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PRODUCTION AND FEASIBILITY OF BIOGAS

Case Company: Osuuskauppa KPO

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Yrityksille on yhä tärkeämpää tavoitella energiaomavaraisuutta niin taloudellisesta, imagollisesta kuin ympäristöllisestä näkökulmasta. Energiaomavaraisuuden tavoitteleminen uusiutuvilla energiamuodoilla antaa yritykselle mahdollisuuden säästää energiakustannuksista tai tuottaa pääomaa. Biokaasun monipuoliset käyttömahdollisuudet tekevät siitä mielenkiintoisen energiamuodon monille eri tahoille. Opinnäytetyön tavoite on tarkastella biokaasun perusteita, sekä tutkia biokaasun kannattavuutta KPO:n yrityksille.

Tutkimuksen pääviitteenä oli tutkia biokaasun kannattavuutta KPO:n alaisille yrityksille. Tarkoituksena oli suunnitella biokaasulaitos, joka tavoittelee parhainta mahdollista biokaasun energian tuottoa, yritysmallia sekä biokaasun hyödyntämismahdollisuuksia. Tutkimuksessa käytettiin kvalitatiivista tutkimusmenetelmää, jossa tietoa kerättiin kirjallisuudesta, internet-lähteistä sekä haastattelemalla alan ammattilaisia.

Tutkimuksessa koostettiin kerätyn tiedon pohjalta kannattavuuslaskenta, jonka tuloksesta luotiin päätelmä biokaasun kannattavuudesta. Tutkimuksen pohjalta voidaan todeta suunnitellun biokaasulaitoksen olevan kannattamaton.

Avainsanat Biokaasu, kannattavuus, kannattavuuslaskenta

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ABSTRACT

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It is becoming increasingly important for companies to pursue energy self-sufficiency from an economic, imaginative, and environmental point of view. Achieving energy self-sufficiency with renewable energy sources can give the company economic savings or create revenue. Biogas is a flexible renewable energy source which makes it an interesting solution for companies. This thesis studies the feasibility of biogas for KPO and its subsidiaries.

The aim was to design a biogas plant that utilizes the best possible business model and to study the possibilities of biogas. The study used a qualitative research method in which information was gathered from literature, online sources and by interviewing the professionals in the field.

The gathered information was used to compile a feasibility study and a profitability calculation. The calculation was used to prove the feasibility of biogas for KPO. According to the research it is not feasible to build a biogas plant according to the parameters outlined in the study.

Keywords Biogas, feasibility, cost Analysis

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ABBREVIATIONS AND TERMS

CHP	Combined Heat and Power
AD	Anaerobic Digestions
VFA	Volatile Fatty Acids
HRT	Hydraulic Retention Time
EIA	Environmental Impact Assessment
DM	Dry Matter Content
GHG	Greenhouse gas
ODM	Organic dry matter content
BMP	Maximum specific biomethane production

1 INTRODUCTION

The constant increase in energy demand gives different businesses and private parties the motivation to invest in new energy systems. The same motivation drives the companies to search for energy solutions that would benefit them in multiple different ways, not only in the energy production. Biogas offers various opportunities in the fields of PR, economical savings and making a greener foot print on earth.

Biogas is a greener and more renewable solution compared to traditional fossil fuels. The emissions are significantly lower and the infrastructure to use biogas is already there. Purified biogas is comparable to natural gas and therefore is usable in almost every natural gas system. The versatility of biogas offers almost endless solutions for today's energy demand. It supports modern trends, such as localization of energy grids, smart energy production and smart grids. Biogas will play a significant role as a transition fuel to carbon neutral energy production.

The aim of the thesis is to study the possibilities of biogas production for the restaurant and food market industry. The focus is on KPO companies in the Vaasa region in Finland. The main idea is to collect the food waste from local KPO companies to produce biogas. The biogas can be used as an energy source in CHP solutions or sold as it is to the local companies. The study focuses mainly on making a profit on small scale biogas plants and to find a solution that has a pay-back period of less than five years.

1.1 Structure of Thesis

The first part of the thesis gives the basic information of biogas production. The parameters which determine the quality and production of biogas are important to understand the decisions that must be made for an economically and technologically stable biogas plant.

The second part is the design and cost management part of the study. The design had to follow the guidelines that the parameter for the pay-back period set. The challenge was to make it work on a smaller scale.

The second chapter explains the basic process of biogas production. The third chapter outlines the different parameters that must be taken into account in anaerobic digestion. The fourth chapter explains different grants, permits and how to connect to the grid in Finland. The fifth chapter gives information on emission from biogas. Chapter 6 explains the most common components in biogas plants. Chapter 7 briefly explains the different products derived from biogas. The eighth chapter outlines the research method. The last chapter is on the feasibility of biogas for the case company.

1.2 Research Question

Companies want to maximize profits and efficiency and cut down costs. This creates an interest in systems that can offer both. Grocery store and restaurant chains, such as KPO usually must discard organic wastes on daily basis. This creates an inconvenience to the company. The organic wastes could be used to produce energy and therefore lower the costs of energy usage and waste disposal. A representative of a KPO restaurant was interested in the potential of biogas for local KPO companies. Under this premise the following research question was formed:

- What is the potential of biogas plant for KPO?

2 THE BASICS OF BIOGAS PRODUCTION

Biogas is produced from bio matter with a microbiological decomposition in an oxygen free environment. This process is called anaerobic digestion (AD). The process produces biogas and digestate. The biogas mainly contains methane and carbon dioxide and digestate is the decomposed feedstock. The biogas is a flammable gas and can be used as an energy source in multiple different energy systems. When biogas is purified to a higher methane content,16 it can be used in most natural gas systems. /1/

The AD process is a four-step chemical reaction that decomposes the organic matter. Each individual step breaks down the matter with different micro-organisms. These organisms break down the matter produced in the previous steps. The Figure 1 shows the simplified diagram of the AD process. The four main steps are hydrolysis, acidogenesis, acetogenesis and methanogenesis. /1/

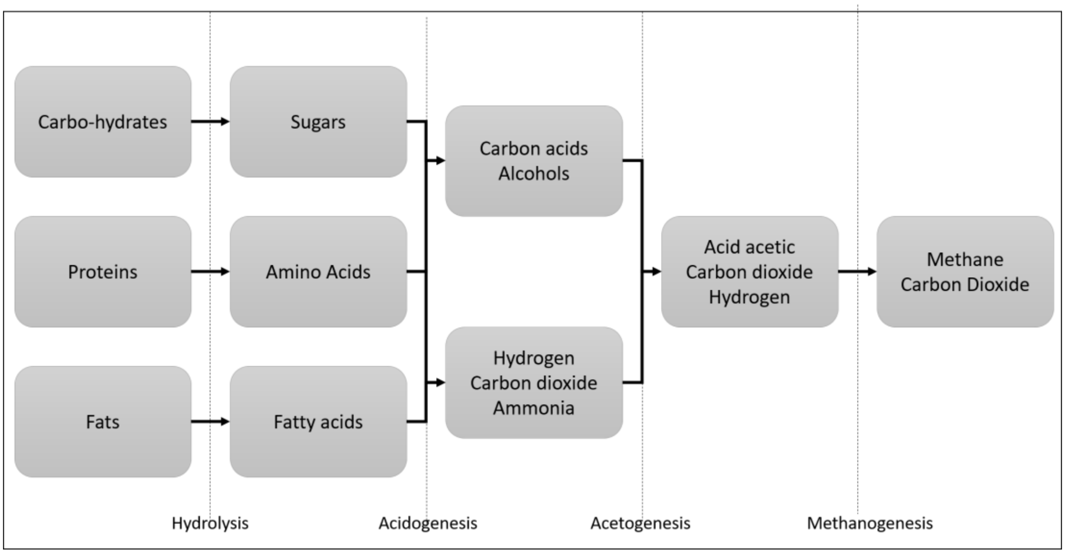

Figure 1. The simplified process structure of anaerobic digestion. /1/

2.1 Hydrolysis

Hydrolysis is considered the first step of the AD process. In this process the complex organic matter known as polymers are decomposed to smaller mono- and oligomers. The polymers, such as carbohydrates, proteins and fats are converted to smaller sugars, amino acids and fatty acids. The hydrolytic micro-organisms excrete hydrolytic enzymes that break down biopolymer structures into more soluble compounds. Hydrolysis breaks down lipids into fatty acids, polysaccharide into monosaccharide and proteins into amino acids. /1/

2.2 Acidogenesis

The substances produced in hydrolysis are further broken down in the acidogenesis. The acidogenic bacteria is the bacteria used in fermentation. The acidogenic bacteria breaks simple sugars, amino acids and fatty acids into methanogenic substrates like acetate, carbon dioxide, hydrogen, volatile fatty acids (VFA) and alcohols. /1/

2.3 Acetogenesis

The products of acidogenesis cannot be directly converted into methane by methanogenic bacteria. Acetogenesis converts the products from acetogenesis into methanogenic substrates. VFAs with carbon chains longer than two units are oxidized into acetate and alcohols with carbon chains longer than one unit are oxidized into hydrogen. The methanogenesis usually runs in parallel with acetogenesis as a symbiosis of two groups of organisms. /1/

2.4 Methanogenesis

The final step in the AD process produces methane and carbon dioxide from the intermediate products. The methanogenesis is carried out by methanogenic bacteria. Acetates, hydrogen and carbon dioxide are converted into methane. The acetate conversion accounts for 70% of the methane produced and the converted hydrogen and carbon dioxide make up rest of the 30%. In the methanogenesis process acetic acids are converted into methane and carbon dioxide and hydrogen and carbon dioxide are converted further into methane and water. /1/

The methanogenesis is a critical step in the anaerobic digestion process. The speed of the digestion process is dependent on the slowest reaction in the chain and in the AD-process the methanogenesis is the slowest one. /1/

3 ANAEROBIC PROCESS PARAMETERS

To successfully convert biomatter into biogas, many different parameters have to be met for efficient and constant conversion. The process is influenced by operating conditions, such as composition of the feedstock, the feeding rate, temperature and pH-value. Changes in these operation parameters can slow down the AD process or completely inhibit it. For methanization to happen, a nutrient ration of the elements C:N:P:S should be at 600:15:5:3. /1/

