessible and reliable investment for as many people and organizations as possible". They are situated in the city of Borås which is a long-leading textile center with the Swedish School of Textiles at the University of Borås. (The Swedish School of Textiles, 2015) FOV Biogas is in a partnership with the University of Borås and collaborates with universities in all parts of the world. (FOV Biogas, 2015)

1 According to another report from the Swedish Environmental Protection Agency the total amount of food waste in 2010 was 1,104,000 tonnes, from which 67,000 tonnes originated from grocery stores. From the same report the figures for 2012 was 1,211,000 tonnes in total, from which 70,000 tonnes came from grocery stores. (Naturvårdsverket, 2014)

Figure 1 - A textile based biogas digester developed by FOV Biogas (FOV Biogas. 2015)

1.3 Purpose

The purpose of this master thesis was to analyze the potential market for a textile based biogas digester in Northern Europe. Thereafter, the aim was to develop a product based on the small scale biogas digester for that market.

2. Methodology

In the following sections the methods used in this project will be described.

2.1 Planning methods

The main planning method that was used in this project was the GANTT chart, which is described in the following section.

2.1.1 GANTT chart

A GANTT chart is a traditional tool for presenting the timing of tasks. (Ulrich, Eppinger, 2012) In this project it was used in the planning phase to create a time schedule for the entire project.

2.2 Data collection methods

When gathering data for market research there are mainly two types of data that can be collected; Qualitative and quantitative data. Qualitative data is sought to increase understanding and conceive insights. An example of a qualitative data is the fact that, “Susan likes the current solution because it is similar to other systems she is using”. Quantitative data is data that can be measured, for example, “25 % of the users are unsatisfied with the current solution”. Qualitative and quantitative data often complement each other. In this project unstructured interviews and an online survey has been used. Unstructured interviews is a way of collecting qualitative data, while surveys can be used to collect quantitative data. (Hague, Hague, Morgan, 2013)

2.2.1 Interviews

Interviews is a traditional and common method for collecting data during market research. Interviews can be conducted in a face-to-face situation, over telephone or in writing. The advantages of interviews is among others the possibility of posing follow-up questions. This increases the chance of obtaining a full picture of the interviewees point of view. (Hague, Hague, Morgan, 2013)

The interviews in this project were unstructured. The subjects of conversation was determined beforehand but the actual conversation went on freely. Four face-to-face interviews were held. The first was with the head chef of a larger conference restaurant. The second with a facility manager in a hotel chain, the third with a head of recycling in a major grocery store chain and the last with the head of a smaller grocery store. In addition ten telephone interviews were held. These were directed towards people with different areas of knowledge, such as an head of waste management in a municipality, a logistics manager at an upgrading plant and a CEO at a manufacturer of gas boilers.

2.2.2 Survey

In this project an online survey was conducted. An online survey is a type of survey where a questionnaire is sent out to a large amount of recipients over the internet. In a questionnaire questions are fixed beforehand and answered without interaction with the interviewer. The advantages of an online survey is the possibility of reaching a large number of recipients. On the other hand, the rate of responses can be quite low. (Hague, Hague, Morgan, 2013)

The survey in this project was directed towards grocery stores. It was on the subject of the grocery stores waste management. The questions were mixed multiple choice questions and questions where the respondents were asked to rank different factors. The survey was sent to the heads of 80 grocery stores in the Västra Götaland region. 22 responded, which yields a response rate of 27.5 %.

2.3 Analysis methods

Several methods exists for analysing business and current market situations. Three of them have been used in this project, and will be presented in the following sections; The SWOT analysis, benchmarking and the stakeholder analysis.

2.3.1 SWOT

A SWOT analysis was conducted since it was considered to give a proper overview of the current business situation. SWOT is an acronym for Strengths, Weaknesses, Opportunities and Threats. It is used to summarize and display internal and external success factors, which is often represented by a two-by-two matrix, as shown in figure 2.

Internal	Strength	Weaknesses
External	Opportunities	Threats

Figure 2 - Graphical representation of a SWOT analysis

Strengths and weaknesses are internal factors, which means that they origin from the company and can therefore be directly influenced. Internal factors are also measured against competitors, while external factors remain equal for the company and its competitors. (Paul, Yeates, 2006)

2.3.2 Benchmarking

Benchmarking is the study of products with similar functions as the product under development. The aim of benchmarking is to reveal strengths and weaknesses within the competitor products. (Ulrich, Eppinger, 2012) In this project different solutions for waste management were benchmarked.

2.3.3. Stakeholder analysis

All projects involves different stakeholders. A stakeholder is anyone interested in the outcome of the project. These stakeholders might not have neither same expectations nor starting-point. In a product development project for example, the customer and user are not always the same person. Both are stakeholders, but can have different requirements and expectations on the product.

The stakeholders can be divided based on two mutual aspects; The power and influence the stakeholders has on the project, and the impact or interest the project have on the stakeholder. This illustrated in figure 3.

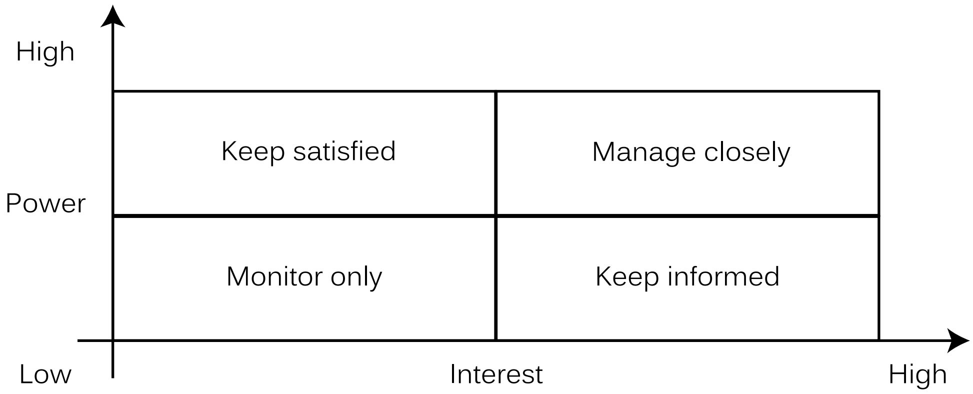


Figure 3 - A graphical presentation of how to manage different types of stakeholders.

The stakeholders that holds high power and interest are naturally those who could be most involved in the project. The stakeholders with high power but low interest need only to be kept satisfied, while the stakeholders with a high interest but low power needs to be satisfied and well informed of the project outcome. (Maylor, 2010)

2.4 Ideation methods

The process of ideation aims to generate solution concepts. A common method for generating concepts is brainstorming, which is described in the following section.

2.4.1 Brainstorming

The purpose of brainstorming is to generate concept solutions by using the team members personal knowledge in combination with their creativity. Four guidelines can be useful to improve the brainstorming; 1. To suspend judgment of ideas, 2. To generate a lot of ideas, 3. To welcome ideas that seem infeasible, and 4. To use graphical and physical media. (Ulrich, Eppinger, 2012) Brainstorming was used continuously during the later part of this project. It was performed using graphical media such as mind maps, flow charts and sketches.

2.5 Evaluation methods

After concept generation, several concepts was formed. Several tools exists for selecting the most promising of these concepts. A commonly used concept selection tool is the Pugh matrix, which is described in the following section.

2.5.1 Pugh matrix

A Pugh matrix is used to quickly narrow the number of concepts down. This is made by comparing all generated concepts with a chosen reference concept. (Ulrich, Eppinger, 2012) In this project several concepts was ranked in a Pugh matrix. This was used in the process of developing the final concept.

3. Background research

The background research in this project contains results from a literature study, interviews and a survey. This will be presented to in the following sections.

3.1 About biogas

The following sections will provide a presentation of biogas; Its constituents, production cycle and areas of applications. The last section will also end up with a review of the benefits and risks of biogas production.

3.1.1 What is biogas?

Biogas consists of a mixture of methane (CH_4) and carbon dioxide (CO_2) saturated with water vapor. In addition minor components of hydrogen sulfide, nitrogen and ammonium is occurring. Methane is the part of biogas that contains most of the energy. Depending on ways of production the amount of methane can deviate from 45 to 85 %. (Naturvårdsverket, 2012b) However, the amount of methane is normally 60-70 %. (Statens energimyndighet, 2014a) The residual product from biogas production is known as fertilizing slurry. It contains almost no energy but is high in nutrients. (Naturvårdsverket, 2012b)

3.1.2 From garbage to energy - the system

Temperature domain	Degrees °C
Phsycrophilic	15 - 30
Mesophilic	35 - 40
Thermophilic	55 - 65

Table 1 - Temperature domains in the digestion process (Norin, 1998)

From biological waste to usable energy there are three main steps; Pretreatment, digestion and energy conversion. The residual product, fertilizing slurry, can be used in agriculture or disposed via the sewer system. The system is illustrated in figure 4.

The purpose of pretreatment is to achieve an appropriate level of hydration in the substrate. This facilitates the production of biogas and makes the substrate possible to pump through the production plant. The amount of dry matter that is wished to achieve is usually 8-15 %. (Carlsson, Uldal, 2009) However, when the substrate is food waste from households or grocery stores, the first step in the pretreatment is to separate the biological waste from packaging and wrongly sorted material. (Naturvårdsverket, 2012b)

The process of digesting biological waste to biogas is normally 15-30 days. This time is known as retention time. (Statens energimyndighet, 2014) The rate of production is dependent on the temperature in the digester. Three different temperature domains exist; The phsycrophilic, the mesophilic and the thermophilic. These are illustrated in table 1. The higher the temperature, the higher the rate of biogas production. (Norin, 1998)

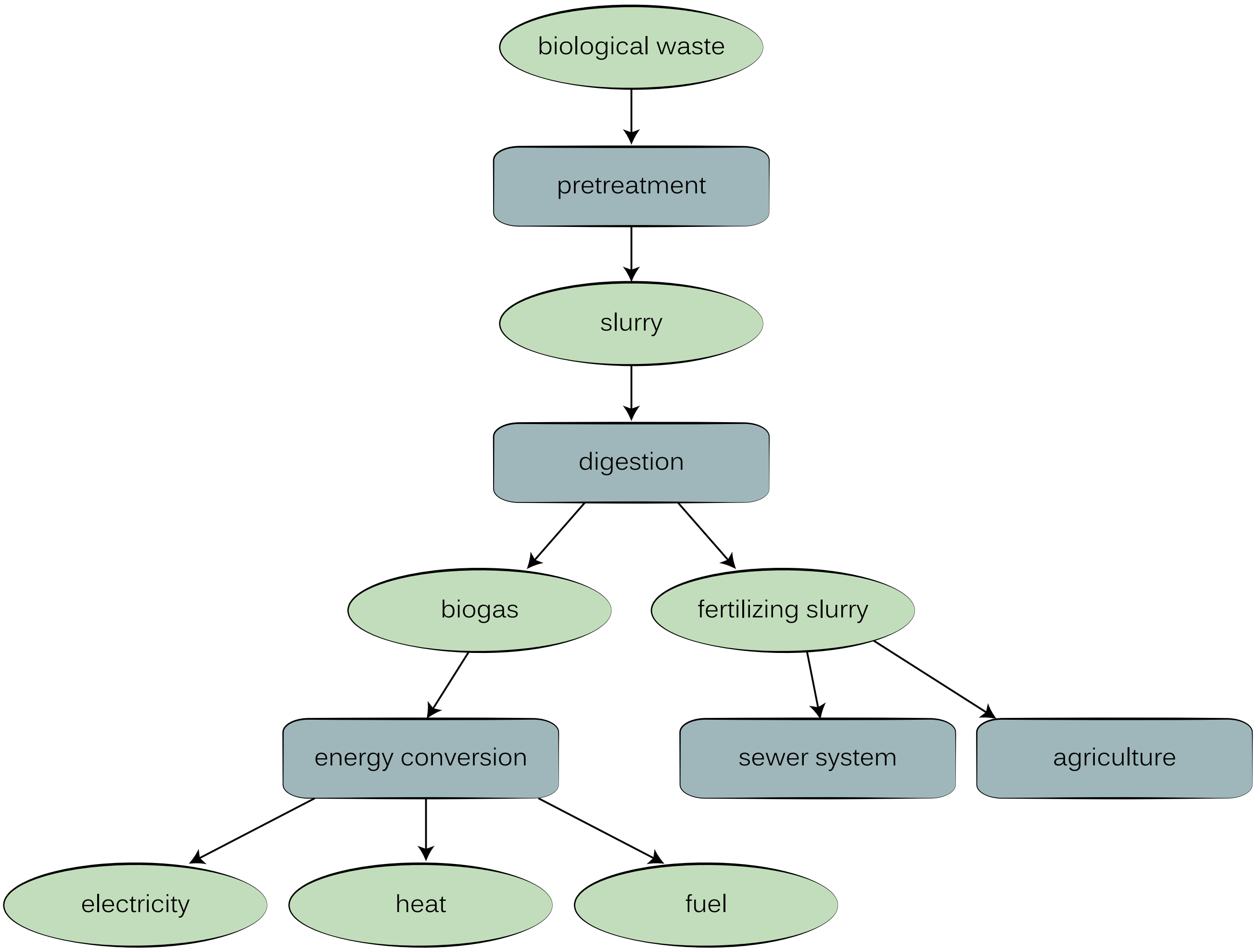


Figure 4 - The system describing the way from biological waste to energi.

