Erik Rannaste

COMPARISON OF JOUTSA BIOGAS PLANT WITH OTHER FINNISH BIOGAS PLANTS

JOUTSAN BIOKAASULAITOKSEN VERTAILU MUIHIN SUOMALAISIIN BIOKAASULAITOKSIIN

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Tämän opinnäytetyön aihe saatiin jyväskyläläiseltä Metener Oy:ltä, mutta työ tehtiin pääasiassa itsenäisesti käyttäen hyväksi erilaisia julkisia lähteitä kuten ympäristölupia ja omia laskelmia. Opinnäytetyön aiheena oli verrata Joutsan biokaasulaitosta (Joutsan Ekokaasu Oy) ja sen ominaisuuksia seitsemään muuhun Suomessa toimivaan biokaasulaitokseen. Näiden ominaisuuksien tietolähteinä käytettiin biokaasulaitoksista tarjolla olevaa julkista tietoa (opintomatkaraportteja, julkilausuntoja sekä uutisia kyseisiin yrityksiin liittyen) sekä laskelmia jotka perustuivat biokaasulaitosten ympäristölupiin.

Tässä opinnäytetyössä tutkittiin pääasiassa investointien määrää eri biokaasulaitoksiin, vuotuista jätteen käsittelykapasiteettia eri laitoksilla sekä biokaasulaitoksista ulos tuotetun energian määrää. Opinnäytetyössä tarkasteltiin, onko näiden edellä mainittujen tekijöiden välillä korrelointia. Yksi mielenkiintoisimmista asioista tässä opinnäytetyössä oli tutkia näiden kolmen tekijän suhdetta yhteensä kahdeksaan prosessi- sekä biologiseen parametriin.

Laskujeni tulosten perusteella Joutsan biokaasulaitos sijoittuu erittäin hyvin vertailussa muihin suomalaisiin biokaasulaitoksiin. Tässä opinnäytetyössä oli monta kategoriaa, jossa Joutsan biokaasulaitos oli ominaisuuksiltaan pienin biokaasulaitos. Tästä huolimatta kyseinen laitos tuottaa enemmän biokaasuenergiaa ulospäin kuin vertailussa olevat biokaasulaitokset, jotka ovat isompia ja joihin on investoitu paljon enemmän rahaa kuin Joutsan biokaasulaitokseen.

Tämän opinnäytetyön johtopäätös oli se, että investointien määrä ei korreloi biokaasun tuotantoprosessin tehokkuutta eri laitoksilla. Pienemmät biokaasulaitokset voivat tuottaa suhteellisesti niiden koko huomioonotettaessa biokaasuenergiaa aivan yhtä tehokkaasti kuin isommat biokaasulaitokset.

Asiasanat: Biokaasu, metaani, biopolttoaine, CBG, vertailu, Joutsa, Metener

ABSTRACT
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The subject for this thesis was received from Metener Ltd. The study was made independently using different public sources and own calculations. This thesis is a brief review of Joutsa biogas plant, where its attributes are compared to seven other biogas plants in Finland. Most of these attributes are based on the public knowledge available and calculations made from the environmental impact assessments and other sources (e.g. public statements from biogas plants, news articles and study tour reports).

The main attributes that are in review in this thesis are; the amount of investments, the annual waste capacity of biogas plants and the energy production outside the biogas plant. This thesis studies if there is any correlation between these three main attributes. One of the interesting things in this thesis is the comparison of how these three attributes would affect the different process and biological parameters. There are eight categories in which the biogas plants are compared against each other.

According to the results of my calculations, Joutsa's biogas plant fares very well against the other Finnish biogas plants. There are several categories in which the Joutsa's biogas plant is the smallest one of the biogas plants in this comparison. Despite this, it still produces more biogas energy than the biogas plants that are several times bigger and that have more investments put into them than the Joutsa's biogas plant.

The conclusion of this thesis is that the amount of investments does not always correlate the effectiveness of the biogas production process. The smaller biogas plants can produce biogas energy as effectively as the bigger plants, but the scale of this is without a doubt smaller in comparison to the bigger biogas plants

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Keywords: Biogas, methane, biofuel, CBG, comparison, Joutsa, Metener

FOREWORD

Oulu, Finland

April 8th, 2016

This thesis is a brief review of Joutsa's biogas plant, where its attributes are compared to seven other biogas plants in Finland. Most of these attributes are based on the public knowledge available and calculations made from the environmental permits etc. Even though the subject for this thesis was received from Metener Ltd, I was willing to make this thesis about the biogas plants in general in order to learn new things about biogas production and its current state in Finland. I also wanted to see out of curiosity the differences between my home commune's biogas plant and other biogas plants in Finland.

I would like to express my deepest gratitude and appreciation to the people of Joutsan Ekokaasu Ltd and Metener Ltd for giving me this opportunity. Also, I have to thank my teachers, Timo Kiviahde and Marjo Heikkinen, for giving me support and great advices thorough this journey. Thanks to my great friends, I was able to finish this second thesis of mine.

My special thanks go to; the CEO Petri Parhiala of Joutsan Ekokaasu Ltd, the CEO Mika Juvonen of Biokymppi Ltd, the CEO Erkki Kalmari and Operations Planner Juha Luostarinen of Metener Ltd.

Erik Rannaste

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VOCABULARY

BG	Abbreviation for biogas. Biogas is a mixture of different gasses, but it consists mainly of methane, CO_2 and little amounts of other sulfuric compounds.
CBG	Compressed biogas. Usually after the name `CBG` comes some number representing the purity percentage of the gas, like CBG100 (CBG100 is gas that is 100% biogas and there is no natural gas added to the biogas). All the biogas using cars in Finland currently use only CBG as alternative fuel.
CH_4	Chemical abbreviation of methane. CH_4 is produced in biogas production process and it is used mainly in energy production.
CO_2	Chemical abbreviation of carbon dioxide. CO_2 is a greenhouse gas that accounts almost 80% of greenhouse gasses produced every year.
HRT	Hydraulic retention time. Tells the amount of days that the organic input spends in the biogas reactor, until it has produced enough biogas to be considered as “used”.
Input	Input is a synonym for substrate. In biogas production organic substrates are needed for the anaerobic bacteria as food.
LBG	Liquefied biogas. Biogas liquefies at -162°C. LBG is not used in Finland in any vehicles.
OLR	Organic loading rate. Expresses the amount of organic input (volatile solids) that is added to the digester every day. Unit used for this term is kg VS / d * m^3.
TS	Total solids. Expresses the weight of organic input when it has been dried. Unit used for this term is a percentage equivalent to the ratio of wet weight.

VS	Volatile solids. Expresses the weight of organic matter in the input. Unit used for this term is a percentage equivalent to the ratio of total solids (TS).

1 INTRODUCTION

This thesis is a brief review of Joutsa's biogas plant and its comparison to other biogas plants in Finland. In the future Finland has to focus on local possibilities in energy and heat production, because oil will not be as cheap as it is now and easy to get access to. Also, the amount of usable biowaste for biogas production thrown into landfills was around 400 000 tons in 2014 **[1]**.

Finland's prime minister Juha Sipilä and his cabinet have stated that the amount of renewable energy in energy production will be raised up to 60 percent by 2034 **[2]**. According to the textbook of Finnish Biogas Association (**3**, page 7), in 2013 the workshop appointed by the Ministry of Transportation and Communications presented that by 2050 almost every car in Finland would be completely independent from oil and its derivates. This would also provide Finland a huge economical boost if local possibilities would be supported more by the government. Before this could happen, the legislation regarding emission taxes for biogas has to be improved.

Currently, the emission taxes for vehicles are calculated based on the emissions caused by the fuel used. In the case of biogas, the calculations used for taxes uses natural gas as the emission factor for biogas. When natural gas (chemically not the same thing as biogas, because natural gas contains more than 98% methane and biogas contains 50 – 75% methane **[4]**) is produced as the side-product of oil pumping, huge amounts of fossil fuels are used compared to biogas production, which reflects the factor used to tax biogas **[5]**. In order to get the majority of Finland's population to use biogas vehicles, tax relieves have to be introduced to the cars using biogas as their main source of fuel.

Biogas production, in its current state, is all about the localization and placement of the production plants. Optimization is needed in everything, from the waste collection to the production of biogas in the plants. Biogas itself gives a great opportunity for communities to create more environmental friendly innovations in the field of heat and energy production, but it also gives the tools to organize social structures in our society.

2 BIOGAS IN FINLAND

This chapter is about the biogas in general, the production of it and the usage of biogas in Finland. It tells more about the terms and basics related to the biogas production. The chemical aspect of biogas production is briefly described in chapter ***2.1.1 Anaerobic digestion process***. This thesis does not focus on the chemistry related to the anaerobic process, because the chemical reactions have been thoroughly studied in other studies and publications before and they are not the main point of this thesis.

2.1 Biogas

When organic matter degrades in the nature, it breaks down into its basic chemical elements using the energy of the environment while releasing some of its own stored energy through the chemical processes. Little living things called ´micro-organisms´ degrade almost all the organic matter within weeks. This previously mentioned series of events occurs most of the time in the presence of oxygen. But what happens when organic matter degrades in the absence of oxygen? The process is the very same as in the presence of oxygen, but the variety of micro-organisms and the amount of metabolic by-products is different. These metabolic by-products produced by the micro-organisms are a gaseous mix which is better known as biogas.

Biogas is a mixture of different gases that are produced via the metabolic system of micro-organisms and through the chemical processes of degradation. The composition of biogas depends on the organic waste that has degraded **[6]**. Biogas is usually 40 to 70 percent methane, around 30 to 60 percent carbon dioxide (CO_2) and the rest of it are very small amounts of sulfuric compounds, like hydrogen sulphide (H_2S_2) **[7]**.

Biogas is formed in an anaerobic environment. The term `anaerobic` means the lack of oxygen. This kind of environments can be found in the nature from wetlands, swamps, bottom floors of the water systems and inside of animal intestines. In a modern society these kind of `ecosystems` are built purposely on different locations, where large amount of organic waste is guaranteed. This kind of locations are wastewater treatment plants, farms and landfills.

2.1.1 Anaerobic digestion process

This chapter is a short description of the anaerobic digestion process. As already mentioned, this thesis does not examine the chemistry behind the anaerobic digestion process more specifically, because the thesis is mainly about the Joutsa's biogas plant and its comparison to other biogas plants in Finland, not the chemical process itself that has been already well-studied.

