Biogas Potential In South Greenland

Arctic Technology 11427 – 2011

Supervised by Arne Villumsen and Adriana Hudecz

Tina Lerøy

12/1/2011

Preface

This project is submitted for the Arctic Technology 11427 course, at the Arctic Technology Centre at the Technical University of Denmark (DTU), and accounts for 15 ECTS. The work has been carried out in three different staged from February 2011 to December 2011. The first part consisted of theoretical and analytical studies of Greenland in general, and preparation for the fieldwork. The second part was developed in South Greenland as fieldwork, under the supervision of Adriana Hudecz. I was in South Greenland from 28.07.11 to 18.08.11. The third and final part consisted of analysis and redaction of the data and conclusion of the project in South Greenland.

The project was conducted under the supervision of Arne Villumsen and Adriana Hudecz. I would like to thank both supervisors for their guidance through the project. I will also thank my contact persons in Greenland; Leif Baadh, Steffen Bertelsen and Jon Rasmussen.

Handed in the 1th of December 2011;

Tina Lerøy (s101362)

Abstract

This report describes the study of potential of biogas production in South Greenland, with main focus on the three cities; Qaqortoq, Narsaq and Nanortalik. The purpose with this report is to investigate it there is potential to produce biogas from available organic waste in South Greenland. It has been evaluated from a management point of view.

It is much food and agricultural production in South Greenland, due to the mild climate. It is therefore much available organic waste, which can be utilized to be a resource instead of a problem. Waste is an overall problem in South Greenland, and there is a need for better waste management. There is no tradition for cleaning the wastewater, and today the wastewater is dumped directly in to the sea. This project looks at the possibilities to use the organic waste and wastewater to produce biogas.

During this report, it will be developed different solution to utilize the organic waste in a biogas production. The main focus on the project will be on management aspects concerning biogas production in the three cities, such as; demand, logistic, production, maintenance, profit, benefits, constraints, and locations. It is investigated how the available organic waste can be used in the best way, and opportunities for profitable biogas production. There has also been done research about the existing waste management in the cities in order to see if it is possible to include biogas production with the existing waste management. Transportation and logistics is also been investigated in order to find the best location and solution for a potential biogas plant.

Finally some different solution will be presented and suggestion about how to go further on with biogas production in South Greenland.

Table of Contents

Figure List:

Table List

1 Introduction

The objectives of this project have been to evaluate the potential of biogas production in South Greenland. The report will have main focus on biogas potential in Qaqortoq, Narsaq and Nanortalik, because this is where the fieldwork has taken place. These are the three biggest cities in South Greenland and are therefore where the biggest possibilities and demands for biogas are.

Most towns and cities in Greenland are located at small areas or islands surrounding the coastline. The infrastructure is more or less nonexistent, due to long distances between the cities, location of the cities, and other natural conditions such as permafrost. One of Greenland's primary energy supply sources is diesel power, making biogas an interesting topic due to the increasing focus on green technology. Looking at possibilities for reducing demand of fossil fuel, biogas production in South Greenland is a way to contribute to sustainable development.

The purpose has been to investigate if it is possible to use biogas to produce local energy as a displacement of fossil fuel. This will reduce the emission of particularly greenhouse gasses, which is harmful to the environment. Another purpose with biogas production is to solve some of the waste problems in Greenland. Today there are not very good solutions of waste management, and waste is a big problem in some of the cities in South Greenland. If it is possible to utilize the waste, which is a problem, to solve another problem it would be very beneficial for the society. Biogas production can also have a positive impact on the local economy, and can generate labor.

Biogas is a very interesting topic, and can have huge potential if organic waste is manages the right way. 5,000 tons of organic waste can under right condition produce energy equivalent to 10.000.000 kWh. In order to utilize the potential and to get the best solution, it is important to investigate and map local constraints which exist in South Greenland.

The main focus on the project will be on management aspects concerning biogas, such as planning, logistic, production, maintenance, profit, constraints, benefits, etc. It will be investigate how one can use the available organic waste in the best way, and opportunities for profitable production.

2 Fieldwork

The field work in South Greenland was carried out 28th July to 18th August. I visited the three cities; Qaqortoq, Narsaq and Nanortalik, where research was done.

The primary objective for the field work was to collect information concerning biogas production. I visited local factories, power plants, farmers, and technical department at all the three cities. I interviewed different potential stakeholders, such as; the manager for technical department, the local manager for the hydropower plant, the manager for the power plant in Nanortalik, workers at the incineration plant in Qaqortoq, workers at “dumpen”, workers at fish factories, workers at Great Greenland, workers at Royal Arctic Line’s office in Nanortalik, etc. I also spooked with random people in order to hear their opinion about biogas, waste management and other relevant subjects.

I collected as much possible data from the technical department, Nukissorifit, and factories. Some was more willing to share information than others.

3 Geographic

The geographic area in this report are based on Kujalleq which is a municipality located in South-Greenland. This chapter will give an overview about Greenland in general, and a more detailed overview over South Greenland, Kujalleq municipality and the three cities; Qaqortoq, Narsaq, and Nanortalik. The geographical area is an important factor for biogas production, and it is important to adapt potential biogas production to the geographical constraints and conditions in order to get the best utilization of the available resources.

3.1 Greenland

Greenland is an autonomous country within the Kingdom of Denmark, located between the Arctic and the Atlantic Oceans, east of the Canadian Arctic Archipelago. Greenland is physiographical a part of the continent of North America, but has been politically and culturally associated with Europe, specifically Norway and Denmark, the last thousand years. Greenland is, by area, the world's largest island that is not a continent, with an area of 2,166,086 km ^{2}. In Greenland, only 410 449 km ^{2} are free of ice, which means that approximately 81% of the island is covered with ice. With a population of 56,615 (January 2011 estimate) it is one of the least densely populated dependencies or countries in the world (Greenland u.d.). The population, are mostly located in the west coast areas.

Greenland is divided into 3 regions, which are: West Greenland, East Greenland, and North Greenland. This was until 2008 divided into 18 municipalities. As a part of the Structural Reform 2009, 4 new municipalities was formed; Kujalleq, Qaasuitsup, Qeqqata and Sermersooq. Sermersooq is the largest municipality, and covers the capital, Nuuk.

3.1.1 Climate

The climate in Greenland is predominantly Arctic. This means that the mean temperature, even in the summer, does not reach above +10 °C. The country large extent leads to significant climatic variations between northern and southern Greenland, but there are also large variations between the coast areas, especially between the area where there is open water all year, and the inland areas.

The open sea has a cooling effect on the air during the summer, while in winter time it has the opposite effect. Therefore, the winters are mild and summers are cooler along the coast of southern Greenland, while the coast north of the open water area has cool summers and cold winters.

Precipitation conditions vary considerably in Greenland. In South Greenland the yearly rainfall fluctuate from ca. 800 to over 1,400 mm. but north and in the inland, rainfall decreases sharply. In the far north and inland is the yearly precipitation below 200 mm, while in some places, the precipitation is so insignificant that the area can be described as an Arctic desert.

Day length varies considerably from different localities in Greenland, depending on the season. Nanortalik in South Greenland, which lies south of the Arctic Circle, has no periods of midnight sun or polar night. At the Arctic Circle, there will be a few days with midnight sun and polar night. The further north, the longer becomes the two periods (DMI u.d.).

3.1.2 Transportation

As Greenland is an island one must either fly or sail to get there. It is one of the most expensive destinations in the world despite the fact that the transport is supported by the government.

The way to get around in Greenland is mainly by helicopters, ships, hiking, and in some areas, dog sleds and snowmobiles, since almost no towns and villages are interconnected by roads. In the cities there are some roads, and there are a large number of cars compared to the population in the cities. There are around 150 km of roads in the whole country; where 60 km of the roads are paved. Two towns are connected by a 4.5km road, Ivittuut and Kangilinnguit; the rest are isolated. Historically the major means of transportation has been by boat around the coast in summer and by dog sled in winter, particularly in north and east. Snowmobiling and dog sledding is still used as an option when there is snow. There are modern liners that sail between the cities and villages in the west coast from north to south, and connect the cities and villages. There are ports at Ilulissat, Kangerlussuaq, Qaqortoq, Narsaq, Nanortalik, Nuuk, Aasiaat and Sisimiut. Several other towns have also small ports. The only two users of the harbors are Royal Arctic Line and Arctic Umiaq Line. Transportation to Eastern Greenland is only by plane and helicopter, and the transport ships do not arrive at 5 months every winter.

Weather conditions often create troubles for the transportation. Shipping can be made difficult because of icebergs and frozen seawater in the winter months, and air travel can also be difficult because of the weather conditions. (Greenland u.d.)

3.1.3 Business and Economy

Although Greenland has an industrial structure that covers most industries, natural household still plays a major role. Natural Household is "unpaid own efforts to provide food for personal consumption". Much of the population live on their own hunting and fishing, and the value of their work are not included in official figures, and numbers, such as gross domestic product (Glomsrød, Holtsmark og Aslaksen 2007).

Climate change means that the traditional hunting culture is in retreat. Warmer climate makes it more difficult to travel by dog sledge, and makes e.g. hunting more difficult. Warmer climate also results in more open water which gives better fishing conditions, and is favorable for the fishing industry, especially fishing boats. One can also see an increasing centralization were people move from small villages to larger towns, which confirms this effect. Greenland's economy is currently dependent on fishing and fish exports, and products from the sea are the largest source of income. Tourism, focusing on accommodation, adventure tours and nature experiences are also a very important, and are today a growing source of income. This is however limited due to a short tourist season and high costs (Norden 2009).

Public sector, including publicly owned companies, plays a major role in Greenland's economy. About half of government revenues comes as grants from the Danish government, and is an important contribution to the economy. Greenland receives approximately 3.5 billion DKK from Denmark each year, which equals 40 percent of Greenland's gross domestic product. The country has relatively large social problems, and the differences between rich and poor are high. Political scientist believes that it can take about 50 years before the country can survive on their own and that they rely on to find oil in the ground in order to earn enough money on their own (Glomsrød, Holtsmark og Aslaksen 2007).

Oil and gas, and extraction of minerals are two industries that are looking for opportunities to create a business in Greenland. The challenge with oil, gas and minerals is that the amount must be large enough, while production costs must be low enough in order to get a profitable result. It can be really expensive to produce oil and gas in Greenland, and one have to be extremely careful so it would not harm the natural resources which are available in Greenland today, e.g. fish (Gautier 2007).

Greenland expert Martin Paldam stated in 2009 that the main problems in Greenland is that state-owned companies are with a deficit, the lack of higher education among the inhabitants, and that the long quest for natural resources like oil, gas and minerals have so far not been very successful (Dagbladet 2009).

3.2 South Greenland

South Greenland is a region full of contrasts, known for its ice-filled fjords, flowering plains and fertile valleys, breathtaking mountains, glaciers and mineral-rich mountain landscapes. The region has a well-developed farming industry with extensive grazing pastures for sheep, horses and also some cows. This is the part of Greenland that is actually very green. One of the first people to realize the great potential in South Greenland was the Viking Erik the Red, who, inspired by the green landscapes, named the country: Greenland. The climate at the time - around 1000 years ago, was relatively mild and conditions were favorable for farming, and this is still true of the climate in South Greenland today (Greenland u.d.).

South Greenland fully lives up to its name, as this is the most fertile part of Greenland. In fact most of the flora of Greenland grows here. The winter climate is relatively mild, and summer temperatures reaching 16-18°C are not uncommon. These high temperatures provides good conditions for modern sheep farming and other types of farming that are not seen in other parts of the country. Because of these conditions, the economic life of this area is also different from the rest of Greenland, with sheep farming and agriculture playing an important part. The sheep farmers are often located isolated among the fjords, some of which have paths and rough roads leading to them, while for others the only contact with the outside world is by boat. The sheep are collected in the end of September, and the lambs are taken on flat-bottomed boats to the slaughterhouse in Narsaq (Greenland Guide u.d.).

The field ice is a remarkable phenomenon of South Greenland. This ice comes from the Arctic Ocean north of Greenland and are in the spring and summertime carried down the east coast, round Cape Farewell and up into South Greenland's bays and fjords. Unlike the icebergs, the field ice consists of enormous sheets of frozen salt water, which are in constant motion. Sometimes cities and villages can be cut off from visiting boats by the field ice for periods in the spring and summer, and then only helicopters can supply the provisions and services. The field ice also brings seals, and seal hunting and fishing contribute to the local economy as well as sheep farming (Greenland Guide u.d.).

The distances between cities and villages are usually quite short in South Greenland compared to the rest of Greenland. The journey from Narsaq to Qaqortoq, for example, takes only one hour by boat and twelve minutes by helicopter. It only takes another twenty minutes by helicopter to reach Nanortalik. Hence to the "short" distances, it is possible to transport e.g. sheep and vegetables from the farmers to the cities and villages without too high transportation casts. (Greenland Guide u.d.)

3.3 Kujalleq Municipality

Kujalleq is a relatively new municipality, which is located in the southern end of Greenland. The municipality was created 1 January 2009, and consists of the former municipalities Nanortalik, Narsaq and Qaqortoq. In addition to these former municipalities, Kujalleq also assigned a larger, but uninhabited, piece of land on the east coast of Greenland (Kommune Kujalleq u.d.).

Figure 1: Map of Kujalleq

With 7,589 inhabitants (January 2010), it is the least-populated municipality in Greenland. The administrative center of the municipality is located in the biggest city in Kujalleq; Qaqortoq (Grønlands Statistik u.d.). Kujalleq is not only the least-populated municipal, but also the smallest of the four municipalities in Greenland, with an area of 32,000 km2.

Kujalleq's coat of arm depicts a ram's head. The head are symbolizing all the sheep in the municipality, which is one of the most important industries in Kujalleq. There are many sheep farmers in this area combined to the rest of Greenland, due to the fertile surroundings. In the figure below, one can see Kujalleq's coat of arm. (Heraldry of the World u.d.)

Figure 2: Kujalleq's coat of arm.

3.4 Qaqortoq

Qaqortoq was founded in 1775 by merchant Anders Olsen, and the name literally means "white". It is South Greenland's traffic, educational and cultural center, and is located between the cities Nanortalik and Narsaq in a beautiful area with lots of opportunities for hiking or sailing. Qaqortoq is called the "capital" of South Greenland, and is South Greenland's largest town with and 3.308 inhabitants' pr. October 2011. The city is the only settlement in South Greenland exhibiting growth patterns over the last two decades, with migrants from the smaller villages reinforcing the trend. The primary industries in the town are fishing, service and administration, and as the centre of education for South Greenland, Qaqortoq's streets are characterized by the many students living here (Greenland u.d.).

Qaqortoq is a seaport and trading station. Fish and shrimp processing, tanning, fur production, and ship maintenance and repair are important activities, but the economy is based primarily on educational and administrative services. The local sealfur industry produces products for export, especially the *Great Greenland Furhouse*, are one of the major employers in the town. Like the rest of Greenland, Qaqortoq is critically dependent upon investment from Denmark, and of all exports produced in Qaqortoq are 70 % headed for the Danish market.

Qaqortoq is the main centre for education in South Greenland, and has a primary and lower secondary school, an upper secondary school, a school of commerce, a folk high school which started as a workers college, *Sulisartut Højskoliat*, in 1977, and a basic vocational school. The town has no educational facilities for higher academic learning (Blue Ice u.d.).

As with the rest of Greenland, unemployment in south Greenland and also in Qaqortoq is high. In 2010, the unemployment was at 10,4 %, an increase of over 1.2% since 2009. Today is the city in economic growth, and is a city with a wealth of opportunities and different activities (Kujalleq Kommune u.d.).

3.5 Narsaq

Narsaq is South Greenland's most fertile town, and the name Narsaq means "the plain" in Greenlandic, and the name is due to the large green plain on which the town lies. The glaciers north of the town ensure that there are almost always icebergs around Narsaq, and the fjords around the Narsaq peninsula are rich in seals, salmon, and whales.

Narsaq is a relatively young town, and was only granted civic status in 1959 at a time when there were only 600 people living in the town. Narsaq has 1.596 inhabitants as of 2011, and is the second-largest town in the Kujalleq municipality. The population has decreased with over 11 percent relative to the 1990 levels, and has been decreasing over the last several years. Most towns and settlements in southern Greenland exhibit negative growth patterns over the last two decades, with many settlements rapidly depopulating (Greenland Guide u.d.).

Today Narsaq has a town hall, two supermarkets, a church, a police station, a forestation, a primary school, several educational facilities, an internet café, a hospital, and several small shops. The only Food Science College in the country is located in Narsaq. The school, INUILI, is the main education center for chefs in Greenland, and it has a staff of 20 (INUILI u.d.).

The majority are employed in fishing or sheep-farming. Fishing is the mainstay of the local economy, and the local fjords are full of marine life. Farming is possible on the plains to the north of the town, with several actively maintained arable fields. Of the 53 registered sheep farms in Greenland, 31 are located in the Narsaq area. The farms produce meat for domestic consumption, and the Narsaq slaughterhouse Neqi is the only slaughterhouse in the country. The third major part of the economy is tourism.

3.6 Nanortalik

Nanortalik was founded as a trading place in 1797. Today it is Greenland's southernmost town with 1,385 inhabitants as of 2011. Nanortalik is the third-largest town in the Kujalleq municipality. The district around Nanortalik is home to around 2,000 people distributed between the town itself, five settlements and a number of sheep farmers. The population has unfortunately been decreasing over the last several years. (Kujalleq Kommune u.d.).

Nanortalik lies in an area of natural beauty consisting of some of Greenland's picturesque fjords, small woodlands and steep mountainsides. The town's name means the "place of polar bears", which refers to the polar bears that occasionally pass by the town in the summer together with the field ice from the Arctic Ocean. Nanortalik is known for its natural "skyscrapers", the steep, jagged peaks and sheer cliffs in. Nanortalik is a Mecca for adventurers who love mountain climbing, rock climbing, hiking and kayaking. (Geenland u.d.).

Nanortalik has little productive trade. Today there are no plants or industry in Nanortalik. The primary occupations beside tourism are mainly fishing, crab trapping, hunting of seals and seabirds in small scales, and service and administration. Tourism is therefore an important industry for the city, especially since the fish factory is no longer running. The city is hoping to expand the tourist industry the coming years. Since nature around the city provides a good basis for adventure tours and hiking, is there a great potential for expansion. In 2003, Nalunaq Goldmine opened 40 km northeast of the city, which employs a number of local resources (Kujalleq Kommune u.d.).

4 Environment

Kyoto agreement is an international agreement where purpose is to protect the earth's climate. The countries acceding to the protocol have to limit and subsequently reduce their emissions of carbon dioxide and five other greenhouse gases, see table 1. The treaty is a continuation of the UN Convention, "(UNFCCC)". The agreement means that global emissions of greenhouse gases must be reduced by 5.2% compared to 1990 levels until 2008-2012. The protocol implies in particular that the EU must reduce its emissions by 8%, USA with 7% and Japan by 6%, 0% for Russia, China and India. Greenland is partly committed through Denmark, but nothing states that Greenland has committed itself to a reduction towards Denmark. However, Greenland wants to be a part of these commitments, and Greenlandic politicians are trying to reduce the country’s import of fossil fuels, by increasing the use of clean energies such as hydropower. (United Nations Framework Convention on Climate Change u.d.)

Greenhouse gases	
Carbon dioxide	CO2
Methane	CH4
Nitrous oxide	N2O
Hydrofluorocarbons	HFCs
Perfluorocarbons	PFCs
Sulphur hexafluoride	SF6

Table 1: Greenhouse gases

4.1 Environment in Kujalleq

One of Greenland’s primary energy supply sources is diesel power, and the government wants to reduce the demand of fossil fuel. The greenhouse gases are just one of the problems concerning fossil fuel. Beside the emissions is it expensive to transport and use fossil fuel in Greenland, and it would have been beneficial if it was possible to reduce the import of fossil fuel.

Another environmental problem in South Greenland is waste and waste management. They have trouble to handle and get rid of waste in the villages and cities, in a sustainable way. Today is it normal to burn the waste in an open fire at a waste deposit nearby the cities. That is not an environment friendly solution, and the energy in the waste is not utilized. Wastewater is also an environmental problem. Today all the wastewater and sewage from the inhabitants and the industry are dumped straight in to the sea. Research done in Sisimut shows that wastewater can have a negative effect on the marine environment.

Since tourism is a very important industry in South Greenland is it important to take care of the nature, and therefore is it important to do something and find some solution which can help them to solve some of their waste problems.