When biogas is produced, there are three different ways of utilizing the energy; Producing heat, producing electricity or upgrading the biogas to fuel, as seen in figure 4. This will be discussed thoroughly in the following section.

3.1.3 Energy conversion methods

Biogas can be converted into energy types as heat, electricity and fuel. These are presented below.

Heat generation

Biogas can be used for heat generation in gas boilers or burners. The only preparation needed before incineration is to remove water vapor. The major part of gas burners and boilers on the market today are developed for natural gas. Natural gas contains 90 % methane (Naturvårdsverket, 2012b), while biogas normally contains 60-70 % methane (Statens energimyndighet, 2014a). The remaining part of biogas consists of carbon dioxide, hydrogen sulfides, nitrogen and ammonium. These remainders can be problematic and decrease life time for affected engine parts.

One technique that is quite new and still under development is condensation gas boilers. These work for natural gas and mixtures of natural gas. (Viessmann, 2014) Ordinary gas burners do not have the same high efficiency as condensation boilers but are suitable for both biogas and natural gas. There are several companies providing gas boilers today, for example Weishaupt, Viessmann, Vaillant and Milton.

Electricity generation

Biogas can be used in combined heat and power systems, CHP, to produce electricity and heat. 30-40 % of the energy can be utilized as electricity, while the rest is used as heat. Alike heat production water vapor need to be removed before usage. The biogas also need to be cleaned from corrosive materials such as hydrogen sulfide. Otto engines, diesel engines and micro turbines can be used for small-scale combined heat and power production. (Naturvårdsverket, 2012b) Companies providing micro turbines suitable for biogas today are for example Bladon Jets and MTT Micro Turbine Technology.

Upgrading to fuel

Biogas used as fuel need to contain at least 95 % methane. It therefore need to be upgraded to this amount. Upgrading biogas to fuel can be made with different techniques, such as amine scrubbers, water scrubbers, PSA units, organic scrubbers and membrane units. Upgrading biogas to fuel is usually very expensive, since the investment cost is more or less equal for a plant with low capacity as one with high capacity. However, two techniques are especially developed for upgrading biogas in small-scale.

The first technique is a special type of water scrubbing using high pressure used by the Finnish company Metener. The high pressure used results in a higher electricity consumption than in conventional water scrubbers. On the other hand, the upgraded biogas produced has a high pressure from start, and can be used at a fuel station with only minor additional compression. The cost of a Metener upgrading system, with a capacity of 60 Nm^3/h, is around 380,000 €.

The second technique is another special type of water scrubber. It has a rotating coil in which the gas is upgraded, and is developed by the Swedish company Biosling. An amount of 94 % methane can be achieved by using the Biosling rotating coil. To upgrade the fuel to 95 % or more, a conventional water scrubber need to be used for the last percents. Since the investment cost arises with the final polishing scrubber, this technique may be more suitable for applications where a lower amount of methane is accepted. The cost of a Biosling upgrading system, with a capacity of up to 72 Nm^3/h, is 360,000 € - 460,000 €, depending on the model.
(Bauer, et al., 2013)

3.1.4 The benefits and risks with biogas

Biogas is a renewable energy source. This means that the carbon dioxide that is released in the incineration of biogas is part of todays biological cycle. The same amount of carbon dioxide would be released if the substrate would moulder in nature. The carbon dioxide that is released by incineration of natural gas is on the other hand part of a biological cycle a long time ago, and is therefore not carbon neutral when it is incinerated today. This gives biogas its environmental advantage. (Naturvårdsverket, 2012b)

Biogas can be produced in almost every location. Unlike oil and natural gas it can be produced in Sweden. Focusing on biogas production is a step towards an independency of fossil energy sources, and in turn an independency of governments in political unstable regions. Focusing on biogas is a strategic step towards a long term sustainable energy supply. (Naturvårdsverket, 2012b)

The residual product from biogas production is known as fertilizing slurry, and can be used as a fertilizer in agriculture. Fertilizing slurry contains large amounts of nutrition from the original substrate. It is in Sweden generally free from pollutants and controlled by the he standard SPCR 120. (Naturvårdsverket, 2012b)

The major downside of biogas production is the risk of leakage of methane. Methane is a 20 times more powerful greenhouse gas than carbon dioxide. This is the reason for incinerating excessive methane in industries, so called gas flaring. (Statens energimyndighet, 2014) Preventing leakage of methane is therefore highly important. On this basis a voluntary undertaking is created by the Swedish Waste Management *(Avfall Sverige)*. The voluntary undertaking is aimed at biogas production and upgrading plants and constitutes of systematic searching for and mapping of leaks, as well as periodically emission investigations by independent measuring consultants. (Avfall Sverige, 2015)

3.2 Results from literature and empirical study

The following sections contains the results from the literature and empirical study. The empirical study contains visits and interviews on site as well as a survey.

3.2.1 Literature study

The literature study regarding small scale biogas has mainly been focused on two reports; “Potential for small-scale biogas, opportunities for grocery stores” (“Småskalig biogas, möjligheter för livsmedelsbutiker”) and “Small-scale biogas plants at large grocery stores” (“Småskalig biogasanläggning vid stora livsmedelsbutiker”). The literature would preferably been focused on more than two reports, however, small scale biogas directed to grocery stores, or businesses comparable to grocery stores, is a relatively new area, and it does therefor not exist a large number of studies in this area. The first report, “Potential for small-scale biogas, opportunities for grocery stores”, is a bachelor thesis from the University of Borås written by Adam Ejervall and Carl-Johan Rydman. The second report, “Small-scale biogas plants at large grocery stores”, is a report from the Swedish Energy Agency written by Bo von Bahr. Both reports includes the scenario of a closed loop, i.e. the biogas digester is placed at site at the grocery store and the energy produced from the digester is utilized in the grocery store. Von Bahr is examining conventional small scale biogas digesters while Ejervall and Rydman are investigating conventional biogas digesters as well as the textile based biogas digester from FOV Biogas. (Ejervall, Rydman, 2013)

Report: “Small-scale biogas plants at large grocery stores” (von Bahr, 2012)

Von Bahr is focusing solely on conventional biogas digesters. The scenario is a medium sized grocery store in the ICA chain with 43 tonnes biological waste per year. The energy amount produced in this scenario is 61 MWh, which should be compared to the total energy consumption of the store. A comparison like this is however not included in the report.

The author makes an extensive evaluation on a systems level between the options of transporting the biological waste to an existing biogas digestion plant and building a small-scale biogas digestion plant at the store. He concludes that it is more beneficial not to have a small-scale biogas plant located on site at the store. Instead, the recommendation for grocery stores is to pretreat their waste to a slurry in which then can be transported to a biogas plant. The reason for this recommendation is the following; It will take a long time before the environmental impact of transporting waste to the existing biogas plant is larger than that of building the small-scale biogas digester. In the meantime there is a risk that the small-scale biogas digester has reached its lifetime and needs to be replaced. Furthermore, the benefits of pretreating the food waste is discussed and presented below.

1. Focus on the core business. No store employees needs to be trained in the operation of the biogas digester and no malfunctions needs to be taken care of.
2. The possibility of promoting the stores work in environmental friendliness remains. Given that the waste becomes biogas somewhere else, the possibility of promoting the store as environmentally friendly remains.
3. No investments needed. The grocery store chain does not need to make a large investment but can instead associate themselves with an existing biogas digester in the region.

The conclusions made by von Bahr is valid for conventional biogas digester, but may therefor not be suitable for textile based digesters. The textile based digesters has a markedly lower investment cost, and lower environmental impact. When the small-scale conventional biogas digester risk to have the same environmental impact during its lifetime as transporting the waste to a large-scale digester, the textile based digester will not run that risk

Von Bahr is also pointing out that transports today do not have the high environmental impact as people generally think. With for example renewable fuels, long distance transports does not need to have a large impact on the environment at all.

The final recommendation made by von Bahr, to pretreat the biological waste, has several benefits. In addition to those described above, he is discussing the advantage of producing a refined product for the biogas digestion plants. By refining the waste to a slurry, the grocery store can offer a product that can be used for biogas production directly, and moreover, be transported more efficiently to the biogas digestion plants. This ought to reduce the costs of waste management for the grocery stores.

Report: "Potential for small-scale biogas, opportunities for grocery stores" (Ejervall, Rydman, 2013)

The report of Ejervall and Rydman evaluates the possibilities for grocery stores to gain profit of a small-scale biogas digester. The report is based on a larger store in the Coop chain, located in Borås. The store produces 182.5 tonnes food waste per year. Today this waste is collected by waste management company of Borås, Borås Energi och Miljö, for a charge of 500 SEK / ton.

Ejervall and Rydman calculates the profits gained in six different scenarios. They cover both a conventional small-scale biogas digester, of the same type as in the report of von Bahr, and a textile based biogas digester from FOV Biogas. For converting the biogas to other energy sources, the following is covered; Heat production, heat and electricity production and fuel production. The investment costs are presented in table 2.

	Conventional small-scale biogas digester	Textile based biogas digester
Heat production	1,760,000 SEK	360,000 SEK
Heat and electricity production	1,768,000 SEK	368,000 SEK
Fuel production	3,060,000 SEK	2,160,000 SEK

´Table 2 - Investment costs of different biogas digesters and energy conversion methods. (Data from Ejervall, Rydman (2013))

The depreciation period of the biogas digester was set to eight years, and the interest rate was 4 %. The savings obtained from using the biogas digester was in the area of 50,000 to 60,000 SEK per year, depending on method for energy conversion. Based on this, a result of the investment after eight years was calculated. It turned out to be a loss in four out of six cases, and a profit in the last two, as seen in table 3.

	Conventional small-scale biogas digester	Textile based biogas digester
Heat production	-1,611,913 SEK	40,087 SEK
Heat and electricity production	-1,531,453 SEK	130,546 SEK
Fuel production	-3,221,180 SEK	-2,190,021 SEK

´Table 3 - The profit of a biogas digester after a depreciation period of eight years. (Data from Ejervall, Rydman (2013))

As can be seen a conventional small-scale biogas digester would not be profitable for a grocery store. The textile based biogas digester on the other hand might be profitable if the energy is used for production of heat and electricity, however not for fuel production.

