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VEBIC, Tekniikan ja innovaatiojohtamisen yksikkö, Markkinoinnin ja viestinnän yksikkö

Biogas Utilization Opportunities in Ostrobothnia Region (BUOOR)

Biokaasun hyödyntämismahdollisuudet Pohjanmaalla

Current State Analysis and interview analysis

Nykytila-analyysi ja haastatteluanalyysi

August 2021

Regional Council of Ostrobothnia

Vipuvoimaa EU:lta 2014–2020

European Union
European Regional Development Fund

Acknowledgements

This report is prepared as part of Biogas Utilization Opportunities in Ostrobothnia Region project by the University of Vaasa. The work has been co-funded by the European Regional Development Fund (ERDF), the Regional Council of Ostrobothnia, Wärtsilä Finland Oy, Westenergy Oy Ab, Ab Stormossen Oy, and Wasaline/NLC Ferry Ab Oy.

Regional Council of Ostrobothnia

Vipuvoimaa EU:lta 2014–2020

European Union
European Regional Development Fund

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Abstract

Due to the current state of climate change we live in, the energy sector is developing itself to decrease its reliance on non-renewable energy sources. As a renewable source of energy, biogas has shown to hold a potential for growth in production and use in the future. Consequently, investigating the current state as a basis to develop the future work of the biogas sector is actual and relevant. We argue that gathering knowledge of and promoting collaboration are very relevant at this time where energy coupling is considered the way in the future.

This report aims to present the current state of the biogas sector through literature and interview findings. The first part focuses on analyzing the current state of the biogas business sector through a literature review and analyzing existing examples. The current state analysis begins with discussing the biogas sector as a whole. It is followed by a presentation of the sector at the EU level, including key numbers and relationships to the transport sector, circular economy, agriculture and local economy. After that the Finnish biogas industry is presented, encompassing legislation, sector goals and actors. Then, the role of biogas in Ostrobothnia to the area and key actors involved are introduced. Finally, biogas ecosystem examples are covered at the farm, industrial and municipal levels as well as distribution and sales networks.

The second part analysis the market environment of the actors involved in this particular network. The focus is on the needs, value creation, critical factors, differences and common characteristics of biogas market actors.

Tiivistelmä

Käynnissä olevan ilmastomuutoksen myötä, energiasektori kehittyy ja muuttuu kun riippuvuussuhdetta uusiutumattomiin energialähteisiin pyritään vähentämään. Biokaasu on uusiutuva energianlähde jonka arvioidaan olevan kasvupotentiaalia sen tuotannon ja käytön alueilla tulevaisuudessa. Tämän vuoksi, nykytila-analyysi rakentaminen kehittääkseen biokaasualan tulevaa työtä on relevanttia ja ajankohtaista. Me arvioimme myös, että tiedonkeruu ja yhteistyöhön kannustaminen ovat hyvin olennaisia tällä hetkellä sillä sektorikytkentä sanotaan olevan tulevaisuutta.

Nykytila-analyysin tavoitteena on arvioida biokaasualan nykytilaa kirjallisuuskatsauksen ja haastattelulöydösten perusteella. Ensimmäinen osa biokaasualan nykyisiä toimintatapoja kirjallisuuskatsauksen ja olemassa olevien esimerkkien avulla. Nykytila-analyysi alkaa esittelemällä biokaasumarkkinaa yleisellä tasolla. Tämän jälkeen alaa tarkastellaan EU-tasolla käyden läpi keskeisiä numeroita ja suhteita kuljetussektorille, kiertotalouteen, maatalouteen and paikalliseen talouteen. Seuraavaksi Suomen biokaasumarkkinaa esitellään lakien, tavoitteiden ja toimijoiden kautta. Tämän jälkeen Pohjanmaan biokaasutilannetta tarkastellaan sekä sen toimijoita. Lopuksi käydään esimerkkejä biokaasuverkostoista maatila-, teollisuus- ja kunnallistasoilla sekä jakelu- ja myyntiverkostojen kautta.

Toinen osio analysoi samassa verkostossa olevien toimijoiden markkinatilannetta. Analyysi keskittyy toimijoiden tarpeisiin, arvon luontiin, kriittisiin tekijöihin, eroihin ja samankaltaisuuksiin.

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Abbreviations

BUOOR Biogas Utilization Opportunities in Ostrobothnia Region

CBG Compressed biogas

LNG Liquified natural gas

LBG Liquified biogas

GHG Greenhouse Gas

TWh Terawatt hour

Glossary

Feedstock - Feedstock refers to the raw material that is required for some industrial process.

Digestate - Digestate is the remaining after the anaerobic digestion of a biodegradable feedstock.

Green deal – The European Green Deal is an EU level response to challenges associated with climate change and environmental degradation. It seeks to ensure modernization, resource-efficiency and competitivity of the economy by aiming to have: no net emissions of greenhouse gases by 2050, economic growth decoupled from resource use and no person and no place left behind.

Biogas solutions – In this report biogas solutions refers to the various products made of biogas.

Tank-to-wheel (TTW) - describes the use of fuel in the vehicle and emissions during driving.

Well-to-wheel (WTW) – includes the production of the energy source (petrol, diesel, electricity, natural gas), fuel supply (transport to the charging point or fuel pump), its use and emissions of each.

1. The biogas sector in a nutshell

Within the current environmental and political context, biogas solutions play an important role in reducing the total amount of greenhouse gas emissions. Biogas solutions commonly involve cross-sectoral cooperation, where waste streams and wastewater flows are transformed into valuable products such as renewable energy and biofertilizer (Lindfors et al. 2019). Systems for producing and using biogas, biomethane and digestate, support waste management and longevity of the nutrient cycle. Biogas and liquefied biogas replace other energy resources used in transportation, industry, heating and electricity production (Hagman and Eklund 2016, Gustavsson and Anderberg 2021). Biogas related activities also create new opportunities for the agricultural sector as farms can provide their organic waste to be used in producing biogas and the remaining nutrients from the production process can be re-used in the fields (Mutikainen et al. 2016).

Altogether, it has been found that biogas solutions can contribute to many of the UN sustainability goals (Gustavsson and Anderberg 2021). Biogas solutions can also strengthen the local economy when biogas is produced from local feedstock, which is processed, and the end products are used nearby. Local production and use reduce logistical costs and emissions as well as contributes to the development of local markets. Simultaneously, the local market development supports the export of know-how and customer solutions as well as the adoption of new technology. The way of working between players, technologies and skills can be exported to other similar regions. (IEA 2020, EBA 2019)

Growth areas of the biogas sector are the use of gas in transportation, use of gas for energy and industry, greater use of waste and the longevity of the nutrient cycle, and utilizing farms as additional biogas producers (Mutikainen et al. 2016).

On a general level the growth of the biogas sector can be supported through changes in statutes and support mechanisms, national strategies and policies, communication and influence, collaboration and new skills (Mutikainen et al.2016). The sector is suffering from the so-called egg-chicken problem where, as an example, considerable investments including plants and filling stations are needed before users invest in biogas vehicles. Investors are thus required to take considerable risk in a context of great uncertainty. (Tolpo 2020)

1.1. The biogas sector in the European Union (EU)

The EU has as its objective to achieve carbon neutrality by 2050 (EBA et al. 2020). The current status varies in each EU Member State. The Renewable Energy Directive (RED II) states that 32% of the energy produced should come from renewable sources by 2030. Renewable energy is the collective name for energy, that is produced using the earth's natural resources, like sunlight, wind, water resources (rivers, tides and waves), heat from the earth's surface, or biomass. The process, by which these renewable resources are converted into energy, emits no net greenhouse gases, which is why renewable energy is also referred to as 'clean energy'. (European Commission 2020)

The European Green Deal pushes the energy sector to develop its efficiency and interconnectedness to achieve net-zero greenhouse gas emissions. It also provides an action plan to boost the efficient use of resources by moving to a clean, circular economy, restore biodiversity and cut pollution (European Commission 2021). The EU focuses primarily on electrification but renewable gas will be needed in areas where it does not suffice, including industry and transportation. In addition, although the potential of hydrogen is valued, biomethane will maintain an important role in the energy sector of the EU (EBA 2020). In the EU in 2025, it is estimated there will be 13 million vehicles that release low and zero CO2 emissions. There will be 1 filling station per 100 full electricity or biogas cars according to the European directive on the deployment of the alternative fuels' infrastructure. (Knuts et al. 2020)

The most common sources for biogas are crops and animal manure feedstock and upgrading biogas to biomethane presents potential as a major source of future growth (IEA 2020). Biogas has been a "hot topic" in the EU because of the indirect land-use change (ILUC). ILUC refers to modifying land to use its feedstock in biofuel production e.g. increasing demand for biofuels leading to agricultural expansion and the conversion of natural lands. The RED II defines high ILUC biofuels as those produced from feedstocks for which a significant expansion onto high carbon stock land is observed. Low ILUC biofuels are defined as those produced from feedstocks that avoid displacement of food and feed crops through improved agricultural practices or the cultivation of areas not previously used for crop production (ICCT 2018). Thus, high ILUC biofuels such as palm and soybean oils, influences food and feed supply and can even negate emission savings resulting from the use of biofuels (European Commission 2019).

The RED II agreement sets a target of 14% renewables in transport by 2030 – part of an overall renewable energy target of 32% (European Commission 2019b). Under the new regime, that began in 2020, EU member states no longer have to meet a certain percentage of their renewable energy obligations through the use of food-based biofuel (high ILUC). Member states may continue using food-based biofuels to meet their renewable transport targets but their contribution will be limited to no more than the amount of biofuels they were using in 2020 – with a maximum of 7%. The rest will need to be met with electricity or advanced biofuels (low ILUC) that are not made from food crops. Additional restrictions will be put on palm and soybean oil biofuels, which can still be used but cannot be at a level above each country's 2019 consumption levels. This should cause the use of palm oil to gradually decline from 2023 onwards until it reaches 0% in 2030 (Euractiv 2018). Figure 1 shows the percentage of EU road and rail energy consumption according to 14 % renewables in transport by 2030 target.

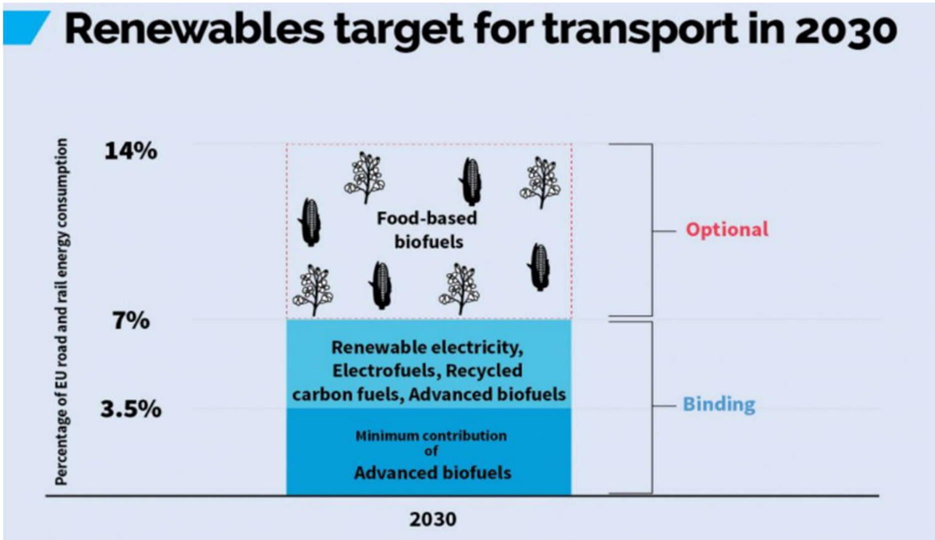

Figure 1 EU Target of 14% renewables in transport by 2030 (Euractiv 2018)

The RED II defines advanced biofuels as biofuels that are produced from feedstocks such as algae cultivated on land in ponds or photobioreactors, biomass fraction of mixed municipal and industrial waste, bio-waste from private households and animal manure and sewage sludge (see part A of Annex IX in RED II). It is important to note that the feedstock, and not the process used to produce the advanced biofuels, determine whether the biofuels are considered to be "advanced". (EAFO 2019)

The current EU bioenergy policies have also been criticized for leading to an increased wood harvest (Harvey 2020, Raven et al. 2021) because it classifies forest biomass as zero carbon in the RED II. This refers to the regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry (LULUCF) and its current forest reference levels (European Comission 2021). As member states have met their 2020 emission targets, the increased need for renewable power has near doubled the amount of energy derived from solid biomass (Euractiv 2021). Using forest biomass for fuel might be a reason behind the rapid increase of harvesting observed in the Nordic countries from 2016 onwards. The increase in the rate of forest harvest is the result of the recent expansion of wood markets, as suggested by econometric indicators on forestry, wood-based bioenergy and international trade. If such a high rate of forest harvest continues, the post-2020 EU vision of forest-based climate mitigation may be hampered, and the additional carbon losses from forests would require extra emission reductions in other sectors to reach climate neutrality by 2050. (Ceccherini et al. 2020)

1.1.1.EU biogas sector in numbers

The amount of biogas produced in the EU was 193 terawatt-hours (TWh) in 2019 and it has been estimated to grow into 370-467 TWh by 2030 and 1008-1020 TWh by 2050 as shown in figure 2. (EBA 2020)

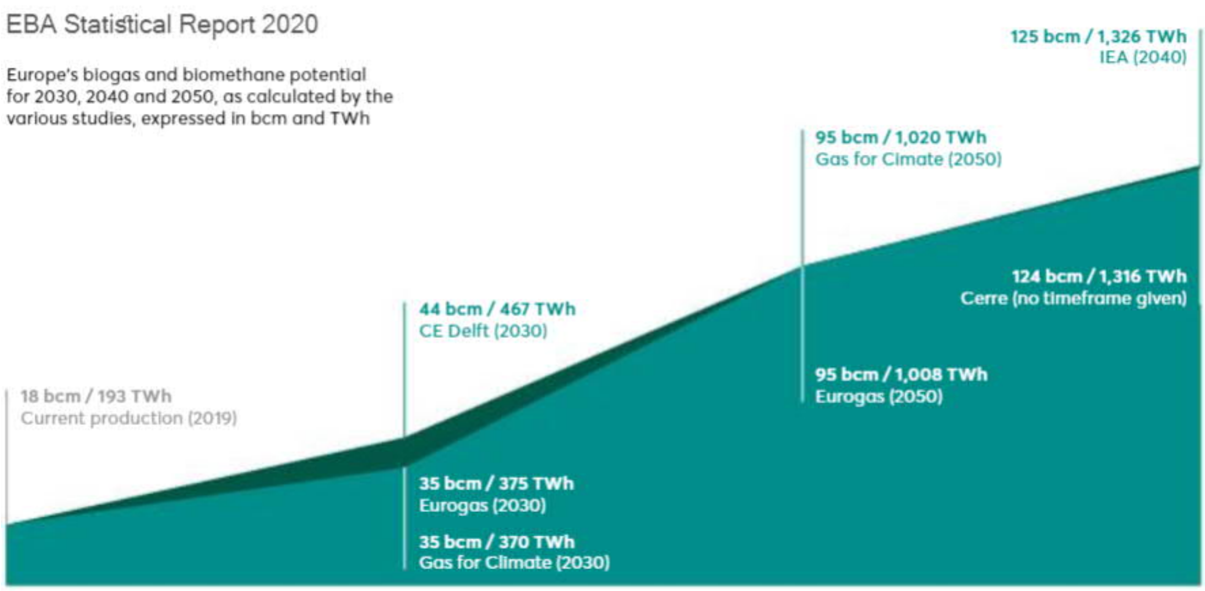

Figure 2 Estimated amount of biogas in the future (EBA 2020).

The growth in the number of biogas plants has slowed to under 3% annually in five years, 2015-2019, with 18 943 plants in the end of 2019 as shown in figure 3. (EBA 2020)

Figure 3 Number of biogas plants in Europe (EBA 2020)

In contrast, within the same period, the amount of biomethane plants in Europe has grown around 15% annually with 725 plants at the end of 2019 as shown in figure 4 (EBA 2020).

Figure 4 Number of biomethane plants in Europe (EBA 2020)

Biomethane plants are most common in Germany (232), France (131), UK (80) and Sweden (70) (GIE 2020a). There exists a vast network of gas pipelines and other storage facilities across Europe. The network is less developed in northern Europe and Serbia. In northern Europe, the network is almost only present by the sea (Sweden and Norway) and in Southern Finland. (GIE 2020b)

In Europe, there is a shift from biogas to biomethane production. Also, the feedstock used is changing from dedicated energy crops to waste and residue feedstocks that have increased in amount, from 40% in 2012 to 65% in 2019. (Gas for Climate & Guidehouse 2020)

1.1.2. Biogas in the EU transport sector

There is increasing urgency to decarbonize different sectors, including transport. The CO2 limits of passenger cars and vans, the Alternative Fuels Infrastructure Directive, the Fuel Quality Directive and the Renewable Energy Directive are being adjusted to support the fulfillment of the EU Green Deal targets. (EBA 2020)

The use of electric cars is currently highly favored at the EU level due to the measurement approach being tank-to wheel rather than well-to-wheels. This means that measurements of emissions are taken through the exhaust pipe rather than considering the life cycle emissions (TEM 2020). The approach can reduce the comparability of electric and gas vehicles although it could be relevant. Such a case would be for example heavy-duty transport which is not able to easily electrify due to its need for large power engines. (EBA et al. 2020)

Heavy-duty and maritime transportation sectors face challenges in reducing the amount of greenhouse gas (GHG) emissions. The possibilities available to transition towards carbon neutral transportation should be simultaneously affordable and available. Liquefied Natural Gas (LNG) provides a way to cut GHG emissions and increase the use of liquefied biogas (LBG) as well. (EBA 2020)

The advantages of LBG are its availability, scalability and competitivity. Its adoption would help reduce GHG emissions in transport by 90% both in shipping and heavy-duty transport. This would mean moving from 31 TWh of LBG production to 380 TWh in 2030. 50% of vessels should be LNG fueled or be able to move to LNG use. Their 20% usage of LBG would reduce GHG emissions up to 34%. In heavy-duty transport the amount of LNG vehicles is now 12000 and is estimated to be 280000 in 2030. Using 10% of European LBG would mean a 40% use of LBG, which would reduce 55% of CO_2 emissions. In heavy-duty transport, 80% LBG use is estimated to lead to carbon neutrality. The EU has already the feedstock needed and pre-existing gas infrastructure. LBG is competitive when compared to other zero-carbon fuels. (EBA et al. 2020)

1.1.3. Circular economy in the EU

The circular economy and the Green Deal cover the areas of waste prevention, waste management and recycling; food sustainability; pollution prevention; protection of diversity; carbon farming and digitalization (EBA 2020).

The Fertilizing Product Regulation that will be carried out by Member States in April 2022 at the latest allows the recycling of separately collected bio-waste to make organic fertilizing products. This would mean that organic products will replace fossil-based chemicals and that the use of digestate born in the biogas production process could develop further (EBA 2020).

