Future Local Gas Infrastructure

Vaasa Region

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Abstract

Vaasa Region is working on building and developing a biogas-based economy, with the help of natural gas as a backup fuel. From previous studies done, lack of infrastructure and gas competence have been cited as the biggest challenges for the region. Vaasa has a target of being a carbon neutral region by 2035, this makes the need for finding alternative sustainable energy solutions very important for the region.

This thesis, done as part of the AIKO Gas CoE project compiles previous studies carried out on the potential of a gas economy and maps out the plans of some of the main drivers of a gas-based economy in Vaasa region. It highlights the technologies, infrastructure developments and environmental challenges for a gas economy. The region is addressing some of the challenges pointed out through the Energy Lab and Technobotnia for competence growth to open new possibilities for the gas through R&D. Infrastructural developments such as upgrading of biogas plants to supply compressed biogas for industrial processes and as vehicle fuel, with filling stations open to the public and more planned for the future is being done. However, the current rate of production will not be able to satisfy the regional consumption if Wärtsilä is to use locally produced biogas.

Language: English Key words: Environment, Gas, Infrastructure, Technology

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Abstrakt

I Vasa-regionen bygger man upp och utvecklar en ekonomi som bygger på biogas, med naturgas som reservbränsle. Tidigare undersökningar har visat att brister i infrastrukturen och bristande sakkunskap om gasbranschen utgör de största utmaningarna för regionen. Vasa har som mål att vara en kolneutral region vår 2035, det är alltså mycket viktigt att hitta alternativa och hållbara energilösningar i den här regionen.

Detta slutarbete gjordes som en del av AIKO gas CoE-projektet, det sammanställer tidigare undersökningar om potentialen för en gasbaserad ekonomi, samt kartlägger de viktigaste faktorerna inom en sådan ekonomi, med fokus på teknologier som bygger på en gasbaserad ekonomi, utveckling av infrastruktur för en sådan ekonomi samt utmaningar för miljön som detta innebär. Regionen försöker lösa några av de utmaningar som framkommit via Energy Lab och Technobotnia, så att man genom ökande kunskap med hjälp av FoU skapar nya möjligheter inom gasbranschen. Utveckla infrastrukturen, till exempel genom att uppgradera biogasanläggningar så att de kan leverera biogas för industriella processer och som bränsle till tankstationer öppna för allmänheten, samt genom andra planerade åtgärder iframtiden. Den nuvarande produktionsnivån tillfredsställer dock inte den regionala förbrukningen, om Wärtsilä ska använda lokalt producerad biogas.

Språk: Engelska Nyckelord: Miljö, Gas, Infrastruktur, Teknik

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Tiivistelmä

Vaasan alueella rakennetaan ja kehitetään biokaasuun perustuva talous, jossa maakaasu käytetään varapolttoaineena. Aiemmista tutkimuksista tiedetään, että puutteita infrastruktuurissa ja kaasualan asiantuntemuksessa muodostavat alueen suurimmat haasteet. Vaasan tavoitteena on olla hiilineutraalialue vuonna 2035, vaihtoehtoisten ja kestävien energiaratkaisujen löytäminen on siis erittäin tärkeätä tällä alueella.

Tämä opinnäytetyö tehtiin osana AIKO kaasu CoE-hanketta, se kokoaa aiemmat tutkimukset kaasutalouden potentiaalista ja kartoittaa kaasupohjaisen talouden tärkeimpiä tekijöitä Vaasan alueella, keskittyen biokaasuun perustuvan talouden teknologioihin, infrastruktuurin kehittämiseen ja ympäristöhaasteisiin. Alueella yritetään ratkaista Energy Labin ja Technobotnian osoittamia haasteita, jotta osaamisen kasvulla ja T&K:n avulla luodaan uusia mahdollisuuksia kaasualalla. Kehittämällä infrastruktuuria, esimerkiksi päivittämällä biokaasulaitoksia jalostetun biokaasun toimittajiksi teollisuusprosesseille ja polttoaineena yleisölle avoimilla tankkausasemilla ja muilla suunnitelluilla toimenpiteillä tulevaisuudessa. Nykyinen tuotantoaste ei kuitenkaan tyydytä alueellista kulutusta, jos Wärtsilän tulee käyttää paikallisesti tuotettua biokaasua.

Kieli: Englanti | Avainsanoja: Ympäristö, Kaasu, Infrastruktuuri, Tekniikka

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Abbreviations

AAV: Ambient Air Vaporizer

BAT: Best Available Technology

CBG: Compressed Biogas

CH_4: Methane

CHP: Combined heat & Power production

CNG: Compressed natural Gas

CO_2: Carbon dioxide

EPC: Engineering, Procurement, Construction

Eq: Equivalent

ETS: Emissions Trading System

EU: European Union

GWP: Global Warming Potential

H_2O: Water/ Vapour

H_2S: Sulfur Hydroxide

kWh: kilo Watt hour

LBG: Liquefied Biogas

LNG: Liquefied Natural Gas

MJ/L: Mega Joules per Litre

MWh: Mega Watt hour

NH_3: Ammonium

Nm^3: Normal cubic meters

NTP: Normal temperature and Pressure

R&D: Research and Development

$(R_2(SiO)_n)$: Siloxanes

TS: Total solids

WWTP: Waste Water Treatment Plant

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1 Introduction

The Vaasa region is a coastal region consisting of seven municipalities namely; Vaasa, Laihia, Mustasaari, Maalahti, Isokyrö, Korsnäs and Vöyri located on the east of the Gulf of Bothnia on the western border of Finland. The region has the biggest energy cluster in the Nordic region and is leader in energy technology innovations. The Vaasa energy cluster is home to more than 140 companies specializing in different energy technologies, 80% in exports, accounting for 30% of Finland's energy exports [1]. The energy cluster is managed by EnergyVaasa which is under Merinova Technological Center and works closely with VASEK. The region is also known as a student region, with 1/5 of the population being students, and has six higher learning institutions offering programs in various disciplines in three different languages [2]. Despite the various technological advancements that Vaasa region has made, one source of energy which is gas, has not been extensively explored but can be instrumental in reaching the set energy and climate targets in the energy mix.

Vaasa has a target of being a carbon neutral region by 2035 [10], this makes the need for finding alternative sustainable energy solutions and developing the infrastructure very important for the region. The current global energy and environmental challenges call for finding means of producing energy in an environmental friendly manner and still meet the ever-increasing energy demands. The International Energy Outlook 2016 projects an increase in CO_2 emissions from 32.3 billion metric tons in 2012 to 35.6 billion metric tons in 2020 and 43.2 billion metric tons in 2040 if left as things are [3, p. 139].

Interest in gas as an energy source in the Vaasa region has grown as seen in how the local companies, schools and the municipalities work together in combined efforts to find sustainable solutions through projects.

1.1 Background

Previous studies done show that there is potential for a gas based economy in the region, but there is a need for improved infrastructure and competence growth to enable the growth of the gas sector

[4, p. 40] . Biogas is a good energy source replacement for fossil fuels or supplement other renewable sources as it is a sustainable solution with environmental, social, and economic benefits. This work is carried out as part of the sub-project "National Competency Clusters in the Gas Industry and Research Enhancement (GasCoE)" funded under the Growth Agreement of the Vaasa Region (AIKO).

The primary objective of the project is to strengthen the region's gas-related research and demo environments and initiate new R & D activities which in the long-term lead to increased skills, increased exports, and significant new investments in a new local energy value chain on gas economy.

1.2 Purpose

This thesis aims at mapping out the current and future local gas infrastructure in the region by compiling previous studies that have been carried out and gathering information from the companies on the current and the future gas infrastructures. It also aims at highlighting the technologies that the companies in the region are currently using and those that may be of use in the future, and environmental challenges of a gas based economy for the region and in general. This is to enable future similar investments to make comparisons and understand some of the challenges.

1.3 Scope

There are many organizations/ companies within the region that may benefit from a good gas infrastructure [4, p. 30]. However, this study covers organizations that are key players in the region and have a direct influence on the growth of infrastructure. These are, VASEK, Wärtsilä Oy, Stormossen Oy, VEBIC, NLC Ferry Oy, Laihia Biogas Plant, Påttska Wastewater Treatment Plant & Sarlin Ltd (Suvilahti Landfill). The use of the term "gas" is limited to biogas and, or natural gas where it is not specified what gas it is. Cost calculations and estimations are not included in this study. However, costs are included if stated in the collected data.

The Cambridge Dictionary defines infrastructure as, "*the basic systems and services, such as transport and power supplies, that a country or organization uses in order to work effectively.*" [5] . This is the definition of infrastructure in this paper.

1.4 AIKO GAS CoE Project

AIKO Gas CoE project is a 2-year project, an initiative collaboration between three universities; the University of Vaasa, the Novia University of Applied Sciences, and the Åbo Akadem University. The project aims at strengthening gas-related competences, R&D, and demonstration activities. Main focus is on the fields that support the industry to evolve the region into a national gas cluster of excellence.

The AIKO Gas CoE project is set to run from 1.1.2017-31.12.2018 and the following work points should be realized at the end of the project:

1. Assessment of the present situation, developing roadmaps for a sustainable, local gas infrastructure
2. Reinforcement of the research infrastructure and experimental demo environments in the region.
3. Generating a joint research and development agenda with new R&D proposals.

In Appendix 1, the project description is presented in more detail.

1.5 Method

Four methods were used to collect the data for this thesis. The first was face-to-face interviews. A draft of the data to be collected was sent before the physical visit to save on time and give the company representatives time to prepare. The drafts differed from company to company depending on company profile and the information required. In some cases, a tour of the plant was also done, to show the processes. Secondly, email correspondence and online shared documents were also used, if a visit to the company was not possible, or all the required information was not available at the time of visit, and lastly, if clarification was needed on collected data.

The third method was attending gas-related seminars to gather related information was also a mean of collecting information. This method gave ideas on the companies to contact, contact persons and general ideas on how to approach the task, events such as the Gas Value exchange of Vaasa Energy Week 2017 and the Biogas in Traffic 2017event in Närpes were attended.

Lastly, retrieving information from previous studies done in relation to gas in the region, such as theses, feasibility studies, gas market reports and projects updates. Furthermore, the use of internet to access documents on legislation, company websites for company descriptions. Online sources such as the Finnish Biogas Association registries to collect data on the records of biogas production and consumption over a certain period.

2 Legislation and Policies

Global challenges that the world faces in terms of climate change and high energy demands are directly linked and conflict each other, in the sense that, the known measures to produce energy efficiently (use of fossil fuels) are not environmentally friendly. Legislation and policies help to drive and direct human activities towards a sustainable energy system that is environmentally friendly and ensuring security of supply. Finland as part of the EU, has an obligation of following and implementing the environmental policies and targets [6, p. 19]set by the EU. Legislation and policies have a direct influence on the outcome of objectives and actions. The following are some of the EU and Finnish government driven policies that are aimed at promoting the use of renewable energy in all sectors of energy, e.g. Transport, power production etc. and seem to favour the gas economy for the region.

First is Directive 2014/94/EU [7] on the deployment of alternative fuels infrastructure is the key to gas infrastructure development, even though it also covers electric vehicles and other renewable fuels. The directive works in line with the EU TEN-T (Trans European Transport network) which is one of the funders for the Midway Alignment project is covered, Vaasa connects major E roads connecting to the TEN-T network.

Secondly, the EU Directive 2009/28/EC [8] on the promotion of use of renewables. Under the Renewable Energy Roadmap, 20% of the total energy consumption should be from renewable energy and a mandatory 10% share of renewable fuels in the transport sector.

Third is the Climate Change Act (609/2015) [6, p. 14] aimed at reducing the greenhouse gas emission by a minimum of 80% by 2050 compared to the 1990 level. To reach this target, there is need for change of fuel or come up with more efficient end-of-pipe technologies, which may result in increased production costs.

The EU directives set minimum standards for the member states on what should be done. The table below shows Finland's renewable energy target in relation to the targets set by EU.

Table 1:Side by side comparison between EU and Finland's energy and climate targets for 2020

	EU	Finland
Reduction of ghg[1]	-20%	EU-level target
ETS Emissions[2]	-21%	EU-level target
Non ETS emission[2]	-10%	-16%
Renewable Energy share of final consumption	20%	38%
Biofuel in Transport	10%	20%
Energy Efficiency improvement[3]	+20%	EU-level target

[1]. 1990 base year levels

[2]. . 2005 base year levels

[3]. Comparing to development estimates in 2007

In Table 1 [6, p. 19] above it can be seen that, Finland has higher limit than the EU on non ETS emissions, renewable energy share of final consumption and biofuel in transport. The higher limits set puts biofuels at an advantage in comparison to the fossil fuels, promoting their use and the growth of the biofuel market.

Finland’s new Energy and Climate Strategy 2030 was published on 24th November 2016 [6] in preparation for the almost carbon neutral 2050 aimed at achieving a minimum of 80% in greenhouse gas emissions reduction of the base year 1990. The main points of this newly approved strategy are; phase out coal as energy source, biofuels in transport to take 30% share, renewable energy share in final energy consumption 50%, 50% reduction in domestic use of imported oil, and a 10% renewable fuel concentration in light engine oils [6, pp. 27-31]. The focal points slowly choke out the use of other fuels as restrictions on them grow, leaving no alternative to producers and users but to switch to renewable energy sources. Possibility of an implementation of a €100 million subsidy for biogas and electric cars between 2017-2020 [9] is being considered by government, as part of the Energy and Climate Strategy 2030 by 2030 [9]. This will help the growth of infrastructure as the market for the gas grows.

Fourthly, even though Vaasa is covered under the Finnish legislation, Vaasa has set long-term target of being a carbon neutral city by 2035 covered under the Energy and Climate program. This was approved in 2016, 1st February by the city council. The city also aims for a 30% reduction of CO_2 emissions by 2020 from the 1990 levels [10]. These decisions directly impact the growth of renewable energy for the region, where as the impact would not be the same if it was absorbed under the national targets.

The above-mentioned policies contribute to the growth of the gas infrastructure as it puts strict restrictions on the fossil fuels, which have been around for a long time and have proven to be reliable and cost effective. The down side being the emissions and rate of replacement. The renewables on the other hand are still in the early stage in terms of technology and reliability.

3 Gases

There are many factors that support the need for the growth of the gas infrastructure in the region, such as security of supply and environmental protection. There are many types of gases used in the energy sector, but this study lays emphasis on two types namely: natural gas (LNG and CNG) and biogas (raw biogas, LBG and CBG). These two gases have been selected because they can be used interchangeably without change of infrastructure. Natural gas is considered a transitional fuel [11, pp. 11-12] due to being a fossil fuel that offer temporal solutions. The difference between natural gas and biogas is that one is a fossil fuel and the other a renewable fuel. The common factor between these two gases is the high methane content after undergoing upgrading, making the two gases compatible, using same infrastructure and same applications and same global warming effect. Methane as a greenhouse gas is more potent than CO_2 and has a GWP [12] (Global Warming Potential) of 25 for 100years, meaning that releasing 1 kg of CH_4 is equal to releasing ~25kg of CO_2. To avoid releasing CH_4 in the air, the excess methane gas can be flared as last option, which breaks down the methane into water $(H_2O)g$ and carbon dioxide $(CO_2)g$.

3.1 Natural Gas

Natural gas is the cleanest combustion fossil fuel [3, p. 141] formed from dead organic matter (plants and animals), compressed over each other in sediments forming hard rocks. The heat from the earth and pressure from the hard rock results in the organic material trapped in between to heat up, forming kerogens, from which oil is produced and further rise in temperature and under favourable conditions transforms kerogens into gas. The process of natural gas formation takes millions of years, that is why it is considered a non-renewable energy source [11, p. 11] . Natural gas is readily available even though it is a fossil fuel, but not easily to accessible. Natural gas in its raw state, consists of different elements depending on source reservoir [13, pp. 3-4], the main component is methane (CH_4). Natural gas is considered a transitional fuel. Despite having similar properties with biogas, its complete life cycle from cradle-to-grave takes away some of the benefits of being a clean fuel. Natural gas can be used as natural gas or compressed to compressed natural gas (CNG) or liquefied to liquefied natural gas (LNG).

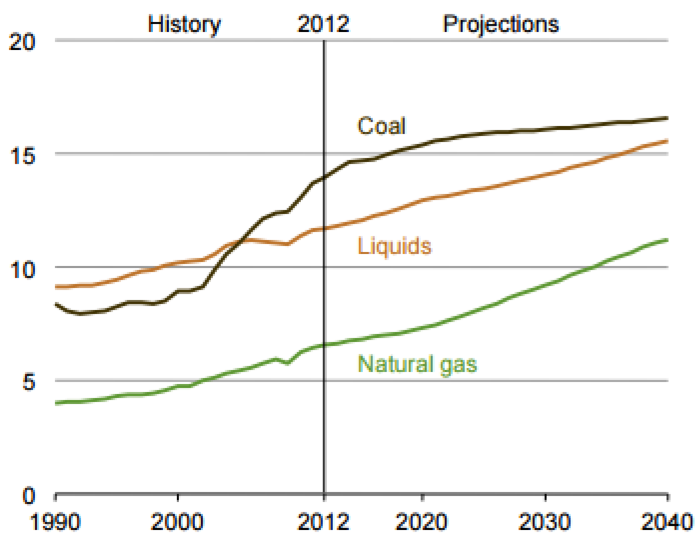

Figure 1: World energy-related CO2 emissions by fuel type 1990-2040 showing comparison between fuels

Figure 1 [3, p. 141] above show that although natural gas is considered the cleanest combustion fossil fuel, it still contributes to CO_2 emission.