The calculations from the report of Ejervall and Rydman is largely based on assumptions, which should be kept in mind. It shows however the large differences that exists between the investment costs of conventional small-scale biogas digesters and the textile based biogas digester from FOV Biogas. If any small-scale biogas digester could bring profit to a grocery store, it need to be the latter one.

3.2.2 Visits and interviews on site

The interviews in this project were unstructured interviews, which means that the questions were formed during the interview, while an agenda was used to assure that everything was covered. These interviews consisted of gathering information during meetings, study visits and telephone calls. Representatives from the grocery industry, the hotel and restaurant industry as well as from municipalities were contacted.

The first interview was more of a study visit than an interview. It was conducted with the head chef at a restaurant who had invested in a vacuum solution for their food waste. In the kitchen as well as at the dish station, waste disposal units were placed. Pipes led the slurry from the disposal units to a container in the basement of the building. This container was emptied by Renova (Fotnot: Renova is a the municipal waste management company in Gothenburg.) and the slurry was used for producing biogas. The head chef confirmed their satisfaction with this system, mainly because of its convenience. Instead of carrying heavy bags of mixed garbage they now threw food waste in the disposal units and sorted the remaining waste out, which lead to fewer and less heavy garbage bags and a more convenient way of working in the kitchen.

The second interviewee was a facility manager from the hotel and restaurant business. He was curious and positive about a small-scale solution for producing biogas from their food waste. The most important aspect for him was the environmental friendliness. The hotel currently worked thoroughly with environmental friendliness, such as an ecological breakfast buffet and energy optimization measures, but the facility manager felt that they did not have a satisfactory solution for the waste management.

That the facility manager was unsatisfied with the hotel's current waste solution is remarkable. In fact, their food waste is collected by the city of Mölndal, who transports it to Borås, where it is digested to biogas. (Fotnot: Telephone contact, Department of technical services, city of Mölndal, 2014-11-05) The biogas plant in Borås is the biogas plant closest to Mölndal, which makes it difficult to find a more environmentally friendly solution. The information given by the city of Mölndal could therefore clearly have been more successful.

"we will never have our store employees opening packaged food" - head of recycling in a major grocery store chain

Furthermore, the facility manager elaborated on the presumed maintenance of the digester, and preferred to know from start how much maintenance the product would need in order to avoid unpleasant surprises after installation. Lastly the importance of adapting the system to the workers were discussed. This was also considered an important aspect from his point of view.

After the influences from the hotel and restaurant business, a meeting was held with a head of recycling in one of the major grocery store chains in Sweden. Alike the hotel facility manager the head of recycling was curious about a way of producing biogas in small scale. He emphasized the grocery stores work in sustainability, and was determined that all their food waste should be treated in an environmentally friendly way, for example using biogas production instead of incineration. Unfortunately, this is not the case today, since it does not exist biogas production plants in the nearby area of all their grocery stores. Furthermore, he made some fundamental statements. Firstly, the grocery store chain was dedicated to focus only on their core business, i.e. providing Swedish households with food and other household goods. To be in charge of plants of small-scale biogas was not in question. He was convinced that this applied to other grocery chains as well. Secondly, a major factor is the convenience for the workers in the grocery stores. He stated clearly that their employees will not be able to manually open packaged food to separate the packaging from the food. They were currently trying a disposal unit especially developed for grocery stores, which accepts packaged food. So far it had been a success among the grocery stores that had tried it. This statements of letting the grocery stores focus on their core business while pretreating the food waste in the store corresponds to the conclusions in the previous mentioned report by von Bahr. Lastly, the head of recycling mentioned their future goal in being able to consider their waste an asset, just as their other products. When food waste is made possible to utilize in the production of biogas, which in turn is a commodity, then it is only a question of time until food waste becomes a commodity as well.

"we would do it for the environment, even if it meant an economical loss" - facility manager at a large hotel chain

After the meeting with the head of recycling described above it was clear that the grocery store business would not be satisfied with a solution that involved them as customers and *"in the long run, we would like to consider our waste an asset"* - head of recycling in a major grocery store chain

users of a biogas digester. Therefore another stakeholder needed to be found, who would have to consider investing in a biogas digester and thereafter provide a service to the grocery stores. The choice fell on the municipalities.

A representative from the environmental department in a smaller municipality in the Västra Götaland region was contacted. She declared that the biological household waste in the municipalities was sorted out and collected by their waste management partner. The waste management company transported the waste to the closest biogas plant, owned by themselves. She declared their satisfaction with the partner and that they have had the same partner for a long time. A contract set up with three neighboring municipalities had resulted in a beneficial negotiating position for the municipalities. While asked if they had considered local small-scale biogas production the answer was that no, it would be a too large and expensive project.

3.2.3 Survey

As a complement to the literature and interview study a questionnaire was distributed. From the literature and interviews three major aspects were identified; Environmental friendliness, convenience and economy. The purpose of the questionnaire was to investigate if this was true, that these factors were the most important, and if, to see if there was any difference in how important they were compared to each other. The questionnaire was sent to the heads of 80 grocery stores of different sizes in the Västra Götaland region. 22 of them responded, which yields a response rate of 27.5 %.

The first aim was to find out how the biological waste was treated today. One of the first questions was therefore if the grocery stores separated biological waste from combustible waste. 18 of the 22 respondents declared that they separated biological waste from combustible waste. Unfortunately, this question was formulated poorly. In grocery stores biological waste is likely to mean everything that contains biological waste, such as packaged food, which was not the meaning of the answer option "Yes, we separate biological waste from combustible waste". The experience from the author as well as the authors friends working in grocery stores is that the food waste is not separated from its packaging in the store.

However, an alarming aspect that came to attention was the lack of knowledge about what happened to the stores' biological waste. 45 %, 10 out of 22 respondents, stated that they did not know what happened to their biological waste after collection.

The major part of the questionnaire consisted of three questions, where the respondents were asked to rate the importance of the following aspects: That the biological waste was treated in an environmentally friendly way; that the waste management occupied little time for the store employees; and that the waste management service had a low price. The rating scale was 1 – 2 – 3 – 4 – 5 where 1 was labeled "not at all important" and 5 was "very important". The answers showed that all aspects were considered very important.

The first aspect, if the biological waste was treated in an environmentally friendly way, received an average rate of 4.14. The second aspect, that the waste management occupied little time for store employees, received an average rate of 4.23, while the last aspect, the price of the waste management service, received an average rate of 4.27. This is illustrated in figure 5.

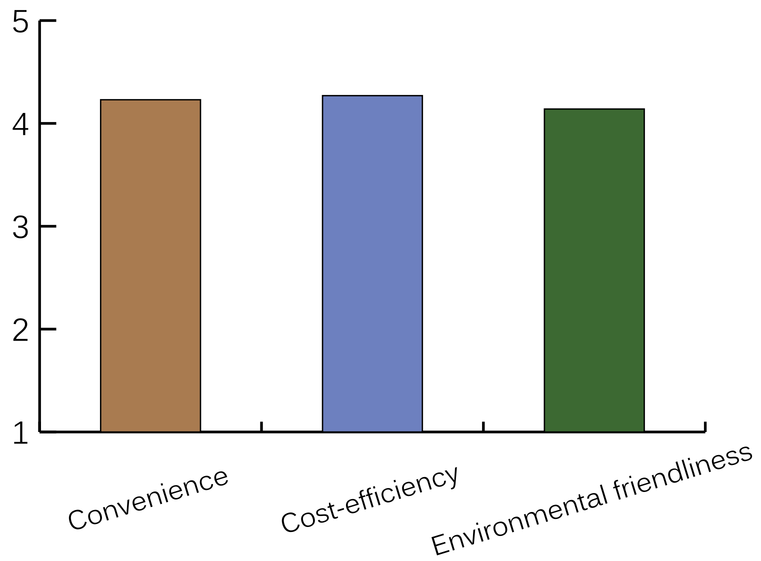


Figure 5 - The importance of the different factors studied in the survey.

Subsequent to these questions, an optional question followed where the respondents were asked to rate the aspects mutually. 11 of 22 respondents answered this question. The aspect rated highest in this question was that the waste was treated in an environmentally friendly way, followed by the price of the waste management service and last the time occupied for the store employees. However, there is an uncertainty in the reliability of the responses here, since 4 of the 11 respondents answered in an inconsistent way. An example is one of the respondents, who had regarded the cost factor alone to be of the highest importance rate in the previous question, and when asked to rate the factors internally did not rate cost as the most important factor. With this in mind the answers from this question can not be regarded as reliable.

The conclusion from the survey is that the aspects retrieved from the literature and interviews can be confirmed to be relevant. However, it was not possible to rate their importance internally. A somewhat unexpected aspect to take into account was the lack of knowledge of what happens to the biological waste after disposal.

3.3 Market description

In the following sections, the market for this study is presented. It includes a general presentation of the chosen market as well as a more specific presentation of the case study.

3.3.1 Market possibilities

This project started out with three main user scenarios; Grocery stores, restaurants and agriculture. Agriculture was soon eliminated since the market for biogas production in agriculture is already well established. The market for restaurants and grocery stores on the other hand, has not been elaborated to the same extent, which makes them intriguing to work with.

Both grocery stores and restaurants were contacted for participation in the project. One of the restaurants chosen was going to become the subject of the case study for this project. Unfortunately they withdrew due to lack of time. Therefore the full focus was put to the case of one grocery store.

3.3.2 Description of the chosen market

The food wastage in grocery stores in Sweden totaled in 70.000 tonnes a year in 2012. 91 % of this, 67.000 tonnes, can be considered unnecessary waste, which means food that could have been sold if handled in another way. (Naturvårdsverket, 2014) Studies have been conducted in order to reduce the food wastage, as for instance a three year project on reducing food wastage in grocery stores at the Swedish University of Agricultural Science, 2010-2013. (Swedish University of Agricultural Sciences, 2013) This project was conducted with support from Axfood, which is one of the three major food retailers in Sweden. Another study in food wastage at the Swedish University of Agricultural Science was conducted with support from Coop, yet another of the three major Swedish food retailers. (Andersson, et al, 2010) There is a clear interest in the retail food industry in reducing the costs of food wastage, and one course of action could be to reduce the amount of food wastage combined with a biogas digester taking care of the food wastage that is created even though.

3.3.3 Description of the case in the study

The case for this study takes place in a smaller municipality in the Västra Götaland region. In that municipality there are eight medium or small grocery stores. One of these stores is the subject for the case study. The store's biological waste management is described below.

Biological and combustible waste are sorted in different fractions. The biological waste contains packaged as well as unpackaged food. The biological waste is placed in a refrigerated room, while the combustible waste is placed outdoors in a container. The biological waste is collected twice a week and transported by truck to a biogas digestion plant 140 kilometers away. An illustration of the current situation is shown in figure 6.

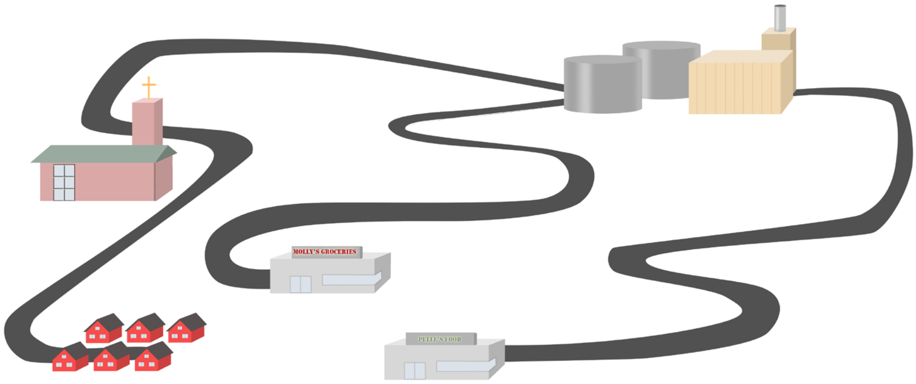


Figure 6 - A schematic image of the grocery store's current waste management situation, i.e. long on road transportations to large scale biogas digestion plants.