Bio-waste, mainly food and garden waste, is a key waste stream with a high potential for contributing to a more circular economy, delivering valuable soil-improving material and fertilizer as well as biogas. Bio-waste accounts for more than 34 % of the municipal solid waste generated, amounting to 86 million tonnes in 2017 in the EU-28 (28 EU Member States for the period 2013-2020). Consequently, bio-waste recycling has a crucial role in meeting the EU target to recycle 65 % of municipal waste by 2035 (van der Linden et al. 2020). Sustainable biogas systems consist of multiple processes: waste treatment, environment protection, conversion of material from low- to higher-value, electricity, heat and biofuel production. Biogas and anaerobic digestion systems are dispatchable, meaning supply can be adjusted based on the demand and as such can also be used in providing renewable electricity irregularly. (Fagerström et al. 2018)

There are several fundamental issues that need to be addressed for biogas production to become truly circular and environmentally-friendly: Firstly, what comes in the biogas plant, as that affects if digestates qualify to be used as fertilizer. Another aspect relates to location as connection costs can be very expensive. Thirdly, there are challenges relates to the process itself and the potential leakage of methane, a greenhouse gas that is about 70-80 times more potent than CO_2. And finally, the size of biogas plants matters, the infrastructure cannot be too small to have economies of scale but you cannot have super-large infrastructure either. (Euractiv 2019)

1.1.4. Biogas impacts on the EU agriculture and local economies

The agricultural sector's contribution to the total GHG emissions of the EU is nearly 10%. By 2030, the Union's emissions should be cut by 40% (30% in non-ETS sectors like agriculture), the share of renewable energy should be at least 32%. Production of renewable energy on farms can help to reduce and avoid emissions, improve the security of supply, bring extra income for farmers and lead even to energy self-sufficiency. (EBA 2021)

The Member States will be granted more responsibility regarding Common Agricultural Policy (CAP) related investment and policy plans. In other words, Member States will manage the design, implementation and evaluation of CAP and present their plans by the end of 2021. The plans should state how they plan to meet the CAP objectives and targets of the Farm to Fork strategy (EBA 2020). CAP will increase the capacity of anaerobic digestion, which supports biogas deployment, production of bio-fertilisers, protein feed, bioenergy and bio-chemicals. The Farm to Fork strategy recognizes biorefineries' role in transitioning to a climate-neutral economy. (EBA 2020b)

The biogas solutions approach that has the most sustainability potential is "the circular economy approach rooted at the local level" (Euractiv 2019). Biogas plays a role in the local economy as it requires collaboration between multiple players, makes local energy sources available and provides new business opportunities. The sector offers local opportunities and reduces the demand of energy transported from outside. Collaboration between players can provide new sources of income and greater valorization of local feedstock and end-products of biogas production. The players can benefit from locally produced heat, electricity, fuel and fertilizer. The upgrade of biogas to biomethane is increasingly attractive as it can be used interchangeably with natural gas. (IEA 2020; EBA 2019)

2. The biogas sector in Finland

Opportunities to the development of the Finnish biogas sector include carbon neutrality goals, the development needs of nutrient recycling, security of supply and regional vibrancy, transport and agriculture emission reduction goals (Virolainen-Hynnä 2021).

The actors of the Finnish biogas sector are generally eager to develop it further. At the EU level, Finland is categorized as a moderately developed biogas market. There is an already somewhat developed production and distribution infrastructure as well as group of users (Kampman et al. 2017). Multiple national players provide construction and development services of biogas plants. There is some distribution infrastructure including a pipe network in Southern Finland (Gasgrid 2021) and filling stations mainly in the South and Western Finland (Kaasuautoilijat 2021). One interviewee from the Biogas Utilization Opportunities in Ostrobothnia Region (BUOOR) project stated that CBG use by biogas private vehicles is competitive cost-wise. They state that, private biogas vehicles and CBG fuel are fairly priced. The price of biogas private vehicles is said to be equal to others and cheaper in use. It is added that private vehicles can be converted to biogas vehicles easily and for a reasonable price. (Mutikainen et al. 2016)

Challenges include the low profitability of biogas production as the market is still under development. This influences decisions made regarding how and if energy production and nutrient management processes should be carried and their extent. The cheap price of fossil fuel is also a factor slowing down development. (Virolainen-Hynnä 2021)

At the national level, the largest issues are the lack of a common infrastructure and an unreliable amount of supply and demand. Currently, the amount of biogas produced remains small compared to its potential (Mutikainen et al. 2016). Building long-term plans appear to be challenging due to the high investment cost and the level of riskiness due to a lack of demand. On the supply side, clients perceive the provision of biogas unreliable. Clients are waiting for more stability in the market (political and strategic) to start adopting biogas. The market is fragmented and there is quite little communication between stakeholders (EU 2020; BUOOR Interviews 2021).

Solutions include policy instruments focused on biogas and nutrient recycling market development. Profitability can be improved through aids, incentives and legislative means. The sector could benefit from predictability for players to be more eager to invest (Virolainen-Hynnä 2021).

2.1. National legislation

At the national level, there is a general eagerness to reduce the amount of emissions. The goal of emission reduction in Finland is set to 51% renewable energy by 2030. In Finland, the most important renewable energy sources are bioenergy, especially wood and wood-based fuels and hydropower. In addition, the use of wind power has been increasing and it accounts for around 10% of annual electricity production. Also, geothermal heat and solar power energy production are increasing. In 2019, renewable energy sources accounted for almost 38% of total consumption and 43% of end consumption compared to 1990 when they represented only 18% of total consumption. The growth pace has increased in the 2010s. The long-term national strategy to reduce GHG emíssions focuses on growth in bioenergy, wind power and geothermal heat pump use. After 2035 the list will also include solar power. The RED II directive also requires that 14% of the energy used in transportation will be renewable by 2030. (Motiva 2021)

The national waste legislation will be renewed in 2021 in response to the goals set to Member States by the EU. Member states should recycle at least 55% by 2025, 60% by 2030 and 65% by 2035. The law will require the collection of biowaste from municipalities with over 10 000 habitants from the beginning of 2024, or the use of compost. (Molok 2021)

According to the national Roadmap for Carbon-free traffic, there is an aim to halve GHG emissions by 2030 and achieve zero GHG emissions in the transportation sector by 2045. In 2030 34% of the fuel used should be from a renewable source, including biogas. The Roadmap notes that biogas and synthetic gases have an important role in reducing road transportation GHG emissions over the mid and long term. The plan includes the following: to integrate biogas and synthetic fuels to the obligation to supply (jakeluvelvoite) and simultaneously ensure that the competitivity of biogas price remain sufficient; to offer support to the production of biofuels, biogas and synthetic fuels during the 2020th century; to support the production, use and infrastructure development through policies; to increase biogas production and vehicles amount to 2,5 TWh in 2030; to ensure that biogas vehicles are considered in the EU law setting limits to GHG emissions of new cars; to support heavy-duty biogas vehicle purchase through an aid also after 2021; continue the vehicle conversion to gas aid; renewing vehicles to lower or zero emission by providing incentives to technologies, fuels and their use; to consider emission trading as a possible action. In addition, a special tax (free of the CO_2-emission component) will be applied. (Liikenne- ja viestintäministeriö 2021)

Public procurement plays a role in the development of the biogas sector, for example through vehicle choices. The EU's Clean Vehicles Directive is planned to be implemented with a new law that aims to more eco-friendly public procurement of vehicles and transport services. The law consists of new requirements. Between 2021 to 2025 38, 5% of vans and private vehicles should produce a maximum of 50 CO_2 g/km and between 2026-2030 38,5% of vans and private vehicles should produce 0 CO_2 g/km. In the case of heavy-duty vehicles, 9% in 2021-2025 and 15% in 2026-2030 should be using alternative fuels biofuel, electricity, gas or hydrogen. The local buses are included in the expectation related to alternative fuels. However, the amount should be 41% in 2021-2025 and 59% in 2026-2030. In addition, 20,5% should be fully electric buses from 2021-2025 and 29,5% in 2026-2030. The directive does not recognize the potential of the biogas vehicles largely. The emission limits should be in line with the directive only nationally and can therefore be regionally varying. (Valtioneuvosto 2021)

2.2. National biogas sector goal: 4 TWh in 2030

The national biogas association Finnish Biocycle and Biogas Association has collaborated with five other associations The Bioenergy Association of Finland, The Central Union of Agricultural Producers and Forest Owners (MTK), Finnish Gas Association, Suomen Kiertovoima ry and Finnish Clean Energy Association in setting the biogas production goal of 4TWh in 2030. Table 1 shows different possible scenarios together with their influence on the growth of the amount of biogas and adopted measures. Overall, the growth of the biogas sector relies heavily on farms. (Virolainen-Hynnä 2021)

Table 1 Scenarios of growth of Finnish biogas sector by 2030 (Virolainen-Hynnä 2021)

	Current state	No change	The government policies planned in 2019 are implemented	Long-term investment – The measures of Clean Baltic sea and roadmap for fossil-free transport
Amount	1 TWh	+ 0,2TWh	+0,7 TWh	+3,0 TWh
Policy measures	energy aid, nutrient cycle investment aid and farms raised investment aid	energy aid, nutrient cycle investment aid and farms raised investment aid	energy aid, nutrient cycle investment aid, farms raised investment aid, raised countryside business investment aid and nutrient cycle compensation	energy aid, nutrient cycle investment aid, farms raised investment aid, raised countryside business investment aid nutrient cycle compensation, additional investments of the sustainable growth program
Cars	12 357	24 357	65 357	130 357
Vans	928	228	998	13928
Heavy Duty Trucks	298	1998	3798	6298
CNG filling stations	55	70	100	247
LNG filling stations	9	14	42	50
GHG emission reduction tCO2/a (transport)	57 000	127 000	451 000	952 000

To achieve the goal of 4 TWh in 2030 action should be taking place in many areas as shown in table 2. These include taxation, vehicles, biomethane competitivity, transport emission reduction, well-functioning permit processing, new technologies & feedstock, nutrients recycling, nutrient cycle compensation, nutrient cycle investment aid, bio-waste, availability and distribution obligation.

Table 2 Measures to achieve the goal of 4 TWh in Finland (Fredriksson et al. 2020)

Taxation	The energy taxation renewal should ensure that biogas maintains its competitivity in relation to fossil fuels. The exemption of tax has acted as a financial incentive and supported the decrease of GHG.
Vehicles	The vehicle emission measurement of biogas should be developed so that the overall emissions are counted for in the EU and that these are taken in account in vehicle taxation in Finland.
Biomethane competitivity	The competitivity of Finnish biomethane should be ensured by taking an active stand in the definition of biomethane and other renewable gases guarantee of origin (GO) system.
Transport emission reduction	Transport emission reduction should be achieved by combining low emission options.
Well-functioning permit processing	A well-functioning permit processing should be expanded to other biogas use areas than electricity.
New technologies & feedstock	Finland should ensure its continuous competitivity in renewable and sustainable synthetic gases development by investing in R&D and maintaining the national gas ecosystem alive.
Nutrients recycling	Nutrient recycling should be granted fixed term funding from the innovation and investment support set to be used in the development of nutrient recycling and products.
Nutrient cycle compensation	Nutrient cycle compensation should be brought into use to increase the use side stream.
Nutrient cycle investment aid	Nutrient cycle investment aid should be applied to biogas and manure processing investment aid.
Bio-waste	The amount of biowaste (including households') used in biogas production should

	increase while the amount of biowaste should decrease.
Availability	Boosting availability of biomethane and improving its price competitiveness to ensure interest from industry and transportation sector.
Extending the biofuel distribution obligation to biomethane	The extension of biomethane to the biofuel distribution obligation should be thoroughly investigated prior to decision-making.

2.3. Actors in the Finnish biogas sector

Actors can be divided into groups according to their roles. Figure 5 shows an example of the different types of biogas-actors in the network and their location within the value chain and wider ecosystem. The actor groups can be identified according to their color. The centrality of the actors within the value chain varies as can be seen from the positioning of the actors along the value chain.

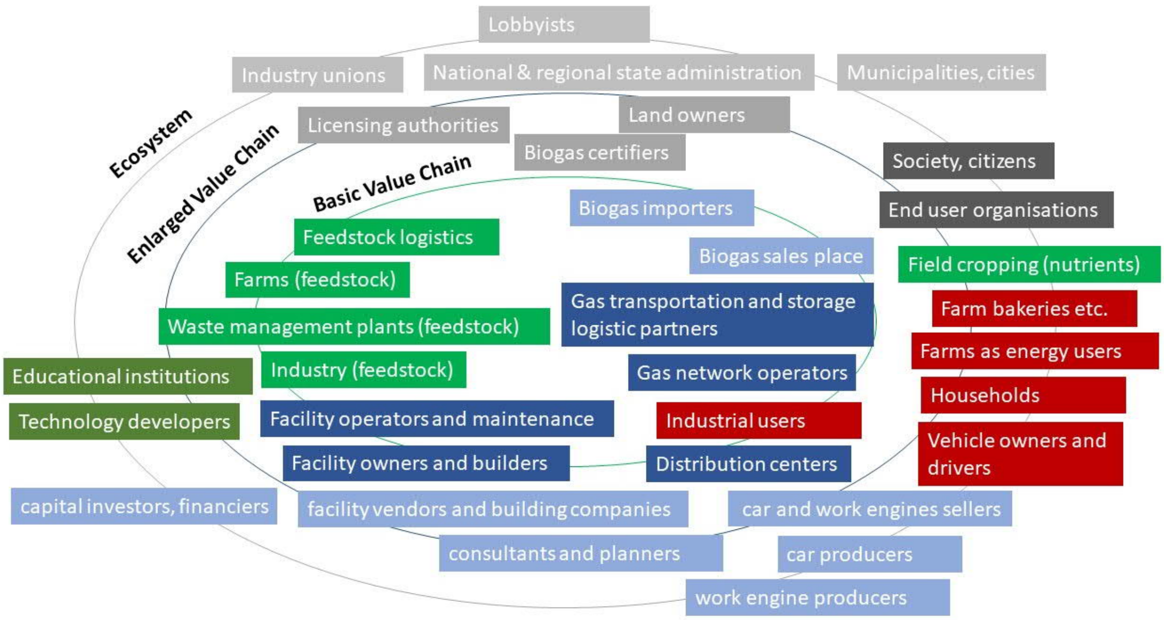

Figure 5 Biogas ecosystem adapted from Mutikainen et al. 2016)

It is argued that the sector could benefit from cooperation between smaller and larger players in the biogas field. Larger players can develop the sector more easily as they have more feedstock available, as well as produce greater volumes and have greater economic capabilities (Virolainen-Hynnä 2021). Table 3 breaks down the different actors according to the level at which they act. To clarify the type of role actors have, table 3 has located the groups of actors of figure 5 into macro, meso and micro levels.

Table 3 Biogas sector stakeholders adapted from (Mutikainen et al. 2016).

Biogas sector actors by levels		
Level	Roles	Actors
Macro	Public authorities, influential parties and regulation makers	Lobbyists, industry unions, nation and regional state administration, municipalities and cities.
		Licensing authorities, land owners, biogas certifiers.
Meso	Primary actors: feedstock producers, collection and transportation companies, biogas producers, distribution network providers	Feedstock logistics, farms, industry, field cropping, waste management
		Gas transportation and storage logistic partners, gas network operators, facility operators and maintenance, facility owners and builders, distribution centers
	Secondary actors	Biogas importers, biogas sales places, facility vendors and building companies, car and work engines sellers, capital investors, financiers, consultants and planners, car producers and work engine producers.
	Tertiary actors	Educational institutions, technology developers
Micro	Early customer and end consumer groups	Society, citizens and end user organizations
		Farms as energy users, households, industrial users, vehicle owners and drivers

The system-level approach to the circular economy divides actors into three level macro, meso and micro levels. At the macro level there are authorities, influential parties and regulation makers. The meso level includes actor networks and symbiosis. The micro level constitutes of the customer and consumer groups. (Vanhamäki et al. 2019). To differentiate the meso level actors were divided into three: primary, secondary and tertiary to distinguish their role in supplying biogas. The meso level primary actors are the ones facilitating the overall production and distribution. Meso level secondary actors offer supporting elements to the primary actors. Meso level tertiary actors perform R&D actions to develop the sector.

Main macro players include the government, the ministries, associations, licensing authorities and biogas certifiers. The government decides the national regulations. Main associations supporting the biogas sector in Finland are the Finnish Biocycle and Biogas Association, The Bioenergy Association of Finland, The Central Union of Agricultural Producers and Forest Owners (MTK), Finnish Gas Association, Suomen Kiertovoima ry and Finnish Clean Energy Association. The Finnish Safety and Chemicals Agency (Tukes) grants licenses for natural gas pipeline or gas filling station construction and for storing natural gas. If the stored amount is 5 tonnes or larger a construction permit has to be granted by Tukes, for quantities below that a notification to Tukes suffices. In addition, an operations supervisor and deputies should be appointed and notified to Tukes before the use of gas can begin. Installation of a gas pipeline or filling station should be performed by operators authorised by Tukes. Inspections tend to be performed by an inspection body. Operation permits are granted by Tukes or an inspection body. (Tukes 2021). For biogas products to be sold as proved renewable, certification is required. Certificates are supplied by Gasgrid Finland Oy (Kaasuautoilijat 2019). Some interviewees of the BUOOR project argued that certificates and obtaining rights takes time that is precious in a market of low profit margin.

Micro actors include end-users of the biogas solutions (Mutikainen et al. 2016). Interviewees from the BUOOR project state potential users of the energy products and processed digestate include industrial customers, heavy-duty traffic, marine traffic, private customers and farms. They argue that their choice to move to biogas reduces their reliance on fossil fuels and increases the use of local fuels whilst reducing GHG emissions. Examples mentioned by few interviewees entail a need for biogas users to also have an alternative fuel in case the flow of biogas is momentarily disturbed. In such cases, natural gas or other energy products may be used. Other interviewees also mention that when used in large amounts gas users tend to prefer LNG or use considerably more LNG than LBG due to better availability and more attractive pricing. LBG is stated to have lower total GHG emissions. Interviewees argue that mixing the two allows access to their qualities.

Meso players are organisations directly or indirectly involved in the actual biogas sector. We have decided to divide them into three groups based on their centrality in the value chain. The primary meso players are feedstock producers, collection and transportation companies, biogas producers, distribution network providers. The secondary players are organisations who sell the gas itself, or products and services which are linked to the production and use of biogas. The tertiary players represent organisations who perform R&D work around the area of biogas.

The macro players won’t be discussed any further in this chapter as they were discussed in the Chapter 1 part more thoroughly. This chapter will continue by discussing meso and micro level actors in the Finnish biogas market.

2.3.1 Meso level - primary biogas actors in Finland:

Feedstock providers

In Finland, the amount of feedstock available is 24 970 600 tons per habitant. The major sources of feedstock are agriculture, sewage sludge, households as well as industrial and commercial organic waste. The largest share of biomass, energy and nutrient cycle potential is available from agriculture. However, this potential is currently underused. Only around 6 % of the manure is processed of which only 1,4% is used in the production of biogas. The amount of sewage sludge is 4,7 million tons a year and 81% of it is used in biogas production. Therefore, it only has small growth potential. (TEM 2020).

The amount of organic waste of households is 0,8 million tons a year, of which around a third, 0,36 million tons are collected. The amount collected should rise to 60% to be in line with the national waste program. (TEM 2020)

The industry has different amounts and types of organic waste with differing use potential. Currently, details of those are not centrally collected and the industry does not hold a large potential for use in biogas production and nutrient cycle. (TEM 2020). Table 4 summarizes the most common feedstock in biogas production and their growth potential in Finland.

Table 4 Most common feedstock in biogas production and their growth potential in Finland (TEM 2020)

Sources of feedstock	Growth potential
Agriculture	Greatest
Households	Second greatest
Industrial & commercial organic waste	Second lowest
Sewage sludge	Lowest

BUOOR interviewees stated that feedstock is either collected by waste management companies or by the feedstock provider themselves. Some added that the logistic costs are paid by the feedstock provider. In addition, it was brought up that feedstock providers have municipal agreements stating to which biogas producer they have to deliver the feedstock such as, in the case of households. One interview highlighted that when this is not the case the logistical partner selects the most cost-effective choice available considering pricing and physical distance to the plant. Another interviewee mentioned the diversity of biogas producers as some biogas producers may accept feedstock free-of-charge while others collect gate-fees to be paid by either the logistical partner or the feedstock provider (BUOOR 2021).

Biogas producers

In Finland, there are currently around 91 biogas facilities (Huttunen et al. 2018). The largest biogas producer Gasum owns 10 biogas plants in Finland. It operates in both natural and biogas sectors in northern Europe (Gasum 2021de). Multiple interviewees mentioned a tendency among actors to collaborate when appropriate for example, through providing feedstock and buying the biogas produced. Relationships like this can lead to interdependencies that can support the continuous flow of feedstock and biogas to customers and make prices attractive to involved parties (BUOOR 2021).

The types of plants are biogas reactor plants, industry wastewater treatment facilities, plants located in farms, municipal solid waste plants and landfill gas recovery plants (Huttunen et al. 2018). The lack of profitability of facilities and potentially the renewable energy sustainability criteria have been limiting a wider production of biogas. Especially the operations of larger plants rely heavily on gate fee revenues. Profitability is largely influenced by the ways biogas is utilized. (TEM 2020). Table 5 summarizes the types and amount of biogas facilities at the end of 2017.

