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Master thesis

Value-chain for organic waste
Production of biogas

MASTERS IN COMMERCIAL BIOTECHNOLOGY

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Acknowledgement

Abbreviations

AD:	Anaerobic Digestion
VFA:	Volatile Fatty Acids
OLR:	Organic Load Rate
HRT:	Hydraulic Retention Time
VS:	Volatile Substrate
Ni:	Nickel
Co:	Cobalt
Fe:	Iron
Fe^0:	Zero-valent iron
O:	Oxygen
Fe_2O_3:	Iron(III)oxide
Fe_3O_4:	Iron(II,III)oxide
GHG:	Greenhouse gases
ABE:	Acetone – butanol – ethanol
t	Tonne
SSB	Statistisk sentralbyrå
CNG	Compressed natural gas

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Abstract

Biogas / biomethane / biohydrogen production is a technology that will certainly have an even greater positive impact on the environment in the future than it has today. A biogas / biomethane / biohydrogen plant is a large and expensive investment and this work is an attempt to find a sustainable business model for such a plant in Innlandet. This work builds on a former report from Klosser AS using traditional technology and only local feedstock at current gate fees. That report showed that such a plant would operate at a loss. This work has therefore investigated new technology, additional sources of feedstock to use spare capacity of the plant, and finally the effect of increased gate fees. New technologies have the potential both to increase biogas production and to give new new products. In order for that to happen, a lot of effort is needed to overcome shortcomings that new technologies bring with them. Taking advantage of the spare capacity of a plant like that described in the report from Klosser AS has only a limited effect on the economy. In the short term, the only way to achieve economic sustainability for a biogas plant in Innlandet seems to be a substantial increase in gate fees.

1. Introduction

In today's modern world demand for energy is growing. In the last century, the industry met its needs almost exclusively by using fossil fuels, which are still dominant. However, people's awareness of the harmful effects of fossil fuels (greenhouse effect) has reversed this trend and today great efforts are being made to replace fossil fuels with renewable energy sources such as solar and wind energy, geothermal energy, biomass energy, tidal and hydro energy. Biomass is one of the oldest forms of energy that people have used since ancient times. Biomass is a renewable energy source that can be used for heating, turn into electricity, converted into biofuel, and many other uses. Biomass is of organic origin and contains plant and animal residues generated during production, waste generated in houses, plant species that are grown with the intention of being used in the process of conversion of a biomass, i.e. any organic matter that can be subjected by biological or chemical methods, so that energy or valuable products can be obtain from it (Roddy, 2013). In the future, biomass will likely play a key role in replacing the finite resources of fossil fuels. Primary biomass resources are plants that collect solar energy through photosynthesis and where carbon dioxide is converted into chemical compounds such as cellulose, hemi cellulose and lignin. The primary energy sources in addition to biomass are also solar energy, nuclear energy, wind and water energy, fossil fuels, where such forms of energy occur in nature. Biomass is the primary source for energy carriers, also called secondary energy sources, which are obtained by technological and biological transformation of biomass. Examples of such energy carriers are methanol, hydrogen, methane and ethanol (Claassen et al., 1999).

1.1 Biogas

The global problem of environmental protection, increased consumption of fossil fuels and unstable political situations in fossil-fuel-rich countries has led to the use of alternative energy sources. The development of renewable energy technologies also solves the problems that arise from the accumulation of organic waste (biomass) generated from industrial production as well as from households. Biogas is the mixture of gases produced by anaerobic digestion or by aerobic decomposition of biomass. Methane, which makes up the largest part of the gas mixture in biogas, can be used in industry as well as in homes for the production of electricity, heat, as a fuel for public transport and biogas can also be purified by removing other gases, i.e. upgraded to bio methane and connect to natural gas pipeline (Weiland, 2010a). For the production of biogas can be used various biological sources such as livestock manures originating from farms, residues from the wood industry that may originate from the furniture or sawmill industry such as wood chips, crops from agricultural lands, residues from the food industry, household waste, municipal waste and biomass from sewage treatment plants that contain high organic content (Biosantech et al., 2013) It is important to note that although it is possible to obtain biogas from almost any biological material, all types of biomass are not equally suitable for Anaerobic Digestion and composition of biomass affects the yield of biogas. Biomass that contains most lignocellulose, which is also the largest source of renewable energy (Chandra & Madakka, 2019), due to its crystal structure it is very hard for bacteria to digest lignocellulosic feedstock. If lignocellulose-rich feedstock is not subjected to pretreatment there may be a decrease in biogas yield (Patinvoh et al., 2017). The composition of biomass also determines both the speed at which bacteria digest raw materials and the speed at which bacteria reproduce so the anaerobic process can become very slow and economically unprofitable if the raw materials are not subjected to pretreatment (Patinvoh et al., 2017). The content of methane in the composition of biogas ranges from 50 -80% and depends on the substrates contained in the biomass as well as on the technologies used in Anaerobic Digestion (AD) such as co-digestion (Lora Grando et al., 2017). Impurities in the composition of biogas such as carbon dioxide, hydrogen sulfide, nitrogen, which affect the calorific value of biogas and transport cost, can be removed by biological and chemical methods (Adnan et al., 2019). By- products or what is left after AD is digestate, slurry mixture (Wei et al., 2020), a valuable resource that can be technologically treated and used as fertilizer (Tampio et al., 2016b).

1.2 Alternative technologies for using biomass as an energy source

Technological processes by which raw materials from biomass can be converted into thermal energy, electricity and biofuels can be divided into biochemical and thermochemical processes (Garba, 2020), as well as esterification of biomass (Wu et al., 2016). In addition to the above processes, biomass containing wood and agricultural residues can be pelletized (mechanical process without changing the chemical composition of biomass) by increasing the energy density of biomass and thus saving transport and storage costs. (Stelte et al., 2011). The processes of decomposition of organic compounds from biomass at high temperatures in the presence or absence of oxygen are called thermochemical conversions. The goal of thermochemical conversion of biomass is to obtain biofuels. Conditions under which thermochemical conversion takes place can be divided into pyrolysis, gasification and direct combustion (Tanger et al., 2013)

- The oldest technology for obtaining energy still used today in both developed and developing countries, is the direct combustion of biomass. Energy generated by direct combustion of biomass can be used for domestic heating as well as for cooking, which would be a traditional use of biomass. In industrial plants, the thermal energy obtained by direct combustion of biomass can be used to generate electricity or in a manufacturing process. The most commonly used feedstock in direct combustion is a wood biomass, but there are other natural materials such as agricultural residues, forest product residues and energy crops cultivated specifically to produce energy (herbaceous and woody crops). Combustion of biomass blended together with fossil fuels such as coal is a technology known as co-combustion or co-firing, reduce emissions of greenhouse gases and demand for fossil fuels (Sahu et al., 2014)

- Pyrolysis is the decomposition of materials of organic origin at a certain temperature without the presence of oxygen to produce gaseous products (hydrogen, carbon monoxide, carbon dioxide, ethane, propane and butane), liquids (tars and bio-oil) and solid products (bio char). The ratio of end products depends on parameters such as heating rate, pyrolysis temperature, and residence time. Based on these parameters, pyrolysis can be divided into slow pyrolysis, fast pyrolysis, and flash pyrolysis. The difference between slow and rapid pyrolysis is reflected on the final products (Dhyani & Bhaskar, 2018). Slow pyrolysis is a technological process where biomass is heated at a slow rate (below 10 C / min) at low temperatures and which is carried out if we want to produce bio char while the yield of gases and bio-oil generated in this process is reduced (Ronsse et al., 2013). On the other hand, if we want the yield of bio oils and gases to be higher than the yield of bio char then fast pyrolysis is performed (Bridgwater et al., 1999).

- Hydrothermal liquefaction belongs to a special form of pyrolysis of biomass that takes place in the presence of water, i.e. biomass that contains a large amount of water (Zhang & Chen, 2018). Although hydrothermal liquefaction is the technology suitable for processing wet biomass it should also be taken into account that biomass with high water content should be pre-treated to avoid high costs due to the complex technological process that would be used to remove excess water from the system (Gollakota et al., 2018). By using this technology it is possible to use a mixture of biomass (with high and lower content of water) from different sources, drying is not always required and thus there are energy and cost savings. The main product obtained with this technological process is bio crude oil which can be used for the production of bio fuel (Gollakota et al., 2018)

- Biomass gasification is a thermochemical process for obtaining products that have a higher value than biomass itself. Biomass gasification differs from pyrolysis because it takes place in the presence of oxygen. The mixture of gases obtained by gasification of biomass consists of carbon dioxide, hydrogen, carbon monoxide and methane and they can be used for the production of heat and electricity with help of gas turbines (Neubauer, 2013).