The anaerobic digestion process can be divided into five phases: 1.) Introduction of input substrates, 2.) hydrolysis of the substrates, 3.) the acidification of hydrolysis products, 4.) acetofication of acidic by-products and 5.) methanogenesis of the end products of acetofication by methanogens (micro-organisms that produce methane as a metabolic by-product) **[8]**. This process is simplified below in *Figure 1* **[9]**.

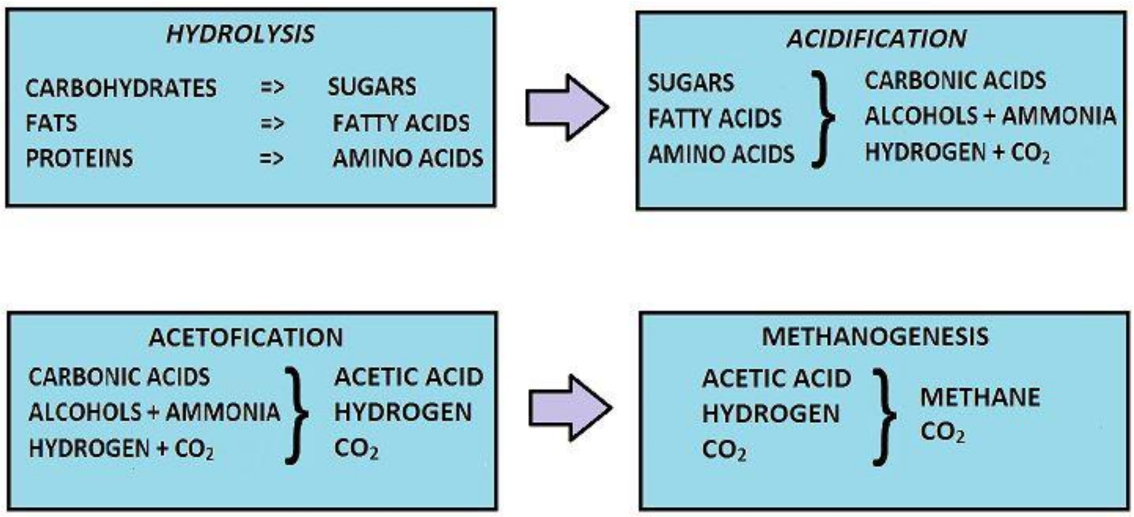

FIGURE 1 Phases of anaerobic digestion (when substrates has been introduced in the process).

In hydrolysis process the carbohydrates, fats and proteins are turned from complex molecules to simpler molecules by the anaerobic bacteria. Hydrolysis, in chemical terms, means a reaction where molecule (in this case carbohydrate, fat or protein) is split into two parts by the addition of water (H_2O). This is the reason why humid waste is needed in the production of biogas **[10]**.

In the acidification process (also known as acidogenesis) sugars, fatty acids and amino acids are turned by the acidogenic bacteria into carbonic acids, alcohols, ammonia, hydrogen (H_2) and carbon dioxide (CO_2). Carbonic acids, alcohols and ammonia are then processed by different kind of bacteria, called acetogenic bacteria, into acetic acid (CH_3COOH), hydrogen and carbon dioxide in a process called acetofication (also known as acetogenesis) **[11]**.

The last part of the anaerobic digestion process is biomethanation process (also known as methanogenesis) where bacteria type known as methanogens turn hydrogen and acetic acid into methane gas. Carbon dioxide is also formed in the process. After this process all the gasses are collected and the digestate left inside the tank is taken out **[12]**. When all the produced gasses from the side reactions are collected, the mix of these gasses can be called biogas. Biogas that is produced by this anaerobic process cannot be used straight up as a fuel for cars, because it is too impure (it has to be at least 98 % pure methane) to be used for cars and it has too much water in it.

As a by-product in biogas production, digestate is also produced, which can be used as fertilizer in the fields. Digestate contains both inorganic and organic materials like cellulose, phosphates, nitrates and other nutrients needed in agriculture **[13]**. Depending on the method used for anaerobic digestion (wet/dry anaerobic digestion) the amount of waste water created is either very little or quite noticeable. If the waste that has been processed has been biowaste that does not have residues of antibiotics or pathogens, the waste water can be used as liquid fertilizer in the fields.

The amount of antibiotics and pathogens in the biowaste is monitored carefully, because in the worst case scenario they could taint the crop and even cause illness in the people that use the crop as food. In Finland, the Centre for Economic Development, Transport and the Environment determines what waste can be used as fertilizer and which not.

2.1.2 Bacterial life cycle

The growth of bacteria follows a certain lifecycle, similar as in Figure 2 below. At first, when the bacteria are introduced to the new environment (e.g. biogas production reactor), it needs a while to get used to it. Bacteria gets its nutrients from the surrounding sludge, but it does not start to multiply. It is getting ready to multiply by collecting all the needed nutrients for the population of the new environment. This phase is called the ´lag phase´ **[14]**.

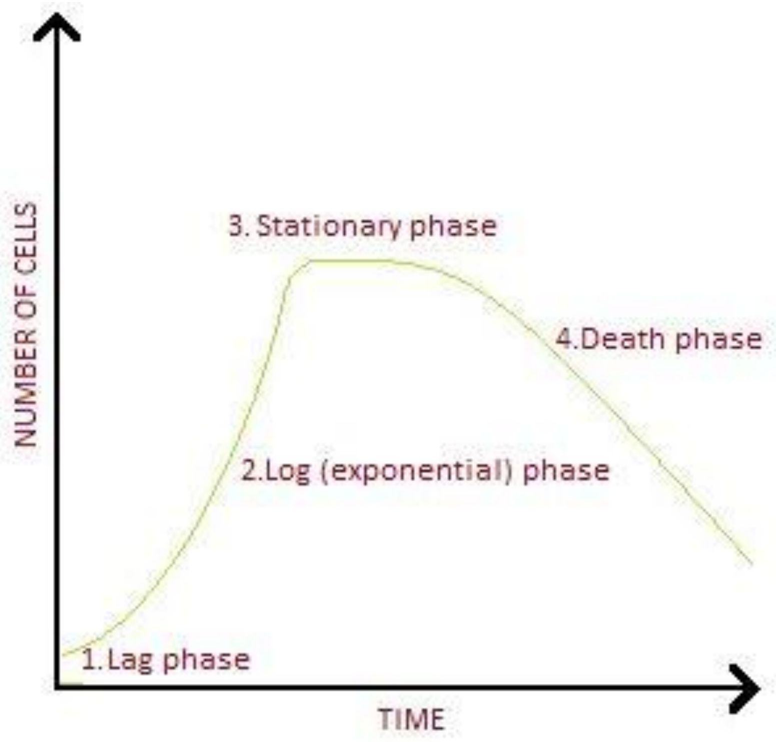

FIGURE 2 Life cycle of bacteria

The second phase is called ´log´ or ´exponential phase´. This is the phase when bacteria multiply greatly. The amount of bacteria cells increases with rapid speed. It can take minutes or days for bacteria to reach the next phase, ´stationary phase´. When the amount of biogas producing bacteria grows, more gas is produced at the same time, but in this phase the bacteria just focuses solely on growing and multiplying **[15]**.

In the third ´stationary phase´ bacteria stops almost completely multiplying. The bacteria produce biogas while it is eating the organic material. This is the phase when most of the organic material in the tank is consumed and most of the biogas is produced. When all the organic material in the tank is consumed, the bacteria starts to age and it loses its ability to reproduce **[15]**.

The fourth and last phase in the bacteria's life cycle is the `death phase`. In this phase every bacterial process in the tank dies away, mainly because the lack of nutrients or space to grow in. This phase is undesirable for biogas production, because you would have to start the process again.

Stationary phase can basically continue forever, but this requires constant feed of organic material and the extraction of dead bacteria cells and digested organic material. If the digested organic waste is not thrown out of the system, the system becomes a feed-batch kind of system where you have to always clean the tank, fill it with new organic waste and throw in some bacteria in order to produce biogas. This costs money and lots of time, therefore it is non-desirable thing for biogas production. The anaerobic digestion process has to be constant and it cannot stop for too long, if a fault of some sort appears. In order to avoid this, process optimization is needed.

2.2 Production of biogas

This chapter is about the production of biogas. The production of biogas becomes a complex process if you have to produce enough biogas for running an entire energy plant constantly or in order to produce alternative fuel for hundreds of cars. With process optimization the amount of biogas can be increased significantly and the process can be made more stable.

2.2.1 Mesophilic and thermophilic biogas production

Biogas production is usually classified under the terms ´mesophilic´ and ´thermophilic´ anaerobic digestion. These terms tell more about the temperature inside the biogas reactor in which the anaerobic digestion process happens. Different kind bacteria are behind both processes.

Mesophilic anaerobic digestion process means a process that occurs in temperatures ranging between 33°C to 43°C **[16]**. This method is the most used in biogas production, because the mesophilic digestion process is more stable, easier to handle due to its lower process temperature and it does not have a risk of producing ammonia and nitrogen so much that it could kill the process **[17]**.

Thermophilic anaerobic digestion process means a process that occurs in a temperature of 55°C or higher. The higher temperature means that the decomposition reaction is shorter, because one of the basic rules in chemistry is that the higher the temperature in which the chemical reaction happens, the faster the rate of reaction is. One of the main advantages in thermophilic anaerobic digestion is that it needs a smaller reactor tank than mesophilic anaerobic digestion. But because the temperature range is so specific and high in the process, it needs more care and surveillance than mesophilic digestion **[16]**.

The waste that goes into a thermophilic process does not need hygienisation in order to get rid of possible pathogens in the waste. Because the thermophilic digestion process happens in such high temperatures, more energy is needed in heat production and in sustaining the temperature. This means that either more end-product (biogas) is used in heat production inside the power plant of biogas plant or more energy is bought from outside the biogas plant.

2.2.2 Wet and dry anaerobic digestion methods

There are two different kind of anaerobic digestion methods that are being used in biowaste treatment. The main difference between these methods is the content of dry solid waste in the feed **[18]**. When new biogas plants are designed, the choice between wet and dry anaerobic digestion is being determined by the type of biowaste that is available for biogas plant. Below in

Table 1 are different values for input types used in the calculations in this thesis. Methane production potential tells how many cubic meters (m^3) of methane can be produced from one ton of volatile solids (VS) from certain input. The total solids (TS) tells how much of the feed is dry matter. When calculating different process parameters, the amount of volatile solids (VS) tells how much of the total solids is organic waste which can be turned into biogas.