3.1.1 Liquefied Natural Gas (LNG)

Liquefied Natural Gas commonly known as LNG is natural gas treated cryogenically to -162 °C, the boiling point for methane, to a liquid. This reduces the volume of the gas by ~ 600 times [13,

p. 2] at NTP and makes it easy to store and transport in larger quantities and reach many places all around the world even to places with no gas pipelines. The liquefaction process improves the energy content of the gas, making it equal to that of propane. The liquefaction process removes sulfur, oxygen, carbon dioxide and water from natural gas, leaving LNG to be almost pure methane. LNG is usually re-gasified before being reused but can be used in liquid form as fuel for heavy duty traffic.

3.1.2 Compressed Natural Gas (CNG)

Compressed natural gas (CNG) is natural gas compressed at high pressure of between 200-300bar [14, p. 23]. This reduces the volume from the uncompressed by 200times and three times more than LNG. Natural gas must undergo upgrading before it can be compressed to remove impurities and water. This prevents corrosion that may occur due to moisture. The upgrading methods are covered in the biogas part due to the similarities in the processes.

3.2 Biogas

Biogas is a renewable gas produced from an anaerobic digestion of organic substances with about 40-70% methane (CH_4) and 30-60% carbon dioxide (CO_2) as main components [15, pp. 4-5]. Biogas can be produced artificially or naturally. Natural production of biogas occurs in landfills and other open places if conditions are suitable (degradation of organic matter) and artificial production is done in a digester where conditions are set to suit the natural process but with strict control of digester conditions. The landfill gas has a low CH_4 content because the conditions are not strictly controlled like in the digester. The benefits of biogas production are that, waste disposal of sewage sludge and bio waste is simplified with by-products as biogas and fertilizers which can be safely used in the soil. Pollution is reduced, either as in emissions from biogas combustion or from the raw biomass. The social and economic benefits are job creation, source of income and clean environment.

3.2.1 Biogas raw material

Biogas is produced from organic material [16, pp. 12-15]. The following are some of the raw materials and their environmental benefits.

Food waste is one of the most renewable raw material as it does not conflict with other human needs such as land use to produce the raw material and takes care of issues like sanitation and prevention of spread of pathogens. It also reduces formation of landfill gases. The challenge is that, with domestic food waste, people may not know how to sort the waste, affecting the quality of the raw material.

Sewage sludge like food waste, is also a good raw material. Sludge disposal is eliminated, preventing eutrophication and the digestate is used as compost with appropriate nutrient composition suitable for vegetation.

There is conflict in use of forest residue because of the biodiversity issues, some organisms depend on the forest residue to grow. This may affect the local vegetation if there is over dependency on forest residue, but the forest residue can be collected in moderation.

Agricultural waste from fields and greenhouses, are also a good raw material. Energy crops as biogas raw material is good because it has a high energy density, but it competes for land and water with food production.

Other raw material is industrial waste from slaughter house, food processing industries, breweries, animal manure and many more. They have the same benefits as the household food waste. The slaughter house waste and waste from food processing industries yield a high methane content per kg of VS because of the waste is rich in protein and fats. The waste product from biogas production is used back on the land as compost for gardens and landscaping soil.

3.3 Properties of LNG and LBG

The properties of LNG/ LBG [13, pp. 3-5]differ from source to source depending on the compositions of the gas. The following are some of the properties of LNG.

Table 2: Common Properties of LNG/LBG

Physical Properties of LNG/LBG	
Chemical formula	CH_4
Energy content	25-21 MJ/L
Storage Temperature	-162°C
Flammable Range	4-15%
Boiling point	-162°C
Ignition Temperature	540°C
Density	430-470kg/m^3

In Table 2 [17]above, the general properties of LNG/LBG are highlighted in terms of values. LNG/LBG is non-toxic, colourless and odourless. The odour is enhanced with mercaptan that gives natural gas a strong odour making it easy to smell leakages.

LNG/LBG is lighter than air, in case of a spillage or leakage in water or soil, it moves above the air. This is what makes it a greenhouse gas.

The boiling point is -162°C [13, p. 2], in case of a spillage on water, the gas evaporates due to the water temperature and forms a vapour on top of the water, there is no water contamination. As a cryogenic substance, it pauses a safety hazard for personnel such as frost burns and for material/ objects it may cause brittleness. Knowledge on handling of the gas is required.

LNG is non- explosive, it cannot explode in confined spaces. This is because of the narrow flammable range of 4-15% oxygen concentration and will self-ignite at 540°C, which is much higher temperature than normal atmospheric temperature. These properties make LNG/LBG safe to work with.

3.3.1 Advantages and Disadvantages of LNG/LBG

The table 3 below highlights the advantages and disadvantages of LNG/LBG [17]. The advantages and disadvantages highlights the strengths and weaknesses of the gas and are drivers on how a fuel can be utilized and improved.

Table 3: Advantages and disadvantages of LNG/LBG

Advantages	**Disadvantages**
Lighter than air	Cryogenic substance, requires a special kind of container and poses a hazard to personnel and none cryogenic objects
Low flammable range, making it safe	Lack of infrastructure, limiting its availability
It can be transported to places without pipelines.	Colourless and adourless, making it difficult to see or smell a leakage without sensors or enhanced smell.
Non-toxic and non-explosive (cannot explode in confined spaces).	Undergoes aging even if not in use
Its energy content is increased	Initial investment costs are high.
Very high auto ignition temperature of 540°C, the heat source needs to be 540°C and above to ignite LNG, making it a safe fuel to work with.	CH_4 GWP takes away some of the benefits
Clean fuel and after liquefaction, emissions are reduced by more than 75%.	
Flammable range of 5-15%, with higher oxygen concentration of more than 15%, it is not flammable.	

3.4 Properties of CNG/ CBG

The physical properties, like with LNG/LBG depend on the composition, which also depends on the source for both natural gas and biogas. Table 4 below shows these properties.

Table 4: Physical properties of CNG/CBG

Physical Properties of CNG/CBG	
Chemical formula	CH_4
Energy content	9MJ/L
Storage pressure	2MPa
Air: Gas combustion ratio	10:1
Boiling point	-162
Operating pressure	1.1 kPa
Density to that of air	0.5537:1

[Source: Compiled from different sources].

Table 4 above shows the physical properties of CNG/CBG. For the compressed gas, it is important to maintain the pressure. The boiling point is -162℃, above that temperature, the gas is in gaseous state, slight variations in temperature may not affect CNG/CBG in comparison to LNG/LBG that must be maintained below -162℃. The air- gas combustion ratio shows how much mass of air to be mixed with a mass of gas, 10kg mass of air for every 1kg mass of gas.

Since CNG/CBG comes from natural and biogas respectively, some of the properties are the same as LNG/LBG. What differentiates the two forms of the gases is the storage method, which in turn affects properties such as energy content.

3.4.1 Advantages and Disadvantages of CNG/CBG

Table 5: Advantages and Disadvantages of CNG/CBG:

Advantages	Disadvantages
Can be easily transported.	One technological disadvantage with CBG is that, more metal is transported (in the form of the cylinder) than the gas.
Has more applications than the normal natural gas.	Occupies 3 times more space than LNG.
Energy content is increased due to the compression.	Storage issues since it should be stored at pressure of 200-300 bar.
Occupies less space than natural gas, hence much easier to store.	As a vehicle fuel, it has not reached a level to compete fairly with other conventional vehicle fuels.
No SO_x and NO_x emissions	As a vehicle fuel low energy density, limiting use to light vehicles.
As CBG, it is renewable fuel	As CNG, it is a fossil fuel

Table 5 [18] above shows advantages and disadvantages of CNG/CBG. From the table, it shows that whilst CBG is easy to transport, challenges are still faced with economical design of transport containers and occupies three times more space than the liquefied form

3.5 Technologies

The technologies covered in this chapter are those that are currently used by the companies in the region and technologies that may be useful in the future for the region to help drive the gas economy.

3.5.1 Anaerobic Digester

The raw material used in biogas production is organic waste products and waste is usually an inhomogeneous fuel. To improve the quality of the substrate, two or more types of substrates are mixed together and is known as co-digestion [19]. The complete decomposition of biomass in the digester occurs in three stages [16, pp. 8-9], some literatures mention four as shown in Figure 2 below.

3.5.1.1 Hydrolysis

The first stage in anaerobic digestion is hydrolysis, where microorganisms break polymers of proteins, fats, and carbohydrates in the absence of oxygen into simpler forms with the help of enzymes. The process is slow and depends on the substrate used. Pretreatment of the substrate that are resistant to anaerobic digestion is done to help speed up the process and improve the methane yield.

3.5.1.2 Acidogenesis

The second stage is called the acidogenesis where the products from the hydrolysis stage are fermented by acidogenic bacteria into methanogenic substrates. The substrate is further broken down into acetate, CO_2, H_2, alcohols and volatile fatty acids.

3.5.1.3 Acetogenesis

The acetogenesis stage depends on the substrate used, it may or may not occur. The substrate that are resistant to the acidogenic bacteria from stage 2 is further acted upon by acetogenic bacteria and oxidized into methanogenic substrates.

3.5.1.4 Methanogenesis

The final stage is the methanogenesis stage. The methanogenic bacteria act on the acetate to form CH_4 and CO_2 and on H_2 and CO_2 to give out CH_4 and H_2O. The final stage requires strict control of the conditions such as temperature, pH etc.

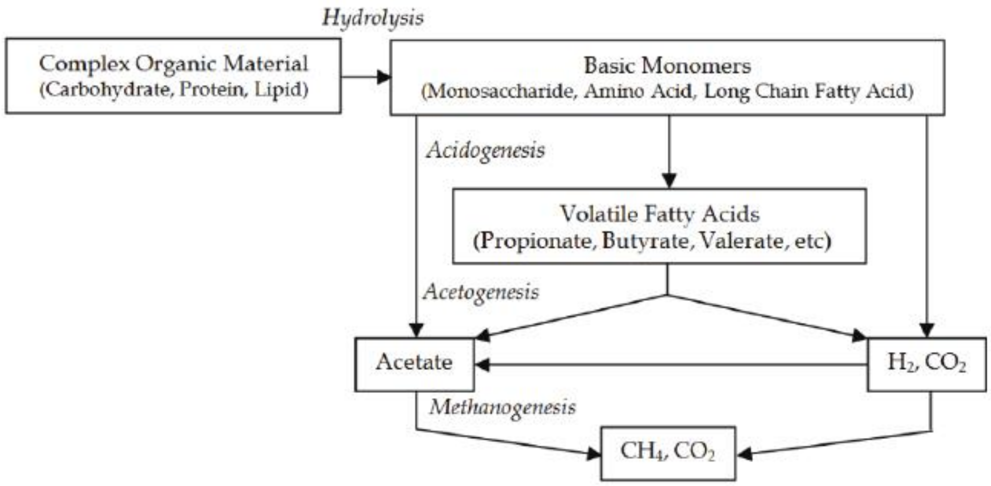

Figure 2: Biogas formation process [20]

The composition of the gas produced depend on the substrate that is used. The substrate rich in carbohydrates produce biogas with a low CH_4 content whilst those rich in fats produce a CH_4 rich biogas. The CH_4 content varies between 60-70% whilst the CO_2 content is between 30-40% depending on substrate [21, p. 11] .The high CO_2 content in comparison to natural gas, makes biogas to be heavier than air. If spilled, it will not rise like natural gas and 10-30% O_2 in the air, biogas is explosive.

All biogas producers in the region, i.e. Stormossen, Jeppo and Laihia Biogas Plants use this technology to produce biogas.

3.5.2 Regasification Process of LNG and LBG

Natural gas is liquefied for economical transportation and storage and to improve the energy content. LNG can be regasified and used for applications that do not required the liquefied form. There are a number of regasification techniques. The techniques listed below are currently used by the companies in the region.

3.5.2.1 Ambient Air Vaporizer

The Ambient Air vaporizer [22]is a simple vertical heat exchanger used for regasification of cryogenic liquids like LNG. It uses heat from the ambient air, pulled in from the top of the vaporizer and passes around the tubes carrying the cryogenic liquid. The vaporizer is suitable for small regasification plant and perform better in warm regions where the ambient air is always warm. AAV are low maintenance vaporizer, requiring defrosting now and then which can be done by turning the system off for some hours.

Ambient conditions affect the performance of the vaporizer such as temperature and humidity and outlet temperature is dependent on ambient temperature. The condensation of moisture in the area surrounding the regasification area can form into fog.

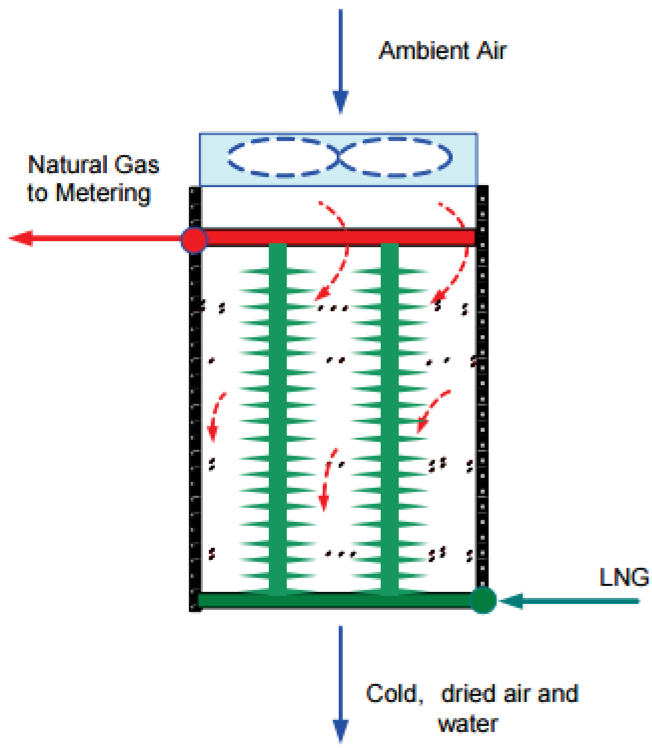

Figure 3: Ambient Air Vaporizer diagram [27]

Wärtsilä used AAV but did not specify which type.

High Pressure AAV is a type of AAV. From the literature found, this type of AAV has a higher capacity send-out due to the forced air flow and has higher maintenance costs due to the moving parts. The high-pressure vaporizers are said to consist fitted stainless steel tubes in the aluminum protruding finned tubes. The maximum operating pressure is 420barg [22]. Stormossen Ltd uses this type of vaporizer. The regasified natural gas is then compressed to use as vehicle fuel. There is not clear literature on this technology, companies manufacturing them give limited information.

3.5.3 Upgrading of Biogas and Natural gas

Biogas and natural gas are upgraded to remove impurities, CO_2, H_2O, H_2S, NH_3 and siloxanes are removed, leaving the gas to be made up of ~98% CH_4. The removal of impurities prevents corrosion and condensation that might occur in the tank due to the high pressure. The gas become usable for other applications other heat and electricity production (common known uses of raw biogas). By upgrading a gas, the following things are achieved;

The Methane content is raised to up to 99% since all other impurities are removed, making the gas to be more stabilized and meets standards. The removal of impurities makes biogas and natural gas more usable as it can be used as a vehicle fuel and other industrial processes compared to raw biogas whose main applications are heat and electricity production. It also prevents corrosion and ice-clogging.

Listed below are technologies currently used in by biogas producers in the region to upgrade biogas.

3.5.3.1 Water Scrubber

Water scrubber [15, p. 10] is a common gas upgrading method. It works on the principle of solubility.

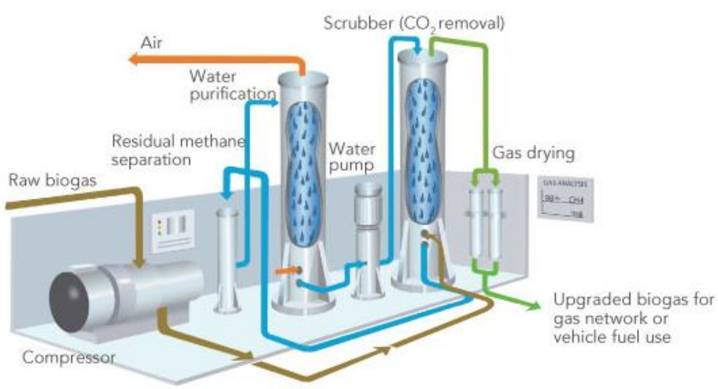

Figure 4: Biogas upgrading using a water scrubber. [18]

The raw biogas is compressed to about 9 bars and enters the scrubber where there is a counter flow of water. CO_2 and the other impurities are highly soluble in water, they dissolve and are taken out with the water. CH_4 which is lighter than water, rises to the top of the scrubber leaving the scrubber at 98% CH_4 content, is dried and ready for either liquefaction or compression. Some little traces of CH_4 leaves the tank in the waste water and is recirculated back to the scrubber.