3.1 Temperature

The operation temperature determines the type of bacteria used in the process and the retention time of the AD process. In high temperatures chemical reactions are faster and therefore the process itself is faster. The temperature ranges can be divided into three different ranges according to the bacteria used. The bacteria are called psychrophilic, mesophilic and thermophilic. Table 1 shows the operation temperatures and the retention time of each specific bacteria. /1/

Table 1. The operation temperature and the retention time for specific bacteria. /1/

Bacteria	Operation temperature	Retention time
Psychrophilic	Below 25 °C	70 to 80 days
Mesophilic	25 °C - 45 °C	30 to 40 days
Thermophilic	45 °C - 70 °C	15 to 20 days

In practical use the psychrophilic bacteria is not feasible to use, for its long retention time and low biogas yield. The mesophilic bacteria is good for its low operation temperature and average biogas yield. The most used bacteria is the thermophilic bacteria. It has the largest biogas yield and the lowest retention time. Figure 2 Shows the different biogas yield for each temperature range. /1/

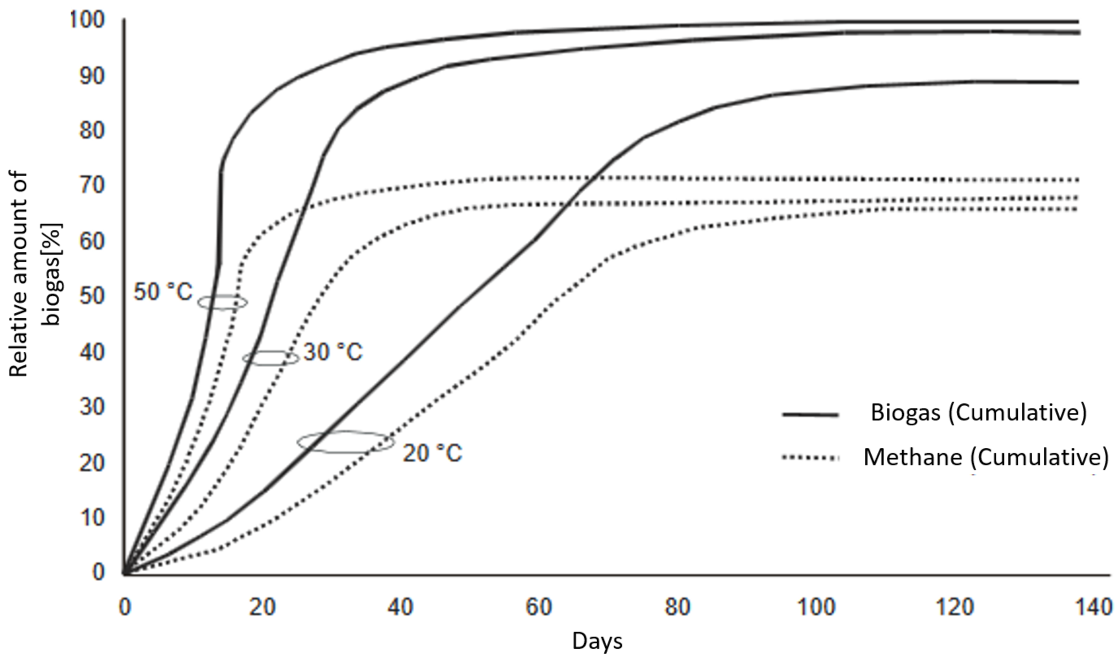

Figure 2. Relative biogas yields, depending on temperature and retention time. /4/

3.1.1 Thermophilic Bacteria

Thermophilic bacteria is the most used bacteria because it can obtain better biogas yields and it has an efficient conversion rate of methane. The thermophilic bacteria has a temperature range that is effective in destruction of pathogens, which may inhibit the AD process. The grow rate of bacteria is also higher in thermophilic temperatures, which improves the retention time. The thermophilic bacteria has improved digestibility, degradation of solid substrates and substrate utilization. /1/

The thermophilic bacteria also has some disadvantages. The specific parameters are much more sensitive to changes than mesophilic bacteria. The thermophilic bacteria has a temperature change tolerance of +/-1°C. If a bigger change occurs the bacteria needs time to adapt before efficient process can occur. Mesophilic bacteria has much higher tolerance at +/- 3°C. The thermophilic bacteria also has larger energy demand due to the high operation temperature. This is usually countered with better energy production when comparing to mesophilic bacteria. The thermophilic bacteria has higher risk of ammonia inhibition. The ammonia has an effect on the pH balance. /1/

3.2 pH – Value

The pH-value signifies the acidity or the alkalinity of a solution. In the AD process the pH-value influences the growth rate of bacteria and methanogenic microorganisms. It also affects the dissociation of compounds with an importance to the AD process. The ideal pH-range is 7.0 to 8.0, but a safe interval is 5.5 to 8.5. The pH-value is usually increased with the introduction or accumulation of ammonia in the process. The ammonia can be introduced with the feedstock, mainly when the feedstock has urine in the mixture. Ammonia can also accumulate during degradation of proteins. Volatile fatty acids have the opposite effect as it lowers the pH-value. Ammonia and volatile fatty acids cancel each other's effects on pH. /1/

The pH-value in the AD reactors are mainly controlled with a buffer solution. The bicarbonate buffer solution stabilizes small changes in pH. The down side of the buffer solution is that if the pH change is greater than the tolerance of the buffer solution, the drastic change of pH in the digester can inhibit the process. The pH value in the digester is dependent on the partial pressure of CO_2 and the concentration of alkaline and acid compounds in the liquid phase. The buffer capacity and pH-value are also dependent on the feedstock. The pH-value should be used as a measurement parameter for the process. /1/

3.2.1 Volatile Fatty Acids (VFA)

The stability of the process is affected by the concentration of pH-value altering compounds like ammonia and VFAs. VFAs are compounds, such as acetate, propionate, butyrate and lactate, which are produced during the acidogenesis. VFAs lower the pH-value of the solution. The buffer solution can stabilize the effects of VFAs to a certain extent, but has the same risk as accumulation of ammonia. If the tolerance of the buffer solution cannot handle the accumulation of VFAs, the effect on pH might inhibit the process. /1/

3.2.2 Ammonia

Ammonia is a nutrient that accumulates in the digester when proteins break down. It can also be introduced to the process with the feedstock. The accumulation of ammonia in the digester can increase the pH-value and therefore if the increase is too high can inhibit the process. The ammonia content should be kept under 80mg/l for this reason. /1/

The amount of ammonia in the process is directly proportional to temperature. This is why ammonia is a bigger problem in the thermophilic temperature range than in lower temperature ranges. The amount of ammonia can be calculated with the following equation:

$$[NH_3] = \frac{[T-NH_3]}{(1+\frac{H^+}{ka})} \quad (1)$$

where

NH_3	The amount of free ammonia in the solution
$[T\text{- }NH_3]$	Total amount of ammonia
Ka	Dissociation parameter

The equation proves that the increase in temperature increases the accumulation of ammonia in the process. /1/

3.3 Nitrogen

Nitrogen is an important nutrient for the micro-organisms in the AD process. The main source of nitrogen accumulation in AD process are proteins that are converted to ammonium. The accumulated ammonium is assimilated by micro-organisms to produce new cell mass. /12/

3.4 C/N Ratio

The Carbon/Nitrogen ration in the feedstock plays an important role in AD process by affecting the cell production of micro-organisms and accumulation of ammonia. The unbalanced nutrients make the AD process less efficient and decreases production of biogas. /12/

The C/N ratio has a role in regulating the accumulation of ammonia as it affects the ammonia inhabitation in high temperatures. A significant increase in ammonia inhabitation can be observed with the C/N ratio of 15 at 35°C and the C/N ratio of 20 at 55°C. The effects can be countered with increase in the C/N ratio. The maximum methane potential can be obtained with the C/N ratio of 25 at 35°C and the C/N ratio of 30 at 55°C. The thermophilic temperature range has a higher risk of ammonia inhabitation, which can be countered by increasing the C/N ratio. /13/

3.5 Operational Parameters

3.5.1 Organic Load

Organic load indicates how much dry matter can be fed to the digester, per volume and time. The reason for calculating the organic load parameters is to maximize plant economy and biogas yield. To get the best possible amount of biogas per amount of biomass introduced to the digester, the retention has to be quite long. This might inhibit the economy of the plant. The organic load is calculated with the following equation

$$B_r = m * c / V_R \tag{2}$$

where

B_r Organic load [kg/d*m^3]

m Mass of substrate fed per time unit [kg/d]

C Concentration of organic matter [%]

V_R Digester volume [m^3]

/1/

3.5.2 Hydraulic Retention Time (HRT)

HRT is the correlation between the digester volume and the volume of substrate fed to the unit per time unit. The HRT is used in dimensioning the digester by the average time interval the substrate is kept inside the tank. The hydraulic retention time is calculated with the following equation

$$HRT = \frac{V_R}{V} \quad (3)$$

HRT Hydraulic Retention Time [days]

V_r Digester volume [m^3]

V Volume of substrate fed per time unit [m^3/d]

According to the equations increasing the organic load reduces the HRT. The retention time must be scaled according to the duplication rate of the anaerobic bacteria. If the retention time is too low, the number of bacteria will degrease due to the removal rate of substrate. The average duplication rate of anaerobic bacteria is 10 days or more. /1/

4 GRANTS, PERMITS AND GRID CONNECTION FOR A BIOGAS PLANT

4.1 Grants

The Finnish government offers two different grants for biogas plants. This is done to increase the production of renewable energy sources. These grants can be taken into account when calculating the feasibility of biogas projects, due to its high probability.