5 Waste

Waste has existed as long as a human has. The main problem with waste today is primarily urbanization, which means that human activities are concentrated into more limited areas than earlier. There are many different definitions of waste. On definition of waste comes from Waste Framework Directive (European Directive (WFD) is:

"Waste is any substance or objects the holder discards, intends to discard or is required to discard. It is objects that no longer have its original value".

It also says that once a substance or object has become waste, it will remain waste until it has been fully recovered and no longer poses a potential threat to the environment or to human health. Waste can also been seen as a resource by recycling and recovery (WFD 2011).

Waste management concerns the collection, transport, processing, disposal, managing and monitoring of waste materials. It usually relates to materials produced by human activity, and is generally undertaken to reduce the effect waste has on, the environment, aesthetics or health. Waste management is a distinct practice from resource recovery which focuses on delaying the rate of consumption of natural resources. Waste management treats all materials as a single class, whether solid, liquid, gaseous or radioactive substances, and tries to reduce the harmful environmental impacts of each through different methods. The practice of waste management is different around the world, and the differences are especially high between developing countries and developed countries (WFD 2011)

5.1 Waste Hierarchy

Waste hierarchy is a common used concept in waste management. The idea of waste hierarchy is to extract the maximum practical benefits from products and to generate the minimum amount of waste. The aim is to achieve minimal environment impact with the most appropriate solution from an economical point of view, where cleaner technology and waste minimization has highest priority. The waste hierarchy refers to 5 steps which are; reduce, reuse, recycle, recovery, and disposal. The steps classify the waste management strategies according to their desirability in order of importance. Underneath one can see figure 2 showing the pyramid (IFF u.d.).

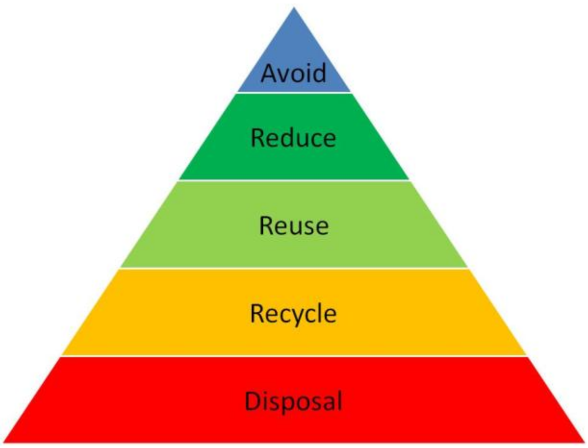


Figure 3: Waste hierarchy

The waste hierarchy is a strong approach and easy to communicate if the purpose is to avoid land filling, but some aspects are not so well addressed. One aspect is that waste minimization and cleaner technology can be very difficult for locals and regional bodies because they do not have the recourses and power to address this. The second aspect is that Kyoto protocol forces many countries to reduce their use of fossil fuel. Therefore are countries using energy produced from solid waste and thereby there is a question about prioritizing material recovery or energy recovery. (Christensen 2011)

Waste prevention is primarily a positive loaded concept. It deals with waste that has a potential reuse value, which includes utilization of materials that have recycling potential before the rest goes to final disposal. It is important to have good handling system of waste and good waste management in order to achieve an efficient result due to reuse of waste. It is therefore necessary to have a broad understanding of resource consumption in the society where the waste reuse takes place. Economic growth, consumption patterns, waste reduction in terms of cost and environmental, are all critical aspects within waste management. It is important to intervene where waste reduction has greatest cost-, and environmental impact, both in production and consumption.

In this report the focus will be on biogas, which is on solution of waste management. Organic waste is biodegradable, which means that it is possible to exploit the waste and produce biogas, which in turn can be utilized locally to e.g. heating or electricity production. In biogas production there is also an opportunity to remedy sewage problem because sewage is also organic waste. To use organic waste to produce biogas is a method that reuses the waste, and can therefore be placed under *Reuse* in the waste hierarchy. One can reuse the energy that consists in the organic waste for produce energy in form of e.g. heat, electrical power, fuel, etc. The biomass that occurs after the process can also be reused as fertilizer. Today it is not realistic to try to reduce the organic waste in South Greenland, and therefore will the focus bee to see if there is possible and realistic to reuse the organic waste in South Greenland in order to produce biogas.

6 Biogas

The main area in this report is the biogas potential in South Greenland. To be able to meet the objectives of the project it is necessary to gather theoretical material. The theoretical materials are needed to be able to analyze the gathered information and data. In this chapter will there be presented some relevant theory concerning biogas, biogas production and biogas plants. It is considered that theory about the chemistry and composition of biogas and biomass is also relevant, and there will also be presented an introduction to that.

6.1 Biogas

Biogas is the gaseous product of the anaerobic digestion (decomposition without oxygen) of organic matter. Biogas is the term of a mixture which mainly consists of methane and carbon dioxide which is formed when organic materials decomposes under anaerobic conditions, with absence of molecular oxygen. The relation between CH4 and CO2 varies, and the composition of final biogas depends on e.g. the composition of the organic material, operation condition of the digester, etc. Biogas also consists of smaller amounts of other compositions, which are shown in the following table. Biogas from landfills may, due to influx of air, have a nitrogen content of up to 20%. Biogas is sometimes called swamp gas, landfill gas, or digester gas. When its composition is upgraded to a higher standard of purity, it can be called renewable natural gas. (cities u.d.)

Methane, CH_4	45 – 70 %
Carbon dioxide, CO_2	25 – 45 %
Vapor, H_2O	0 – 10 %
Nitrogen, N_2	0,1 – 5 %
Hydrogen sulfide, H_2S	0,1 – 0,5 %
Ammonia, NH_3	0 – 0,5 %
Oxygen, O_2	0 – 2 %

Table 2: Typical composition of biogas

Biogas can be burned directly for heating, in production of electricity in gas turbines; it can be processed in to gaseous fuel, converted to liquid fuel, or converted to electricity in fuel cells. Biogas can also be used as an alternative vehicle fuel in the same forms as conventionally derived natural gas: compressed natural gas (CNG) and liquefied natural gas (LNG). (Afds Energy u.d.) Depending on the use, it may be necessary to purify the gas for H2S and H2O because these lead to corrosion problems in fittings, burner and engines. When upgrading the gas to liquid fuels can leads traces of H2S to catalyst poisoning. Carbon dioxide and nitrogen is inert, but does not contribute to the burning value and are therefore removed in applications where higher heating value is necessary.

Biogas is used in many different applications worldwide. In some communities small-scale digesters provide biogas for single-household cooking and lighting. China alone is estimated to have 8-17 million small-scale digester. Large-scale digesters provide biogas for electricity production, heat and steam, chemical production, and vehicle fuel. In 2003, the United States consumed 147 trillion BTU (British thermal unit) of energy from landfill gas, about 0.6% of their total natural gas consumption (Afds Energy u.d.)

The chemical process that happens in a biogas plant is: **$4\ H_2 + CO_2 \rightarrow CH_4 + 2\ H_2O$.**

6.2 The various substrates eligible for anaerobic digestion

As shown in figure 3, are substrates for anaerobic digestion derived primarily from one major source. Historically anaerobic digestion has mainly been associated with animal manure and sewage sludge from aerobic wastewater treatment plants. The increased environmental consciousness in the 1970s accompanied by the demand for new waste management strategies and renewable energy, industrial and municipal wastes became more normal to use (Steffen, Szolar og Braun 1998).

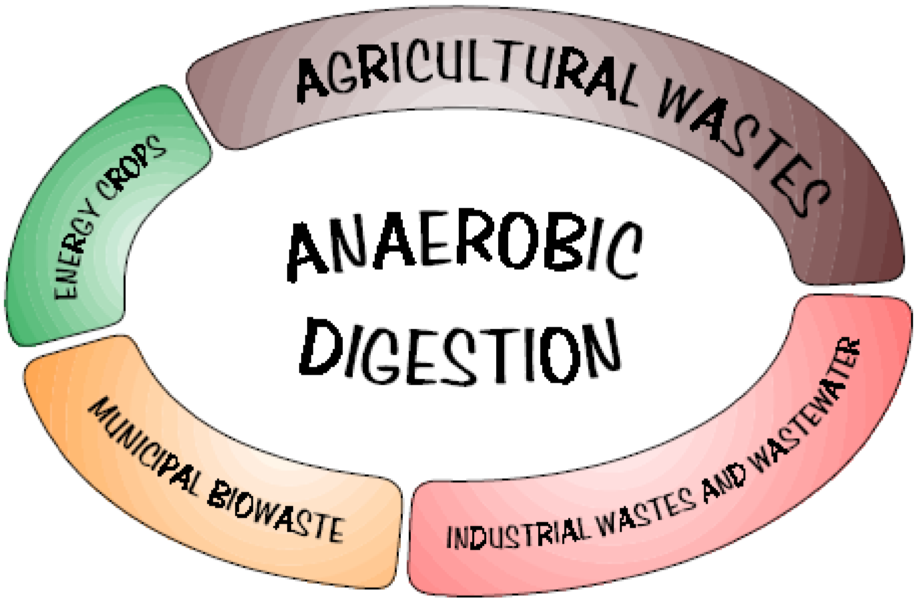


Figure 4: Sources of eligible substrates for anaerobic digestion

Concerns over land filling of solid wastes stimulated engineers to consider new approaches to their treatment before disposal. For example solid and semi-solid wastes such as the organic fraction of municipal solid waste, currently commonly disposed of to landfills or aerobically composted, may be treated anaerobically, saving landfill space and converting the organic material partially to energy.
Table 3 shows an overview of various substrates assigned to the three different sources of organic matter. Agriculture accounts for the largest potential feedstocks and most current applications.

Source	Substrates
Agriculture	•Manure e.g. cattle, pig, poultry •Energy crops •Algal biomass •Harvest remains •Etc
Communities	•Organic fraction of municipal solid waste •Sewage sludge •Garden waste, etc. •Food remains •Etc
Industry	•Food/beverage processing •Dairy •Sugar industry •Pulp and paper •Slaghterhouse/rendering plant •Etc.

Table 3: Various substrates assigned to the three different sources of organic matter

6.3 Anaerobic Digestion

Anaerobic digestion is a well-established technology suited for wastewater or wastes containing high levels of organic matter. Anaerobic waste and wastewater treatments are cheaper and simpler to operate than aerobic processes, as there is no need for energy for the aeration system and the reduction of the sludge volumes is relatively high. Collections of biogas also reduce the emissions of greenhouse gases to the atmosphere and are a source of renewable energy (Anaerobic Digestion 2011).

Anaerobic digestion is the degradation of organic materials by microbial activity in the absence of air transforming it into biogas and biomass. There are several steps that has to be followed when convention organic matter in to biogas. It is an anaerobe digestion where microorganisms break down biodegradable material without any access of oxygen. After, the biogas must be treated to exploit the methane for renewable energy generation, generating heat and electricity.

The process is a complex microbiological process where consortiums of microorganisms are involved, where some microorganism use what other separates. One can divide this complicated collaboration process into 4 stages:

- **Hydrolysis** is where larger molecules, as proteins, polysaccharides, carbohydrates , fats, and cellulose become converted into smaller monomers as amino acids, nucleotides, water and sugar compounds. This makes the degradation easier for the bacteria.
- **Acidogenesis** is where the monomers are fermented in to fermentation products such as alcohols, CO2, hydrogen, ammonia and organic acids.
- **Acetogenesis** is where the organic acids are formed with acetogens bacteria. The bacteria responsible for the third phase, the acetogens are highly sensitive to temperature fluctuations.

- **Methanogenesis** is where methane is formed from acetic acid, hydrogen and carbon dioxide. These bacteria are sensitive to e.g. time, temperature, pH, etc.

One can see the four step process illustrated in the figure 4 below.

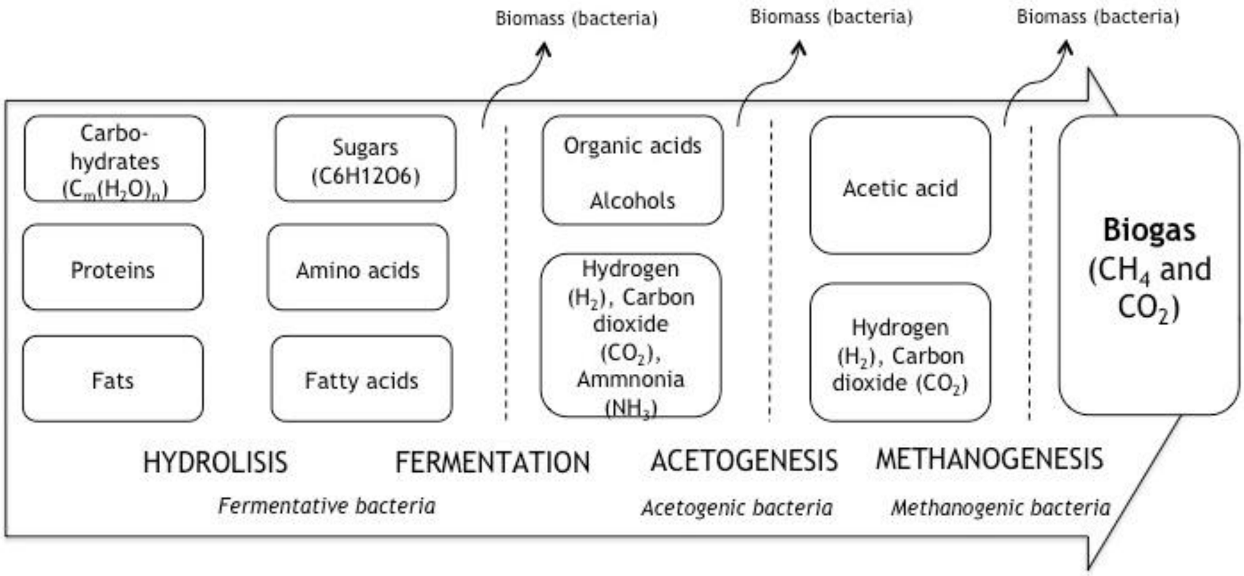


Figure 5: Microbiological process

Each of the steps are dominated by different types of microorganisms, with partly different environmental requirements e.g. pH-value, temperature, tolerance for ammonium, organic acids and other growth-limiting factors. These factors are described more thoroughly in next chapter; Environmental conditions for bacteria. It is especially in the last step, the formation of methane, which is performed by metanogene organisms that requires strictly anaerobic conditions.

The metanogene microbes, shall have relatively neutral pH, from 6.5 to 7.5, and are sensitive to high concentrations of ammonia. They have the highest activity at 30 to 38 º C (mesophile micro-organisms) or by 50 to 60 ° C (thermophilic micro-organisms).

It is developed many different types of biogas processes, from very simple small biogas plants used in developing countries in Asia for centuries, to high tech industrial facilities. Manure and organic waste with high water content such as sewage, food waste, waste from the food industry, growth, residues from agriculture, and energy crops are all well suited as substrates for biogas production. Heavier biodegradable material with a high content of lignocellulose can also be appropriate to use. It turns out that the production is often more robust and more effective when different substrates are mixed than when they are used separately (Schnürer og Jarvis 2009). Figure 5 shows a typically biogas production.

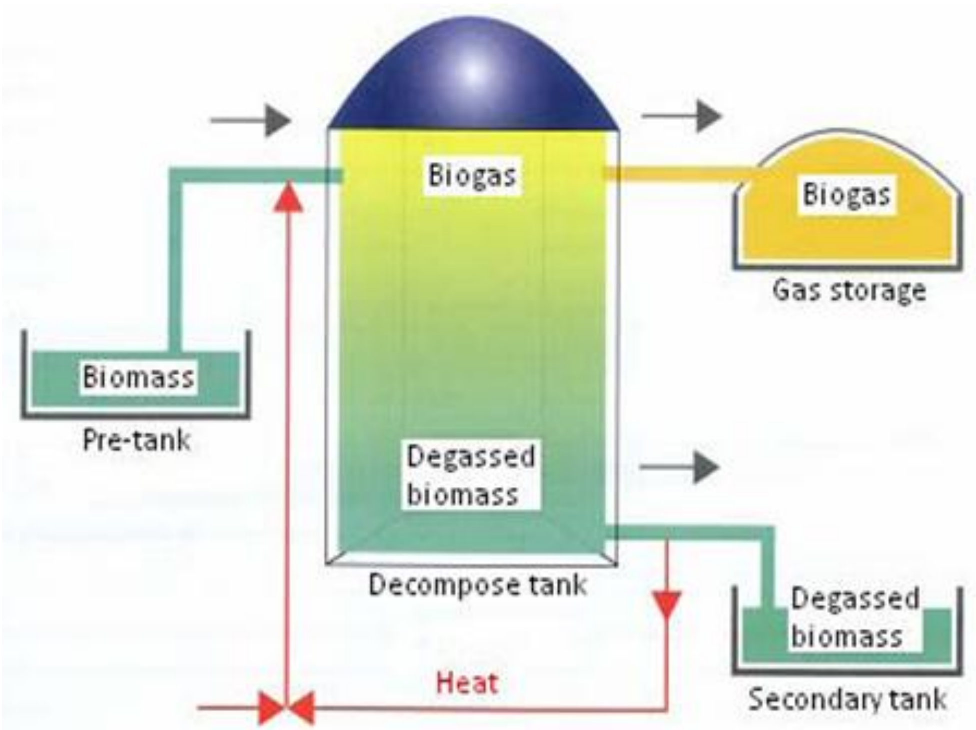


Figure 6: Biogas production

6.4 Environmental conditions for the bacteria

For the digestion to be effective, it should operate as a finely balanced, living system – carefully controlled and closely monitored – in order to create optimal conditions for the growth of the bacteria responsible for anaerobic digestion. Therefore, several factors should be considered for design and processing of biogas.

6.4.1 Temperature

The bacteria are very sensitive to temperature. It is therefore important that the temperature of the fermented is being kept at a certain level in order to not kill the different bacteria. Anaerobic fermentation is in principle possible between 3°C and approximately 70°C. Differentiation is generally made between three temperature ranges:

- The psychrophilic temperature range lies below 20°C,
- The mesophilic temperature range between 20°C and 40°C and
- The thermophilic temperature range above 40°C.

The volume of bacteriological methane production increases with temperature. Since the amount of free ammonia also increases with temperature, the bio-digestive performance could be inhibited or even reduced as a result. In general, unheated biogas plants perform satisfactory only where mean annual temperatures are around 20°C or above or where the average daily temperature is at least

18°C. The gas production increases when the mean temperature is 20-28°C. If the temperature of is below 15°C, gas production will be so low that the biogas plant is no longer economically feasible (Kossmann og Stefan u.d.).

The methanation process is very sensitive to temperature changes. The degree of sensitivity depends on the temperature range. Thermophilic bacteria are more sensitive to temperature changes than mesophilic bacteria, and it is therefore more difficult to control a thermophilic digestion than a mesophilic. The bacteria sensitiveness to temperature range is:

- Psychrophilic range: ± 2°C/h
- Mesophilic range: ± 1°C/h
- Thermophilic range: ± 0,5°C/h

The temperature fluctuations between day and night are no great problem for plants built underground, since the temperature of the earth below a depth of one meter is practically constant.

6.4.2 Available nutrient

Nutrients are important to build up cell materials. Bacteria need nutrients, vitamins and minerals in order to survive. Bacteria need more than organic substances as a source of carbon and energy, in order to grow. They also need certain mineral nutrients. Without oxygen, carbon and hydrogen, the bacteria also need; nitrogen, sulfur, 12 phosphorous, potassium, calcium, magnesium and a number of trace elements such as; iron, manganese, molybdenum, zinc, cobalt, selenium, tungsten, nickel etc. "Normal" substrates such as agricultural waste or municipal sewage usually contain adequate amounts of these requirements. Higher concentration of some substance can have an inhibitory effect. Therefore are analyses recommended on a case-to-case basis to determine if different nutrients needs to be added, in order to maintain good conditions for the bacteria (Kossmann og Stefan u.d.).

6.4.3 Retention time

Retention time is the time the organic matter is inside the digester, and is an important parameter to characterize the digester. It varies from case to case as everything else, but normally uses; phychrophilic bacteria around 100 days, mesophilic bacteria around 20 days, and thermophilic around 8 days. The retention time will get faster at higher temperature, but higher temperature also demands more energy. It is therefore necessary to make an energy balance plan of the system in order to find the most efficient temperature due to the retention time. The retention time also depends on the amount and type of the organic matter, and the configuration of the digester system (Roca og Sánchez 2009).