3.5.3.2 Amine Scrubber

An amine scrubber [15, p. 11] is a chemical absorption technique used to clean biogas to get a higher CH_4 percentage of up to 99%. Raw biogas is fed into the scrubber at high pressure and the amine solution, alkyl amines family is introduced in the scrubber from the top. CO_2 is attracted to the amine solution and reacts with it. Methane is separated and rises to the top of the scrubber where it is collected, at literature values of 98% CH_4 content (local companies gave up to 99%).

When the solution is saturated with CO_2, it is moved to the stripper where the amine solution is regenerated for reuse in the scrubber. Heat is introduced and CO_2 separates from the amine solution. The collected CH_4 is passed through a dryer to dry out all moisture to prevent corrosion.

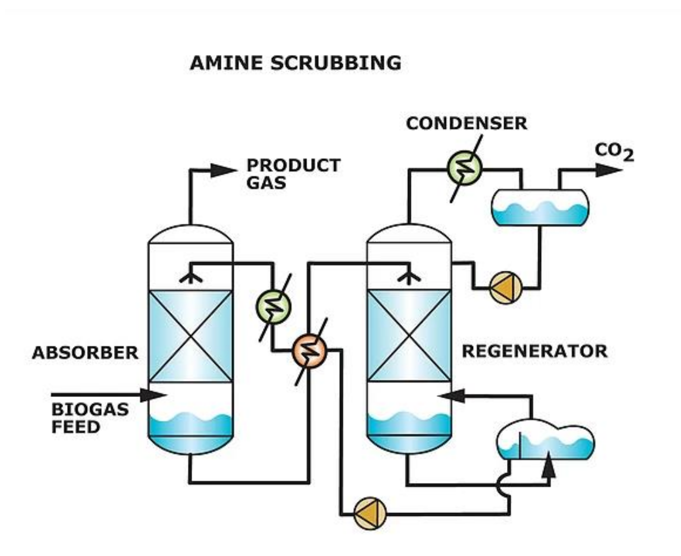

Figure 5: Amine Scrubber

Figure 5 above shows the raw biogas cleaning techniques using chemicals.

3.5.4 Landfill gas collection

The landfill gas CH_4 content varies from time to time, with CH_4 content between 35-60% [15, p. 5]. To prevent methane going in to the atmosphere, landfills are flared or collected and used for heat and electricity production. Two technologies used in the region for landfill gas collection are;

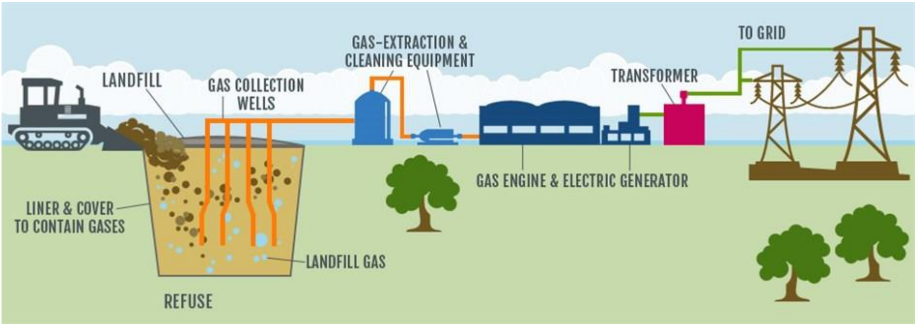

Figure 6: Landfill gas collection and utilization [23]

3.5.4.1 Microturbine

Gas is collected from the landfill and pretreated using a gas purification system. The system removes most of the impurities and gas is send to the microturbine. The variations in the methane content makes landfill gas problematic for combustion engines. Microturbines are considered efficient because it reuses exhaust heat to preheat the fuel. A microturbine is suitable for combusting landfill gas because it is flexible to the CH_4 content variations [24], and can produce heat and electricity on small scale and promote decentralized energy distribution.

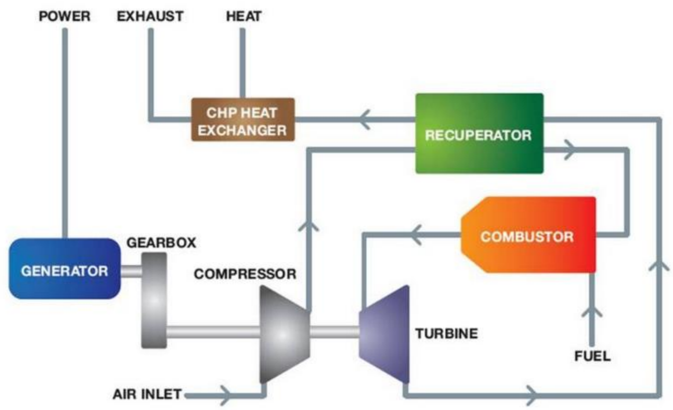

Figure 7: Functionality of a Microturbine

Figure 7 above shows how a microturbine cycle is, all these components are incased in one casing.

3.5.4.2 Gas fuel cells

Fuel cells convert chemical energy of a fuel to electrical energy. Fuel cells are suitable for fuels rich in hydrogen. The flat solid oxide fuel cell is used in the Sarlin Power Plant in Suvilahti to utilize landfill gas for heat and electricity production. This flat solid oxide fuel cell is a Wärtsilä produced fuel cell capable of using different fuels. The flat solid oxide fuel cell (SOFC) has high efficiency and high operating temperatures [25]. Unlike other batteries, a fuel cell cannot be used to store energy, it is just used for conversion when there is a supply of the fuel. Figure 8 below shows a flat solid oxide fuel cell.

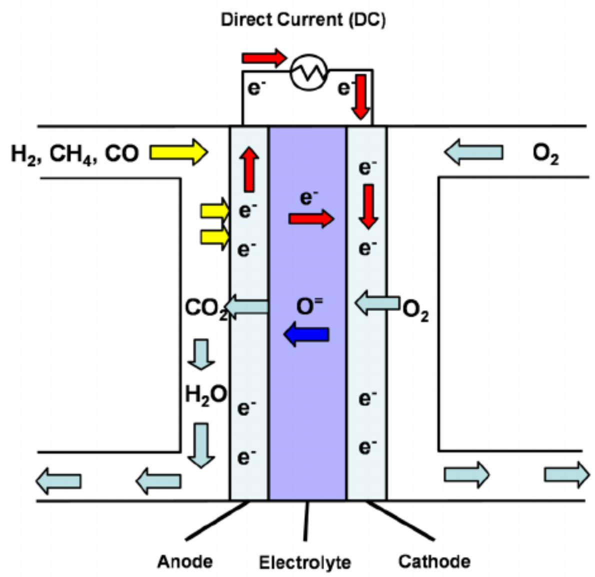

Figure 8: How a flat solid oxide fuel cell (SOFC) works

3.5.5 Synthetic Methane Production: Power to Gas

Renewable intermittent energy such as solar, wind, tidal and wave energy have high potential as an energy source in the Nordic region. According to a study from Uppsala University, Sweden, the Nordic region can meet all its energy demands with renewable energy [26]. The challenge with these sources is that, they are totally dependant on nature. Taking solar energy for instance, the cold periods that require more energy are the periods characterised by limited sunshine and more sunshine when the energy demands are low in the nordic region. The challenge becomes on how to balance the laws of nature and human needs. Electric energy can be stored in batteries but battries discharge with time and would require more space for the batteries to store a substancial amount. Another way is to transform the electric energy into another form of energy.

Synthetic methane production (Power to Gas) is the conversion of electrical energy from rewable sources to chemical energy in the form of methane gas. This creates a long term energy storage solution. The energy stored in gas can be converted back to electric energy or heat energy or used as stated in chapter 3.6 below.

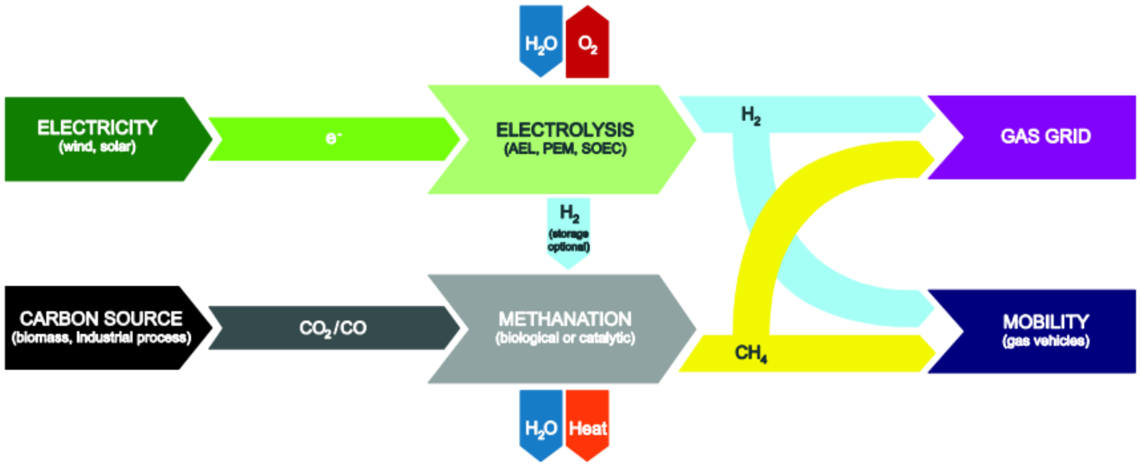

Figure 8: How electrical energy is converted to methane gas in the Power- to-Gas process.

Figure 8 above shows the process of converting electric energy from renewable sources to methane and hydrogen gas, which can then be used as normal methane gas. This technology is not yet available in the region but is of great interest, as the region try to strengthen a gas-based economy. The excess energy from the renewable sources can be converted to gas. This technology is in the laboratory stage and currently too expensive [27, pp. 22-25].

3.5.6 Liquefaction Processes

As the region works towards growing the gas-based economy, there are certain challenges such energy content and economical transportation that can be solved through liquefaction of the gas, whose benefits are covered in chapter 3.4.1 above. There is no current liquefaction of the gas done in the region, but there are possibilities in the future with increased demand, for storage purposes (3 times less space than compressed gas and 600 times less than the normal gas.) and diversification of application such as vehicle fuel for heavy traffic. There are different technologies used in liquefaction depending on scale.

3.5.6.1 Mixed Refrigerant Process (MR)

Gas liquefaction uses regrigeration cycle technology. The Mixed Refrigerant (MR) [13, pp. 150-151]technology is a liquefaction process of natural gas using a mixture of refrigerants comprising mainly of light hydrocarbons and nitrogen. There are two type of MR technologies; the Single Mixed Refrigerant (SMR) working on as a reverse Rankine cycle and Dual Mixed Refrigerant (DMR). The MR compared to other technologies has an advantage of having less moving parts, which means less maintenance costs. The down side taking the SMR for instance is that it has a lower thermal efficiency than other technologies.

Wärtsilä recommends the SMR for biogas liquefaction due to low investments costs and short construction time [28]. The SMR is the simplest liquefaction technology.

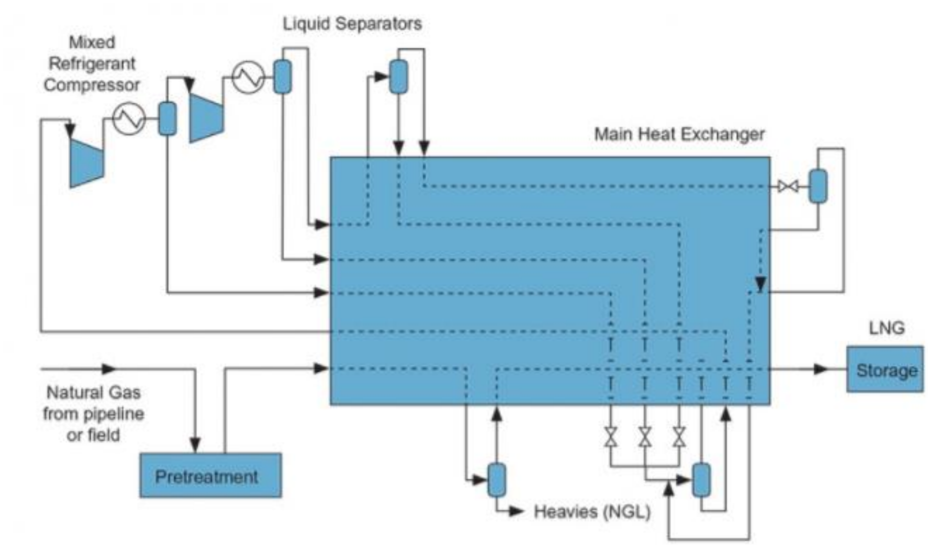

Figure 9:Single Mixed Refrigerant Liquefaction process

3.6 Applications of Biogas and Natural Gas

The applications for all the gas types are covered together as these gases have similar applications. It must be noted that CNG and CBG are the same, just differentiated by source, same as LNG and LBG.

Biogas needs to be upgraded before it can be used as a vehicle fuel. The energy content is improved and with compression, the biogas works with the light traffic. For use in trucks and ferry to be feasible, it must undergo liquefaction which has an even higher energy content than the compressed form and liquefied gas takes up three times less space than the compressed gas.

Electricity and heat production is the most common use for raw biogas and natural gas. For boilers and microturbines. The fluctuations of the CH_4 content percentage does not affect microturbine performance, that makes it possible to utilize the landfill gas. Other engines are sensitive to the fluctuations and require a stable biogas, this is achievable by producing biogas in a reactor where conditions are strictly controlled.

The use of biogas in Research and Development opens more possible applications for the gas. It also enables for the continuous development of the gas, enabling it to compete with other energy sources. Biogas/ natural gas is used in industrial process. Some of the commercial uses are in the food processing industry like Snellman AB, Pulp-and-Paper industry.

4 Company Profiles

The company profile highlights the company's role to gas infrastructure growth in the region and giving the company's gas profile to be able to map out the infrastructure. These companies drive infrastructure growth by providing a platform for idea sharing and the business knowhow, being producers and consumers of biogas, a source of biogas raw material, service provider, end user of natural gas and, or has technological knowhow.

All capacities are converted to MWh in the results and graphs. The capacities are given in different units in the raw data collected and the tables below help the reader estimate equivalents in a respective unit of measurement.

Table 6: Fuel conversion table from volume in Nm^3 to energy equivalent in kWh

Volume/Energy Fuel Conversion Table	
Fuel (Volume)	**Energy (kWH equivalent)**
1Nm^3 Biogas (97%)	9.67
1 Nm^3 Biogas (~60%)	6.60
1Nm^3 Landfill gas	4.40
1 Nm^3 Natural gas	11.00
1L Petrol	9.06
1 L Diesel	9.80
1L E85	6.60

Source: Compiled from different sources.

Table 7: Table of equivalent measurements

Equivalent Measurements	
1 Ton	1,000 kg
1 Nm^3	1,000 L
1 MWh	1,000 kWh
1 Ton	2.193 Nm^3

Table 6 and 7 above can be used for the conversion of the energy (kWh) of biogas and natural gas to volume equivalent in Nm^3 where volume is not given and it is known what type of gas it is. The volume and kWh equivalent can also be calculated, given the mass. The values (Table 6) may differ from the actual ones because, the table above has biogas with 97% CH_4 and some cases biogas has higher CH_4 content and the raw biogas value will be used for all raw gas to give a rough picture. The landfill gas has very low CH_4 percentage content compared to raw biogas.

4.1 VASEK

4.1.1 Brief History

The Vaasa Region Development Company [29] (VASEK, Finnish acronym) was founded in 2003 and is jointly owned by seven towns and municipalities (Vaasa, Mustasaari, Isokyrö, Korsnäs, Vöyri and Laihia) on the West Coast of Finland. VASEK promotes and reinforces growth and competitiveness in the region. This is done by improving the preconditions for business activities in the Vaasa region in cooperation with the regional authorities, municipalities, local action groups and enterprises.

As the region is known for its entrepreneurial spirit and traditions, it is also equipped with a strong will to succeed. Outsourcing and the increasing use of subcontractors contribute to the fact that increasingly small and medium-sized companies are being established. Their main objective is to help these SMEs to grow and be a part of the flourishing Vaasa Region - one of the most attractive and innovative environments in Finland for companies and employees.

VASEK spearheads projects on behalf of the municipalities that own it and other local players, and that is the role VASEK plays in the growth of a gas economy in the region.

4.1.2 Gas Infrastructure: Midway Alignment of the Bothnian Corridor

The Midway Alignment of the Bothnian Corridor, also known as the Kvarkenlink [30] is an all year maritime transport connection between Finland and Sweden connect via Umeå and Vaasa. The midway alignment of Bothnian corridor [See Appendix II for map], also connects three major European roads, E12, E8 and E4.