4.1.1 Feed-in Tariff

The Finnish Energy Authority offers a feed-in tariff for biogas plants in Finland. The minimum price paid is 83.50€/MWh and if heat is utilized 50€/MWh is paid per heat premium. The feed-in tariff is paid for 12 years from commissioning and for the energy output applied for. /3/

There are certain requirements for applying for the feed-in tariff. The biogas plant has to have a minimum nominal power of 100 kVA. The power plant has to be new and without any used parts in its system. The feed-in tariff is granted when 19MVA of power plants apply for the tariff. The power that the power uses itself doesn’t account for the tariff. /3/

4.1.2 Investment Grant

The Ministry of Employment and the Economy of Finland can give a grant of 8% - 30% of the total investment cost for a biogas plant in Finland. The grant is meant for a biogas power plant that cannot apply for the feed-in tariff. It can be applied by a store chain or a private company. The main condition for applying for the grant is the aim for reducing the usage of fossil fuel powered systems. It is important for the Ministry of Employment and the Economy that the grant is essential to make the project feasible. /3/

4.1.3 Choosing the Right Grant

The right grant for the project can be the factor that makes a project feasible. The investment grant is a great way to increase the feasibility of the project, but the focus is on the feasibility, not profitability. The investment grant is an opportunity to improve the energy system and make a green impact on energy production. The best way to make a biogas plant project profitable is to apply for the feed in tariff. The Figure 2 show the most important factors when choosing the right grant.

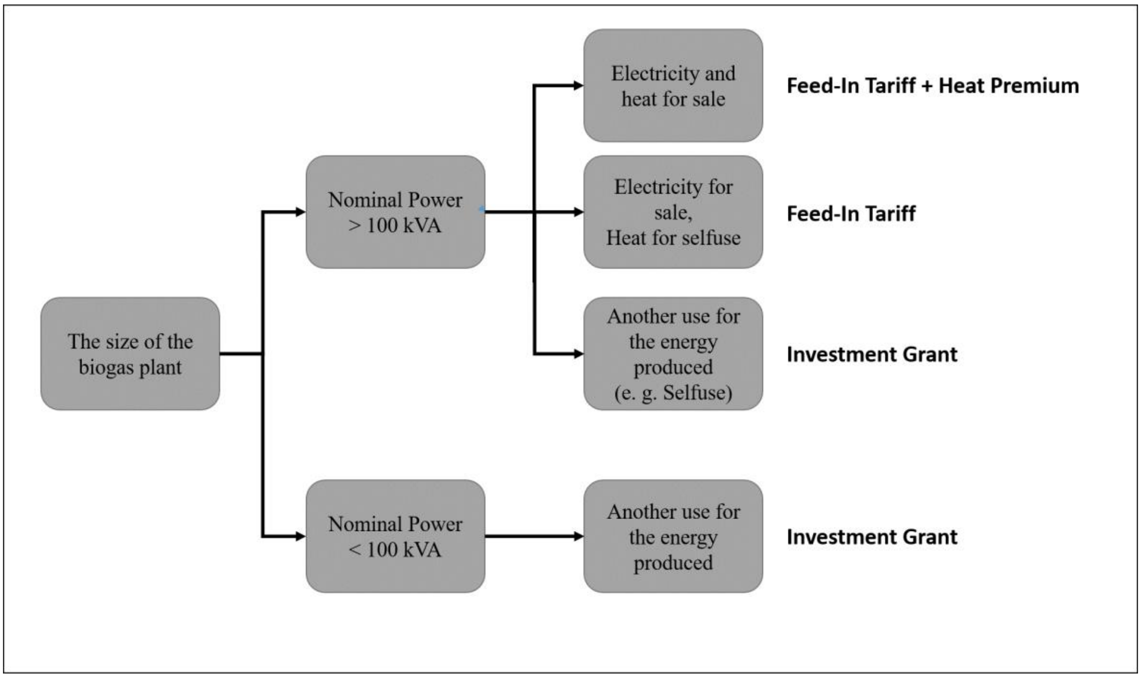

Figure 3. The flow chart for determining the grant.

4.2 Permits

There are multiple different permits that are needed to construct a functioning and legal biogas plant. The main permits are environmental permit, building permit, power plant approval, ATEX-approval and contracts between the local electricity and grid companies.

4.2.1 Environmental Permit

The main point of the environmental permit and the Environmental Protection Act is to prevent the contamination of the environment, secure healthy and comfortable environment, promote the sustainable usage of natural resources and make the assessment of environmental impacts better. /5/

The environmental permit is mandatory when a project has effects on the environment. It is applied if the project has emissions, soil contamination, negative effects on health and the nature and if it changes the nature of the surrounding environment. Emissions can originate from matter, noise, vibration, radiation, light, heat and smell. /5/

The permit includes outline of the location of the power plant, the processes in use, the equipment and the environmental impacts. The power plant also has to go through the environmental impact assessment procedure if the amount of bio matter used exceed the amount of 20 000 tons annually. /6/

4.2.2 Building Permit

Biogas power plants need a building permit according to the building law (132/1999). The authority that grants the building permit is the local municipal building authority. The permit requires a blueprint of the power plant. When the biogas plant is ready for commissioning, a final inspection is carried out. /6/

4.2.3 ATEX – Approval

The ATEX directive outlines the equipment used in an explosive environment. The equipment must be tested, approved and marked by an ATEX certificate. DSEAR is the United Kingdom’s implementation of the ATEX directive and it outlines an explosive atmosphere as a mixture of dangerous substances with air, under atmospheric conditions, in the form of gases, vapours, mist or dust in which, after ignition has occurred, combustion spreads to the entire unburned mixture. /7/

The produced biogas in the biogas plant is an explosive mixture due to the high methane content in the biogas. Biogas is explosive in atmospheric conditions when the ambient air contains biogas 5% - 15% and the temperature is over 20 °C. Therefore, a biogas plant must be ATEX approved. The local rescue department may want to approve a new ATEX area before commissioning. /6/

4.3 Connecting to the Grid

Small scale energy production is considered to be all power plants that have nominal power of 0-2000 kVA. Power production needs a grid according to the amount of produced energy. The local energy grid company usually have guidelines on how to connect and what to take into account when designing a power plant. When connecting a small production system to the grid in Finland there are few requirements for the system. /14/

4.3.1 Requirements for Connecting to the Grid

The local energy grid companies need a switch between the production equipment and the grid, which can easily be accessed by a representative of the local grid company. The production system has to be type tested according to the Finnish SFS-EN 50438 or the German VDE-AR-N-4105 standards. To further develop the safety procedures of the power plant, the production equipment and the switchgears must have clear warning signs for rear feed danger and instruction on how to safely disconnect the production equipment from the grid. The self-used electricity must be connected to the production system with a fixed or semi-fixed installation. The production equipment cannot be connected to the grid without permission from the local grid company. The power plant must be evaluated by a representative of the local grid company. /14/

4.3.2 Responsibility of Duty on Electricity

Duty on electricity applies only for production systems that have a nominal power of over 100 kVA and produce more than 80 000 kVh of electricity annually. If a production system has a nominal power under 100 kVA the duty does not apply.

All production systems that have a nominal power of 100 kVA or more have to register to the customs as an energy producer. If the annual produced energy exceeds 80 000 kVh and the production system has nominal power of over 100 kVA the power plant has responsibility to pay duty on electricity. /14/

5 EMISSIONS

Burning fossil fuels releases carbon dioxide that was stored in earth's crust for millions of years and is now released into the atmosphere in a much shorter time. Carbon dioxide is also produced when biogas is burned, but this is compensated by the carbon dioxide that is absorbed by the plants used to produce the biogas. Therefore, burning biogas is carbon-neutral. Crude biogas is mainly methane and carbon dioxide, which both are greenhouse gases. Methane is 23 times more potent greenhouse gas than carbon dioxide. Therefore, it is much more important to focus on the methane leakage than the carbon dioxide emission in the power plant. During the operation of a biogas plant it is important to keep leakage to a minimum due to economic and environmental losses. /1/ /11/

Even though biogas plant has greenhouse gas emission it is far more environmental friendly compared to fossil fuel powered plants. A study conducted in Hungary shows a 93,7% decrease in emission in the life cycle of a biogas plant compared to the regular Hungarian energy production structure. The amount of SOx and NOx emission is minimal when burning biogas. Therefore, NOx and SOx don't need extra attention when designing emission control systems. When replacing biogas as an energy source in transportation and energy production, the overall emissions are decreased and thus contributing to the mitigation of global warming. /11/

Biogas can obtain negative GHG emissions during its production cycle. The amount of GHG emissions are bigger if livestock manure is composted or just stored, compared to it being used to produce biogas. This is because livestock manure has methane emission in ambient conditions that are bigger than the emissions from burning biogas. In plant based raw materials the carbon dioxide is absorbed to the plant during its life cycle. The absorbed carbon dioxide is the same amount that what is released when biogas is burned. This makes plant based biogas a carbon neutral fuel. By recycling the digestate to be used as a fertilizer to produce more raw material for the power plant, a closed production cycle can be obtained. /15/

6 BASIC COMPONENTS

A biogas plant has a complex system controlling the plant, but the main components and the system usage configuration is quite simple. The Figure 4 shows the main steps of biogas production. Each step is divided in to processes. The system is straight forward where biogas is produced from bio matter in a linear way through series of different processes. /1/

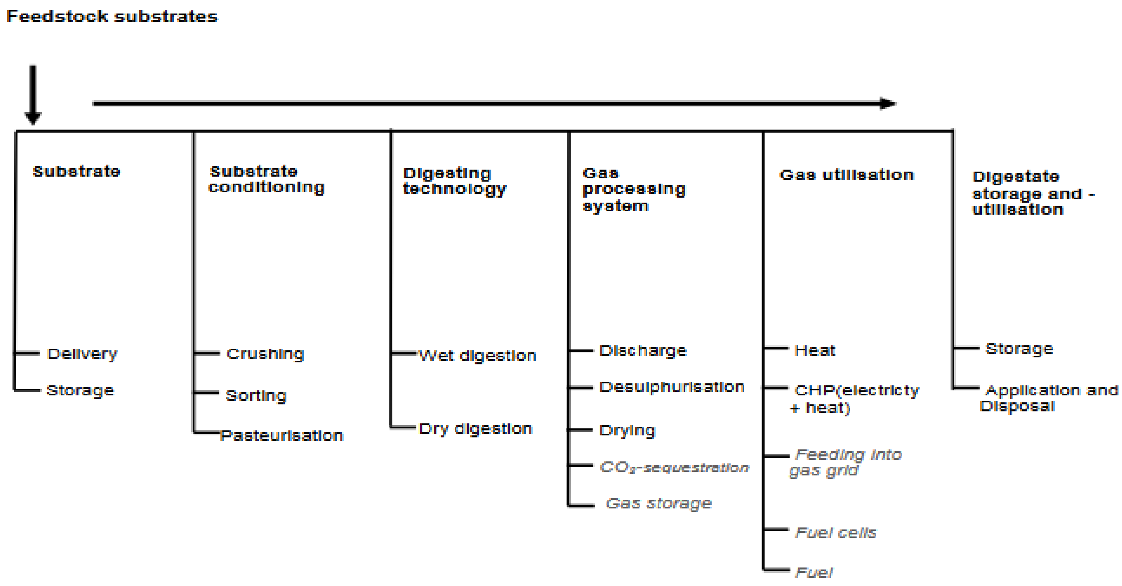

Figure 4. Process steps of biogas production. /4/

The main components are shown in Figure 5. The outlines show the components used in each process stage. The components are dependent on the type of substrate, the type of bacteria and the digesting technology in use. The figure does not show any pumps, valves or security systems that are essential to the operation of the power plant.