Table 5 The amount of biogas facilities in Finland at the end of 2017 (Huttunen et al. 2018)

Type of facility	Amount
Biogas reactor plants	16
Industry wastewater treatment facilities	4
Plants located in farms	15
Municipal solid waste plants	18
Landfill gas recovery plants	38
Total	91

Plants can be divided into three types according to their size. The large plants are located physically close to feedstock and they handle large amounts of wastes coming from a different set of actors. They can process more than 35 000 tons per annum (t/a) of feedstock. The midsized plants can be owned by one actor or few actors as a shared facility that handles farm biomass and/or gate fee waste. These plants process from 20 000 to 35 000 t/a of feedstock. The smaller plants are composed of one or few actors' shared facility that handles farm biomass and/or gate fee waste. The feedstock processing capacity of these plants is below 20 000 t/a. (TEM 2020)

Plants of different sizes play different roles in the development of the biogas sector. Smaller plants can support nutrient cycle optimization and energy self-sufficiency. As the trend is that plants are growing and centralizing so will the end products of the feedstock. Solutions regarding the distribution of end products will have to be made. In the end, cost efficiency and environmental impacts influence the use of biomass of farms. (TEM 2020). The biogas producers use the gas as their source of energy and can sell it as heat, electricity and fuel. Some producers process digestate to be used as fertilizers whereas others struggle to do so. The producers of the gas tend to also sell the gas they produced by themselves. Some plants sell biogas to then be sold by another biogas producing party (BUOOR interviews 2021).

The gas produced is moved either by truck or pipe. The extent of centralization influences the costs associated with biogas production. Moving the gas is cheaper if the filling stations are closer but if the areas covered by each plant are growing so are the distances to the filling stations (BUOOR interviews 2021).

Distribution network providers

At the national level in Finland, there is no large existing infrastructure. There are 67 filling stations that provide CNG, CBG, LBG and LNG. There is also one 1210 km long pipeline which goes through Imatra, Lappeenranta, Kotka, Kouvola, Lahti, Mäntsälä, Helsinki, Espoo, Inkoo, Hämeenlinna and Tampere. Currently, the infrastructure is mostly developed by the largest players in the biogas field Gasgrid and Gasum. The pipe network has been built to transport LNG from abroad. However, in addition to LNG biogas is also inserted into the pipe in Espoo, Kouvola, Lahti, Hamina and Riihinmäki. There are also separate, smaller pipes owned by private companies (Gasgrid 2021, Kaasuautoilijat 2021). Some interviewees of the BUOOR project argue the filling station and pipeline networks have to grow to support the movement of gas and the development of biogas demand.

2.3.2. Meso level - secondary biogas actors in Finland

Consultants

Consultants are used widely in planning, constructing, maintaining and developing plants and developing the knowledge of market players. The plant manufacturers develop their offering so that it is adaptable in versatile contexts both nationally and abroad. In Finland, there exist many facility vendors and building companies such as Pro-group, Sarlin, Doranova Oy, Metener and Demeca (automation). Metener and Demeca, which built their business initially by constructing plants to their farms, are one of the pioneers in the area and they provide both consultant services and facilities (Metener 2021, Demeca 2021). There are also other consultants such as Afry, Vaisala, Watrec Oy, Doranova Oy, Envitecpolis Oy , Biokymppi Oy, Ductor Oy, Kiertokasvu Oy and Vogelsang Oy. Regarding finance, in practice, project interviewees said financing is obtained through multiple investment organizations, investment aids and bank loans (BUOOR interviews 2021).

Conversion service providers

In transportation, vehicles can be converted to use gas. Conversion service providers include Terra Gas Finland and Action Car Service ACS Oy. There are also gas vehicles and engines sold by different companies. An important number of used biogas cars are imported from abroad. Also, the conversion of traditional cars to biogas is financially supported (TEM 2020). A couple of interviewees of the BUOOR project say that the purchase price and availability of private cars is currently not an issue.

2.3.3 Meso level – tertiary biogas actors in Finland

Research centers and educational institutions play a role nationally and regionally. These include research area specific centers, universities and other development organizations. National research centers that perform research around biogas are, to mention some the Natural Resources Institute Finland (LUKE 2015), the Finnish Environment Institute (SYKE 2020) and VTT (Nylund et al. 2015). There are also universities that research biogas including the University of Helsinki (University of Helsinki 2020), Tamk (Scania 2019), Centria (Habitus 2020) and the University of Vaasa (University of Vaasa 2021).

2.3.4 Micro level - the end users

The users include the general society: heating, transportation and electricity solutions selected by private individuals, businesses, municipalities and public organizations. Transportation users include private cars, the municipalities and businesses operating in the shipping and freight businesses, recycling, as well as farms. (EBA et al. 2020; BUOOR project Interviews 2021).

Profitability in the industry is largely influenced by the ways biogas is utilized (TEM 2020). The products resulting from the biogas processing are multiple: heat, electricity, fuel and digestate. Fuel can be in the form of CBG and LBG. Following table 6 shows the main biogas products and their end-users as well as demand in Finland in 2030 (Fredriksson et al. 2020).

Table 6 Biogas products, demand and end users in Finland 2030 (Fredriksson et al. 2020)

Type of biogas products	End users	Estimated demand in 2030	Estimated growth in demand
LBG	Heavy duty trucks	2,5-4TWh	Large
Biomethane	The industry	0,5-4 TWh	Large
LBG	Ships	0,85-4 TWh	Large
Heat and electricity	Nearby buildings and energy network	0,4-2 TWh	Medium
CBG	Cars	0,5-1TWh	Small
CBG	Buses	0,5 TWh	No
Digestate	Agriculture	Unknown	Location specific

Fuel is the most attractive usage method in terms of profitability and its use typically also reduces the most emissions. However, for now, biomethane demand is low and unstable. Therefore, entering the market represents a considerable risk. Refining biomethane from biogas also adds investment and use expenses (TEM 2020).

Currently, the amount of biogas and electricity vehicles is growing and hydrogen vehicles are coming. Electric vehicles are leading the market as alternative fuel transport and this trend seems to continue. As seen on Finland's Integrated Energy and Climate Plan, support for electric vehicle infrastructure (charging stations) and promotion is increasing. By 2030, it is estimated there could be around 250 000 electric and 50 000 gas vehicles in Finland (Knuts et al. 2020).

The biogas sector plays an especially important role in answering the needs of larger users through the liquification of biogas (LBG). These include for example heavy-duty trucks, ships and industrial machinery. The increasing adoption of LBG is one of the fuels contributing to achieving national energy self-sufficiency according to the climate plan. Currently, LBG is only produced in one large scale centralized biogas plant in Finland (EBA et al. 2020, Ojanpää 2020).

In transportation, the role of biogas is growing due to the national targets of reducing the transportation related emissions by 50% from 2005 to 2030. The aim requires that fossil fuels in the transportation sector should be replaced by renewable energy and other emission free options. The use of biogas as a fuel in transportation helps to achieve the emission reduction targets as well as support national and regional economic state and energy self-sufficiency. The national distribution network plan for alternative transport fuels targets that road transportation should result into nearly no emissions by 2050. In the biogas road transportation sector, the target translated in a target of 50000 passenger cars and 3000 delivery vans by 2030. The plan does not have targets for larger vehicles, nor for vehicles using liquified methane. In the autumn of 2019, there were 8106 passenger cars and 680 delivery vans using biogas. (TEM 2020).

Producing heat is the easiest and most economical way of using biogas. In that case, the produced methane is burned and used as hot water. The heat can be used in the reactor itself and in buildings nearby. As often the energy produced is not fully needed for heating, it is attractive to also produce electricity from the biogas. In such cases, typically around one-third energy produced is electricity and two-thirds is heat. The local use of electricity and heat is more economical than sharing it to the respective network. (TEM 2020).

If the biogas production plant is in the gas network, biogas can be refined to biomethane and shared through the network. In this case, the gas can be used as electricity, heat and fuel. The biogas used for vehicles can be prepared at the plant itself and distributed to gas stations. Biogas can also be liquified making its volume shrink. Transportation in that form is more economical and it can be used for heavy-duty trucks. (TEM 2020).

Digestate includes phosphorus and nitrogen that can be used as fertilizers reducing nutrient loss and improving the nutrient cycle. The use of digestate is a part of a larger national nutrient recycling program. (TEM 2020). According to the BUOOR project interviewees, local use of processed digestate reduces the negative impact of transportation the most. An interviewee stated one way to do this is to use biogas fuel trucks that transport both feedstock from and digestate to the farms.

3. The biogas sector in Ostrobothnia

The capital of Ostrobothnia, Vaasa is the home of EnergyVaasa, the largest and leading energy technology hub in the Nordic countries. Consequently, it is a world leader in multiple technological areas including smart electrical solutions, sustainable energy, flexible power generation and digitalisation. 80% of the products and services of the hub companies are exported. The area is considered the most innovative area in Finland where educational institutions, companies and municipalities work together in developing research, products, innovation and education. (Vaasa 2021)

In the biogas sector, it has led to different players working together. The municipal player Stormossen entered the market in 1990 and has collaborated with multiple actors over the years. The industrial player Jeppo Biogas has successfully cooperated with the food industry. The municipality has contributed to the development of the biogas infrastructure through its energy choices. The further development of the region is possible due to the availability of feedstock, knowledge and development potential. (Knuts et al. 2020)

Ostrobothnia has over 30 years of experience in the production of biogas. The area could foster its development by building a common plan regarding biogas production and distribution. Based on the number of cars in 2019 there will be 10 000 fully electric cars and 2 000 gas cars already in 2030. This would require 100 charging stations and 20 gas filling stations which are estimated to be a total of 9,6 million euros investments. As the volumes and costs are rising, the area could benefit from a shared gas network. Making the decision to use biogas in transportation is a valuable way to be sustainable and competitive in the market. (Knuts et al. 2020)

It is recommended to build a common plan regarding biogas production and distribution which will investigate the gas network of Ostrobothnia as well as its conditions and possibilities. This should include actors, costs, infrastructure, volume, routing, capacity and environmental influences. Also, it could be beneficial to perform a cost estimate of an LBG production plant focusing on technical and economic aspects. LBG could serve as a local alternative to LNG. Finally, important areas to consider when building an industrial biogas plant include environmental and investment issues, continuous feedstock availability, short distances, the use of biogas (primarily as fuel) as well as the use of digestate as fertilizer. (Knuts et al. 2020)

An area that has potential for improvement is the use of digestate as fertilizer through processing. There is already some knowledge around this topic and there is potential to develop it (Knuts et al. 2020). In Finland, the company Soil Food provides digestate processing and sales services to owners of biogas plants (Soil Food 2021). Table 7 summarizes the actors and their roles in Ostrobothnia.

Table 7 Biogas sector stakeholders in Ostrobothnia adapted from (Mutikainen et al. 2016)

Biogas sector actors by levels			
Level	Roles	Actors	
Macro	Public authorities, influential parties and regulation makers.	Lobbyists, industry unions, nation and regional state administration, municipalities and cities.	The cities of Ostrobothnia: Kaskinen, Korsnäs, Kristiinankaupunki, Kruununpyy, Laihia, Luoto, Maalahti, Mustasaari, Närpiö, Pedersöre, Pietarsaari, Uusikaarlepyy, Vaasa and Vöyri. The regional association: Regional Council of Ostrobothnia and local politicians.
		Licensing authorities, land owners, biogas certifiers.	The regional Centre for Economic Development, Transport and the Environment
Meso	Primary producer: feedstock producers, collection and transportation companies, biogas producers, distribution network providers, environment	Feedstock logistics, farms, industry, field cropping, waste management	Waste management companies move the feedstock. The industrial area in Jepua, other biowaste from households, waste water treatment facility, and elsewhere
		Gas transportation and storage logistic partners, Gas network operators, Facility operators and maintenance, Facility owners and builders, distribution centers	In Ostrobothnia gas is transported and stored by the biogas plant owners. They are also the owners and operators of the gas network including the filling stations. They operate by themselves. They may use partners for maintenance and building.
	Secondary actors	Biogas importers, biogas sales place, facility vendors and building companies, car and work engines sellers, capital investors, financiers, consultants and planners, car producers, work engine producers.	Gas as fuel is sold by the producers directly. In case of gas sold as electricity or heat entering the supplier is Gas energy. The facility vendor and building companies are national players. Car vendors are national. Locally Wärtsilä is both a biogas engine manufacturer and an energy service provider. There are also capital investors, financiers, consultants and planners that act nationally.
	Tertiary actors	Educational institutions, technology developers	These include development businesses and academic institutions in the region.
Micro	early customer and end consumer groups	Society, citizens and end user organizations	Ostrobothnia as a forerunner in sustainable energy
		Farms as energy users, households, industrial users, vehicle owners and drivers	Public procurement in Vaasa, public tendering, private vehicles, marine sector, industry, heavy duty traffic.

Local macro level actors include the local cities, politicians and associations. Local authorities in Ostrobothnia include the municipalities and cities of Ostrobothnia. These are Kaskinen, Kornäs, Kristiinankaupunki, Kruununpyy, Laihia, Luoto, Maalahti, Mustasaari, Närpiö, Pedersöre, Pietarsaari, Uusikaarlepyy, Vaasa and Vöyri. These cities can influence the local biogas sector through their decisions regarding transportation choices, heat and electricity types. They can also choose to support biogas locally for example by providing storage facilities for liquified biogas. The Regional Council of Ostrobothnia drives the change towards a digitally-minded and greener economic area. Its focus areas include biogas and circular economy (Pohjanmaanliitto 2020). The Centre for Economic Development, Transport and the Environment of Ostrobothnia states the need for an environmental influence assessment based on the documentation given by biogas producers (ELY-keskus 2017).

3.1 Meso level biogas actors in Ostrobothnia

3.1.1 Feedstock providers in Ostrobothnia

The feedstock sources in Ostrobothnia currently include the industry, waste management and sludge. Agriculture actors could in theory pay for their biowaste to be transported but this might be costly. Currently, there is no farm level biogas plants in Ostrobothnia although there is feedstock available. Most of the agricultural actors in Finland are located in Eastern Finland. The type of feedstock available in Ostrobothnia includes greenhouse produce, potatoes and pig manure (Ruokatieto 2021). Due to the growth potential of the use of feedstock from agriculture, there is plenty of room for increasing the amount of agriculture feedstock used in producing biogas. There is also feedstock collected from a water treatment facility in Vaasa, the landfill of Stromossen and the industrial area around Jeppo Biogas. Figure 6 demonstrates the main agricultural activities in different parts of Finland.

Figure 6 Agriculture in Finland (Ruokatieto 2021)

3.1.2. Biogas producers in Ostrobothnia

The feedstock used in biogas production in the Ostrobothnia area is currently processed in Jepua, Laihia, Koivulahti and Vaasa. Two are waste management plants and two are biogas plants. The current operators are Stormossen, Jeppo Biogas and Laihian Nuuka Lämpö. Farms are increasingly entering the network. There are plants planned to be built at least in Kyrönmaa, Kristiinankaupunki, Närpiö, Kruununpyy and Vöyri. Stormossen is a public waste management company for the municipalities of Vaasa, Korsnäs, Maalahti, Mustasaari, Isokyrö and Vöyri. Jeppo Biogas is co-owned by industrial companies whose feedstock it processes. Laihian Nuuka Lämpö produces biogas only to its sole use. The producers of the region also take the roles of infrastructure builder and salesperson of the biogas. Figure 7 locates the 3 biogas plants on the map of Ostrobothnia.

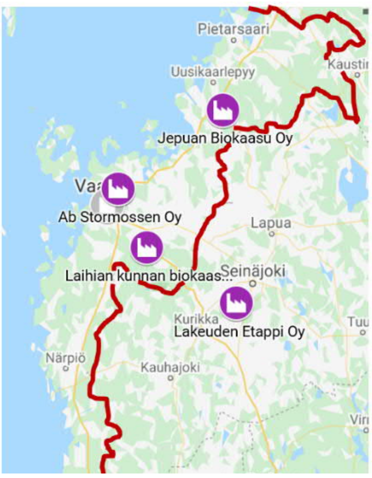

Figure 7 Biogas plants in Ostrobothnia 2021
(Suomen Biokaasu ja Biokierto ry 2021)

3.1.3. Distribution network providers in Ostrobothnia

In Ostrobothnia private vehicles and buses can use biogas as a result of the existing network. CBG filling stations are located in Vaasa, Jepua, Pietarsaari, Isokyrö, Uusikaarlepyy and Koivulahti. The two operators in the area include BIG (Stormossen) and, Jeppo Biogas. There are two stations that should be opened in 2021 in Vöyri by Vörå Energiandelslag and in Pännäinen by Ab Jan-Ove Management Oy (Kaasuautoilijat 2021). Gasum is planning to open a LNG distribution center which may be useful in the case LBG will enter the market in the future due to pre-existing infrastructure. The filling stations are located relatively close to the plants and the location is influenced by the investment aid policies. Figure 8 demonstrates the location of filling stations in Ostrobothnia.

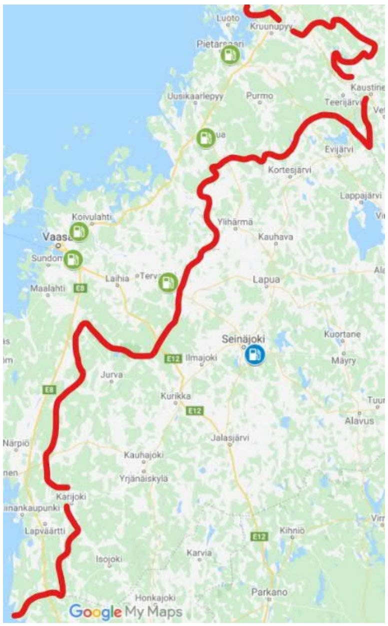

Figure 8 Filling stations in Ostrobothnia 2021 (Kaasuautoilijat 2021)

3.1.4. Logistical partners in Ostrobothnia

Waste management companies transport the feedstock from the source to the treatment facilities. In the Vaasa region the companies include Ab Nordqvist-Trans Oy, Ekoman Ympäristöhuolto Oy, Storsveds Sopservice, Häggblad M. Fastighetsservice, Lassila & Tikanoja Oyj, LUH-Konepalvelut Oy, Pohjanmaan Hyötyjätekuljetus Oy, Storsveds Sopservice, Oy Rune Bergström Renhållning Ab ja Remeo Oy. Sewage sludge is also transported by various companies and actors. The transportation partner varies depending on the city, the type and location of the sludge. In addition to transporting feedstock Remeo Oy also uses the resulting biogas as a fuel in its trucks in Ostrobothnia (Remeo 2020).

3.1.5. Tertiary actors in Ostrobothnia

The local research and development organisations include VASEK, Ab Företagshuset Dynamo Yritystalo Oy and Oy Pietarsaaren seudun Kehittämisyhtiö Concordia. Local research institutions include the University of Vaasa, VEBIC and VAMK. As the region is so energy focused there is a lot of local expertise available and activity taking place focusing on sustainability and the role of biogas. The expertise is used in practice through activities aim to support local public and private actors.

3.2 Micro level users of biogas in Ostrobothnia

Interviewed actors of this BUOOR project outline and examples of biogas ecosystems describe biogas-derived products and their use. They state that heat and electricity produced from biogas tend to be used by the local biogas producer plants and other industrial players nearby. They bring also mention that CBG is used in transportation by small vehicles and LBG has potential as a fuel of the future.

According to some interviewees of this project, the most attractive characteristic of the CBG is its price. The biogas fuel price is considerably lower than traditional fuel. Remeo has biogas trucks that make them competitive in cases of public procurement. Private vehicles also use biogas. Other costs associated with the use of biogas vehicles do slow down the transition to biogas vehicles. These include switching costs, the cost of the vehicle and the small number of stations.

In Vaasa, public procurement has had a positive role in the development of the local biogas sector. One BUOOR project interviewee elaborated that the choice of the city of Vaasa to use biogas buses has provided a reason to build a distribution network to make fuel available. This provides a basis for market development as there is pre-existing demand and supply (Arfan 2019). The city of Vaasa has 12 biogas buses in public transport (Kuntaliitto 2019). They also mentioned they aim to support renewable energy through public procurement tendering. Another interviewee exemplified this through the environmental management company Remeo which has biogas trucks that make them competitive in cases of public procurement. In the first workshop and during BUOOR interviews Taxi's were introduced as potential future users of biogas in the future.

The use of liquified gas can be attractive to various users. In Ostrobothnia BUOOR project interviewees mention opportunities in industry users, ships and heavy traffic. Players of the industry and maritime shipping have already agreed to use LNG provided by Gasum (Gasum 2021). Interviewees also consider mixing LNG and LBG more attractive than sole use of LBG as the total GHG is expected to be lower and the mixture has a more attractive price.