Biological waste are mainly sorted out in the mornings before opening. Discarded fruit, vegetables and bread are placed in the waste bins for biological waste. They are first placed in smaller boxes on carts and then transported to the waste room. Each box filled with fruit, vegetables or fresh supplies. 3-4 boxes of fruit and vegetables are discarded every day. Fresh products, such as dairy and meat, that have exceed their expiry date, are sorted out every evening. 1-2 boxes of fresh products are discarded every day. It should be noted that the boxes are usually not filled to the brim, which means that the amount of biological waste most likely corresponds to 20-30 kg fruit and vegetables a day and 10-15 kg fresh products a day.

Bread that has exceed their expiry date is handled differently. The bread baked in the store is sorted out as biological waste and discarded at mornings in order to make place for fresh baked bread. The amount of bread discarded every day is equivalent to 4-5 boxes or 10-15 kg. The bread produced by the three major bread distributors in Sweden, Pågen, Fazér and Polfärskt, are not sorted out with the other biological waste. Instead it is returned to the bread supplier who makes use of it as animal feed, and in some cases when there is no interest in the bread as animal feed, it is incinerated.[2] (Pågen, 2014) (Fazér, 2014)

On the account of the amounts of biological waste it should be considered that this store is part of a project where the grocery store chain is testing a new concept with a wider assortment, which in the beginning includes larger amounts of biological waste than an average store in the same chain.

Persona, Lisa

From interviews and the authors experience from working in a grocery store, a personas was made, Lisa. Lisa is 40 years old and working full time in the store. She is healthy and works mixed mornings and evenings shifts. During the morning shifts she can be in

2 Customer service, Polfärskt Gothenburg, telephone contact, 2014-12-15

charge of discarding the fruit. Sometimes she lifts the entire box with 10 kg of fruit and vegetables while throwing it in the waste bins, and sometimes she throws parts of the contents first, before lifting the entire box. Mostly she wants it to be fast. During the evening shifts, she might be responsible of sorting outdated fresh products out. The same as during morning applies here; she might throw away some heavy parts first, while then throwing the content of the rest of the box away. The most important aspect for Lisa during mornings as well as evenings is that the time it takes to throw away waste is short.

3.4 Market analysis

In the following sections the market analysis will be presented. The analysis contains a SWOT analysis as well as a competitor analysis.

3.4.1 SWOT analysis

A SWOT analysis consists of four factors; Strengths, weaknesses, opportunities and threats. The methodology of the SWOT analysis is described in section 2.3.1. SWOT analysis.

Strengths

A major strength of the FOV Biogas digester is the flexibility and price of the product. A conventional small scale biogas digester costs approximately 1.700.000 SEK including additional equipment and installation, while the textile biogas digester from FOV costs approximately 300.000 SEK including additional equipment and installation. (Ejervall, Rydman, 2013) Additional costs will naturally occur for the chosen energy conversion method, such as conversion to heat or electricity. These are however equal for both types of biogas digesters.

Production of biogas from biological waste is an environmentally friendly and sustainable way to generate energy. This will in turn bring an opportunity for the involved actors to communicate their environmental commitment and thereby use it in commercial purposes.

Weaknesses

The actors on the waste collection market in Sweden today are quite large, as for example Renova and Hans Andersson that operate in the Gothenburg area. To enter a market embracing only a couple of large size companies might be difficult, especially if there are public procurements involved.

Upgrading the biogas to fuel is a promising option for using biogas. The technology for upgrading biogas today is however expensive, as seen in section 3.1.3 Energy conversion methods, and is not profitable for smaller scale biogas production.

Opportunities

The awareness regarding waste management and environmental impact is high. The aims of the Swedish Environmental Agency is that in 2018, at least 50 % of the food waste from household, commercial kitchens, grocery stores and restaurants should be treated biologically. During 2010, 9,7 % of the food waste from these businesses were digested to biogas, and 13 % were composted. The remaining 77,3 % were incinerated. (Naturvårdsverket, 2012a) This gives a picture of the current situation, and which direction the Swedish government is aiming for. The FOV Biogas digester could be of great benefit in achieving those aims.

To expand the biogas production with conventional biogas digesters could be expensive, which results in another opportunity for marketing the less costly textile based biogas digester. As mentioned earlier the cost of a conventional biogas digester is relatively high, and might not be considered cost efficient in the sparsely populated parts of the country.

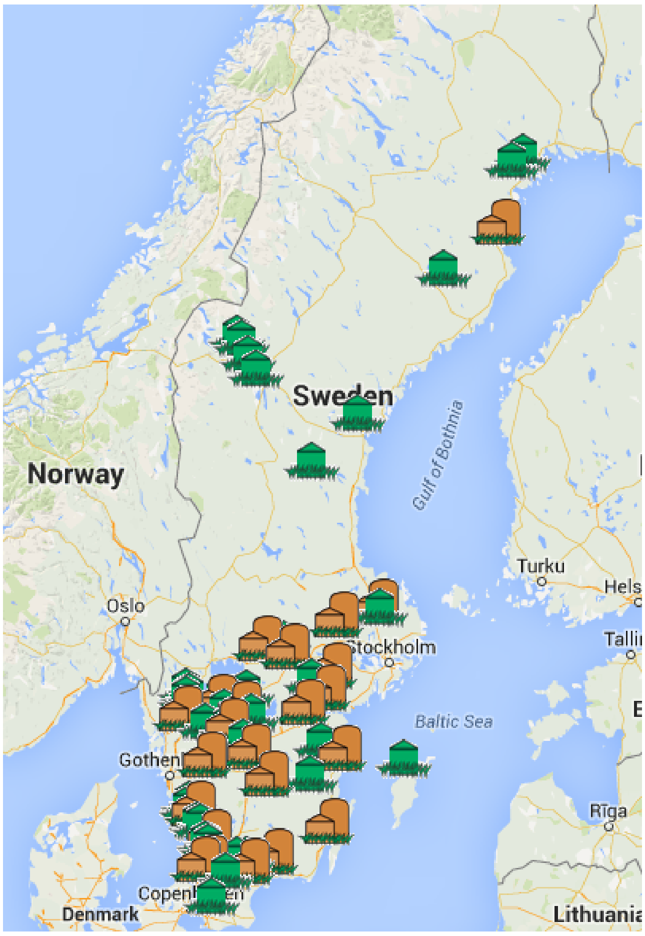


Figure 7 - Biogas digestion plants for combined substrates as well as farm biogas digesters that existed in 2013. The orange figures are plants for combined substrates while the green figures are farm biogas digesters. (Biogasportalen, 2014a)

Presented on the map in figure 7 are the Swedish biogas digestion plants for combined substrates as well as the smaller scale farm biogas digesters that existed in 2013. Sewage treatment plants and industry biogas digesters are not presented in figure 7, since they are currently not combining their waste with food waste, even though it has been tested. (Rogstrand et al., 2012) Neither is biogas plants at landfills presented while it since 2005 is prohibited to dispose organic waste on landfills. (Biogasportalen, 2014b) This map shows that there are large parts of the Sweden that does not have a biogas digestion plant in the nearby area. Especially in the scarcely populated northern parts of the country, there are vast distances between biogas plants. The far north, that is not visible in this figure, does not possess a biogas digestion plant at all. It is worth noticing that there are large distances between biogas plants in the south of Sweden as well, which might not be perceived through the figure because of the size of the symbols used. In all areas with a large distance to a biogas plant FOV's textile biogas digester could be a cost-efficient option.

The sale of natural gas and biogas as vehicle fuel has been increasing rapidly over the last decade, which can be seen in figure 8. In 2013 147 million normal cubic meters of natural gas and biogas was sold, which is equivalent to 1,493 GWh, of which 90 million normal cubic meters was biogas. (Gasbilen, 2014) The sale of biogas has thereby taken the lead over natural gas, and are increasing steadily as for today. There is a clearly a demand for biogas in as vehicle fuel today.

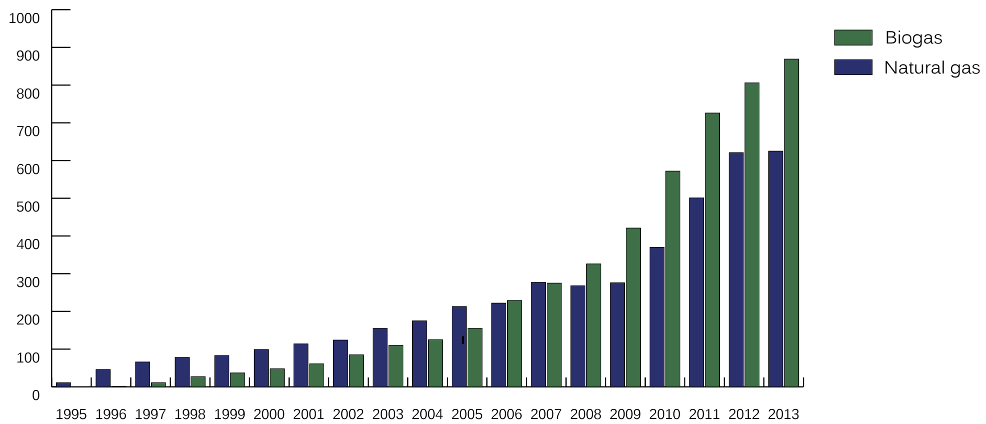


Figure 8 - Sales of natural gas and biogas as vehicle fuel, Sweden, 1995 - 2013. (Data from Gasbilen, 2014)

Threats

There are several policy instruments that are used within the energy sector today. These can be considered both opportunities and threats depending on how they are changing in the years to come. Examples of these are climate bonuses, support for investments and methane reduction support. (Holmström et al., 2013)

The food waste from grocery stores is in the context of municipal responsibility considered comparable to household waste. The municipalities are responsible of handling household waste, which implicates that food waste from grocery stores also becomes the responsibility of the municipalities. It is a responsibility, but can from another point of view be considered a monopoly. A consequence of this is that the grocery stores losses their ability to make a profit of their own assets, i.e. the food waste. There are however a possibility for the municipality to make an exception from the responsibility, if certain reasons occur. The insecurity of who is in charge of the food waste from the grocery stores could be a threat while marketing a biogas digester to privately owned businesses. Another approach could be to market the digester towards municipalities and thereby take advantage of the responsibility. (Avfall Sverige, 2013)

If the service developed in this project is directed towards municipalities, the following could be useful to keep in mind. Over the years, the municipalities in Västra Götaland have gathered in common contracts with waste management companies. An example of this is the waste management service company Renova, which is owned by the following municipalities; Ale, Göteborg, Härryda, Kungälv, Lerum, Mölndal, Partille, Tjörn, Stenungsund and Öckerö (Renova, 2015b). In the northern part of Bohuslän the municipalities Tanum, Sotenäs, Lysekil and Munkedal has founded the waste management company RAMBO (Rambo AB, 2015), and in Dalsland the municipalities Bengtsfors, Mellerud, Dals-Ed and Färgelanda has commonly procured the waste management service by Ragn-Sells.[3] With this in mind, it might be difficult to negotiate with a single municipality, while a more successful approach could be to contact the municipalities together, as well as representatives from the current waste management companies.

3.4.2 Competitor analysis

The competitors in this project can be divided in three groups. The first group consists of the competitors that provides waste management solutions today, the second consists of the companies that are able to provide small-scale biogas solutions based on existing small-scale biogas plants, while the third group contains producers of portable small-scale biogas digesters. All these groups are competitors to FOV in different ways, which will be discussed in the following paragraphs.