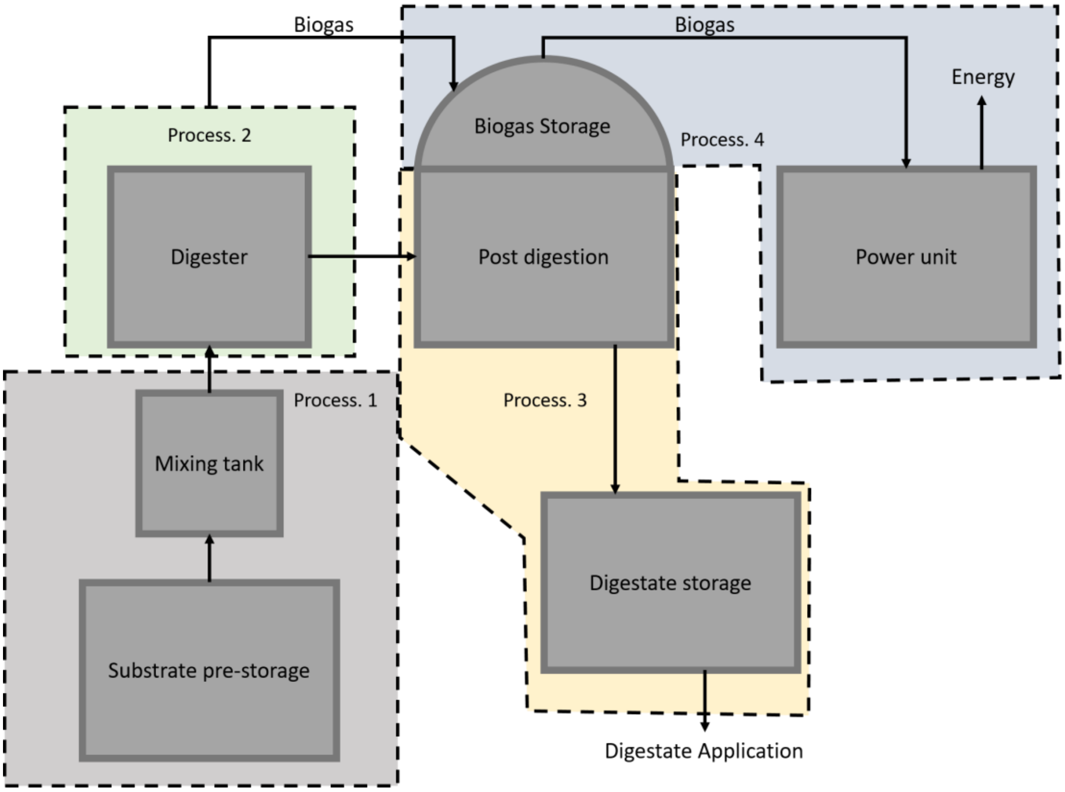

Figure 5. Main components of a biogas plant and the processes they serve. /1/

Biogas plant operation can be divided into four different processes as shown in Figure 5.

1. Transport, delivery, storage and pre-treatment of feed stock
2. Biogas production
3. Storage of digestate and post production of biogas
4. Storage and usage of biogas

The processes in anaerobic digestion can be shown as a process flow chart as in Figure 6. /1, 6/

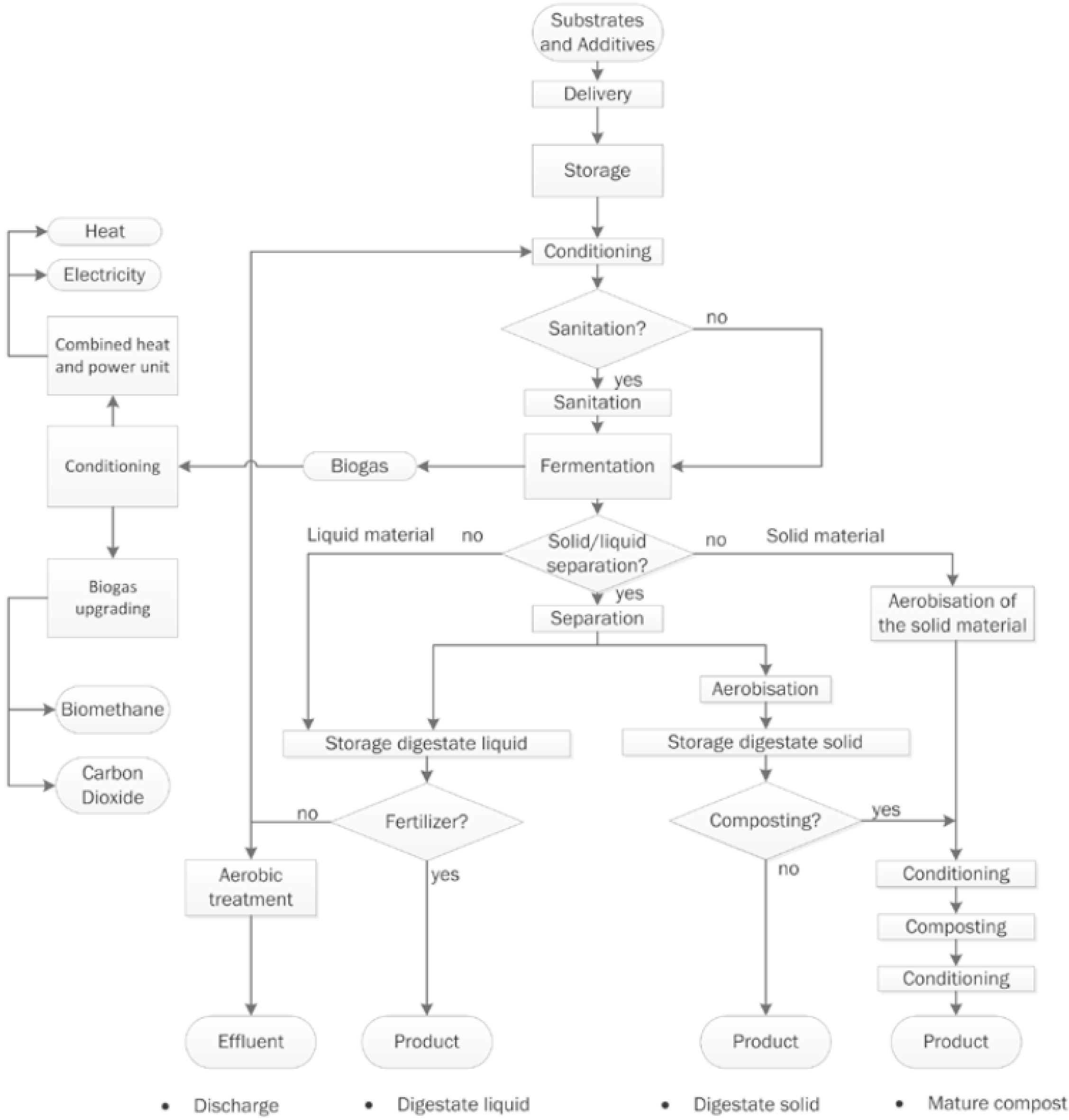

Figure 6. Possible process components and processes in anaerobic digestion. /10/

6.1 Transport, Delivery, Storage and Pre-treatment of Feedstock

The process of producing biogas usually starts with the transportation of feedstock to the feedstock receiving unit. The receiving unit is also the first step in quality control. The feed stock is inspected by eye and moved to the feedstock storage unit.