In the first BUOOR project workshop (organized by the university of Vaasa 25 March 2021) two core customer actors of the marine sector shipping and freight businesses, Wasaline and Wärtsilä, were identified. Wasaline ships travel from Vaasa to Umeå, Sweden moving both passengers and cargo. Wärtsilä provides gas engines to the marine sector. Interviewees also stated road cargo transport companies might benefit from biogas in the future through the use of LBG (BUOOR Interviews 2021).

The recycling company Westenergy plans to increase its amount of use of biogas in its logistics chain. In general, there are many industrial players which could start using biogas in the area possibly for example the largest industrial players in the Vaasa region: Wärtsilä, ABB, Alteams Finland Oy, Crimppi Oy, Danfoss, Finnfeeds Oy, Logset Oy, Oy Botnia Marin Ab, Oy KWH MIRKA AB, Oy Primo Finland Ab, Riitan Herkku Oy, Scott Health & Safety Oy, UPC Konsultointi Oy, VEO Oy. (VASEK yrityshakemisto 2021)

The interviewees of BUOOR project consider biogas a source of competitivity. Some argue that the adoption of LBG at the local level could result in a competitive advantage to the area of Ostrobothnia nationally and abroad. Some also mention that from the perspective of the organisations the companies could develop their sustainability image and act as examples of successful business cases at a global level.

Digestate could act as a source of income for producers of biogas in Ostrobothnia. As visible from Figure 9 below the need for fertilizer in crop farming varies, Western Finland has the most fertilized land whereas Northern and Eastern Finland has the least. Therefore, digestate could act as a significant export product from Ostrobothnia to other parts in Finland or beyond. (Luostarinen et al. 2019)

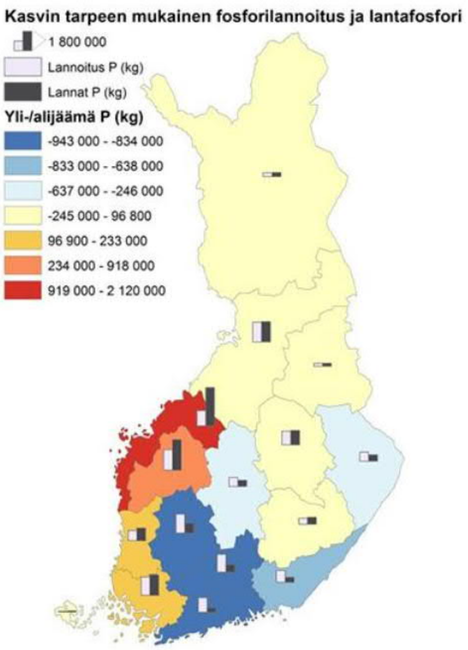

Figure 9 Need of fertilizer (Luostarinen et al. 2019).

According to some of the interviewees of the BUOOR project, processing digestate from biogas production into fertilizer is an attractive activity in many ways. Many argued that its main attractiveness is its nutrient circularity effect but also some mentioned its business opportunities due to the high density of nutrients and renewability. For now, it is considered expensive and risky by respondents as it is a still untouched market lacking supportive policies.

4. Examples of biogas collaborative networks

In this report, existing biogas networks are presented and organized according to their business models and collaborative networks. Tables 8-11 gather examples of biogas ecosystems in farm, industry and municipal level network and distribution networks.

Energy solutions can be divided into centralized and decentralized energy solutions. Centralized energy solutions refer to energy production in households, energy businesses or industrial large sized plants, where there are economies of scale and where societal energy self-sufficiency is made possible. In this type, the customers may be located far away from production. Centralization is often a necessity for profitable biogas production. Decentralized energy solutions are typically smaller in size and closer to customers. They are also characterized by systems of local actors and shared ways-of-working. (Okkonen & Blomqvist 2020)

Table 8 Comparison of biogas plant networks in Finland through farm level examples

Location and Name	Uusikaupunki, Southwest Finland Biolinja Oy	Hyvinkää (Palopuro), Uusimaa Palopuro Symbiosis	Mikkeli, Eastern Finland Biohauki Oy	Central Ostrobothnia Habitus project
Type of biogas business model	Farm level decentralised	Farm level decentralised	Farm level decentralised	Farm level decentralised

Amount	Capacity: 18 000 t/a Biogas production: 13 932 MWh/a total, 374 MWh/a electricity and 13 558 MWh/a heat.	Raw materials input: 3380 t/a. Biomethane 1628 MWh/a, power 0, fuel 1528 MWh/a and heat 310 MWh/a	Capacity: 14 000 t/a Biogas production: 700 t/a	10-15 Nm^3/h per farm
Collaborating parties and ownership of plant	Collaborators: Biolinja Oy, Pieni Kalatila, VG EcoFuel Oy and Kotipellon puutarha Mimis. Owner: Biolinja Oy	Biogas plant builder: Palopuro Biokaasu Oy. Owners: main owner Nivos Energia Oy, Knehtilä farm, Metener Oy and Lehtokumpu farm.	Owner: owned by Etelä-Savon Energia Oy and 13 local farmers.	Coordinated by the University of Applied Sciences Centria

Table 8 presents 4 biogas collaboration models where farms play a central role. The networks vary in terms of their size, collaborating parties and their roles. The farm centred collaboration examples show that their biogas plants tend to be relatively small, and relatively decentralised both customer and feedstock wise.

Table 9 Comparison of biogas plant networks in Finland through industry level examples

Location and Name	Norrköping, Sweden Norrköping Industrial Symbiosis Network	Kankaanpää, Satakunta Industrial area of Kirkkokallio	Vehmaa, Southwest Finland Industrial area of Vehmaa	Tammisaari, Southern Finland Jalotofu plant
Type of biogas business model	Industry level centralised	Industry level centralised	Industry level centralised	Industry level decentralised
Amount	Upgraded biogas to vehicle grade (~ 4.2 million Nm3/a).	Capacity: 60 000 t/a Biogas production: 35 GWh/a	Capacity: 90 000 t/a Biogas production: 30 GWh/a	capacity: around 1900 t/a expected need: around 950 t/a
Collaborating parties and ownership of plant	Municipality of Norrköping, Händelöverket heat and power plant, Lantmännen Agroetanol bio-ethanol plant, Svensk Biogas biogas plant and Econova product producer from waste	Collaboration: Gasum, Honkajoki Oy, Vatajakosken Sähkö, Ownership: Gasum (sold by Honkajoen Biotehdas Ky).	Owner: Gasum Multiple industrial collaborators	The biogas plant is built next to Jalofoods factory. The owner and maintainer is One1 Oy.

Table 9 presents 4 biogas collaboration models where industrial actors play a central role. The networks vary in terms of their size, collaborating parties and their roles. Based on examples found a tendency of physical proximity appears to be related to industrial player collaboration. The feedstock is in this case usually collected from the local companies and sold to them/or to customers farther away.

Table 10 Comparison of gas distribution and sales solutions in Finland through examples

Location and Name	Vaasa, Gasum LNG distribution	Turku, LBG distribution	Multiple locations Gasum business	Multiple location SEO
Type of biogas business model	Sales agreement of LNG for maritime use. Centralised	Distribution and sales of LBG. Centralised	Sales agreement of liquified gas for transportation. Centralised	Distribution and sales of CBG. Decentralised
Collaborating parties and comments	Wasaline and Wärtsilä	This is the first liquification plant in Finland	Posti, Ikea and Lidl for heavy-duty and private vehicles	Independent businesses that are part of the cooperative

Table 10 presents gas distribution and sales collaboration networks. These were chosen to demonstrate examples of recent collaborations and developments in sales and distribution in the gas market. The aim was to present the diversity of networks in that specific area.

Table 11 Comparison of biogas plant networks in Finland through municipal level examples

Location and Name	Multiple locations BIG	Oulu, North Ostrobothnia Kiertokaari	Lahti, Päijänne Tavastia Kujala Waste Center
Type of biogas business model	Marketing company for municipal biogas producers.	Municipal centralised	Municipal level centralised
Amount	7 filling stations	Capacity: 60 000 t/a Biogas production: 15 000 MWh/a.	Capacity 80 000 t/a Biogas production: 50 000 MWh/a
Collaborating parties and ownership of plant	The marketing company is co-owned by Stormossen in Vaasa, Pirkanmaan Jätehuolto in the Tampere region and Etelä-Karjalan Jätehuolto.	Kiertokaari is co-owned by multiple municipalities: Hailuoto, Ii, Kempele, Lumijoki, Oulu, Pudasjärvi, Raahe, Siikajoki. Owner: Gasum (plant). Other collaborators: Oulun Energia and industrial players	Key actors are LABIO Oy biogas and composting plant, Tarpaper Recycling Finland Oy waste management plant, Gasum Oy biogas upgrading plant, NCC Roads Oy asphalt station and soil upgrade station. Labio Oy is co-owned by Lahti Aqua (60%) and Salpakierto Oy (40%)

Table 11 shows some collaboration networks built by municipal actors. The municipal actors receive household waste. Their feedstock providers and end customers do not tend to be close to them.

4.1. Farm centered biogas collaborative models

The farms' example below are symbiosis where the players depend on each other for the activity to continue. They demonstrate the multiple opportunities that arise from collaboration at a farm level and combination of different types of collected feedstock whilst supporting the local symbiosis.

4.1.1. Case Uusikaupunki, Southwest Finland

The biogas ecosystem example located in Uusikaupunki is the result of the collaboration between Biolinja Oy, Pieni Kalatila, VG EcoFuel Oy and Kotipellon puutarha Mimis. Biolinja Oy is a closed nutrient cycle that receives feedstock from the industry, households and agriculture in Southwest Finland. The biogas production at Biolinja Oy results into heat and digestate. The heat is sold to the heat grid and to the greenhouse Kotipellon puutarha Mimis. The digestate product is used as fertilizer in the local fields. The feedstock produced by the fish farm Pieni Kalatila and the local greenhouse Kotipellon puutarha Mimis is used to produce bio-oil and biogas. The bio-oil plant VG EcoFuel Oy produces biofuel from the biofuel and recycled vegetable oil. The fish farm water is filtered from nutrients that are used by Kotipellon puutarha Mimis. (Biolinja 2021; Motiva 2021). This closed network provides incentives for participating organisations to develop and communicate with each other. Figure 10 shows visually the actions taking place between players.

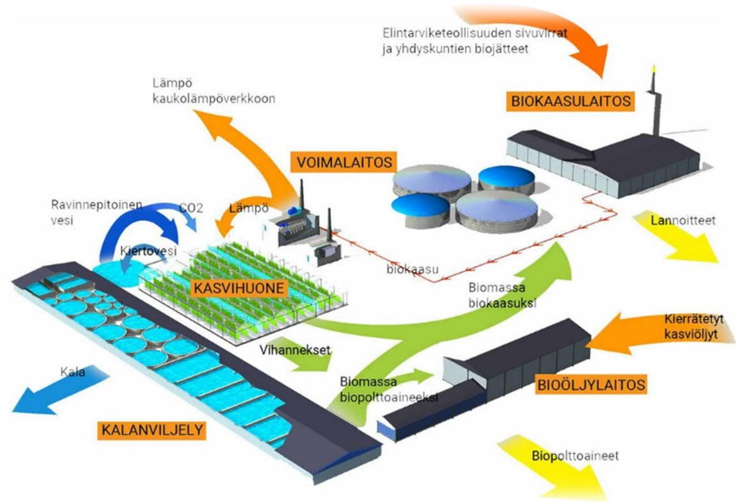

Figure 10 Farm level centralised biogas plant in Uusikaupunki, Southwest Finland (Biolinja 2021)

4.1.2. Case Palopuro, Southern Finland Symbiosis

The biogas ecosystem example located in Hyvinkää is the result of the collaboration between Knehtilä farm, local henhouse, local biogas plant owned by Nivos Energia Oy, local vegetable farms.

The feedstock used in biogas production includes grass, horse manure and chicken manure. The idea is to produce local food, support nutrient cycling, produce energy and increase profitability. The business model of the symbiosis was built with the support of Envitecpolis Oy, who produced a business plan and a profitability estimate. Although initially planned the bakery is not yet included in the symbiosis due to cost issues. Heat is produced for the farm and the rest of the biogas is processed into CBG for cars and trucks of the farm. The symbiosis consists of a close collaboration between the farm and the biogas plant. The farm offers grass for free as feedstock and is given processed digestate in return. The digestate is also used as a fertilizer by the vegetable farms. The horse and chicken manure use are subject to gate fees. The main source of income for the plant is the CBG. The builder of the biogas plant is Metener Oy. The idea of this symbiosis is to support the standardization of farm level biogas plant constructions. (Helenius et al. 2017). Figure 11 shows the planned actions and exchange of resources.

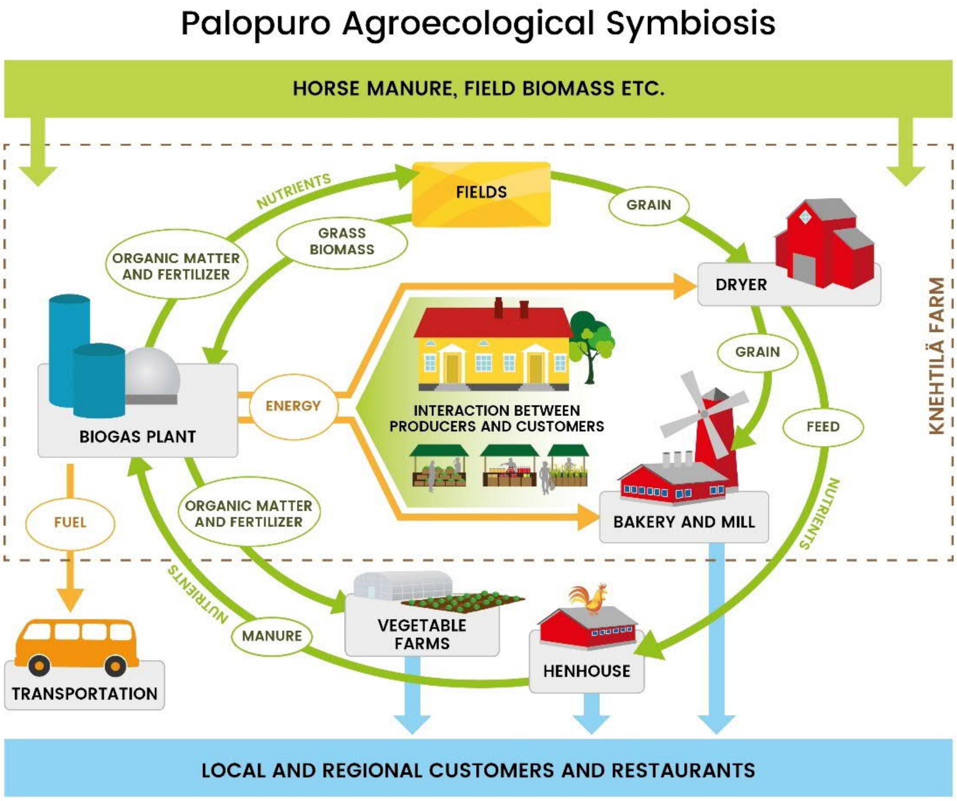

Figure 11 Farm level centralised biogas plant in Hyvinkää, Southwest Finland (University of Helsinki 2020)

4.1.3. Case Biohauki, Eastern Finland

Biohauki Oy is owned by Etelä-Savon Energia Oy and 13 local farms. The feedstock used includes agricultural by-products, cow and chicken waste and surplus hay. The company produces biogas and digestate. The biogas can be used for heating purposes and to produce biogas rich in biomethane. Biogas production supports local development of the circular economy and regional economy as the products are sold locally. As sales increase, the plan is to produce more biogas and develop production processes in the future. (Biohauki 2021). Figure 12 shows the main activities and exchange of resources taking place at Biohauki.

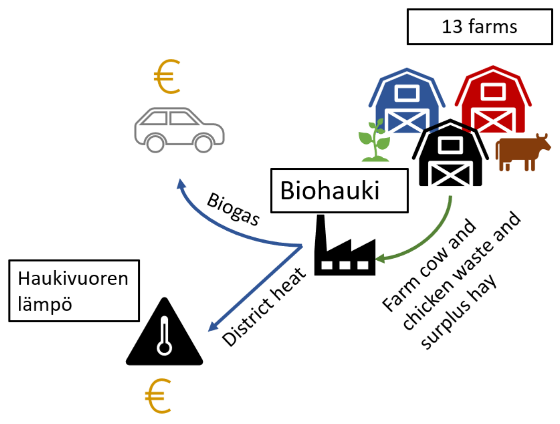

Figure 12 Farm level decentralised biogas plant in Mikkeli, Eastern Finland based on description (Biohauki 2021)

4.1.4. Case Habitus, Central Ostrobothnia

The project Habitus is coordinated by Centria and Anne-Riikka Rautio. The collaborators are the city of Kokkola, Kannus, Kaustisen Seutukunta, Kosek and Perho.

This decentralized model consists of multiple farms that each have local biogas reactors and liquefication facilities that transform biogas into LBG. Each farm uses its own feedstock. The digestate coming out from the process is treated locally to increase its concentration and make it reusable in the form of fertilizer. The LBG is stored at each farm and will be driven to a shared fuel station by trucks. The model provides income from farming both through the use and sales of LBG. The aim is to support profitable processing for the farms and the local economy. (Habitus 2020). Figure 13 shows actors and the planned activities.

The pilot has several aims. One aim of the pilot is to develop a technology suitable for farm LBG production. The second aim is for the feedstock used in biogas production to not be subject to gate fees. The third aim is to reduce the costs of moving feedstock to the biogas plant. The fourth aim is to manage the digestate. The fifth aim is to make biogas production more affordable. (Habitus 2020)

The idea is for the farms to operate as a cooperative where each of the players involved are co-owners. The cooperative would own the liquefication plant together. An online cooperative has already been built. The solution is planned for farms sized 10-15 Nm^3/h. The liquefication unit is sized 1,86 m x 1,8 m x 54 cm. (Habitus 2020)

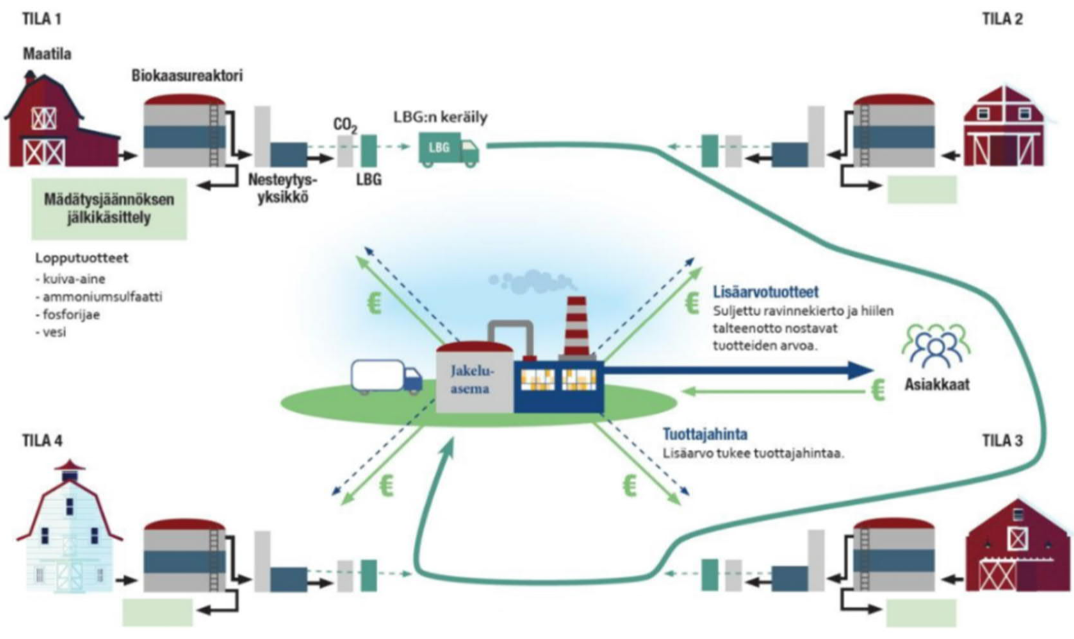

Figure 13 Farm level decentralised biogas plant project Habitus coordinated by Centria in Central Ostrobothnia (Habitus 2020)

4.2. Industry centered biogas collaborative models

The industrial examples demonstrate the possibilities arising when larger players are involved and they cooperate together.