Providers of waste management solutions

Two waste management companies that collects biological waste operates in the Gothenburg area, Renova and Hans Andersson recycling. Renova is owned by the city of Gothenburg while Hans Andersson is a privately held company. In addition to these waste management companies, a smaller company named AllWin collects food waste for charity purposes. AllWin collects edible food from grocery stores and donates is to chari-

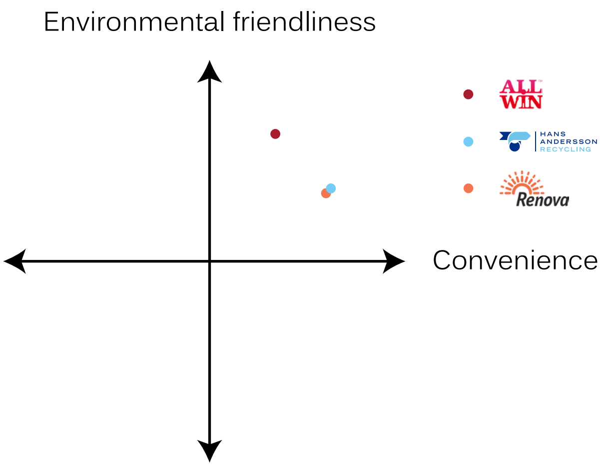


Figure 9 - The relationship between the environmental friendliness and the convenience of the waste management services that is provided on the market in Västra Götaland today.

3 Gunilla Andersson, Bengtsfors kommun, telephone contact, 2015-01-14

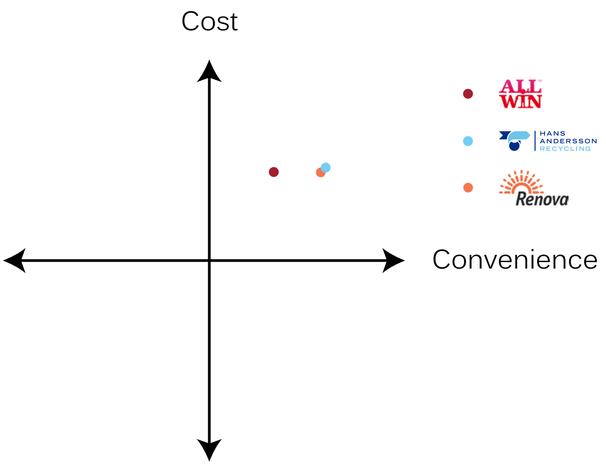


Figure 10 - The relationship between the cost and convenience of the waste management services that is provided on the market in Västra Götaland today.

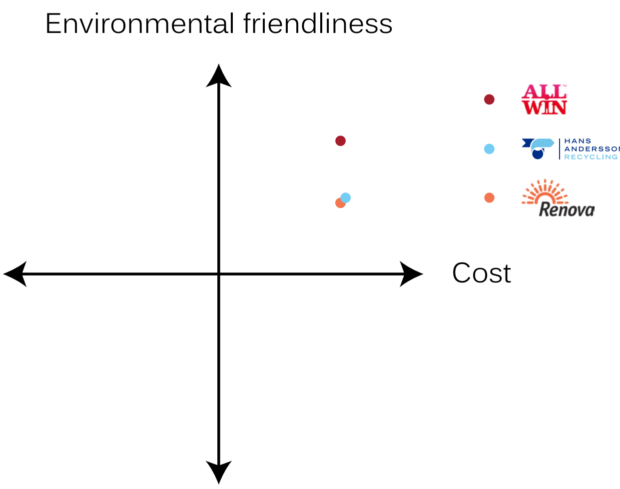


Figure 11 - The relationship between the environmental friendliness and cost of the waste management services that is provided on the market in Västra Götaland today.

ty organizations. Of ethical reasons, edible food is not considered subject for biogas production, which makes AllWin not competitors but a compliment. However, AllWin is an actor on the food waste market and will therefor be taken into account in this section.

In figure 9 the environmental friendliness of the different companies is presented. AllWins model is considered more environmentally friendly while the food is eaten, and not digested. The final outpost for the waste collected by Renova and Hans Andersson is the biogas digestion plant in Borås, owned by Borås Energi och Miljö. Renova pretreats the waste in their plant in Marieholm, while the waste from Hans Andersson is pretreated as well as digested in the plant in Borås.[45]

In figure 10 the convenience versus cost of the current services is presented. All the current services is considered relatively convenient. Renova and Hans Andersson collects packaged and unpackaged food in the same waste bins, from the grocery stores. AllWin uses the same type of bins, where the grocery store employees has placed only edible food.[6] The sorting of edible food is the reason why AllWin's service is considered less convenient than Renova and Hans Andersson's.

The cost for the services provided by all companies are equal, which can be seen in figure 11. Renova and Hans Andersson charges 625 SEK per ton biological waste collected from grocery stores.[34] AllWin charges a lower sum per ton, but they collect food waste more often than Renova and Hans Andersson, which makes the total charge equivalent to the others.[5]

Providers of small-scale biogas solutions based on existing biogas plants

An actor that could provide a small-scale biogas solution is farmers. In 2013, 39 farm biogas digestion plants existed throughout the country. (Statens energymyndighet, 2014) The strength of the farm biogas plants is their location, which is often in smaller municipalities

4 Customer service, Renova, telephone contact, 2014-12-16

5 Robert Sandberg, Hans Andersson recycling, telephone contact, 2014-12-16

6 Simon Eisner, AllWin, telephone conversation, 2014-12-16

without a large scale biogas plant. Their weakness is however, that any service connected to farm biogas digesters, would make the farmers divert from their core agricultural business.

Producers of portable small-scale biogas digesters

On the market today there is another company producing small-scale biogas digesters, Terratellus group. MR 120 is their biogas digester, which has a volume of 120 m^3 and digests 11,2 m^3 substrate per day. The digester operates in the thermophilic temperature domain, with a temperature of 50-60 °C. (Terratellys group, 2014) An example of the investment cost for a MR 120 digester, including additional equipment, is 5,000,000 – 6,000,000 SEK.[7]

3.5 Conclusion

Biogas is a renewable energy source that can be used for heat production, electricity production or fuel after upgrading to a minimum of 95 % methane. Biogas can, unlike oil and natural gas, be produced in Sweden. Focusing on biogas production is a step towards an independence of fossil energy sources, and in turn an independence of governments in political unstable regions. Focusing on biogas is a strategic step towards a long term sustainable energy supply. (Naturvårdsverket, 2012b)

A downside of biogas production is the risk of leakage of methane. On this basis a voluntary undertaking is created by the Swedish Waste Management *(Avfall Sverige)*. The voluntary undertaking is aimed at biogas production and upgrading plants, and constitutes of systematic searching for and mapping of leaks, as well as periodically emission investigations by independent measuring consultants. (Avfall Sverige, 2015)

The market analysis was focused on the portable textile based biogas digester from FOV Biogas. The strengths was the flexibility and price of the product, while a weakness was the small size of the company. The opportunities identified was the current awareness of climate change and positive attitude towards renewable energy sources. Furthermore, the vast distances between existing biogas digestion plants in Sweden today was considered an opportunity, as well as the increasing trend in sales of biogas as vehicle fuel. The threats identified were potential policy instruments, and municipal regulations.

The chosen market in this project was grocery stores. The food wastage in grocery stores in Sweden totaled in 70,000 tonnes in 2012. (Naturvårdsverket, 2014) There is a clear interest from the grocery stores to reduce the costs of food wastage. One course of action could be to reduce the amount of food wastage combined with a biogas digester taking care of the food wastage that is created even though.

7 Anders Ericsson, Värmex, mail conversation, 2015-01-09

Based on the results of the literature and the empirical study a number of core aspects was identified. The aspects that were most important to the stakeholders were cost efficiency, environmental friendliness and convenience. In addition to that, an aspect that was not stated directly but considered of significant importance, was the use of information, or the lack of information. The lack of information was prominent in one of the interviews, as well as in the survey. 45% of the respondent heads of the grocery stores did not know what happened to their biological waste, it is a factor that is needed to be taken into account in the concept development.

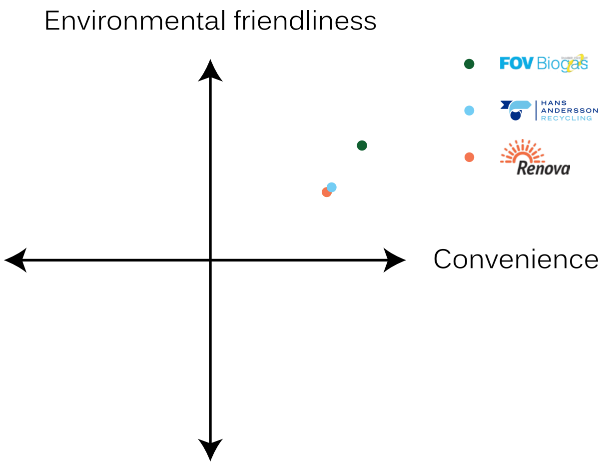


Figure 12 - The ideal environmentally friendly and convenient service that is the mission of this project.

In the competitor analysis two competitors were identified, Renova and Hans Andersson. They both provide a convenient and relatively inexpensive waste management service. The challenge is to provide a more environmentally friendly service, that ideally also is more convenient. This vision is illustrated in figure 12.

4. Requirements

In this project two different business models have been identified. The first implies that a grocery store purchases a biogas digester and produces biogas on site from their own food waste. The second option is that a third party actor purchases the biogas digester and collects food waste from the grocery stores for the biogas production. This third party actor could be a waste management company or a municipality. The benefits of the second option is that waste can be collected from several businesses, and heat or electricity spread to a larger area. Based on the findings in interviews and literatures, this is the most promising alternative, and will therefore be developed further. The owner of the biogas digester will be the municipality. They will in turn need to attract grocery stores to purchase their waste management service.

All different stakeholders in this option is shown in figure 13.

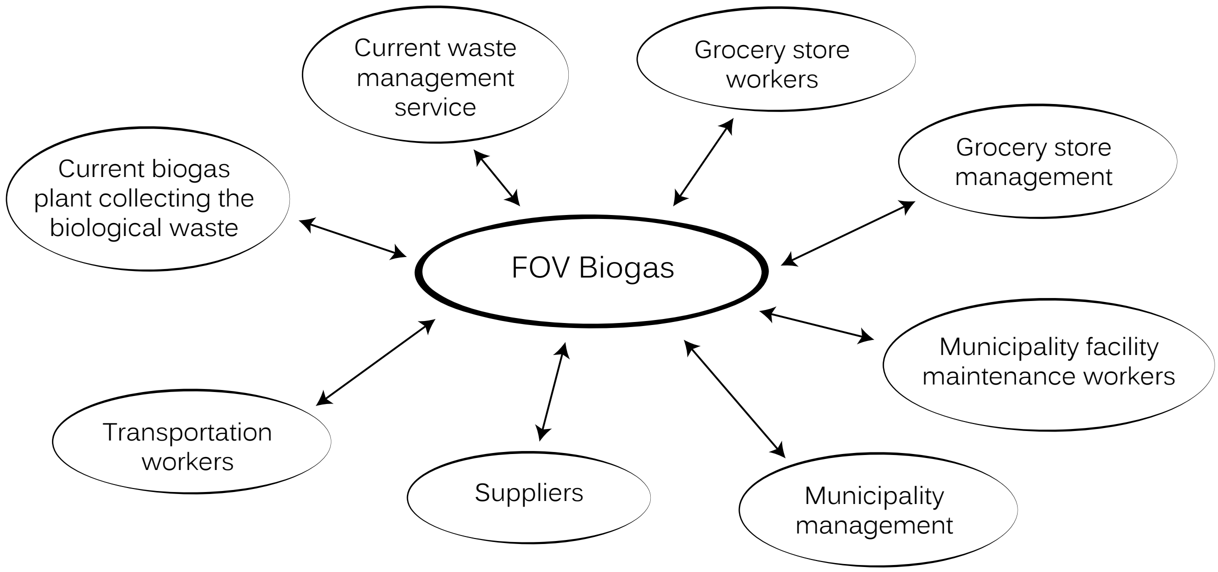


Figure 13 - The different stakeholders in this project.