6.1.1 Feedstock Storage Unit

The storage unit is chosen according to the physical state of the feedstock and it is sized according to quantities stored, delivery rates and quality of feedstock. The storage units need a continuous supply of feedstock to ensure a steady and efficient production of biogas. There are two main types of storage units: bunker silos and storage tanks. /1/

Bunker silos are used when the feedstock is in solid state. The solid feedstock can be stored on the ground or in a concrete silo. The bunkers are relatively cheap to produce and can be built on site according to the specific characteristics of the site. The storage time for the bunkers is more than a year. This makes continuous supply easier and more reliable. /1/

Storage tanks are for liquid feedstock like animal slurries and municipal liquid waste. The storage tanks are more complex than bunkers and need to be watertight to prevent leakage. The tanks need limited maintenance to remove sediments and to maintain the proper working parameters for pumps and pipes. If the storage tanks are in closed quarters, the system also needs bio filters and efficient ventilation to reduce smell pollution. /1/

6.1.2 Feedstock Conditioning

Feedstock should be conditioned before introducing it to the digester. This is done to prevent inhabitation caused by plastics, metals and harmful substrates. The conditioning has a positive effect on the flow and efficiency of the AD process by increasing digestion rates and biogas yields. Conditioning is carried out by feedstock sorting and separation. The impurities in the feedstock are removed from the feedstock. The removal of impurities is important if the main source of feedstock is household waste, which may contain plastics and metals from food packaging and mistakes done in recycling. /1/

6.1.3 Sanitation

Sanitation is an important procedure for the operation of the digester and the use of the produced digestate. The sanitation of the feedstock has to be done before the digester to prevent the introduction of harmful bacteria and substrates to the digester. This way the contamination of the whole feedstock can be prevented. The sanitation is usually done in separate, heated stainless steel tanks. The parameters that determine the sanitation process are temperature, minimum guaranteed retention time, pressure and volume. In the sanitation process the feedstock is heated and therefore the temperature is higher after the sanitation than in the digester. For the temperature difference the feedstock should pass through a heat exchanger before entering the digester. This is done to keep the temperature in the digester as constant as possible. Sanitation can be utilized for pre-heating the feedstock. /1/

6.1.4 Crushing and Mashing

Crushing is done to reduce the size of the feedstock particles. The reduction in size increases the decomposition process. Crushing does not increase biogas yield, but it has a positive effect on the efficiency of the process and retention time. The crushing is usually directly connected or integrated into the feeding system. /1/

Mashing is the process of homogenizing the feedstock and is done to obtain feedstock with higher water content. It usually takes place in the container and predigester. The homogeneity of feedstock ensures best possible biogas yield. Changes in the feedstock can degrease the efficiency because the micro-organisms need time to adapt and by homogenizing the feedstock this can be prevented to a certain extent. Mashing can be done with raw liquid manure, digestate, process water or fresh water. Fresh water is not recommended to be used as process liquid due to the high cost of fresh water. Digestate is best used for containing AD micro-organisms, but can increase salt and nutrient content of the feedstock, which can lead to system imbalances. Digestate should be used after it is sanitized. Liquids that contain chemicals may be harmful to the micro-organisms and should not be used in mashing. /1/

6.1.5 Feeding System

The feeding system is designed by the feedstock in use. The main design parameter is the pumpability of the feedstock. Pumpable feedstock, such as slurries and oils need pumps and pipes to feed the feedstock to the digester. Non-pumpable feedstock are usually fibrous materials and solids that use tipping and pouring systems or screw pumps. The feeding systems can be used simultaneously. /1/

An ideal situation is continuous feeding to the digester, where the digester is fed multiple times per day. The continuous feeding saves energy and ensures efficient production of biogas. The feeding system should also take into account the temperature changes during the seasonal changes. The sanitation process can be used for heating the feedstock. /1/

The AD process includes a series of different armatures and pipelines. The pipelines must be corrosion-proof to prevent leakage caused by corrosive substances. The materials used in the armatures and pipelines depend on the use and should be designed to handle specific types of matters, mainly biogas and biomass. The pipelines should take into account the temperature, solidity, corrosiveness and flowrate of the feedstock. /1/

6.2 Biogas Production

6.2.1 Digester

A digester is an air proof and oxygen free container. The type of digester is determined by the feedstock and the production type of biogas. The two production types are wet and dry digestion. The type of digestion is dependent on the dry matter content (DM) of the feedstock. Wet digestion digester use feedstock that has DM lower than 15%. Dry digestion is used when the DM is higher than 15% in the feedstock. The average DM value in dry digestion is 20% - 40%. /1/

The type of production is determined by the production rate of biogas. Batch-type digesters are filled with feedstock, operated until the biogas is produced from the feedstock and emptied out. Batch-type digester are simple to build and to operate and is usually used for dry digestion. The energy consumption of a batch-type power plant is higher compared to the continuous-type digester. /1/

The more commonly used digester is the continuous-type digester, where the feedstock is continuously fed into the digester using either mechanical movers or movers that utilize pressure differences. When using a continuous system, biogas production is constant and predictable. The continuous system has to be maintained regularly to prevent sedimentation and blockages. /1/

6.2.2 Heating System

The heating system is essential to obtain the best possible biogas yield. The heating system is critical when using thermophilic AD micro-organisms, especially in cold climate. Temperature changes in the digester can inhibit the process, so it is important to keep the temperature as constant as possible. The temperature changes can be caused by mistakes done in the construction or operation of the biogas plant. The main mistakes are insufficient insulation and bad heating element placement. Insulation plays an important part in extreme ambient temperatures. Sometimes the new introduced feedstock may change the digester temperature if the temperature differences between the substances is substantial enough. /1/

The heating system can be done by internal or external heating systems. The internal system is usually located along the inner walls of the digester. The heating is done by circulating heated water or by heating elements. Heating can be sustained by keeping the feedstock the same temperature as the digester by preheating the feedstock or cooling it down after sanitation. The stirring system makes sure there are no temperature differences within the digester. /1/

6.2.3 Stirring System

Stirring is done to produce more biogas efficiently. In most digesters passive stirring is not enough for good operation performance. Stirring is done to introduce AD organisms to new feedstock, homogenizing the digestate, get the new and old feedstock stirred together and prevent sediment formation. /1/

Stirring should be done multiple times per day in sequences or continuously. Continuous stirring is effective but consume a lot of energy. Sequential stirring can be optimized with plant specific parameters to obtain the same results as continuous stirring. One of the most reliable stirring methods is continuous stirring mounted on the top of the digester for easy maintenance. /1/

There are three main types of stirrers; mechanical, pneumatic and hydraulic stirrers. Mechanical stirrers are moved by a prime mover and the speed can be adjusted according to the plant specifications. It usually uses a series of paddles or propellers in the digester. The mechanical stirrer motors are usually installed outside the digester, which makes the maintenance easier. Mechanical stirrers are good for breaking the top sediments and floaters. /1/

Pneumatic stirrers or gas stirrers compress the forming gases and feed them through the bottom of the digester to stir the feedstock. Hydraulic stirring is done with pumps and vertical pivoted vents. The sludge is pumped from the digester and reintroduced at high speeds. The basic operation style is the same in pneumatic and hydraulic stirring style only the stirring medium is different. Hydraulic and pneumatic stirring are only used for thin liquid feedstock and neither stirring can break the top sediments or floaters. /8/

6.3 Storage of Digestate and Post Production of Biogas

The digestate obtained from the AD process is rich in nutrients and microbes and therefore a great fertilizer for agricultural purposes. The digestate needs to be processed to be better suited for agricultural use. Dewatering or separating the digestate makes it easier to store and makes it lighter while still having the nutrients and microbes. Some applications need very dry solid product. In these situations, thermal drying can be used to obtain over 95% solid matter. This fertilizer is easy to transport, odourless and easily stored. /8/

6.3.1 Post-digestion

Post-digestion is used to further produce biogas from the feedstock. It is done in a separate digester and can utilize a different AD micro-organism than in the main digester to scale the retention time and biogas yield to obtain better efficiency and biogas yield. Post-digestion at 55°C can produce 11.7 % more biogas with HRT of 5.3 days. The amount of biogas produced in post-digestion is dependent on the same variables and parameters as the main digester. /9/

6.3.2 Separation and Storage of Digestate

The liquids and solids can be separated from the digestate to further use the digestate. The liquid digestate can be used for mashing and introducing AD micro-organisms to new feedstock. The solid digestate can be used as it is for fertilization or for composting. /1/

The storage of digestate is dependent on the state of the digestate. Solid digestate is easy to store on the ground or in a bunker. Liquid digestate needs to be stored in a water-tight container. /1/

6.4 Storage and Usage of Biogas

The storage of biogas is carried out by airtight, UV-, temperature-, weatherproof and pressure resistant tanks. The tanks can be either low, medium or high-pressure tanks. The minimum capacity is ¼ of daily biogas production but the recommended time is 1 to 2 days. /1/

6.4.1 Low Pressure Tanks

Low pressure tanks are usually membranes installed over the post-digester or in the vicinity of the plant. The pressure inside the low-pressure tanks is 0.05 – 0.5

mbar. Most plants use double integrity membrane to prevent leakage due to membrane failure. Low pressure tanks are low cost, easy to install and do not require power to operate. The down side is a low biogas amount per unit of volume. /1/

6.4.2 Medium and High-Pressure Tanks

Medium and high-pressure tanks are either bullet type stainless steel tanks or flat bottom tanks constructed on site. Medium and high-pressure tanks are high cost investments compared to low pressure tanks. The pressure inside these tanks vary from 5 bars to 250 bars. Medium and high-pressure tanks need energy to operate. The amount of energy used is dependent on the pressure inside the tank. 5-10 bars need 0.22kWh/m^3 and 200-300 bars need 0.31kWh/m^3. The high operation costs need to be taken into account when calculating the feasibility of the power plant. The reason that medium and high-pressure tanks are widely used is the energy density in the tanks. High pressure tanks can hold much more biogas per unit of volume compared to the low-pressure tanks. /1/

6.4.3 Biogas Usage

Biogas has multiple different applications. Upgraded biogas can be used in every natural gas system as a renewable energy source. The applications differ from large scale energy production to commercial vehicle fuel. In small scale biogas production, the biogas is used for sustaining the facility and self-use. This is quite common in farms where there are systems that consume a lot of energy. It is also quite common to sell most of the produced energy to the grid due to the feed-in tariffs.

Combined heat and power is the most prevalent way to use biogas. A CHP unit uses the same engine type as used in most vehicles. In the engine a piston pressurizes the gas, which after ignition and combustion moves a shaft which turns the generator. Biogas used in a CHP unit is a good way to secure the operation in the biogas plant. The produced thermal energy and part of the produced electricity can be used to sustain the facility. Even in the case of a blackout, the plant will continue to operate. A CHP plant is also more energy efficient system compared to plant that produces only thermal or electrical energy. /8/

6.5 Biogas Upgrading

The unprocessed biogas is about 50%-70% methane and 25%-50% carbon dioxide. Methane is the main substance that the energy is chemically bounded to. The crude biogas itself is suitable for energy production but due to impurities in the biogas it is not recommended to use as it may cause corrosion and sedimentation. The biogas has to be purified to obtain the best possible operation parameters. After the purification process the methane content in the biogas is more than 95% which is the same that of natural gas. The upgrading gets rid of carbon dioxide and other impurities in the biogas. The upgraded biogas is often called biomethane. /1/

6.6 Control Unit

A biogas plant is a complex collection of components that needs to operate as one unit. The complexity of the facility makes a central controlling unit essential for operation. The control unit is used for safety procedures, controlling and to avoid failures in the system. By documenting the parameters and operation of the biogas plant, the best possible efficiency can be obtained. The documentation also ensures the detection of anomalies in the system and makes early intervention and corrective measures possible. /1/

The control unit uses modern automation equipment to increase efficiency and process accuracy. The automated control unit can control units, such as feedstock feeding, sanitation, digester heating. Stirring, sediment removal and detection, separation, desulphurization and energy output. /1/

6.6.1 Measuring System

The monitoring system collects information on the parameters in the biogas plant. With this information optimisation can be carried out. The measuring system should monitor at least the type and quantity of feedstock, process temperature, pH value, gas quantity and composition, short-chain fatty acid content and filling level. /1/

7 BIOGAS AS A PRODUCT

In today's energy market, one of the most feasible solutions is to sell the produced biogas directly or indirectly to the consumers. This cuts investments on grid connection and electricity production equipment. Biogas can be sold directly to the consumer by selling it as transportation fuel or for heating purposes. Other possibility is to sell the biogas indirectly to a gas distributor company that sells it the consumer.