4.2.1. Case Norrköping, Southeast Sweden

The Norrköping symbiosis represents economic and environmental benefits that collaboration between industrial, urban and agricultural actors can create. Norrköping is an industrial city located by the sea. The network has plenty of actors, of which the key actors are the municipality of Norrköping, Händelöverket heat and power plant, Lantmännen Agroetanol bio-ethanol plant, Svensk Biogas biogas plant and Econova producer of waste-based products. Similar ecosystems take place in Sweden also in Lidköping and Helsingborg. (Industriellekologi 2021abc)

The biogas plant of the symbiosis was put into operation in Norrköping in 2007. The raw biogas produced in this facility is upgraded to vehicle grade (~ 4.2 million Nm3/y) and fuels biogas busses and cars in Norrköping. The biogas plant uses household organic waste and stillage from Agroethanol. The digestate is used by the local farms. (Industriellekologi 2021a). Figure 14 shows the exchange of resources between actors.

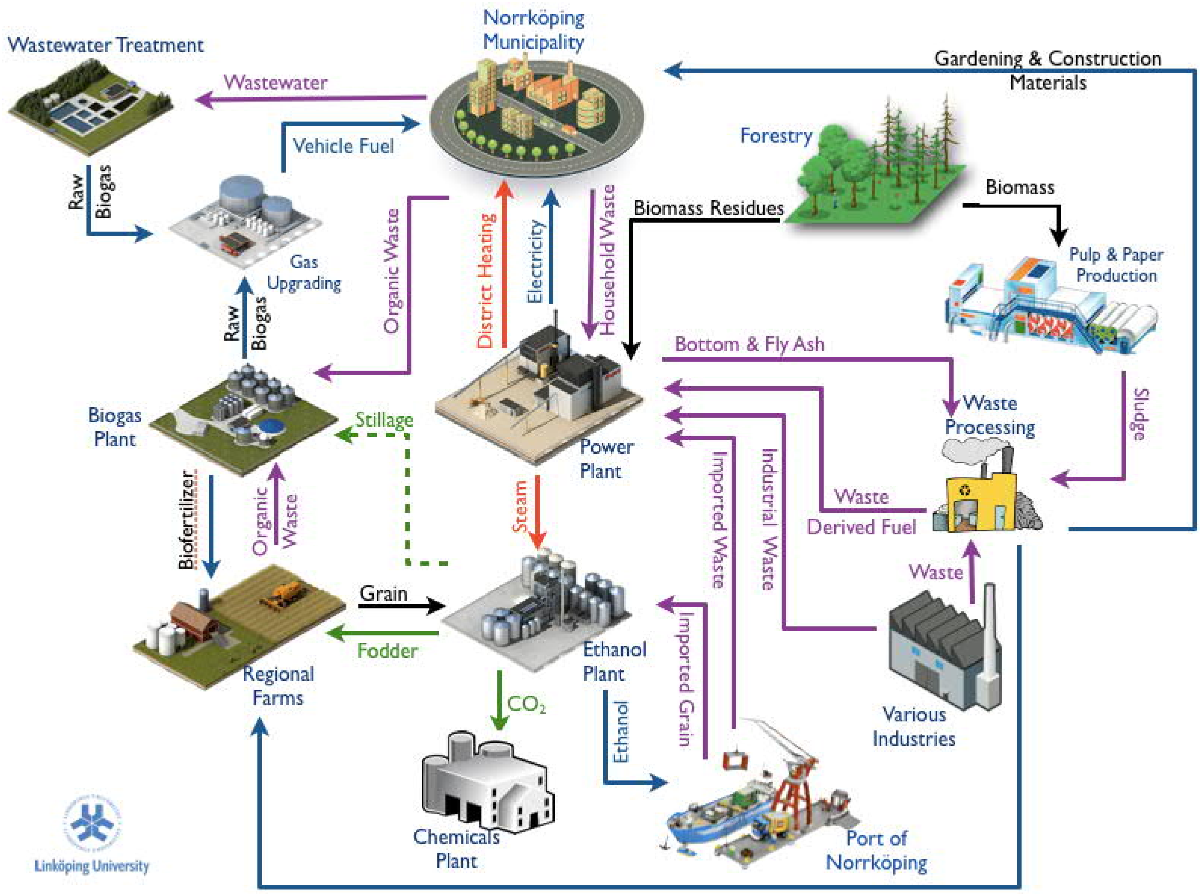

Figure 14 Industry level centralised biogas plant in Norrköping, Sweden (Industriellekologi 2021a)

4.2.2. Case Honkajoki biokaasu, Western Finland

The biogas plant of Honkajoki was built by Taaleritehdas Oy. It manages food industry feedstock, separately collected biowaste and packed biowaste. Located within a food industrial area there are multiple growth and collaboration opportunities. The plant has its own management line for packed biowaste and separately collected biowaste that separates the biowaste and packaging. The packaging is transported for energy use and biowaste enter the biogas production process. The biogas plant collects gate fees with at least some actors. The plant does not collect household waste which decreases the complexity of waste processing. The feedstock includes waste from water treatment plants, sewage sludge, vegetables, meat industry side waste. There is a pipeline built between Gasum and Honkajoki Oy. The feedstock is moved by its own staff due to the proximity, 500m-1km. (Gasum 2021a; Honkajoki Oy 2021; Honkajoki 2014)

The biogas produced is sold to a nearby energy company's storage water heater and combined heat and power machine to create electricity, heat and process steam. The digestate is used in agriculture. The excess water is reused to minimize the use of fresh water. (Gasum 2021b; Honkajoki Oy 2021; Honkajoki 2014)

The ecosystem partners are motivated to work with each other, as there is synergy and dependence on one another. The actors are in correspondence with one another to make sure they are satisfied and there is no hostile behavior due to dependency between actors. The actors have long term agreements with one another. Honkajoki upgrades biogas into heat to be used by agriculture as it is the most efficient way of using it. Organic waste is provided by the organisations of the network, and from organizations further away. Honkajoki Oy seeks to extend the lifetime of the products it receives. It sends to biogas plant only what it cannot longer use. It also produces products for farming that reduces the amount of GHG emissions. (Honkajoki Oy 2021) The involved actors can be seen from Figure 15 below.

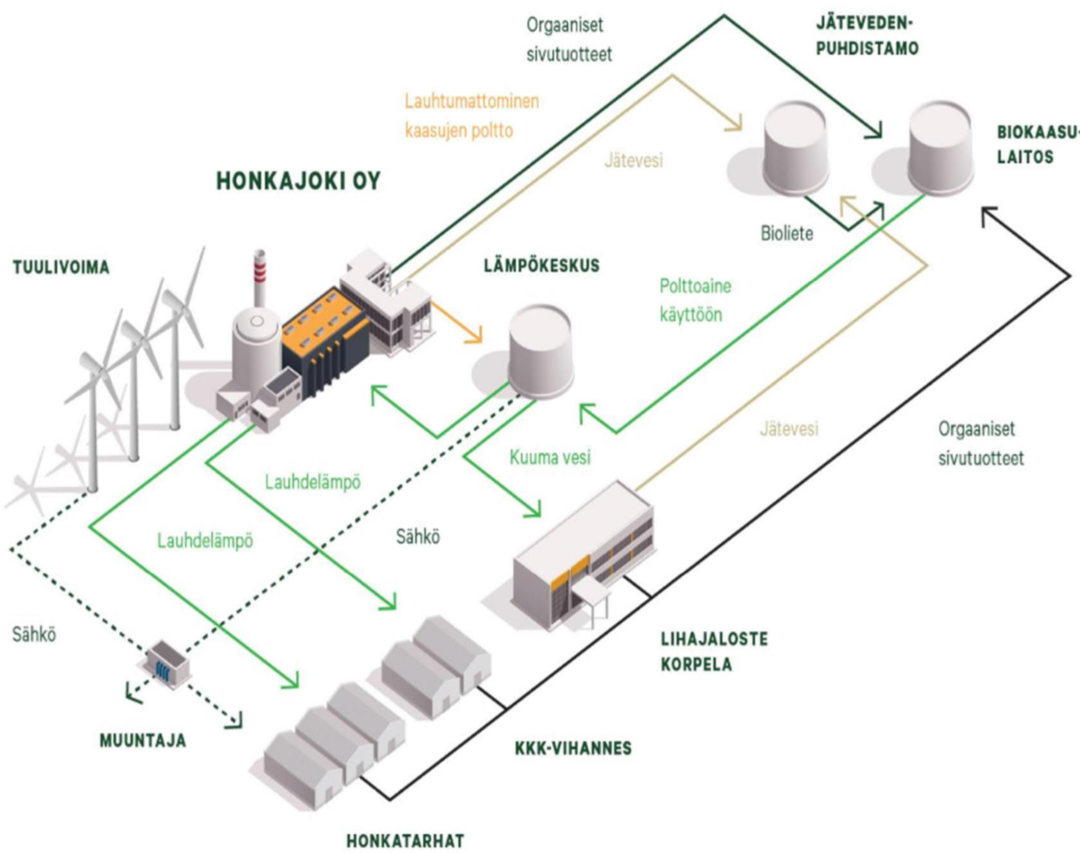

Figure 15 Industry level centralised biogas plant in Kankaanpää, Satakunta (Honkajoki 2021)

4.2.3. Case Vehmaa, Southwest Finland

The Vehmaa biogas plant is Finland's oldest industrial-scale biogas plant. The plant mainly processes enzyme industry side streams, food industry side streams and pig farm sludge. Biogas from the plant is used to generate electricity and heat with the plant's own CHP engines. Heat is used in the plant's processes and also sold to a nearby greenhouse. (Gasum 2021c)

All sanitized digestate at the Vehmaa plant undergoes centrifugation. Solid digestate is used in agriculture as a fertilizer product. The evaporator treatment of reject water at the plant is a unique solution in Finland. (Gasum 2021c)

In the evaporator, water and concentrated nutrients are separated from reject water. The water undergoes reverse osmosis and, having been fully purified, is then discharged into a local river. Nutrient concentrates are used as fertilizers in agriculture and as wastewater treatment plant nutrients in the pulp industry. (Gasum 2021c)

4.2.4. Case Tammisaari, Southern Finland

Jalofoods is planning to build a biogas facility that will use side streams of soy beans. The plant will be built right next to the factory of Tammisaari where plant-based protein products are produced. Soy bean side streams will be used to make biogas to be used as a source of energy by the factory. Jalofoods seeks to achieve energy self-sufficiency. The biogas plant’s capacity is 2200 MWh, but current needs correspond to only half of that. However, as the protein-based protein segment is expected to grow, so is the capacity of the biogas plant. This project combines the nutrient cycle and environmental sustainability. Since the one million investment represents a fourth Jalofoods’ turnover, a partner One1 Oy is joining in the project. It is an owner, and support building the biogas plant and maintaining its activity. The biogas plant is delivered by Sauter Biogas Finland directly on the plot, avoiding extra transportation. The estimated payback time is 10 to 12 years which simultaneously include the goal of becoming energy self-sufficient. In the future, the plant is expected to bring financial advantage to Jalofoods. (Jalotofu 2021). Figure 16 shows the key components of biogas production and the role of each.

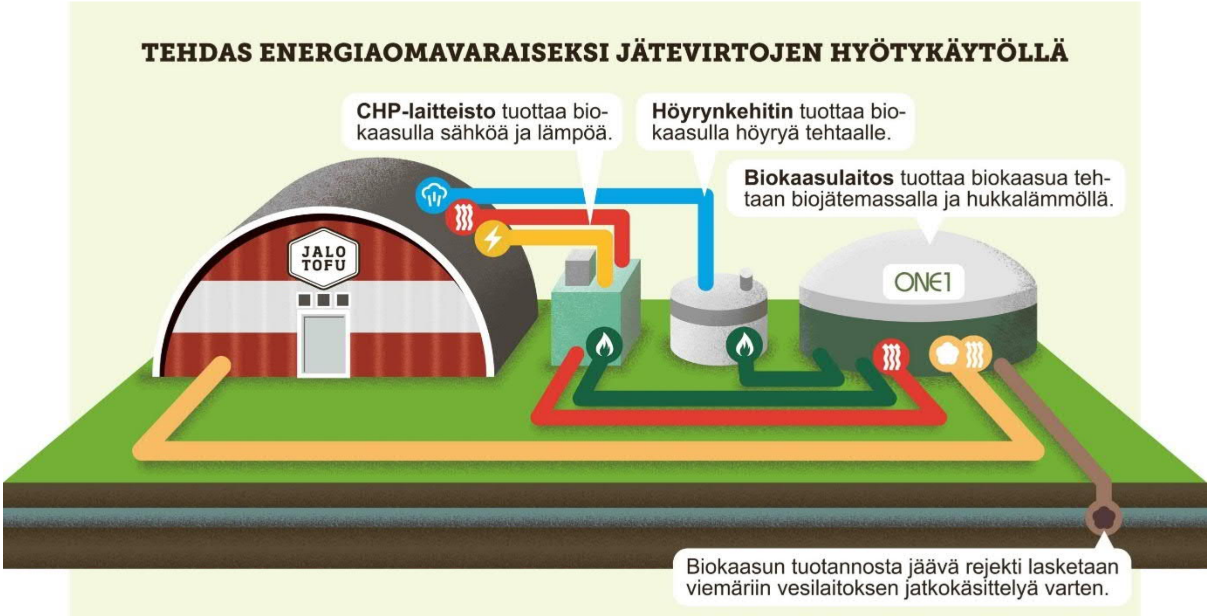

Figure 16 Industry level decentralised biogas plant in Tammisaari, Southern Finland (Jalotofu 2021)

4.3. Municipal centered biogas collaborative models

The municipal examples show what municipal waste management biogas networks can look like.

4.3.1. Case BIG – a common brand for biofuel stations

BIG Biogas is a brand name for biogas filling stations. Currently, the stations are filled by waste management companies producing biogas. These include Stormossen in Vaasa, Pirkanmaan Jätehuolto in the Tampere region and Etelä-Karjalan Jätehuolto in South Karelia. BIG is inviting other partners to join in building a wide network of biogas stations. Figure 18 demonstrates the CBG production and distribution process in a visual manner.

The feedstocks are collected in the respective local areas of each waste management company. The biogas is also produced by each organization separately. The biogas or liquified biofuel are then transported to the biogas stations under the same brand. (BIG 2021)

Figure 17 Demonstrates the process of CBG production (Biogas 2021)

4.3.2. Case Lahti symbiosis

In Lahti, there is an industrial symbiosis in which key actors are LABIO Oy biogas and composting plant, Tarpaper Recycling Finland Oy waste management plant, Gasum Oy biogas upgrading plant, NCC Roads Oy asphalt station and soil upgrade station. (CircHubs 2021). LABIO oy combines composting and gas production. LABIO oy and Kekkilä Oy have soil processing plants in Kujala where the compost produced is processed and becomes raw soil material and fertilizer allowing nutrient circulation. Only a small amount of the incoming waste is placed in the landfill site. The site produces methane used as a process steam by Hartwall Oy. The biogas plant is able to manage many different types of biowaste, including household, industrial and commercial waste, as well as sewage sludge. (SmartLahti 2021). Labio Oy is co-owned by Lahti Aqua (60%) and Salpakierto Oy (40%). After the biogas has been produced, it is inserted into a biogas tank and pressurized by Gasum Oy (Labio Oy 2021). Gasum Oy sells at its filling station the following fuels: CNB, CBG, LNG and LBG (Bioenergy International 2019). Figure 19 shows the involved partners in the network.

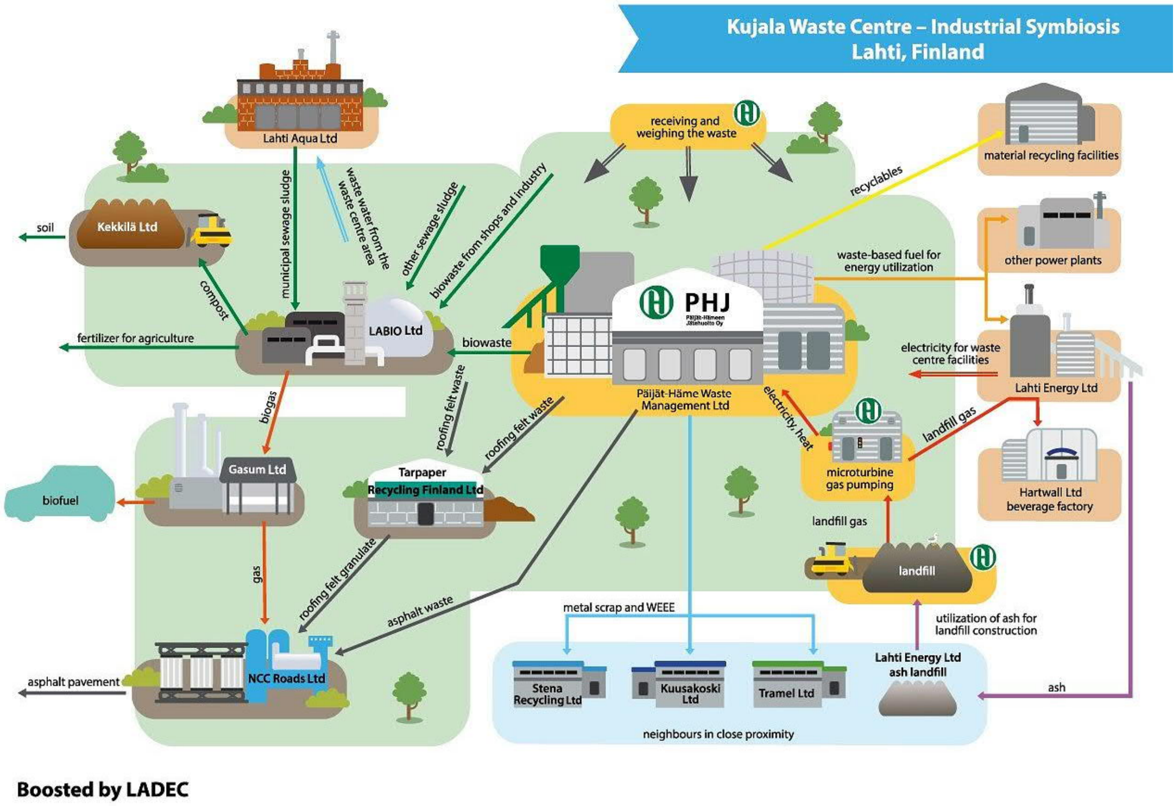

Figure 18 Municipal level centralised biogas plant in Lahti, Päijänne Tavastia (Circhubs 2021)

4.3.3. Case Kiertokaari

Kiertokaari is co-owned by multiple municipalities: Hailuoto, Ii, Kempele, Lumijoki, Oulu, Pudasjärvi, Raahe, Siikajoki. The waste collection includes the owners and the municipality of Simo. The biogas plant was sold to Gasum and now the processed and raw biogas is bought from Gasum. Biogas is also pumped from the Rusko waste management plant and Ruskotunturi. In 2020 9 470 MWh of biogas was pumped and 5 314 MWh was bought by Gasum totalling 14 744 MWh of which 5 675 MWh is sold to the industry and 3 273 MWh as fuel. The 144 MWh heat produced and 5 436 MWh heat and electricity produced are used by the waste management plant. The fuel is sold at the Rusko biogas filling station. The biogas sold to the industry is delivered through a privately-owned pipeline network. The main pipeline was an investment made by Kiertokaari. Nowadays the industrial partners have changed over time and Kiertokaari seeks to expand the amount of clientele. To join the network, the business, need to invest in a connection pipeline as a joining fee. The prices are tied to a moderate index with little fluctuation. The price of the energy is calculated based on monthly measurements. All customers are advised to have an alternative source of energy available. Figure 20 shows the principal actors and actions related to the biogas production of Kiertokaari. (Kiertokaari 2021abc)

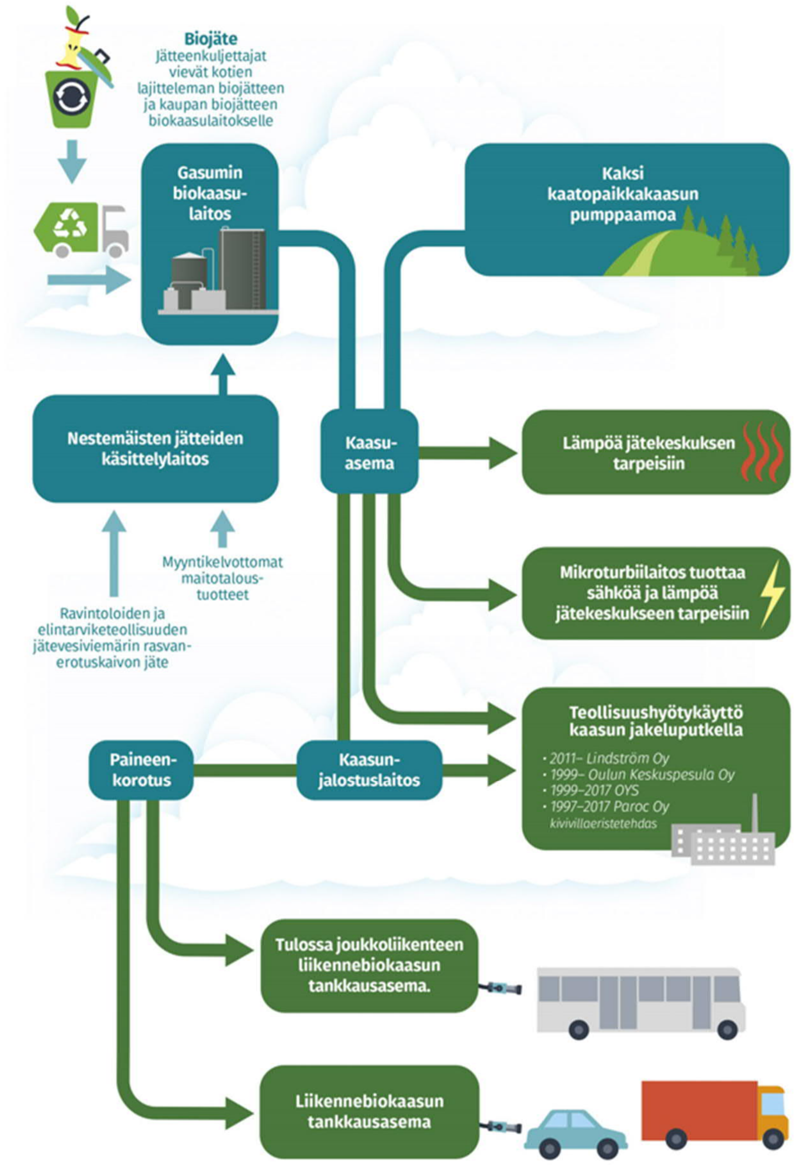

Figure 19 Municipal level centralised biogas plant in Oulu, North Ostrobothnia (Kiertokaari 2021a)

4.4. Distribution and sales of gas centered biogas collaborative models

These are some example of sales and distribution of gas ecosystems in Finland.