TABLE 1 Different feeds and their attributes **[19]**

Feed	Methane Yield Potential [m^3 of CH_4/t of VS]	Dry Matter Content, TS [%]	Volatile Solids, VS [%]
Slaughterhouse waste	500	40 %	90 %
Fish- and gutting waste	520	17 %	85 %
Biowaste	400	27 %	90 %
Field biomass	350	35 %	90 %
Pig manure	300	5 %	80 %
Cattle manure	200	7 %	80 %
Sewage sludge	300	20 %	70 %
Food industry by-products	550	30 %	90 %
Grease residues	800	40 %	90 %
Septic tank and cesspit sludge	300	2 %	70 %
Food industry sewage sludge	300	20 %	70 %
Animal solid manure	200	33 %	78 %

Wet anaerobic digestion uses organic biowaste that has a high moisture content. The sludge that is used in the process usually consists of 10 to 15 % of dry solids, the rest of it is water and inorganic material **[20]**. The wet anaerobic digestion process cannot use all kinds of organic waste; it is more specific about its waste and impurities in comparison to dry anaerobic digestion. The waste has to be pumpable and mixable sludge, because it would otherwise block the pipes needed for adding the organic input and removing the digestate **[21]**.

Dry anaerobic digestion uses biowaste that has a low moisture content. The amount of dry solids in the process is higher than in wet anaerobic digestion. Usually the amount of dry solids in dry anaerobic digestion is between 20 to 40 percent of the total amount of the waste, the rest of it is water and inorganic material **[20]**. The dry anaerobic digestion process can use waste that has impurities (e.g. sand, stones, lignin) in it without disturbance in the process. Also, the systems that use dry anaerobic digestion are smaller, less complex in design and in equipment used for biogas production. Main disadvantages for using dry anaerobic digestion in a biogas production is that it has lower biogas yields than wet anaerobic digestion **[3]**.

2.2.3 Components needed for biogas production

When producing biogas, four main components are needed: 1.) a reactor where the anaerobic digestion happens, 2.) organic waste for the degradation reaction, 3.) the correct type of bacteria that can degrade organic waste but also in the meantime produce methane and 4.) working inorganic waste removal system.

The reactor in the biogas production can be as simple as a cylinder that is airtight and it can handle the pressure that all the waste and biogas produces. But the efficiency of biogas production is correlated with the complexity of the reactor. If the reactor is as simple as depicted before, it needs continuous monitoring because the process itself is basically a living ´thing´ **[22]**.

In a more complex reactor there are meters that measure pH, humidity, mixing of the rotors, oxygen levels and the pressure inside the tank. These variables alone can tell the state of the bacteria inside the reactor. The main reason why these variables are monitored is that it can be said which production phase the biogas reactor has entered in. The production of biogas happens in big airtight reactors, because the bacteria needed for biogas production is anaerobic. Anaerobic bacteria are organisms that does not need oxygen to live or for growth, oxygen is toxic for some types of anaerobic bacteria **[23]**.

Bacteria in the process needs food (organic waste) and space to grow and multiply, but also the correct environment (temperature, low oxygen levels, mixing) to live in. If even one of these things is off-course, the growth of bacteria meets the limit of the said factors and it stops growing, which results into the end of biogas production. The type of bacteria changes inside the biogas reactor, when certain nutrients are more available in that environment than the others. This opportunity favors bacteria that uses more efficiently those nutrients than the other competitors inside the reactor. When that said opportunist bacteria start to flourish in a new environment compared to the others, the dominating bacteria starts turning the environment (pH, temperature) more appropriate for itself. This change in the environment kills most of the competitors and therefore helps the dominating bacteria type. When all the nutrients are used and they are turned into new metabolic products and by-products, a new circulation of this nutrient war starts.

When biowaste is degraded, some of it does not degrade completely. The remaining waste is inorganic waste that the bacteria cannot use as food. In the case of a closed biogas reactor, the automated process keeps feeding more biowaste into the reactor. When that waste is then degraded by the bacteria, the inorganic waste keeps piling up if it is not cleaned up. If the waste keeps piling up, the biogas reactor loses slowly its operational volume and the amount of produced biogas drops significantly.

If all the previously mentioned components are working, the biogas production will keep going on for long periods of time.

2.2.4 Environmental factors

The production of biogas is highly affected by the environmental factors and they should not be neglected. There are many ways to stop the biogas production process accidentally. Because the production of biogas happens through the series of different bacterial processes, it is very sensitive for changes in the environment (temperature, pH, presence of nitrogen and oxygen). Accurate measuring devices and control systems are needed and used to monitor the situation inside the reactor tanks.

For example, the amount of nitrogen affects significantly to the anaerobic degradation process of organic material. If the nitrogen content of input is high, the chemical processes in the anaerobic digestion slow down and the total amount of biogas produced lowers. This is called as `nitrogen inhibition`, because the nitrogen in the input inhibits the chemical processes. The amount of nitrogen in the input is therefore carefully monitored **[24]**.

Changes in temperatures should be avoided, especially during the winters, and they are usually taken into consideration when new biogas plants are designed and built. Especially in Finland this feature is highlighted due to our cold and long winters. Depending on the anaerobic digestion process (thermophilic/mesophilic) that has been used in biogas plant, it can handle a certain temperature shock. Thermophilic anaerobic digestion is notorious for not being able to handle even a small drop in temperature, when mesophilic digestion process can handle bigger drops in temperature.

The need for new organic material inside the reactor is almost a continuous process. If the bacteria cannot get enough nutrients and trace elements (like iron, nickel, cobalt…) from the input to sustain itself, it will die slowly away. These nutrients and trace elements should be added, if needed, to the process to keep it running. The process can be stopped accidentally by adding toxic inputs (like antibiotics, zinc, copper, ammonia…) in it. These previously mentioned toxic inputs in big doses will kill the bacteria needed to degrade the organic material, but in smaller doses it will slow down the digestion process **[25]**.

2.3 Waste used to make biogas

In the biogas production different input substrates are used to make biogas. Depending on the input substrate and the pre-treatment of it, the amount of biogas produced in the reactor can be increased greatly. According to the study of Ferrer – Ponsá – Vázquez – Font**,** by pre-treating the waste in low temperatures they were able to increase the biogas production by 30 % **[26]**.

There are roughly four different classes of organic materials that the bacteria can easily use to produce biogas **[25]**. The following classes (2.3.1 – 2.3.4) are not in the order of most used waste class for biogas production.

2.3.1 Municipal organic waste

Municipal organic waste material used to make biogas is the waste that is produced daily due to our eating and drinking habits. Usually this means the leftover waste (banana peels, bread crumbs, coffee filters…) that is created when we are making something to eat/drink and also the things we leave without eating. According to the Natural Resources Institute Finland's research (Food Waste Research 2013) about consumer behavior, approximately 20 – 26 kilograms of food waste is produced every year per capita. Usually this waste is collected from recycling points by the municipalities and then delivered to biogas plants. This waste might include unwanted materials (plastic, metals) in it because of the lacking recycling skills of the people **[1]**.

2.3.2 Green biomass from nature

The term "green biomass from nature" refers to all the green plant parts that does not contain woody matter which could have lignin in it. Lignin is a plant polymer that does not get digested easily by the bacteria in the biogas production process. Biomass from the nature that is used in the biogas process usually consists of leaves, straws, plants and grass. Usage of this kind of biomass is higher in the biogas plants that are either close to the farms or part of them. This is because of the close proximity of the input substrate. If the input substrate would be too far away, it would be too unprofitable to use it to make biogas. Optimization process of the waste shipments is needed **[27]**.

2.3.3 Industrial food waste

When food products like minced meat, filets and other pretreated/prepared foods are made, lots of industrial food waste is created. Industrial food waste includes things like inedible animal parts (like cartilages, tendons…) from slaughterhouse waste, parts of edible plants that are not used commonly in foods (like rice husks, oat hulls…) and vegetable leftovers. Waste from plants and vegetables are not usually treated before use in biogas production, because they do not pose a big health hazard. Slaughterhouse waste has to be specifically treated in certain ways so that it does not smell nor cause any health issues **[25]**.

2.3.4 Liquid or solid manure

Liquid and solid manure is mostly received from municipal waste water treatment plants and animal farms. The main differences between the manure received from the municipal waste water treatment plants and animal farms is the way how the manure is treated and the amount of water in the manure. Manure that is received from municipal waste water treatment plants is usually sieved and drum dried in order to get rid of the unnecessary solid particles and the excessive water in the manure. Manure from the animal farms is treated less, because the amount of nitrogen in the animal manure is higher. The high amount of water dilutes the nitrogen content of the animal manure. As previously mentioned, the high nitrogen contents would cause inhibition in the anaerobic digestion process.

Manure has to be pre-treated before use in biogas production, because it usually contains high levels of heavy metals, antibiotics and solid particles that cannot be used in the process. The biogas production process needs water especially in the hydrolysis process. This water comes from the sewage waters and manure itself. The amount of water in the manure ranges from 75 to 95 percent. In addition, manure also provides good amount of natural bacteria needed for the biogas production **[28]**.

2.4 Usage of biogas in Finland

According to the Huttunen and Kuittinen (**29**, page 57), there are 16 biogas plants that mainly handle the waste coming from municipal wastewater treatment plants. 14 biogas plants treat solid municipal waste; 3 biogas plants treat anaerobically wastewater coming from industry. In Finland alone there are 13 biogas plants that are operating as a part of farm of some sort. Currently, there are 24 public gas refueling places operating in Finland **[30]** and 20 private ones that offer biogas **[31]**.

Most used applications for biogas in Finland can be found in the field of heat and electricity production, but also in the field of transportation as a fuel of vehicles. In 2014 over 610 GWh worth of biogas was used in heat and energy production and 17 GWh was used in transportation **[29]**. In the future these amounts will rise significantly in Finland, due to new legislations passed on parliament and fall in the price of biogas technology.

2.4.1 Combined Heat and Power production

Biogas is used mostly in heat production, because the equipment needed for burning biogas and converting its energy into heat are more simple and cheaper than the ones used for electricity production. But there are many power plants that do not only use biogas for heat production but also for the production of electricity. These power plants are called CHP **-**plants.