The project is scheduled for 2012-2018. The 1st phase has been completed, and was scheduled for 2012-2015, after which it should achieve some of the following things; preparation of activities and carrying out a feasibility study. It also dealt with concept development for the improvement of the transport link, and port infrastructure. The final part of the 1st phase was to design and develop a ferry with icebreaking capacity for use in the Kvarken strait.

4.1.2.1 Future Gas Infrastructure

The 2nd phase of the Midway Alignment of the Bothnian Corridor project is called Midway Alignment- Botnia Atlantica (MABA) II, to be carried out between 2016-2018 [30]. The lead partner in this phase is Kvarken Council working with Infrastktur I Umeå (SE) and Vaasa Region Development Company (VASEK) (FI). The estimated budget for the project is 827,500 EUR. The MABA II aims at having well prepared background material, reports, and analyses to enable the continuation of the development process of the transport corridor. It also aims at the regional, national, and EU-level authorities to decide on the future measures. The reports and analyses should cover the Kvarken ports TEN-T status and TEN-T core links. The planning work on the development of the port, terminal areas and new ferry should be commenced. In this stage, other potential financing options should be identified.

Under the Midway Alignment project, the terminal will either be in Vaasa on the Finnish side or Umeå on the Swedish side. In Vaasa, the terminal's proposed location is in Vaskiluoto and an estimated capacity of 3000-7000 Nm^3. The terminal is expected to have the following features, truck loading for easy loading of trucks to distribute to other parts of the region, 150-200km radius from Vaasa. Bunkering for the ferry, bullet-tanks, existing infrastructure on the chosen site and a 9m fairway. The terminal would cover the onsite demand from Vaskiluodon Voima and Wärtsilä laboratories located in Vaskiluoto. It would also open possibilities of using LNG for district heating as well as supplying greenhouses for cooling. Another intended use is being a backup for the biogas industry, increasing stability of the commodity as the biogas industry grow to match demand.

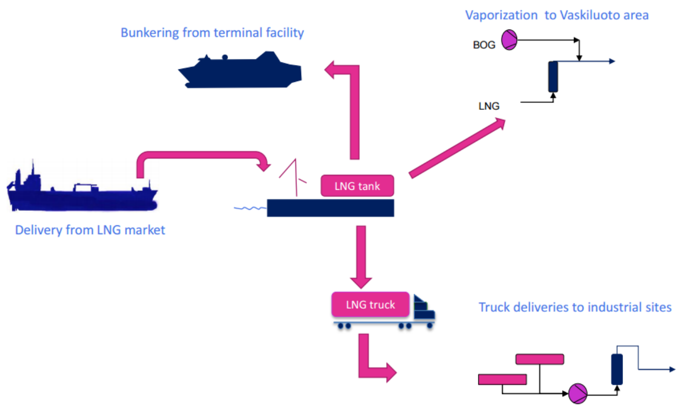

Figure 10: Layout of the terminal and its functionality

Figure 10 above shows what functions the terminal would perform. According to the feasibility study made, there are no conflicting issues such land use, ground water etc. on the Finnish side to prevent the construction of the terminal. [31]

The ferry is another important part of the MIBA II project and will operate between Vaasa and Umeå throughout the year. The interesting feature of the ferry is its ice-breaking capability enabling it to be used throughout the year and its fuel will be LNG/LBG. The use of LNG/LBG by the ferry is a platform for potential technological breakthroughs in R&D for Wärtsilä and VEBIC. They can carry out actual tests on a physical ferry instead of just simulations.

The Midway Alignment of the Bothnian Corridor brings economic, social, and environmental benefits if realized through, easy transportation of cargo, reduced ghg emissions (LNG/LBG ferry), job security, security of supply and increased business due to the connection to the E12, E8 and E4 routes and the ferry being an all year ferry.

4.2 Wärtsilä Oy

4.2.1 Brief History

Wärtsilä [32]is a global leader in advanced technologies and complete lifecycle solutions for the marine and energy markets. Wärtsilä maximizes the environmental and economic performance of the vessels and power plants by focusing on sustainable innovation and total efficiency, giving the customer added value. Wärtsilä has approximately 18, 000 employees spread over 70 countries and in more than 200 locations. The company makes an annual investment of 2.6% or roughly 130M€ for R&D mostly in Finland. Wärtsilä's 2016 net sales was 4.8billion euro.

Vaasa is one of the many locations where Wärtsilä is located and as a local company, Wärtsilä has shown commitment to being part of developmental projects and innovativeness by having strong relations with the municipality, other business houses and the local schools, working together to find lasting sustainable solutions.

Wärtsilä's role in the growth of the gas economy in the region is its extensive experience and technological break throughs in the field of gas. With a background in delivering complete lifecycle gas solutions such as LNG terminals (Manga Terminal Oy as a local reference), storage solutions and vessels worldwide through its three divisions; Energy Solutions, Marine Solutions, and Services, it comes with the know how that the region needs and as a consumer.

Wärtsilä has ~60 people working directly with LNG in Vaasa; 35 people in Marine Solutions, 25 in Energy Solutions and 2-3 people in service

4.2.2 Gas Infrastructure

Wärtsilä uses LNG for engine test runs and product development through research and development (R&D), all the LNG delivered is used for the above purposes only and does not in a way affect the availability of gas in the region for other consumers, but it makes Wärtsilä one of the main consumers in the region.

Wärtsilä's LNG history dates back to1992. In Vaasa, Wärtsilä has two locations where it has gas infrastructure; the Järvikatu Factory and a laboratory in Vaskiluto which was established in 2010. The Vaskiluoto laboratory is used for research and development.

In 1996, the Järvikatu Factory was upgraded with an LNG Field within the engine factory. A mixing station consisting of 2 tanks of $40Nm^3$ and a bigger one of $52Nm^3$. The mixing station enables for the mixing of the now evaporated natural gas with other gases such as ethane, propane, hydrogen to achieve a desired composition before injecting the gas into the engines. The engine test runs are carried out in the engine factory.

LNG is transformed back to its gaseous state using Ambient Air Vapourizers, ~3400kg/ hour of gas. The laboratory in Vaskiluoto is equipped with a much smaller tank of capacity 20 Nm^3 installed in 2010. Wärtsilä buys LNG from Gasum, Porvoo and is transported to Vaasa by road, the only means currently possible.

4.2.2.1 Future Gas Infrastructure

Wärtsilä is making changes to its factory due to the increase in gas engines testing capacities. The increase is due to the transferring of the engine testing done in Italy to Vaasa. Järvikatu factory will undergo upgrading in gas infrastructure with a gas pipeline being built between the workshops. The gas field will be modified, one old tank will be replaced by a bigger one of capacity 108 Nm^3. Between 2018-2019, the Vaskiluoto factory will undergo similar changes.

There are three companies currently producing biogas in the region. The landfills are not included because the biogas produced diminish with time and the CH_4 content of the gas produced varies from time to time, hence not mixed with the gas produced in the bioreactors. Biogas from reactors has CH_4 content of ~65%, and can be raised with upgrading techniques, some of which are described in chapter 3.5.3 to CH_4 content of ~98%. The figure below shows the comparison in MWh of the biogas locally produced to the Wärtsilä deliveries, which are assumed to be the consumption, this is to show the current status of regional production in comparison to Wärtsilä's demand.

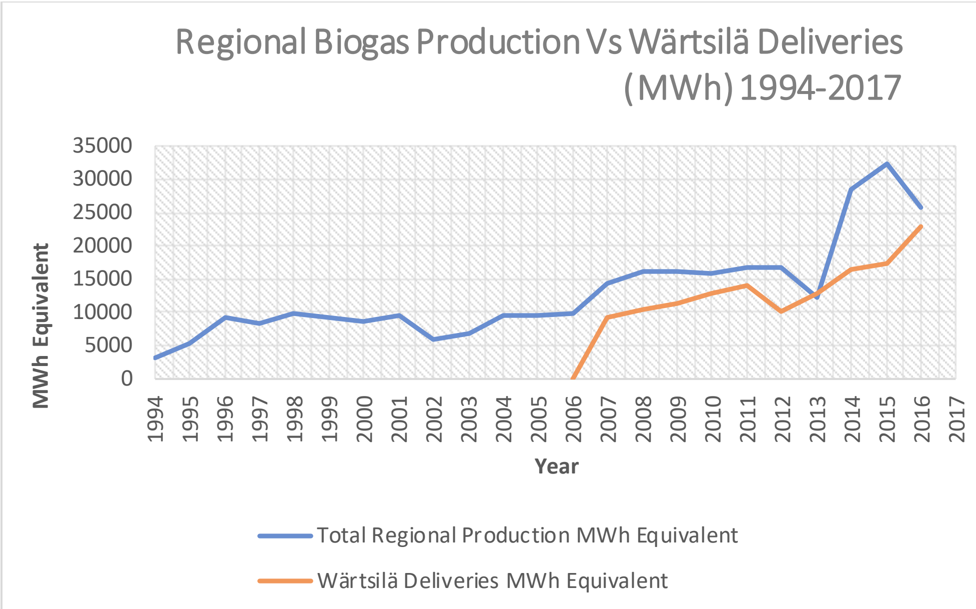

Figure 11: Regional biogas production compared to Wärtsilä consumption 1994-2016

In Figure 11 [Appendix 5 & 9] above, even though Wärtsilä LNG history dates to 1992, the data obtained had values from 2006 to 2016. The upgraded biogas with same CH_4 content as LNG can be used interchangeably with LNG. This creates a local market for the biogas produced in the region and cost savings for logistics costs for Wärtsilä. From the graph above, the regional production is enough to supply Wärtsilä if it is the only consumer. The production for 2016 does not include values from Stormossen Ltd but nevertheless, the consumption for Wärtsilä is expected to increase with the changes planned beginning end of 2017.

Other indefinite plans include expanding the R&D to other than just engines, make demos for customers and working on finding other LNG applications. Wärtsilä sees the ferry project as a positive thing as it could open possibilities of doing some tests on a real ferry and not just on simulations, making the ferry a “living lab”, which may lead to greater break throughs in LNG technology.

4.3 Stormossen Oy

4.3.1 Brief History

Stormossen Ltd [33] is a regional waste management company, owned by six municipalities – Vaasa, Isokyrö, Korsholm, Vörå, Malax and Korsnäs, with a total of approx. 107,000 inhabitants. The main physical location of the company is in Kvevlax in Korsholm. Most of the waste received at the Kvevlax waste treatment plant is utilized either as materials, energy, or nutrients for soil improvement. In 2015, Stormossen Ltd recycled 96% of municipal waste. Stormossen Ltd biogas plant produces biogas for use in vehicles or as electricity and heat, as well as humus material out of the biodegradable fraction, i.e. food waste. Waste that is detrimental for the environment, i.e. hazardous waste is transported to a specialized treatment plant where it is processed appropriately. Stormossen Ltd combines a cost-effective waste management system with a high level of service, while remaining compatible with sustainable development.

Stormossen Ltd's role in the growth of the gas economy in the region is as biogas gas producer and service provider who has a direct influence on the growth of gas infrastructure. Stormossen Ltd has recently opened a filling station to the public and one for 12 City of Vaasa buses with 14 slots.

4.3.2 Gas Infrastructure

Stormossen Oy started producing biogas [34] in 1990. The company started with one bioreactor (1 500Nm^3), and acquired a 2nd one (1700 Nm^3), and a gas engine in 1994 bringing production to 330kWe.

The company started supplying Fågelberget industrial area and Bothnia Halli, a sports hall with biogas in 1995 through a pipeline. Another gas engine was acquired in 2009 bringing the production to 730kWe.

Sewage sludge and food waste are the only substrates currently used by Stormossen. The sludge comes from the waste water treatment plant (Påttska WWTP) located in Vaasa. The sludge is transported by trucks (16 000t/year with 20% DM). A pipeline was contemplated but it was too expensive Bío-waste from the residential and commercial areas from all around the catchment area delivered by trucks.

Gas produced is converted into heat and electric energy, 70% of electricity is used by Stormossen for its own needs and district heating and electricity for the City of Vaasa. For Bothnian Halli and Fågelberget industrial area, gas is sent through a pipeline to the user's boiler.

The collection of landfill gas started in 2007. Due to variations in CH_4 percentage content of landfill gas, the gas collected is not mixed with the biogas from the digester. The landfill gas is used for own heating.

In 2014, Stormossen signed an agreement with the City of Vaasa to supply biogas for 12 public busses operating on local routes. The busses began operating in January 2017, and ran on LNG which is backup fuel until the upgrading of the plant was completed. The LNG is bought from Porvoo or Pori, Sköldvid terminal. A public filling station has been opened with CBG100 (100% compressed biogas) being supplied. Before the agreement with the City of Vaasa, all the biogas produced was used for heat and electricity.

The plant has undergone some infrastructural upgrading which includes, an amine scrubber that is used for upgrading the raw biogas to a biogas with a high CH_4 content of up to 98%. The scrubber is run for 12 hours straight and then turned off. The upgrading of biogas is done to remove impurities to eliminate corrosion and raise CH_4 content, the compressors are used to make the biogas more economical to store, transport, and raise the energy content of the biogas. A regasification unit using High Pressure Ambient Air Vaporizer for regasification of LNG/LBG, though currently it is only LNG. There are storage bottles for the CBG and an $80Nm^3$ LNG tank to ensure security of supply, as LNG is used as backed fuel. The upgraded biogas is currently used as a vehicle fuel only. The new layout of the biogas plant is shown in Figure 12 below.

Digestate is composted, treated, and used as soil for landscaping using the sludge digestate and gardening from the bio-waste digestate.

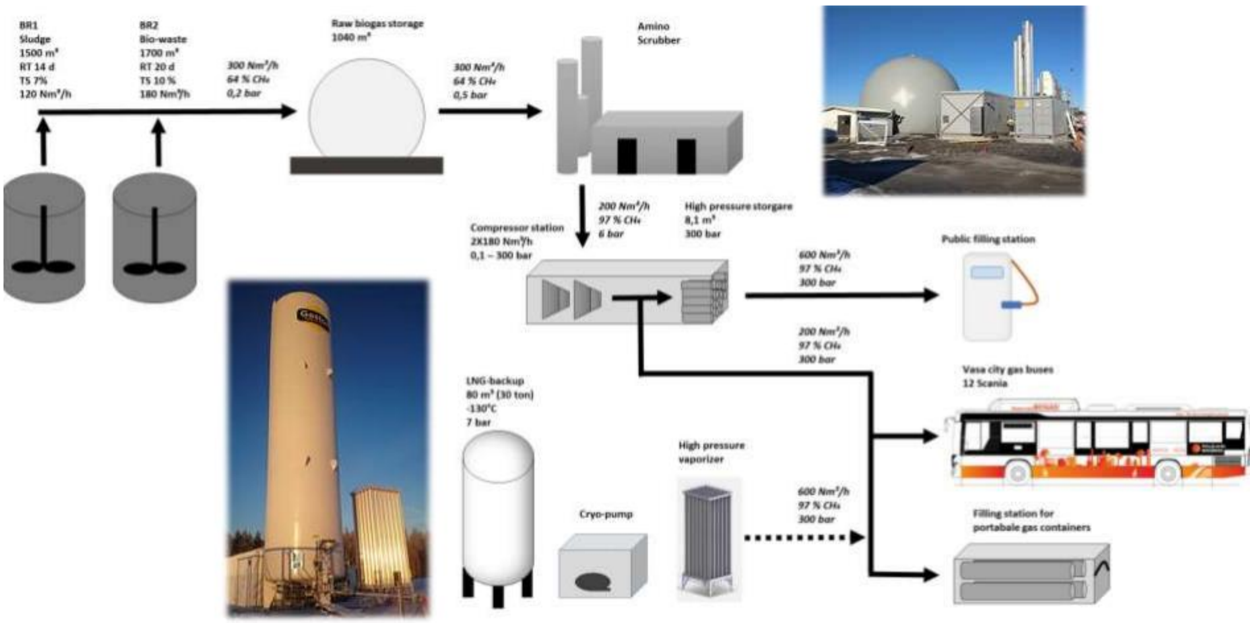

Figure 12: Stormossen Oy: From waste to fuel [Source: Stormossen presentation]

Figure 12 above shows the current upgrades that the biogas plant has undergone, both filling stations have been running since beginning of 2017.

The figure below shows how Stormossen Oy as a producer contribute to the regional consumption.