6.4.4 Batch-type and continuous plants

The retention time can only be accurately defined in batch-type facilities. For continuous systems, the mean retention time is approximated by dividing the digester volume by the daily influent rate. Depending on how the digester are built, the mix of organic matter, etc. the effective retention time often vary widely between different plants. Selection of a suitable retention time does not only depending on the process temperature, but also on the type of material and the organic waste that is used (Kossmann og Stefan u.d.).

6.4.5 Cost efficiency

There are many parameters that are important when optimizing the process in order to make it cost efficient. That can be parameters such as; retention time, process temperature, substrate quality, volumetric load determine, etc. But since each m3 digester volume has its price, heating equipment can be costly and high quality substrates may have alternative uses, the cost-benefit optimum in biogas production is almost always below the biological optimum.

6.4.6 pH-value

The bacterium that produces methane has it best under neutral or slightly alkaline conditions. Once the process of fermentation has stabilized under anaerobic conditions, the pH will normally take on a value of between 7 and 8.5. If the pH-value becomes lower than 6.2, the medium will have a toxic effect on the methanogenic bacteria.

6.4.7 Nitrogen and C/N ratio

There are two chemical elements in organic matter that are extremely important, especially in their proportion to each other. The elements are carbon and nitrogen, and all organic waste contains some amounts of both of them. The C/N ratio is very important when it comes to handle organic matter. Carbon is important because it is an energy producing factor and nitrogen because it builds tissue. Table 4 shows the nitrogen content and the C/N ratio in various organic matters. With high pH-values, even a low nitrogen concentration can inhibit the fermentation process. But microorganisms also need nitrogen together with carbon for assimilation into their cell structures. The optimal C/N ratio varies from 10 – 30 in different literatures, but various experiments have shown that the metabolic activity of methanogenic bacteria can be optimized at a C/N ratio of 15 – 25. The optimal value will of cause vary from case to case, and are depending on the nature of the substrate (Kossmann og Stefan u.d.).

Substrate	N in %	C / N
Cow manure	1,8	19.9
Chicken manure	3,7	9,65
Horse manure	2,3	28
Sheep manure	3,8	33
Human manure	5,5 – 6,5	6 -10
Kitchen waste	1,9	28,6
Corn stalks	1,2	56,6
Rice straw	0,7	51
Seaweed	1,9	19
Algae	1,9	100
Fish scrap	6,5 – 10	5,1
Slaughterhouse waste – Soft parts	7 -10	4
Slaughterhouse waste – Stomach/intestinal		22 -37

Table 4: Nitrogen content and C/N ratio in various organic matters. (Kaltwasser 198)

6.4.8 Other Parameters

There are also other parameters that can have an effect on the bacteria environment. They are:

- The water has to content at least 50% substrate so the methane building bacteria can work and reproduce themselves.
- A dark environment is important. Light slows the process down, so a dark environment supports the digestion process.
- Surface are important, the larger the specific surface area, the better the digestion process will develop.
- Continuous feed of organic matter. To prevent the bacteria from being overfed, it is important to create a substrate flow which is as continuous as possible.
- Gas outlet. The easier the biogas can escape from the substrate, the higher the production will be. A good gas outlet is therefore necessary.
- Avoidance of disturbing substances. Some substances have a disturbing or even devastating effect on the biogas production, such as oxygen and antibiotics.
- For a well operating system, mixing has to be provided by mechanical stirring, gas circulation or displacement under gravity. Intensive mixing is important for the process to allow the bacteria contact with every degradable material. Mixing therefore improves the processing rate (Müllegger 2011).

- The presence of heavy metals, antibiotics, and detergents can have an inhibitory effect on the process. Lead, copper, and zinc are all toxic components to biomethanogenesis. Lead at the concentration of 10 µg/ml completely stopped methane production.

In order get the most out of the organic matter, it is important to create an environment for the bacteria so they have best possible conditions. The best possible environment depends from different biogas processes, biogas plants, organic matter, and climate. Therefore one has to have all these factors in mind when setting up a new biogas plant (BioEnergyFarm u.d.).

6.5 Waste handling and digestion properties

There are many other parameters that have an influence on biogas production than dose concerning the specific biogas process. Such parameters can be waste generation, the arrangement of waste collection, infrastructure, transport and occasionally required storage. All of these parameters can be crucial to the overall process and have an effects on the overall process economics.

Different wastes require an effective strategy prior to digestion. Common procedures include removal of material which is not organic such as plastics, sand, metals, glass etc. The material may have to go through some cutting and grinding so the biomass does not contain any big pieces. Homogenizing of the organic matter is also important. Substrates, such as biogenic wastes, garden wastes or kitchen and restaurant waste, often require expensive pretreatment procedures.

Hygienic considerations are also a particular concern in co-digestion. Waste from slaughterhouse, food remains, sewage, and animal manure can contain some dangerous bacteria. Most countries have specific rules and laws concerning maximum concentrations of indicator organisms, and limits concentrations heavy metals and other toxic substances. Finally, the feedstock composition, together with local soil, climate and legal conditions can be crucial for the biogas potential in a specific area. (Steffen, Szolar og Braun 1998)

7 Energy content in Biogas

As mentioned earlier in the report can biogas be recovered and used for many different purposes, e.g. directly for cooking, lighting or transformed in any kind of thermal, electrical or mechanical energy. It can also be compressed, much like natural gas, and used to power motor vehicles. Methane is the valuable component under the aspect of using biogas fuel. The calorific value of biogas is about 6 kWh/m3, which correspond to a half liter of diesel oil (SSWM u.d.).

Table 5 shows biogas converted to kWh for conventional fuels. With unstable oil marked, resource as biogas can become a very valuable resource.

Fuel	Amount
1 m3 biogas (60% methane)	6,24 kWh
1 m3 upgraded biogas (97% methane)	10,1 kWh
1 m3 Natural gas	11 kWh
1 liter Gasoline	9,6 kWh
1 liter Diesel	9,8 kWh
1 liter E 85	6,6 kWh
1 m3 of upgraded biogas	1,1 liter gasoline/1 liter diesel
1 m3 of natural gas	1,2 liter gasoline

Table 5: Biogas converted to kWh for conventional fuels

The table 6 below shows typical amount of methane gas which is produced from different substrate:

Substrate	Content of solid (% of liquid weight)	Methane production (m3 methan pr ton wet weight)
Liquid pig manure	8	18
Cow manure	9	14
Sweetcorn	30	95
Food waste	35	130
Deep fat	90	700
Offal	30	90

Table 6: Amount of methane gas which is produced from different substrate (Bondelaget 2010)

8 Technology of Biogas Production

Production of biogas is as mentioned, a very complex microbiological process with many different microorganisms. The process is divided in to four steps where each step is dominated by different microorganism, with different environmental requirements, e.g. pH-value, temperature, etc. These processes can either be separated in time (occur sequentially as in a "plug flow" reactor), in place (happens in different reactors, e.g. 2-stage reactors) or in the microenvironment, where small microorganisms lives in small balls (granules) or in bio-films and where the organisms have a different functions.

8.1 Today's technology:

It is developed many different types of biogas processes, from very small and simple plants used in developing countries for centuries, to high tech industrial facilities. The processes can be classified by various criteria (Ohr, Førland og Birkenes 2002):

- The type of substrate: manure, food waste, industrial organic waste, mixed municipal waste, sewage, or a mixture of these.
- The number of process steps: One-stage or multi-step processes
- Free microorganisms or bio-film processes
- Flow: Plug flow or total mixed system (CSTR - Continuously stirred tank reactor)
- Temperature: mesophilic (30 - 38 º C) or thermophilic (40 - 60 º C)
- Solid content: dry, semi dry or wet processes

Wet biogas processes are a process where the solids content (TS) are lower than 16% and the substrates have to be so liquid so it is possible to pump it in to the digester. The substrates cannot contain any big parts that can get stock in the pipes or pumps. Wet processes are the most common processes, both in Scandinavia and elsewhere in the world. They are well suited to handle slurry from cattle and pigs which has high water content. Also drier substrates as energy crops and food waste can get processed in wet processes, then with the addition of water.

In manure and other agricultural waste is the substrate often inhomogeneous and have normally a TS between 2 and 12 %. Therefore, it is often used a reactor with continuous stirring (CSTR - continuously stirred tank reactor). Such reactors are also well suited to use in processes where different types of substrates are mixed. Stirring is important in order to mix new substrates quickly with the microorganisms. It is also necessary to distribute the heat evenly, prevent precipitate and foam, and release gas which is bound in the liquid. The disadvantage is that some raw biomass comes out with the decaying biomass (Morken, et al. 2005).

Two-stage biogas processes provide opportunities to distinguish between the hydrolysis and biogas production. This provides a better opportunity for a more efficient hydrolysis and a produces a higher amount of gas. Two-step processes have a higher investment costs and is more complex to operate than a one-step process (Ohr, Førland og Birkenes 2002).

Two-step processes can be well suited for energy crops because heavier degradable substrates may require more of the hydrolysis step. By varying the ratio between the volumes in the hydrolyze reactor and the biogas reactor, can the residence time be different, which gives a far better opportunity for an optimal process. The pH-value can also be different, and in principle also the temperature. Two-stage system can for example be concentric constructed with the main reactor in the center and a "donut" - around the reactor. This is a design which reduces the heat loss. Such solutions can be very relevant in cold climate such as Greenland, where heat loss has a great significance (Ohr, Førland og Birkenes 2002).

Dry processes have often a solid content around 25 - 35% and are used in biogas processes with relatively dry substrates such as sorted food waste and energy crops. The advantage with the dry processes is that one does not need to handle large amounts of biomass after the biogas production. The water demand is also less, but the overall biogas produced is often lower in this type of processes. The produced biomass can be used as composted soil in gardens, but it is normally not an N-rich product that can replace mineral fertilizers in agricultural sector.

A flow system (plug flow) is a process which is often designed so that the substrate flows slowly through a passage with a large surface area, as in a heat exchanger. The microorganisms are placed on the surface the liquid substrate passes. The hydrolysis starts in the beginning of the process while acid formation and methane formation occurs sequentially throughout the process. The process is also developed for dry processes where the substrate mass goes through a tubular reactor, e.g. a vertically tube where the substrate are filled at the top and taken out in the bottom. The process occurs sequentially down the tube/reactor (Ohr, Førland og Birkenes 2002). The process can be operated in both, thermophilic or mesophilic mode and has been developed for the anaerobic treatment of solid substrates with dry matter (TS) contents between 15 and 45%. Figure XXX show one example of a plug flow digester.

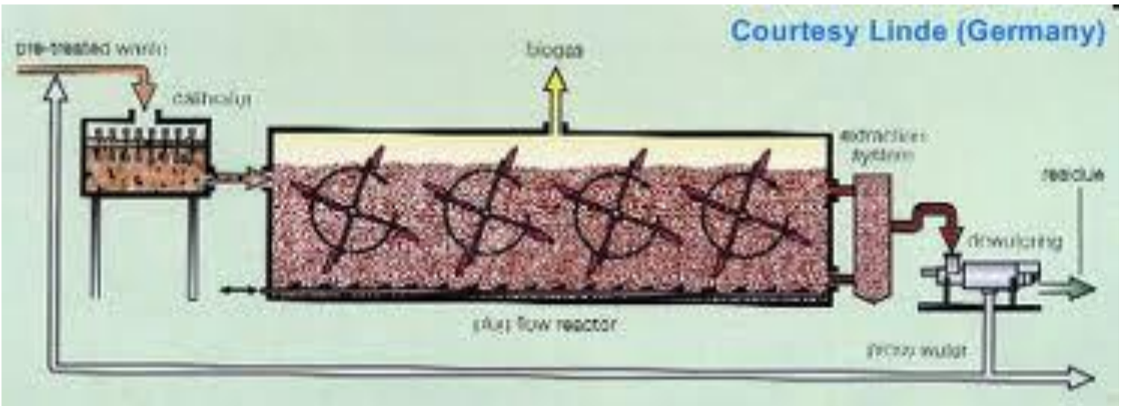


Figure 7: Pug Flow (anaerobic-digestion 2010)

9 Biomass after biogas production

In biogas production is it possible to use all residual products. Products which come out of biogas production are electricity, heat, fuel, and fertilizers. The final biomass can also be burned in an incinerator in order to produce electricity and heat.

9.1 Biomass

After the organic matter has gone through a decomposition process that provided the biogas, it remains a final biomass. The remaining biomass is called digestate, and is the solid material remaining after the anaerobic digestion of a biodegradable feedstock. Digestate is produced both by acidogenesis and methanogenesis and each has different characteristics. The digester composition depends on the raw matter as well as the digestion conditions, but it mainly contains many essential elements for the flora, as nitrogen, phosphorus, potassium and trace quantities of metallic salts.

Acidogenic digestate is fibrous and consists of structural plant matter including lignin and cellulose. Acidogenic digestate has high moisture retention properties, and can also contain minerals and remnants of bacteria. Methanogenic digestate is sludge and is often high in nutrients such as nitrates and phosphates.

The primary use of digestate is as a soil conditioner. Acidogenic digestate provides moisture retention and organic content for soils. This organic material can break down further, aerobically in soil. Methanogenic digestate provides nutrients for plant growth, and is therefore excellent to use as a fertilizer. It can also be used to protect soils against erosion. Digester is used as fertilizer which feeds the plant, improves the soil proprieties, increasing the water holding capacity and beneficiating its structure. One of the most important elements of the fertilizer is nitrogen; it has a vital role in nutrition and growth of the plants (PPM u.d.).

The standard of digestate can be assessed on three criteria, chemical, biological and physical aspects. Chemical quality needs to be considered in terms of heavy metals and other inorganic contaminant, Depending on their source, biomass can contain bacteria, which can lead to the spreading of human, animal or plant diseases if not appropriately managed. The physical standards of digester include mainly appearance and odour factors and do not present a problem with health. The digester often has to be let for few weeks in an open tank or some months in a closed tank, to decrease the ammonia contain, which can be toxic for plants. One can control the final quality of the product by having quality control of the feedstock (OAKTECK 2006).

10 Uses for Biogas

In this chapter there will be given an overview over what biogas can be used to. Biogas can have the following applications:

- Direct combustion – residential heating, lighting or cooking
- Combined power and heat production in e.g. piston engines or gas turbines
- Bio-methane as gas fuel
- Catalytic conversion to liquid fuels
- Translated to electricity in fuel cells.

Figure 7 shows schematic relationship between cost, capacity, quality demand, and complexity.

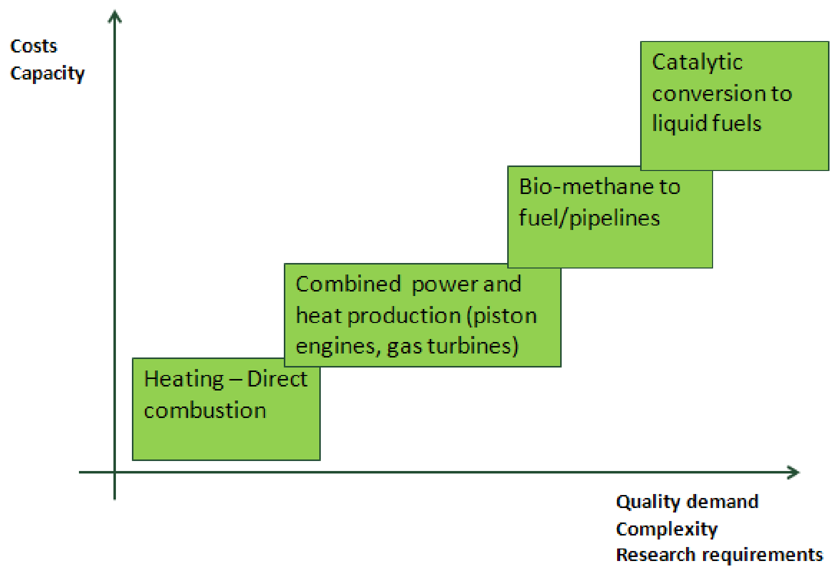


Figure 8: Relationship between cost, capacity, quality demand, and complexity.

Depending on the application, a further processing can be necessary where H2S, CO2 and H2O are being removed from the gas. CO2 are reducing the heating value of the gas. It does not contribute to the heating value of the gas and are therefore removed in applications where higher heating value is required. H2S gives corrosion problems in aggregates, pipes, heater and motors. It also forms SO2 after combustion. H2O are also giving corrosion problems, and increases the pressure in the motors which is not good.

The simplest systems to use biogas are the micro system where the gas is being used in a direct combustion for heat and cooking and heating. The challenge for this type of use is that the Greenlandic infrastructure does not support a system like that, and this type of energy is undeveloped. In Central Europe the use of gas for warming is widespread and the infrastructure is well established.

For small-and medium-scale biogas plant consist the configuration often of a combined power and heating plant where a combustion engine or micro turbine provides electricity production. It is also normal to use the energy from the cooling water from the engines, either to use them self to heat the biogas digester, or for sale. These systems are widely used in e.g. Germany

For large-scale biogas plants is a combination of heat production, electricity production and upgrading of the biogas to fuel, possible. The bio-methane can be used as gas supplied to exiting gas distribution, or compressed and sold as fuel.

One type of biogas plant that uses the gas directly is farm sites. In farm sites, direct combustion in either a gas turbine or in an internal combustion engine will be most efficient because there is no need to clean the gas, which reduces the complexity and the costs of the plant. Simple systems such as this have low requirements for the gas quality and are therefore more flexible due to the organic waste which is used. There are also large-scale power plants, but they are quite complex and expensive to build.

11 Waste Management in South Greenland

This chapter will look at the overall waste management in South Greenland. Organic waste and biogas is only a part of the overall waste management, and is therefore important to look at how the waste management is in general, in order to get a better overview and understanding of the situation. Fist a short presentation of the waste management strategy of municipality Kujalleq will be given. After I will look more deeply in to how the waste management actually is practiced in to three cities.

11.1 Waste Management generally in Kujalleq municipality

South Greenland is as the rest of Greenland, known for its magnificent and pure nature. A clean and pure nature has a great value to both locals and visitors, and is important to attract tourism. Therefore, it is important for Kujalleq to ensure a clean environment and a sustainable development. On Kujalleq's homepages it stands that the municipality prioritize public cleanliness very high, and has a high focus on waste management. Waste management is in practice managed by the technical department in the municipality.

The main objective is that inhabited areas should look clean and nice. In order to do that they want to abolish all waste as fast as possible so they can have a clean and nice environment and avoid risks of health hazards. The municipality will keep citizens informed about fundraising campaigns, etc. undertaken during the year (Miljø u.d.).

Technical department in Kujalleq are responsible for technique, housing, and environment in the municipality. The department tasks includes everything from; building inspection, municipal buildings, roads and green areas, sewerage, bus and taxi services, spatial planning, land use, nature conservation, waste handling, environment, urban development, fire service and the approval and supervision of enterprises according to environmental regulations. It is therefore the technical department task to provide and maintain a good waste management, which is consistent with the objectives and requirements the municipality has for renovation and waste management. The technical department has their main office located in Qaqortoq, but they also have smaller office in Narsaq and Nanortalik.

In Qaqortoq is the waste collected and burned in the city’s incinerator. In Narsaq and Nanortalik is the waste collected and dumped in “dumpen” outside of the cities, where it occasionally is burned under open air. This is obviously an environmental and health problem that Kujalleq municipality is aware of. Today it is a project ongoing about transport of combustible waste from Narsaq to combustion in the incinerator in Qaqortoq. Kujalleq whishes to have a incinerators in all the big cities one time in the future.

As mentioned is the waste management managed by the technical department in the three cities. Even though Kujalleq municipality has an overall strategy for waste management is there a big difference in the three cities.

11.2 Wastewater

There is no tradition to clean and purify wastewater in Greenland, it is just dumped directly and untreated in to the sea. Wastewater includes sewage, and wastewater from humans and from the industry. This direct emission is based on the theory that the wastewater is mixed with the sea, and is diluted in such an extent so it does not have any effect or consequences on the seawater or the marine environment. Studies of the marine environment in Sisimiut and Ilulissat, made by students from DTU, have documented negative environmental effects on the marine as a consequence from discharge domestic and industrial sewage and wastewater directly in the sea. Since it is documented that this has a negative effect in Sisimiut and Ilulissat, is it likely to assume that it has an effect on the marine environment in South Greenland as well (Brogaard og Jørgensen 2006). Wastewater can be used in biogas production and become recourse instead of a problem.