The term \`CHP\` means Combined Heat and electricity Production. Power plants usually produce only electricity, but in CHP -plants they produce also heat. When fuel (biogas, coal, wood…) is burned in CHP-plants, the energy released from the fuel warms a huge water tank. When water starts boiling inside the tank, it starts producing steam. This steam is then forwarded into a turbine that starts spinning, because the steam is forced to come through it. The motion from the spinning of turbine blades is turned in a generator as electricity. The steam from the previously described process is then forwarded straight as steam for customers to use or used to warm household water.

CHP- plants lower the amount of usable energy that has been wasted in normal power plants. According to some estimates **[32]**, the amount of saved energy could be up to 25 % per power plant if they would be converted into CHP - plants.

2.4.2 Transportation

According to the Finnish Biogas Association, biogas is used in vehicles both as CBG (Compressed BioGas) and as LBG (Liquified BioGas) **[33]**. The difference between these terms (CBG and LBG) is the fact how the biogas is stored. As the name indicates, the other is about storing the biogas in liquid form and the other storing the biogas under pressure (compression). The vehicles that use either CBG or LBG as their fuel do not have to undergo huge mechanical modifications in order to be able to use biogas as their fuel.

In Finland only CBG100 (Compressed BioGas, that is 100 % biogas and does not contain any added natural gas) and CNG (Compressed Natural Gas) are used in vehicles. Our neighbor Sweden uses both CBG and LBG in their cars **[31]**. If biogas is used in vehicles, it has to be purified up to 98 % pure and all the excessive water and impurities, like CO_2 and sulfides, have to be removed from it before it could be used as fuel in vehicles. Otherwise the biogas engines could not run properly, because of the fuel impurities and corrosion caused by the impurities. Because of this, biogas engines would also need inspections and maintenance more often than once a year.

Biogas is a cheaper and eco-friendlier way to make fuel for cars than bioethanol or other types of biofuel. When biogas is compared to bioethanol, the most significant difference comes in the input that goes into making bioethanol or biogas. Biogas production can use any kind of organic matter as input. Bioethanol production needs input that has a high amount of carbohydrates in it. This carbohydrate input is then fermented and converted by the bacteria into ethanol. Bioethanol production process cannot use “waste” as its input, because the impurities would make the bioethanol unusable. Bioethanol is usually made from edible crops, like wheat and corn. This reduces the amount of food produced yearly, which could be used for feeding the hungry people in the world **[34]**.

3 JOUTSAN EKOKAASU LTD

Joutsan Ekokaasu Ltd was founded by the five communes (Joutsa, Hartola, Kangasniemi, Hankasalmi and Laukaa) local waste management entrepreneurs and biogas entrepreneur Erkki Kalmari. Part of company's shares are also in the hands of Gasum Oy and private motorists who wants to support the building of Joutsa's biogas plant **[35]**. A total amount of 1 600 000 € has been invested to the Joutsa's biogas plant **[36]**.

The construction of Joutsa's biogas plant started in the end of May 2013. The biogas plant was opened the 4th of October 2014, but the plant was already operating and producing biomethane earlier in the spring **[37]**. The plant is a bit small-sized when compared to other plants in Finland, but it does its job well.

*FIGURE 3 Illustration picture of Joutsa's biogas plant (**38**, page 58)*

The biogas plant of Joutsa is illustrated in ***Figure 3*** and other buildings vital for its operation. The two grey buildings on the left are the buildings of Joutsa's Water Treatment Plant. They are not part of this thesis, but one thing is worth mentioning. The biogas plant of Joutsan Ekokaasu Ltd gets some of its organic material that it needs in biogas production from those buildings.

The most vital buildings for the operation of Joutsa's biogas plant are the hall for the incoming feed where the processing of it happens (***Figure 4***), two biogas reactors (***Figure 5***) and the biogas upgrading unit (***Figure 6***) with biogas purifying system that can increase the purity of biogas up to 98 %. This purified biogas is then compressed into CBG after which it could be used in cars **[39]**.

FIGURE 4 Hall for the incoming feed

The biowaste that Joutsa's biogas plant receives is processed at first in the hall seen in ***Figure 4***. All the organic material that is used in the biogas production is fed from this hall to the hygienization unit outside the hall. Part of the hygienization unit can be seen in ***Figure 4*** on the right corner **[40]**.

Hygienization unit is a thermally insulated tank (20 m^3) that has been equipped with a mixer pump. The thermally insulated tank of the hygienization unit is heated by the biogas produced in the biogas plant itself. As the name of the "hygienization unit" tells, it is the unit in the biogas plant where all the pathogens in the input are killed. When new organic input is fed into the tank, the computer controlling the process heats the tank up to 70°C and keeps that temperature for a one hour **[40]**. When the new input has been treated and the possible pathogens killed, it can be fed into the biogas reactors seen in ***Figure 5***.

FIGURE 5 Biogas reactors (750 m^3 and 1000 m^3)

The main biogas production process takes place in the smaller reactor unit of 700 m^3, which can be seen in forefront in **Figure 5**. This small reactor account for 85 % of the total biogas produced in the process. The bigger reactor behind the smaller one is the second gasification reactor, where 15 % of the total biogas is produced in the second gasification process **[40]**.

FIGURE 6 Biogas upgrading unit (made by Metener Ltd)

The biogas upgrading unit of Joutsa’s biogas plant is shown in ***Figure 6***. The raw biogas has to be purified and compressed, before it can be used in cars as fuel. Joutsa’s biogas plant produces enough compressed biogas for almost 200 cars annually **[35]**.

FIGURE 7 Joutsa's biogas plants gas refueling station

Price of biogas from Joutsa’s plants own refueling station (above in ***Figure 7***) is around 1,37 €/kg **[40]**. Biogas is not sold in liters, because biogas changes its volume in the accordance of temperature. This is one of the basic rules in physics and chemistry. If one cubic meter (m^3) of biogas is taken into a container, the mass of biogas remains the same regardless of the temperature but the volume of the gas changes, which could result into rupture in the container and/or leakage of the gas from the containers weak spots.

Besides selling the biogas as fuel to motorists, Joutsa’s biogas plant gets its income from collecting gate fees from the waste transports. Gate fees are collected from every waste transport to the biogas plant **[36]**. The amount of gate fee depends on the type of waste that is brought in. In the next page in ***Table 2*** is presented the gate fee (euros per ton of waste) for different types of waste.

3.1 Waste collection

The biogas plant in Joutsa gets its waste from the neighboring municipalities and their waste management plants. This waste is then shipped from the municipalities to Joutsa. The biogas plant uses mainly the organic waste created in the nearby area roughly 100 kilometers wide. As it can be seen in ***Table 2***, approximately 4750 tons of different types of biowaste is processed every year. If needed, the biogas plant can process up to 6175 tons of biowaste per year **[40]**.

*TABLE 2 Amount of raw material into Joutsa's biogas plant (**36**, page 59)*

Feed	Amount [tons/year]	Gate fee [€/ton]
Biowaste	1000	60
Sewage sludge	2000	40
Grease pit sludge	750	70
Septic tank and cesspit sludge	1000	10

3.2 Biogas production capacity

Joutsa’s biogas plant is not the biggest biogas plant in Finland nor in the Central Finland. Despite this, it still produces a noticeable amount of biogas every year. If Joutsa’s biogas plant processes approximately 5000 tons of waste every year, almost 100 000 m^3 of methane is produced every year **[37]**. As a by-product of biogas production process, almost 4400 tons of digestate is produced and sold from Joutsa’s biogas plant as fertilizer every year **[40]**.

Joutsa’s biogas plant uses four different input classes in biogas production; biowaste, sewage sludge, grease pit sludge, septic tank and cesspit sludge. Each input class has its own unique value that is used to estimate the methane production potential, the amount of dry solids and the amount of volatile solids in the input. These unique values for different inputs can be seen in the ***Table 1***, page 16.

$$V_{BIO} = \frac{E_{TOT}}{U}$$ *FORMULA 1*

V_{BIO} = Amount of biogas [m^3]

E_{TOT} = Total amount of biogas energy [kWh]

U = Energy content of biogas per cubic meter 6 $\frac{kWh}{m^3}$

Based on my calculations, Joutsa's biogas plant produces over 800 tons of volatile solids every year. These volatile solids are turned by the anaerobic bacteria into methane. According to my calculations, biogas production in the Joutsa's biogas plant is over 400 000 m^3 every year. If the estimated total amount of biogas energy (2 GWh) from Joutsa's biogas plant was turned into a volume of biogas using the ***Formula 1*** above, the estimated total volume of biogas produced every year would be over 330 000 m^3.

These two results are close enough to each other, so it could be said that my calculations are close enough to the realization of biogas production capacity in the biogas plant of Joutsa. These calculations and other important process parameters are handled in the next chapter **4 Comparison of Biogas Plants**.

3.3 Energy production

Joutsa's biogas plant produces more energy than it needs for its operations. Production process of the biogas uses 15 to 25 % of the produced energy **[41]**. Roughly 2 GWh net worth of biogas energy is produced and brought outside the plant every year **[42]**. The produced biogas energy is mainly burned in the torch of the biogas plant, due to the low demand and amount of consumers that use biogas as fuel in their vehicles. The torched biogas energy could be sold as fuel for vehicles. Joutsa's biogas plant could be able to produce 1,6 GWh net worth of biogas energy to be used as fuel in cars. In reality, a small portion of the total amount of produced biogas (approximately 0,5 GWh) ends up being used in biofuel cars as fuel.

4 COMPARISON OF BIOGAS PLANTS

In this chapter the table values of different biogas plants are compared to Joutsa's biogas plant. These values in the tables were collected from different public sources like environmental permits, study tour reports, news and other releases. The environmental permits are the most reliable sources of information in this thesis, because the items that are managed in them (like the amount of waste processed annually and other important production parameters) are supervised both by the companies themselves and by the government officials.

4.1 Attributes in comparison

There are eight categories in which the biogas plants are compared against each other. The following chapters **4.1.1 – 4.1.8** tell more about the things compared in the different biogas plants and the results of this comparison. These chapters have tables that include a column named “factor” in them. This “factor” tells how many times greater or lesser a certain attribute is in the biogas plant compared to the Joutsa's biogas plant. Joutsa's biogas plant acts as a control for every attribute in these comparisons.

These factor values should be reviewed only as a numbers, not as a definitive truth about the greatness of that specific biogas plant in comparison to others. Every biogas plant has been carefully designed to meet certain requirements and they usually do this extra-ordinary well.