4.4.1. Case Gasum – LNG distribution to start in Vaasa

In transportation, there is also an increase in the demand for liquified gas in the heavy-duty vehicle industry (Gasum, 2019), which can also influence the region of Ostrobothnia. A liquified natural gas (LNG) source in Ostrobothnia is under development and liquified biogas (LBG) source may well be built in the future. In Finland, both LNG and LBG sources are available.

The national gas plant owner and distributer Gasum has signed a cooperation agreement with the city of Vaasa, NLC Ferry and Wärtsilä. Gasum will supply Liquified natural gas (LNG). It will be used by Wasaline's vessel and Wärtsilä's Smart Technology Hub. (Gasum 2021) Wärtsilä and Wasaline are clients of the producer of biogas. Wärtsilä constructs gas engines that can run also with biogas. Wasaline is planning to use Wärtsilä's engines. Both organizations depend on the recurring availability of biogas for their operation. Vice versa, the producers are dependent on the demand the potential clients provide. As Gasum will start building the infrastructure and demand for the use of liquified gas it may provide local possibilities for beginning the production of biogas in the form of liquified biogas (LBG). Mixing the two can help users respect the emission targets and limits.

4.4.2. Large plant producing LBG

The biogas plant of Gasum in Turku is the first plant producing LBG in Finland. It was originally built in 2009 and the expansion work for LBG production began in 2019. The plant mainly processes sewage sludge. The centrifuged solid digestate is processed into compost and soil improvers by a partner company. Nutrients are recovered from centrifuge reject water as nitrogen concentrates, after which reject water is transported via the sewage system to a wastewater treatment plant. Figure 17 shows the production and distribution processes. (Ojanpää 2020)

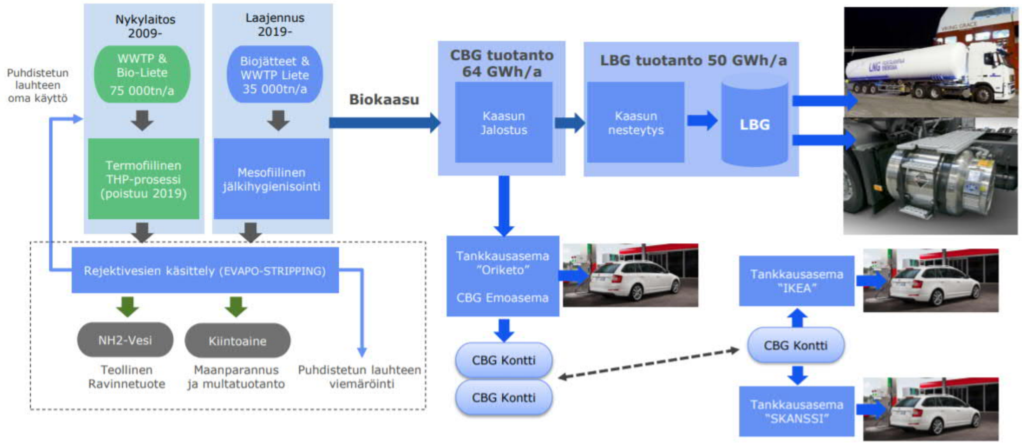

Figure 20 Biogas plant producing CBG and LBG in Turku (Ojanpää 2020)

4.4.3. Transportation collaboration with Gasum

The food waste of Ikea Finland is used in the production of biogas for transportation. Gas stations have been opened next to the IKEA's in Espoo, Vantaa and Raisio. These stations are only for private vehicles. New gas stations are planned for Kuopio and Tampere. In Kuopio it is planned that the gas stations would provide both gas for private vehicles and large goods vehicles. (Bioeconomy 2018)

Lidl has begun using a biogas truck in its logistics. The truck uses biogas liquified biogas and transports products to and waste from its stores. That way the amount of energy and emissions caused by logistics is reduced. (Kauppalehti 2019). The largest national liquified biogas user in trucks is Posti. Posti has begun using 10 liquified biogas fuel trucks and became the largest owner of biogas trucks in Finland in 2020. It had previously invested in 6 trucks using liquified natural gas. (Posti 2020)

4.4.4. SEO – The Finnish Energy Cooperative

SEO, the Finnish Energy Cooperative allows customers to support Finnish entrepreneurship and employment. The cooperative has over 200 filling stations across Finland of which 2 are currently biogas filling stations. It is estimated the amount will increase as society will take more steps towards carbon neutrality. (SEO 2021ab)

5. Central findings from interview analysis

Data about needs, value creation and critical factors of biogas sector actors were collected through a set of 17 semi-structured interviews. The interviewees were selected as they operate within the biogas industry. Most of them hold different roles along the biogas production value chain in Ostrobothnia. Few actors outside of the Ostrobothnia were interviewed to obtain expert knowledge and examples. The interviewees were selected based on an initial list created by the project team, named persons during interviews and electronic sources describing biogas ecosystem examples.

The interviewees described both the current state and estimated future directions of the biogas sector. They also showed distinguishable differences and similarities among actors. The findings introduce central findings through table 9 below. The table is followed by further description of each finding illustrated by quotes of interviewees.

Table 12 Central findings from interview analysis – description of current and estimated future directions

Needs	Value creation	Critical factors	Differences	Similarities
Collaboration	Aid	Legal	Priority	Incentives
Clear legislations & Aid	Public procurement	Marketing	Ways-of-working	Financial, legislative, market emerging, environmental
Interaction between actors	Gate fee	Infrastructure development	Private, municipal and actor size	Challenges
Collection of feedstock	Ownership	Biomass availability	Financial possibilities	Pricing, ability to see the opportunities and evaluating them, solving the challenges, infrastructure and evaluating the whole.
Long term plans	Knowledge and development	Knowledge (broadly, general and practical)	Knowledge	
Broad thinking	Accounting environmental sustainability values more strongly.		Availability of feedstock and type of feedstock.	
Continuity				
Price				

Infrastructure				
Customer identification				

Biogas was recurrently considered a source of energy that can contribute positively to the emission reduction goals worldwide at EU and national levels by interviewees. The economic potential was also brought up in regards to income and local source use. However, the emission reduction value to Ostrobothnia was not brought up by itself. Instead, the branding potential was brought up as well as the nutrient cycle value to the area were mentioned.

Sector coupling and forerunner in energy transition

The most commonly raised issue (by interviewees) was that biogas is related to climate issues and subsequent legislative changes. In the interviews, as well as the recent EnergyVaasa Talks 2021 held by VEBIC (26.05.2021) focusing on the future of gaseous fuels, biogas was considered part of the change in the energy industry. The transition will focus increasingly on decentralising, from the dependence on specific energy sources and instead move towards diversification and global energy markets. Therefore, building collaboration models for biogas actors in Ostrobothnia is not only a step towards building synergies and sharing resources within the biogas sector. In addition, it could act as a stepping stone to a larger change in actions. Central to this is to have actors of different levels: macro, meso and micro and across each level working with each other.

> “At national level electricity and lately also hydrogen has joined the discourse and its use. The issue with biogas is that it does not have much of a position as part of a larger discourse except in Finland and a little bit in Sweden.”

5.1. The needs of actors

A core need of actors is to start to collaborate more. As expressed in the interviews, actors are active within their own roles but they struggle to move beyond organisational limits which restricts profiting from biogas opportunities together. Also, based upon the expert discussions in the EnergyVaasa Talks 2021 there appears to be an expected long-term trend moving beyond solely biogas solutions towards sector coupling and global sales of energy.

> “Many of owner organisations produce biogas. So it would be useful to locate new use areas and consequently increase the volumes of gas use.”

Interviewees mention a need for a more supportive environment at the macro level. This includes legislation and aids. Setting the legislative environment so that actors can plan their actions accordingly is considered central. Consequently, stabilising and reducing the changes will decrease uncertainty. Interviewees mentioned multiple upcoming changes to emission reduction targets geographically and in different sectors. This means that actors need to both change and anticipate future directions simultaneously. Almost all interviewees say they (would) rely on aids and other support available since the market is relatively new. Some actors stated a need to have supportive measures available to be attracted toward a business opportunity as the investments are so large and the level of profitability tends to remain low. Thus, justifying the investment choices and lack thereof. Central interviewees to the development of the biogas sector in Ostrobothnia show that actors can benefit from active participation to macro level dialogue and that one has to balance uncertainty and grasping the opportunity to succeed. Meaning, a well thought through risk has to be taken for the sector to advance.

Based on the interviews, at the meso level it seems that organisations are not particularly aware of each other's day-to-day activities and circumstances. Hence, it could be useful for actors to interact with each other more, to learn, understand each other and consequently be able to find out about collaboration possibilities. Interviewed actors recognise development possibilities to the sector but they cannot name the specific direction nor steps towards them. As one interviewee brought up: It could be useful to define a common long-term plan for the biogas sector (or beyond) in Ostrobothnia and then measure its performance.

The biogas specific strengths mentioned by interviewees include its nutrient cycle, economic and sustainable impact which show the shared motivation to develop the sector. Also, interesting business areas that interviewees are eager to explore include digestate processing into fertilizer, biogas liquefication for heavy-duty traffic and vessels and biogas as a source of energy within the industry. In addition to business areas, according to the discussions, education and improvement regarding own activities are planned. The actors should, however, discuss these together during the planning and execution phase to account for those when determining the role of the plan and its influence. It could also be useful if actors could then see the sector as a whole, enabling them to account it when making decisions.

The planning could also allow discussing multiple other themes including emission reduction, branding of Ostrobothnia, branding of own business and ability to work together, roles of actors and their division, the relationship of biogas to other energy sources, best use areas, customer areas and plans to build those, plan to digestate production, the ability to transition and approaches to considering future outlook.

> "If there is no clear view of the future direction, it can lead to very different types of investments which can make the sector disparate. Or if the future is too unclear we don't have the courage to invest."

More practically, interviewees raised that continuity in the supply of feedstock and biogas is needed for customers to feel secure about moving to biogas use. For example, in case the biogas producers should decide to begin liquefication of biogas, the expected customers will be ones requiring large and stable amounts of availability. Thus, engaging farmers and looking for potential collaboration solutions can be valuable. Some interviewees raised that farmers cannot afford to pay gate fees which motivates them to build their own biogas plant. Few actors argue that finding an entrepreneur which would push farmers to provide biowaste and start producing it, could be an option. Another actor estimates that the new waste legislation to households should increase the amount of feedstock arriving to Stormossen consequently increasing production.

> "Do you feel secure to invest in this when you have this, who will be the expert in this, who will be the technical director, because you will need to have one of those."

Based on the interviews it seems there is some struggle in defining what is and should be the role of biogas now and in the future. Establishing the value of biogas as related to other energy sources is important to find where it provides the most value and why and targeting those areas. A value approach would be more than its market price and instead also, highlight its strengths, benefits and role as an energy source. An analysis could help to define customer segments and steps to be taken towards them. Adopting such an approach could help justify the expensive price of biogas as compared to fossil fuels. The benefits of biogas including CO2 emissions and nutrient cycle could serve as a marketing and awareness increase tool to customers and the larger society.

> “What is the most important is to get the nutrients to circulate, such as phosphorus. Gas is really just energy, phosphorus represent the most important part here. And to take carbon back to the ground.“

Many interviewees stated that the gate fees and end price are unattractive, uncompetitive, even unworthy to consider. Therefore, it could be useful to look at the costs comprehensively to find ways to reducing the price. For example, could the purchase of LBG or other biogas products reduce gate fees of feedstock provided. Another example discussed by an interviewee would be customers using a mixture of LNG and LBG which provides benefits of biogas whilst also decreasing the overall price for customers. Generally, a price reduction could be possible by developing work with actors and production to reduce costs. Also having an increasing amount of biowaste used to produce biogas could allow price reduction.

There seems to be a strong need for new infrastructure: Including filling stations and pipe network, but also attachment to terminals and other related infrastructure. It is argued that the number of filling stations should increase, and they should be spread to be near customers. The centre of Vaasa is mentioned as an example of a location from which for example taxis and private customers would benefit from a filling station. In the interviews, some described the ideal route of a potential pipe network that could be built to Ostrobothnia. The pipe network could enable sharing costs between players which could equalise costs and reduce them over time. As it would link the players together, it could also facilitate collaboration between them. The sector coupling idea could also be considered, for example, the possibility to move also hydrogen in the future or to build the two solutions simultaneously. Taking into account sector coupling could also enable taking other aspects of energy sector collaboration to reduce barriers to potential future collaborations across energy sectors. It could also be useful for actors to identify stakeholders on whom to base development steps.

> ”It has been stated that filling stations should be around 15 to 20km away from users. If the distance is larger, people do not buy biogas vehicles nor drive long distances to refuel.”

Interviewees consistently underlined the importance of location and logistics. They added that it is important to have feedstock, production and users not too far from each other. A few mentioned it has been shown that this should not be an issue as there appears to be a considerable amount of feedstock within a reasonable distance from Vaasa (within a 100km radius). Some mentioned that there is a division of greenhouse and animal farming between south and north Ostrobothnia which can influence both location and logistical issues.

> “With one word: price. It may be worth driving more far if it is cheaper there.”

5.2. Value creation of actors

It is argued that for value potential to be addressed aid should be available to those areas. Value is supported by the availability of aid that enables the existence of the sector in many sense. Therefore, aid policies should be aligned to support the specific areas in which improvement is considered beneficial. Some central areas presented include digestate processing and the inclusion of farms.

Public procurement can support the development of the sector comprehensively as we have seen in Vaasa through the feedstock, biogas production, distribution, infrastructure and as a user. A central interviewee to this success story highlighted that it was a result of a lot of work within the city organisation, other organisations, so far as to macro level decision-makers. Many interviewees recognised the many facets of value, simultaneously the city has been able to reduce its emissions and been able to build a sector that supports the local economy.

> "At the city it works, and it wouldn't be working if the city management and council had not put work towards it and then an eager and motivated official like myself would have pushed the issue forward, it is largely about putting work in."

Interviewees argue that some areas hold more value potential than others. In regards to feedstock, the greatest amount is available from farms. Logistically closeness of actors within the value chain is valuable since it reduces costs or sustainably planning logistics both economic and environmental. To producers, value exist in improving their production process. Also, producers can get value from biogas by using it by themselves. For users, the value is built by balancing marketing effects, sustainability, price and compliment with current legislation. Consequently, although the benefits of biogas may be acknowledgeable it is not the most attractive option.

> "In the South of Vaasa, there are feedstock from farms. If these will be utilized in the production of biogas then we will obtain above 6 million kilos of biogas."

The most attractive sector to biogas producers and sellers is transportation, both financially as well as for the environment. Sold for transportation, the profit margin of biogas is the highest, and environmentally it is the most attractive as there are other options available for heating and electricity. More specifically liquified biogas is described as better than electricity for transporting heavy weight to long distances, proposing opportunities in heavy-duty traffic and marine vessels.

> "The heavy-duty traffic cannot be solved with electric options. "

> "The liquified biogas growth is likely to be important in the upcoming years. And it that area there are users in road traffic. So that would mean there could be multiple filling stations for heavy-duty traffic in the area of Vaasa. There is already one in Seinäjoki. But here at the coast, I presume there is not. And then there is the marine traffic in the area of Vaasa."

To distributers increasing the amount of filling stations is attractive as it contributes to the value available for consumers who will then have more filling station options. The distribution network can also benefit from building a distribution network together which consist of moving from the use of trucks to a common pipe that would allow movement of gas between actors. The sellers of biogas can create value by branding biogas to customers. Branding takes place through filling stations as well as customer segments and offering to clients. The interviewees argue for marketing through filling stations as many mention the BIG brand launched by Stormossen with partners.

The production of fertilizer from digestate is described as an attractive area of business in terms of emission reduction and expanding nutrient cycle longevity as well as a business opportunity. However, interviewees also say that since it is a new unexplored market there is a lack of policies, knowledge and profitability. In cases where gas is not used as fuel, it is argued that supply to the industry could be an option. Although the profitability may not be as high, some interviewees state the demand can be attractively large.

Some actors believe that customers will follow rather than they should be present on the way throughout the process. This can result in situations where the offering does not match the wants of customers. This includes missing filling stations, unsatisfied customers, commitment and marketing issues. On the other hand, others argue that one large customer should be present from the start to build commitment. As production has started commitment can be enabled through supply and sales agreements.

The use of gate fees hinders the biogas sector which unfortunately remains largely dependent on this system. To many producers, the gate fees enable their business whilst reducing the attractiveness to provide feedstock to the plant which could help reduce gate fees as a consequence of increased sales. To biomass holders, feedstock provision is a cost, used when no alternative option is available. The cost is paid by the provider or logistic partner. In the case of farmers, starting their own production could allow them to avoid gate fees. Therefore, it could be wise to address the need of feedstock providers to have reduced or no gate fees as well as the dependency on gate fees for biogas production to take place.

> ”The yearly cost is really large.”

The type of ownership affects how the value created is shared and used. The centrality of the biogas to the core business of the organisation and the number of owners can influence the agility to make decisions and the type of decisions made. Some interviewees brought up that multitude of roles that biogas producers currently hold simultaneously (biogas producer, infrastructure builder and seller) is hindering the development of the sector.

The profitability of biogas businesses varies. Where possible owners affect future value creation by the decisions they make regarding investments. The amount of knowledge and ability to develop influence the ability to develop operative and business aspects as well as the ability to be responsive to market development. Generally, starting to develop the sector requires thorough knowledge and skill set. Understanding and acknowledging environmental issues are important to value formation as transitions are happening in energy use of heat, electricity, fuel and fertilizer. At the same time, they are valuable business wise over the long term.

> “They work in two areas so they work as gas distributor, infra builder and gas producer, gas importer.”