The stakeholders have different requirements and expectations on the product. They can also be divided in terms of power and interest, as presented in section 2.3.3 Stakeholder analysis. The division becomes as follows.

The highest power and interest holds the grocery store and municipality management. These are the functions where decisions will be made, and the requirements these groups state will therefor be ranked the highest. The requirements from suppliers will also be ranked high, while they are a high power stakeholder. Meanwhile, the workers in for example grocery stores or municipal facilities will be thoroughly informed about eventual changes, since they possess a high interest, even though a low power. This is illustrated in figure 14.

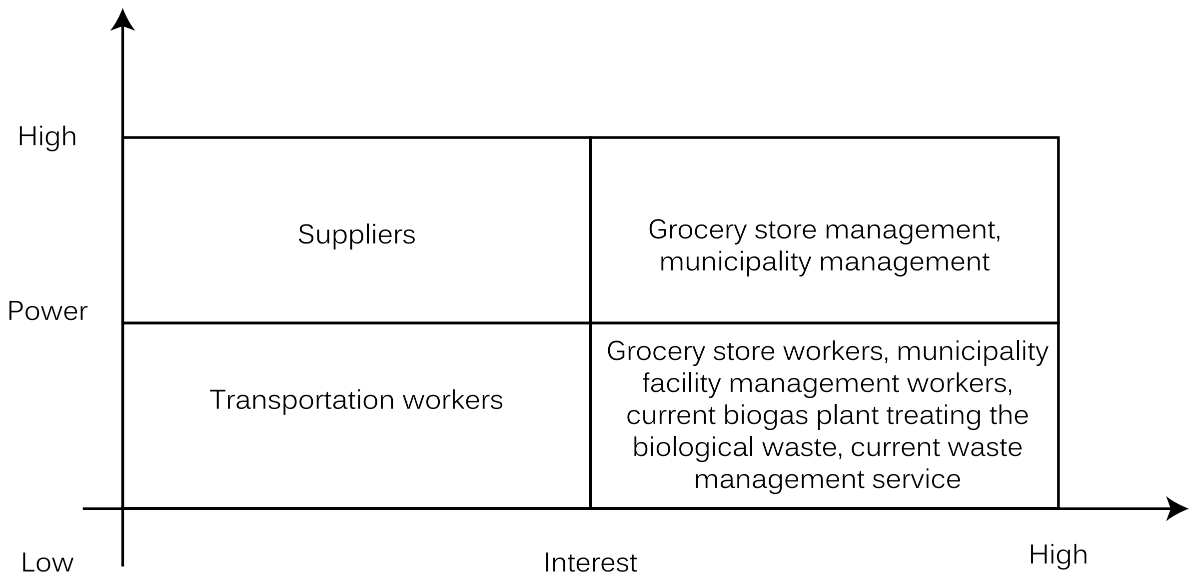


Figure 14 - An illustration of the power and interest of the different stakeholders.

Requirement specification

The requirement specification includes the requirements from the grocery stores, which the municipalities needs to relate to in order to attract grocery stores as a customer for their waste management service. The requirement specification is presented in table 4.

Needs	Requirements	Weight
The time to handle biological waste is short	It is convenient to use the waste collection facility	5
The staff does not need to separate food from its packaging	The waste collection facility is able to handle both packaged and unpackaged food	5
	The waste collection facility is able to handle packages in both plastic and paper	5
	The waste collection facility is able to handle packages in metal and glass	2
The staff is able to throw all waste away at the samme time that they normally do	The waste collection facility is able to handle the amount of waste that is thrown at the same time	5
The store strives to have a sustainable waste management system	The service is more environmentally friendly than the competitors	5

The store strives to have a cost-efficient waste management solution	The service has a lower price than its competitors	4
The store aims to gain profit of their waste	The service provides an ability to use food waste as a commodity	3
The stores need to focus on their core business	The stores should not be in charge of a biogas digester	5

Table 4 - Requirement specification for the grocery store.

The needs of the municipality is not further investigated, but it is assumed that a reliable product that requires a small amount of maintenance is preferred.

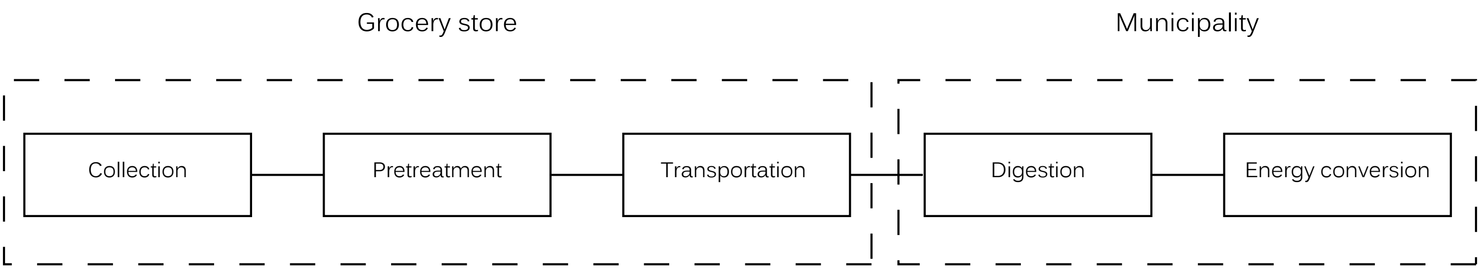
5. Concept development

From the background research three aspects were identified, in which to focus the concept development on. They were; Cost efficiency, environmental friendliness and convenience.

The total system contains of five functions, which is illustrated in figure 15. These functions are; Collection of the biological waste, transportation, pretreatment, digestion and conversion of the biogas to another energy source. The energy conversion methods included in this report is heat production, combined electricity and heat production and upgrading the biogas to fuel.

Figure 15 - The total system of biogas production.

The background research revealed the need of dividing the system into two parts,with two different main stakeholders. This is further illustrated in figure 16. The first part of the system consists of collection, transportation and pretreatment, while the second part consists of digestion and energy conversion. For the first part of the system, the main stakeholder is the grocery store, while the municipality is the main stakeholder for the second part.



Figur 16 - An illustration of the different main stakeholders for the different parts of the system.

When the first concepts were created, a Pugh matrix was used for analyzing the concepts. The methodology of the Pugh matrix is described in section 2.5.1 Pugh Matrix. The selection criteria for the Pugh matrix was as follows,

1. Investment cost
2. Possibility of gaining profit
3. Environmental friendliness
4. Convenience
5. Feasibility

Investment cost, possibility of gaining profit, environmental friendliness and convenience derives directly from the background research. The formulation in the conclusion of the background research is cost efficiency, which is here divided into investment cost and possibility of gaining profit from the product or service. Feasibility on the other hand, is not stated in the background research, but is included in order to screen the variety of solutions and eliminate infeasible solutions in an early stage.

5.1 Grocery stores as the main stakeholders

The parts of the system where grocery stores are the main stakeholders are; Collection, pretreatment and transportation to the biogas digestion plant. The aspect that is ranked highest for the employees in the stores is the convenience of the waste solution. The department purchasing waste management solutions will also consider environmental friendliness as well as the economical aspect.

5.1.1 Collection of the biological waste

Today, the most common method for collecting food waste is by waste bins. A common size is 370 liters. This is also a common way of collecting waste from households. An illustration of standardized waste bins can be seen in figure 17. Other options are refuse chutes or large size containers. Another factor to take into account is the placement of the waste collection facility, namely how it will be accessed by the grocery store staff as well as for transportation.

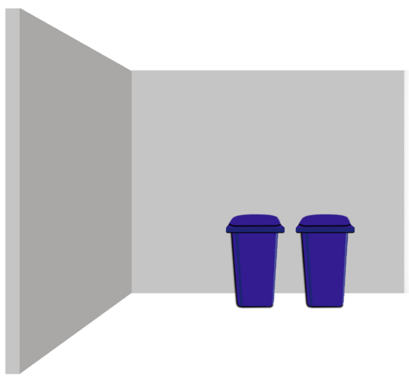


Figure 17 - Ordinary waste bins that can be used in grocery stores.

A product that is currently under development is the BioSimplex, from SITA. BioSimplex is developed especially for grocery stores. It is a pretreatment facility, which is placed in the grocery store, and has a throw-in window for an inlet. An illustration of the BioSimplex thrown-in window is shown in figure 18.

Figure 18 - The throw-in window of a BioSimplex. (SITA, 2014)

One of the highest rated requirements is that the time needed to throw away waste should be short. The first thing that comes to mind is the idea of a simple opening in the wall, without a cover. To keep the container hygienic, the waste needs to be transported into a sealed compartment. This is made by BioSimplex, while it pretreats the waste for biogas production, and keeps the slurry in a sealed container.

The disadvantage with an opening in a wall is the lack of flexibility. A throw-in window would be placed at one site. Waste bins, on the other hand, has wheels, and can be transported to several different departments of the store, where the waste occurs. They are thereafter simply transported to a waste room. The flexibility is likely most important in larger stores, while a throw-in window would be preferred in smaller stores.

The question of convenience does therefore not have a straight answer. The grocery store presented in the case in section 3.3.3 is however a smaller sized store, and the most promising collection method in this project will therefor be a throw-in window.

5.1.2 Pretreatment

To produce biogas out of food waste, the waste needs to be pretreated. The procedure of pretreatment is described in section 3.1.2. From garbage to energy – the system. There are two different options for placing the pretreatment facility. It is either placed in the store, or at the biogas digestion plant. This choice will affect the choice of transport of the waste. Today, the most common solution is to pretreat all waste at biogas digestion plants.

The grocery store aims at using their waste as a commodity in the future. By pretreating their food waste in the grocery store, to a slurry, they will have a more sought after product than regular food waste. This slurry could be used directly for biogas production. One option, for pretreating food waste in the store, is by a product like SITA's BioSimplex. BioSimplex accepts both packaged and unpackaged food. It grinds the waste and separates the solids parts, such as plastic, into a combustible fraction, while producing a slurry of the remainder of the waste.

The second option is to pretreat the biological waste on site of the biogas plant. This is currently the most common solution. It requires transportation of mixed biological waste while the first option requires transportation of a slurry, which is discussed further in the following section.

The pretreatment part is the part where a stakeholder conflict is becoming present. The grocery stores would like to use their waste as a commodity, and could therefore pretreat it to provide a more refined and demanded product. The question is however, of whom this refined product would be demanded. The large scale biogas digestion plants in Borås, for example, possesses pretreatment facilities of their own. If a new actor would invest in a biogas digester, they would also most likely need to invest in a pretreatment facility in order to be able accept untreated waste. On the other hand, the market for biogas production is increasing, as discussed in section 3.4.1. SWOT. This indicates that there might be a shortage of biological waste in the future, which will increase the demand of all biological waste.

The question of transport now becomes apparent. It will be discussed in the following section, and the selection of the location of the pretreatment facility will be determined there as well.

5.1.3 Transportation to biogas digestion plant

In the previous section the decision of pretreating the waste in store or not, was discussed. This is reflecting on the choice of transport to the biogas digestion plant. If the waste is pretreated in the store, a pumpable slurry will be transported, which can be made either by truck or through pipelines, and is illustrated in figure 19.

Figure 19 - The biological waste from Molly's groceries is transported to the biogas digestion plant either through pipelines or by truck.

A company specialized on pipelines for waste transportation is Envac. An example of how pipelines could transport waste is built in Hammarby Sjöstad, Stockholm. This is built by

Envac and illustrated in figure 20.