One has to hygienise the biomass when wastewater and sewage are mixed with the rest of the biomass, if it shall be used in agriculture. This is done by either heating the biomass to at least 70 ˚ C for one hour, or to have the biomass retention in a digester minimum ten hours at a temperature of at least 52 ˚ C. Table 8 shows average content of urine and feces from a person pr. year (Jørgensen 2007).

	Total (kg)	C (kg)	N (kg)	P (kg)
Feces	40	9	0,55	0,18
Urine	550	8	4	0,37

Table 7: Average urine and feces from human pr. year.

11.3 Waste Management in Qaqortoq

The waste management in Qaqortoq is actually quite good. They have an incineration plant in the city where they burn all burnable waste from the city. Today it is produces around 1 500 ton burnable waste. The energy from the incineration plant is used to heat up water to the district heating system which is in the city. This is good utilization of the waste, where they produce heat while they get rid of the waste problem. But there are some problem conserving the incineration plant. The plant was built in 1998, and is starting to get old. It is some pollution and emission problems, and since the plant lies more or less in the city. When the wind blows in the "wrong", direction the whole city becomes affected by the emissions from the plant. One can see where the incineration plant lies in figure 8.

Figure 9: Map over Qaqortoq city

Wastes that are hazardous or because of other reasons cannot be burned are placed at the dump. In Greenland they call their waste deposit for "dumpen". At "dumpen" in Qaqortoq, they sort the waste in different categories. When the deposit is full of hazardous waste they transport it to Denmark, where it is taken care off in a proper and sustainable way. Below one can see some pictures from "dumpen" in Qaqortoq.

Figure 10: ”Dumpen” in Qaqortoq

11.3.1 Wastewater in Qaqortoq

Almost all the houses in Qaqortoq are connected to the sewers network in the city. Today is it only two residential areas with approx. 20-30 houses which is not included in the sewers. The sewer goes straight out in the sea without any form for cleaning or treatment. They justify this with the large difference between high and low tides, and because of the large differences are the sewage quickly blended with the seawater. The houses which are not connected to the sewers are the sewage collected in bags and dumped directly in to the sea, while the bags are burned. Appendix 1 shows a map of all the houses which are included in the sewers in Qaqortoq. Since almost all the houses are connected would it not be extremely expensive to lead all the sewage directly in to a potential biogas plant, instead of dumping it in to the sea.

11.4 Waste Management in Narsaq

There are some major problems with waste disposal in Narsaq. Narsaq has no incinerators and all waste is being thrown at the local dump, where combustible material is burned by open burning. There is broad consensus that the current situation is not sustainable or good for the environment. It is also tough odors from the open burning, when the wind blows towards the city. Today there is an ongoing pilot project where the waste is transported from Narsaq to Qaqortoq's incinerator. There has therefore been purchased a plant to compress and pack the waste in bales, which are transported to Qaqortoq and burned in the incinerator. Figure 10 shows the press which is used to compress the waste.

Figure 11: Compression of waste in Narsaq

The aim with this project is to solve the waste problem in Narsaq. It is estimated that Narsaq produces approx. 700 ton domestic waste per year. Today is the waste burned or buried in the open dump, which is located right next to Narsaq bay. The waste which are shipped to Qaqortoq are combustible waste and normal domestic waste. Hazardous waste such as batteries, electronic waste, waste oil, domestic appliances, etc. are still being treated at the dump in Narsaq and sent to MOKANA in Denmark.

11.4.1 Transportation

In 2010 and 2011 has some of the waste from Narsaq been transported with boat to Qaqortoq. Wate is collected two times a week in Narsaq and transported in to the press machine. When the waste is compressed it comes out as "waste balls", which is ready to bee sailed to Qaqortoq. In this testing project they sailed the waste from Narsaq every second week, where they transported around 15 "waste balls" with a weight around 900 kg.

It has not been any capacity problems in the incineration plant after they stared to get extra waste from Narsaq. The 15 "waste balls" was burned in just some days, together with the rest of the waste from Qaqortoq. The waste has to be stored outside the incineration plant, and they can only take one ball at the time in to the burner. Because of limited storage capacity is it preferably not to get too much waste at once. It may be better to sail the waste every weak due to the storage capacity and since the waste will begin to rot if it is left too long wrapped, and can attract unwonted animals and birds, but it will off cause be more expensive. Below one can see some picture from transportation of the waste.

In the future they will try to transport the waste with Royal Arctic Line. The waste will be placed in a 20" container each week. Royal Arctic Line is at Narsaq every week. One of the problems with transporting the waste with Royal Arctic Line is that the ship goes up to Nuuk after it has been in Narsaq, which gives a much longer transportation time. But it is also more sustainable, because there is no need for an extra boat, since Royal Arctic Line already transports other thing the same rout anyway.

Figure 12: Transportation of waste from Narsaq to Qaqortoq

Kujalleq has estimated how much transportation costs they will have by using Royal Arctic Lines to transport the waste. I gave got this information from Leif Baadh from technical department in Qaqortoq. Table 8 shows the estimated costs.

Expenses	Amount DKK
Transportation costs	4.361,46
Handling costs NRQ	980,49
Handling costs QAQ	980,49
CAF/BAF	1.074,81
Investments allowance	196,00
Total Royal Arctic Line pr. Container	**7,593,25**
Transportation NRQ – from dump to port	3.000,00
Transportation QAQ – from dump to port	3,000,00
Total transportation on land pr. container	6,000,00
Total transportation costs pr. container	**13.593,25**
Total transportation costs pr year (52 containers)	**706.849,00**

Table 8: Transportation costs

11.4.2 Wastewater in Narsaq

The wastewater system in Narsaq is the same as in Qaqortoq, and is dumped directly in to the sea. In Narsaq is the sewers network smaller and there is more common with shitybags. They are collected once a week and dumped in the sea. The local in Greenland calls the dumping place for the "chocolate factory".

11.5 Waste Management in Nanortalik

If there are major waste problems in Narsaq, than the waste problems in Nanortalik is catastrophic. They do not have any good waste management at all. The waste is collected once a week and duped at “dumpen”. “Dumpen” is located near the port and is almost the first you see when you come to Nanortalik, and it is not a pleasant sight. The waste is just dumped at “dumpen” and is occasionally burned by opening burning. The plan is to burn the waste weekly, but when the wind blows towards the city they cannot burn it. It is quite often wind which blows towards the city, and it can sometimes take many weeks before they burn some of the waste. When I visited Nanortalik it was quite a lot of waste at the disposal, and it was some weeks since they had burned anything. They said it was because of the wind. I was in the city for ten days total, and it was only two days there was wind. But even when it was perfect condition they did not burn the waste. I think they do not want to burn the waste every week, because that is extra work for them. This was a problem, because when so much waste was laying open at the dump and when it was blowing, the wind bowed much of the waste in to the sea or in to the nature around the city. When walking around in Nanortalik it was much waste lying all over the beautiful city, like in the pictures below:

Figure 13: Waste in Nanortalik

Hazardous wastes such as batteries, electronic waste, waste oil, domestic appliances, etc. are as in the other cities sorted out and not burned. But in the other cities they take special care of the hazardous waste and ship in to Denmark. In Nanortalik they just sort the waste and dump it together with the rest. When walking around at the dump one could see everything from old cars, refrigerators, old batteries, TV’s, oil cans, etc. The way the hazardous waste was treated was from mine opinion not sustainable at all, and could not be compared with how they handled waste in the tow other cities. There has not been taken any sample of the quality of the water around Nanortalik, but I think it has to be some emissions from the waste deposit. Especially since much of the hazardous waste actually lies in the sea. Below one can see some pictures taken at “dumpen” in Nanortalik.

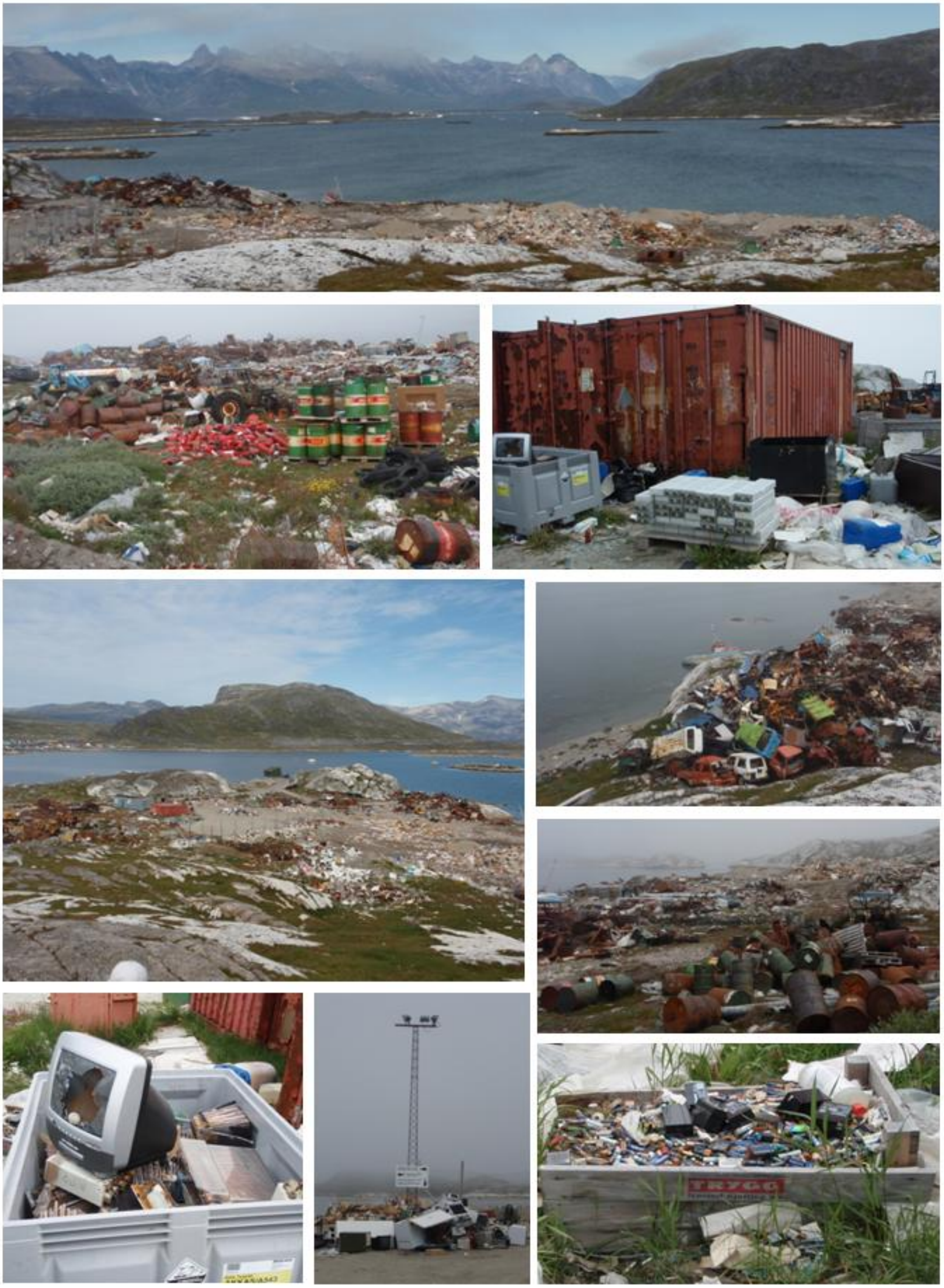


Figure 14: "Dumpen" in Nanortalik

The technical manager in Nanortalik did not think they have any major problems with their waste, and I did not get the impression that they planned to improve it in the nearest future. I do not think the way waste is handle in Nanortalik is not in line with how Kujalleq want their waste management. Tourism is a important industry in Nanortalik, and they have to take better care of their nature it they want to attract tourist in the future. Tourist comes to Nanortalik to see beautiful nature, not waste.

It would be a good solution to improve the waste situation in especially Nanortalik. But they have to realize that they have a serious problem, before on can do anything with it.

11.5.1 Wastewater in Nanortalik

The wastewater system in Nanortalik is more or less the same as in Narsaq, and is dumped directly in to the sea. They have a sewers network but many of the houses use shitybags. The shitybags are collected once a week and dumped in the sea. The local in Greenland calls the dumping place for the "chocolate factory". The pictures below shows the "chocolate factory" in Nanortalik, where the shitybags are dumped in to the sea.

Figure 15: Chocolate factory in Nanortalik

12 Heat and Electricity

The large distances between cities and villages, means that it is not possible to supply the cities with electricity from one network. Instead there is something called "ø-drift" which means that all production of electricity and heat are produced at local plants. That means that there are different types of production of heat and electricity in the cities and villages.

The three cities in South Greenland have all different production and consumption of heat and electricity. The chapter will present how the cities are provided with heat and electricity. An evaluation of the heat and electricity production will provide a better understanding in order to see if biogas production are sustainable, realistic, efficient, or if it is economical feasible in the different cities. It will also give a better indication about where the best location of a biogas plant is, or if it is better to have some small plants in every city.

12.1 The Qorlortorsuaq hydropower plant

The Qorlortorsuaq hydropower plant provides the nearby towns Qaqortoq and Narsaq, with a combined population of 5500, with electricity. The energy production of the two power units is 27.5 GWh/a, and it has a capacity of 7.2 MW. The hydropower plant was completed in 2007, and has replaced diesel generators which were used to provide the two cities with electricity. Qaqortoq and Narsaq are today the only cities in Greenland which gets energy from the same plant, and Qorlortorsuaq hydropower plant is the only facility, which supplies two cities simultaneously. The hydropower plant is part of the plan of the Greenland Home Rule government to replace fossil fuelled energy production and storage with sustainable power production (QORLORTORSUAQ Hydroelectric Project – 7.5 MW 2009).

12.2 Heat and Electricity in Qaqortoq

As mentioned is all the electricity in Qaqortoq produces by hydropower from Qorlortorsuaq hydropower plant. The heat is produces partly from electricity from Qorlortorsuaq and partly from the incineration plant. The electricity costs in Qaqortoq is today 2,75,- DKK kWh, and the heat from the district heating costs 643,- DKK MWh, see more details in appendices 2 (Nukissiorfiit, Nukissiorfiit 2010).

12.2.1 Incineration Plant in Qaqortoq

Each year is around 1,500 ton of waste burned in the incinerator in Qaqortoq city. According to the manufacturer of the plant, has the incineration plant a combustion capacity of approx. 3,000 tons per year, operating 365 days a year. The plant must often shut down due to lack of waste. The incinerator in Qaqortoq has therefore much more capacity to burn waste from other cities as well as their own. A larger volume of waste will provide a more continuous and economic operation of the plant and therefore result in an overall better use of existing investments. A more continuous operation will have an environmental impact since the plant can have a more constant optimum operating temperature, for a longer time. Table 9 show the plants operation journal from October

2011. One can see that the el consumption is much higher when the plant starts up production. One can also see that they need to by electricity those days when they start the production. It would therefore be much better if they had enough waste so that the plant could run continuous.

Forbrændingsanlægget i Qaqortoq - driftsjournal Oktober 2011

Dato	Køletårn MWH	Salg MWH	Total MWH	Køb MWH	El-forbrug KWH	Spildolie Liter	Brændt affald tons
01-okt			0,00				
02-okt			0,00				
03-okt			0,00				
04-okt	3,15	49,00	52,15	0,90	1422		
05-okt	1,59	20,00	21,59	0,00	373		
06-okt	1,63	21,30	22,93	0,00	426		
07-okt	1,48	21,30	22,78	0,00	425		
08-okt	1,72	22,50	24,22	0,00	454		
09-okt	1,39	18,50	19,89	0,00	389		
10-okt	1,25	17,20	18,45	0,00	415		
11-okt	1,98	21,80	23,78	0,00	445		
12-okt	1,42	19,70	21,12	0,00	437		
13-okt	1,06	16,40	17,46	0,00	406		
14-okt	0,94	16,50	17,44	0,00	430		
15-okt	0,78	15,30	16,08	0,00	445		
16-okt	1,28	20,70	21,98	0,00	451		
17-okt			0,00				
18-okt			0,00				
19-okt			0,00				
20-okt			0,00				
21-okt	3,03	28,40	31,43	1,10	1516		
22-okt	2,72	25,90	28,62	0,00	565		
23-okt			0,00				
24-okt			0,00				
25-okt	2,20	20,10	22,30	0,50	1089		
26-okt	2,23	24,80	27,03	0,00	578		
27-okt	2,31	22,50	24,81	0,00	576		
28-okt	2,19	23,10	25,29	0,00	554		
29-okt	2,08	17,50	19,58	0,00	515		
30-okt	1,93	22,20	24,13	0,00	579		
31-okt	1,59	20,40	21,99	0,00	529		
I alt	**39,95**	**485,1**	**525,05**	**2,5**	**13019**	**0**	**0**

Samlet mængde varme produceret =	**525,05 MWH**
Samlet Køb af varme =	**2,5 MWH**
Samlet El-forbrug =	**13019 KWH**
Samlet mængde spildolie afbrændt =	**0 Liter**
Den samlede mængde affald =	**0 Tons**

El aflæsning start :	198430
El aflæsning slut :	211449
El aflæsning i alt :	13019

Table 9: Operation journal October 2011

The incinerator produces heat for district heating Nukissiorfiit's when there is need. However, there is not so much need of the heat in the summer months, but in the cold months, virtually all the heat can be sold to Nukissiorfiit (Baadh 2011).

12.3 Heat and Electricity in Narsaq

As mentioned is the electricity in Narsaq produced from hydropower from Qorlortorsuaq. In Narsaq they do not have any incineration plant so the heat is mainly produced by diesel oil. There is not much district heating in Narsaq, just a few public hoses, and private houses have their own diesel burner which produces the heat. Therefore is almost all heating in Narsaq produced from diesel oil. On a typical winter day with an outdoor temperature on - 5˚ C is it used around 15 liters oil to heat a 70 m2 big house (Nsted, 2007). The large oil consumption is partly because the low efficiency of the oil owns, and partly because of bad insulation of the houses.

Technical department in Narsaq wants to build out the district heating system in the future. They want to build an electrical heater, which heats up the water in the district heating. This is sustainable since the electricity is produced from hydropower, but the capacity of the hydropower plant in Qorlortorsuaq almost reached. There are some plans about build out Qorlortorsuaq in the future, and a electrical heater in Narsaq is probably not realistic before the electrical production at Qorlortorsuaq is expand (Bertelsen 2011).

12.4 Heat and Electricity in Nanortalik

Nanortalik is not connected to the hydropower plant and has instead its own power plant which produces electricity and heat from diesel oil. They use the energy in the hot cooling water for district heating production. But in Nanortalik do they not have a very large district heating network, and it is only a few communal houses which are connected to it. That means that the heat from the electricity production is not utilized. Instead they have separate oil burns like in Narsaq. This is not sustainable at all, especially since they already have heat which is not used. The argument for why they do not have very much district heating was that it is expensive to build, which it is. But it will most likely be a good investment in the future. Today is the diesel oil quite cheap compared to the prices in the rest of the world, and the prices will most likely increase in the future.

When visiting Nanortalik in August, they were building a new school. I got a guided tour around in the new school, and it was really modern and nice. They had spent a lot of money on it, and education was very important for the people in Nanortalik. But there was one thing I was questioning, there was not any district heating in the school. They told me that it was to expensive so it was not prioritized. Yes, of cause would it be some expenses, but they had not done any investigation about it at all. They had just assumed that district heating would be expensive, and had not looked into the overall expenses for the coming ten years. Yes, it would most likely been some extra costs if they connected to the district heating system, but it would have been a good solution for the future. I do not think it would be that much more costs by connecting the school to the district heating network when they already was building a new school not far from the power plant. This is an example on that they are not very concerned about the environmental aspects. It is much more environment friendly to use all ready produced heat to heat up buildings, instead of diesel oil. They are more concerned about the best solution at the moment, not about the best solution over a longer period.

Figure 15 shows how much liter diesel oil the power plant in Nanortalik has used the last ten year. in order to produce electricity. Figure 16 shows how much kWh they have produced. One can see that it is used very much diesel oil every year just to produce electricity in the city. In 2010 they used a total amount of 1.018.643,00 liter diesel oil in order to produce 3.852.060,00 kWh.