1.3 Anaerobic Digestions

Anaerobic digestion is a microbiological process of biomass decomposition that takes place in the presence of anaerobic bacteria. The absence of oxygen is necessary because the methanogenic bacteria involved in the process of anaerobic digestion are sensitive to its presence (Jarrell, 1985). During the AD process, a mixture of gases (biogas) is produced, that mainly consists of methane and carbon dioxide. Other gases like nitrogen and hydrogen sulfide are also present in biogas in small amount (Pourzolfaghar et al., 2014) By products or what is left after AD is digestate, slurry mixture (Weiland, 2010b), valuable resource that can be technologically treated and used as fertilizer (Tampio et al., 2016a). In the last few decades, AD is used on a large scale to treats various types of raw materials (biomass) for production of biogas, such as: municipal waste, agriculture residues, industrial waste, food waste, wood waste. Thus, anaerobic digestion not only recovers energy from the raw feedstock but also successfully removes waste and reduces pollution. Biological waste that is not subjected to the AD process in reactors intended for that, remains on landfills, undergoing anaerobic decomposition and emitting methane directly into the atmosphere contributing to global warming (Chynoweth et al., 2001). The whole process of biomass degradation is carried out by different types of bacteria and archaea (Amin et al., 2021) in four phases (Gujer & Zehnder, 1983a). The way in which biogas is produced is the result of a series of complex, synergistic processes of anaerobic microorganisms where biomass is decomposed into simpler substrates and the whole process involve four metabolic phases (Vavilin et al., 2008) :

- Hydrolysis
- Acidogenesis
- Acetogenesis
- Methanogenesis

1.3.1 Hydrolysis

The first phase of AD, called hydrolysis, involves the degradation of complex macromolecules into simpler compounds. At this stage, carbohydrates, proteins and lipids are hydrolyzed by enzymes secreted by bacteria to simple sugars, amino acids, fatty acids, compounds that have the property of dissolving in a solvent such as water (Gujer & Zehnder, 1983b). The process of hydrolyses includes several separate processes such as enzyme synthesis, adsorption on particles, reaction and deactivation of enzyme (Weiland, 2010b). Each enzyme secreted by bacteria during the hydrolysis process is specific in the sense that it is able to hydrolyze only a specific group of compounds. Breaking of peptide bonds in proteins occurs in a presence of enzymes called proteases. Hydrolysis of proteins to amino acids in the presence of enzymes secreted by anaerobic bacteria can be represented by a general scheme: protein > polymer> dimer> amino acids. Hydrolysis of carbohydrate macromolecules to simple sugars and dimers Equation 1 (Abbasi et al., 2012) , such as cellulose, is performed by enzymes belonging to the cellulase group. Problems that occur during lignocellulosic feedstock hydrolysis are caused by the presence of lignin and hemicellulose that physically and biochemically block cellulase activity (Álvarez et al., 2016). Lipases are also one of the digestive enzymes secreted by microorganisms during biomass hydrolysis. Their activity consists in breaking the ester bonds in lipids such as triacylglycerides (Berlemont & Gerday, 2011) , resulting in monoglycerides, diacylglycerides, glycerol and fatty acids Equation 3 (Moraleda-Muñoz & Shimkets, 2007). Lipids that can be found in high concentrations in wastewater or other feedstock originating for example from slaughterhouses represent a great potential for the production of biogas. Cirne et al., (2007) however, concluded that although we have a positive effect on lipid hydrolysis by the addition of lipase enzymes, the overall effect in biogas production is minimal, because during lipid hydrolysis high molecular weight fatty acids are formed and act inhibitory to AD. The breaking of the ester bond takes place in the presence of enzymes, acids or high temperatures and can be represented by a general equation 3 (Adlercreutz, 1994).

$(C_6 H_{10} O_5)n + n H_2 O \rightarrow n (C_6 H_{12} O_6)$
(1)

The cleavage of the protein peptide bond takes place in the presence of enzyme and water as shown in Equation 2 (Allen, 1981)

$$\begin{array}{l} \quad\;\; R_1 \quad O \quad H \quad R_2 \quad O \qquad\qquad\qquad\qquad\qquad\qquad R_1 \quad O \qquad\qquad\qquad R_2 \quad O \\ \quad\;\; | \qquad\quad\; | \quad\; | \qquad\qquad\qquad \text{ENZYME} \qquad\; | \qquad\qquad\qquad\qquad | \\ NH_2—CH— C —N— CH—C—OH \; + H_2O \; = \; NH_2—CH— C—O^- \; + \; {}^+H_3N—CH—C—OH \end{array} \quad (2)$$

$$\begin{array}{lcl} H_2C—O—CR{=}O & & H_2C—OH \qquad HO—CR{=}O \\ \quad | & & \quad | \\ HC—O—CR'{=}O & +3H_2O \; \xrightarrow{H^+} & HC—OH \; + \; HO—CR'{=}O \\ \quad | & & \quad | \\ H_2C—O—CR''{=}O & & H_2C—OH \qquad HO—CR''{=}O \end{array} \quad (3)$$

1.3.2 Acidogenesis

Further fermentation of the compounds formed in the hydrolysis phase continues in a process called acidogenesis. At these stage amino acids, simple sugars and fatty acids are fermented by anaerobic bacteria such as Syntrophobacter (Cai et al., 2016) to volatile fatty acids (VFAs), acetate, hydrogen and carbon dioxide (Gujer & Zehnder, 1983c). One of the limiting factors that determine the rate of acidogenesis is the oxidation of fatty acids where the rate of the chemical reaction is inversely proportional to the chain length (Loehr & Roth, 1968). A problem that can also occur at this stage is the acidification of the reactor due to the high concentration of volatile fatty acids. This problem occurs due to reactor overload. Low buffer capacity of mainly bicarbonate ion and high accumulation of volatile fatty, cause pH to drop which result in creation of toxic conditions that lead to the inhibition of methanogenic microorganisms (Akuzawa et al., 2011)

1.3.3 Acetogenesis

Acetogenesis is the AD phase where during the catabolism of fatty acids and alcohols carried out by acetogenic bacteria, hydrogen and acetate are produced (Stams & Plugge, 2009).

Acetogenesis requires a symbiosis of acetogenic bacteria and archaea because acetogenesis releases hydrogen that inhibits acetogenic bacteria, while archaea uses that hydrogen in the process of methane synthesis (Schink, 1997). This symbiosis between microorganisms is called syntrophy and in this case is associated with partial hydrogen pressure which must be maintained at a low level to maintain the activity of acetogenic bacteria (Thauer et al., 2008).

1.3.4 Methanogenesis

Methanogenesis is the last, fourth step in the catabolism of substrates produced in the previous three phases. Methanogenesis takes place exclusively in the presence of anaerobic archaea, which have the ability to conserve energy in the form of ATP in the process of methane synthesis (Borrel et al., 2013). In relation to the substrate used by archaea during methanogenesis, methane production can have three different metabolic mechanisms, involving three different groups of archaea. One of the most important groups of arachea when it comes to methane synthesis is acetoclastic methanogens which use acetate as a substrate for their growth and where methane is produced as a by-product of the enzymatic reaction during acetate metabolism (Ferry, 1992) . The second group of methanogenic archaea includes hydrogenotrophic methanogens that use hydrogen and formate to reduce carbon from carbon dioxide to methane (Bapteste et al., 2005). Substrate like trimethylamine, methyl sulfides and methanol are converted to methane in the presence of methylotrophic methanogens, which belong to the third group of methanogenic archaea that are able to transform methyl group using enzymes into methane (Liu & Whitman, 2008). It should be noted that archaea is not able to use formate as a direct substrate for methane production but must oxidize it to carbon dioxide with the help of enzymes belonging to the group of formate dehydrogenases (Liu & Whitman, 2008). Conversion of methanol to methane take place in the presence of hydrogen (Dridi et al., 2012) while the conversion of methyl amine to methane is catalyzed by methyl - coenzyme M (Shima & Thauer, 2005).

1.3.5 Temperature

The complex biological processes that take place in the four phases during the decomposition of biomass in the AD process depend on the operating temperature of the digestive reactors. The diversity of microorganisms in reactors and conditions under which AD is performed are closely related, i.e. whether AD takes place under mesophilic or thermophilic temperatures (Levén et al., 2007). Thermophilic conditions positively affect the yield of biogas (Varel et al., 1980), however when the temperature of reactor is increased to 65 °C., that leads to reduced activity of methanogenic bacteria in phase 4 of AD , accumulation of VFA, indicating reactor imbalance (Ahring et al., 2001). Chae et al., (2008) showed that even small temperature changes have a remarkable effect on gas yield and on the activity of complex microbial communities, and that a temperature drop of only a few degrees can lead to a sharp decrease in gas yield. It should also be considered that although thermophilic operating conditions lead to an increase in gas yield, the energy costs required to maintain the thermophilic temperature as well as the increase in ammonia concentrations that acting as an inhibitor for growth of methanogenic bacteria ,suggest that the whole process must be well harmonized (Sung & Liu, 2003).