Figure 20 - Hammarby sjöstad, an area in Stockholm where the household waste is transported through pipelines. (Envac, 2015)

If the waste on the other hand is not pretreated in the store, the solid waste can also be transported by truck or through pipelines, but with pipelines of a larger dimension than for the slurry. Transporting waste by truck could be made in a environmentally friendly way, by for example using biogas as fuel. The same applies to transportation by pipe-lines, where the energy could be derived from an environmentally friendly source. The remaining factor becomes the local environment, meaning the environment we experience every day. The load of traffic on our roads is one factor. By decreasing this traffic through eliminating the trucks transporting food waste, a step will be taken towards an more peace and quiet environment in our nearby areas as well as decreased traffic congestion on high ways around our cities.

Here something might need to be clarified. The FOV Biogas digester is a small scale di-gester, and the biogas plant in question will therefore also be of small scale. The transport to this small-scale biogas plant will therefore not be of the same length as the previous distances to conventional biogas digestion plants. There will however be transports, and the reason for that is the explicit request from the head of recycling in a major grocery store chain, of not having biogas digesters directly connected to the grocery stores.

With the request from the grocery stores in mind, of being able to use their waste as a commodity, combined with the possibility of decreasing on road transportation, the most promising choice of pretreatment and transportation was a pretreatment facility in store, combined with pipelines transporting the slurry, away from the grocery stores, up to the biogas digestion plants.

5.2 Municipalities as the main stakeholders

The second part of the system contains digestion and energy conversion. These parts are mainly controlled by the municipality in which they are located.

5.2.1 Digestion

There are two options for managing the digestion with the FOV Biogas digester. The first option is that the municipalities manage the digester, and the second that a privately held company manage it. The main difference between these alternatives would be the business model, where the privately held company would put higher emphasis in making profit of the digester. In this scenario, only food waste from grocery stores are considered, while in the future, there will be a possibility of expanding to other sources of biological waste, such as household waste.

The main advantage of running a small-scale biogas digester is the benefits of the products that it produces, i.e. biogas and fertilizing slurry. The biogas can be utilized in several ways, which is discussed in the following section “5.2.2 Energy conversion”. Fertilizing slurry on the other hand, is not as easy to gain profit of. The possibilities are however, to market it towards local farmers, ideally organic farmers, with perhaps a deal of them being able to sell the crops at the local grocery stores, from where the waste originated.

In the final concept the municipality is chosen as the owner of the biogas digestion plant as well as the energy conversion system.

5.2.2 Energy conversion

For utilizing the energy from biogas, three energy conversion methods has been considered; Conversion to heat, conversion to electricity and heat and upgrading the biogas to fuel.

Conversion to heat

To convert biogas to heat is a quite common way of utilizing the energy of biogas. The alternatives for using the heat is either for heating a single building, or to heat a district heating system. To use it in a single building could be beneficial in buildings that is currently heated by oil or natural gas, and thereby has an internal heating system that easily could be connected to a gas boiler.

The second alternative is to use the heat in a district heating system. The benefits of utilizing the biogas in a larger system is the possibility of compensating for potential fluctuations in the amount of biological waste. In addition, judging on the amount of waste produced in the example in this study, see page xx, compared to energy consumed, the amount of biological waste will not be sufficient for heating a larger district heating system and complementing energy source will therefore be needed.

The conclusion is therefore that the most promising heating alternative is to use the energy in a district heating system.

Conversion to electricity and heat

As for conversion from biogas to heat, there are two different alternatives for electricity conversion. The first alternative is to produce electricity for a single building, and the second is to use it in a larger system. To produce electricity for a single building is costly. It is usually made with combined heat and power facilities, and are considerably more costly than gas boilers used for heating. Furthermore, the efficiency when producing electricity is about 30 %. To illustrate how much electricity that can be generated from food waste, an example of a grocery store is presented below.

Filling the electricity demand of a grocery store by biogas from the stores own food wastage?

This example is calculated for a Coop Forum store, i.e. a large grocery store in the Coop chain. The store is located in Borås. This store has an amount of biological waste of 182.5 tonnes per year (Ejervall, Rydman, 2013). An average Coop Forum store consumes 370 kWh/m^2 retail area yearly. (KF, 2014)

The retail area of Coop Forum in Borås is unknown, why an average area of three other Coop Forum store has been calculated. Coop Forum Karlshamn has a retail area of 3700 m^2 (Coop, 2015), Coop Forum Karlskoga has a retail area of approximately 3000 m^2 (Konsum Värmland, 2015) and Coop Forum Varberg has a retail area of 4100 m^2. (Byggfolio, 2015) This yields an average retail area of 3800 m^2.

182.5 tonnes biological waste a year yields an amount of 21.900 Nm^3 biogas, which in turn yields an energy amount of 113.880 kWh, where 34.164 kWh can be utilized as electricity. (Ejervall, Rydman, 2013) The electricity produced then corresponds to 2,5 % of the electricity consumption of the Coop Forum store. Even though large parts of the remaining energy can be utilized as heat, this is far from sufficient for the energy demand of the store.

Upgrading to fuel

Another alternative is to upgrade the biogas to fuel. This can be made in small scale in-house, or be outsourced.

Upgrading biogas in small scale is expensive. As mentioned earlier in the report, there are two providers of small-scale upgrading plants, Biosling and Metener. The investment cost for an upgrading plant from Biosling is 360.000 – 460.000 €, depending on the size, while a plant from Metener costs around 380.000 €. These plants have a capacity of 60-70 Nm3 / hour, which is considered small-scale, but still considerably more than is needed for the grocery store in the example above. (Svenskt gastekniskt center, 2013)

The second alternative is to outsource the upgrading. The biogas could be sold to companies with larger upgrading plants, for example Göteborg Energi or Swedish Biogas. Göteborg Energi has an upgrading plant in Arendal, Göteborg, while Swedish biogas has upgrading plants in Vårgårda and Lidköping, among other places. During telephone contact with Swedish Biogas they were asked however they would consider purchasing biogas for upgrading from smaller-scale producers. This was not something they performed today, but they were open for the possibility in the future. According to this, it seems to be no active market for trading small amounts of biogas today, but there is a possibility that it might change in the future.

The advantages of upgrading the biogas in-house is the possibility of selling the fuel locally, and thereby create an entire system, from collection of waste to usage of the energy retrieved, locally. This can in turn enhance the residents trust and positive view towards the waste collection system. On the other hand, the advantages of outsourcing the upgrading of the fuel contains several advantages. Firstly no investment costs in equipment is needed, and no equipment needs to be maintained. Secondly, the environmentally friendly solution can still be communicated towards the residents, even if the upgrading plant is not to be seen in the nearby area.

However, even though upgrading biogas to fuel through outsourcing is a promising alternative, the energy conversion method that was considered most promising was to use the biogas for heat production in a district heating system.

5.3 Communicating the good news

One thing that became apparent in the survey study was the lack of knowledge from the grocery stores in what happened to their food waste. This will therefor be especially considered in the final concept.

The first things to consider is;

1. What information to convey.
2. To whom this information should be directed.

The answer of the first question is in this project, as much as possible. Most of the information from Renova and Hans Andersson emphasizes the fact that the food waste becomes biogas, but it does not tell how and where this happens. The idea in this project is to tell people about these things too. An example of an image that can be used is taken from Renova’s website, and can be seen in figure 21. It shows the steps for the waste from collection to biogas in a simple way and reveals both the procedure of biogas production as well as the location of the biogas plant, in this case Renova’s pretreatment plant in

Marieholm, Gothenburg.

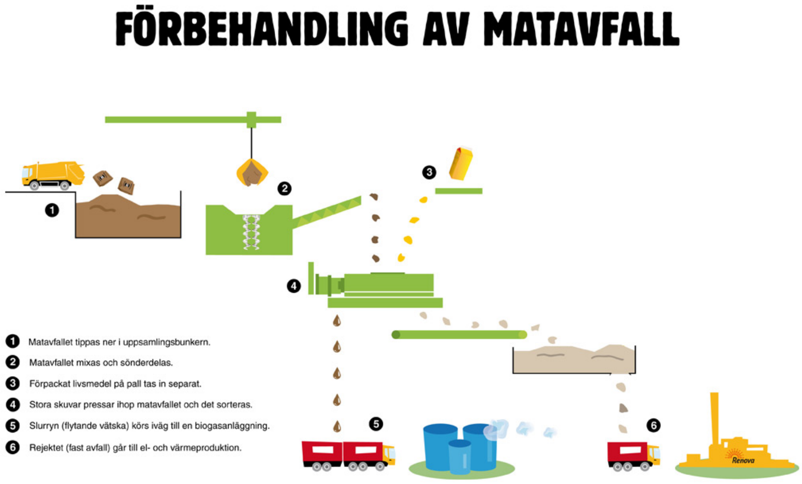


Figure 21 - An information poster from Renova regarding the process of producing biogas. (Renova, 2015a)

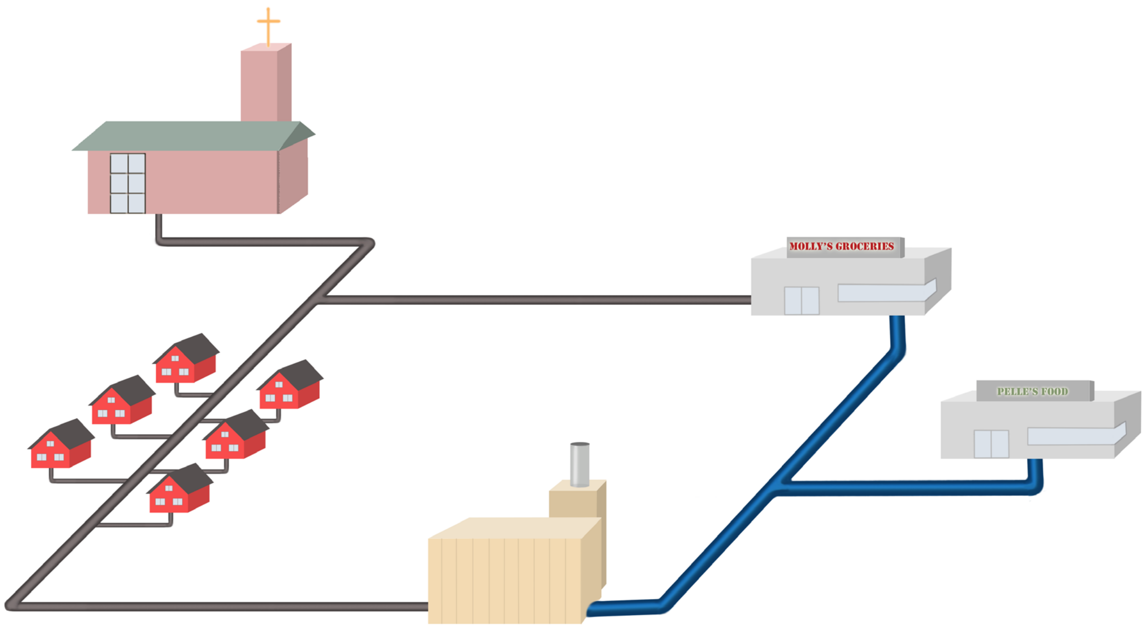
This leads to the second point, to whom to address the information. Naturally, the grocery store workers should be directed, by for example placing a similar image as figure 21 in garbage rooms and on garbage bins or containers. However, it would be beneficial not only for the grocery store workers to know what happens to their food waste, but to engage the whole community, in order to facilitate for a future expansion of the food waste collection to households.

So which words to use for conveying the information? An idea was to use commonly known slogans, that are already used in ecological advertising today. Words that are associated with a sustainable society and sustainable lifestyles. “Locally produced”, “Natural”, “Organic”, “Green”, “Eco friendly” are a couple of examples. This emerged in the slogan “Locally produced biogas”. This slogan could be used on information sheets on the waste management service, for example. If the fertilizing slurry can be used for local food production, this is also a way to convey the information of the local biogas production. “Organic vegetables from Anna’s farm – grown with fertilizer from our own common waste” is a sentence that could be used on the vegetable signs or packages.