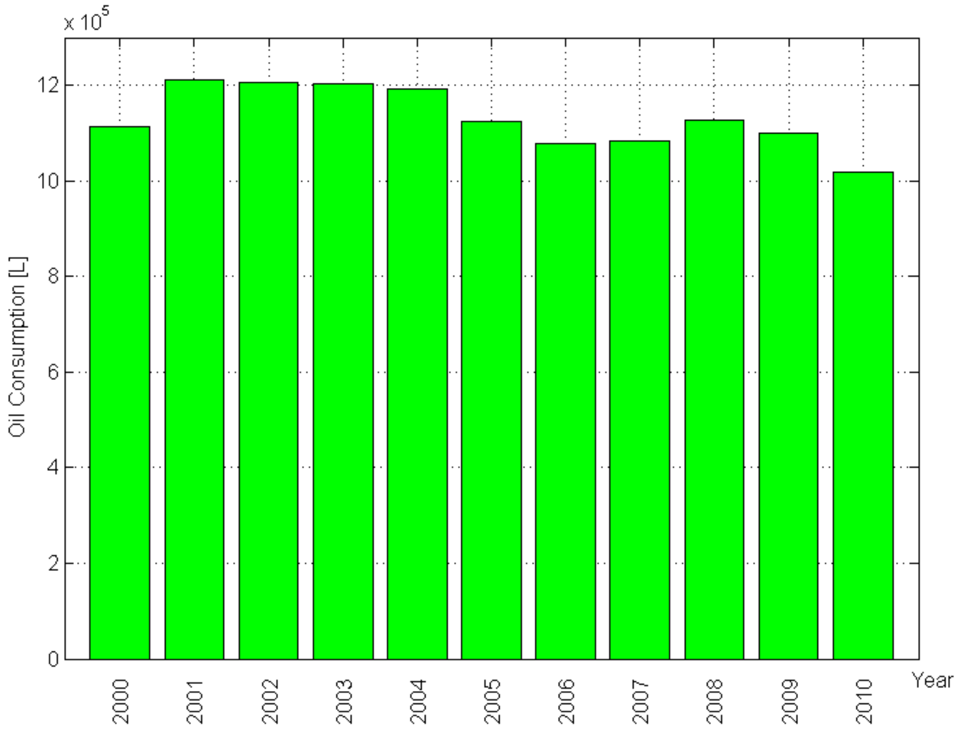


Figure 16: Liter diesel oil used in the power plant in Nanortalik

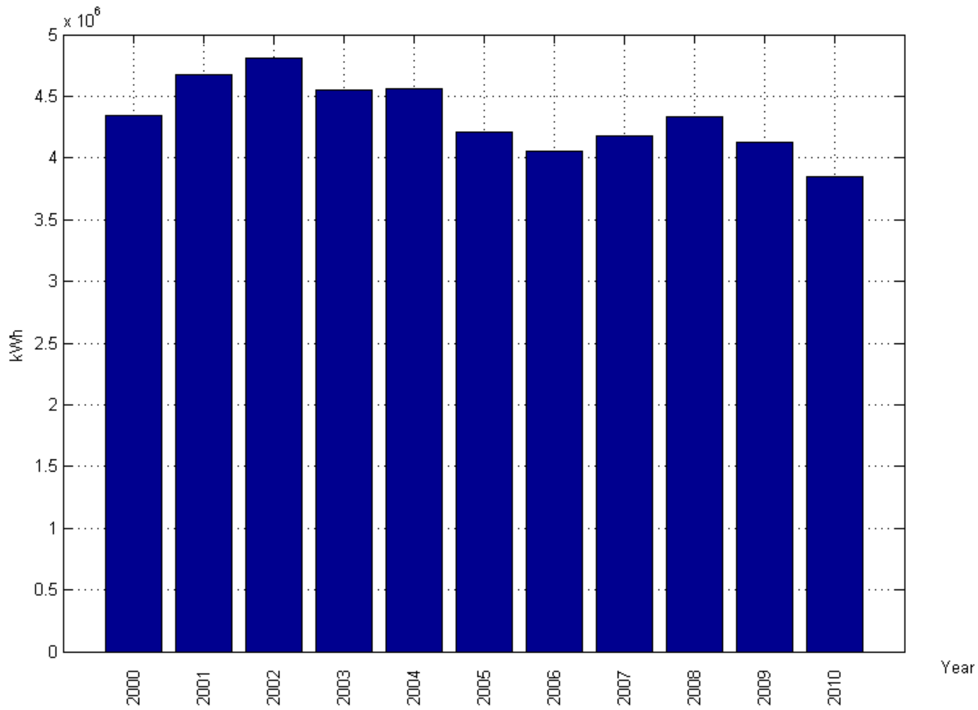


Figure 17: kWh produced in the power plant in Nanortalik

12.5 Costs

Figure 17 shows excerpts of Nukissiorfiit price table. This shows that the electricity costs in Nanortalik is much higher than in Qaqortoq and Narsaq, which is natural since they produce electricity from hydropower instead of using expensive diesel oil to produce it (Nukissiorfiit, Nukissiorfiit 2010).

NUKISSIORFIIT	2010-mi innaallagissamut nukimmullu ataatsimut aningaasartuutit — Enhedsomkostninger lys og kraft 2010 (Kr. / kWh)						2010-mi imermut aningaasartuutit — Enhedsomkostninger vand 2010 (Kr. /m³)					
	Atortussanik atuineq Vareforbrug	Sulisunut aningaasartuutit Personaleomkostninger	Pisinnaa. aningaasartuutit Kapacitetsomkostninger	Nalikillilinerit Afskrivninger	Erniat Renter	Nioqqutissap akerpiaa Kostpris	Atortussanik atuineq Vareforbrug	Sulisunut aningaasartuutit Personaleomkostninger	Pisinnaa. aningaasartuutit Kapacitetsomkostninger	Nalikillilinerit Afskrivninger	Erniat Renter	Nioqqutissap akerpiaa Kostpris
NANORTALIK	1,40	0,75	1,51	0,41	-	4,08	2,13	0,53	37,85	23,32	10,38	74,22
AAPPILATTOQ	1,50	2,61	0,68	0,84	0,28	5,91	-	-	45,85	94,60	38,53	178,98
NARSAQ KUJALLEQ	1,36	1,35	0,98	0,47	0,42	4,59	-	-	19,48	423,10	173,54	616,13
TASIUSAQ	2,12	2,68	1,60	2,85	0,83	10,08	-	-	106,45	332,27	104,68	543,40
AMMASSIVIK	1,65	1,91	1,95	1,75	0,48	7,75	-	-	230,73	193,80	49,60	474,13
ALLUITSUP PAA	1,58	1,20	0,77	1,18	0,30	5,04	11,26	-	99,02	228,44	86,41	425,12
QAQORTOQ	0,08	0,38	1,37	0,67	0,26	2,75	0,73	3,71	14,11	15,77	6,61	40,94
SAARLOQ	1,72	0,34	0,39	1,85	0,63	4,94	64,78	555,87	118,72	374,17	65,16	1.178,71
EQALUGAARSUIT	1,77	0,27	0,71	0,96	0,45	4,16	-	108,57	59,76	239,42	99,20	506,96
QASSIMIUT	1,70	1,02	1,91	0,98	0,63	6,24	5,83	44,87	18,22	74,73	19,75	163,41
NARSAQ	0,08	0,38	1,37	0,67	0,26	2,75	0,98	4,10	17,43	31,01	9,81	63,33
IGALIKU	1,85	2,16	0,39	0,89	0,24	5,53	11,34	-	45,85	94,60	38,53	190,33
QASSIARSUK	1,96	0,78	0,41	1,69	0,56	5,40	7,16	16,43	39,01	23,65	12,13	98,38
PAAMIUT	1,30	0,43	0,90	0,24	0,23	3,11	0,70	2,18	12,16	11,89	4,80	31,73
ARSUK	1,49	1,53	0,40	0,49	0,11	4,00	1,41	-	13,39	128,64	40,16	183,61
NUUK	0,01	0,14	0,35	0,28	0,14	0,91	0,82	1,76	9,47	7,25	2,61	21,90

Figure 18: Excerpts of Nukissiorfiit price table

Table 10 shows how the price of 1 liter diesel oil has increased the last years. The diesel oil price has almost increased with 50 % since January 2008. If the price continues to increase with same speed the coming years, will the electricity price in Nanortalik be very high. The diesel price in Greenland is unrealistic low and will increase the coming years, but it is difficult to say how fast, and the increase will affect the society in many ways. It is therefore important that the municipality have that in mind and tries to reduce the effect it will have. Biogas can be one solution, to reduce the effect a higher diesel price will give.

Date	Price (DKK)
January 2008	3,72,-
June 2008	4,22,-
January 2010	4,22,-
June 2010	4,47,-
December 2011	5,57,-

Table 10: Diesel oil prices

13 Infrastructure

The infrastructure in South Greenland is not very good. Along with most other major populated places in Greenland, are none of the three cities connected to any other populated place via roads. Fairly well trodden hiking trails lead to some farmers at Qaqortoq and Narsaq, but for any motorized transportation terrain vehicles are needed. Since there is none roads between the cities are boat and helicopter the only transportation form.

All the three cities get supplies from Denmark shipped with Royal Arctic Lines once or twice a week. Narsaq and Qaqortoq have arrivals of ships from Denmark every week, while Nanortalik only has every twice week. Royal Arctic Line does also have smaller boats which transport supplies between the cities and the villages in South Greenland, through the whole year. Appendix 3 shows some of the schedule for a boat which goes in South Greenland (Royal Arctic Line 2011). Since there are boats and ships that goes between the cities and villages is it possible to transport waste between the cities, but it will of cause be some extra expenses and it have to be evaluated if it is appropriate. The ships and boats do have extra capacity today, but there is some limits to how much they can transport.

The climate in South Greenland is as mentions not as cold as the rest of Greenland, and the sea is not frozen to ice during the winter. It is therefore possible to sail too, and between the cities through the whole year. It can of cause be some period where there is some ice, and the boats cannot come to the cities, but it is rare, and not for longer periods as it is in North Greenland.

14 Summary of the three cities

This chapter will give a detailed overview and summary to the three cities in South Greenland, which are; Qaqortoq, Narsaq and Nanortalik. Information that can have direct or indirect relevance to potential biogas production, such as; electrical and heat production, infrastructure, district heating, industry, waste management, are listed up in order to make it easier to get an overview over the situation, and to compare the three cities,

	Qaqortoq	Narsaq	Nanortalik
Inhabitants	3.308	1.596	1.385
El production	Hydropower	Hydropower	Diesel generators
El price	2.75 DKK/kWh	2.75 DKK/kWh	4,08 DKK/kWh
Heat production	Incineration plant and hydropower	Diesel and slightly hydropower	Diesel
District heating	Yes	Some, not much	Some, not much Not utilized the available
Infrastructure	Good inside the city	Good inside the city	Good inside the city
Waste management	Ok	Ok, potential for improvement	Bad
Wastewater and Sewage	Dumped directly in to the sea	Dumped directly in to the sea	Dumped directly in to the sea
Waste logistic	Collected once a week from each household	Collected once a week from each household	Collected once a week from each household
Local industry	-Fish factory – Arctic Prime Fisheries -Great Greenland Furhouse -Tourism	-Neqi – Slaughterhouse -Sheep farm -Narsaq Ilua -Narsaq Seafood - Tourism	-Fish Factory – CLOSED -Tourism
Nearby farmers	Yes, but not road connection	Yes, in the city	Yes, but not road connection
Use of fuel oil	Not much	Yes, heating	Yes, heating and electricity
Royal Arctic Line	Every week	Every week	Every second week
Boat access all seasons	Yes	Yes	Yes
Need for biogas	Partly	Partly	Yes

Table 11: Overview of the three cities.

15 Climate in South Greenland

As mentioned earlier is the climate in Greenland predominantly arctic which means that the mean temperature, even in the warmest month, does not reach above +10 °C. It can be really cold in the winter months, and it is extreme light and temperature differences through the year. The extreme temperature differences can be a problem when producing biogas. The microorganism in the biogas process does not like temperature changes, and the bacteria are very sensitive to temperature. It is therefore important that the temperature is kept at a certain level in order to not kill the different bacteria. The volume of the biogas production does also increases with temperature, and the temperature shall be at least above 20°C or more.

It can be difficult to keep a constant temperature in an arctic climate, and one have to use much energy in order to keep the temperature of de digester high. This can be expensive and can result in that one have to use much of the biogas produced to keep the biogas process running. South Greenland is therefore much more suited to build a biogas plant than other parts in Greenland. The temperature changes are not that high in South Greenland compared to the rest of Greenland, and it is not extremely cold in the winter. The normal temperature in the winter month is actually almost the same than it is in Oslo in Norway. In figure 18 one can see the normal temperature in Qaqortoq, which is a city in South Greenland and Oslo, the capital of Norway. One can see that in the winter time the normal temperature is around – 4 °C in both of the cities, and that the coldest temperature in Qaqortoq is -9 °C, while it is -19,3 °C in Oslo. One can see from this that the temperature condition is actually better I South Greenland than Oslo due to biogas production. In Norway there are around 30 biogas plants, and some of them are placed in areas much colder than Oslo. This means that the climate in South Greenland is not constrain and that it are possible to use experience from Norway when considering the climate challenges in South Greenland. It is also a positive thing that the lowest temperature is not lower then -9 °C .

The climate in Greenland is also changing because of the global warming. This means that it will probably become warmer in Greenland in the future, and it will be easier produce biogas. But it can also lead to higher temperature differences which has a negative impact on biogas production.

The warm climate in South Greenland is also optimal for farming and agricultural production. If the C/N ratio is low in the available organic matter it can be necessary to grow some plants to mix with the organic matter in order to get a better C/N ratio. South Greenland's climate is well suited to grow plant such as Lupines which contains a high C/N values and be a substitute to get a better C/N ratio in the biomass. Today the agricultural development in South Greenland is evolving together with the climate changes. For 30 years ago was it unthinkable to grow vegetables in Greenland. Today there is produced over 100 ton potatoes each year. At Upernaviasuk research station they grow everything from green salad, cauliflower, and strawberries, just to name a few. The climate changes will probably lead to even more food and agriculture production in the future, which means that it will be more available organic waste in South Greenland.

From these aspects one can conclude that the climate in South Greenland is suited to produce biogas. It is maybe not perfect conditions, but the climate is not the biggest challenge concerning biogas production. Due to the climate, South Greenland is the best geographic area to produce biogas in Greenland.

Tabular view for temperature and precipitation per month **in Oslo**

Months	Temperature				Precipitation			Wind	
	Average	Normal	Warmest	Coldest	Total	Normal	Highest daily value	Average	Strongest wind
Oct 2011	7.6°C	6.3°C	16.8°C Oct 1	-2.2°C Oct 21	75 mm	84 mm	24 mm Oct 10	2.6 m/s	11.0 m/s Oct 18
Sep 2011	12.7°C	10.8°C	21.9°C Sep 29	3.0°C Sep 24	150 mm	90 mm	21 mm Sep 5	2.4 m/s	9.4 m/s Sep 7
Aug 2011	16.1°C	15.2°C	26.5°C Aug 1	6.7°C Aug 12	189 mm	89 mm	25 mm Aug 10	2.4 m/s	9.3 m/s Aug 28
Jul 2011	18.0°C	16.4°C	28.0°C Jul 28	9.6°C Jul 16	107 mm	81 mm	27 mm Jul 24	2.8 m/s	10.7 m/s Jul 22
Jun 2011	15.9°C	15.2°C	27.1°C Jun 3	8.0°C Jun 13	157 mm	65 mm	32 mm Jun 11	2.6 m/s	11.3 m/s Jun 2
May 2011	11.3°C	10.8°C	23.5°C May 9	0.0°C May 4	68 mm	53 mm	17 mm May 15	3.0 m/s	9.3 m/s May 24
Apr 2011	9.4°C	4.5°C	20.3°C Apr 29	-0.8°C Apr 14	40 mm	41 mm	20 mm Apr 13	2.5 m/s	12.8 m/s Apr 8
Mar 2011	0.6°C	-0.2°C	14.9°C Mar 23	-8.1°C Mar 6	16 mm	47 mm	5 mm Mar 9	2.5 m/s	10.0 m/s Mar 24
Feb 2011	-4.9°C	-4.0°C	5.7°C Feb 3	-18.1°C Feb 13	53 mm	36 mm	15 mm Feb 11	2.3 m/s	12.9 m/s Feb 11
Jan 2011	-3.5°C	-4.3°C	5.1°C Jan 1	-12.8°C Jan 27	47 mm	49 mm	9 mm Jan 9	2.1 m/s	11.5 m/s Jan 1
Dec 2010	-9.2°C	-3.1°C	0.0°C Dec 16	-19.3°C Dec 22	15 mm	55 mm	4 mm Dec 5	2.2 m/s	10.6 m/s Dec 19
Nov 2010	-2.0°C	0.7°C	9.2°C Nov 1	-12.1°C Nov 30	24 mm	73 mm	8 mm Nov 3	4.0 m/s	12.4 m/s Nov 10

Tabular view for temperature and precipitation per month **in Qaqortoq**

	Temperature			Precipitation
Months	Normal	Warmest	Coldest	Normal
January	-5.5°C	-2.0°C	-9.0°C	9
February	-5.0°C	-1.3°C	-8.4°C	7
March	-4.4°C	-0.5°C	-7.9°C	8
April	-0.6°C	3.2°C	-4.0°C	8
May	3.3°C	7.5°C	0.0°C	7
June	5.2°C	9.8°C	1.7°C	10
July	7.1°C	11.7°C	3.7°C	10
August	7.2°C	11.6°C	4.1°C	9
September	5.0°C	8.5°C	2.2°C	9
October	1.2°C	4.2°C	-1.4°C	8
November	-1.9°C	1.1°C	-4.8°C	9
December	-4.4°C	-1.2°C	-7.7°C	9

Figure 19: Tabular view for temperature in Oslo and Qaqortoq (YR u.d.)

16 Biogas potential in South Greenland

There will in this chapter be presented an estimate of how much organic matter which are available in South Greenland, mainly in the three largest cities; Qaqortoq, Narsaq and Nanortalik. The numbers and results presented in the chapter come from various sources. Some of the members are collected in the field trip to Greenland and some are from earlier research done by others. It is uncertain how accurate all the numbers are, but it gives a rough overview over the biogas potential.

16.1.1 Available Household Waste in the Cities

Qaqortoq produce approximately 1 500 ton waste each year. This is burnable waste, and hazardous and special waste is not included.

Narsaq produce approximately 700 ton burnable waste each year, which they are going to send to the incineration plant in Qaqortoq.

I do not have the exact amount in Nanortalik, but I assume the produce the same amount pr. inhabitant as in Narsaq. The two cities are almost the same size with relatively equal amount of inhabitants.

Waste per inhabitant in Narsaq:

$$\frac{700\ ton\ waste}{1596\ inhabitants\ Narsarq} = 438.6\ kg/inhabitant$$

Total amount of waste in Nanortalik:

*438.6 * 1385 inhabitants = 607 456 kg = 608 ton*

Total amount of waste in Qaqortoq, Narsaq and Nanortalik per year is:

1 500 + 700 + 608 = 2 808 ton/ per year

Environmental Engineering and PhD student Rasmus Eisted and some master students from DTU did in 2009 some research concerning waste in Greenland. They counted and sorted the waste in Sisimut in order to identify whether there was a basis for sustainable waste contractor in Greenland. The research showed roughly that in the waste composition in Sisimut was quite similar to the one in Denmark, but there was some different. Approx. 43 % of total household waste was organic and consisted of food waste, trimmings from food preparation, hunting waste, meat, vegetables, flower bouquets, used coffee filters and generally everything which can be converted biologically.

From this one can assume that the content of waste is approximately the same in all the larger cities in Greenland. One can therefore assume that 43 % of the waste in Qaqortoq, Narsaq and Nanortalik is organic waste, which can be used in biogas production. Considering some of the waste is bones and other things that are not suited for biogas production, one can assume that there is potential to use approx. 40 % of the household waste produced in the cities.

Available organic matter from household waste:

*2 808 * 0.40 = 1 123.2 ton/per year*

From the assumption and the research done earlier, is it realistic to assume that there is produced 1 123 ton organic waste each year from household waste in the three largest cities in South Greenland.

16.2 Organic waste from the industry

In South Greenland there are also other sources of organic waste than only the household waste.