4.1.1 Investments in the biogas plants

Investment is an economical term that means a certain sum of money that has been invested e.g. into a plant in order to make it operate and to keep it running constantly. ***Table 3*** illustrates the amount of investments put into different biogas plants in Finland.

The amount of investments put into a biogas plant can be as low as 1,6 million euros, but you have to keep in mind that the amount of investments often correlates with the size of biogas plants and conclusions can be made about the annual waste capacity of the specific plant. Joutsa's biogas plant has the lowest amount of investments invested into it out of the eight biogas plants in this comparison.

TABLE 3 Amount of investments in the biogas plants

Plant's name and location	Investments	Factor
Joutsan Ekokaasu Ltd / Joutsa	1 600 000 €	1,0
Satakierto Ltd / Köyliö	4 000 000 €	2,5
Haminan Energia Ltd / Virolahti	5 000 000 €	3,1
BioKymppi Ltd / Kitee	5 500 000 €	3,4
Biotehdas Oulu / Rusko	8 000 000 €	5,0
Labio Ltd / Lahti	15 000 000 €	9,4
Lakeuden Etappi Ltd / Pojanluoma	17 000 000 €	10,6
Ämmässuo Waste Treatment Center / Espoo	40 300 000 €	25,2

Table 3 also shows that the five of biogas plants with the lowest amount of investments are quite cheap in comparison to the three biogas plants that have greater amount of investments put into them. The amount of investments in Ämmässuo Waste Treatment Center are 25 times greater than the ones put into Joutsa's biogas plant. It would be logical to assume that everything in Joutsa's

biogas plant would be 25 times smaller in comparison, but the truth is far more colorful than we could expect.

As a side note; the total amount of investments (40 300 000 €) put into Ämmässuo Waste Treatment Center are not investments that have been already invested into it by the time this thesis is published. The investment amount of 40 300 000 € is a prediction of how much money will be invested into the plant between years 2015 and 2019 **[43]**.

Figure 8 illustrates the amount of investments in a more graphical way, the contents of the figure are the same that are listed in ***Table 3*** above. All the biogas plants in this thesis are bigger than the Joutsa's plant, but the difference is not that big if the four smallest plants are compared between each other.

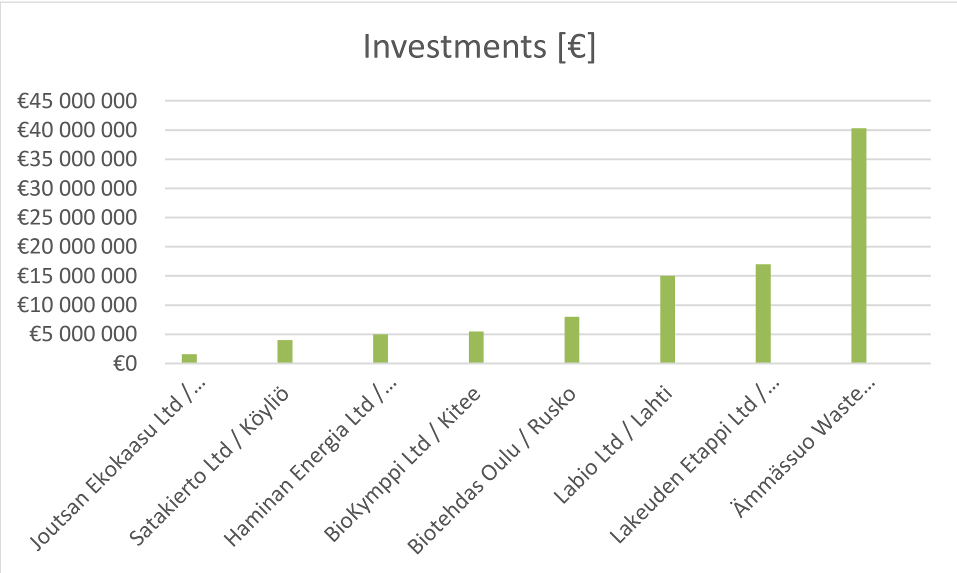

FIGURE 8 Amount of investments

Figure 8 is a good illustration about the biogas plants that were chosen into this thesis. In this thesis there are 4 low investment plants, 3 medium investment plants and 1 high investment plant in this comparison. The distribution percentage of these plants depicts well the amount of different sized biogas plants in Finland.

4.1.2 The annual waste capacity of the biogas plants

Annual waste capacity means the amount of waste that a biogas plant can handle within a time period of one year (1 year = 365 days is used in calculations). Because we are talking about biogas plants in this thesis, the waste type in question is biowaste. These values for annual waste processing capacity for each biogas plant were received from the environmental permits.

In the previous chapter ***4.1.1 Investments in the biogas plants*** different amounts of investments in the biogas plants is presented and compared between each other. Based on the amount investment that was made into a plant, a thing or two could be said about the annual waste capacity of the biogas plant. Higher amount of investments in the plant indicates more than often that the plant's size is noticeable and its annual waste capacity is greater.

TABLE 4 Annual waste capacity of biogas plants

Plant's name and location	Annual waste capacity [tons / year]	Factor
Joutsan Ekokaasu Ltd / Joutsa	4 750	1,0
Satakierto Ltd / Köyliö	19 000	4,0
Haminan Energia Ltd / Virolahti	19 500	4,1
BioKymppi Ltd / Kitee	19 000	4,0
Biotehdas Oulu / Rusko	19 000	4,0
Labio Ltd / Lahti	60 000	12,6
Lakeuden Etappi Ltd / Pojanluoma	55 000	11,6
Ämmässuo Waste Treatment Center / Espoo	60 000	12,6

According to the ***Table 4***, the smallest biogas plant in this category is Joutsa's biogas plant. It is significantly smaller (4,0 times) than the second smallest biogas plant of Satakierto Ltd.

FIGURE 9 Annual waste capacity

Despite the difference in investments between Ämmässuo Waste Treatment Center and Labio Ltd, they are equal in the amount of annual waste capacity that they can process as can be seen in **Figure 9** above. This could be explained by the type of anaerobic digestion process that is used in either plant. One of the positive things in dry anaerobic digestion process is that the process is much faster than the wet anaerobic digestion process. This allows the dry anaerobic digestion process to digest more biowaste, which then can be seen in the amount of annual waste processing capacity.

Other biogas plants than the three biggest ones are pretty much on the same line with each other, except Joutsa's biogas plant. There is a simple explanation for the low annual waste processing capacity of Joutsa's biogas plant: the amount of biowaste that is available close to the plant. Joutsa's biogas plant handles the municipal biowaste created by Joutsa and the four neighboring communes (Hartola, Kangasniemi, Hankasalmi and Laukaa) **[41]**. The amount of people living in these five communes (37 351 people in total) is not overwhelming, when they are compared to bigger communes like Oulu (198 584) or Lahti (118 848) **[44]**. Bigger population means more waste and therefore more biowaste for biogas plants to use. It would also be more expensive to collect biowaste from every household in the commune rather than collect the biowaste from centralized waste management centers.

According to the study made by JLY – Finnish Solid Waste Association (**45**, page 60), the average total annual cost for waste disposal services in a certain property is correlating the amount of people that use the service. The average total annual cost of waste disposal (mixed waste) for a high-rise resident can be as low as 66,3 €/year, when a terraced house residents pay on average 83,6 €/year and detached house residents 87,8 €/year. This annual waste disposal service fee includes the acquisition costs needed for the waste collection containers and their maintenance services (waste collection etc.).

4.1.3 The size of reactor

In ***Table 5*** is listed the size of reactors in different biogas plants. The size of the reactor is dependent on the anaerobic digestion process used in the biogas plant. Wet anaerobic digestion process needs a bigger reactor compared to dry anaerobic digestion process, because the input used in the process consists more of water than the solid organic matter which raises the volume of the sludge.

TABLE 5 The size of reactors in the biogas plants

Plant's name and location	Size of reactor(s)
Joutsan Ekokaasu Ltd / Joutsa	700 m^3
Satakierto Ltd / Köyliö	2300 m^3
Haminan Energia Ltd / Virolahti	6 x 130 m^3
BioKymppi Ltd / Kitee	3000 m^3 (reactor 1) + 1000 m^3 (reactor 2)
Biotehdas Oulu / Rusko	2700 m^3
Labio Ltd / Lahti	4 x 900 m^3
Lakeuden Etappi Ltd / Pojanluoma	2 x 3200 m^3
Ämmässuo Waste Treatment Center / Espoo	2 x 2400 m^3

In comparison to other biogas plants, the biogas plant of Haminan Energia uses extraordinarily small-sized reactors for its biogas production. According to the environmental permit of the biogas plant, the reactors used in the plant are modular shipping containers used to deliver goods across the oceans. These containers are easy to maintain and change, if they would break in the use.

The different amounts of annual waste processing capacities are shown in ***Table 4***, where the biogas plant of Haminan Energia processed annually almost 19 500 tons of biowaste. It is 4 times more than the biogas in Joutsa can handle annually. This difference is mainly due to the dry anaerobic digestion process used in the biogas plant of Haminan Energia.

4.1.4 The different types and amounts of input

Depending on the type of biowaste (see ***Table 1***, page 16), the biogas production potential is much higher with some types of waste. ***Table 6*** below shows the various types of inputs that the biogas plants use. The abbreviation \`WTP\` means \`Water Treatment Plant\`.

TABLE 6 Types of input in the biogas plants

Plant's name and location	Input
Joutsan Ekokaasu Ltd / Joutsa	Biowaste (home + industry); grease residues; sludge (WTP)
Satakierto Ltd / Köyliö	Biowaste (home + industry); sludge (industry + WTP)
Haminan Energia Ltd / Virolahti	Biowaste (industry); sludge (agricultural)
BioKymppi Ltd / Kitee	Biowaste (home + industry); grease residues; sludge (WTP + agricultural)
Biotehdas Oulu / Rusko	Biowaste (home + market + industry); sludge (WTP)
Labio Ltd / Lahti	Biowaste (home + industry); sludge (WTP)
Lakeuden Etappi Ltd / Pojanluoma	Biowaste (home + industry); sludge (WTP)
Ämmässuo Waste Treatment Center / Espoo	Biowaste (home + industry); animal solid manure

It seems that biogas production potential in certain food waste types is higher the more processed and unhealthier the food product is. The organic material that the processed food waste contains is in much easier chemical form for bacteria to degrade it into other substrates. Another biowaste type that has a great biogas production potential is grease residues. They contain lots of short chains of amino acids and fats that are easy to digestate, in the viewpoint of bacteria. Each biogas plant uses a wide variety of different inputs, but the thing that matters in the end is the whole package.