7.1 Transportation Fuel

Biogas has to be upgraded to biomethane and sold as a transportation fuel to obtain the best possible energy density. Biogas is still more expensive than natural gas in Finland but in areas that does not have a pipeline connection, biogas is a viable option. To sell fuel for transportation, a filling station should be built. This increases the investment costs but the gas can be sold at a bigger price per unit of energy compared to electricity or heat. Transportation fuel is not in high demand in Finland due to the chicken and egg problem and the small amount of gas powered cars. The infrastructure needs improvement but cannot be done without increase in demand. The increase in demand is slow because the infrastructure is not there. To make transportation fuel feasible, the right consumer sector has to be found.

7.2 Heat

Crude biogas can be sold or used to produce heat without being upgraded. Converting biogas into heat and selling it to the local district heating grid is a viable solution but the cost of district heating connection is expensive. Heat production is usually done with a CHP unit and the produced electricity is self-used and the excess sold. To make the investment cost smaller, the biogas can be used to produce only heat. This is done by burning biogas to heat circulating water. The heating can be done within the process cycle of the biogas plant or it can be produced at the estate that needs heating. Selling biogas for heating purposes is low investment but the price point of crude biogas is smaller than biomethane.

7.3 Biogas

Natural gas pipelines can be used to transport biomethane. This enables a way to sell the biogas as it is. By selling only biogas as a product, investment costs are lower because there is no need for power production equipment. Biogas can also be transported with trucks. This is done especially in regions where a pipeline connection is non-existent. In areas that methane is not widely in use as an energy source, selling the biogas may be trivial. Selling produced biogas as a product has one of the best cost efficiencies compared to other biogas products. Even crude biogas can be feasible.

8 RESEARCH METHOD

The methodology used in this thesis was the qualitative research method. The qualitative method is a research method that compiles multiple different source materials to study one or multiple phenomena. A Case study is a part of qualitative research method, where a premise or premises are being proved through selected samples. These samples can be collected through questionnaires, test groups or interviews. Qualitative research can also try to predict future happenings through premises collected in the research. This thesis tries to predict the possible feasibility and potential of biogas for KPO.

8.1 Data Collecting Method

The main sources for information were interviews with sales experts from biogas companies and with the managers from KPO. The topics for the interviews were amount of produced food waste, cost of biogas production equipment and the structure and basic operation of said equipment. The interviews were conducted by email and phone calls.

The numerical values given in the project parameters are rough estimates that were derived from official sources by the managers of KPO or collected from literature and online sources. Because of the nature of biogas, exact numbers cannot be collected or need sophisticated laboratories to obtain. Therefore, the given values should be considered as directional. The focus for the values was to justify the chosen technologies and to calculate the overall values for production of biogas and to analyse possible revenues. The literature references were collected from verified publishers and the equations used in the thesis were all compiled from literature mentioned in the references. The location specific information was collected from internet sources. These sources were the web sites for the local companies. Table 2 Shows the data collected from each interviewed person.

Table 2. The people interviewed.

Profession of interviewee	Company	Collected data	Date
Hotel Manager	KPO	Amount of food waste from restaurants	8.2.2018
Sales Engineer	Puxin	Cost and operation parameters of the Puxin biogas plant.	19.4.2018
Sales and customer service	BioGTS	Cost and operation parameters of the BioGTS system.	22.3.2018
Manager of Prisma	KPO	The amount and type of food waste collected from Prismas	16.4.2018
Development manager of market sales	KPO	The amount and type of food waste collected from S-markets and sales.	16.4.2018

The research was conducted in a chronological order where the previous information was used in the next research phase. Figure 7 shows the chronological flow of research and the research method design.

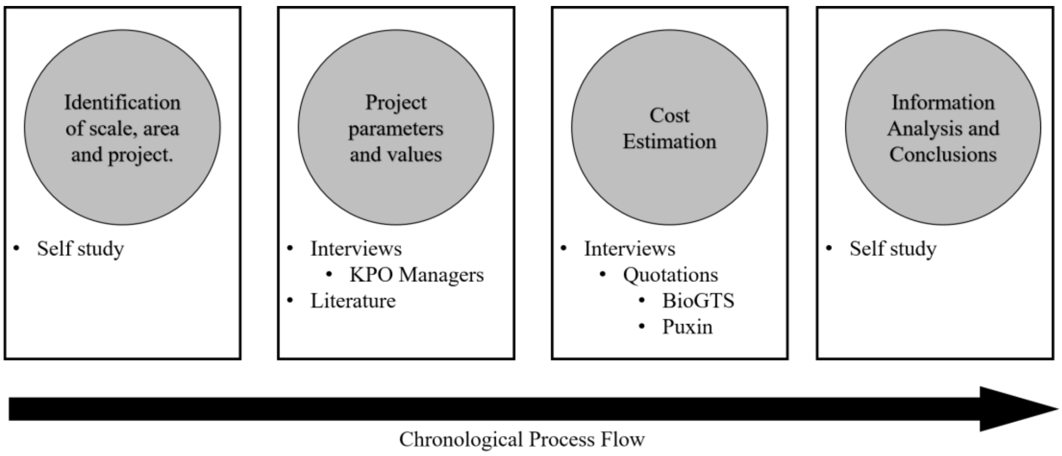

Figure 7. Research method design.

9 PROJECT PARAMETERS – CASE KPO

9.1 Bio matter

The collected bio matter for the biogas plant is mainly composed of food waste. These wastes include vegetables, different meats, grain products, coffee grounds and rice. The bio matter is collected from KPO restaurants and stores in the Vaasa-Kokkola axis and the Vaasa-Seinäjoki axis. These two main routes have four (4) big grocery stores – Prismas, 42 medium sized grocery stores - S-Markets and 34 small grocery stores – Sales. The routes also include 14 different KPO restaurants. On average the annual food waste is shown in Table 3. The two main routes are shown in Figure 8.

Figure 8. Two main collection routes.

Table 3. Total amount of food waste.

Source	Number of sources	Annual food waste per source	Total annual food waste
Prisma	4	100 000 kg	400 000 kg
S-Market	42	20 000 kg	840 000 kg
Sale	34	11 000 kg	374 000 kg
Restaurants	14	136 500 kg	136 500 kg
In Total	94	267 500 kg	1 750 500 kg

This creates a daily feed stock of about 3.9 tons. Part of the food waste in grocery stores goes to different charities that collect edible food for animals and people. Restaurants do not give food to charities, but some restaurant sell the leftover food with services, such as ResQ Club, but this is not taken into account in the amount of food waste due to difficulties in approximations. The amount of food that goes to charity depends on the type of food waste. The main food types that go directly to waste are fruits, vegetables, dairy products and restaurant leftovers. Table 4 shows three likely percentages of food waste that goes to charity and the amount that is left.

Table 4. The possible amounts of food waste after charity.

Source	Amount of food waste left if 50% goes to charity	Amount of food waste left if 20% goes to charity	Amount of food waste left if 30% goes to charity
Prisma	200 000 kg	320 000 kg	280 000 kg
S-Market	420 000 kg	672 000 kg	588 000 kg
Sale	187 000 kg	299 200 kg	261 800 kg
Restaurants	136 500 kg	136 500 kg	136 500 kg
In Total	943 500 kg	1 427 700 kg	1 266 300 kg

The restaurant supplies almost a constant amount of food waste. The food waste is mainly restaurant and kitchen left-overs. The restaurants are located in Vaasa, Kokkola and Seinäjoki. Table 5 Shows the restaurants and the weekly and annual food waste.

Table 5. The amount of food waste from restaurants.

Restaurants			
		Per Week [kg]	Per Year[kg]
Vaasa	Amarillo	175	9100
	Frans & Nicole	350	18200
	Kokokana	175	9100
	Rosso	175	9100
	Venn	175	9100
	Villa Sandviken	175	9100
	Wazaka	175	9100
Kokkola	Mustakari	175	9100
	Amarillo	175	9100
	Ravintola Kaarle	175	9100
	Rosso	175	9100
Seinäjoki	Rosso	175	9100
	Amarillo	175	9100
	Lakeus Matador	175	9100
	Total [kg]	**2625**	**136500**

9.2 System Requirements

The first step in the process would be the separator, which separates bio matter and unwanted products like plastics. The digester is sized according the following equation.

$$V_d = S_d * R_t \tag{4}$$

Where

V_d Size of the digester [m^3]

S_d The daily amount of feedstock introduced to the system [m^3/d]

R_t Retention time [days]

The digester would have to be at least 56,85m^3 to accommodate 3,9 tons of collected bio matter per day and retention time of 15 days. This is calculated by assuming that the bio matter is compressed and has a density of 1029 kg/m^3. /16, 17/

The size of the biogas storage is calculated according to the type of storage, theoretical gas production and average storage time. The average theoretical gas production is about 400-600m^3/d and the average storage time is four (4) days at minimum. The size should be calculated with bigger than average values. The biogas production is 500 m^3 and the storage time is seven days. With these parameters the size of the storage should be at least 3500m^3. Because the needed size the type of biogas storage should be the double integrity bullet tank. This is done so that the biogas can be compressed. The biogas storage can be significantly smaller if the biogas is directly used for heat and electricity production or if it is sold directly to a gas pipe.