16.2.1 Neqi – Slaughterhouse in Narsaq

There is a slaughterhouse in Narsaq named Neqi. According to the manager Henning Sønderup, produces Neqi organic waste from approx. 22 400 lamb and sheep every year. In pure waste, without bones, gives that approx. 280 ton organic waste. Sønderup says that this amount of waste will most likely stay constant to next 5 – 10 years.

One of the problems is that all this waste comes on same time, since the slaughter period is only from 20th of September to 28th of October. That means that Narsaq does not have capacity to handle it together with the rest of the waste. Today, the slaughter waste is buried down in the area not far from "dumpen" in Narsaq. This is not a good solution, and the manager for the technical department in Narsaq, Steffen Bertelsen, is not happy about it, but he says that they do not have any other solutions. The picture below shows where they each year digs up a large area and dumps all the waste from the slaughterhouse. This is waste of good resources which can be used to produce biogas and become a resource instead of a problem.

Figure 20: Where the dump the slaughterhouse wastes.

It is a good solution to use the organic waste from Neqi in biogas production, but there are also some constrains. One can see from table 4 that slaughterhouse waste has a relatively low C/N ratio, aside from the stomach/intestinal waste. It is therefore important to mix this waste with other organic matter that have a higher C/N ratio, e.g. agricultural waste which has a high C/N ratio. All the waste from the slaughterhouse comes within one month, and it is not possible to use all of the waste within such a short time limit due to the mixing and capacity problems.

The bacteria in the biogas process like to have equal conditions, and it is best to have an equal biomass and not too much variations. Therefore is it not preferred to have huge amount of slaughterhouse waste one month in the year, but an even biomass mix through the whole year.

Organic matter has in some cases been pretreated and stored for the subsequent utilization later. The waste has to be placed in sealed containers so the volatile component concentration remains consistent, and so it does not attract unwanted animals. The organic matter shall be stored in a refrigerator until it is ready to use (A. Sluiter 2008). This means that it is possible to store the slaughterhouse waste, but it will be inefficient if one need to use the energy produced from the biogas to refrigerate the waste. This is not a big issue in Greenland dough, since the normal temperature is almost below freezing point in October, see figure 18. It can therefore be possible to store the waste from the slaughterhouse without too high extra costs.

16.2.2 Sheep farmer in Narsaq

There is a big sheep farm almost in the city of Narsaq, where there are good prospects for organic waste. I have tried to contact the farmer but have not got any answers. I went to his farm when I visited Narsaq, but he was not home. I talked to Steffen Bertelsen, and he told me that there probably is some waste from the farm. The manure from the sheep is used as fertilizer, but would be possible to use this in biogas production instead, and use the biomass which comes out after the biogas process as fertilizer, which actually is a better fertilizer.

Steffen also told me that there are also some cows at the farm, which is used to meet production. This is the only cattle production in Greenland. Neqi, the slaughterhouse does not have capacity to slaughter cows, and therefore it is done at the farm. Due to that it is also produced some slaughterhouse waste at the farm. The cow production is in an early phase, and according to Steffen is it good possibilities to increase the production. Since I have not been able to contact the farmer, I do not have any numbers on the available organic waste at the farm. But there are at least some, and this recourse of organic waste should be investigated further on.

Figure 21: Cows in Narsaq

16.2.3 Narsaq Seafood

Narsaq Seafood is a company that purchases and processes crab, but other fish products are also expected to be a part of the future product range. The company's primary market is the Greenlandic home and export. The company started in August 2009 and has approx. 12 employees in production, and additionally 20 employed fishermen. Narsaq Seafood wants to protect the external environment as much as possible and also wants to be ahead of regulatory requirements for the external environment. I do not have any exact numbers for how much organic waste they have, but they have at least some organic waste.

Upernaviarsuk Experimental Station and Horticulture

Upernaviarsuk experimental station is Greenland Self-Government experimental farm and school for the agricultural industry in Greenland. The horticulture at Upernaviarsuk consists of both outdoor areas, hotbeds and two large greenhouses. The outdoor arenas are used for vegetable production, especially potato production. There is some organic waste from Upernaviarsuk, especially in the fall when the potatoes are harvested.

16.2.4 Fish Factory in Narsaq

The fish factory in Narsaq does not have any organic waste at the moment. The fish are cut and cleaned at sea, and the fishers do not bring the waste in to land.

16.2.5 Isortoq Reindeer Station

Isortoq Reindeer station is located approx 100 km from Qaqortoq and Narsaq. The station is currently the third largest reindeer farm in the Nordic countries, and there are each year much organic waste when the reindeer are slaughtered. There has also been done research about lupine production which can supplies the slaughter waste in a biogas production. I do not have any exact numbers, but there is much potential waste in Isortoq in order to produce biogas (DTU 2011).

16.2.6 Fish factory in Qaqortoq – Arctic Prime Fisheries

The factory has the latest years produced organic waste equivalent to 25 % of the total production. In 2010 they produced 735 ton fish which was a reduction from the last years. In the summer they did not have any numbers for the production in 2011. Arctic Prime Fisheries manager; Marcus Jacobsen think the production will increase the coming years, and are hoping to have a production around 1 500 – 2 000 ton a year. If we estimate that they will be able to produce at least 1 000 ton fish in the coming years, the organic waste will be:

*1 000 * 0.25 = <u>250 ton/per year</u>*

16.2.7 Great Greenland Furhouse

Great Greenland Furhouse is a modern tanning and production company that processes furs and sells clothing, fashion wear and other products made of Greenland fur and seal skin. The production factory is located in Qaqortoq. The company purchases seal skin from all over Greenland. The fabric only buys the skin, not the whole seal, which means that is not very much organic waste at the factory. But there is seal blubber at the skin they receive, which is removed and thrown as waste at the factory, so there will be some organic waste available.

16.2.8 Fish factory in Nanortalik

It has not been any production in the fish factory in Nanortalik since 2009. When visiting Nanortalik there was some rumors about someone wanted to start up algae and seaweed production in the factory, but nothing was decided yet. I do not know how serious the plans are, but the people I spoke to said that is were serious plans. I do not have any numbers how much organic waste there is from such a production, but it will always be some. As one can see from table 4 has algae a C/N ratio around 100. Because of the high C/N ratio can it be a good product to mix with slaughterhouse waste which has a to low C/N ratio.

If they will start up with any production is hard to tell, and the people I have talked with did not know very much about it. It is therefore impossible to estimate any waste from this factory, but it is relevant to investigate more if a biogas production is starting up in South Greenland.

16.3 Waste water

As mention earlier are the wastewater and sewage dumped directly in to the sea. Wastewater and sewage are organic matter and could instead be used in biogas production. It could be a good thing to include wastewater in the biogas production, not only because of the environmental benefits, but also to maintain the right amount of water in the biomass.

I do not have any exact amount of wastewater and sewage from the cities. Since they just dup it in the sea does they not have any logging system for it. But it would be possible to calculate an average value. The wastewater and sewage are today either leaded to the sea in a server network, or collected and dumped in to the sea. It would therefore be easy to lead or dup this in to a biogas plant instead of the sea, and it would not be much extra expense or work compared to what they already does.

16.4 Total

From this one can estimate that there is at least some organic waste available in South Greenland. The total amount from the number presented earlier is:

Household waste = *1 123.2 ton/per year*

Neqi= *280 ton/per year*

Arctic Prime Fisheries = *250 ton/per year*

Total= 1 653.2 ton/per year

It is difficult to say how much biogas on can produce from 1 650 ton organic waste, because it depends on different parameters such as; what the waste consist of, the biogas plant, climate, etc. In some biogas plant one con produce 1000 liter oil from 2 500 kg cow manure (Olesn 2010). I estimate that 3 000 kg of the mixture of organic waste in South Greenland gives 1000 liter oil.

1 653 200/3 = 551 067 liter

551 067 liter* 5,57 DKK/liter = 3 069 441 DKK

This number is only estimates, and it has to be done better calculations with more reliable numbers it a biogas plant shall be built.

17 Logistics

Biogas production will make a significant contribution to reducing greenhouse gas emissions from agriculture, and from waste deposit. To achieve the reduction, one have to achieve a reduction of emissions through treatment, replace non-renewable energy with renewable biogas or bio-fuel, and to reduce the use of mineral fertilizers in agriculture.

Biogas production is linked to activities within the "Biogas process." Biogas is a renewable energy source, and the energy source it replaces, will determine the reduction potential which can be achieved (avoided burden). Logistics solutions for transport of biomass to biogas plants, and removal and spread of digestate will give some emissions, and will have an impact of the overall environmental effect. Logistic solutions in order to transportation of the biomass and digester can contribute to greenhouse gas emissions and use of fossil resources. In order to assess the extent to which the biogas plant is good for the environment, one has to evaluate the entire supply chain of the biogas process, from the production of waste, collection systems, treatment solutions, the distribution of gas and digestate.

Accordingly, the utilization of biogas from organic waste products has to been seen holistically, and includes the produced energy, logistics associated with waste transport into the plant, handling and use of the digestate, and optimization of fertilizer value of the digestate. Due to the logistics, it is very important where one chooses to locate a biogas plant. Development of analytical tools that can be used to evaluate the entire chain of processes from waste production, collection systems, treatment solutions, optimization of the biogas process from different waste fractions, transportation and logistics for the use of digestate. It is important to evaluate and optimize all this different factors in order to avoid investments in facilities that do not work as intended.

Because of the big distances in South Greenland, is logistic very important. And it can have a significant role for the profitability and efficiency for a potential biogas production. Today, Royal Arctic Line has weekly calls at the three cities, and as mentioned is it an ongoing project about transporting burnable waste from Narsaq to Qaqortoq. Since the ships is all ready sailing between the cities, will it not be any extra emissions if waste are transported between the cities, but it will be extra costs. It could be possible to transport organic waste in same way as they transport the burnable waste today.

18 Use of Biogas in South Greenland

Best utilization of biogas is to production of electricity and heat in one. But this does not have the same utilization level if one can produce electricity and heat in a better, more efficient and environmentally friendly manner, such as hydropower, than is the most economical solution is to use gas for fuel. Since the three cities in South Greenland is quite different will vary from what the best solution of the gas is.

In order to achieve the wanted purpose with biogas production it is necessary to consider how biogas shall be utilized in best possible way. South Greenland’s goal considering biogas is as mentioned earlier; reducing the emission of greenhouse gases, but also to improve the waste management in the cities and create an energy substitute. It is concluded that utilization of biogas and the fuel the biogas replaces has great impact on the amount of saved greenhouse gas emissions.

Research has concluded that biogas is the most environmentally friendly fuel that can be found in the market, both in terms of greenhouse gas emissions and also for a number of other local pollution categories. In order to achieve the best effect of the local environmental benefits, shall biogas, as fuel, primarily be used for transportation purposes in urban areas (Raadal, Modahl og Lyng 2009). South Greenland is not very urban and does not have that much emission due to local transportation in the cities. There are large distances in South Greenland and it is normal to travel by boat, since there are no roads between the cities. The biogas could therefore be used as fuel to the boats.

Challenges due to the utilization of biogas are related to the application the gas is intended and the processing which are chosen. The economic framework conditions, such as capital, operating costs and potential earnings, will most often be a direct result of the selected application.

In smaller plants will the construction costs become dominant and prevent processing of the gas. The challenges are therefore related to process optimization or simplification, cost of construction components and process optimization. The biggest challenges are given if the biogas is being converted into liquid fuels (DME or diesel), this technology is not developed sufficient for small scale biogas plant.

The best solution in South Greenland is properly to use the gas in a combined power and heat production. This way one get good utilization of the gas, and the system is not very complex and does not demand a very high quality of the gas. The costs are much lower to build a plant that produce electricity and heat, than if the gas shall be convert into diesel oil. There is not enough competence in South Greenland to start up a very complex biogas plant, and a simpler plant is much more realistic. There is a big demand for producing biodiesel, so it could be a solution in the future, when they have more experience and knowledge about biogas production.

In Nanortalik is there a great demand for a substitute for diesel which is used to produce electricity and heat. A potential biogas plant could be built in combination with the existing power plant in Nanortalik and supply the generators with fuel. Since the district heating system in the town is not very large will the heat not be totally utilized. But a biogas plant need to have a constant temperature through the whole year, and much of the heat which is produced have to be used to heat up the biogas plant.

In Qaqortoq they have a big district heating network, but today they produce heat to the district heating with an incineration plant, and it will not be profitably justifiable to change this with a biogas plant. But in some years, when they have to replace the old incinerator, maybe biogas could be a better solution.

19 Culture

Today there is not much culture of sorting waste at South Greenland. But in the latest year have there been much more focus on waste, and the people who lives there are starting to see why waste management is important. The waste management is much better than it was for only 20 years ago, when it was normal just to throw waste outside their houses. Today they try to sort the waste, and the municipality has realized that they need to do something with their waste problem. It is also a good thing that two of three cities are sending their hazardous waste do Denmark instead of burning it. It is easier and cheaper to just burn the waste, but it is not good for the environment.

The inhabitants also see the importance of tourism, and understand that they have to do something about their waste problem in order to be more attractive for the tourist.

Since it is not normal for the people to sort their waste, is it important to inform them why it has to be done. In order to use domestic waste in biogas production is it necessary that the people sort their organic waste. I do not think that is a problem, as long as the people understand why they have to do it, and feel that they will get some benefits from it. Biogas production can lead to cheaper electricity, heat or diesel, which can be a motivating factor for the inhabitants in Greenland.

The people I talked to in South Greenland thought it was possible to sort their organic waste. Why should not they be able to do it, when other can? Many of the older people is use to sort their organic waste. In older days they had to use the resources which were available, and organic waste was often sorted and given to animals. But even if they thought they could sort their waste, did they not understand why it was necessary.

Another cultural challenge can be their attitude. They do not like big changes, and do not always think about the future. As long as things work in present, they do not see the importance of changes. Today South Greenland is prioritizing school and education, and the inhabitants in the cities are better and better educated. This is a positive trend, and young people are more open for changes. The younger people I spooked with, was more positive to biogas production then the older. The Greenlandic people have to wake up and be a part of the changes that goes on in the world.

Figure 22: Illustrates that the world are changing

Another cultural problem concerning biogas production can be maintenance. It is currently not a very widespread culture of maintenance in Greenland generally. One of the reasons is because they often do not have enough knowledge and equipment to maintain machines, etc, and they just run the machines to they do not work anymore. I got the impression that the culture for maintenance is much better today than it was for ten years ago. Kujalleq municipality has today a relatively big technical department, with offices in all the three cities. There is good technical knowledge in this department, and some of the employees are educated engineers or has mechanical background. The technical department helps to increase the maintenance culture in the society.

20 Alternative Solutions

To start with biogas production in South Greenland can be a good investment, but there are many different solutions for how and where a potential biogas plant shall be. In this chapter will there be presented and discussed some different solution for biogas production in South Greenland.

One can see from the research presented earlier in the report, that there are potential for biogas production in South Greenland. But there are different needs, and constraints in the different cities. There is not an urgent need for biogas in Qaqortoq. Today they get electricity from hydropower, which is very sustainable. They also have heat production from an incineration plant where they burn all the burnable waste in the city. The waste management is good in the city, and they do not have much organic waste which is not burned in the incinerator. The incinerator has also much more capacity so there is today actually a lack of waste, and they need to burn all the waste which they have. If the organic waste was used in biogas production instead, it would have a negative effect on the heat production.

Narsaq is the city with most available organic waste, compared to the population. There is waste from the fish factory and from the slaughterhouse. There is also a big farm in the city, which produces much organic waste. The farm can also use the digestate from the biogas production as fertilization and it would not be high transportation costs since the farm lies in Narsaq ity, with road connection. In Narsaq they also get electricity from the hydropower plant, and there is not a huge need or demand for electricity. But they use much diesel oil to heat the buildings in. Diesel oil is not a good environmental solution, and is also quite expensive, and will probably be more expensive in the coming years. It could therefore be a good solution to have a biogas plant in the city which can produce biodiesel that can be used for heating instead of normal diesel oil.

There is also waste problem I Narsaq, and they are struggling to get rid of their waste. There is today an ongoing project about transport the burnable waste from Narsaq to the incineration plant in Qaqortoq. Since they are already transporting waste, could it be possible to transport organic waste from Qaqortoq back to Narsaq, in order to produce biogas in Narsaq. In this way one will get a good utilization of both, the organic and the burnable waste.

In Nanortalik diesel oil are used to produce both, electricity and heat. In 2010 they used *1.018.643* liter diesel oil to produce 3.852.060 kWh. It is very expensive to produce electricity from diesel oil, and it is not a sustainable or environmental good solution. A biogas plant would therefore be a very good solution in Nanortalik. A biogas plant could supply the diesel generators in Nanortalik with fuel. It would have reduced the emissions as well as the diesel costs. There is a big need and demand for biogas in Nanortalik, the problem is just that it is not very much organic waste there, accept for the domestic waste. There are today none fish factory in the city, and there are not any farms in the city either. The waste problem in Nanortalik is huge, and there is a need to do something with the situation as fast as possible.

Since Nanortalik is the city where the demand for new energy recourse is biggest, can a solution be to expand the waste transporting project. If it is possible to ship waste from Narsaq to Qaqortoq can it also be possible to ship waste between Nanortalik and the other cities. The incineration plant in Qaqortoq has capacity to burn 3 000 ton waste. The total amount of waste produced in the three cities are approx. 2 800 ton, where 40 % are organic waste. Without the organic waste will the three cities together produce approx. 1 800 ton burnable waste.

In order to utilize the energy in biogas the best way, would a big biogas plant in Nanortalik be the best solution. Than the organic waste from Narsaq and Qaqortoq can be shipped to Nanortalik with Royal Arctic Line, while the rest of the burnable waste can be shipped from Nanortalik and Narsaq to the incineration plant in Qaqortoq. This solution will provide a solution for the waste problem in Narsaq and Nanortalik, and there will be a better utilization of the heat in the incineration plant in Qaqortoq. And Nanortalik can reduce their use of diesel oil. It is expensive to transport the organic waste between the cities, but since there already are ships are sailing between the cities weekly is it possible. One will also reduce transportation costs of the diesel oil to Nanortalik.

Another solution could be to build a biogas plant together with a factory, which could produce and provide the factory with electricity and heat. That could be a solution in Narsaq, e.g. Neqi could have their own biogas plant and be self-sufficient with electricity and heat. One of the reasons that there is not any fish production in Nanortalik shall be due to the high electricity costs in the city. It is more economically appropriate to move the production to a city with hydropower and lower electricity costs. If the factory had their own biogas plant could they be self-sufficient with electricity and heat, and reduce many of their expenses.

If there is a biogas plant in all or one of the cities will it be appropriate to lead the wastewater and sewage directly in to the biogas plant instead of in to the sea. It will not be appropriate to transport wastewater or sewage between the cities. It contains too much water, and would be expensive to transport. If only one biogas plant is build will it therefore only be appropriate to use the wastewater and sewage from this city, not the other cities.

20.1 Summary of possible solutions in South Greenland:

- One big biogas plant in Nanortalik, as a substitute for the diesel generator which produce electricity and heat today. Transport organic waste from the other cites to Nanortalik, and also transport burnable waste to the incineration plant in Qaqortoq.

- Smaller biogas plants in all the cities. Reduces the transportation costs, but there will be higher building, operating and maintaining costs. Will not solve the main waste problem in Nanortalik.

- Smaller, private biogas plant connected to factories. Can be a good solution to factories which produces much organic waste. Will be a shorter value chain, and less people and processes are involved. One can produce the waste and biogas at same place, and also use the gas with none distribution. This is a good solution since the infrastructure in South Greenland does not support transportation very well. One problem is the digestate which remains after the biogas process. The factories can sell it as fertilizer to farmers, but then it will be transportation costs, since it is not road connection to most of the farmers.

- Biogas production in the farms in South Greenland. Use the available organic waste from the farm in a small biogas plant. The biogas can be uses to heating and directly combustion, and provide the farms with electricity and heat. Good solution for the farmers, but does not solve the waste problems in the cities.