Interviewees also outlined that for marine actors the attractiveness of LBG is diminished by its large price as compared to LNG which becomes even larger as the fuel is not taxed in marine. Some stated the measurement approach from the tank does not allow to measure the relatively minimal total emissions of biogas as compared to fossil fuels. Simultaneously, the use of LBG can be a way of marketing oneself as green, emission reducing, forerunner in responsible travelling not only for marine actors but beyond Vaasa, Ostrobothnia and Finland.

> “If you measure the emissions from the vessel. Then, it doesn’t matter if it is biogas or natural gas. The measured amount is the same. And if that is the only factor that matters. Then it makes no sense to use biogas unless it is cheaper or that it can be counted that the emissions released are just returned to nature.”

The nutrient cycle aspect of biogas is considered a major strength by interviewees however the market is perceived the most uncertain since it is a new market. Simultaneously, it is considered a valuable potential product that could replace non-sustainable options and permit circularity.

> “We would need some kind of tool to make use of recycled nutrients. And these aids will be reduced progressively as the market develops.”

When processed the digestate containing valuable products won’t be left on the land of the producers and instead be used where it holds the most value. The digestate processing of the biogas segment suffers from a lack of aid which makes it unattractive and risky although it is also considered attractive, as brought up in the first workshop of this project.

5.3. Critical factors to actors

The law sets the scope of action due to consequential limitations and opportunities. Some central legislations were brought up by interviewees. For municipal players, the amount of household biowaste will increase nationally in Finland which will then increase the potential amount of biogas produced. Public procurement will be pushed nationally towards electric vehicles but the extent of this varies regionally as the goal is only nation-wide. The roadmap for fossil-free transport in Finland will influence private drivers and companies which will have to adjust to the new regulations.

Some interviewees argue that the aid and rights processes should be simplified with more equal guidance and granting styles. Receiving decisions can take a considerable amount of time. Knowledge of procedures has to be acquired and assistance sought as needed. Different parties may provide differing guidance and may offer different aid in the same conditions.

> ”A clarification of support schemes.”

Many interviewees considered marketing to be very important so that the understanding of consumers and stakeholders could increase. To the interviewees, marketing is a tool to maintain current actors within the network and attract new ones. It is also viewed as a way to compete with other actors. If the development of the biogas sector continues the role of marketing may grow as competition increases.

> “A shared marketing. To attract more consumers.”

To remain competitive, it could be beneficial to look beyond own role and the biogas sector to consider the work of organisations within the ecosystem not only now but in the future. This enables sustainable development towards long term goals. Interviewees appeared to already do this to varying extents and to have a motivation to take a step forward together. The relationship between biogas, electrification and hydrogen is discussed by interviewees. The data also show that the need to collaborate is acknowledged. This could include building awareness of the diverse viewpoints of others and taking steps to potentially share roles or divide them differently when judged suitable. In the context of households, the new waste management regulation would provide a good situation to spread information about biogas and raise awareness of its benefits.

The Chicken-egg problem of demand and supply is an issue brought up by interviewees who call for actions to decrease that challenge. Some interviewees argue that the problem has already be addressed and there is a strong base on which to build the sector through a willingness to take measured risk. The development of the infrastructure is a requirement for the sector's development as customers find the closeness of filling stations important. Simultaneously, the availability of feedstock is crucial to the development of the sector.

Some interviewees argue that increasing the amount of knowledge comprehensively, business wise, technically and operationally is important and it would be good to have some sort of educational material available. Other interviewees not as central to biogas production mention they are not too familiar with the sector. VAMK is already planning courses related to counting carbon footprint, carbon neutrality and circular economy which could be interesting to biogas sector actors. The course offering could potentially be extended to discuss biogas related knowledge, renewable energy source networks, sector coupling etc. As the knowledge already exists spread between interviewees and beyond, it would make sense to collaborate in developing educational materials. For new entrants and for current players to improve their skills in biogas production it could be useful to have some materials easily available.

> "What is the challenge is that to if you become a biogas entrepreneur is that knowledge in Ostrobothnia is at a very general level."

5.4. Differences and common characteristics between actors

The interviews show that the extent to which the biogas sector is a priority varies between players. For energy sector players, the area is quite relevant due to change, environmental and legal pressure. To other actors the sector does not appear to be a priority and more important can be other sustainable solutions or the profitability of their business. Currently, the biogas sector is not supported due to the emission measurement approach from the tank rather than well-to-wheel approach, or even the lifetime emission approach. There are cheaper solutions that are in line with the current expectations of emissions reductions. However, the emission reduction goals are expected to rise over time which will make meeting them even more challenging. Emission reduction is a long-term action and therefore companies who look at their sustainability over the long term could benefit by adopting the smarter approach rather than switching multiple times as emission reduction goals grow in ambition. For some actors and use purpose, the use of biogas is a better fit than others. In the best case, biogas is used where it best fits.

Interviewees also demonstrated differences in conditions between sectors and persons. Some sectors and persons among the interviewed appeared more forerunners and eager to develop and others are more careful and conservative. The data showed that in many ways the producers of biogas in Ostrobothnia are forerunners as well as the region in the energy sector as a whole. However, it also disclosed that to players where biogas is not a core activity the role of biogas is not seen as central and incentives are lacking to motivate them. The main reason that was raised was the price and lack of financial support which makes action unworthy. It is also visible that actors to whom biogas is not central appear to have less knowledge of it. Greenhouses, for example, have plastic that should be separated prior to biogas production, limiting their options since such biomass is not accepted at every plant. More largely farmers may be motivated to build their own plants but these motivations are limited by time constraints. To end-users, total cost makes considering other options such as electric vehicles more attractive.

> "First of all the purchasing price is higher to the equipment and then depending on the weather the user costs can also be larger."

The research showed that private companies and municipal actors approach the sector differently. The private sector has more financial pressure to be business-oriented whereas the municipal side is not limited by that necessarily as much, which can allow for example more long term planning. Their income and costs are different. Private companies appear to focus mostly on their business areas whereas municipal actors have many other areas of focus. To municipal actors it is a source of income, it may be more of a cost reduction method and a tool to impact municipal politics than a business opportunity. The type of waste received also varies as municipal players receive feedstock from households and industrial waste streams. The industrial players are more attracted to be client-oriented because their action is based on that. In the case of municipal actors the household's biowaste is collected as required by the law, paid by the households and the revenues are collected by the municipality owners.

The actors also raised common characteristics in the interviews. The actors are motivated by the financial opportunities, such as cost reduction and possibility for additional income, the legislative field, the market orientation, answering to customers wishes and expectations and also their creation. The environment is also important to actors. When considering the goals set by Finland, the EU and globally the goal set will increase in terms of importance in the long term.

> "We have been following the markets within the five years timeframe and from times to times we have accepted budget offer for liquification plants. But we have never had the courage to go there, as there was no market yet. It is not very mature right now either, but it is likely it will be increasing."

The actors also share challenges. The price of biogas influences actors' sales and purchase agreements and customers interest in biogas. Actors need support in growing awareness of possibilities of the biogas sector and to evaluate those. Development organisations and universities can help with this. Actors are finding it challenging to build a path towards the solutions by themselves. The infrastructure is a challenge to all actors and its development means simultaneously large investments and taking risks. Interviewees also demonstrated hardship in evaluating the overall sector beyond their own lens which collaboration within the sector would support.

> "Surveys are always a good base for us when we have to make decisions."

6. Conclusion

There is political and environmental pressure for the renewable energy source market and the biogas market to grow in the EU, Finland and Ostrobothnia. The sector is expected to grow with an increasing focus on LBG. Biogas solutions provide many opportunities of which the main ones include the use of feedstock from farms and agriculture, usage of gas in transportation and processing of digestate. Issues to be considered from a sustainability perspective are the choice of biomass (e.g. challenges in using feedstock from forest biomass, high ILUC or municipal waste if it includes a lot of pollutants), localization of the units to avoid transport and connection costs as well as the size of the plant. Also controlling the possible methane leakages of plants and vehicles is crucial and requires a skilled workforce.

Altogether, the future direction of biogas solutions in Ostrobothnia, as well as Finland, is still unclear due to legislative issues, investment costs and lack of knowledge. Should the biogas industry receive sufficient support the industry can be expected to grow considerably and within different business areas.

The climate strategy of Ostrobothnia includes the following themes: energy management, living and building, traffic, waste management and manufacturing (Pohjanmaan liitto 2015). According to the vision of Ostrobothnia, the Energy coast 2040 includes the following points: In Ostrobothnia, we collaborate energetically and make courageous and long-term decisions; our societies are structurally sustainable and good habitat to a growing population; our region is energy self-sufficient and all energy is produced using renewable sources; our local food, energy, waste management and clean tech knowledge are international and national export products. The goals of the Ostrobothnia climate strategies include: a sustainable energy system; an optimal urban structure; no waste – everything can be a commodity; knowledge, collaboration and trust; and an environmentally smart countryside. (Pohjanmaan liitto 2015)

There are some specific parts related to biogas solutions. The region has planned to reduce the amount of biowaste taken to landfills, use forest-based biomass to replace coal, increase local biomass based energy production and use, develop closed nutrient and material cycles in farmed based energy production, developing the network of biofuel filling stations (Pohjanmaan liitto 2015). The capital of the region of Ostrobothnia, Vaasa is seeking to become carbon neutral by 2035. The carbon emissions have decreased by 28 % between 2011 and 2016 within the capital. (Deloitte 2018)

Following the vision and goals mapped out for Ostrobothnia, it seems that amplifying the availability of biogas solutions would serve the region, both as support for a strong local economy as well as answering the sustainability challenges. More collaboration between regional actors provides opportunities for new, innovative ways to make business, export knowledge and technology while supporting the quality of life by protecting the local biodiversity and combating climate change.

References

Arfan, M. (2019). Biogas Value Chain in Gävleborg Feedstock, Production and Use. Gävle University Press. [online] Gävle University Press. Available at: <http://hig.diva-portal.org/smash/get/diva2:1360909/FULLTEXT01.pdf> [Accessed 29 April 2021].

Big (2021). Big-biokaasu. [online] Big-biokaasu. Available at: <https://big.fi/> [Accessed 29 April 2021].

Bioeconomy (2018). IKEA foodwaste gets a new life as pure Gasum biogas. [online] Bioeconomy. Available at: <https://www.bioeconomy.fi/ikea-foodwaste-gets-a-new-life-as-pure-gasum-biogas/> [Accessed 29 April 2021].

Bioenergy International (2019). Gasum opens LNG/LBG filling station in Lahti. [online] Bioenergy International. Available at: <https://bioenergyinternational.com/storage-logistics/gasum-opens-lng-lbg-filling-station-in-lahti> [Accessed 29 April 2021].

Biohauki Oy (2021). Biokaasu.[online] Biohauki Oy. Available at: <https://www.biohauki.fi/biokaasu/> [Accessed 29 April 2021].

Biolinja Oy (2021). Biokaasulaitos. [online] Biolinja Oy. Available at: <https://biolinja.fi/biokaasulaitos> [Accessed 29 April 2021].

Biotalous (2015). Agroekologinen symbioosi toimii bioenergialla ja kierrättää ravinteet. [online] Biotalous. Available at: <https://www.biotalous.fi/agroekologinen-symbioosi-toimii-bioenergialla-ja-kierrattaa-ravinteet/> [Accessed 29 April 2021].

Ceccherini, G., Duveiller, G., Grassi, G. et al. (2020). Abrupt increase in harvested forest area over Europe after 2015. Nature 583, 72–77. [online] Available at: <https://doi.org/10.1038/s41586-020-2438-y> [Accessed 26 June 2021].

CircHubs (2021). Kujalan Jätekeskus. [online] CircHubs. Available at: <https://circhubs.fi/toimija/kujalan-jatekeskus/> [Accessed 29 April 2021].

Deloitte (2018). Kuntien ilmastotavoitteet ja -toimenpiteet, Liite 2 Suomen 50 suurimman kunnan ilmastoprofiilit. [online] Deloitte. Available at: < https://media.sitra.fi/2018/10/12124312/deloitte-sitra-liite-2-kuntaprofiilit.pdf> [Accessed 26 June 2021].

Demeca (2021). Maatilat kuntoon. [online] Demeca. Available at: < https://demeca.fi/> [Accessed 29 April 2021].

EAFO (2019). WHAT ARE ADVANCED BIOFUELS? [online] Advanced biofuels. European Alternative Fuels Observatory. Available at: <https://www.eafo.eu/alternative-fuels/advanced-biofuels/generic-information> [Accessed 1 June 2021].

EBA (2019). Biogas trends for this year, EBA, Brussels. [online]. European Biogas Association. Available at: <https://www.europeanbiogas.eu/biogas-trends-for-this-year/> [Accessed 29 April 2021].

EBA (2020b). Biodiversity and Farm to Fork strategies: positive push for biogas development. [online] European Biogas Association. Available at: <https://www.europeanbiogas.eu/13412-2/> [Accessed 29 April 2021].

EBA (2021). Sustainable and efficient agriculture - Developing a resource-efficient agriculture [online] European Biogas Association. Available at: <https://www.europeanbiogas.eu/legislation-on-sustainable-agriculture/> [Accessed 16 June 2021].

EEA (2020). Bio-waste in Europe — turning challenges into opportunities. [online] European Environment Agency, EEA Report No 4 published 17 June 2020. Available at: <https://www.eea.europa.eu/publications/bio-waste-in-europe> [Accessed 1 June 2021].

ELY-keskus (2017). Etelä-Pohjanmaan ELY-keskus on antanut lausunnon Jeppo Biogas Ab:n Jepuan biokaasulaitoksen YVA-selostuksesta (Pohjalaismaakunnat). [online] ELY-keskus. Available at: <https://www.ely-keskus.fi/-/etela-pohjanmaan-ely-keskus-on-antanut-lausunnon-jeppo-biogas-ab-n-jepuan-biokaasulaitoksen-yva-selostuksesta-pohjalaismaakunnat-> [Accessed 29 April 2021].

EU. (2020). In focus: Renewable energy in Europe. [online] Energy News 18 March Brussels. Available at: <https://ec.europa.eu/info/news/focus-renewable-energy-europe-2020-mar-18_en> [Accessed 18 may 2021].

Euractiv (2018). Palm oil to be phased out in EU by 2030. [online] Dave Keating in Euractiv News 14 June 2018 (updated: 20 June 2018). Available at: < https://www.euractiv.com/section/future-of-mobility/news/palm-oil-to-be-phased-out-in-eu-by-2030/>. [Accessed 18 May 2021].

Euractiv (2019). The future of biogas in Europe: it's a local affair. [online] Frédéric Simon in Euractiv News 20 September 2019. Available at: <https://www.euractiv.com/section/energy/news/the-future-of-biogas-in-europe-its-a-local-affair/> [Accessed 3 June 2021].

Euractiv (2021). How the EU's Renewable Energy Directive risks destroying Europe's forests. [online] Dominic Scott, Jan Rosenow and Samuel Thomas in Euractiv News 22 June 2021. Available at: < https://www.euractiv.com/section/biomass/opinion/how-the-eus-renewable-energy-directive-risks-destroying-europes-forests/> [Accessed 28 June 2021].

European Commission (2019). Sustainability criteria for biofuels specified. European Commission [online] Available at:<https://ec.europa.eu/commission/presscorner/detail/en/MEMO_19_1656>

European Comission (2019b). Renewable Energy – Recast to 2030 (RED II). EU SCIENCE HUB, European Comission [online] Available at:< https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii> [Accessed 28 June 2021].

European Commission (2020). In focus: Renewable energy in Europe. European Commission [online] Available at: <https://ec.europa.eu/info/news/focus-renewable-energy-europe-2020-mar-18_en> [Accessed 28 June 2021].

European Commission (2021). A European Green Deal Striving to be the first climate-neutral continent. European Commission [online] Available at <https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en> [Accessed 28 June 2021].

European Comission (2021b). Land use and forestry regulation for 2021-2030. [Online]. European Commission, Climate Action. Available at: <https://ec.europa.eu/clima/policies/forests/lulucf_en> [Accessed 26 june 2021]

Fagerström, A., Al Seadi, T., Rasi, S., Briseid, T, (2018). The role of Anaerobic Digestion and Biogas in the Circular Economy. Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2018: 8 [online] Available at:

<https://www.ieabioenergy.com/wp-content/uploads/2018/06/Integrated-biogas-systems_WEB.pdf> [Accessed 28 June 2021].

Fredriksson, T., Kainulainen, A., Virolainen-Hynnä, A. Kauppinen, H., Eksymä, R., Tuomi.,T. (2020) KOTIMAISEN BIOKAASUN 2030 TAVOITTEEKSI 4 TWH. [online]. Biokaasu2030 Available at: <https://biokaasu2030.fi/> [Accessed 29 April 2021].

Gas for Climate & Guidehouse (2020). Market state and trends in renewable and low-carbon gases in Europe. Gas for Climate & Guidehouse [online] Available at: >https://www.europeanbiogas.eu/wp-content/uploads/2020/12/GfC_MSTReport_2020_final.pdf> [Accessed 29 April 2021].

Gas Infrastructure Europe (2020a) European Biomethane Map. Gas Infrastructure Europe [online] Available at:< https://www.gie.eu/product/european-biomethane-map> [Accessed 29 April 2021].

Gas Infrastructure Europe (2020b). LNG MAP Existing and planned infrastructure 2019. Gas Infrastructure Europe [online] Available at: <https://www.gie.eu/product/gie-lng-map/> [Accessed 29 April 2021].

Gasum (2019). Nesteytetyn kaasun käyttö kasvaa raskaassa liikenteessä – Edullinen tapa vähentää päästöjä syy vaihtaa kaasuun. [online] Gasum. Available at: <https://www.gasum.com/ajassa/puhdas-liikenne/2019/nesteytetyn-kaasun-kaytto-kasvaa-raskaassa-liikenteessa//> [Accessed 29 April 2021].

Gasum (2021). Gasum to supply LNG to Wasaline and to Wärtsilä's new technology hub. [online] Gasum. Available at: <https://www.gasum.com/en/About-gasum/for-the-media/News/2021/gasum-to-supply-lng-to-wasaline-and-to-wartsilas-new-technology-hub/> [Accessed 29 April 2021].

Gasum (2021b). Honkajoen biokaasulaitos. [online] Gasum. Available at: < https://www.gasum.com/kaasusta/biokaasu/biokaasulaitokset/honkajoen-biokaasulaitos/ >[Accessed 29 April 2021].

Gasum (2021c). Vehmaa biogas plant. [online] Gasum. Available at: <https://www.gasum.com/en/About-gas/biogas/Biogas-plants/vehmaa-biogas-plant/> [Accessed 29 April 2021].

Gasum (2021d) Gasum biogas plants in Nordics. [online] Available at: <https://www.gasum.com/en/our-operations/biogas-production/biogas-plants/> [Accessed 1 June 2021]

Gasum (2021e) Together towards a carbon-neutral future. [online] Available at: <https://www.gasum.com/en/About-gasum/Information-about-Gasum/Gasum-in-brief/> [Accessed 1 June 2021]

Gustafsson, M and Anderberg, S. (2021). Dimensions and characteristics of biogas policies – Modelling the European policy landscape. Renewable and Sustainable Energy Reviews, 135. [online] Available at: <https://reader.elsevier.com/reader/sd/pii/S1364032120304901?token=9C3FEC868672BBB3B6E68C10BB2601E4909A025D5471063926B888B4B4E1D2A07A958914947F2F4C5B7FD988FD7FE9FC&originRegion=eu-west-1&originCreation=20210806052602> [Accessed 2 June 2021]

Habitus (2021). Hajautettu biokaasun tuotanto ja nesteytys Suomessa. [online] Centria Ammattikorkeakoulu Available at: <https://tki.centria.fi/hanke/habitus/2296> [Accessed 29 April 2021].

Hagman, L., & Eklund, M. (2016). The role of biogas solutions in the circular and bio-based economy. Biogas Research Center. [Accessed 2 June 2021]

Harvey, F. (2020). Europe losing forest to harvesting at alarming rate, data suggests - Rise in harvesting could affect ability to combat climate crisis due to carbon absorption capacity reducing [online] Trees and forests in The Guardian 1 July 2020. Available at: < https://www.theguardian.com/environment/2020/jul/01/europe-losing-forest-to-harvesting-at-alarming-rate-data-suggests> [Accessed 16 June 2021].