The biogas plant also needs a post digester and digestate drying system. The drying system is needed to produce fertilizer that is easy to transport and sell. The sludge that is obtained from the digester usually has high water content and therefore efficient drying system is needed.

9.3 Theoretical Gas Production

Theoretical biogas production is calculated by parameters set by the bio matter and it is usually represented as the maximum biogas yield that can be obtained from the feedstock. The parameter that affects the production are dry matter content, organic dry matter content, methane production percentage, specific gas production per ton of bio matter and the amount of bio matter. Food waste has parameters shown in Table 6.

Table 6. The specific biogas production parameters for food waste. /18/

	Dry matter content (DM)	Organic dry matter content (oDM)	Maximum specific biomethane production (BMP)	Methane percentage ($\%CH_4$)
Unit	% of fresh material	% Dry matter	m3/t of organic dry matter	% of biogas produced
Food Waste	20	85	650	60

The given values are rough estimations, because food waste is composed of multiple different organic materials. This makes the values inaccurate. To obtain accurate values, the food waste should be studied in a laboratory. The values chosen for the calculation are average values for compressed food wastes.

The specific biogas production parameters are used to calculate the theoretical gas production. The dry matter content (DM) is the amount of solid matter in the bio matter and the rest is mainly water and other substances that do not produce biogas. Part of the dry matter is inorganic and therefore does not produce any biogas, the organic dry matter content (ODM) accounts for the rest. To calculate the matter that produces biogas the fresh feedstock has to be multiplied by the DM and ODM contents. From this organic dry matter, a specific amount of methane can be produced (BMP). The amount is dependent on production parameters and the type of bio matter used. The produced gas consists of methane and carbon dioxide. By dividing the methane amount with the methane percentage, the amount of produced biogas can be calculated. This value determines the energy content of the produced biogas. The amount of methane can be calculated with the following equation:

$$CH_4 = m_b * DM * ODM * BMP \quad (5)$$

where

CH_4 The amount of methane [m^3]

m_b The mass of bio matter [ton]

DM Dry matter content [%]

ODM Organic dry matter content [%]

BMP Maximum specific biomethane production [m^3/t of ODM]

The amount of produced biogas can be calculated with the equation:

$$V_b = \frac{CH_4}{\%CH_4} \quad (6)$$

where

V_b The total amount of biogas [m^3]

CH_4 The amount of methane [m^3]

$\%CH_4$ The percentage of methane in biogas [%]

The total amount of biogas is mainly methane and carbon dioxide and the maximum theoretical biogas production is the amount obtained in ideal conditions. Table 7 shows how much the annual production of biogas is if ideal conditions are met.

Table 7. The theoretical maximum production rates annually. /25, 26/

	50% of biomass to charity		20% of biomass to charity		30% of biomass to charity	
	Volume[m3]	Mass [t]	Volume[m3]	Mass [t]	Volume[m3]	Mass [t]
Biomethane	96 715.1	**63.4**	154 744.2	**101.5**	135 401.2	**88.8**
Biogas	161 191.9	191.1	257 907.0	305.8	225 668.6	267.6

The mass of biogas is the most important value when calculating the amount of energy that can be obtained from the biogas. It also determines the revenue from sold biogas. The most likely case is that from the total food waste 30% goes to charity. With this amount yearly methane production is about 102.5 tons and biogas production is 308.7 tons.

9.4 Cost Estimation

9.4.1 Puxin system

Puxin is a Chinese company that specialized in municipal micro scale biogas plants. Their customer base is mainly farm houses with small amounts of bio matter. The system chosen for cost estimation was the Puxin 20ft Container Anaerobic Treatment System. It consists of eight container enclosed AD systems and all the essential parts shown in Table 8. The system includes fertilizer drying system, desulfurizer system and a basic storage system. /19/

Table 8. Cost structure of the Puxin Container system.

Puxin - Container AD system	QTY	RMB	Euro	In Total
Waste shredder	2	¥10 200.00	1 317.7 €	2 635.5 €
Sewage Pump with a Knife	2	¥1 690.00	218.3 €	436.7 €
Container AD system	8	¥185 400.00	23 951.8 €	191 614.6 €
20ft Container room	1	¥54 000.00	6 976.3 €	6 976.3 €
Console	1	¥45 000.00	5 813.6 €	5 813.6 €
Dehydration 250L	1	¥9 500.00	1 227.3 €	1 227.3 €
Desulfurizer	1	¥12 500.00	1 614.9 €	1 614.9 €
Fe_2O_3 Desulfurizer pellets	200	¥2 000.00	258.4 €	51 676.0 €
Biogas storage bag 100m^3	1	¥14 450.00	1 866.8 €	1 866.8 €
Pressure Release valve	1	¥1 800.00	232.5 €	232.5 €
Biogas pump	1	¥15 000.00	1 937.9 €	1 937.9 €
Biogas pump	1	¥6 900.00	891.4 €	891.4 €
Ultrasonic biogas flow meter	1	¥7 200.00	930.2 €	930.2 €
Solid liquid separator	1	¥30 000.00	3 875.7 €	3 875.7 €
Sewage treatment system	1	¥332 763.00	42 989.7 €	42 989.7 €
Hot water circulation pump	2	¥9 300.00	1 201.5 €	2 402.9 €
CHP unit 20/22 kW	1	¥65 000.00	8 397.4 €	8 397.4 €
		¥802 703.00	103 701.2 €	**325 519.1 €**

The Puxin system is cheap and easy to construct. It is suitable for food waste and is specifically designed for the amount of bio matter produced by the companies in the area. Even though the system is cheap it does not include a plastic separator for pre-treatment of bio matter and it does not have an option for biogas upgrading unit. This could increase costs if critical parts break from the system. /19/

The negative aspects of the Puxin system are the availability of spare parts and the absence of plastic separator. The Puxin system is constructed in China and the spare parts are located in the same area. In the case of system failure due to spare part malfunction, the time that it takes to get the spare part and to fix the problem can be critical for monthly or even annual revenue. The Puxin system is not suitable for this project. The suggested CHP unit is much smaller that is needed for the project.

9.4.2 BioGTS system

BioGTS manufactures patented, factory-made biogas and biodiesel plants that allow for more profitable processing of biodegradable waste and biomass, as well as the generation of bioenergy. BioGTS is located in Finland. BioGTS was chosen for comparison and cost estimations because it is one of the leading biogas companies in Finland and it offers multiple different option for the biogas plants. The Table 9 Shows the cost of biogas plant that was chosen for the feasibility study.

Table 9. The cost breakdown of the BioGTS system.

BioGTS System	Cost
Biogas plant	2 096 000.0 €
Options	
CHP-Unit 137kW	307 782.0 €
Gas purification unit	287 000.0 €
High pressurising unit	68 900.0 €
Total (Transportation fuel)	**2 451 900.0 €**
Total (CHP)	2 403 782.0 €

The CHP unit is much bigger in the BioGTS system, but the initial investments costs are also much higher. The BioGTS system is made for large scale biogas production and technology and it is more suitable for the project. The investment costs are the main downside of the system. The profitability is better when selling transportation fuel compared to selling electricity. According to BioGTS selling biomethane to the transportation sector is more feasible. /22/

9.4.3 Heavy Machinery

The power plant needs regular introduction of fresh feedstock. To collect the bio matter from 93 different sources, a good solution is to buy a garbage truck. The cost of garbage truck can vary from 4000€ to 35 000€. Because the distances are long, it is recommended to buy a better equipped and more efficient garbage truck. The overall cost of a garbage truck is about 30 000€. This increases the total investment cost substantially. The distances also add up fast and the cost of fuel comes a critical cost parameter. Therefore, the employees should be trained in efficient driving and environmentally safe work ethics. /20/

9.4.4 Employee Costs

The biogas plant needs to be operated by a qualified person and the waste must be collected from previously specified area. These work phases can be combined and completed by one employee. The power plant needs at least one trained worker to ensure reliable working times and to minimize risks in operation. During summer and winter holiday's substitutes can be used. Table 10 shows the overall cost of one employee that collects the waste and operates the power plant. /21/

Table 10. The monthly cost of an employee to the employer. /21/

Base salary	€/month	2700		€/month
Pension contribution	%	18.95		511.65
Social security	%	0.86		23.22
Mandatory insurances	%	0.8		21.6
Unemployment fund	%	2.6		70.2
Holiday bonus	%	4.5		121.5
Other social expenses	%	2		54
Voluntary expenses	%	1		27
Social expenses	%	30.71		829.17
Employer expenses				**3529.17**

Yearly two employees cost 84 700€. This has to be taken into account when calculating the yearly cash flow from the power plant.

9.4.5 Total Cost Estimation

The total cost estimation is the sum of all investment costs. This includes the power plant, garbage truck, construction and transportation of parts. Tables 11 and 12 shows the total investment cost and project parameters.

Table 11. The total investment cost of Puxin system and operation parameters. /19/

MW and type	0.02	MW
Power Electricity	20	kW
Power Heat	22	kW
Annual kWh	175200	kWh
Annual Heat	192720	kWh
Total investment cost	**441 519 €**	
Puxin power plant	325 519 €	
Foundation and infrastructure	30 000 €	
Internal cables and grid connection	3 000 €	
Garbage Truck	30 000 €	
Permits/ Legal and Financing	3 000 €	
Transportation - Freight	50 000 €	
Availability rate	95 %	

Table 12. The total investment cost of BioGTS system and operation parameters.

MW and type		
Annual Biomethane	88 000	tons
Total investment cost	**2 487 900 €**	
Biogas Plant (Incl. Biogas purification)	2 451 900 €	
Internal cables and grid connection	3 000 €	
Garbage Truck	30 000 €	
Permits/ Legal and Financing	3 000 €	
Availability rate	95 %	

The power plant also needs to be operated around the year. This means that there are different operational expenses such as spare parts, employee salaries and operation costs. The annual operation and maintenance costs are shown in Table 13.