TABLE 7 Amounts of different inputs in the biogas plants

Plant's name and location	Estimated amount(s) of input annually
Joutsan Ekokaasu Ltd / Joutsa	Sewage sludge 2000 tons; Separately collected biowaste 1000 tons; Grease residues 750 tons; Septic tank and cesspit sludge 1000 tons
Satakierto Ltd / Köyliö	Biowaste 550 tons; Sewage sludge (extractor dried) 7000 tons; Cattle manure 6000 tons; Food industry sewage sludge 5450 tons
Haminan Energia Ltd / Virolahti	Cattle manure 9 000 tons; Field biomass 10 000 tons; Fish- and gutting waste 100 tons; Food industry by-products 400 tons
BioKymppi Ltd / Kitee	Biowaste 5200 tons; Food industry by-products 1900 tons; Separately collected park waste 400 tons; Grease residues 2800 tons; Sewage sludge 4500 tons; Cattle manure 1200 tons
Biotehdas Oulu / Rusko	Biowaste 12 000 tons; Food industry by-products 5000 tons; Food industry sewage sludge 2000 tons
Labio Ltd / Lahti	Biowaste (home + industry) 35 000 tons; Sewage sludge 25 000 tons
Lakeuden Etappi Ltd / Pojanluoma	Biowaste 12 000 tons; Food industry by-products 4 400 tons; Sewage sludge 38 600 tons
Ämmässuo Waste Treatment Center / Espoo	Biowaste 37 000 tons; Animal solid manure 642 tons; Food industry by-products 14 000 tons

In ***Table 7*** above can be seen the estimated amounts of input that biogas plants process annually. Biogas plant of Biokymppi Ltd uses the greatest variety of different inputs in its biogas production. In the case of many biogas plants, like Ämmässuo Waste Treatment Center or Labio Ltd, it was hard to find accurate information about the biowaste that it uses. Or more specifically, the exact classes of biowaste. Therefore, I made the crude generalization about the types of waste under terms like “biowaste”, “food industry by-products” and “sewage sludge”.

4.1.5 Biogas production capacity

The energy content of biogas is 6,0 kWh/m^3, when it is assumed that the biogas contains 60 % methane in room temperature (25°C) **[45]**. The annually produced amount of biogas m^3 was converted into kWh using this value. The sources for these biogas amounts are listed in ***Attachment 1***. In the ***Table 8*** can be seen the converted values for each biogas plant. In this thesis the amounts of energy content were not converted into kilowatt-hours (kWh), but instead into gigawatt-hours (GWh). This was done in order to round up some of the results.

One of the surprising results in ***Table 8*** below is the difference of produced biogas energy between Labio Ltd and Lakeuden Etappi Ltd. The amount of investments (see ***Table 3***, page 31) invested in both of the biogas plants were almost equal to each other, but it does not seem to correlate the amount of produced biogas energy in the biogas plants. Labio Ltd produces 2 times the amount of biogas energy that the biogas plant of Lakeuden Etappi Ltd produces annually. In comparison Joutsa’s biogas plant is a small biogas plant, when it comes to the amount of biogas energy produced annually.

TABLE 8 Biogas production capacity in the biogas plants

Plant's name and location	Biogas production capacity [GWh / year]	Factor
Joutsan Ekokaasu Ltd / Joutsa	2,0	1,0
Satakierto Ltd / Köyliö	4,6	2,3
Haminan Energia Ltd / Virolahti	15,0	7,5
BioKymppi Ltd / Kitee	13,1	6,6
Biotehdas Oulu / Rusko	16,2	8,1
Labio Ltd / Lahti	50,0	25,0

Lakeuden Etappi Ltd / Pojanluoma	23,6	11,8
Ämmässuo Waste Treatment Center / Espoo	129,0	64,5

Figure 10 illustrates the fact that despite the size and the huge investments put into the plant, the biogas plant of Lakeuden Etappi Ltd produces almost the same amount of biogas energy annually like the other low and medium investment biogas plants. This could be explained by the reason how the biogas plant of Lakeuden Etappi Ltd uses the biogas energy it produces.

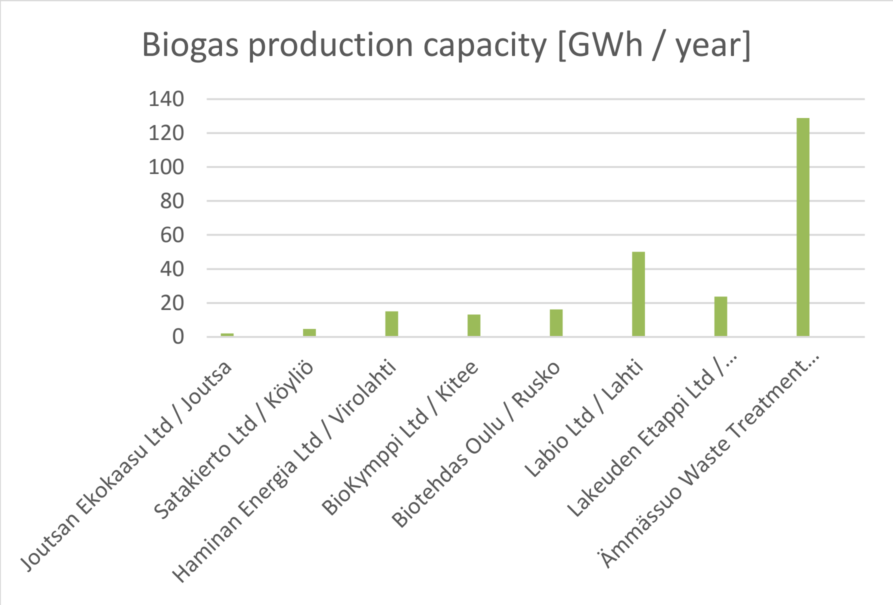

FIGURE 10 Annual biogas production capacity

The biogas plant of Lakeuden Etappi Ltd uses mainly the biogas it produces for the production of heat. The heat produced is then used for the production of water steam, that is used for thermal drying of the digestate. The digestate from the anaerobic digestion process, after it has been dried with the thermal drying process, will be sold as dry fertilizer out of the plant **[46]**.

Approximately 80 to 90 % of biogas energy produced is used in the heat production. The rest of the biogas energy produced that is not used in heat production right away is stored in tanks **[46]**. The excessive biogas is torched, if the storages are full. In order to avoid unnecessary torching in the biogas plant, the biogas production process is carefully monitored and controlled. The biogas production potential is deliberately limited. This could explain the low biogas production capacity that Lakeuden Etappi Ltd has.

TABLE 9 Produced biogas energy per 1 € invested in the plant

Plant's name and location	Biogas production per invested € [kWh / 1 €]
Joutsan Ekokaasu Ltd / Joutsa	1,25
Satakierto Ltd / Köyliö	1,15
Haminan Energia Ltd / Virolahti	3,00
BioKymppi Ltd / Kitee	2,38
Biotehdas Oulu / Rusko	2,03
Labio Ltd / Lahti	3,33
Lakeuden Etappi Ltd / Pojanluoma	1,39
Ämmässuo Waste Treatment Center / Es-poo	3,20

In ***Table 9*** above can be seen the amount of biogas energy in kilowatt-hours that the biogas plant produces annually for each euro that has been invested into the plant. Joutsa's biogas plant produces 1,25 kilowatt-hours worth of biogas energy for one euro that has been invested into the plant. Few things that could be said about the values seen on ***Table 9*** is that the other plants are either more efficient with their biogas production processes or they are bigger biogas plants productively than the Joutsa's biogas plant. Other biogas plants produce more energy for each euro that has been invested into the plants.

4.1.6 Process parameters

This chapter is mostly about the calculations I have made regarding different process parameters. These calculations are mostly based on environmental permits and different public sources. I have included the following process parameters in this thesis; the annual and daily amounts of volatile solids, the computational CH_4 production, the amount of produced biogas energy outside the plant, the hydraulic retention time and organic loading rate.

The amount of volatile solids (VS) dictates the potential amount of produced biogas in any anaerobic digestion process. The amount of VS tells how much of the total solids (TS) is organic waste which can be turned into biogas. While calculating the total amount of volatile solids in the input used by the different biogas plants, the ***Formula 2*** below was used.

$$M_{VS} = M_{IN} \times C_{TS} \times C_{VS} \qquad \textit{FORMULA 2}$$

M_{VS} = Amount of volatile solids in the input $\left[\frac{tons}{year}\right]$

M_{IN} = Amount of input $\left[\frac{tons}{year}\right]$

C_{TS} = Dry matter content [%]

C_{VS} = Volatile solids content [%]

In the next page in ***Table 10*** can be seen the daily amount of input that is fed into the biogas reactors. The daily amount of input was calculated using the values in ***Table 7*** which included the estimated amounts of input fed into the biogas plants annually. This was done in order to get as realistic biogas production figures as possible.

Another way would have been to calculate the amount of input fed into biogas reactors using the annual waste capacities from the environmental permits (see ***Table 4***, page 29). But if these values from the environmental permits are used, they would have raised drastically the total amount of input fed into the reactors daily, which would have affected to the results in the calculations used to calculate the hydraulic retention time. The hydraulic retention time would have been much shorter than it would really be.

TABLE 10 Amount of volatile solids in biogas plants

Plant's name and location	Amount of input [tons / day]	Total amount of volatile solids [tons / year]
Joutsan Ekokaasu Ltd / Joutsa	13,01	807
Biotehdas Oulu / Rusko	52,05	4546
BioKymppi Ltd / Kitee	43,84	3608
Lakeuden Etappi Ltd / Pojanluoma	150,68	9508
Labio Ltd / Lahti	164,38	12005
Haminan Energia Ltd / Virolahti	53,42	3776
Ämmässuo Waste Treatment Center / Espoo	141,48	12549
Satakierto Ltd / Köyliö	52,05	2213

The daily amount of input that is fed into the biogas reactor of Joutsa's biogas plant is not much in comparison to the other biogas plants. This is not a big problem, considering the fact that Joutsa's biogas plant has a small-sized reactor (700 m^3). If the amount of input added daily to the biogas reactor is larger, the organic loading rate would rise and the hydraulic retention time would shorten. This would cause the anaerobic bacteria to have too much organic matter to handle in a shorter time period and this would lead into reduction of the biogas production.