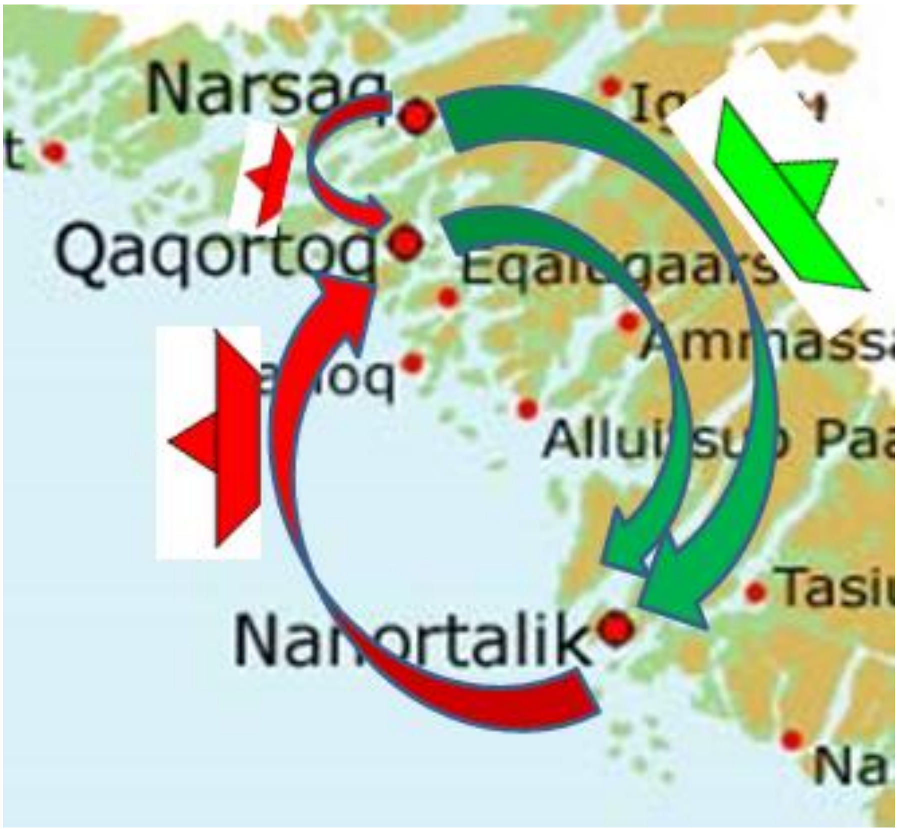


Figure 23: Illustrates transportation of organic and burnable waste between the cities

21 Benefits

There are many benefits and advantages with biogas production. Biogas is the most environmentally friendly fuel which is on the market today, both in terms of greenhouse gas emissions and also for a number of other local pollution. These are some of the benefits with biogas in South Greenland:

- Biogas plant produces high-grade carbon-neutral energy
- Biogas is consider to be CO2 neutral
- Biogas is a renewable, multi-purpose fuel.
- Biogas has high calorific value
- Is clean and economical to produce
- Biogas process is not polluting, and no smoke are produced
- Biogas creates a positive energy balance in South Greenland
- Biogas is a good substitute for diesel oil
- The costs of diesel oil will most likely increase the coming years, and biogas production can reduce the negative effect a price increase can have on the society.
- If factories produce biogas of their own waste, they will have a better competitive advantages compared to other factories if electricity costs increases.
- Reduce import of fossil fuel
- Reduces the dependence on fossil fuels
- Self-sufficient energy resource.
- Biogas production which includes the wastewater and sewage will protects the marine environment
- Reduce water pollution by decomposing sewage, waste and human excreta.
- Biogas production can solve some of the waste problems in South Greenland.
- Use one problem(waste) to solve another problem (energy)
- Reduces landfill sites
- Provides nutrient rich fertilizer
- Biogas can give an economical profit it is managed correctly
- Creates more jobs for the locals, when it is built, operated and maintained

22 Constraints

Challenges in relation to the utilization of biogas are related to the application the gas is intended to have, and which processing that is chosen. The economic conditions such as capital, operating costs and potential earnings will be a direct result of the selected application. In smaller plant will the construction and building coasts become dominant and prevent a processing of the gas, challenges are therefore related to process optimization (or simplification) and cost of construction components and process optimization. There will now be presented some different constraints concerning biogas production in South Greenland. The constraints do not have to be a limitation, but is important to know about them and take it in to consideration when planning a biogas project in the future.

22.1.1 General

When there is a mix of different waste fractions in a biogas plant, it is important to take into account factors such as substrate solids (TS), content of organic matter, nutrient composition, biogas yield, and needs for pre-treatment. Different types of waste have different nutritional composition, and a mixture of them can provide a more suitable nutrient composition of the biogas plant and thus improve the biogas yield, if it is mixed together in a sensible way. If the substrates are not mixed well and comes in fairly equal proportions over time, it may cause operational problems, with uneven biogas production as a result. Different waste types will also affect the digestate and its application.

One of the biggest constraints with biogas production in South Greenland is lack of knowledge and competence about biogas. Biogas production is a complex process and there are many factors which have to be taken in to consideration. Today there are none biogas plan or biogas production in South Greenland and there are no one that has any experience with it. In order to start up with biogas production is there a need for more knowledge about the biogas process, about the energy utilization of the produced biogas, and utilization of the digestate which is the remaining biomass after the biogas process.

Another generally constraint is the long supply and value chain which biogas production has. There is many how has to be involved in the entire process. The supply chain consist of; sorting waste, waste collection, waste storage, transportation, biogas plant, use of biogas, use of digestate, etc. production and use of biogas requires coordination cooperation along the entire value chain, and there are many people which has to be involved. This can be difficult in South Greenland where the distances are large, and the coordination between different cities is not always very good. A solution to avoid this can be s small scale biogas plant, e.g. at the farm in Narsaq.

- Smaller biogas plants (<10 000 ton/year) should produce electricity and heat as it will not be profitable to upgrade the biogas to fuel.
- It is higher risk associated with the establishment of a biogas plant for domestic waste than investment in incineration plant. There is much more knowledge about this incineration plant than biogas plant, and biogas production is a much more complex process.
- Receipt of food waste requires an advanced pre-treatment, both mechanically and manually as in the form of sorting. Can they handle that in South Greenland?

- A biogas plant requires strong security and safety procedures, since there is dangerous gases in the plant, which can explode. Can they handle these requirements in South Greenland?

- Extra time is required for biogas production compared with other energy resources. This 'time lag' needs to be factored in.

- Biogas chain is linked to markets for raw materials, process and products. There is a need for identification, quantification and assessment of market size, pay and stability

- Some of the available organic waste is seasoned, such as the waste from the slaughterhouse.

22.1.2 Economic

First of all has a biogas plant high initial cost of installation, and one have to have a high start capital if one shall build a biogas plant.

The resources are spread, and there are large distances between all the recourses. That can require too much effort and expenses in order to collect the resources, and it is maybe not economically beneficial. One solution can be to have many small plants, but then there are construction, operation, and maintenance costs.

The infrastructure does not support biogas production at South Greenland. There is not any network where one can sell the biogas directly. The district heating is not large in the cities, except from in Qaqortoq where there is not any need for biogas. There are none roads between the cities, and it will be expensive and time-consuming to transport any biomass between the cities. There will be very expensive to build out and improve the infrastructure in South Greenland.

Another constrain is the general expenses. Is there economy to invest in such a project? Who shall pay for the biogas plant, the municipality, private investors, or both? Today there is not room for any investments in biogas in Kujalleq's budget, and there is other issues concerning waste management they will priority before any biogas production. Even if the biogas production can be profitable in the longer run, it requires a lot of money to build a biogas plant.

It will be expensive to educate and train workers to operate a biogas production, and there is also a need to invest in knowledge updates and education in the future.

22.1.3 Technical

- Biogas plants often cause odor to a greater or lesser degree, and there are often problems in relation to localization due to the smell.

- There are technical constraints due to available knowledge and competence in South Greenland. There is lack of expertise in order to run a biogas plant.

- If the digestate from the biogas production consists of wastewater and sewage are there some strict hygiene requirements, especially if the digestate shall be used as fertilizer. If these requirements are not followed dangerous bacteria can grow in the digestate. It is therefore necessary to have knowledge about these requirements.

- There is also need for maintenance at a biogas plant. If the biogas plant has a break down, can it take weeks before new parts arrives South Greenland. It is therefore important to have a good maintenance plan in order to prevent break downs.

- Biogas plant can be dangerous due to the produced gases. It is important to have a contingency plan if an emergency occurs.

- There is also much administrative work due to production of biogas. There is documentation, certification, and regulation which have to be followed.

- The biogas has to be cleaned if it shall be used as fuel. Contaminants in the form of dust must be removed to avoid wear and tear on mechanical equipment of engines, etc. Sulfur in the form of hydrogen sulfide is highly corrosive and must be removed. Water, together with carbon dioxide or hydrogen also be corrosive and must be removed.

22.1.4 Climate

During biogas production, a loss of energy occurs which normally corresponds to about 40% of the theoretical biogas potential. Approx. 25% is used to warm up the biogas plant and 15% is because of engine loss. Because of the arctic climate a bigger energy loss can be expected. It is not any biogas plant in Greenland and one does not have much experience with biogas in a arctic climate. The biogas technology is not proven in the arctic. But the climate in South Greenland is quite similar to the climate in Norway, where there is some experience with biogas production. South Greenland is probably the best place to produce biogas in Greenland, due to the mild climate.

23 Important aspects due to biogas in South Greenland

This chapter will present and discuss some important aspects due to biogas production in South Greenland. There are many things and factors one has to think about and take in to consideration when planning a biogas production. This is especial important in Greenland since there are not much experience with biogas production in arctic area. It is some risks related to a big investment, especially without much experience and knowledge. It is therefore extremely important with good planning and to look at all possible aspects and factors which can have an effect on the biogas production.

23.1.1 Socioeconomic vs. Commercial profitability

Production of biogas is socioeconomic profitable since it contributes to reduced emissions of greenhouse gases, and is a solution to some of the waste problems in South Greenland. However, it is not profitable if the biogas is used to production of electricity, where hydropower is available. It is much more economically to produce electricity from hydropower, but that does not solve any waste problems. Even if one does not earn much money from biogas production, it will have huge socioeconomic benefits for the society. There is also a value in the biomass after the biogas process, and the remaining biomass can be used as fertilizer. There are good agricultural environments in South Greenland and it will be beneficial if farmers can use the biomass instead of importing chemically fertilizer.

23.1.2 Sustainability along the entire chain

All along the whole value chain in biogas production are the challenges related to logistics, efficiency, greenhouse gas accounting, environmental impacts, and social and business administration. All this aspects are important to take in to consideration in basis for assessing the potential for business development and environmental effects, due to biogas. It is also important to establish effective solution which can bring development in the biogas value chain in a desired direction. There is a need for research that quantifies logistic, economic and environmental effects of biogas production. In sum, biogas can be described as a sustainable solution, but it is important that all proposals for biological and technical solutions must be followed up by sustainability analysis, where a LCA (life-cycle analysis) is a good tool to use.

23.1.3 Raw materials and preparation

Organic matter which can be used as biomass in biogas production can vary to a large extent. The variations are partly due to differences in the chemical structure and complexity of the organic matter. The materials composition and quality affect the biogas process. For the process to be controlled predictably and optimally it is necessary to know the exact composition of the organic matter. It is therefore important that it is done research to know the exact composition of the available organic matter in South Greenland, and with research find the best mixture and ration of different organic waste in order to get the best utilization of the organic matter.

23.1.4 Process technology

The biological processes which convert organic matter into biogas is a well-known technology, but it is still challenges related to efficiency and basic understanding of the ecological interaction in the biogas processes, both in small and big plants. It is necessary to understand the interaction between raw material quality, the produces gas and quality of the produced fertilizer product. Although biogas process is a well-known technology is there still need for research related to the development of the technological solutions to ensure year-round biogas production in Greenland. It is also important that the supply of entrepreneurs, investors and local initiatives are stimulated. Furthermore needed venues for communication and which stimuli for good cooperation between the actors. This is really important if domestic waste is going to be used in the biogas production. Then the inhabitants have to be informed and motivated in order to sort their organic waste. Energy economic benefits and costs of different solutions must also be assessed. For example, treatment of manure with food waste, fish waste and other organic waste could increase the efficiency of biogas production.

23.1.5 Stakeholders and investors

It is difficult at present to achieve profitable biogas production. Which stakeholders will be natural drivers and investors of the growth any biogas plant? Will this be a municipal task since such systems are Socioeconomic profitable rather than economically profitable? How can natural stakeholders as a raw material suppliers and power producers be encouraged to biogas production as long as the prospect of profitable operations is unclear? What other forces than prospects for profitable operations can stimulate biogas production?

24 Conclusion

From the investigation and research done in the three cities in South Greenland, can one conclude that there are great potential for biogas production. There are available organic matters which can be used in the production, and there is an energy demand, especially in Nanortalik.

It is much food and agriculture production in South Greenland, which results in much organic waste. Due to the climate change will it most likely be even more food production in South Greenland the coming year, and there are already an ongoing project on cattle production in Narsaq. Therefore will it most likely be even better potential for biogas in the future. The climate is also good for biogas production, compared to the rest of Greenland.

Biogas is a good solution in Greenland, especially where they produce electricity from diesel oil. The waste is a growing problem and it is expensive to do anything with it. It is therefore a very good solution if it is possible to solve the waste problem by producing biogas. It is necessary to do something with the waste situation as fast as possible. Fish and tourism is almost the only industry they have in South Greenland, and the waste can have a negative effect on both if they do not do anything with it. Tourist comes to South Greenland to see the beautiful, pristine nature, and not huge waste disposals. South Greenland has to take care of their reputation, and their nature recourses and they have to see and realize the value in good waste management.

South Greenland is probably the best area to start up with biogas production in Greenland. The climate conditions are relatively good, and there is as mentioned much available organic waste. There is a demand for a substitute to fossil fuel, and better waste management in the rest of Greenland as well. If South Greenland starts up with biogas production is there possibility that other cities and villages in Greenland will follow. It is necessary with more knowledge and experience around biogas production, and South Greenland has the possibility to build up expertise, which later can be used in the rest of Greenland. In Qaqortoq, they have a workers college, *Sulisartut Højskoliat*, and it could be a solution to include biogas production as a subject at the school.

The best solution of biogas production in South Greenland is probably to transport all the organic waste to Nanortalik and build a biogas plant there, which can supply the power plant with biogas in order to produce electricity and heat. In this way, one could reduce the use of fossil fuel. The two other cities get their energy from a hydropower plant, and do not have the same needs for more energy. It is rarely a good solution to transport waste, but in this situation are they already doing it, and the ships are sailing between the cities anyway. Organic waste can be transported to Nanortalik while burnable waste is transported to Qaqortoq. In this way they can get rid of much of the waste problems, and also utilizes the waste in order to produce electricity and heat.

It will be expensive to build up a big biogas plant in Nanortalik, although it would be profitable in the long run. The people in the municipality do not see the benefits and need for biogas production in South Greenland. As it looks today, it is not realistic to think that the municipality will support such a project financially.

Although I think that a big biogas plant in Nanortalik is the best overall solution, is it not the solution which is most realistic. I think it will be easier to convince some of the local industry to start up with a private biogas plant in relation to the factory. It is best potential for such a solution in Narsaq, e.g. the fish factory or the slaughterhouse. If some of the factories start with biogas production I think it will be possible that the municipality supports them with available organic waste. Cooperation like that would be beneficial for both, the factory gets free energy resources, and the municipality gets rid of waste in a sustainable way. It would also probably be easier for the municipality to start up with biogas production if they sees that someone else success with it, and they can see the big potential there is in the waste.

Finally, there is a prioritizing question. Is biogas the first thing to be prioritized in South Greenland? From my opinion, I think that they have to solve their waste problem first. The best way is to include biogas production in their waste management, but there is not economy to do that with the budget Kujalleq has today. In Nanortalik is there huge problems with how they handle their waste, and it is not the organic waste which is the main problem.

Yes, there are potential to start up with biogas in South Greenland, but there is a long road to go before such a project can be beneficial. The overall potential may be larger with the increase of oil prices. There are many things which have to be investigated further, and the biggest problem today is the lack of knowledge and experience. Planning will be very important and they have to look in to every possibility before they decide which solution is the best.

25 Discussion

The project presented in the current report has many parts which could be improved with a longer time of study, and with better knowledge about biogas.

This project about the biogas potential in South Greenland was chosen mainly because I wanted to travel together with another group which was doing their fieldwork in South Greenland. I asked if there was some potential project in South Greenland for a management student and this biogas project was proposed. I thought it was very interesting and decided to go for it. Since I did not have any knowledge about biogas was it necessary to spend much time just to learn about the theory for biogas and biogas production, and how it works. It was more theory to learn than I first thought, and I realize now that the project maybe was too big for one person without any biogas background. It had maybe been better to look at biogas potential in only one of the three cities, or to look at a one specific biogas project. It could be possible that other students can look deeper in to some of the suggestions which come out of this report, and go deeper in to some of the possibilities.
The project has been very interesting, but also challenging. I have learned very much about South Greenland and how the system and management is there, and I have off cause learned much about biogas in general. I also learned a lot during the fieldwork. It was not easy to get in contact with people and plan meetings with them before I traveled, but when I was there was most of them very open and wanted to help as much as they could.

There has been problem with getting the information I wanted, and to get in contact with the right people. I was in Greenland from 28.07.11 to 18.08.11, which was in the middle of the summer holidays. That was a problem, because many of the people I wanted to meet and talk with was on holyday. I have tried to call and write email to them, but there has been difficult to get any answers. It has also been difficult to get exact numbers and values from the municipality and companies; maybe it is because they do not log very much data and information. I have used all the information I have got in the best way, and some people have been very helpful. Since I have not got many exact numbers have it been difficult to do any calculations, and the calculations I have are mostly rough estimates. There has to be done better estimations and research in order to get more exact numbers. But the calculations give an overview and can be used as a good indication of the biogas potential.

The report gives an overview over the situation in South Greenland, and shows that it is potential for biogas production. This lack of information about operation conditions, prices of the equipment required, etc. made the realization of a complete and deep economical study impossible. Biogas plant is a big investment, and there has to be done much more investigation before one can decide what, where and how to build a biogas plant.

26 Bibliography

A. Sluiter, D. Hyman, C. Payne, and J. Wolfe. *NREL*. Mars 21, 2008. http://www.nrel.gov/biomass/pdfs/42627.pdf (accessed October 10, 2011).

Afds Energy. http://www.afdc.energy.gov/afdc/fuels/emerging_biogas_what_is.html (accessed Mai 2011).

Anaerobic Digestion. 2011. http://www.sswm.info/category/implementation-tools/wastewater-treatment/hardware/processes/anaerobic-digestion-general (accessed October 20, 2011).

anaerobic-digestion. 2010. http://www.anaerobic-digestion.com/html/dry_digestion_process.php (accessed October 12, 2011).

Andersen, Vibeke. "Motivation Lecture." 09 2011.

Bertelsen, Steffen, interview by Tina Lerøy. *Narsaq* (August 2011).

BioEnergyFarm. http://www.bioenergyfarm.eu/en/the-portal/about-bioenergy/biogas (accessed November 10, 2011).

Blue Ice. http://www.blueice.gl/Roundtrip_6days_qaqortoq.html (accessed November 06, 2011).

Bondelaget. 2010. http://www.bondelaget.no/getfile.php/Om%20Bondelaget/Nettbutikk/Kunnskapsmateriell/Biogass%20fakta.pdf (accessed September 19, 2011).

Brogaard, and Jørgensen. *Udledning af fiskerispildevand ved Sisimiut.* Lyngby: DTU, 2006.

Baadh, Leif. *Fragt af affald fra Narsaq til forbrændingsanlægget i Qaqortoq.* Qaqortoq: Kommune Kujallq, 2011.

Christensen, Thomas H. *Solid Waste Technology & Management* . John Wiley and Sons, 2011.

cities, Tulsa clean. *Tulsa clean cities.* http://tulsacleancities.com/about-alternative-fuels/biogas/ (accessed April 19, 2011).

Dagbladet. June 19, 2009. http://www.dagbladet.no/2009/06/19/nyheter/utenriks/selvstyre/okonomi/politikk/6783878/ (accessed October 20, 2011).

DMI. http://www.dmi.dk/dmi/index/gronland/klimanormaler-gl.htm (accessed Novenber 09, 2011).

DTU. 2011. http://www.adm.dtu.dk/upload/centre/artek/artek%20event%20innovation/at-konfbog11-low.pdf (accessed November 09, 2011).

Fincham, Rhodes. "Principles of Organizational Behaviour." 335-340. New York: Oxford University Press Inc., 2005.