1.3.6 pH

Bacteria and archaea that participate in the formation of methane are very sensitive to changes in pH, and very small changes can affect their metabolism, growth and thus to reduced biogas production. Methanogenic archaea, which participates in stage 4 of AD, is particularly affected by high concentrations of ammonia, an AD inhibitor that is causing the accumulations of VFA and pH drop. The changes that occur if the pH decreases to e.g. pH 5.5 are more than unfavorable for their growth (Latif et al., 2017), while pH 7 favoring the growth of methanogenic microorganisms(Agdag & Sponza, 2005) . Hydrolysis of biomass is optimal in acidic conditions in the range of 5.5 -6.6 pH (Heo et al., 2003), and further decrease in pH is reflected in reduced substrate production for further fermentation due to enzyme inactivation (Doran, 2013). The conditions in which acidogenesis takes place are quite similar to the conditions of hydrolysis and the optimal pH in which the acidogenesis bacteria are most active is around pH 6 (Yu & Fang, 2003). One of the most important factors for maintaining a constant pH corresponding to AD conditions is the buffer capacity, which in this case represents the bicarbonate and carbon dioxide buffer system (Lin et al., 2013). The concentration of bicarbonate can be adjusted artificially to maintain pH, for example by adding sodium bicarbonate or by selecting several types of raw materials for a special form of AD called co-digestion, achieving a balance that increases biogas yield (Gaur & Suthar, 2017). Variations in pH can either inhibit or favor the growth of methanogenic and fermentation bacteria, and the optimal environmental pH for methane production is in the range of pH 6.5 - 8.5 (Weiland, 2010c).

1.3.7 One and Two Stage Anaerobic Digestion

The oldest and simplest system of anaerobic digestion used to remove organic waste consists of a single reactor (one stage AD) in which anaerobic bacteria decomposes waste into four phases. Conditions in one stage reactor in which AD occur are not always ideal for all microorganisms species responsible for the decomposition and conversion of waste into biogas in four phases but the process can be controlled and optimized for the most sensitive phase, methanogenesis , in which arachea participate (Ziemiński & Frąc, 2012). Biogas yields in one stage reactor depend a lot on factors such as OLR (organic load rate) and hydraulic retention time (HRT). The OLR is an important variable that tells us the amount of biomass we can process per unit time (g / L-d) in the reactor. The OLR placed in the reactor must contain a sufficient amount of Volatile Substrate (VS) to produce VFA, and if the reactor is overloaded with VS there would be an accumulation of VFA and methanogenic bacteria that do not grow at the same rate as acidogenesis, would be inhibited by pH drop (Aslanzadeh et al., 2014) Also one of the very important factors that determine the efficiency and economic profitability of one stage AD is hydraulic retention time (HRT), which represents the time that microorganisms and biomass spend in bioreactor (Shi et al., 2017a) Short HRT has a major impact on gas yield because bacteria's involved in methanogenesis must have sufficient time to grow and degrade substrates, and longer HRT is necessary to try to achieve optimal operation condition (Shi et al., 2017b). OLR and HRT are two interrelated parameters that affect biogas yield. OLR increases with decrease HRT brings the reactor into a state of instability, and result of such condition is decreased gas production (Aramrueang et al., 2016). The biogas plant in one stage (**Figure 1**) consists of one digester which is constantly fed by the substrate from the substrate reactor and where all four phases take place in it (Xiao et al., 2018). The frequency of feeding the reactor with the substrate is extremely important for the gas yield because it is better to distribute one amount of substrate that is introduced into the digester in several smaller portions than to put the whole amount at once (Svensson et al., 2018). Adverse conditions of AD that occur during the digestion of biomass in one stage AD is possible to overcome with AD in 2 stages. Two stages AD takes place in 2 separate digestive reactors where hydrolysis and acidogenesis take place in the first reactor, while methanogenesis takes place in the second reactor (Schievano et al., 2014)By separating acidogenesis and methanogenesis, it is possible to control the conditions corresponding to acid bacteria in the first reactor, and by controlling process condition in the second reactor it is possible to improve kinetics of methanogenesis , thus achieving higher biogas yield better than in the one stage AD (Kunte et al., 2004). The two-stage AD plant (figure 2) consists of a substrate reactor and two separate digesters where hydrolysis and acidogenesis are separated from acetogenesis and methanogenesis, achieving better system stability which leads to a higher gas yield of 6 to 8 percent than with a single digester.

Figure1. Biogas plant with one digester (one stage)

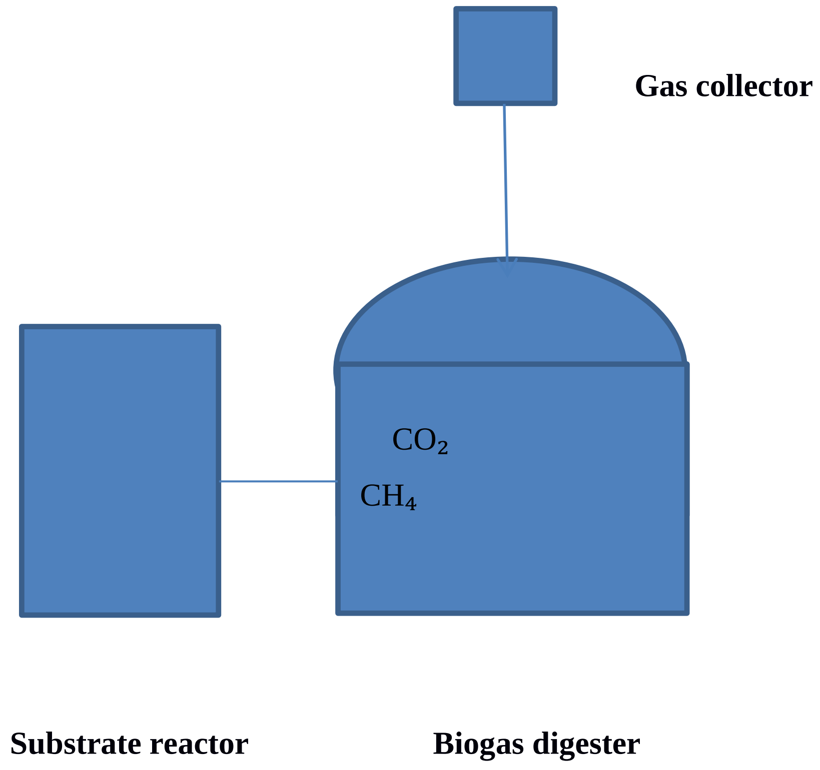
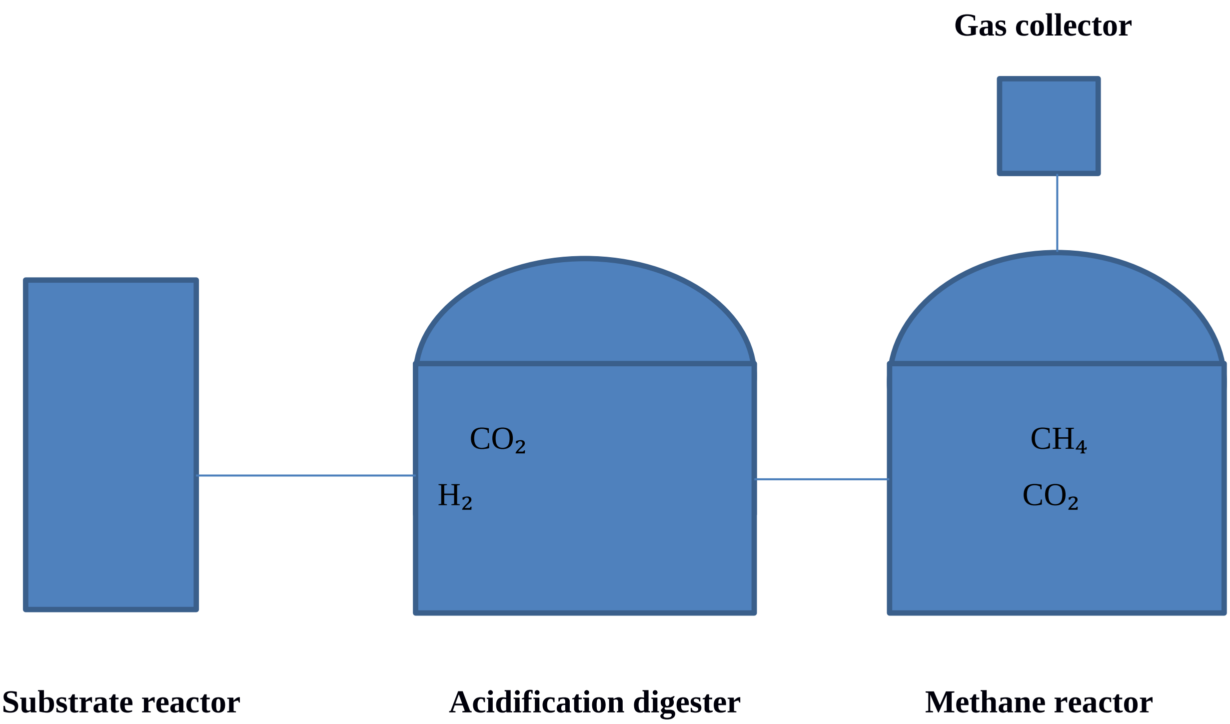


Figure2. Biogas plant with two digester (two stages)