In ***Table 11*** are the computational CH_4 production values calculated for different biogas plants. The table also contains the converted CH_4 values for each biogas plants from their known energy production (see ***Table 8***, page 34). By comparing these two values, the differences between my calculations and the "real" values can be seen. ***Formula 3*** below was used to calculate the computational gas production. The values for different input methane yield potentials, VS and TS contents were taken from ***Table 1***. The annual amounts of input were taken from ***Table 7***.

$V_{COM} = M_{IN} \times C_{TS} \times C_{VS} \times V_{MET}$ FORMULA 3

V_{COM} = Computational methane production $\left[\frac{m^3}{year}\right]$

M_{IN} = Amount of input $\left[\frac{tons}{year}\right]$

C_{TS} = Dry matter content [%]

C_{VS} = Volatile solids content [%]

V_{MET} = Methane yield potential $\left[\frac{m^3\ of\ biogas}{1\ ton\ of\ VS}\right]$

As it can be seen from ***Table 11***, my calculations and "real" values have significant differences. My calculations are roughly 2 – 4 times bigger than the "real" values. This difference is mainly due to my overly optimistic assumption in my calculations that every gram of volatile solids turns into biogas through the anaerobic digestion process, which does not happen in reality. Therefore, the values I have calculated are greater than they really are.

TABLE 11 Comparison of computational and converted methane production

Plant's name and location	Computational CH_4 production [m^3]	Produced biogas energy converted into CH_4 [m^3]
Joutsan Ekokaasu Ltd / Joutsa	401400	200000
Biotehdas Oulu / Rusko	1992900	460000
BioKymppi Ltd / Kitee	3181890	1500000
Lakeuden Etappi Ltd / Pojanluoma	3441000	1310000
Labio Ltd / Lahti	4452000	1620000
Haminan Energia Ltd / Virolahti	1270214	5000000

Ämmässuo Waste Treatment Center / Espoo	5006775	2360000
Satakierto Ltd / Köyliö	643560	12900000

The efficiency of the biogas production process is usually determined using a value called the "daily volumetric production of CH_4". This value tells the amount of produced CH_4 (m^3) in relation to the size of one cubic meter of the biogas reactor. Higher value means that the production process of CH_4 is more efficient in the said biogas plant. The volumetric amount of CH_4 produced daily was calculated using the ***Formula 4*** below.

$$V_{DAY} = \left[\frac{V_{COM}}{V_R}\right] x \left[\frac{1}{365}\right]$$

FORMULA 4

V_{DAY} = Daily volumetric production of methane

V_{COM} = Computational methane production $\left[\frac{m^3}{year}\right]$

V_R = Size of reactor [m^3]

In ***Table 12*** are the calculated values of daily volumetric CH_4 production for different biogas plants. The biogas plant of Haminan Energia Ltd is the most efficient plant in energy production according to the table. What is surprising, is that Joutsa's biogas plant is more efficient in CH_4 production than Lakeuden Etappi Ltd, which had over 10 times higher investments put into the plant. This could be explained by the efficiency of the process used in both biogas plants. Because Joutsa's biogas plant is smaller in comparison, it is theoretically much easier to handle the biogas production process in the reactors and optimize it.

TABLE 12 Daily volumetric production of CH_4

Plant's name and location	Daily volumetric CH_4 production
Joutsan Ekokaasu Ltd / Joutsa	1,571
Biotehdas Oulu / Rusko	2,022
BioKymppi Ltd / Kitee	2,179
Lakeuden Etappi Ltd / Pojanluoma	1,473
Labio Ltd / Lahti	3,388
Haminan Energia Ltd / Virolahti	4,462
Ämmässuo Waste Treatment Center / Espoo	2,858
Satakierto Ltd / Köyliö	0,767

The two of the most important factors to the efficiency of biogas production are hydraulic retention time and organic loading rate. Hydraulic retention time (HRT) tells the amount of days that the input spends in the biogas reactor. Recommended HRT for biogas production is somewhere between 30 – 100 days, depending on the input used in biogas production **[22]**. In ***Formula 5*** below can be seen how HRT is calculated using the size of reactor and the amount of input fed into the reactor daily.

$$HRT = \left[\frac{V_R}{M_{IN}}\right] x \left[\frac{1}{365}\right] \qquad \text{FORMULA 5}$$

HRT = Hydraulic retention time [days]

V_R = Size of reactor [m^3]

M_{IN} = Amount of input $\left[\frac{tons}{year}\right]$

Organic loading rate (OLR) determines the `speed` of the process. To be more precise, it tells how many kilograms of new volatile solids are fed into reactor daily. Recommended daily OLR for biogas production is around 2 – 3 kilograms of new volatile solids fed per each reactor cubic meter, depending on the anaerobic digestion process (mesophilic/thermophilic) used. In thermophilic anaerobic digestion process the OLR can be even higher. ***Formula 6*** below was used to calculate the OLR of different biogas plants.

$$OLR = \left[\frac{M_{VS}}{V_R}\right] x \left[\frac{1}{365}\right]$$ *FORMULA 6*

OLR = Organic loading rate $\left[\frac{kg}{m^3}\right]$

M_{VS} = Amount of volatile solids in the input $\left[\frac{tons}{year}\right]$

V_R = Size of reactor [m^3]

OLR and HRT correlates between each other. Higher OLR means that the amount organic matter in the biogas reactor grows but the HRT shortens. The hydraulic retention time should not be too short, because otherwise the anaerobic bacteria does not have enough time to degrade organic material into substrates that they can turn through their metabolism into biogas. This lowers the production of biogas and in the end, the total amount of produced biogas is lower.

In ***Table 13*** below are the calculated values for HRT and OLR. All the calculated values for HRT are looking reasonable enough, except in the case of Biokymppi Ltd.

TABLE 13 Organic loading rate of biogas plants

Plant's name and location	**Hydraulic retention time [days]**	**Organic loading rate [kg VS/days*m^3]**
Joutsan Ekokaasu Ltd / Joutsa	54	3,159
Biotehdas Oulu / Rusko	52	4,613
BioKymppi Ltd / Kitee	91	2,471
Lakeuden Etappi Ltd / Pojanluoma	42	4,070
Labio Ltd / Lahti	22	9,136

Haminan Energia Ltd / Virolahti	15	13,265
Ämmässuo Waste Treatment Center / Espoo	34	7,163
Satakierto Ltd / Köyliö	44	2,636

The biogas plant of Biokymppi Ltd has the highest HRT, because when I was calculating HRT for the mentioned biogas plant I noticed that the biogas plant has two different sized reactors (1000 m^3 and 3000 m^3) in it. In any of the sources I had found there was no mention about the ratio of how the biowaste is distributed between these two reactors.

Without the knowledge about the ratio of the biowaste distributed between these two reactors, I was left with two options: either I would use the combined reactor size of 4000 m^3 in my calculations or I would try to guess the amount of biowaste fed daily into the reactor. I chose to use the combined reactor size of 4000 m^3 in my calculations, because it would not affect the results as badly as the guessing would have.

Higher OLR values for the Haminan Energia Ltd, Labio Ltd and Ämmässuo Waste Treatment Center are explainable by the thermophilic anaerobic digestion process they use. As previously mentioned, the thermophilic anaerobic digestion process OLR can be even higher than the `normal` 3 kilograms of new volatile solids fed into the reactor per each reactor cubic meter.

4.1.7 The amount of energy produced outside the plant

In this thesis one of the main attributes in review is the amount of energy that the biogas plants produce to the municipal power grid outside the plant. Some of the biogas plants in this comparison were built solely on the purpose of producing energy needed for the factories next to them. For example, the biogas plant of Lakeuden Etappi Ltd produces biogas energy to cover its own consumption of energy needed for its operations. This saves a significant amount of money on an annual basis. Although some biogas plants do not produce energy outside the plant, they still reduce significantly the amount of fossil fuels used annually in Finland for the production of energy and heat.

TABLE 14 Energy production outside the biogas plants

Plant's name and location	Energy production (outside the plant) [GWh / year]	Factor
Joutsan Ekokaasu Ltd / Joutsa	1,5	1,0
Satakierto Ltd / Köyliö	0,0	0,0
Haminan Energia Ltd / Virolahti	12,5	8,3
BioKymppi Ltd / Kitee	10,0	6,7
Biotehdas Oulu / Rusko	14,0	9,3
Labio Ltd / Lahti	47,0	31,3
Lakeuden Etappi Ltd / Pojanluoma	0,0	0,0
Ämmässuo Waste Treatment Center / Espoo	124,0	82,7

Table 14 contains the amount of energy produced outside the biogas plants in gigawatt-hours. Despite the small size of Joutsa's biogas plant and total investments put into the plant, it still beats the biogas plants of Satakierto Ltd and Lakeuden Etappi Ltd easily. Due to this, it is easy to say that the amount of investments does not guarantee the superiority of a certain biogas plant in every aspect.

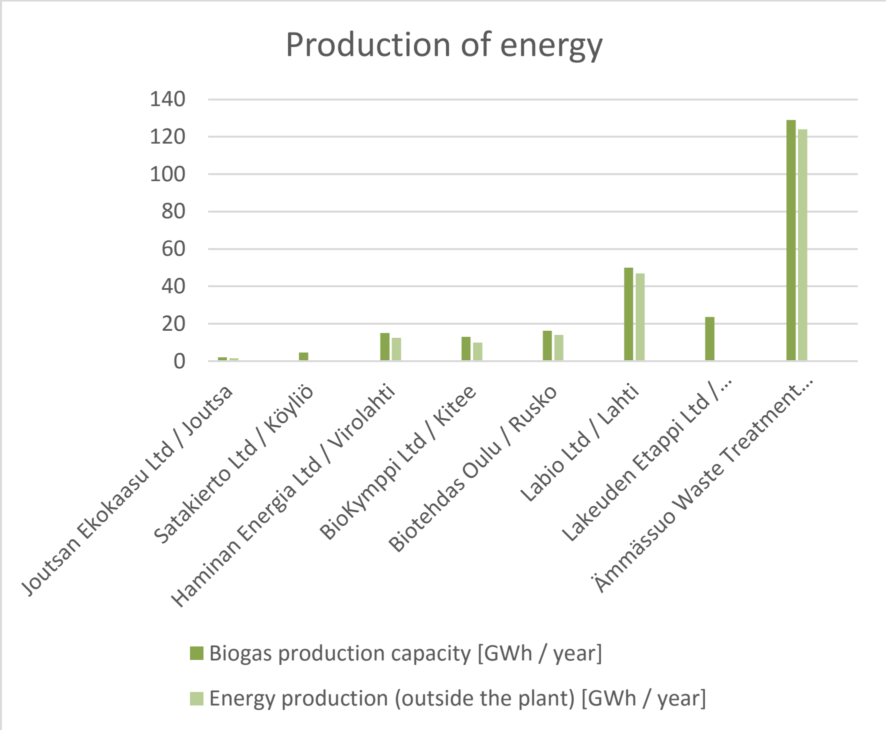

FIGURE 11 Production of energy and its exportation outside the biogas plants

Figure 11 is a graphical illustration about the annual biogas production capacity (see ***Table 8***, page 38) that each biogas plant has and the amount of energy they produce outside the plants into the municipal grid.