Fincham, Robin, and Peter Rhodes. *Principles of Organizational Behaviour.* Oxford University Press, 2005.

—. *Principles of Organizational Behaviour.* Oxford University Press, 2005.

Gautier, Donald L. *Assessment of Undiscovered Oil and Gas Resources of the East Greenland Rift Basins Province.* August 2007. http://pubs.er.usgs.gov/publication/fs20073077 (accessed October 16, 2011).

Geenland. http://www.greenland.com/en/explore-greenland/sydgroenland/nanortalik/om-nanortalik.aspx (accessed 10 September, 2011).

Glomsrød, Solveig, Bjart Holtsmark, and Iulie Aslaksen. *Økonomi, miljø og levekår i Arktis.* Feb 2007. http://www.ssb.no/emner/08/05/10/oa/200702/aslaksen.pdf (accessed October 15, 2011).

Greenland. http://www.greenland.com/en/about-greenland/kultur-sjael/historie.aspx (accessed October 10, 2011).

Greenland. http://www.greenland.com/en/ (accessed September 20, 2011).

Greenland. http://www.greenland.com/en/explore-greenland/sydgroenland.aspx (accessed October 15, 2011).

Greenland Guide. http://www.greenland-guide.gl/reg-south.htm (accessed October 15, 2011).

Grønlands Statistik. http://www.stat.gl/default.asp?lang=da (accessed September 2011, 10).

Gyldendal. Gyldendal. 2. oktober 2011. http://www.denstoredanske.dk/Krop,_psyke_og_sundhed/Psykologi/Psykologiske_termer/femfaktormodellen.

Heraldry of the World. http://www.ngw.nl/heraldrywiki/index.php?title=Kujalleq (accessed September 10, 2011).

Hersy, and Blanchard.

Hogan, Joyce, and Deniz S. Ones. "Handbook of Personality Psychology." 849-870. Elsevier, 1997.

Hogskolen I Oslo. http://home.hio.no/~araki/arabase/teo/herbla3.html (accessed November 12, 2011).

Høgskolen i Oslo. http://home.hio.no/~araki/arabase/teo/fiedler3.html (accessed October 12, 2011).

IFF. http://isustainfairfield.org.au/My-Home/i-sustain-recycling (accessed September 10, 2011).

INUILI. http://inuili.com/ (accessed nOVEMBER 07, 2011).

Jørgensen, Marianne Willemoes. *AFFALD FRA FISKERI OG FANGST I ARKTIS.* Lyngby: DTU, 2007.

Kaltwasser, Bernd. "Biogas, FRG." 35-36. Wiesbaden, 198.

Kausel, Edgar E, and Jerel E Slaughter. "Narrow personality traits and organizational attraction: Evidence for the complementary hypothesis." *Organizational Behavior and Human Decision Processes*, 2011.

Kets De Vries, M., and E. Engellau. *Are Leaders Born or Made: The Case of Alexander the Great.* London: Karnac Books, 2004.

Kommune Kujalleq. http://kujalleq.gl/dansk/index-dansk.htm (accessed Septemper 2011 10).

Kossmann, Werner, and Habermehl Stefan. "Biogas Digest Volume I Biogas Basic."

Kujalleq Kommune. http://kujalleq.gl/dansk/by/10-1.htm (accessed 10 September, 2011).

L.Battisti. *Relevance of icing.* Dept. of Mechanical and structural engineering. University of Trento, Italy, 2010.

Miljø. http://kujalleq.gl/dansk/tek/7-7.htm (accessed November 20, 2011).

Morken, John, Bernt Sørby, Ivar Sørby, and Knut Birkeland. 2005.

Müllegger, Elke. *Sustainable Sanitation Practice.* Vienna: Medieninhaber, Herausgeber und Verleger, 2011.

Mørkved, Øystein Ulleberg and Andreas. *Renewable Energy and Hydrogen system concepts for remote communities in the west Nordic region- The Nòlsoy case study.* Mikael Forss,Nordic Energy Research/Nordic council of Ministers, 2008.

NNFCC. http://www.nnfcc.co.uk/tools/evaluation-of-opportunities-for-converting-indigenous-uk-wastes-to-fuels-and-energy-report-nnfcc-09-012 (accessed November 20, 2011).

Norden. Sep 27, 2009. http://www.norden.org/no/aktuelt/nyheter/klimaendringer-truer-inuittene-paa-groenland/?searchterm=Klimaendringer%20truer%20inuittene%20p%C3%A5%20Gr%C3%B8nland (accessed Oct 16, 2011).

Nukissiorfiit. http://www.nukissiorfiit.gl/fileadmin/user_upload/PDF_filer/Priser/Enhedsomkostninger/Enhedsomkostninger_2010.pdf (accessed November 03, 2011).

—. *Nukissiorfiit.* 2010. http://www.nukissiorfiit.gl/fileadmin/user_upload/PDF_filer/Priser/Enhedsomkostninger/Enhedsomkostninger_2010.pdf (accessed November 10, 2011).

NunaGIS. Department of Housing, Infrastructure and Transport, Planning and Projects, Nuuk Greenland. <http://www.nunagis.gl> (accessed 04 28, 2011).

OAKTECK. 2006. http://www.alexmarshall.me.uk/index_files/documents/ResponsetoConsultationonthesourcesegregationrequirementinParagraph7AofSchedule3totheWasteMan.pdf (accessed November 20, 2011).

Ohr, Kristian, Ola Saua Førland, and Valborg Ø Birkenes. *Biogass – Energiproduksjon og avfallbehandling.* Prosjekt nr. 703012 ORIO-programmet, Asplan Viak, 2002.

Olesn, Bent B. "Biogasanlegg i Grønland." 2010.

Pcierd Dost Gov. www.pcierd.dost.gov.ph/index.php/.../doc.../82-what-is-biogas (accessed Mai 2011).

PPM. http://www.processplantandmachinery.com/ (accessed November 20, 2011).

QORLORTORSUAQ Hydroelectric Project – 7.5 MW. 2009. http://www.verkis.com/media/innri/verkefnavefur/skjol/virkjanir%20orkuflutningur/KY0086_Qorlortorsuaq_enska.pdf (accessed November 10, 2011).

Roca, Sara Sorribas, and Verónica Martínez Sánchez. *Biogas Production from the waste of the shrimp manufacture in Sisimiut.* Cophenhagen: DTU, 2009.

Royal Arctic Line. 2011. http://www.ral.gl/ (accessed November 21, 2011).

Raadal, H.L., I. S. Modahl, and K-A. Lyng. *Klimaregnskap for avfallshåndtering, Fase I og II.* Forskning, Østfold: Østfoldforskning OR, 2009.

Schnürer, A, and Å Jarvis. *Mikrobiologisk handbok för biogasanlägningar.* Sverige: Avfall Sverige Utvecling, 2009.

SSWM. http://www.sswm.info/category/implementation-tools/reuse-and-recharge/hardware/reuse-energy-products-form-waste-and-was-2 (accessed October 20, 2011).

Steffen, R, O Szolar, and R Braun. *Feedstocks for Anaerobic Digestion.* Vienna: University of Agricultural Sciences Vienna, 1998.

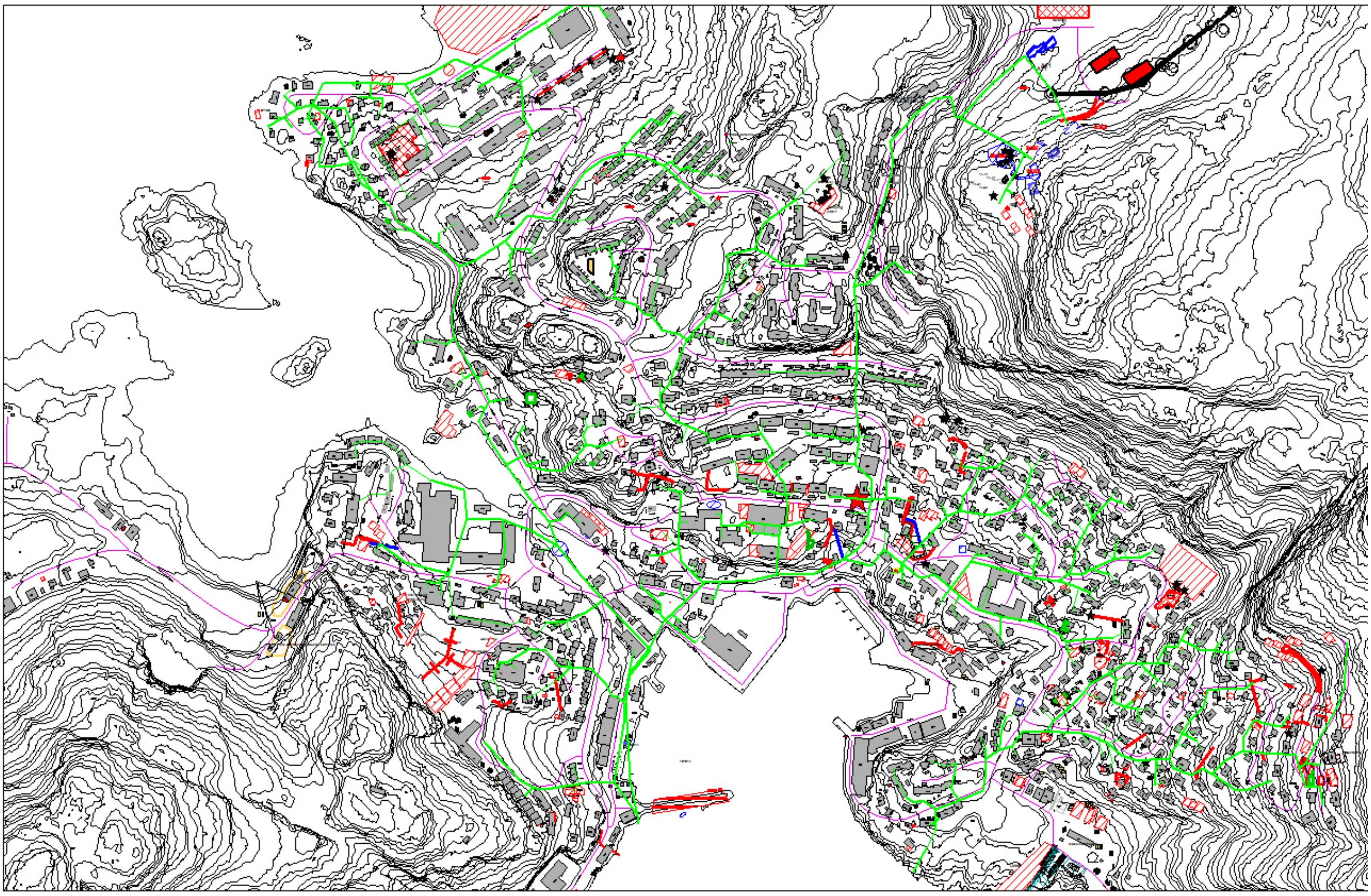
United Nations Framework Convention on Climate Change . http://unfccc.int/kyoto_protocol/items/3145.php (accessed October 1, 2011).

WFD. *WFD.* 2011. http://eur-lex.europa.eu/LexUriServ/site/en/oj/2006/l_114/l_11420060427en00090021.pdf (accessed September 17, 2011).

Wise Geek. http://www.wisegeek.com/what-is-biogas.htm (accessed Mai 2011).

YR. *2010.* http://www.yr.no/place/Norway/Oslo/Oslo/Oslo/statistics.html (accessed Novenber 15, 2011).

Appendiks 1



Appendiks 2

(Nukissiorfiit u.d.)

NUKISSIORFIIT

dsomkostninger 2010

2010-mi innaallagissamut nukimmullu ataatsimut aningaasartuutit

Enhedsomkostninger lys og kraft 2010 (Kr. / kWh)

	Vareforbrug	Personaleomkostninger	Kapacitetsomkostninger	Afskrivninger	Renter	Kostpris
NANORTALIK	1,40	0,75	1,51	0,41	-	4,08
AAPPILATTOQ	1,50	2,61	0,68	0,84	0,28	5,91
NARSAQ KUJALLEQ	1,36	1,35	0,98	0,47	0,42	4,59
TASIUSAQ	2,12	2,68	1,60	2,85	0,83	10,08
AMMASSIVIK	1,65	1,91	1,95	1,75	0,48	7,75
ALLUITSUP PAA	1,58	1,20	0,77	1,18	0,30	5,04
QAQORTOQ	0,08	0,38	1,37	0,67	0,26	2,75
SAARLOQ	1,72	0,34	0,39	1,85	0,63	4,94
EQALUGAARSUIT	1,77	0,27	0,71	0,96	0,45	4,16
QASSIMIUT	1,70	1,02	1,91	0,98	0,63	6,24
NARSAQ	0,08	0,38	1,37	0,67	0,26	2,75
IGALIKU	1,85	2,16	0,39	0,89	0,24	5,53
QASSIARSUK	1,96	0,78	0,41	1,69	0,56	5,40
PAAMIUT	1,30	0,43	0,90	0,24	0,23	3,11
ARSUK	1,49	1,53	0,40	0,49	0,11	4,00
NUUK	0,01	0,14	0,35	0,28	0,14	0,91
QEQERTARSUATSIAAT	1,27	0,71	0,49	0,54	0,12	3,13
KAPISILLIT	1,96	1,37	1,20	1,09	0,30	5,91
MANIITSOQ	1,30	0,52	0,63	0,30	0,07	2,72
ATAMMIK	1,87	1,28	1,22	0,78	0,30	5,45
NAPASOQ	2,43	1,18	3,01	0,78	0,12	7,51
KANGAAMIUT	1,47	0,05	0,79	0,60	0,16	3,07
SISIMIUT	0,21	0,24	0,50	0,42	0,25	1,62
ITILLEQ	2,20	1,83	1,66	0,71	0,20	6,61
SARFANNGUIT	1,28	0,99	0,57	1,24	0,32	4,41
KANGAATSIAQ	1,39	0,97	0,74	0,67	0,23	4,00

2010-mi imermut aningaasartuutit

Enhedsomkostninger vand 2010 (Kr./m³)

	Vareforbrug	Personaleomkostninger	Kapacitetsomkostninger	Afskrivninger	Renter	Kostpris
NANORTALIK	2,13	0,53	37,85	23,37	10,38	74,22
AAPPILATTOQ	-	-	45,85	94,60	38,53	178,98
NARSAQ KUJALLEQ	-	-	19,48	423,10	173,54	616,13
TASIUSAQ	-	-	106,45	332,27	104,68	543,40
AMMASSIVIK	-	-	230,73	193,80	49,60	474,13
ALLUITSUP PAA	11,26	-	99,02	228,44	86,41	425,12
QAQORTOQ	0,73	3,71	14,11	15,77	6,61	40,94
SAARLOQ	64,78	555,87	118,72	374,17	65,16	1.178,71
EQALUGAARSUIT	-	108,57	59,76	239,42	99,20	506,96
QASSIMIUT	5,83	44,87	18,22	74,73	19,75	163,41
NARSAQ	0,98	4,10	17,43	31,01	9,81	63,33
IGALIKU	11,34	-	45,85	94,60	38,53	190,33
QASSIARSUK	7,16	16,43	39,01	23,65	12,13	98,38
PAAMIUT	0,70	2,18	12,16	11,89	4,80	31,73
ARSUK	1,41	-	13,39	128,64	40,16	183,61
NUUK	0,82	1,76	9,47	7,25	2,61	21,90
QEQERTARSUATSIAAT	2,84	0,67	31,34	51,84	25,98	112,66
KAPISILLIT	47,35	6,00	359,46	241,32	108,42	762,56
MANIITSOQ	2,00	4,94	16,07	18,91	7,45	49,36
ATAMMIK	15,02	30,44	74,21	133,32	59,89	312,88
NAPASOQ	43,51	67,23	43,51	252,05	94,27	500,57
KANGAAMIUT	6,32	75,51	46,62	65,58	18,29	212,32
SISIMIUT	0,05	1,00	6,81	3,69	1,12	12,65
ITILLEQ	-	20,14	541,82	524,11	191,62	1.277,69
SARFANNGUIT	22,20	-	55,27	379,51	113,11	570,08
KANGAATSIAQ	6,74	(2,38)	45,48	101,99	26,99	178,82

2010-mi kiassarnermut aningaasartuutit

Enhedsomkostninger varme 2010 (Kr./MWh)

	Vareforbrug	Personaleomkostninger	Kapacitetsomkostninger	Afskrivninger	Renter	Kostpris
NANORTALIK	1	-	81	39	16	137
AAPPILATTOQ						
NARSAQ KUJALLEQ						
TASIUSAQ						
AMMASSIVIK						
ALLUITSUP PAA						
QAQORTOQ	475	25	64	58	205	827
SAARLOQ						
EQALUGAARSUIT						
QASSIMIUT						
NARSAQ	-	-	51	-	-	51
IGALIKU						
QASSIARSUK						
PAAMIUT	288	79	86	119	67	639
ARSUK						
NUUK	23	12	81	126	83	325
QEQERTARSUATSIAAT						
KAPISILLIT						
MANIITSOQ	346	38	129	76	17	607
ATAMMIK						
NAPASOQ						
KANGAAMIUT						
SISIMIUT	174	56	104	286	220	840
ITILLEQ						
SARFANNGUIT						
KANGAATSIAQ	-	-	-	-	-	-

Appendiks 3

Aqqaluk Ittuk

Havn	Rejse	Ankomst			Afgang		
Nanortalik	1145	ETA	28.11.2011	23:45	ETD	29.11.2011	10:00
Narsaq	1145	ETA	29.11.2011	19:25			
Qaqortoq	1146				AFG	30.11.2011	10:00
Narsaq	1146	ETA	30.11.2011	12:30	ETD	30.11.2011	14:30
Qassimiut	1146	ETA	30.11.2011	19:30	ETD	30.11.2011	20:30
Arsuk	1146	ETA	01.12.2011	04:35	ETD	01.12.2011	10:00
Kangilinnguit	1146	ETA	01.12.2011	12:00	ETD	01.12.2011	13:30
Qaqortoq	1146	ETA	02.12.2011	03:15	ETD	02.12.2011	11:00
Narsaq	1146	ETA	02.12.2011	13:30	ETD	02.12.2011	15:30
Narsarsuaq	1146	ETA	02.12.2011	19:00	ETD	02.12.2011	20:30
Qassiarsuk	1146	ETA	02.12.2011	21:00	ETD	02.12.2011	22:00
Qaqortoq	1146	ETA	03.12.2011	03:20	ETD	03.12.2011	11:00
Igaliku	1146	ETA	03.12.2011	14:30	ETD	03.12.2011	15:30
Eqalugaarsuit	1146	ETA	03.12.2011	19:30	ETD	03.12.2011	20:30
Saarloq	1146	ETA	03.12.2011	21:30	ETD	03.12.2011	22:30
Qaqortoq	1146	ETA	04.12.2011	00:45	ETD	04.12.2011	10:00
Arsuk	1146	ETA	04.12.2011	21:05	ETD	05.12.2011	10:00
Qaqortoq	1146	ETA	05.12.2011	21:05	ETD	05.12.2011	22:05
Narsaq	1146	ETA	06.12.2011	01:00			
Narsaq	1147				ETD	05.12.2011	10:00
Alluitsup Paa	1147	ETA	05.12.2011	15:00	ETD	05.12.2011	16:30
Ammassivik	1147	ETA	05.12.2011	17:30	ETD	05.12.2011	18:30
Nanortalik	1147	ETA	05.12.2011	22:30	ETD	06.12.2011	10:00
Tasiisaq	1147	ETA	06.12.2011	12:00	ETD	06.12.2011	13:00
Narsarmijit	1147	ETA	06.12.2011	16:30	ETD	06.12.2011	17:30
Aappilatseq	1147	ETA	06.12.2011	19:30	ETD	06.12.2011	20:30
Nanortalik	1147	ETA	07.12.2011	01:00	ETD	07.12.2011	10:00
Alluitsup Paa	1147	ETA	07.12.2011	13:30	ETD	07.12.2011	15:00
Qaqortoq	1147	ETA	07.12.2011	19:00	ETD	08.12.2011	10:00
Narsaq	1147	ETA	08.12.2011	12:30	ETD	08.12.2011	15:30
Nanortalik	1147	ETA	09.12.2011	01:05	ETD	09.12.2011	10:00
Qaqortoq	1147	ETA	09.12.2011	17:50	ETD	09.12.2011	18:50