1.4 End report for project Hedmark biogas

The main objective of the End report for project Hedmark biogas was to define obstacle and possible economic viability of the biogas plant in Innlandet. This report relies on another report that has started in the fourth quarter of 2019. The report was to consider whether to invest in a biogas plant with or without sewage sludge treatment as well as to consider more comprehensive economic aspects of possible investments, business model as well ownership model. Also, the report should have considered more comprehensively the possibility of selling carbon dioxide, which is one of the by-products of AD, as well how much money needs to be invested for an investment. Some objects in the report that needed to be addressed in more detail such as a possible ownership model, intensive discussions with potential partners, were affected by the outbreak of the pandemic and were not covered in detail in the report as envisioned. A possible investment for a biogas plant is considered with or without sewage sludge processing, where the plant was to process livestock manure, household waste, industrial waste and sewage sludge(in the case of plants with sewage sludge treatment). The investment for sewage sludge treatment was 30 million kr more expensive. Also, the plant with sewage sludge treatment is more demanding to manage, requires more manpower and the sludge treatment process itself consumes more energy but biogas yield is higher. The scenario involving a plant with sewer sludge makes a difference of 6.9 million kr in earnings due to gate fee and higher biogas yield. Maintenance of such a plant also requires additional costs, filter cleaning, energy consumption is higher, more employees costs for sludge transport, and the difference in maintenance costs is 4.2 million kr. However, in both scenarios, a plant with or without sewage treatment doesn't cover the investment. Possible solutions for the plant ownership model were only copied from the previous report because none of the law firm that was contacted responded to the project's inquiry. In the commentary on the ownership model, it can be seen that the private or communal ownership model depends on many factors such as the amount of waste that can be treated, whether the waste is obtained from other communes or private business, leaving the recommendation for deeper consideration. The report also mentions scenarios that had a positive cash flow. The scenario where a plant with or without sewage sludge would receive waste from SØIR was also considered, and the results showed that it is theoretically possible to generate revenues of 0.3 million kr with a sewage sludge plant. The report also deals with the scenario where biogas is produced only from livestock manure. The solution for one such plant would be provided by the company Antec biogas, which has its own technology and which provided solutions for multiple projects. However, even in this scenario with positive operating profit it is not possible to pay off the investment. Consulting firm Multiconsult helped analyze a possible scenario where the factory would sell carbon dioxide, which is a by-product of biogas production. The conclusion was that with today's technology it would not be possible to cost-effectively produce carbon dioxide given the small amount of CO_2 that would be produced in the plant. The conclusion of the commission that participated in this project is that it is not possible to profitably produce biogas if we take into account the raw materials found in the region. Possible solutions that could lead to profit and return on investment would be machine leasing, plant financing without credit, revenue from increased fees and other revenues.

1.5 Aim of the study

The aim of this study is to create a business model for the future biogas processing plant and to see what are the elements that could affect the economic stability of the future plant. The specific objectives of this study are:

1. What are the new technologies' for biogas / biohydrogen production that could affect the economic stability of the plant.

2. Search for alternative products that can be obtained from biomass that are used today for biogas production

3. Map available biomass sources in Innlandet County.

4. Estimate the impact of gate fee and available biomass on the economic stability of the plant

2. Material and Methods

The method of data collection in this study was secondary, which means that the data sources in this study used data that had already been published and that were collected by researchers for their research. The literature used in this study was found in a database of websites such as ScienceDirect, National Center for Biotechnology and Google scholar. In addition to the literature sources listed above, company reports were also used, as well as End report for project Hedmark biogas by researchers from Klosser Innovasjon. The tool used to describe the suggested business model is Osterwalder and Pigneur's business model canvas. The details of it will be evident from its use in the methods chapter. Work with budgets for the biogas plant followed the template used by the report from Klosser AS.

3. Results

3.1 The effects of nanoparticles on fermentation

Efficient and economically viable production of biogas in the AD process, in addition to converting biomass into fuel (bio methane) and fertilizer, plays an exceptional role in reducing the hazardous impact of biological waste on nature. The biogas obtained in the AD process is the result of complex relationships of microorganisms involved in the decomposition of biomass. If conditions are not conducive for the joint work of microorganisms, biogas yields are reduced and in some cases unfavourable conditions can lead to complete failure of AD. The last few decades have been filled with efforts to find technological solutions for AD that would increase biogas yield and quality. In addition to many factors influencing the AD process such as digester temperature, HRT, biomass composition etc., the addition of metals such as iron, cobalt and nickel to the digester in low concentrations make a great impact on methanogenic bacteria and thus on biogas yield (Goswami et al., 2016). The last couple of decades have been marked by nanotechnologies and their application in medicine, pharmacy and biotechnology.Utilization of nanotechnology in biogas production especially attracting the attention of scientists, especially metal nanoparticles. The effects of Fe on AD have been studied extensively because Fe is a cofactor of enzymes secreted by microorganisms involved in methanogenesis (Kaster et al., 2011). Liu et al. (2012) studied the effects of Fe^0 nanoparticles on acidogenic reactor in a two stage AD, wherein the Fe^0 concentration was 20,000 ppm at a psychrophilic temperature in reactors. In this study, both reactors, acidogenic and control reactor had HRT in the range of 6-2 h as well as the same ORL (3000 mg / l). The study noted that at the same HRT of 6h and 4h in both reactor, the reactor with the addition of Fe^0 and control reactor, the removal of COD is not the same, but in the reactor with Fe^0 nanoparticles is higher, i.e. after HRT of 6 hours the COD in the control reactor was 1600 ppm, while in the reactor with Fe^0 it was 1400 ppm. The concentration of propionate in acidogenic reactor with added Fe0 nanoparticles was lower than in the second reactor (without Fe^0), and after transferring effluents from both reactors into the two separate methanogenic reactors, Liu et al. (2012) noted a higher biogas yield in the methanogenic reactor with Fe^0 effluent. By analysing the composition of microorganisms in both acidogenic reactors, authors found that the reactor with added Fe^0 nanoparticles had a higher number of microorganisms responsible for acetogenesis and acidogenesis than in reactor without Fe^0. An experiment conducted by Lizama et al. (2019) was to determine the effect of Fe^0 on AD of sewage sludge. The size distribution of Fe^0 was in the range of 40–60 nm and three different Fe^0 concentrations were used in the samples.Lizama et al. (2019) also performed a comprehensive analysis of all important AD parameters such as pH, ORP etc. to determine what effect the addition of Fe^0 has on digester efficiency. The results obtained by Lizama et al. (2019) showed that the highest biogas yield was in the sample having a Fe^0concentration of 9 mg / gVS and where the biogas yield after forty days of digestion was 135% higher compared to the control sample without Fe^0. By analysing the composition of biogas, Lizama et al. (2019) found that the percentage of methane in the sample with added 9mg / gVS Fe^0 increased by ~ 185% compared to the control sample. Lizama et al. (2019) explained the increase in methane yield by the influence of Fe^0 on AD. Fe^0 is not the only nanoparticles that have impact on AD. Abdelsalam et al. (2016a) studied AD of cattle slurry manure and influence of nanoparticles such as Ni, Co, Fe_2O_3 and Fe^0 on biogas and methane yield. Metal concentrations was not randomly determined and it was based on an experiment performed by (Abdelsalam et al., 2016b) prior to this experiment. After the experiment, the impact of nickel (2 ppm) nanoparticles on biogas production after 5 days was greatest, and it should be noted that other digesters with metals added in the form of nanoparticles had a higher biogas yield than the control digester without nanoparticles. On the other hand, the digester with manure and added Fe_3O_4 20 ppm nanoparticles, on average in the first five days of AD had the highest methane content in biogas of 31.79%. Abdelsalam et al. (2016) also noted that the methane content in the biogas was highest between 24 and 26 days, approximately 79% in the digester with Fe_3O_4 nanoparticles. However, Abdelsalam et al. (2016) found that the cumulatively highest amount of methane and biogas after completion of AD was in the sample with added 2 ppm Ni nanoparticles. Strong effect of metal nanoparticles on AD and visible changes in biogas yield and microbial community composition has been confirmed in many other studies (Yin et al., 2017 ; Baek et al., 2014). Iron as a cofactor of almost all enzymes that promote the growth of methanogenic microorganisms (Zhou et al., 2014) is also of a great importance in the removal of hydrogen sulphide. Hydrogen sulphide is formed in the absence of oxygen in digestive reactors containing biomass rich in sulphur compounds in the presence of sulphate and sulphur reducing microorganisms (Okoro & Sun, 2019). Hydrogen sulphide is a gas that in addition to being an inhibitor of methanogenesis, its presence in high concentrations increases the cost of refining biogas, and hydrogen sulphide corrosion in the system leads to very expensive system components (Huertas et al., 2020). Fe^3 ion is also inhibitor of methanogenesis in higher concentrations by affecting enzyme function and by disrupting metabolic cycles. (van

Bodegom et al., 2004). (L. Zhang et al., 2009) demonstrated that a Fe^{3+} ion concentration of 21 ppm added to sewage leads to a drop in methane yield of up to 80 % and decrease in sulfate reduction. Iron is not the only metal necessary for the growth of methanogenic bacteria and for the successful conversion of biomass to biomethane. Metals such as nickel, molybdenum, cobalt, zinc are also very important trace elements a lack of which can lead to poor biogas yields, noting that their roles in such a complex system as biomass have not yet been fully elucidated (Demirel & Scherer, 2011). Nanoparticles will undoubtedly be of great importance in the production of biogas and therefore great efforts should be made to elucidate the mechanisms of their complex influence on microorganisms involved in methanogenesis as well as on enzymes. The use of nanoparticles in large-scale production should be cost-effective and therefore technologically viable nanoparticle synthesis processes must be found. In the near future, we can expect metal nanoparticles to be designed on such a way to improve the digestion of lignocellulose, which due to its complex structure has very poor digestion and which is the most abundant raw material on the planet.