But as I stated before, every biogas plant helps to reduce the amount of CO_2 - emissions produced annually. Currently it seems that new biogas plants are being built constantly around Finland. If the current trend continues, Finland might be one of the leading countries in the use of biogas technology in the future.

4.1.8 Possible detriments to the environment

Biogas production is not a risk-free way to produce environmental friendly energy. Sometimes there are unpredictable situations in which detriments to the environment are possible. These detriments to the environment are not severe, but they could affect some harm to the people living near the biogas plants. In ***Table 15*** is mentioned the possible detriments of biogas production to the environment. The information in the table was collected from the environmental permits of different biogas plants. In ***Table 16*** are listed the docket numbers of the previously mentioned environmental permits.

TABLE 15 Possible detriments of biogas production to the environment

Plant's name and location	Detriment(s) of the environment
Joutsan Ekokaasu Ltd / Joutsa	Possible odor emissions, small amounts of wastewater
Satakierto Ltd / Köyliö	Possible odor emissions, amount of wastewater 15 000 m^3/year
Haminan Energia Ltd / Virolahti	CO^2 -emissions from the process, small amounts of wastewater
BioKymppi Ltd / Kitee	Not specified
Biotehdas Oulu / Rusko	Possible odor emissions, mixed waste around 200 kg/year, other types of waste around 10 to 15 % of received waste (incl. metal-, glass- and plastic waste)
Labio Ltd / Lahti	Possible odor emissions, amount of wastewater around 250 – 400 m^3/year. Wastewater can contain hydrocarbons, sulfuric compounds, fats and other impurities
Lakeuden Etappi Ltd / Pojanluoma	Possible odor emissions, amount of wastewater 127 750 m^3/year
Ämmässuo Waste Treatment Center / Espoo	Odor emissions, there is no mention about the amount of wastewaters but presumably significant due to the type of the waste landfill

Joutsa's biogas plant produces small amounts of wastewater due to the biogas purification process used. This waste from the production process is called concentrated wastewater, because the water contains all kind of organic compounds from the biowaste that has been processed. In the case of Joutsan Ekokaasu Ltd, the biogas plant reuses the concentrated wastewater produced in the biogas production process.

Table 16 contains the specified docket numbers for the environmental permits of different biogas plants. Certain important values and pieces of information used in this thesis were mostly collected from these environmental permits. Environmental permits include lots of things that mostly handle the effects or risks caused by the production of biogas to the environment.

TABLE 16 Environmental permits of different biogas plants

Plant's name and location	Environmental permit docket No.
Joutsan Ekokaasu Ltd / Joutsa	11/60/602/2011
Satakierto Ltd / Köyliö	LOS - 2004 -Y - 1047 - 121
Haminan Energia Ltd / Virolahti	ESAVI / 164 / 04.08 / 2012
BioKymppi Ltd / Kitee	ISAVI / 110 / 04.08 / 2010
Biotehdas Oulu / Rusko	POPELY / 4217 / 2015
Labio Ltd / Lahti	ESAVI / 179 / 04.08 / 2012
Lakeuden Etappi Ltd / Pojanluoma	LSSAVI / 357 / 04.08 / 2010
Ämmässuo Waste Treatment Center / Espoo	ESAVI / 705 / 04.08 / 2010 ESAVI / 510 / 04.08 / 2010

As a side note, the biogas plant of Biotehdas Oulu does not have their environmental permit admitted yet for the expansion of their plant. The Environmental Impact Assessment for the expansion of the plant has been started recently **[47]**.

5 SUMMARY

This thesis is a brief review of Joutsa's biogas plant, where its attributes are compared to seven other biogas plants in Finland. Most of these attributes are based on the public knowledge available and calculations made from the environmental permits and other sources (e.g. public statements from biogas plants, news articles and study tour reports). ***Attachment 1*** lists some of these sources used in the tables and calculations.

The reliability of some of these sources is questionable, because they mostly base on the statements and studies that the companies make. I am not saying in this thesis, however that these statements from the companies or certain individuals are completely false or that they base on half-truths. They still are very reliable source of information that gives the scale needed for understanding the measure of their operations in the biogas plants. But the accuracy of these sources could be higher, from the scientific point of view.

The environmental permits are the most reliable sources of information in this thesis, because the various things that are managed in them (like the amounts of waste processed and other important production parameters) are supervised both by the companies themselves and by the government officials.

The amount of investments put into a working biogas plants can be as low as a few tens of thousands of euros. However, the biogas plants compared in this thesis are more expensive than that, because they are producing biogas on a much bigger scale. Even the smallest biogas plant of Joutsan Ekokaasu Ltd in this comparison had 1,6 million euros invested in it and it is able to produce biogas energy worth of two gigawatt-hours annually (see ***Table 8***, page 39). Sources used for these investments can be seen in ***Attachment 1***.

There are lots of different sized biogas plants that can handle varying amount of biowaste annually. The difference in the amount of processed biowaste was concluded to be due to the anaerobic digestion method used. Other biogas plants were processing 4 to 12 times more waste annually (see ***Table 4***, page 33) than the Joutsa's biogas plant.

There is no one way to design a biogas plant. The individuality of the biogas plants can be seen in the amount of different reactor sizes they use in their plants (see ***Table 5***, page 35). If there is one reactor size that would work for any biogas plant, they would use it.

The amount of different types and amounts of input in the Finnish biogas plants is overwhelming. These biogas plants are often built next to the source of input usable in biogas production. A great example of this are the small-sized biogas plants built next to the farms and water treatment plants. Depending on the size of the reactor and anaerobic digestion process used in the biogas plant, certain compromises have to be made regarding the amount and type of input used. Joutsa's biogas plant uses a fair amount of different types of biowaste, but it is no match to the other biogas plants in this comparison (see ***Table 7***, page 37). The other Finnish biogas plants use almost 4 to 12 times more waste than the biogas plant in Joutsa.

It is very hard to determine the exact amount of methane yield potential for each input used in the biogas production, because the amount of variables (e.g. pH, temperature of the reactor, the amount of volatile solids in the input…) in it are countless and every variable affects another. The calculations that I used are only indicative estimations, because I do not know the exact realistic amounts of input that is being used in different biogas plants annually. Those numbers regarding the amount of biowaste used in the biogas plants are often company secrets. Based on the results of my calculations (see ***Table 8***, page 39), Joutsa's biogas plant is one of the smallest biogas plants. The amount of investments put into the biogas plant correlates the most of this attribute.

When I was calculating different process parameters, I noticed that the results of my calculations for the amount of methane produced were often much higher than the results considered as realistic were (see ***Table 11***, page 44). I pointed this out to be the cause of my optimistic assumption in the calculations that the whole process of biogas production works perfectly and everything goes as in the textbook. In the reality this does not happen. All the other calculated values for organic loading rates and hydraulic retention times seemed to be quite normal.

The amount of energy produced outside the biogas plant was one of the things in review of this comparison. Every biogas plant reduces the amount of total energy produced annually by the usage of fossil fuels and therefore they also reduce significantly the amount of CO_2 -emissions. Some of the biogas plants in this thesis were built solely to produce enough biogas energy for themselves and the factory next to them. These biogas plants produce very little or no energy to the municipal power grid. Because of this, Joutsa's biogas plant produces more energy outside the plant to the municipal power grid and it even beats in comparison some of the bigger biogas plants. One of the biggest biogas plants that Joutsa's biogas plant beat in this comparison was Lakeuden Etappi Ltd (see ***Table 14***, page 49), that had investments of 25 times greater than the biogas plant of Joutsa (see ***Table 3***, page 31).

The production of biogas is not risk-free to then environment. These risks even at worst are still quite harmful, when compared to the energy production using nuclear power or fossil fuel. Joutsa's biogas plant had some of the lowest risks to the environment in the whole comparison (see ***Table 15***, page 51).

But in the end of this thesis, what can I say about these biogas plants in Finland? In my opinion, each biogas plant in the world is a true display of skillful engineering. As I previously stated on this thesis, there is no one way to design and built a biogas plant. The amount of requirements and variables are different in each case. These things are not an insurmountable obstacle, they just are a mere slowdown for the engineers planning these plants. Using the local possibilities is the future of biogas production in Finland. Hopefully in the future we will see more of these domestic biogas plants similar to the plant of Joutsan Ekokaasu Ltd. The ever-continuing job of testing different process parameters and input compositions will continue in Metener Ltd and countrywide in Finland.

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ATTACHMENTS

ATTACHMENT 1 Sources for different biogas plants

Plant's name and location	
1	Joutsan Ekokaasu Ltd / Joutsa
2	Satakierto Ltd / Köyliö
3	Haminan Energia Ltd / Virolahti
4	BioKymppi Ltd / Kitee
5	Biotehdas Oulu / Rusko
6	Labio Ltd / Lahti
7	Lakeuden Etappi Ltd / Pojanluoma
8	Ämmässuo Waste Treatment Center / Espoo

SOURCES:	
1.	http://www.joutsa.fi/d5web/kokous/2011652-6.PDF
	http://www.agronomiliitto.fi/site/assets/files/4708/erkkikalmari.pdf
2.	https://portal.savonia.fi/img/amk/sisalto/teknologia_ja_ymparisto/ymparistotekniikka/Biokaasulaitoskierros%20syyskuu%2009.pdf
3.	https://asiakas.kotisivukone.com/files/biolaitosyhdistys.palvelee.fi/Ristola_20152.pdf
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