Table 13. Annual costs for the power plant.

Annual Costs		
Cost of one employee	43 500 €	per year
Annual operating expense %	3 %	of total investment cost
Insurance expense	0.30 %	of revenue
Management and administration	5.00 %	of revenue
Spare Parts Expense (Puxin)	3.00%	Investment cost
Spare Parts Expense (BioGTS)	22 000€	Annually

These parameters were used when calculating the feasibility of the project. As shown in the table the cost of transportation increases the total costs substantially.

9.5 Revenue

9.5.1 Digestate Sold as Compost Soil

A biogas plant produces composted soil as a by-product. The amount of soil depends on the amount of biogas produced from the digestate. If the soil is sold at 15€ per ton, revenues of 11 285€ to 16 828€ can be obtained. The amount of soil is dependent on the amount of food that goes to charity. Table 14 shows the amount of soil, the mass loss compared to fresh feed stock and the revenues.

T**able 14.** Amount of soil, the mass loss and revenue from digestate.

	50% of biomass to charity	20% of biomass to charity	30% of biomass to charity
Soil	752.4 tons	1121.9 tons	998,7 tons
Mass loss	20.3 %	21.4 %	21.1 %
Revenue from digestate	11 285.86 €	16 828.88 €	14 981.21 €

9.5.2 Puxin System

The Puxin system produces heat and electricity with a 20 kW CHP system. The system is run constantly through the year with only momentary maintenance breaks. The CHP system produces 175.2 MWh of electricity. Part of the produced energy is used to operate the power plant. Because the power plant is under 100 kVA it is not suitable for the feed-in tariff. The heat and electricity can be self-used. If the cost of electricity is 0.04 € per kWh and the transmission cost is 0.038 € per kWh and if the amount of food that goes to charity is 30%, the Puxin system would save 12 982.32€ annually from electricity costs. These savings can be considered direct revenues from the power plant.

The revenues are substantially lower that the annual costs. The revenue do not even cover the salary of one operator. The CHP unit is under scaled and the biogas cannot be sold for transportation. This creates a critical problem for the Puxin system. Even if the digestate is sold at 15€ per ton of soil creating cash flow of 16 828.88€ annually, the revenues are not high enough to compensate the basic costs. The main flaw of the Puxin systems is its lack of modularity. The company does notoffer any plastic separators or biogas upgrading units. For this reason, the Puxin system is not feasible and is not taken into account in the final feasibility calculations of the power plant.

9.5.3 BioGTS System

The BioGTS system is more modern and more efficient system compared to the Puxin system. The BioGTS system is also more suitable for a project of this scale.

The BioGTS system on average runs 8500 hours annually. The biogas plant produces 88 tons of pure methane. The methane can be sold at 1.45€/kg. Assuming all the biogas is sold at the current market price, the revenues of 87 333.5€ - 139 816.25€ can be collected annually. The total revenue is the revenue collected from the biomethane and the digestate. Because the revenue is much higher in the BioGTS system, it will be used in the final feasibility calculations.

9.6 Sensitivity Analysis

9.6.1 Best Case

The best case scenario has the biggest amount of food waste with the assumption that only 20% of food goes to charity. The biogas yield is also best possible at 650 m^3/ton of ODM assuming that the DM and ODM values stay the same. The investment grant is the maximum of 30%. With these values the BioGTS system produces annual revenues of 139 816.25€ from biomethane. The total annual revenues are 156 645.13€ which includes the biomethane and the digestate. The total expenses are 234 432 € annually. This includes the depreciation expense. The depreciation expense was calculated as a straight-line depreciation for 20 years for all the cases. The expenses cover the cost of one employee, spare parts, administrative expenses, insurances and operating expenses. The annual operating income (EBIT) is -77 787.03 € and the net cash flow of 9 289.47 €. This means that the biogas would make an annual profit. Table 15 shows the income statement for the first year of operation. Because biogas has a tax exemption when sold as an energy source, the income statement does not include taxes. /19/

Table 15. Income statement in the best-case scenario.

Income Statement	
Year	1
Revenue	156 645.13 €
Annual operating expense	74 637 €
Insurance expense	408.60 €
Management and administration	6 810.06 €
Depreciation expense	87 076.50 €
Spare part expense	22 000.00 €
Work Force	43 500.00 €
Total Expense	234 432 €
Operating income (EBIT)	-77 787.03 €
Net cash flow	9 289.47 €

The payback time can be calculated using the total investment cost with the grant and the net cash flow with the following equation:

$$Payback = \frac{Investment\ Cost}{Net\ Cash\ Flow} \tag{7}$$

The payback period in the best-case scenario would be 187.5 years. The calculation does not take into consideration possible costs for transportation and collection of organic waste.

9.6.2 Worst Case

The worst-case scenario has the smallest amount of food waste. The amount of food that goes to charity is 50%. This makes the amount of annual food waste substantially smaller. The biogas yield is small at 500 m^3/ton of ODM assuming that the DM and ODM values stay the same. In the worst-case scenario the power plant does not get the investment grant. The revenues collected from the biomethane are 67 222.00€ annually. The revenues from the digestate are 11 285.86€. The total annual revenues are 78 507.86€. Table 16 shows the income statement for first year in the worst-case scenario. The operating income is -193 242.80€ and the net cash flow -68 847.80€.

Table 16. The income statement for the worst-case scenario.

Income Statement	
Year	1
Revenue	78 507.86 €
Annual operating expense	74 637 €
Insurance expense	408.60 €
Management and administration	6 810.06 €
Depreciation expense	124 395.00 €
Spare part expense	22 000.00 €
Work Force	43 500.00 €
Total Expense	271 751 €
Operating income (EBIT)	-193 242.80 €
Net cash flow	-68 847.80 €

9.6.3 Most Likely Case

Most like case is that the average amount of food that goes to charity is 30%. The biogas yield is 650 m^3/ton of ODM assuming the DM and ODM values stay the same. The grant covers 20% of the total investment cost. The annual revenues from biomethane are 121 220€. The revenues from the digestate are 14 981.21€ annually. The total revenues are 136 201.21€ annually. Table 17 shows the income statement for the first year in the most likely scenario.

Table 17. Income statement in the most likely scenario.

Income Statement	
Year	1
Revenue	136 201.21 €
Annual operating expense	74 637 €
Insurance expense	408.60 €
Management and administration	6 810.06 €
Depreciation expense	99 516.00 €
Spare part expense	22 000.00 €
Work Force	43 500.00 €
Total Expense	246 872 €
Operating income (EBIT)	-110 670.45 €
Net cash flow	-11 154.45 €

10 CONCLUSIONS

The three different income statements all show one fact, the project would not be feasible. The high investment cost, cost of employees and operation, the low demand and price of biomethane and constrictions set by the project parameters all drive down the feasibility of the project. Under current project parameters the power plant would steadily lose money during its lifetime. The income statement does not take into account the costs from transportation. These costs include the operation and maintenance of the garbage truck and cost of fuel.

The amount of bio-waste needed to produce feasible amounts of biogas are much higher that can be obtained from the KPO companies. In the best-case scenario, the net cash flow is positive, but the payback period is still long. The main constraint is the distance between the collection points. The collection area should be minimized to one local producer to make the project feasible. The plastic separators, possible CHP units and gas purification systems increase the investment costs substantially. According to BioGTS sales person, the most feasible way to make a profit on biogas, is to sell the crude biogas to an energy company. This would degrease the investment costs and simplify the process. To summarize, the construction of a biogas plant for local KPO companies would not be feasible as it would create negative or minimal cash flows.

The thesis had some limitations of research. The main limitations were the poor return rate for quotations and the time limit. The thesis was a preliminary study on feasibility and had no correlation on actual project done by KPO. Because of the nature of the study most biogas companies did not send quotations for biogas systems. The biggest biogas companies with the most competitive prices usually get numerous quotations weekly regarding theses or school assignments and do not have the time and resources to answer every question. The number of received quotations was little which hindered the progress of the study. The other main limitation for research was the time limit. Because of the short schedule received quotations came very near to the end of the scheduled time and most quotations never arrived. The two quotations that came through were significantly different. The Puxin system was unsuitable for multiple reasons and the high investment costs of the BioGTS system both made the project unfeasible. With the most competitive price with the most suitable modular system, a biogas plant could in fact, be feasible.

Biogas is easy to produce and implement in many different energy structures. It excels as a transportation fuel and can be used to produce electricity and heat. These qualities make biogas a great transition fuel from fossil fuels to carbon neutral energy structure. The flexibility of biogas makes it one of the most interesting renewable energy sources in the future.

The rising demand of energy motivates companies like KPO to search for alternative energy production solutions. Biogas offers efficient circular economy, energy storing solutions and constant production of energy. In the Ostrobothnia region biogas and LNG are rising trends in the energy business, which increases the interest in biomethane. The methane based gases could be important pieces in the energy structure in the future. There are multiple different methane based project in the design phase or already running in Vaasa. This solves the chicken and egg dilemma that is often seen in biogas projects.

Biogas plant for the KPO company and its subsidiaries in the Vaasa-Kokkola-Seinäjoki axis could mainly be used for PR or in hope that the future methane price increases. Otherwise, it cannot be feasible due to long distances between the collection points and the small amount of bio-waste. The stores do not produce high amounts of bio-waste, contrary to what was thought before the study. Different efforts in reducing food waste have efficiently lowered it. To make a project like this to work with the same amount of biowaste, the collection points should be much closer together. The presence of Stormossen biogas plant also decreases the feasibility for a second biogas plant. At the moment building a biogas plant is highly costly and the revenues collected from the plant are minimal. The operation costs are much higher than the revenues. This means that the biogas plant would lose money when operated.

The main value for building a biogas plant is not the feasibility but the environmental, marketing and PR aspects. Today, renewable energy and environmental friendly solutions are popular trends and companies that value these trends tend to be recognized. By building a renewable energy source from food waste could make a company like KPO a forerunner of renewable energy in the restaurant and grocery store markets. The biogas plant would not make any money, but it would be recognized by the consumers and create interest in the company. Renewable energy is the future of energy production, but to get there, we need more innovations and new ambitious projects.

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