3.2 Dark Fermentation

The use of hydrogen as an energy source in recent years has attracted increasing attention both due to the greenhouse effect and due to limited fossil fuel reserves. Especially interesting is the use of hydrogen as a fuel for vehicles with internal combustion engines due to zero emissions, i.e. when hydrogen is burned, water and heat are released, and heat is used to power the engine. It is especially important to point out the energy density of hydrogen, which is 120 MJ / kg and which is more than twice as high as carbon based fuels. Although hydrogen is the most abundant element on earth, it is found mainly in the form of compounds and in a very small percentage in its elemental state in the atmosphere. One of the most important things in hydrogen production is the cost of production. Many hydrogen production technologies are known for a while and many are also being developed to reduce production costs. One of the oldest and most common technologies for obtaining hydrogen is methane steam reforming, which accounts for half of the world's hydrogen production (Basile et al., 2015). In the last decade, attention has focused on production of hydrogen from renewable energy sources through biological processes such as photofermentation and dark fermentation. Due to the time constraints of this master thesis, I will briefly mention that the biggest problem with photofermentation is the hypersensitivity to oxygen of the enzyme hydrogenase secreted by photosynthetic bacteria, which makes the process of obtaining hydrogen very technologically complicated (Hallenbeck & Benemann, 2002). Dark fermentation is a process for production of hydrogen and other products such as butyrate acid from various organic feedstock (crop residues, lignocellulose raw materials, etc.) without the presence of oxygen and light (Łukajtis et al., 2018). Dark fermentation is a process that is still at an early stage when it comes to large-scale hydrogen production, however great efforts are being made to improve the process itself not only due to the production of valuable substrates but also due to the ecological way of bio waste disposal. The biggest disadvantage of dark fermentation is the very low hydrogen yield because it is very difficult to maintain the conditions in the reactor that favor the production of bio hydrogen. Bacteria that produce bio hydrogen in the DF process grow under conditions without the presence of light on substrates containing carbohydrates (Masset et al., 2012). Hydrogenases are enzyme responsible for both the oxidation of hydrogen to protons and the reduction of protons to hydrogen (Levin et al., 2004). Some bacteria that are able to produce hydrogen are strictly anaerobic such as Clostridiaceae family (Taguchi et al., 1995) while some bacteria such as Enterobacter aerogenes, which are also able to produce hydrogen are resistant to the presence of oxygen because they are facultative anaerobes (Davin-Regli & Pagès, 2015). Although it has been proven that anaerobic bacteria can produce hydrogen even when they are in the stationary phase (Mu et al., 2014), Clostridium species produce hydrogen to the highest degree while growing (Kapdan & Kargi, 2006). The theoretical yield of 4 moles of hydrogen during the fermentation of one mole of glucose is possible only if the metabolic pathway is such that acetic acid is obtained as the final product in addition to hydrogen (Equation 4) (Hawkes et al., 2007).

$$C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2 \quad (4)$$

However, conditions in the reactor such as HRT, pH and hydrogen partial pressure can lead to other metabolic directions where the final product is not hydrogen , so the final hydrogen yield is always lower than theoretical (Khanal et al., 2004). If the fermentation conditions are such as to favor the production of butyric acid as the final fermentation product in addition to hydrogen then the maximum yield is 2 mole of H_2 (Equation 5) (Hawkes et al., 2007).

$$C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2 \quad (5)$$

Hydrogen production by fermentation can be carried out using only one type of bacteria, i.e. with pure culture or by using several types of bacteria (Elsharnouby et al., 2013). Although it is possible to achieve a higher yield of hydrogen by using pure culture than with mixed culture, energy cost should be taken into account, i.e. the costs that need to be invested to maintain sterile conditions (D.-J. Lee et al., 2011). The advantages offered by the use of mixed culture are a variety of pretreatments that are not expensive and that are effective in removing microorganisms that use molecular hydrogen in their metabolism as a source of energy (Pachapur et al., 2016). Pretreatment such as heat shock or acid/base pretreatment are one of the effective ways to suppress activity of methanogenic bacteria (H. Zhu & Béland, 2006). In their work Cui & Shen, (2012) showed that pretreatment of grass with hydrochloric acid gave better results in hydrogen yield than raw material that was not subjected to chemical pre-treatment. The yield of hydrogen obtained by pretreatment of grass with sodium hydroxide was far lower than pretreatment with acid in the same experiment (Cui & Shen, 2012). Acid and base pretreatments has been also confirmed in many experiments as a successful method for better hydrogen yield (Wang & Yin, 2018; K. Zhang et al., 2011),but it also raises the cost of production because it is necessary to have equipment that is resistant to corrosion, there is a problem of disposal of waste generated by pretreatment and the appearance of compounds that act as inhibitors to bacteria that participate in hydrogen fermentation (Bundhoo et al., 2015). HRT is also one of the essential parameters that must be controlled to ensure the best possible hydrogen yield. Z.-P. Zhang et al., (2006) obtained a higher hydrogen yield by reducing HRT from 8 to 6 hours which they explained by eliminating the bacterial population that negatively affects hydrogen yield. Laurent et al., (2012) demonstrated that by reducing the partial pressure of hydrogen above the solution in the bioreactor has a positive effect on hydrogen yield and that the increase in partial pressure has an inhibitory effect on the dark fermentation process. Hussy et al., (2005) showed that the negative consequences of increased partial pressure of hydrogen can be eliminated by nitrogen flushing of bioreactors. Conditions in which bacteria can produce hydrogen can be both mesophilic and thermophilic, and due to a very complex fermentation process where there are many variables that affect hydrogen yield from the literature itself it is very difficult to conclude what is the ideal temperature range that favors fermentation (Guo et al., 2010a). K.-S. Lee et al., (2006) showed in their experiment where fermentation was carried out at 4 different temperatures in the range of 30-45 c that the highest yield was at 40 C, but also that at 45 C there was inhibition of fermentation due to denaturation of essential bacterial enzymes. The simplest reactors used for hydrogen production are batch reactors which are used to discover the best fermentation parameters as well as to determine possible hydrogen yields for a different types of substrates (Guo et al., 2010b). The advantage of the batch reactor is low cost, biomass is put at the same time together with the inoculum in the bioreactor with all necessary nutrients and nothing more is added to the reactor until the process itself is completed (J. Zhang & Smith, 2004). The downsides of the batch bioreactor is the time that it takes for the reactor to be prepared for the next load because the reactor needs to be cleaned, i.e. there is no constant inflow of raw materials into the reactor (Jornitz et al., 2011) and production must be stopped until the reactor is brought to condition in which it was before the first load. When it comes to hydrogen production, the most commonly used bioreactors are continuously stirred-tank reactors (CSTR), which differ in size from methane digesters that are larger in volume due to longer HRT (Jung et al., 2011). The advantages offered by CSTR are good contact between the enzymatic bacteria and the substrate, because the bacteria are suspended in the reactor, while good control of parameters such as pH and temperature are also possible (Show et al., 2011a). One of the advantages of continuous stirred reactor is also reflected in the reduction of the partial pressure of hydrogen, which leads to a higher yield of biohydrogen (C. Li & Fang, 2007). The problems that occur with CSTR reactors are a consequence of the short HRT and the production can fail (biomass washout) due to bacteria that grow very slowly and that participate in DF (Show et al., 2011b).

3.3. Available biomass for biogas production in Innlandet

According to Solberg et al., (2021) the area occupied by forests in Norway represents 33% of the total area. Of the total forest resources located in Norway, the county Innlandet has the largest wood resource a total of more than 50% (Hagos, 2016). Three species of trees dominate in Norway and make up 90% of all other trees found in Norway, namely spruce, pine and birch (Nibio, 2021). The production of biogas, ethanol and other biofuels from lignin-rich biomass is possible, but the cost of pretreatment and the current technology are obstacles that must be overcome in order to achieve production that would be economically viable.

According to the Sandberg, et al., (2020), the total value of the meat industry was 19 billion crowns in Norway. The authors also explained that these are not absolutely accurate results but that the value is within these limits. According to the authors of the report, Innlandet County has a total of 11 percent of the total number of meat industry employees in Norway, and based on that, it can be easily concluded that the value of the meat industry in the Innlandet district is approximately 2 billion kroner. The authors also stated that a part of the waste from the meat industry is exploited, but a huge part is not used. Meat processing waste is 40% according to the authors, and therefore a great potential for bio waste processing lies in the processing of residues from the meat industry. Due to the time constraints of the master thesis, it was not possible to analyze the data for each individual factory in the meat industry in a deeper and more precise way in order to find exact data.