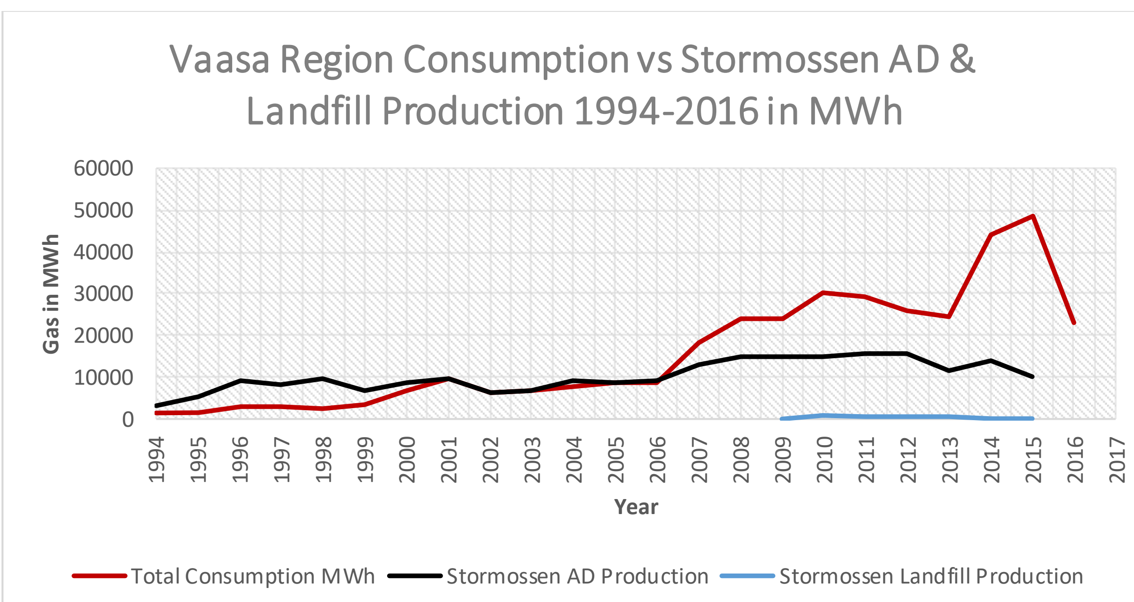

Figure 13: Comparison of Stormossen production to the Vaasa Region total consumption in MWh -1994-2016

In Figure 13 [Appendix 5&9] above, from 1994, the production from Stormossen AD was sufficient for the total regional consumption, because Stormossen Oy was the main producer. Jungerå Farm Biogas Plant is mentioned in literatures but it is not mentioned how the biogas produced was used, an assumption is own use for heating and values assumed to have an insignificant effect on the regional consumption. Laihia Biogas Plant started producing in 2003 but the regional consumption could have not been affected so much, Laihia plant uses part of its production for own heating only. From 2007, the consumption exceeded the production because of the LNG for Wärtsilä usage, and extra biogas from Jeppo Biogas Ab from 2014 which surpassed Stormossen Oy's production. The production went down to 1.6million Nm^3 because of lots of process changes and reconstruction of the plant.

4.3.2.1 Future Gas Infrastructure

Some of Stormossen Oy's plans include a 2nd filling station scheduled for opening between 2018-2019 to be in the southern part of the City of Vaasa, and a 3rd one in ~2025. Depending on demand, a pipeline is planned to feed gas to the 2nd filling station, otherwise gas will be transported to the filling station in CBG containers. The pipeline from Stormossen is expected to go through Runsor, which is an industrial area, making it feasible for other industries to tap from the pipeline. Stormossen Oy is also planning to work on extended use of pipe gas and collaborate with external industries to enhance expertise by utilizing the Energy Lab and possibly acquiring a Power-to-Gas unit for research. Stormossen also plans to work on process development and develop knowledge networks. At double capacity of production at ~40GWh, Stormossen would consider a liquefaction plant so that it can supply LBG for long distance trucks, among other things.

4.4 VEBIC

4.4.1 Brief History

VEBIC [35] is short for Vaasa Energy Business Innovation Center also known as the Energy Lab. It is a platform for new research and business innovations under the University of Vaasa.

The VEBIC infrastructure is a tool of solidifying the image of the University of Vaasa as an international leader in energy technology whose core focus is Energy and Sustainable Development. The main objects of VEBIC are, to offer research infrastructure for businesses and other universities, and research and academic needs for both international and local businesses and schools.

Several local industries are stakeholder, these are; ABB, Citec, Danfoss, Leinolat, Pohjanmaa Chamber of Commerce, Tekes, University of Vaasa, Vaasan Sähkö, VEO, Wapice and Wärtsilä Finland

VEBIC's role in the growth of a gas economy for the region is the know how that will come from the research and the improvement of the gas competence in the region, opening new markets for the gas.

4.4.2 Gas Infrastructure

Part of the VEBIC objective is to provide a research platform for research to be able to respond to the global energy needs. To be able to accomplish this, VEBIC needs a fully equipped lab and has the following infrastructure, an Engine lab for internal combustion engines and a Fuel lab for Fuel development.

VEBIC's current challenge is how to get the gas to the lab premises. At the time of compiling the information, it was not definite on what will be the final option. Initial plan was to have a pipeline from the Wärtsilä factory on Järvikatu or an LNG tank but both are too expensive. Biogas is a viable option.

Up for discussion are;

1. Aquiring a biogas container, priced at 180,00-200,000€ per container. There is ongoing consultation with Stormossen Oy, Jeppo Biogas Ab and Gasum Oy for a possibility of renting two containers.
2. In addition to the biogas container, a pressure reduction unit is needed. Cost for the pressure reduction unit is between 100,000-150,000 €. Discussions are ongoing with Metener Oy, Fingas Oy and Gasum Oy. It may also be possible to rent such unit from Gasum Oy.

Settling for buying would cost 1.36 million €, plus some other costs. Funding is still unclear and they are looking for the cheapest possible solution.

The lab is expected to be operational in 2018, using either LNG or biogas. The capacity is 40-50MWh container of which two containers are required. If the capacities given reflect annual gas needs (80-100MWh) for the Energy Lab, the regional consumption's increase is almost insignificant.

4.5 Påttska Waste Water Treatment Plant

4.5.1 Brief History

Påttska WWTP is a part of Vaasan Vesi, the municipal water utility company. Påttska cleans waste water from all around the city of Vaasa and Mustasaari, cleaning ~7.6 million Nm^3 of waste water per year [36]. The value varies depending how the winter and, or spring was, increased runoff water for heavy snow winters and very rainy spring.

Påttska is an important part of the gas infrastructure because of the waste product from the waste water treatment process, sewage sludge which is used as a digestate in the production of biogas. Centrifuge sludge dewatering process pretreats the sludge, where some of the water is removed to enable economical transportation of the sludge to Stormossen Ltd in Koivulahti, where it is used as a substrate in biogas production.

The change in the treatment process of the waste water may affect the amount of sludge, Stormossen gets circa 30% of its raw material from Påttska.

4.6 NCL Ferry Oy

4.6.1 Brief History

NCL Ferry Oy [37] is a company co-owned by the Umeå Municipality of Sweden, and the City of Vaasa of Finland.

The Company in turn owns a shipping Wasa Line, which runs between Vasa and Umeå with M / S Wasa Express.

Company NLC Ferry AB / OY was founded in 2012 as the previous private operator could not continue their mission. Local authorities wanted to secure a long-term stable transport link across the strait, a key part of the E12 street and bought jointly in a ferry. They also took over operation of the traffic.

4.6.2 Gas Infrastructure

The ferry is a key factor in the development of gas infrastructure as it would be a consumer of the gas, possibly locally produced gas. The ferry will run on LNG/LBG and bunkering of the ship will require a terminal, this drives infrastructural development and the terminal can be used for more than just bunkering. For the ferry bunker, there are currently no regional local suppliers on the Finnish side, because demand is still low, even for the CNG. The presence of the ferry would lead to liquefaction plants, not just to supply to the ferry but other users such as industries and heavy trucks, as well as other application. For local companies like Wärtsilä and the VEBIC Energy Lab, it is seen as a "Living Lab", enabling them to carry out test on a real ferry, which would give more concrete results than just simulations which are an imitation of a real thing. This can lead to technological breakthroughs with the fuel and product development.

The ferry is under VASEK because it is covered in the Midway Alignment of Bothnia Corridor project and VASEK is named as a partner. [30]

4.7 Laihia Biogas

4.7.1 Brief History

The Laihia municipality owns the Laihia Biogas Plant. The plant was built in 2003. Laihia Biogas plant uses up to 3,000tons [38]of waste per year. The sewage sludge comes from the municipality and industrial users. The plant is small and located far from the residents, it is not feasible to supply heat to the homes, the biogas produced is used to heat the plant throughout the year.

4.7.2 Gas Infrastructure

The biogas from the Laihia Biogas Plant is anaerobically produced, CH_4 content of ~60-65%. The biogas is used in its raw form for heating of the plant. The graph below shows the production against consumption of the plant from 2003 -2016. Unlike the other producers in the region, it is the only plant producing biogas only for own use, heating.

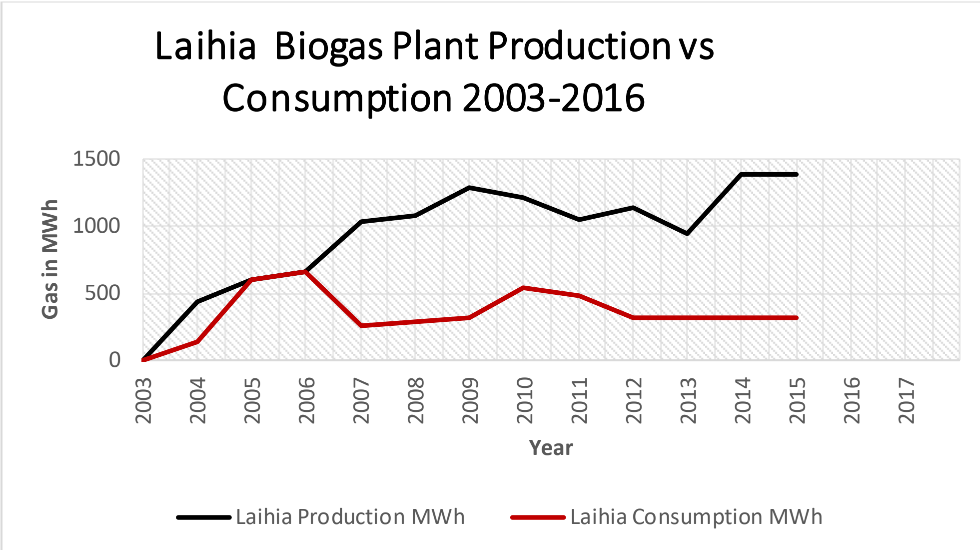

Figure 14: The production and consumption of biogas from Laihia Biogas Plants 2003-2016

Figure 14 [Appendix 5&9] above show the production and utilization of biogas from Laihia Biogas Plant. From 2003 to 2006, the surplus biogas was very narrow. There is no explanation for the increase in production and reduction in consumption from 2007 onwards, especially that the biogas is only used for own heating. The difference between the amount produced and utilized shows that the plant could be used more efficiently and find alternative methods of utilizing the gas. The plant is located too far from homes to supply heat. The plant would be self-sufficient by producing its own electricity or the surplus biogas could be transported to an upgrading facility and distributed as normal. The are no new values for the plant from the year 2014 in the registries. One possible explanation is the attempt to sell off the biogas plant to Nuuka Lämpö Oy in 2014 but Nuuka Lämpö Oy did not see any advantages in buying the plant

The future of the plant is unknown, there was no contact with Laihia Biogas Plant or the municipality to get clear facts on the future of the plant. Talks for expansion to optimize operation of the plant by the farmers by fallowing to produce more biomass cannot be done as it would require an extra bioreactor. However, there is mention of a private entrepreneur starting a waste plastic processing plant near the biogas plant [38]This would put the biogas produced to better use, as distance to other consumers has been cited as a challenge.

There is mention of a landfill which was closed early in the year 2000 in Laihia but there is no documentation on it.

4.8 Jeppo Biogas Ltd

4.8.1 Brief History

Jeppo Biogas Ltd [39] is a company that aims at the recycling of nutrients and the production of renewable energy. Their main goal is to create energy and environmental friendly fertilizer products from organic waste produced in the community farms. Self-sufficiency in energy is important for them, as well as local production in agriculture. The biogas plant has been in operation since autumn 2013. Continuous development of their plant has now led also to a public CBG100 refueling station for vehicles located at the plant premises.

There are currently 5 employees working within Jeppo Biogas Ltd

Jeppo has an industrial symbiosis with Snellman Ltd. The animal waste products from Snellman Ltd are used as raw material by Jeppo Biogas Ltd. Snellman buys gas from Jeppo Biogas.

Its role in the growth of the gas economy is that it produces and upgrades biogas, this improves the security of supply for the region and stabilizes the gas market. Jeppo Biogas Ltd has a CBG100 filling station open to the public. The filling station helps the growth of use of biogas vehicles in the region as availability of the commodity has been a hindrance to growth of biogas use, among other things.

4.8.2 Gas infrastructure

The biogas plant [40] built in 2013 consisting of three anaerobic digesters of 4000Nm^3 and a gas buffer of 6000Nm^3. The plant has raw biogas upgrading unit, a water scrubber, to remove impurities from the raw biogas to raise the CH_4 content of the gas. The upgrading allows for the biogas to be stored under stable conditions. The compression allows for economical storage, transportation and for use as vehicle fuel.

The substrates used are agricultural sludge which is delivered through the sewage grid, agricultural biomass, industrial and slaughter house waste which is obtained from Snellman. Jeppo Biogas Ltd processes 90,000Nm^3 of waste annually obtained from the local farms and food industries. The waste is delivered to the plant through a pipeline.

The graph below shows how Jeppo Biogas Ltd compares to the regional consumption if all gas utilised was produced locally and Jeppo was the only producer in the region.

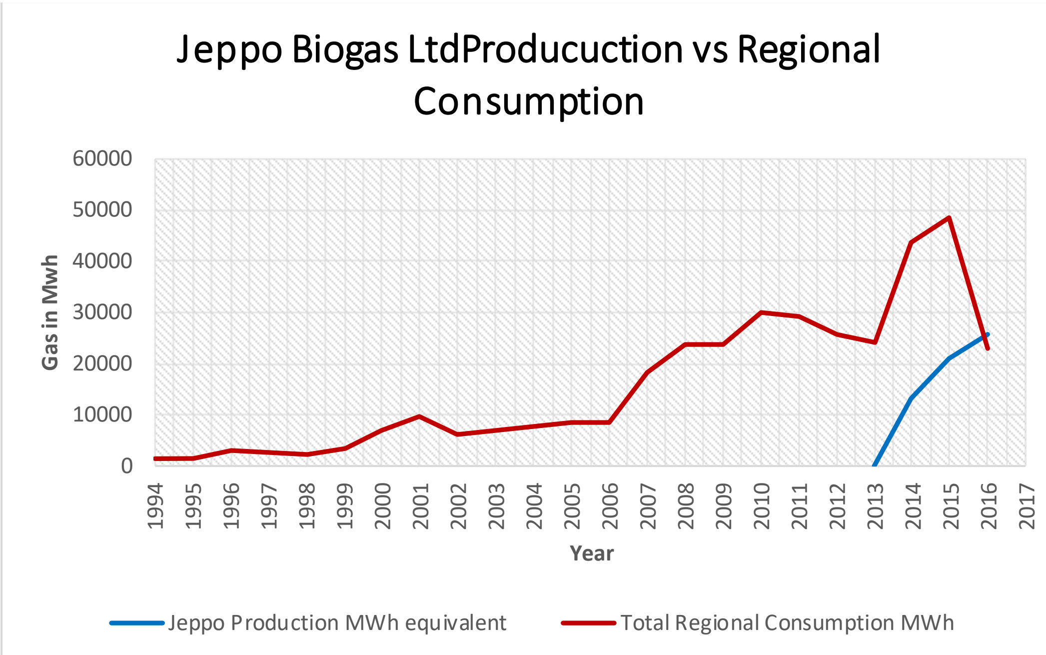

Figure 15: Jeppo Biogas Ltd production compared to the regional gas consumption between 1994-2016

In Figure 15 [Appendix 5&9] above, the year 2016 represent the consumption values for Wärtsilä only. At this rate, Jeppo Biogas plant can satisfy the Wärtsilä demands, if it was the only consumer in the region. Part of the biogas produced is used in its raw form for heat production for own and nearby industries sent through a 4km pipeline. The rest is upgraded to ~99% CH_4 and compressed to 250bar, used industrial applications such as Snellman Ltd food processing industry and a fraction as vehicle fuel [41]. VEBIC is contemplating the possibility of buying upgraded biogas from Jeppo Biogas Ltd, that is possible because VEBIC is planning on a consumption of ~100 MWh (two containers of 40-50MWh) and does not affect the regional consumption values so much. The upgraded biogas is stored and transported to the end customers in containers

Depending on the demand, there is a possibility to expand to liquefaction of biogas but it is too early to tell. Liquefaction of the gas if the market allows is a long-term plan for the company to be able to supply fuel to ferries and heavy trucks.

4.9 Suvilahti Landfill- Sarlin Ltd

4.9.1 Brief History

The Suvilahti Landfill was declared closed in the year 2000 because it was too close to the residential area. In 2008 [42], the Vaasa Housing Fair show-cased new residential area close to the sea in Suvilahti. The area was designed to use locally produced heat and electricity. The sources of energy are the closed landfill and the seabed heat.