An example of how to get the entire community engaged is to show the financial effect for the community. “Last year 5 % of the district heating originated from biogas produced from food waste from our community. This corresponds to 100,000 SEK, which in turn corresponds to 10 % of the renovation costs of the library. Together we create a sustainable community.” Note that the figure in the example are made up only to illustrate an example.

6. Final concept

The final concept in this project contains all parts that has been discussed in the concept development. It contains a pretreatment facility in the store, pipelines for the pretreated slurry to the biogas digestion plant and a combined site for the biogas digester and heat plant. The heat plant is connected to a district heating system, which is illustrated through the gray pipes in figure 22.



A waste management service based on small-scale biogas

Figure 22 - The entire system in the final concept.

The title of this thesis mentions a service. The system described above and in the concept development provides an opportunity for a municipality to create a waste management service directed towards grocery stores. This service can be formulated as follows; The municipality provides a product for pretreatment of waste in stores, as illustrated in figure 23.

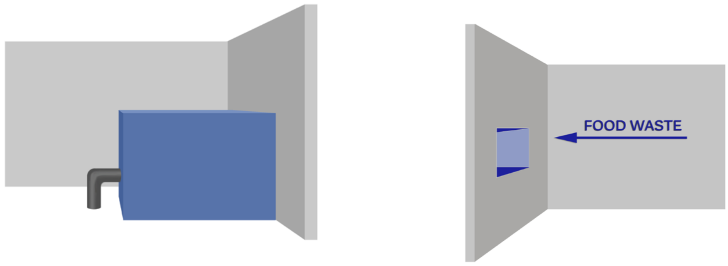


Figure 23 - Throw-in window to the right, and a pretreatment facility to the left, all in the grocery store.

The grocery stores and municipality commonly decides to lay pipelines from the store to the biogas digestion plant, and the food waste is thereby transported from the grocery store to the digestion plant. This system will be convenient for the grocery store workers, it will be an environmentally friendly solution and it will most likely also be cost-efficient, however the cost-efficiency is not as certain as the other factors. The estimated relationship between convenience and environmental friendliness for the final concept as well as their competitor is shown in figure 24.

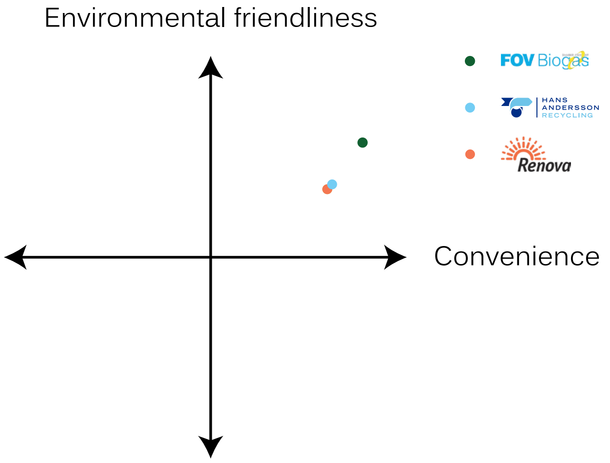


Figure 24 - The estimated relationship between environmental friendliness for the final concept compared to its competitors.

Lisa at Molly's groceries

In section 3.3.3. a case was presented. The scenario took place at Molly's Groceries, and an employee, Lisa, was personified. At that time, the food waste was transported 140 km to the biogas digestion plant. With the new system, the food waste is transported through underground pipelines to the local biogas digestion plant. When laying pipelines to Molly's Groceries the municipality, in cooperation with the grocery stores, decided to lay pipelines to the competing grocery store as well, Pelle's Food. This has resulted in a closer cooperation between the business sector and the municipality. The next step is setting up an agreement with a local grain farmer for handling the fertilizing slurry. In order to enhance local organic farming, the fertilizing slurry is now distributed to smaller organic farmers without charge. The crops from these smaller size farms are being sold at Molly's Groceries. And Lisa is satisfied. Throwing away food is now more convenient as well as less time consuming as before.

CARROTS FROM ANNA'S FARM

Grown with fertilizer from our common food waste

What was left after biogas production has grown these potatoes

7. Discussion

In this project the concepts has been compared to the waste management alternatives that exists in Sweden today. This alternatives are large scale biogas production and incineration. Landfilling of food waste is prohibited. This is not the case in others countries throughout the world, which puts the FOV biogas digester in another perspective. In areas where food waste today is landfilled, the benefits of a small scale biogas plant is increadibly larger than in Sweden today. Hence, the benefits of a product like this all comes down to what the alternatives are.

Validity of results from the survey

The background research methods used in this project was a literature study, interviews and an internet based survey. In hindsight, at least one conclusion can be drawn; The outcome of a survey reflects the clearness and respectfulness of the questions posed. In this project, some of the questions could have been formulated more clearly. The result of this was that the answers from one of the survey questions could not be used in the study, since the recipients answers were inconsistent with the other questions. This also questions the benefits of using a survey at all, while on the other hand, 22 heads of grocery stores answered the survey, persons who would most likely not have had time for a telephone interview. Even though the survey contained parts that afterwards could not be used, other parts of the survey still provided a lot of useful information.

Validity of results from the interview study

The final concept was developed based of the statements from especially one interview. This approach can be questionable in a product development project. However, this interviewee was a senior head of recycling in a major grocery store chain in Sweden and does therefore possess a insight of the general view in the business today. Even if a study based on mainly one interviewee is not ideal, in this case, it is still considered reliable.

Market possibilities

As discussed in section 3.4.1 SWOT analysis, not many smaller-scale local biogas plants exists in Sweden today. Instead there are a couple of large biogas digesters that covers large parts of the biological waste. The research in this project showed that the major part of the food waste from grocery stores in the Västra Götaland area is digested in the biogas plants in Borås or Trollhättan. In that sence, it seems like the market of producing biogas out of food waste from grocery stores in southern Sweden is saturated. The possibilites here is to expand to sources of biological waste, such as food waste from restaurants or commercial kitchens, or to focus on another area of location. This area could be the northern part of Sweden, where the land is more scarcely populated and the existance of biogas digestion plants far more rare.

Future development

During this project a first exploration of the market of small scale biogas in Sweden has been conducted. This work could however be continued with further exploration and investigations. One thing to focus on in particurlar is the approximations of investments needed for entire systems as the one in the final concept, as well as the savings that can be made by performing these investments.

Sustainable waste management?

You have now reached the end of this master thesis report about small-scale biogas production, and one thing is hopefully clear. Biogas is good. Biogas is a renewable energy source that has a low ecological footprint. It is even better if is made out of waste. And we would like to have more biogas, which we have seen for example in the sales of biogas fuel. But we do not need more waste. The more waste we produce, the more goods we have produced, and this production affects the environment tremendously. Ideally we would have less food waste than we have today, and a 100 % of that would be biogas, which is illustrated in figure 25. This means that a future market for producing biogas out of solely food waste is probably not a great opportunity. Instead, developing a solution that accepts mixed substrates such as food and energy crops might be a better solution for the future.

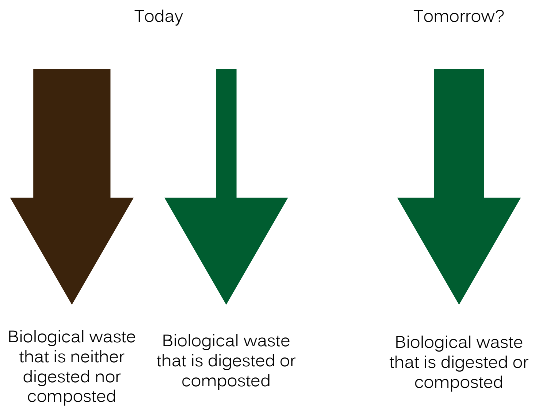


Figure 25 - An illustration of the relationsship of the amounts of biological waste that is treated in a biological way and the waste that is not treated in a biological way, today and in the future.

8. Conclusion

There is a possibility of a future market for small scale biogas in Sweden. If the small scale biogas plant is to attract biological waste from grocery stores it however crucial that it is not connected to, and not to be run by, the grocery store. Furthermore, the waste management market in the Västra Götaland county is today dominated by a few large size actors, both governmental and privately held, which reflects the situation in the entire country. Hence, the most promising action would be to direct a business proposal towards municipalities or one of the larger waste management companies.

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Appendix

Survey

Hämtning av biologiskt avfall

Välkommen till den här enkäten om hämtning av biologiskt avfall. Den är en del av ett examensarbete inom produktutveckling på Chalmers. Den tar 3-5 minuter att fylla i.

Om ni önskar ta del av resultatet av examensarbetet, hör vänligen av er till almegius@ student.chalmers.se.

Tack för din medverkan!

Med vänliga hälsningar
Helena Almegius
Student, Chalmers tekniska högskola, Göteborg
almegius@student.chalmers.se

1. Vänligen välj typ av butik.
- ICA Maxi
- ICA Kvantum
- ICA Supermarket
- ICA Nära
- Coop Forum
- Coop Konsum
- Coop Nära
- Coop Extra
- Willy:s
- Willy:s Hemma
- Hemköp
- Annan [blank field for comments]

2. Separerar Ni biologiskt avfall och brännbart avfall i olika kärl?
- Ja
- Nej
- Kommentar [blank field for comments]

3. Vilket företag hämtar Ert biologiska avfall idag?
- Renova
- Mölndals stad

- Hans Andersson
- Allwin
- Annan [blank field for comments]

4. Vad händer med Ert biologiska avfall idag, efter att det hämtats hos Er?

- Det blir biogas
- Det förbränns
- Det deponeras
- Vet ej
- Annat [blank field for comments]

5. Hur viktigt är det att Ert biologiska avfall behandlas på ett miljövänligt och hållbart sätt?

Inte alls viktigt Mycket viktigt

6. Hur viktigt är priset när Ni väljer tjänst för hämtning av biologiskt avfall?

Inte alls viktigt Mycket viktigt

7. Hur viktigt är det att avfallshanteringen tar lite tid för butikspersonalen? Med avfallshantering menas här även sortering av olika sorters avfall.

Inte alls viktigt Mycket viktigt

8. Om flera av aspekterna ovan varit mycket viktiga, har Ni möjlighet att rangordna de olika aspekterna vid val av tjänst för hämtning av biologiskt avfall här?

[1, 2 or 3] Att avfallet behandlas på ett miljövänligt och hållbart sätt

[1, 2 or 3] Att priset är tillfredsställande

[1, 2 or 3] Att avfallshanteringen tar lite tid för butikspersonalen

Tack för din medverkan! Har du några övriga kommentarer får du gärna lämna dem här. [blank field for comments]

Pugh matrix

Grocery store

Selection criterion / Concept	Reference Current system = Waste bins + Trucks	Concept 1 Throw-in wall opening + Pipelines (Transporting untreated food)	Concept 2 Throw-in wall opening + Pretreatment + Pipelines	Concept 3 Throw-in wall opening + Pretreatment + Trucks	Concept 4 Like current system but with local small scale biogas production
Feasability	0	-	-	0	0
Investment cost	0	-	-	-	0
Possibility of gaining profit	0	0	+	+	0
Environmental friendliness	0	+	+	0	+
Convenience	0	+	+	+	0
Total	0	0	1	0	1

Biogas digestion plant owner

Selection criterion / Concept	Concept 1 = Reference District heating in the community	Concept 2 Heating of a certain building	Concept 3 Electricity and heat production for the community	Concept 4 Electricity and heat production for a certain building	Concept 5 Upgrading to fuel inhouse	Concept 6 Selling the biogas to an upgrading company, such as E.on or Swedish Biogas.
Feasability	0	0	-	-	-	-
Investment cost	0	0	-	-	-	+
Possibility of gaining profit	0	-	0	-	+	+
Environmental friendliness	0	0	0	0	0	-
Convenience	0	0	-	-	-	+
Total	0	- 1	- 3	- 4	- 2	1