The TINE annual report showed that organic industrial waste which remained after their production was 12,564 tons for whole Norway in 2018. TINE is the dominant chain of dairies in Norway. The figures given in the report according to TINE are not exact when it comes to organic waste. The TINE annual report from 2018 did not include data on the amount of organic waste for individual counties in Norway. On the website Statistisk sentralbyrå (SSB) one can find information that on 01.03. 2021, the total number of dairy cattle in whole Norway was 213190 and at the same time, Innlandet had 37758 dairy cattle. The total amount of organic waste from TINE dairy for Innlandet County is:

$$12564\ t : 213190 = X : 37758$$

$$X = 2225.2\ t$$

Where,

213190 Number of dairy cattle in whole Norway

37758 Number of dairy cattle in county Innlandet

12 564 t Organic waste for whole Norway

2225.2 t Organic waste for Innlandet

In addition to the previously mentioned biomass that could be potentially available for fermentation, in Final report for project Hedmark biogas" other available raw materials are listed (Table 1).

Table 1 - Other available raw materials in District Innlandet

Raw materials	**Volume (t)**
Sewage sludge	5533
Manure	67000
Potato	6080
Waste from households GIR	2220
Industrial waste*	2840

*: This may include some of the feedstock described above.

3.4. Sustainable business model

3.4.1 Business Model Canvas

One of the objectives of this master thesis is to develop a sustainable business model for a biogas plant in Innlandet. The results obtained in this chapter reflect my previously limited knowledge of the biogas business, the limited time to expand the knowledge as well as the limited information contained in End report for project Hedmark biogas on the basis of which the business model was to be created. The business model used in this chapter is Osterwalder and Pigneur's business model canvas, an extremely popular tool that can help all parties directly or indirectly involved in a business or future project to understand the way the business is conducted and to visualize the relationship between all the elements involved in this model. The business model canvas can be applied to a company that sells biogas as main product and to a company that sell biomethan obtained from biogas because the activities and technologies that would be implemented into these two companies are very similar.

The customer segment can be divided into two basic groups. In the first group we can classify customers who are not primarily interested in the product that biogas plant sells, but pay for the disposal of waste that can be fermented into biogas / hydrogen. This group includes municipalities, wastewater treatment companies, industries that produce large quantities of bio-waste materials during production as well as construction and demolition companies. They are more interesting in the price of waste disposal but disposing waste in the landfill would lead to uncontrolled fermentation, releasing biomethane that would go directly into the atmosphere. The second group consists of customers who are interested in the product such as transport companies that use biogas / biohydrogen as fuel, customers who are willing to pay for fertilizer, industrial companies that use biomethane / biohydrogen in their production process and companies that deal with biomethane refining. Publicly owned customers, such as bus companies, will look for green solutions due to the political agenda of its owners. The number of taxis in Norway on fossil fuels will increase and due to the growing awareness of people about the harmfulness of gases, biomethane will become more attractive in this segment. According to Nevzorova & Kutcherov, (2019) if a biogas plant have technical capacity to purify biogas as well as an available gas grid system where purified biogas could be injected, it could lead to new customers such as companies that using natural gas for district heating. There is also potential for another customer segment that could include companies that buying carbon credits. Such scenario would be possible if biogas plant have technology to capture CO_2 and use it, for example, to produce other compounds, which would lead to negative CO_2 emissions (H. Li et al., 2017).

Value proposition for the customer segment interested in waste disposal should be presented from an environmental point of view, where it would be emphasized that anaerobic digestion is a green technology used to convert bio waste into biogas / biohydrogen which is a substitute for fossil fuels that pollute our planet. Customers in this segment may also be influenced by politicians who have an agenda to reduce waste and pollution, so they may be willing to pay a higher gate fee if the waste is treated in an environment friendly way . Biowaste processing plant offers safe disposal of waste that is transformed by technological processes into useful products and by-products, reducing air, soil and water pollution.

Value proposition for the customer segment that would use biogas as an energy source should also highlight environmental benefits such as the reduction of GHG. There are also other benefits such as stability of supply as well as the price of biogas which according to (Bhatt & Tao, 2020) could be far lower in the future due to technologies being developed today, while fossil fuels are subject to large price changes . The value proposition for the carbon certificate offers opportunity to company to plan their industrial growth and to be sure that the emissions of harmful gases that would occur due to industrial growth are neutralized in a convincing way.

The key activity is the transformation of biomass into valuable products such as biogas / biohydrogen and biproducts that can be sold while reducing the impact of gases that can affect climate change. Key activities can be subdivided further to biomass collection, its storage, biomass pretreatment to increase biogas yield, biogas production, storage and enrichment of biogas to biomethane if the plant has such technology, marketing and distribution - sale of biogas / biohydrogen and by products.

The key resources include tangible assets without which the business model would not be able to function like plant, contract with suppliers of feedstock, buildings, machines, cash, as well as all other items relevant to a company's business. The key intangible resources are patents, license and trademarks.

The key partners in this business model are gas companies, companies engaged in the transport of fermentation products, companies that maintain plants, suppliers of spare parts and financiers. If plant does not have technology to enrich biogas into biomethane, a strategic partnership with R&D company is a good strategy.

According to the Osterwalder and Pigneur cost structure refers to all company's costs which make their business model functional. Costs can be variable such as labor costs, raw materials, and these costs depend on the volume of production. The cost structure also includes fixed costs that do not depend on the volume of production, such as depreciation, property taxes and rents that the company has to pay to banks.

The channels through which biogas-biohydrogen will be distributed depend on the local network, as well as on whether biogas or biomethane is delivered. Delivering of biogas with trucks is not economically viable but biomethane can be delivered as compressed natural gas (CNG) by road transport. The sale of biogas-biomethane at stations owned by biogas plant is also possible with additional investments. The revenue streams are generated by selling gas and fertilizer. Gate fee and carbon credit are also included in revenue streams. If the company has a patent, then the revenue can also be generated by licensing.

Customer relationships are established by telephone, mail and through representatives of companies located at biogas- points of sale. The company can also assign a personal assistant to very important customer According to Osterwalder's and Pigneur's this type of relationship is called dedicated personal assistance.

<table>
<tr>
<td rowspan="2">Key partners

Suppliers of spare parts

Transport companies

Power companies

Suppliers

Financiers and government

Technology partner</td>
<td>Key activities

Biomass collection,

Storage

Pretreatment

Biogas production,

Enrichment of biogas

Marketing, distribution and sale</td>
<td rowspan="2">Value proposition

Biogas and biomethan which is generated by processing of biomass

Effective waste removal

Fertilizer for agriculture use</td>
<td>Customer relationships

By mail and phone

Personal assistance

Dedicated personal assistance</td>
<td rowspan="2">Customer segments

Business to business

Industry sector

Business to customer

Farmers that buying fertilizer

User that use biogas-biomethan for heating, as a fuel and for electricity</td>
</tr>
<tr>
<td>Key resources

Row feedstock

Tangible and intangible resources</td>
<td>Channels

Local gas pipelines and gas station

Road transport of CNG</td>
</tr>
<tr>
<td colspan="3">Cost structure

Digestion plant investment and plant maintenance

Technology licensing and plants equipment

Infrastructure and government fees

Cost of distribution The cost of labor</td>
<td colspan="2">Revenue streams

Biogas-biomethan sales

Gate fee and carbon credit

Revenue from intellectual property

Sale of fertilizer</td>
</tr>
</table>

Figure3. Business Model Canvas for production of biogas in Innlandet

3.4.2 Requirement for economic sustainability

In this section, several scenarios were tested that could contribute to the economic viability of the future biogas plant in Innlandet. The scenarios in End report for project Hedmark biogas were tested with different types of raw materials as well as with two different plants, one plant with technical capabilities for sewage sludge fermentation and one plant without such technical solutions.

Scenario with raw materials from TINA dairy

In section 7.1 of the End report for project Hedmark biogas, the authors tested impact on the economic viability of a biogas plant with sewage sludge with waste that biogas plant could receive from SØIR,. The scenario with waste from SØIR showed that the theoretical operating profit was 0.3 million NOK (see Appendix A). In this section, economic viability was tested with organic waste from the TINA dairy presented in chapter 3.2. where the table (see Appendix A) from End report for the Hedmark biogas project was taken as the starting point for calculation. Gate fee in the scenario with organic waste from TINA dairy was 650 NOK/ton, same as for household waste plus sales of gas and fertilizer which is 350 NOK/ton that would be obtained by fermentation of biowaste from TINE.

2 225.2 t x 1000 NOK/Tonne = 2 225 200 NOK

650 NOK/Tonne + 350 NOK/Tonne = 1000 NOK/Tonne

Where,

2 225.2 t Organic waste from TINE for Innlandet

350 NOK/Tonne Revenue from sale of gas and fertilizer per Tonne

650 NOK/Tonne Gate fee for household waste

1 000 NOK/Tonne Gate fee for household waste plus sales of gas and fertilizer per Tonne

2,225,200 NOK Gate Fee revenue plus sales of gas and fertilizer from TINA dairy

When waste from TINE dairy and SØIR was included in the calculations (Table 2), the biogas plant would have a theoretical operating profit of 2,607,164 in the first year of operation, i.e. 2023, and an operating profit of 2,616,762 in year 2024. The calculation for year 2024 includes inflation of 2%, a salary increase of 3% as well as an increase in energy prices.