4.9.2 Gas Infrastructure

A small power plant [25] consisting of a microturbine by Sarlin Ltd with an output power of 130kW electricity and 230kW for heating. There is also a gas fuel cell [42] (Flat Solid Oxide technology) from Wärtsilä Oy with an output power of 20kW for electricity and 14-17kW. The plant uses biogas from the landfill resulting in about 30% of the gas collected being used for electricity production and 60% for heat production. Through this power system, 40 single unit homes and 3 blocks of apartments, total of 150 households get their heating and electricity.

All gas collected from the landfill is used up using a microturbine and fuel cell to produce electricity and heat. The landfill in Suvilahti sells heat and electricity to Vaasan Sähkö which is used up in the housing area in Suvilahti, supplying energy to 40 housing units (electricity) and 3 apartment buildings (heating).

The graph shows how the consumption from the landfill produced gas compares to the regional production. The consumption from the landfill is used instead of the production because the supply from the landfill will end at one point and alternative means of energy sources will be needed to meet the demand.

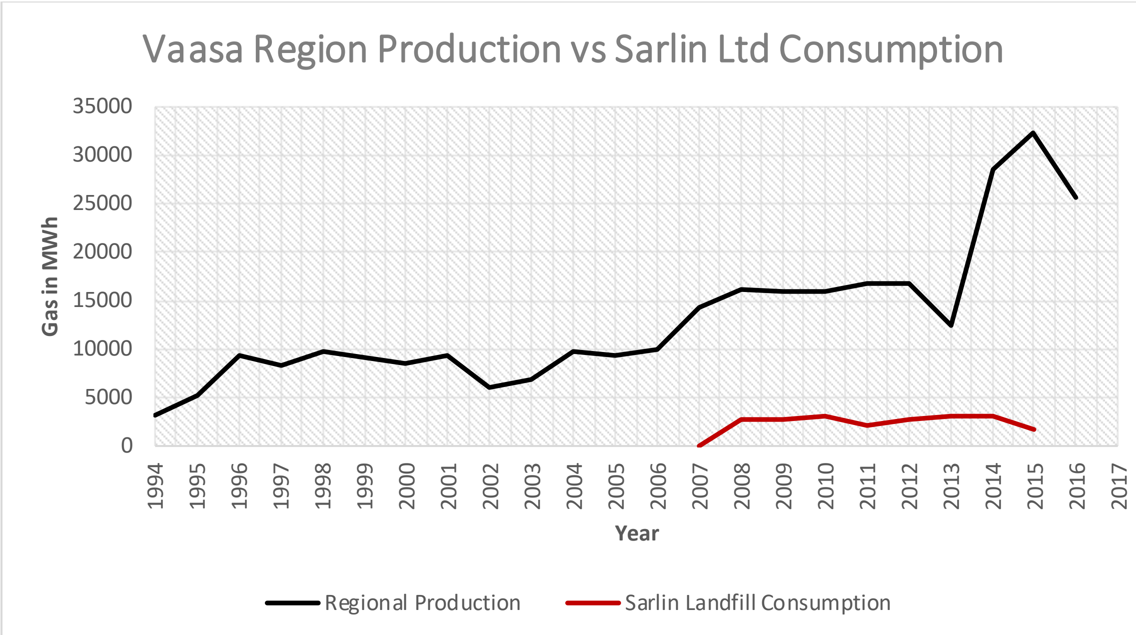

Figure 16: How the consumption from the Suvilahti Landfill compares to the regional production from 1994-2016

From Figure 16 [Values in Appendix 5&9] above, the consumption from the landfill gas can be covered in the regional production.

The production and consumption of gas from the landfill is equal, all the biogas collected from the landfill is used up. Despite fluctuations in the capacities produced per annum, the consumption equals the amount produced, this is because all the gas collected is converted to heat and electricity, with some losses in the process. It is also a possible indicator that the gas collected is not enough to meet the demand, considering that the values have reduced considerably from the initial period when the area to be supplied was made. Hence, using the consumption capacities instead of production capacities even though the landfill is a producer.

In 2016, heat energy sold to Vaasan Sähkö Ltd from the landfill gas accounted for less than 2% of the total heat sold to the company [43]. From the graph in Figure 16 above, the lowest produced (production = consumption) was 2015, going by the trends of a landfill, the values for 2016 could be equal or slightly less than that of 2015.

The city of Vaasa handed over the ownership of the landfill to Sarlin Ltd.

5 Results: Mapping Gas Infrastructure

This result section has three parts, the total biogas production for the region, the consumption, and the comparison of the production to consumption, the period covered is between 1994-2016 and capacities in MWh. The results chapter will elaborate trends in production and consumption and give a summation of the consumption against production, to show whether the current infrastructure can satisfy the current demand without looking outside the region. This part also elaborates how the planned future infrastructure affect or contribute to the availability of the commodity in the region.

5.1 Biogas Production for Vaasa Region 1994-2016

The figure below shows the total biogas production for the Vaasa region from 1994-2016. In this graph, all sources of biogas available in the region are listed and their individual capacities per year. In the graph below, the points where the respective plants touch the graph y=0, is the year when they were founded, and the first recorded values are for the year after being founded. An exception is Stormossen AD which started production much earlier, that is why the line does not start from y=0.

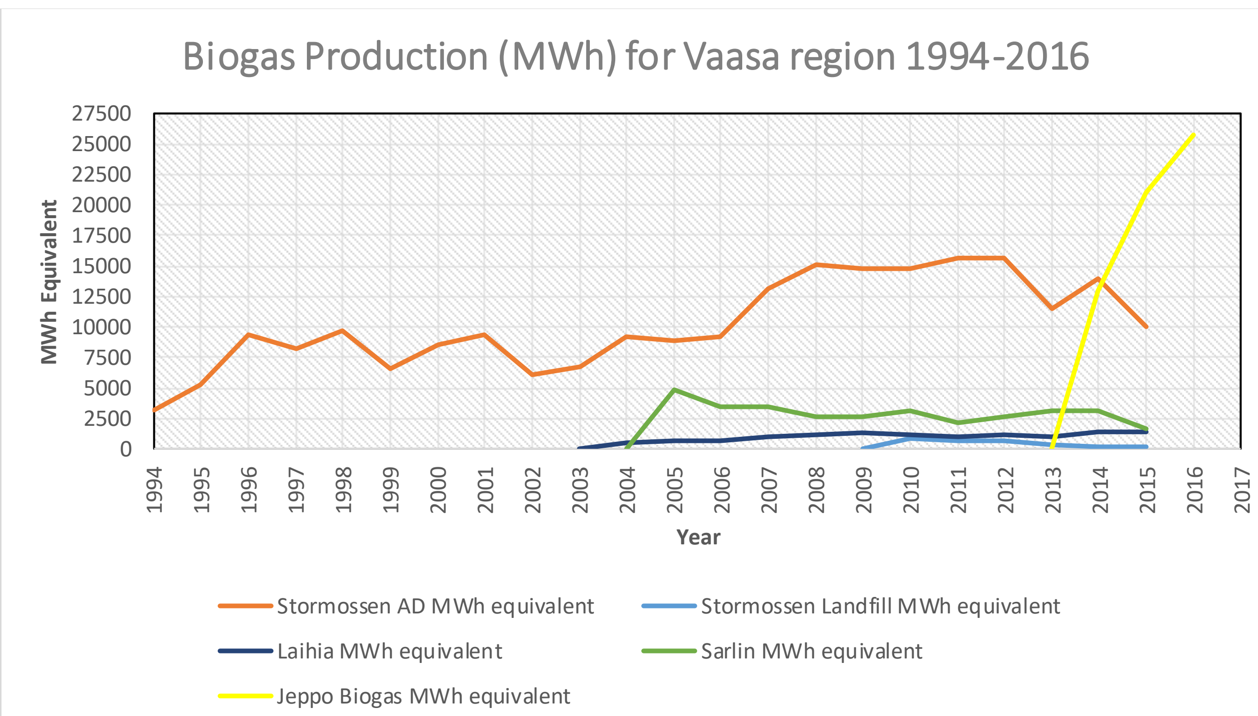

Figure 17: Vaasa Region Biogas Production (MWh) 1994-2016

From Figure 17 [Values in Appendix 5] above, Stormossen AD has the longest history in biogas production. There are two parts for Stormossen because the biogas from the reactor is not mixed with the biogas from landfill due to unstable CH_4 content of landfill biogas. There is no clear explanation to the fluctuations in the amount produced per year, except from 2009 when Stormossen acquired a bigger engine. The drop in 2015 was due to the upgrading carried out on the plant. The production is expected to rise from 2016 to values closer or more than before upgrading of the plant. The Jeppo plant is the biggest producer and newest one, less than 5 years old. Jeppo Biogas Ltd is a key player in meeting demand, it upgrades most of its biogas for industrial use and a smaller fraction for vehicle fuel. Future production for Jeppo Biogas Plant will depend on demand. Raw biogas is used for own heating and nearby industries. Laihia Biogas plant looks stable, though there are no new records since 2014.

Similar trends can be seen in the two landfills (Stormossen and Sarlin), the amount produced per year keeps reducing until there will be insignificant amounts produced. This is normal for a landfill and an indicator for alternative source of gas or other energy sources. Not included on the graph is Jungerån Farm Biogas plant, Jeppo, established in 1995, a production of 200Nm^3 was recorded in 2000, but the years after, the volumes produced has been insignificant []. Malax Bioenergi Ab has been registered but has not started any production and not enough data on it. Apart from the terminal, which is not a producer but contributes to the availability of the gas in the region, there are no future planned producers for now.

5.2 Gas Consumption for Vaasa Region 1994-2016

The regional consumption shows how much is consumed from each source in the region per year between 1994-2016. The sources (producers) are used because the full distribution system is not known, especially for big producers like Stormossen and Jeppo Biogas Ltd who has multiple applications for the gas produced. Wärtsilä is the only company in this graph that is a total consumer of the values displayed.Wärtsilä uses LNG but it can be replaced with biogas, that is why there is one graph to show the total regional consumption. The graph below shows these consumptions.

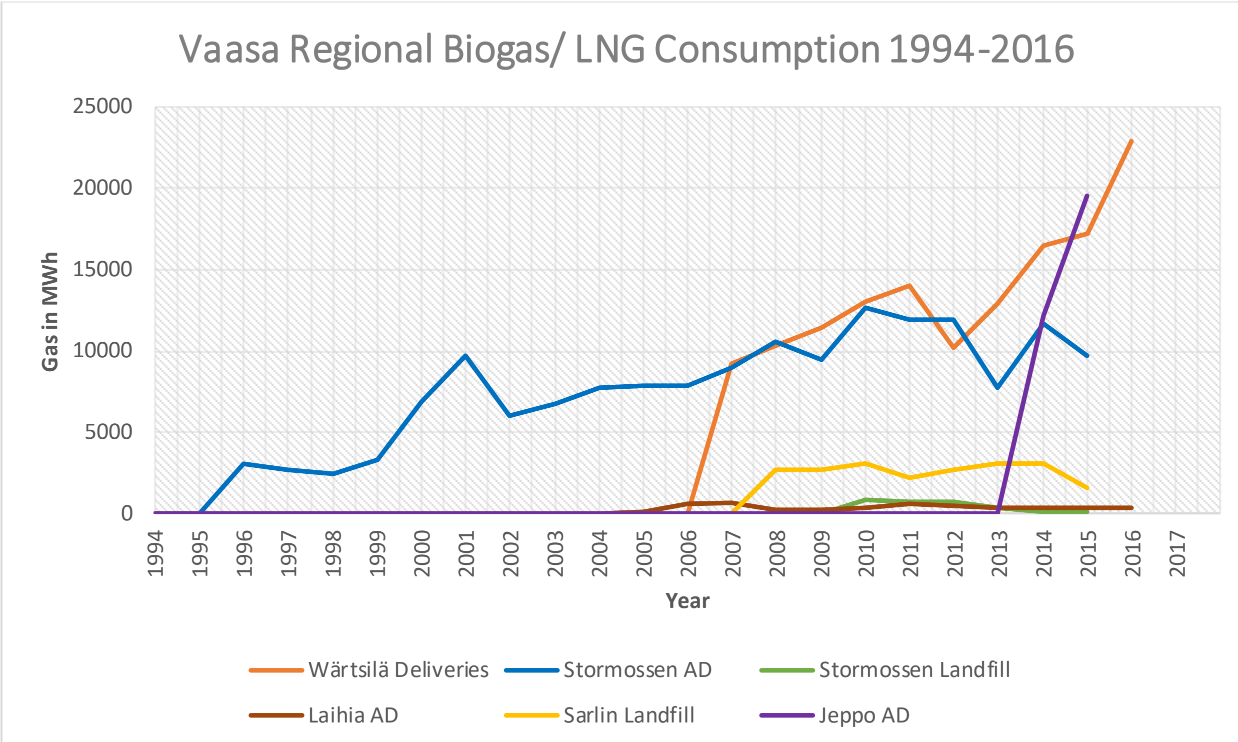

Figure 18: Vaasa Region Biogas/LNG Consumption 1994-2016

Figure 18 [Values in Appendix 9] aboves shows how much biogas is consumed from each source. The biogas is used for own use in running the plants, district heating, electricity, and recently adding industrial use and vehicle fuel in the form of CBG. Even though there is a drop in 2015, the consumption will increase, and so will production. Stormossen has started upgrading biogas for vehicle fuel and a 2nd filling station scheduled for 2018.The Wärtsilä consumption/ deliveries is LNG from outside the region, but is included as LNG is considered a transitional fuel and is intercheangable with LBG. The Wärtsilä consumption is expected to increase from 2018, as all engine testing previously done in Italy will be done in Vaasa. Laihia Biogas Plant is the only plant that uses the biogas only for own heating, consuming less than 50% of what it produces. An assumption would be that, the plant could now be using up the surplus gas from previous years. From the landfills, everything that is produced is used up regardless of the fluctuations in amounts produced from year to year. The total consumption being equal to the production is because the landfill gas is converted to heat and electricity through microturbines, fuel cells and boilers. The CH_4 content varies and may be difficult to store compared to the biogas produced from the reactor.

5.3 Total Regional Production and Consumption 1994-2016

In this part, the total production for the region does not include the biogas from the landfills, because landfill gas production decreases with time until nomore gas can be obtained anymore. The graph below shows the total regional production and consumption. To elaborate the consumption more and for future planning purposes, the Wärtsilä deliveries (consumption) is included in the total regional consumption and also shown alone . The regional biogas consumption is also included in the graph, this is to show how the regional consumption, if Wärtsilä continues to buy LNG from outside the region looks like. It also shows how much more should be produced to include Wärtsilä as a consumer for the locally produced biogas.

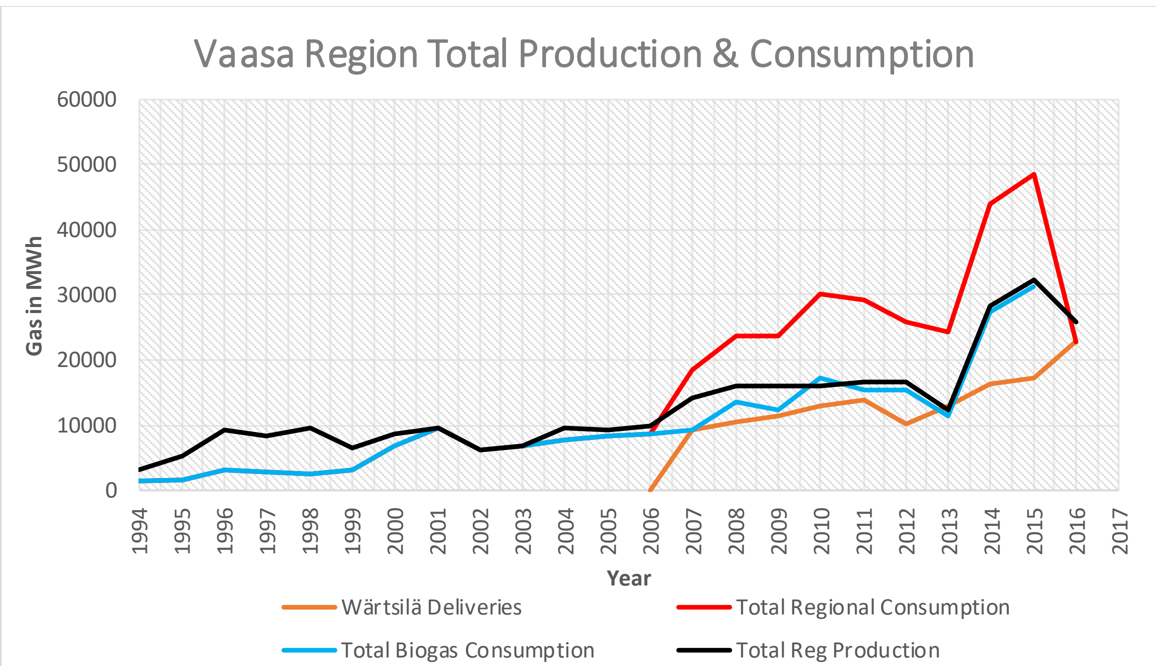

Figure 19: Total Vaasa region production and consumption

Figure 19 [Values in Appendix 5&9] above shows the Production vs Consumption trends from 1994-2016 for Vaasa region. Stormossen was the main producer of biogas in the region until 2003 when the Laihia plant was built. The low consumption in the beginning is because Stormossen was the only source of biogas for the region and the Wärtsilä values from earlier years was not obtained. The sudden increase in total regional consumption from 2007 is due to the values from for Wärtsilä LNG deliveries. Even though Wärtsilä has been using LNG earlier 2007, the data obtained was from 2007. A study done on the compatibility of Stormossen raw biogas with Wärtsilä engines showed that they are not compatible but upgraded biogas is [Appendix 6]. This is due to the raised CH_4 content, and it is the reason the Wärtsilä consumption is included in the total regional consumption. There is a drop in the consumption and production in 2016, this is because, it is only Jeppo plant's production capacity that was gotten, the value could be higher with values from Stormossen and Liahia plants, so far, the production has not affected the commodity availability in the region, because it produces for own use. For the consumption, it is only Wärtsilä values in 2016. The trends in the biogas consumption and production from 2012 shows that, almost all the biogas produced is used up.

VEBIC Energy Lab and the ferry will contribute to the rise in consumption, with an estimated consumption of 80-100MWh for the Energy Lab. The LNG/LBG terminal planned capacity is 3000-7000Nm^3 but the LNG terminal which has a 50/50 chance of the terminal coming to Finland will contribute to the availability of the gas in the region. The ferry and terminal have a possibility of driving the gas economy to a more stable level and a learning platform for the schools and industry.

6 Environmental Challenges

In comparison to other renewable energy sources, a gas based economy for the region is a more reliable form of renewable energy, because of higher security of supply. There is no intermittence and storage issues but the gas economy faces challenges of its own in the region and outside the region in general.

6.1 Quality of Raw material

There are properties of biomass that determine whether it is will give a high or low methane yield for the biogas. Waste is a common raw material for biogas production, but it is a heterogeneous fuel. The fuel quality depending on the source. The industrial waste is more uniform compared to the home food waste which may contain inorganic waste depending on how well the waste producer can sort. More education is needed on the important of sorting the waste from source to reduce pretreatment costs. Raw material such as cash crops give a higher one. It is a challenge to economically produce biogas from a low energy density substrate. The solution is to mix these materials if they are available.

6.2 Biomass Prioritization

The pyramid in Figure 20 [44, p. 5] below shows how the use of biomass can be prioritized. The pharmaceuticals and health are considered high value, meaning that available biomass should first be used for pharmaceuticals and health if it is suitable, then reuse waste product for the next in the pyramid. Energy is last on the pyramid and considered least valuable. This pyramid shows the environmental challenges that a biogas economy can face in the region. Currently at Stormossen, food waste and sewage sludge are the only substrates used, due to legislation restrictions with what can be used and where it can be collected for a company like Stormossen. The Vaasa region has a population of about 100 000 people, can they produce enough waste, when waste reduction is top on the waste hierarchy?

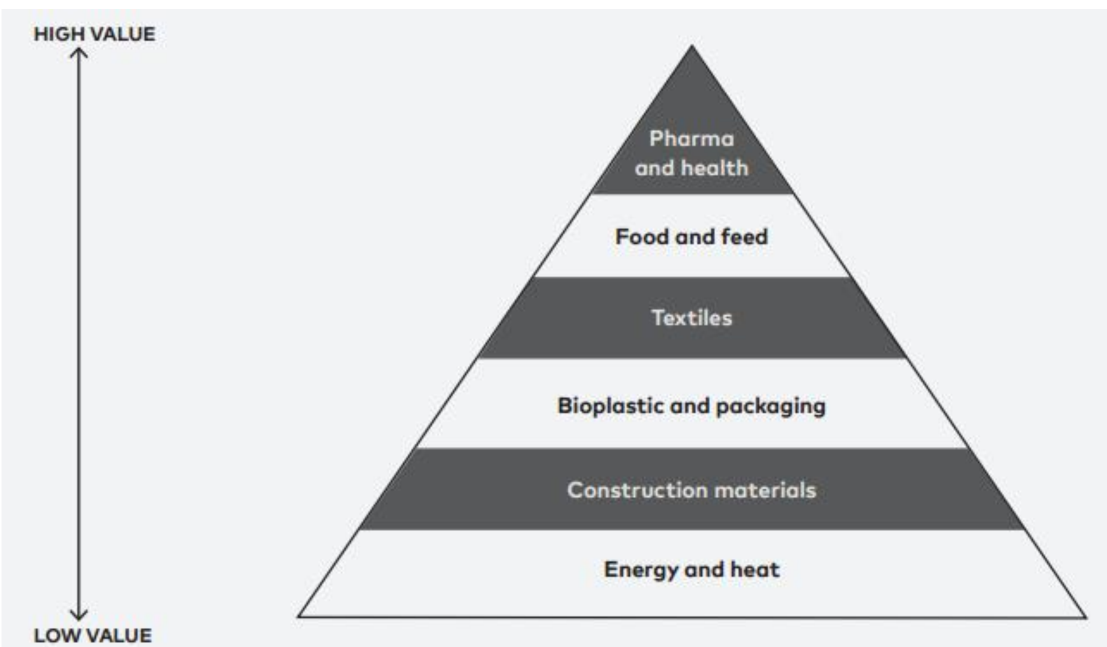

Figure 20: Biomass Pyramid

6.3 Land Use

Land use conflict is not an issue in this region but for other places it might be, as food competes with energy crops for land and water. Ostrobothnia currently utilizes only 9% [Stormossen presentation] of its biogas potential. Depending on how the biomass (forest residue) is harvested or collected, there is a threat to the biodiversity, which in turn might affect the vegetation and a possibility of extinction and new species coming up that are not fully understood.

6.4 Prejudice

The by-products of an anaerobic digestion are biogas and digestate as waste product which is treated, and used for landscaping and agricultural use. The problem is people are skeptical of using that soil, so how to get rid of it becomes a problem. If production is increased, the end products increase too. Another challenge is that, the end user for the biogas does not fully understand [14, p. 49]the benefits of using this fuel and will choose a fossil fuel simply because they understand it better. There is need for educating the customers to change the mindset.

6.5 Safety and Health Risk to People

Biogas production require strict control and maintenance of facilities. Biogas like most fuels is explosive at a certain oxygen concentration. Biogas is explosive in confined spaces when there is a concentration of 10-30% of air. An explosion cause injury and fatalities to human. Biogas can leak from valves but raw biogas has a distinct rotten egg smell from the hydrogen sulfide and easy to detect, but inhaling biogas can cause suffocation caused by hydrogen sulfide. Waste is a raw material in the biogas production. Personnel working in the biogas plants need protective clothing to prevent infection and spread of pathogens from the waste [45]. The plant must be far from the residential areas because of the bad odour and possible spread of pathogens from the raw material.

The environment is also affected if the explosion is big. Air pollution from burning things and possible burning of the surrounding areas if the fire is not controlled.

6.6 Demand Challenges

If the demand does not increase, distributing the gas by road is practical, but in high demand there would be need for pipelines. The challenge comes if no such infrastructure is planned for when planning new areas. There is also a challenge to deliver services to already planned areas, challenges like construction of infrastructure close to the end user. An example is the failed pipeline from Stormossen to Påttska for transporting the sewage sludge.

7 Studies on Potential of Gas Economy for the Region

The potential of a gas economy for the region is evident from the studies that have carried out under various projects. The following are some of the studies that will help the growth of the gas economy for the region.

7.1 Energy Village

The Energy Village project was funded by Manner-Suomen Maaseudun Kehitysohjelma, and done by Levon Institute, Novia UAS and Metsäkeskus. The project ran between 2011-2014

Surveys showed that people on the country side (villages) spent more on fuel for transportation in energy costs. A total of 13 villages have been assessed (in and outside Ostrobothnia). The main objective of the project was to find means of locally producing a fuel, an easy to implement BAT. The fuel that suit this was biogas, given that there was availability of raw material.

Full report can be accessed from the AIKO Gas CoE Project archives.

7.2 Biogas in Traffic

The "Biogas in Traffic" project was born from the "Energy Village Project". The project is scheduled for 1.6.2016-30.4. 2018, after extending the period by one year. The catchment area for this project is Ostrobothnia. The project is financed by EAKR (Finnish acronym) Structural Fund- managed by the Ostrobothnia Regional Council.

The Biogas in Traffic project aims at carrying out studies on the of biogas production in Ostrobothnia. In the project, traffic hubs should be identified as well as the possible large customers for replacing oil used for heating. The potential of biogas production in Ostrobothnia will also be analyzed. From the studies, the vital locations in Ostrobothnia where the supply may equal the demand should be identified. Biogas is new in Ostrobothnia and needs acceptance from the end users, the project also aims at raising awareness about biogas and to bring about a new business and biogas consumption, with the aim of breaking the egg-chicken cycle.

For more information on the above two projects [7.1 & 7.2] contact:

Ari Haapanen,
Levon Institute,
University of Vaasa.

7.3 Surveys Gas Market Potentials

Three surveys have been carried on the commercial potential of gas in the region by three different bodies;

1 Report: Estimated LNG needs for the Vaasa Region (old Vaasa region) by 2020 (*translated from Swedish, title may differ slightly*)**.** The report dated 13.2.2014 was published by Merinova Technological Center. The areas covered in the report are, Vaasa region, Senäjoki region, Kokkola region, Pietarsaari region and Narpes region's total estimated consumption of 460 GWh (circa 79,000Nm^3 / year of LNG) [46]. Full report in the AIKO Gas CoE Project archives available in Finnish and Swedish only.

2 Bothnian Marketing/SSPA that estimated the consumption for Vaasa region at 17,317 Nm^3 on short term and 60,932 Nm^3 /year for long term [31].

3 Strategic Group working the Midway Alignment of the Bothnian corridor estimated for Vaasa region at 21,000 Nm^3 /year. The report was not accessed.

8 Discussion

The legislation currently leans heavily on the side of renewable energy. The challenge is that, it is not only biogas that is a renewable energy, the other types that have reached advanced technological levels are bound to take a bigger share of the renewable energy market. Taking CBG as a vehicle fuel for instance, while the price is favourable compared to diesel and petrol at 1.45€/kg, equivalent to 1.5 litres petrol which costs 1.40€/L, there is need for frequent servicing of the cars for the vehicles fitted with CBG/CNG kits. Long term, it takes away the benefit of a cheaper fuel.

In the beginning, the applications for biogas was heat and electricity only. One possible explanation is that, things like biogas are policy driven, use of biogas for other than electricity and heat was known but the environment (economics and people's perception) was not yet right. Raw biogas has limited applications, most common is electricity and heat production, but by upgrading the gas to a methane gas, more applications are identified and finding efficient ways for the current applications through R&D.

The current gas infrastructural growth is focused on upgraded biogas, opening many possible applications for the gas. From the information collected, only Wärtsilä has been using LNG in the region, until 2017 when Stormossen procured some LNG as backup fuel for the biogas powered busses before completion of the upgrades on the plant. With upgrading technologies, biogas can compete with natural gas (upgraded) for the market share, but from Figure 17 above, the regional production is not ready to take over the market to satisfy the total regional demand, unless the LNG/LBG terminal is built on the Finnish side. Natural gas will be part of the picture for some more years to come going by the current production rates. LNG used as backup fuel side by side with biogas gives room for the biogas to gradually grow, but LNG is a fossil fuel and cannot be used as the backbone for the gas based economy for the region.

From the previous studies, lack of infrastructure and competences have been identified as among the factors in the hindrance to the growth of the gas economy in the region. Looking at the infrastructure growth in comparison from 5 years ago, and planned infrastructure for gas, it is evident that the region is tackling key areas that are needed to drive a gas based economy. VEBIC would help competence growth in the region and together with the Wärtsilä labs, through R&D can make technological break throughs that will broaden the use of biogas and natural gas. Current common applications of upgraded are transport, industrial use and in R&D, with technological break throughs, more applications would be found that would help stabilize the market for biogas.

The ferry would contribute to economic, social, and environmental development of the region due to job creation, efficient transport facilitating for the movement of cargo and people all year round and environmental protection through reduced emissions from fuel type. Another benefit for the region is the technological development through R&D. Wärtsilä and VEBIC would have a possibility of carrying out tests on a real ship, and compare with simulations.

The terminal's location has not been decided, Appendix 3 shows the planned distribution network for the terminal. If the terminal is built on the Swedish side, the same distribution network could still be implemented with the use of biogas, with backup from the Pori Terminal as a start, which is only 200km from Vaasa.

The construction of more filling stations will increase the number of vehicles running on biogas which in turn would lead to a stable market for biogas. The strategic areas have already been identified in "Biogas in Traffic" project. Whilst it will take time to reach numbers that other fuels have, the little that would be available could be placed strategically, an example being the 2nd filling station that will be in Runsor. Runsor area has lots of industries with workers living in all parts of the region. Having two filling stations located in the north and south of the city is a good start and broadens the chances of the growth of biogas vehicles in traffic.

The City of Vaasa has set an example by procuring 12 buses running on biogas, more municipalities could consider doing the same, especially those municipalities whose waste produce the biogas. The municipalities procuring biogas buses is a big step in stabilizing the biogas market. Biogas needs to be promoted more so that people could learn to understand it and its economic, social, and environmental benefits for the world and region.

9 Conclusion and Recommendations

In conclusion, the gas based economy for the region is slowly growing but still needs natural gas as backup to help the market to steadily grow. During the writing of this paper, there has risen some areas of interest within the paper for the author, that given more time, would have liked to analyse more.

Lack of infrastructure is cited as a challenge, but existing infrastructure may pause a challenge to feasible development of gas infrastructure. A pipeline between Stormossen and Påttska could not be constructed because it was impossible, but because it was not feasible. It was too expensive. The question comes to how the current infrastructure will affect the growth of gas infrastructure if demand was too high to bring the commodity closer to the end user.

Though projects in chapters 7.1 and 7.2 above identifies potential areas for biogas plants, biogas plants are expensive to construct and maintain, and this limits how many of those areas could be utilized and the period for implementing those ideas would be much longer. The biogas is intended for use as vehicle fuel and for heating, an upgrading and storage systems are required. Given more time, an analysis of the optimal sustainable solution to utilize the identified resources could be of interest to know. Comparing whether to construct small plants in the hot spots or have a central plant, receiving raw material from the identified hot spots and distributing the gas to these areas is feasible, and the challenges with each option.

Another point of interest is the Laihia Biogas Plant. There is more gas left over compared to what is used. If production continues, finding ways of utilizing the surplus gas to contribute to the regional needs. Is transporting the surplus biogas to an upgrading biogas plant like Stormossen,

~20km away and have the gas distributed as normal (how Stormossen distributes its biogas) feasible? The plant is located far from the residential areas and cannot use the gas for heating in homes due to lack of infrastructure.

Gas competence in the region is a challenge for the region, but through VEBIC and Technobothnia Education and Research Center, there is focus on gas competence but it is focused on certain disciplines of engineering. The region still needs to find ways of implementing the gas competence in all the disciplines of study across the board because it requires more than a certain branch of engineering to drive a gas based economy.

Lastly, the biggest challenge encountered during the preparation of this thesis was establishing contact with companies, that limited the number of companies covered. Another challenge was theory for some of the technologies. Most technologies are covered in company catalogues which do not give detailed descriptions of how these technologies work.

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APPENDICES

Appendix 1: About Gas CoE Project

Gas CoE – National Gas Cluster of Excellence

1.1.2017–31.12.2018

The aim of the Gas CoE project is to strengthen the gas-related educational, R&D and demonstration activities in the region, particularly in fields that support the industry to evolve the region into a national gas cluster of excellence.

The Gas CoE project serves as a core initiative and as a driving force in promoting future R&D activities as well as competence development within the region. This two-year project forms one of many actions that in time will lead to the creation of a unique R&D environment and -expertize in the Vaasa region.

The project results in access to a strengthened infrastructure built in VEBIC as well as in Technobothnia, available for students, research-, educational-, and laboratory personnel at all of the regions universities and higher education institutions as well as for local businesses utilising the provided service, expertize and equipment.

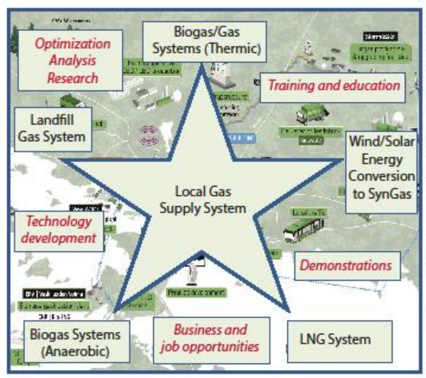
The project consists of three different work packages:

WP 1: Assessment of the present situation, developing roadmaps for a sustainable, local gas infrastructure

Activity 1: Developing organisation specific and joint road maps for knowledge development and research activities that in long term leads to reinforcement of the gas cluster (**Competence roadmap**).

Activity 2: Generating a vision for a **sustainable, local gas infrastructure**. Mapping of the future R&D requirements and demo environments (**Infrastructure**).

Activity 3: Forming an action plan and a gradual approach towards a sustainable gas economy (**Gas Value Chain**).