Table 2- Impact of waste from diary TINE and SØIR on operating profit of a biogas plant with sewage sludge

Budget 1st operating year	2023	2024
Gas revenues	9 720 000	9 914 400
Income sludge treatment	5 543 000	5 653 860
Income household waste	2 067 650	2 109 003
Net income from SØIR	1 700 000	1 734 000
Income other industry	144 900	147 798
Income from subsidies to agriculture	1 487 446	1 517 195
Net income from TINE	2 225 200	2 269 704
Total operating revenues	**22 888 196**	**23 345 960**
Variable costs:		
Raw materials	3 695 000	3 768 900
Transport	4 404 532	4 492 623
Total Variable costs	**8 099 532**	**8 261 523**
Contribution margin	**14 788 664**	**15 084 437**
Indirect costs		
Salary and Social costs	4 254 500	4 382 135
Energy costs	681 000	694 620
Maintenance costs	6 246 000	6 370 920
Accounting, auditing etc.	200 000	204 000
Other operating expenses	800 000	816 000
Total indirect costs	**12 181 500**	**12 467 675**
OPERATING PROFIT (EBITDA)	**2 607 164**	**2 616 762**
Depreciation	6 246 000	6 246 000
Interest	3 750 000	3 625 000
Net financial expenses	3 750 000	3 625 000
RESULT	**-7 388 836**	**-7 254 238**

Scenario where gate fee for sewage sludge is doubled

In this section, a scenario was tested where gate fee (End rapport) for sewage sludge was doubled, which means that it was 2000 NOK, while in the End report for project Hedmark biogas port gate fee for sewage sludge was 1000 NOK.. A table from End report for project Hedmark biogas (see Appendix A) was chosen as the starting point, where authors tested scenario with SØIR raw materials and a 20-year depreciation period. Income from sludge treatment when gate fee is doubled is calculated as follows:

5,543,000 x 2 = 11,086,000

Where,

5,543,000 Income from sewage sludge when gate fee is 1000 NOK

11,086,000 Income from sewage sludge when gate fee is 2000 NOK

When gate fee for sewage sludge was doubled (Table 3), biogas plant would have a theoretical operating profit of 8,150,164 NOK in year 2023 and 8,270,622 NOK in year 2024. In the calculation for year 2024 inflation of 2%, a salary increase of 3% and increase of energy prices are also included.

Table 3 – Impact of doubled gate fee for sewage sludge on operating profit of biogas plant

Budget 1st operating year	2023	2024
Gas revenues	9 720 000	9 914 400
Income sludge treatment	11 086 000	11 307 720
Income household waste	2 067 650	2 109 003
Net income from SØIR	1 700 000	1 734 000
Income other industry	144 900	147 798
Income from subsidies to agriculture	1 487 446	1 517 195
Net income from TINE	2 225 200	2 269 704
Total operating revenues	**28 431 196**	**28 999 820**
Variable costs:		
Raw materials	3 695 000	3 768 900
Transport	4 404 532	4 492 623
Total Variable costs	**8 099 532**	**8 261 523**
Contribution margin	**20 331 664**	**20 738 297**
Indirect costs		
Salary and Social costs	4 254 500	4 382 135
Energy costs	681 000	694 620
Maintenance costs	6 246 000	6 370 920
Accounting, auditing etc.	200 000	204 000
Other operating expenses	800 000	816 000
Total indirect costs	**12 181 500**	**12 467 675**
OPERATING PROFIT (EBITDA)	**8 150 164**	**8 270 622**
Depreciation	6 246 000	6 246 000
Interest	3 750 000	3 625 000
Net financial expenses	3 750 000	3 625 000
RESULT	**-1 845 836**	**-1 600 378**

Scenario where gate fee for sewage sludge, industry and household is doubled

In this section it was tested scenario when gate fee for industrial and household waste was increased from NOK 650 (End report) to NOK 1300, as well as when sewage sludge gate fee was increased from NOK 1000 (End report) to 2000 NOK. The impact of inflation, increase in wages as well as increase of energy prices on profit was also taken into account in the calculation for year 2024. Gate fee for raw materials from TINE and SØIR was same as for industrial and household waste. Income when gate fee is doubled for raw materials from TINE and SØIR, household waste and sewage sludge is calculated as follows:

5,543,000 NOK x 2 = 11,086 000 NOK

2,067,650 NOK x 2 = 4,135,300

(1700 Tonne + 2225, 2 Tonne) x 650N NOK/Tonne = 2,551,380 NOK

Where,

5,543,000	Income from sewage sludge when gate fee is 1000 NOK
11,086,000	Income from sewage sludge when gate fee is 2000 NOK
2225, 2 Tonne	Organic waste from TINE for Innlandet
1 700 Tonne	Waste from SØIR
2,551,380 NOK	Extra gate fee from SØIR and TINE
2,067,650 NOK	Income from household waste when gate fee is 650 NOK
4,135,300 NOK	Income from household waste when gate fee is 1300 NOK

When gate fee was doubled (Table 4) biogas plant had a theoretical operating profit of 12 769 194 NOK for year 2023. Under these conditions, the plant does not only have an operating profit, but can also pay down the investments.

Table 4- Scenario with doubled Gate fee for industrial waste, household waste and waste from TINE and SØIR

Budget 1st operating year	2023	2024
Gas revenues	9 720 000	9 914 400
Income sludge treatment	11 086 000	11 307 720
Income household waste	4,135,300	4,218,006
Net income from SØIR	1 700 000	1 734 000
Income other industry	144 900	147 798
Income from subsidies to agriculture	1 487 446	1 517 195
Net income from TINE diary	2 225 200	2 269 704
Extra gate fee from SØIR and TINE	2 551 380	2 602 408
Total operating revenues	**33 050 226**	**33 711 231**
Variable costs:		
Raw materials	3 695 000	3 768 900
Transport	4 404 532	4 492 623
Total Variable costs	**8 099 532**	**8 261 523**
Contribution margin	**24 950 694**	**25 449 708**
Indirect costs		
Salary and Social costs	4 254 500	4 382 135
Energy costs	681 000	694 620
Maintenance costs	6 246 000	6 370 920
Accounting, auditing etc.	200 000	204 000
Other operating expenses	800 000	816 000
Total indirect costs	**12 181 500**	**12 467 675**
OPERATING PROFIT (EBITDA)	**12 769 194**	**12 982 033**
Depreciation	6 246 000	6 246 000
Interest	3 750 000	3 625 000
Net financial expenses	3 750 000	3 625 000
RESULT	**2 773 194**	**3 111 033**

Scenario where gate fee for sewage sludge and household is doubled

Since TINE is a commercial customer and may be sensitive to an increase price of Gate fee, in this scenario (Table 5) Gate fee for SØIR, sewage sludge and household waste is the same as in Table 4 and only Gate fee for TINE is not doubled. Operating profit in this scenario is 12 769 194 NOK (Table 5) for year 2023. Under these conditions, the plant does not only have an operating profit, but can also pay down the investments.

Extra gate fee from SØIR: 1 700 Tonne x 650 NOK/Tonne = 1 105 000 NOK

Table 5- Scenario with doubled Gate fee for industrial waste, household waste and waste from SØIR

Budget 1st operating year	2023	2024
Gas revenues	9 720 000	9 914 400
Income sludge treatment	11 086 000	11 307 720
Income household waste	4,135,300	4,218,006
Net income from SØIR	1 700 000	1 734 000
Income other industry	144 900	147 798
Income from subsidies to agriculture	1 487 446	1 517 195
Net income from TINE diary	2 225 200	2 269 704
Extra gate fee from SØIR	1 105 000	1 127 100
Total operating revenues	**31 603 846**	**32 264 851**
Variable costs:		
Raw materials	3 695 000	3 768 900
Transport	4 404 532	4 492 623
Total Variable costs	**8 099 532**	**8 261 523**
Contribution margin	**23 504 314**	**24 003 328**
Indirect costs		
Salary and Social costs	4 254 500	4 382 135
Energy costs	681 000	694 620
Maintenance costs	6 246 000	6 370 920
Accounting, auditing etc.	200 000	204 000
Other operating expenses	800 000	816 000
Total indirect costs	**12 181 500**	**12 467 675**
OPERATING PROFIT (EBITDA)	**11 322 814**	**11 535 653**
Depreciation	6 246 000	6 246 000
Interest	3 750 000	3 625 000
Net financial expenses	3 750 000	3 625 000
RESULT	**1 326 814**	**1 664 653**

3.5. Alternative pathways and uses for biomass than today

In addition to its use for the production of biohydrogen and biomethane, biomass can also be used as a raw material for the production of very valuable compounds that can be used in various industries such as pharmaceutical or food industry (Galbe & Wallberg, 2019).

- Methanol belongs to the group of alcoholic fuels that can be produced from biomass rich in lignocellulose and which can contribute to reducing emissions of harmful gases into the atmosphere because methanol is an alternative energy source for petroleum fuels and is also used in chemical industry (Kumabe et al., 2008). Methanol production on a large scale today mainly takes place by catalytic transformation of syngas obtained from fossil sources (Andersson et al., 2014) but also with the development of technologies can be expected in the future higher production of biomethane from renewable energy sources. Sheets et al., (2016) identified microorganisms that were in the reactor for a special type of anaerobic digestion called Solid-state AD and demonstrated that microorganisms can transform both pure methane and biomethane into methanol. Ge et al., (2014) stated that microorganisms (methanotrophs) that could convert biogas to methanol and which are resistant to compounds such as hydrogen sulfide (byproduct of AD), could give reduce cost of methanol production in the future because there would be no more need for expensive biogas to methane refining. The production of methanol by oxidation of biomethan is possible in the presence of bacteria from the methylotroph group (Fei et al., 2014). In order to make biomethanol production economically viable, many challenges need to be overcome. One of the challenges is the further oxidation of methanol to carbon dioxide in the presence of Malate dehydrogenase (MDH enzyme) which is why it is necessary to use inhibitors that are able to deactivate the MDH enzyme without deactivating Methane monooxygenase enzyme (MMO) which is responsible for the oxidation of methane to methanol (Bjorck et al., 2018).

- Butanol as well as methanol and ethanol are a member of compounds called alcohols and for production of butanol it is also possible to use lignocellulosic biomass (Birgen et al., 2019). The molecule of butanol has more carbon and hydrogen atoms than the molecules of ethanol and methanol, which is why it has a higher calorific value and also butanol can be used as fuel in engines in pure form and in diesel mixtures in any ratio without making any changes to the engines (Birgen et al., 2019). According to (Ezeji et al., 2007) production of butanol from Acetone – butanol – ethanol fermentation (ABE) on a large scale is still expensive due to problems such as expensive extraction of butanol from liquid broth, low yield and expensive raw materials. A study of (Zheng et al., 2009) predicted that butanol production by fermentation from biomass would increase when economically viable pretreatments for lignocellulosic biomass were found that would improve butanol yield.

4. Discussion

According to Hox & Boeije, (2005) when it comes to secondary data analysis special attention should be paid to the quality of the data and whether the secondary data are appropriate for the study being conducted. The authors also emphasize that the advantages of secondary analysis are cost and time compared to primary data analysis where the researcher is directly involved in data collection. The problems that arise in secondary data analysis are, according to the authors, the time it takes to tailor secondary analysis data from primary sources because it is sometimes time consuming to find data that explains data from primary research. This study is based in part on the End report for project Hedmark biogas from Klosser and information on the data sources on which the End report for project Hedmark biogas was written was not available. The main aspect of this study was to create a sustainable business model for a biogas plant in Innlandet County while environmental and sociological sustainability seems unproblematic. The Paris Agreement was signed by the Norwegian state in 2016 and Norway is persistent in reducing greenhouse gas emissions 55% by 2030 compared to the year 1990 greenhouse gas emissions (Ministry of Climate and Environment, 2020). In this study, the approach for economic viability of the plant was based on new technologies, mapping of available biomass to increase biogas production and by altering gate fee to be paid by industrial actors as well as households which would have to be a political decision.

The current study found that in the near future, pre-treatment of biomass with nanoparticles will reach a point where it will be economically viable, but it is necessary to overcome today's khaki technological and fundamental problems. The concentration and type of nanoparticles added to biomass is the most important thing when it comes to fermentation because not all nanoparticles contribute to the increase in biogas yield (Romero-Güiza et al., 2016).

Mu et al., (2011) showed that nanoparticles such as TiO_2, Al_2O_3, SiO_2, did not show a significant effect on biogas production from sewige sludge while ZnO showed an inhibitory effect at concentrations of 150 mg / g-TSS and 30 mg / g -TSS while at a concentration of 6 mg / g-TSS did not show a significant effect. Su et al., (2013) showed that there was a positive effect on the fermentation of sewage sludge in the presence of Fe^0, where the presence of Fe^0 also led to a decrease in the concentration of hydrogen sulfide, which is an inhibitor of methanogenesis. In addition to Fe^0, Iron oxides also have a positive effect on biogas yield, but due to experiments that are performed in different conditions in the reactor and with different types of biomass, it is impossible to conclude from the available literature what is the optimal concentration of Iron oxides that lead to the highest biogas yield. The use of nanoparticles in biomass pretreatment is still in the experimental phase and in order to use them on large scale it is necessary to answer many questions. The way in which nanoparticles react with biomass and microorganisms is very complex, and it is very important to examine the impact of the same type of nanoparticles on different types of biomass as well as on different types of reactors (Zhu et al., 2021).

Dark fermentation is a process for obtaining hydrogen from biomass that has been recognized as one of the most important ways to obtain hydrogen on a large scale in the future due to available raw materials from which it is possible to obtain hydrogen as opposed to today's production of hydrogen from fossil fuels (Trchounian et al., 2017). In order to be successfully applied on a large scale, the dark fermentation process must be technologically advanced. The problem that arises when using mix culture bacteria for hydrogen production is the suppression of bacteria that use hydrogen during their metabolism (Hafez et al., 2011). Various pretreatments and specially designed reactors are used to suppress methanogenic bacteria in order to favor the production of biohydrogen over methanogenesis (Hafez et al., 2011). Wang & Wan, (2009) showed that most dark fermentation research has been conducted in batch reactors because they are very easy to handle. The author also compared biohydrogen yields from continues and batch mode where pure culture was used and the values were very different so further research is needed to conduct in order to find optimal conditions for continues mode which is more preferred in fermentation. Dark fermentation is mentioned in the Results chapter as alternative to biogas production, This technology is still in development and problems such as low hydrogen yield, accumulation of volatile fatty acids, unclear mechanisms leading to proton reduction as well as the problem of reactor design must be overcome (Chandrasekhar et al., 2015) . Many efforts are being made to make Dark fermentation economically viable such as the extraction of volatile fatty acids used in the production of very valuable compounds (Sekoai et al., 2021).

In this study business model canvas was used (Osterwalder & Pigneur, 2010), which is an outstanding tool that serves to gain an idea of all components of a business model in a picturesque and efficient way. According to Osterwalder & Pigneur, (2010), the business model should give us an answer how a company creates value for its customers, how that value is delivered to customers and what are the mechanisms by which company can make a profit. The main and central building block in Osterwalder’s and Pigneur’s business model is the Value proposition. The term Value proposition is first mentioned in a paper by Lanning, M. J., & Michaels, E. G. (1988), in which authors explained that behind a successful business strategy implemented by a company is a value proposition that offers price and benefits for the product or service.

By testing different scenarios with double Gate fee and waste from TINE contained in the Results chapter, this study has shown that it is possible to achieve the economic viability of a biogas plant. Table 4 and Table 5 show the impact of the doubled Gate fee on economic viability and that it is possible to make a positive operating profit as well as that it is possible to repay the investment. Table 5 shows that it is not even necessary to double the Gate fee for TINE in order to make a profit with which the plant would operate positively and repay the investment. According to the Rolewicz-Kalińska et al., (2016) the most important source of revenue for biogas plants is the Gate fee. The authors also stated that the impact of the gate fee on economic viability is far greater than the profit made by selling biogas. It is still an increase in the Gate fee. Acording to Winquist et al., (2019) plants that use different types of biowaste for fermentation generate 80 percent of the revenue from the Gate fee alone. Increasing the Gate fee is a political issue and its alternative is landfill, where such a solution would lead to the emission of harmful gases and further pollution of our planet. Therefore, it seems fair that the increased Gate fee should be charged to households.

5. Conclusion

The potential that Innlandet County has in the raw materials for the production of biogas and biohydrogen is great. But above all, it refers to raw materials that are rich in lignin and that would be obtained from forests. The results from this study showed that a biogas plant would have to have a higher amount of organic waste for fermentation as well as a higher price for the gate fee if we wanted to have a sustainable business, which means that biogas production and GHG reduction come with a high price. . This study also mentioned new technologies that will contribute to higher biogas yields, but for large-scale production it is necessary to overcome many technological problems. Hydrogen production is also emerging as one of the alternatives to biogas production. Dark fermentation is a technology that will overcome the problems of low hydrogen yield in the near future. A higher gate fee would contribute to the economic viability of the plant. Further research needs to be done when it comes to new technologies. Oil prices are likely to increase as a result of increased fuel taxes and biomethane may in the future be priced higher.

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Appendix A - Table from the End report for project Hedmark biogas located in section 7.1 of End report for project Hedmark biogas

Budget 1st operating year	2023	2024
Gas revenues	9 720 000	9 914 400
Income sludge treatment	5 543 000	5 653 860
Income household waste	2 067 650	2 109 003
Net income from SØIR	1 700 000	1 734 000
Income other industry	144 900	147 798
Income from subsidies to agriculture	1 487 446	1 517 195
Total operating revenues	**20 662 996**	**21 076 256**
Variable costs:		
Raw materials	3 695 000	3 768 900
Transport	4 404 532	4 492 623
Total Variable costs	**8 099 532**	**8 261 523**
Contribution margin	**12 563 464**	**12 814 733**
Indirect costs		
Salary and Social costs	4 254 500	4 382 135
Energy costs	681 000	694 620
Maintenance costs	6 246 000	6 370 920
Accounting, auditing etc.	200 000	204 000
Other operating expenses	800 000	816 000
Total indirect costs	**12 181 500**	**12 467 675**
OPERATING PROFIT (EBITDA)	**381 964**	**347 058**
Depreciation	6 246 000	6 246 000
Interest	3 750 000	3 625 000
Net financial expenses	3 750 000	3 625 000
RESULT	**-9 614 036**	**-9 523 942**