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WP 2: Reinforcement of the research infrastructure and experimental demo environments in the region

Activity 1: Advanced power plant engine technology for future energy systems in **VEBIC** (Experimental gas research and demo activities).

Activity 2: Gas technology and energy systems in **Technobothnia** for demonstrations and experimental activities in laboratory that serves the educational- and experimental activities.

Activity 3: Living Lab Sites for a more efficient integration of the local gas infrastructure into R&D activities.

WP 3: Generating a joint research and development agenda with new R&D proposals

Activity 1: Assembling a regional research and development agenda.

Activity 2: Dissemination of responsibilities and prioritizing R&D proposals.

Activity 3: Processing project proposals and applications, focusing on both national and international sources of financing.

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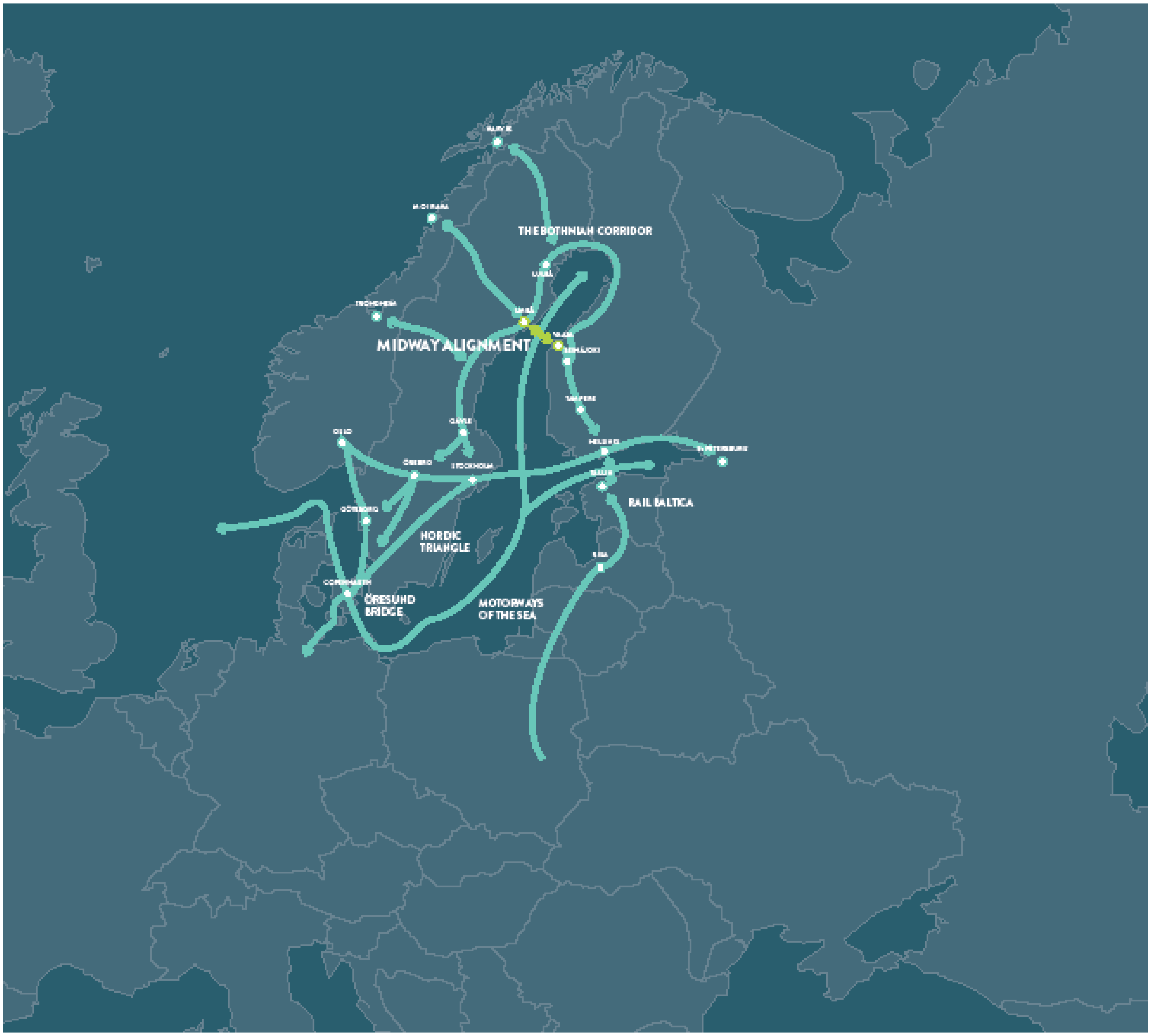
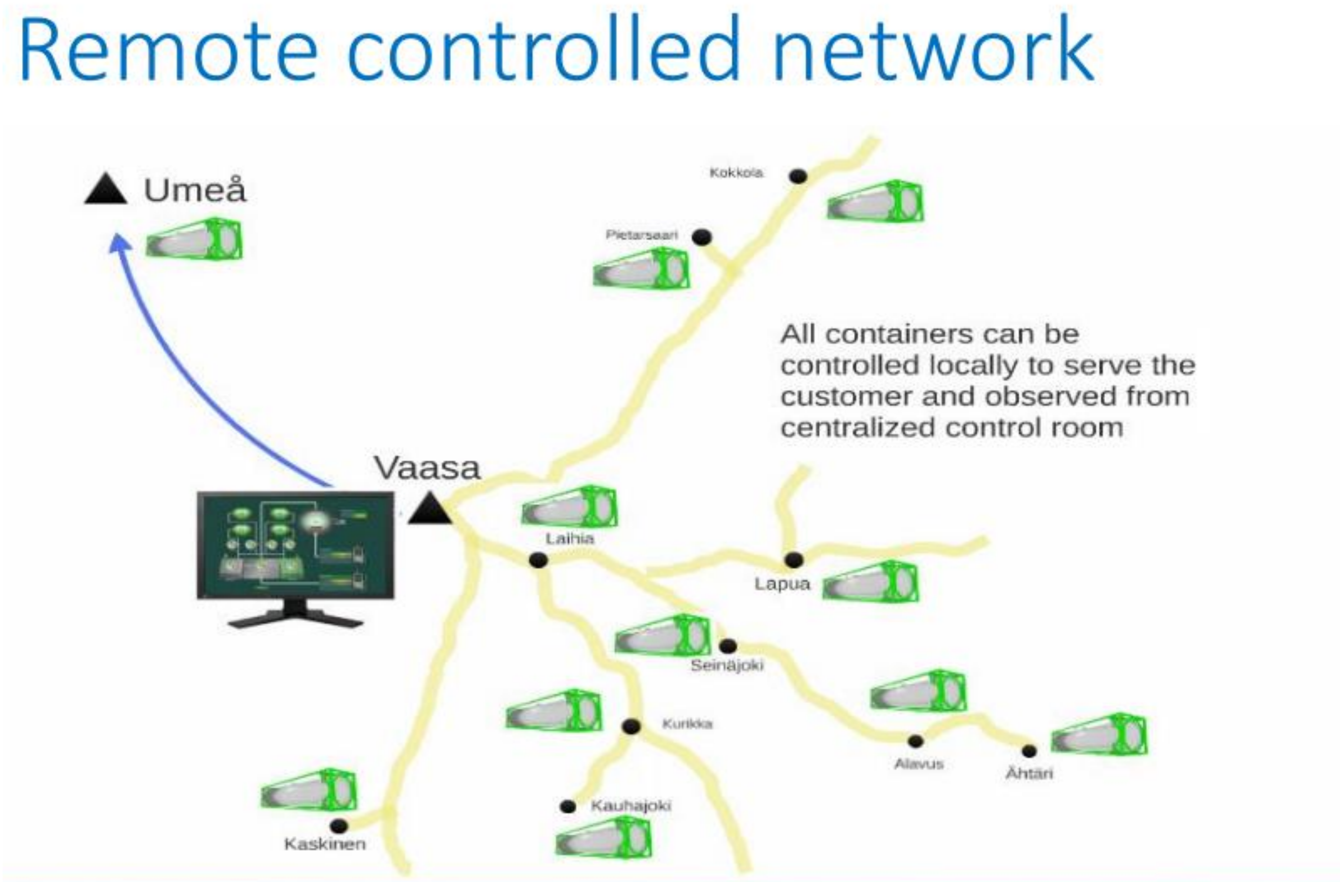
Appendix 2: Map showing the Midway Alignment of the Bothnian Corridor



Source: http://midwayalignment.eu/

Appendix 3: Remote controlled Gas Distribution Network



Source: Vaasa LNG Presentation

Appendix 4: Table of values for the Vaasa Region biogas production in Nm^3 1994-2016 [a] [47]

Vaasa Region Production 1994-2016 in Nm^3						
Year	**Stormossen AD**	**Stormossen Landfill**	**Laihia Biogas Plant**	**Sarlin Landfill**	**Jeppo Biogas Plant**	**Total Regional Production+**
1994	480920					480920
1995	801760					801760
1996	1410100					1410100
1997	1245000					1245000
1998	1470000					1470000
1999	1000000					1000000
2000	1300000					1300000
2001	1427000					1427000
2002	920000					920000
2003	1031000		0			1031000
2004	1400000		66000	0		1466000
2005	1335000		90000	1100000		1425000
2006	1400000		100000	800000		1500000
2007	1996000		156000	800000		2152000
2008	2282000		163000	600000		2445000
2009	2237000	0	194000	600000		2431000
2010	2228000	192000	183000	700000		2411000
2011	2370000	161000	159000	500000		2529000
2012	2370000	161000	173000	600000		2543000
2013	1730000	77000	144000	700000	0	1874000
2014	2125000	32000	210000	700000	1974000	4309000
2015	1507000	33000	210000	370000	3180000	4897000
2016					3900000	3900000
2017						

a: Raw data

Appendix 5: Table of values for Vaasa Region biogas production 1994-2016 in MWh equivalent[b]

Vaasa Region Production 1994-2016 (MWh Equivalent)						
Year	**Stormossen AD**	**Stormossen Landfill**	**Laihia Biogas Plant**	**Sarlin Landfill**	**Jeppo Biogas Plant**	**Total Vaasa Regional Production+**
1994	3174					3174
1995	5292					5292
1996	9307					9307
1997	8217					8217
1998	9702					9702
1999	6600					6600
2000	8580					8580
2001	9418					9418
2002	6072					6072
2003	6805		0			6805
2004	9240		436	0		9676
2005	8811		594	4840		9405
2006	9240		660	3520		9900
2007	13174		1030	3520		14203
2008	15061		1076	2640		16137
2009	14764	0	1280	2640		16045
2010	14705	845	1208	3080		15913
2011	15642	708	1049	2200		16691
2012	15642	708	1142	2640		16784
2013	11418	339	950	3080	0	12368
2014	14025	141	1386	3080	13028	28439
2015	9946	145	1386	1628	20988	32320
2016					25740	25740
2017						

b: Calculated data

Appendix 6: Comparison between Wärtsilä Gas Engine Requirements and Stormossen Ltd Biogas Quality [48]

Property	**Unit**	**Limit**	**Stormossen Ltd Biogas lab-analyzed Composition**	**Stormossen Ltd Biogas measured Composition**
Lower Heating Value (LHV_v), min	MJ/Nm^3	+	20.29[a,b]	20.1[a,b]
Methane number, min		+	140[b]	140.5[b]
Methane (CH_4) content, min	%v/v	70	59.73	60.09
Hydrogen Sulfide (H_2S) content, max	% v/v	0.05	0.02	-
Hydrogen (H_2) content, max	% v/v	3	-	-
Water & H_2 condensate before engine, max	% v/v	Not Allowed	-	-
Ammonium content, max	mg/Nm^3	25	<0.20	-
Chlorine+ Fluoride content, max	mg/Nm^3	50	<3.34	-
Particles/ solids size in engine inlet, max	µm	5	-	-
Gas Inlet temperature	°C	0-60	-	6

a: Calculated using online calculator

b: Converted data based on the biogas density of $1.53G/m^3$

+: No clarified Limits

-: Not Determined

Appendix 7: Vaasa Region Gas Consumption by Individual Companies 1994-2016 in Nm^{3} ^{a} [47]

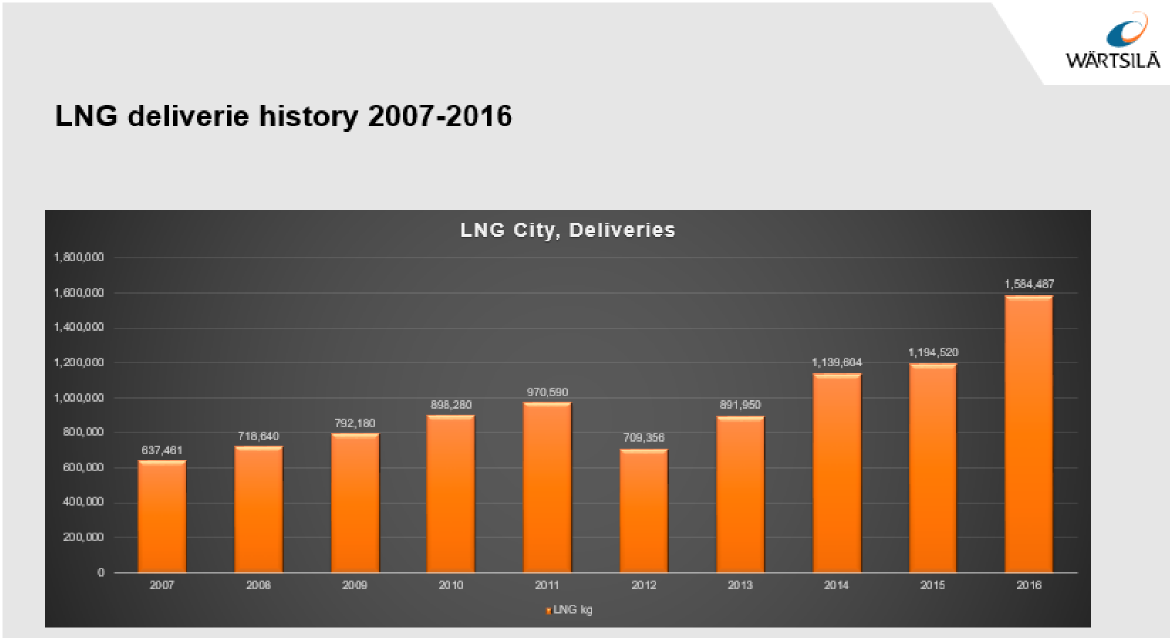
Vaasa Region Gas consumption in Nm^3 1994-2016							
Year	**Wärtsilä Deliveries+**	**Stormossen AD**	**Stormossen landfill**	**Laihia Biogas Ltd**	**Sarlin Landfill**	**Jeppo Biogas Ltd**	**Regional Total Consumption**
1994	+	217727					-
1995	+	250151					-
1996	+	462000					-
1997	+	416000					-
1998	+	369000					-
1999	+	495000					-
2000	+	1038000					-
2001	+	1472000					-
2002	+	920000					-
2003	+	1031000		0			-
2004	+	1163000		22000			-
2005	+	1191000		90000			-
2006	+	1199000		100000			-
2007	+	1362000		40000	0		-
2008	+	1596000		43000	600000		-
2009	+	1430000	0	47000	600000		-
2010	+	1918000	192000	83000	700000		-
2011	+	1800000	161000	72000	500000		-
2012	+	1800000	161000	47000	600000		-
2013	+	1166000	77000	47000	700000	0	-
2014	+	1769000	32000	47000	700000	1842000	-
2015	+	1465000	33000	47000	370000	2960000	-
2016	+						-
2017	+						-

\+ Values in kg and shown in Appendix

\- Unable to determine total consumption Nm^3 due to differences in methane content of the biogas from the reactors and landfill.

a: Raw data

Appendix 8 Wärtsilä LNG Deliveries 2007-2016 (kg)



Source [Wärtsilä Personnel]

Appendix 9: Vaasa Region Consumption 1994-2016 (MWh)[b]

Vaasa Region Gas Consumption 1994-2016 (MWh Equivalent)							
Year	**Wärtsilä Deliveries**	**Stormossen AD**	**Stormossen Landfill**	**Laihia AD**	**Sarlin Landfill**	**Jeppo Biogas Ltd**	**Total Regional Consumption**
1994		1437					1437
1995		1651					1651
1996		3049					3049
1997		2746					2746
1998		2435					2435
1999		3267					3267
2000		6851					6851
2001		9715					9715
2002		6072					6072
2003		6805		0			6805
2004		7676		145			7821
2005		7861		594			8455
2006	0	7913		660			8573
2007	9209	8989		264	0		18463
2008	10353	10534		284	2640		23811
2009	11445	9438	0	310	2640		23833
2010	12977	12659	845	548	3080		30109
2011	14022	11880	708	475	2200		29286
2012	10248	11880	708	310	2640		25787
2013	12886	7696	339	310	3080	0	24311
2014	16464	11675	141	310	3080	12157.2	43827
2015	17252	9669	145	310	1628	19536	48540
2016	22891						22891
2017							

b: Calculated data