Honkajoki Oy (2014). Honkajoelle rakennettava biokaasulaitos täydentää kierrätysideologiaa. [online] Honkajoki Oy. Available at: <https://www.honkajokioy.fi/honkajoelle-rakennettava-biokaasulaitos-taydentaa-kierratysideologiaa/>[Accessed 29 April 2021].

Honkajoki Oy (2021). Kasvua kierrättämällä. [online] Honkajoki Oy. Available at: < https://www.honkajokioy.fi/> [Accessed 29 April 2021].

Huttunen, M. J., Kuittinen, V., & Lampinen, A. (2018). Suomen biokaasulaitosrekisteri N:o 21. [online] UEF. Available at: <http://epublications.uef.fi/pub/urn_isbn_978-952-61-2856-6/urn_isbn_978-952-61-2856-6.pdf> [Accessed 10 May 2021].

ICCT (2018). Analysis of high and low indirect land-use change definitions in European Union renewable fuel policy. [online] Working paper 15th November 2018 by Stephanie Searle and Jacopo Giuntoli. The International Council on Clean Transportation. Available at: <https://theicct.org/publications/analysis-high-and-low-iluc-definitions-eu> [Accessed 1 June 2021].

IEA (2018). The role of Anaerobic Digestion and Biogas in the Circular Economy [online] IEA Bioenergy Task 37 August 2018. Available at: < https://www.ieabioenergy.com/blog/publications/the-role-of-anaerobic-digestion-and-biogas-in-the-circular-economy/> [Accessed 1 June 2021].

IEA (2020). Outlook for biogas and biomethane: Prospects for organic growth. [online] World Energy Outlook special report. Fuel report March 2020. Available at: <https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth> [Accessed 1 June 2021].

Industriellekologi (2021a). Norrköping Industrial Symbiosis Network. [online] Industriellekologi. Available at: <http://www.industriellekologi.se/symbiosis/norrkoping.html> [Accessed 29 April 2021].

Industriellekologi (2021b). Lidköping Industrial Symbiosis Network. [online] Industriellekologi. Available at: <http://www.industriellekologi.se/symbiosis/lidkoping.html> [Accessed 29 April 2021].

Industriellekologi (2021c). Industrial Symbiosis in Helsingborg. [online] Industriellekologi. Available at: <http://www.industriellekologi.se/symbiosis/helsingborg.html> [Accessed 29 April 2021].

Jalotofu (2021). Rohkea askel kohti kiertotaloutta ja energiaomavaraisuutta: rakennutamme oman biokaasulaitoksen! [online] Jalotofu. Available at: <https://jalotofu.fi/rohkea-askel-kohti-kiertotaloutta-ja-energiaomavaraisuutta-rakennutamme-oman-biokaasulaitoksen/> [Accessed 16 June 2021].

Kaasuautoilijat ry (2019). Kysymyksiä biokaasusta [online] Kaasuautoilijat ry. Available at: <https://kaasuautoilijat.fi/2019/07/01/10-kysymysta/> [Accessed 26 June 2021].

Kaasuautoilijat ry (2021). Kaasun tankkaaminen - Tankkausasemat. [online] Kaasuautoilijat ry. Available at: <https://kaasuautoilijat.fi/2019/07/24/tankkausverkosto/> [Accessed 29 April 2021].

Kauppalehti (2019). Biojätteestä biokaasuksi – näin Lidl hyödyntää hävikin polttoaineeksi. [online] Kauppalehti Available at: <https://studio.kauppalehti.fi/gasum-puhtaampaa-energiaa/biojatteesta-biokaasuksi-nain-lidl-hyodyntaa-havikin-polttoaineeksi> [Accessed 29 April 2021].

Kampman, B., Leguijt, C., Scholten, T., Tallat-Kelpsaite, J., Brückmann, R., Maroulis, G. , Wageningen Research: Lesschen, J. P., Meesters, K., Sikirica, N., Elbersen, B. (2017). Optimal use of biogas from waste streams An assessment of the potential of biogas from digestion in the EU beyond 2020 [online] European Commission. Available at: <https://ec.europa.eu/energy/sites/ener/files/documents/ce_delft_3g84_biogas_beyond_2020_final_report.pdf> [Accessed 1st June 2021].

Kiertokaari (2021a). Kiertotalouden edistäminen ja hiilineutraliteetti. [online] Kiertokaari Oy Available at: <https://kiertokaari.fi/kiertokaari-oy/kiertotalouden-edistaminen-ja-hiilineutraliteetti/> [Accessed 29 April 2021].

Kiertokaari (2021c). 2020 Vuosikertomus. Kiertokaari [online] Available at: <https://kiertokaari.fi/wp-content/uploads/2021/04/KIERTOKAARI_vuosikertomus2020-low2.pdf> [Accessed 14 April 2021].

Kiertokaari Oy (2021b). Kiertokaari Oy:n tehtävä. [online] Kiertokaari Oy Available at: <https://kiertokaari.fi/kiertokaari-oy/tehtava/> [Accessed 29 April 2021].

Knuts, T., Östberg, G., & Hautala, R. (2020). Pohjanmaa Matkalla Muutokseen Kestävän kehityksen ja kiertotalouden tiekartta. [online] Available at:<https://www.vasek.fi/cerm-tiekartta/> [Accessed 26 June 2021]

Kuntaliitto (2019). Kuntien kiertotaloustärpit - Vaasa: Kotitalouksien biojätteet ja lietteet hyödynnetään joukkoliikenteen ja yksityisautojen biopolttoaineena. [online] Kuntaliitto. Available at: <https://www.kuntaliitto.fi/yhdyskunnat-ja-ymparisto/ymparisto/kiertotalous/kuntien-kiertotaloustarpit/vaasa> [Accessed 29 April 2021].

Labio Oy (2021). LABIO Environmentally friendly, reliable and responsible biogas and composting plant in Kujala, Lahti. [online] LABIO. Available at: <https://www.labio.fi/> [Accessed 26 June 2021].

Liikenne- ja viestintäministeriö (2021). LUONNOS FOSSIILITTOMAN LIIKENTEEN TIEKARTTA – VALTIONEUVOSTON PERIAATESPÄÄTÖS KOTIMAAN LIIKENTEEN KASVIHUONEKAASUPÄÄSTÖJEN VÄHENTÄMISESTÄ. [online] Liikenne- ja viestintäministeriö. Available at: <https://api.hankeikkuna.fi/asiakirjat/d99a3ae3-b7f9-49df-afd2-c8f2efd3dc1d/e4e97efb-1f23-4c22-bdf1-f1fc27809030/LAUSUNTOPYYNTO_20210115060016.PDF> [Accessed 29 April 2021].

Lindfors A, Feiz R, Eklund M, Ammenberg J. Assessing the Potential, Performance and Feasibility of Urban Solutions: Methodological Considerations and Learnings from Biogas Solutions. Sustainability. 2019; 11(14):3756. [online] Available at: <https://doi.org/10.3390/su1114375> [Accessed 26 June 2021].

LUKE (2015) New methane bioreactor produces environmentally friendly energy and mitigates climate change [online] Available at: < https://www.luke.fi/en/news/new-methane-bioreactor-produces-environmentally-friendly-energy-and-mitigates-climate-change/> [Accessed 26 June 2021].

Luostarinen, S., Tampio, E., Niskanen, O., Koikkalainen, K., Kauppila, J., Valve, H., Salo, T. & Ylivainio, K. (2019). Lantabiokaasutuen toteuttamisvaihtoehdot. Luonnonvara- ja biotalouden tutkimus 40/2019. Luonnonvarakeskus. Helsinki. 75 s.[online] Luonnonvarakeskus. Available at:

https://jukuri.luke.fi/bitstream/handle/10024/544244/luke-luobio_40_2019.pdf?sequence=1&isAllowed=y [Accessed 26 June 2021]

Metener (2021). Fossiilitaloudesta Biotalouteen. [online] Metener. Available at: <http://www.metener.fi/> [Accessed 29 April 2021].

Molok Oy (2021). Ajantasainen jätelaki – tämä sinun tulisi tietää. [online] Molok Oy. Available at: < https://www.molok.com/fi/blogi/ajantasainen-jatelaki >[Accessed 29 April 2021].

Motiva (2021a). Sybimar Oy, Suljetun kierron konsepti. [online] Motiva. Available at: <https://www.motiva.fi/ratkaisut/uusiutuva_energia/palvelut/greenenergycases/sybimar_oy_suljetun_kierron_konsepti.13.html> [Accessed 29 April 2021].

Motiva (2021b). Uusiutuvan energian RED II – direktiivi. [online] Motiva. Available at: <https://www.motiva.fi/ratkaisut/ohjauskeinot/direktiivit/uusiutuvan_energian_red_ii_-direktiivi> [Accessed 29 April 2021].

Mutikainen, M., Sormunen, K., Paavola, H., Haikonen, T., & Väisänen, M. (2016). Biokaasusta kasvua. Sitran Selvityksiä, (111), 124. Available at: <https://www.sitra.fi/julkaisut/Selvityksiä-sarja/Selvityksia111.pdf> [Accessed 26 June 2021].

Nylund, N., Tamminen, S., Sipilä, K., Laurikko,J., Sipilä, E., Mäkelä, K., Hannula, I., Honkatukia, J. (2015) Tutkiumusraportti – Tieliikenteen 40%:n hiilidioksidipäästöjen vähentäminen vuoteen 2030: Käyttövoimavaihtoehdot ja niiden kansantaloudelliset vaikutukset. VTT [online] Available at: <http://www.transsmart.fi/files/248/Tutkimusraportti_VTT-R-00752-15_liitteineen.pdf> [Accessed 26 June 2021].

Ojanpää M. (2020). Biokaasun ekosysteemi Varsinais-Suomessa. Gasum [online] Available at: <https://circvol.fi/wp-content/uploads/2020/05/Biokaasu-Varsinais-Suomessa-GASUM-20200505.pdf> [Accessed 26 June 2021].

Okkonen & Blomqvist (2020) Biokaasun liiketoimintamalleja -UusiutuWat. Karelia-amk. [online] Available at: <https://energiaraitti.karelia.fi//content/uploads/2020/12/Biokaasun-liiketoimintamalleja_verkko.pdf> [Accessed 26 June 2021].

Pohjanmaan liitto (2015). Pohjanmaan ilmastostrategia 2040 Tausta-aineisto. [online] Pohjanmaan liitto Available at: <https://www.obotnia.fi/assets/Sidor/1/60/Energiarannikko-Pohjanmaan-ilmastostrategia-2040-raportti-1.pdf> [Accessed 26 June 2021].

Pohjanmaan liitto (2020). Alueellinen elpymissuunnitelma tukee vientiteollisuutta ja vihreää siirtymää. [online] Pohjanmaan liitto Available at: <https://www.obotnia.fi/fi/pohjanmaan-maakunta/ajankohtaista-liitosta/alueellinen-elpymissuunnitelma-tukee-vientiteollisuutta-ja-vihreaa-siirtymaa-> [Accessed 29 April 2021].

Posti (2020). Case: Biokaasulla raskaan liikenteen päästöistä 90 % pois. [online] Posti. Available at: < https://www.posti.com/vastuullisuus/kaytannon-esimerkit/case-biokaasulla-raskaan-liikenteen-paastoista-90--pois/> [Accessed 29 April 2021].

Raven P., et al., (2021). Letter Regarding Use of Forests for Bioenergy. To President Biden, President von der Leyen, President Michel, Prime Minister Suga, and President Moon. [online] Scientist Letter to Biden, von der Leyen, Michel, Suga & Moon Re. Forest Biomass February 11, 2021. Available at: < https://www.woodwellclimate.org/letter-regarding-use-of-forests-for-bioenergy/> [Accessed 1 June 2021].

RED II (2018). Renewable Energy Directive (RED II) Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources. [online] Official Journal of the European Union. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32018L2001&from=EN> [Accessed 1 June 2021].

Remeo (2020). Remeo mukana biokaasun tutkimushankkeessa. [online] Remeo. Available at: < https://remeo.fi/remeo-mukana-biokaasun-tutkimushankkeessa/> [Accessed 29 April 2021].

Ruokatieto (2021). Maatalous eri osissa Suomea. Ruokatieto [online] Available at: <https://www.ruokatieto.fi/ruokakasvatus/ruokaketju-ruuan-matka-pellolta-poytaan/maatilalla-kasvatetaan-ruokaa/maatalous-suomessa-perustuu-perheviljelmiin/maatalous-eri-osissa> [Accessed 16 June 2021].

SEO (2021a). SEO HUOLTOASEMAT JA LÄMMITYSÖLJYT. [online] SEO. Available at: < https://seo.fi/> [Accessed 16 June 2021].

SEO (2021b). SEO biokaasu. [online] SEO. Available at: <https://seo.fi/biokaasu/> [Accessed 16 June 2021].

SmartLahti (2021). Kujala waste symbiosis. [online]. Smart & Clean Lahti. Available at: <https://www.smartlahti.fi/content/kujala-waste-symbiosis/> [Accessed 16 June 2021].

Soil Food (2021). Biokaasu- ja bio-etanolilaitokset [online] Soil Food. Available at: <https://soilfood.fi/palvelut-teollisuudelle/biokaasu-ja-bioetanolilaitokset/> [Accessed 16 June 2021].

Suomen Biokierto ja Biokaasu ry (2021). Suomen biokaasulaitokset. [online] Suomen biokaasulaitokset. Available at: <https://www.google.com/maps/d/viewer?mid=1RJ8Zkag_PTw_T3FkLFJohBMtV7g&ll=63.167847105644164%2C22.85462414377998&z=8> [Accessed 29 April 2021].

SYKE (2020) Nutrients, energy and livelihood for the countryside from a biogas plant (BioRaEE). [online] Available at: <https://www.syke.fi/en-US/Research__Development/Research_and_development_projects/Projects/Nutrients_energy_and_livelihood_for_the_countryside_from_a_biogas_plant_BioRaEE > [Accessed 29 May 2021]

The European Biogas Association (2020). Annual Report 2020 European Biogas Association. [online] The European Biogas Association. Available at: < https://www.europeanbiogas.eu/eba-annual-report-2020/> [Accessed 29 April 2021].

The European Biogas Association, Gas Infrastructure Europe, The Natural & Bio Gas Vehicle Association and Sea-LNG (2020). BioLNG in Transport: Making Climate Neutrality a Reality. [online] The European Biogas Association, Gas Infrastructure Europe, The Natural & Bio Gas Vehicle Association and Sea-LNG. Available at: <https://www.europeanbiogas.eu/wp-content/uploads/2020/11/BioLNG-in-Transport_Making-Climate-Neutrality-a-Reality.pdf> [Accessed 29 April 2021].

Tolpo, A., 2020. 15 miljoonan euron biokaasulaitos pakottaa avaamaan kannattamattomia tankkausasemia pikkukyliin: "Jos ei ole asemia, ihmiset eivät hanki autoja". [online] Yle Uutiset. Available at: <https://yle.fi/uutiset/3-11354542> [Accessed 29 April 2021].

Tukes (2021). Natural gas and biogas. [online] Tukes. Available at: < https://tukes.fi/en/industry/natural-gas-and-biogas> [Accessed 29 April 2021].

University of Helsinki (2020). Palopuro Agroecological Symbiosis. [online] University of Helsinki. Available at: <https://blogs.helsinki.fi/palopuronsymbioosi/english/> [Accessed 29 April 2021].

University of Vaasa (2021) Biokaasun hyödyntämismahdollisuudet Pohjanmaalla. [online] Available at: <https://www.uwasa.fi/fi/tutkimus/hankkeet/biokaasun-hyodyntamismahdollisuudet-pohjanmaalla>[Accessed 29 May 2021]

Vaasa (2021). ENERGYVAASA - THE NORDIC HUB FOR ENERGY TECHNOLOGY. Vaasa. [online] Available at:< https://www.vaasa.fi/en/energyvaasa/> [Accessed 29 May 2021]

Valtioneuvosto (2021, 29. April). New government proposal: public procurement of vehicles and transport services must be eco-friendly. Valtioneuvosto [online] Available at https://valtioneuvosto.fi/en/-/new-government-proposal-public-procurement-of-vehicles-and-transport-services-must-be-eco-friendly [Accessed 1 May 2021]

Van der Linden, Reichel, Brusselaars, Winterstetter, Dils, Arnold, Teittinen, Braekevelt & Ullstein (2020). Bio-waste in Europe — turning challenges into opportunities. EEA report 04. [online] Available at: <https://www.eea.europa.eu/publications/bio-waste-in-europe> [Accessed 15 July 2021].

Vanhamäki S., Medkova M., Malamakis A., Kontogianni S., Marišová E., Huisman Dellago D. & Moussiopoulos N. (2019) Bio-based circular economy in European national and regional strategies. International Journal of Sustainable Development and Planning (14:1) 31-43. [Accessed 29 April 2021].

VASEK (2021). Yrityshakemisto. VASEK [online] Available at: <https://vasek.yrityshakemistot.fi/default.asp?op=NaytaYritykset> [Accessed 29 April 2021].

VEBIC, University of Vaasa (26.05.2021) EnergyVaasa talks: Gaseous fuels as a booster of energy transition – reality or a distant dream? [online] Available at: <https://www.uwasa.fi/en/event/energyvaasa-talks-gaseous-fuels-booster-energy-transition-reality-or-distant-dream> [Accessed 26th May 2021].

Virolainen-Hynnä A. (2020). Biokaasun tuotanto ja käyttö Suomessa 2030. Suomen Biokierto ja Biokaasu ry. [online] Available at: <https://biokierto.fi/wp-content/uploads/2020/06/Biokaasu2030_raportti_17062020.pdf> [Accessed 1st March 2021].

Virolainen-Hynnä, A. (2021, 16. helmikuuta). Biokaasusektorin visio ja toimenpiteet 2030 -työpaja.

Watrec (2021). Honkajoen laitos Jatkuvuutta ja toimivuutta tuova jätteenkäsittelyratkaisu. [online] Watrec. Available at: <https://watrec.fi/referenssit/jatkuvuutta-ja-toimivuutta-tuova-jatteenkasittelyratkaisu/> [Accessed 29 April 2021].

Appendix 1 SWOT & PESTEL

		+	-
Internal environment of the biogas sector		Strengths	Weaknesses
		Eagerness to develop the sector, emission decrease possibilities, local economy.	Lack of a common infrastructure, unreliable demand and supply, market is fragmented and little cooperation.

		Moderate market maturity: production technology and some infrastructure. Fair pricing: vehicles and fuels (private vehicles)	
External environment of the biogas sector		Opportunities	Threats
	Political & legal	EU and national legislative environment Taxing regime Public procurement Collaboration	EU and national legislative environment Lack of regional and municipal policies Other non-fossil fuels. Electric cars Certificates and obtaining rights
	Economic	State aid and process integration CNG network	Relies on aid (low profitability), expenses
	Social:	General awareness and municipalities	Lack of knowledge
	Technological	Conforming feedstock (emissions)	
	Environment:	Role of biogas in Circular economy transition both in industry and nutrient cycle closure	Odor and other environmental harm

Appendix 2 Biogas plant examples

Location and Name	Type of biogas business model	Amount	Collaborating parties and ownership of plant	Feedstock	Revenue generation

Uusikaupunki, Southwest Finland Biolinja Oy	Hyvinkää (Palopuro), Uusimaa Palopuro Symbiosis	Mikkeli, Eastern Finland Biohauki Oy
Farm level centralised	Farm level centralised	Farm level decentralised
Capacity: 18 000 t/a Biogas production: 13 932 MWh/a total, 374 MWh/a electricity and 13 558 MWh/a heat.	Raw materials input: 3380 t/a. Biomethane 1628 MWh/a, power 0, fuel 1528 MWh/a and heat 310 MWh/a	Capacity: 14 000 t/a Biogas production: 700 t/a
Collaborators: Biolinja Oy, Pieni Kalatila, VG EcoFuel Oy and Kotipellon puutarha Mimis. Owner: Biolinja Oy	Biogas plant builder: Palopuro Biokaasu Oy. Owners: main owner Nivos Energia Oy, Knehtilä farm, Metener Oy and Lehtokumpu farm.	Owner: owned by Etelä-Savon Energia Oy and 13 local farmers.
Household, shop and restaurants packed and unpacked feedstock, vegetable and gardening wastes, animal manure, dairy and brewery industry wastes and food industry side waste (3rd class)	Farm side streams: mainly silage, also horse and chicken manure	Animal manure, food industry side streams, organic bio granules
Reducing costs by using the biogas for electricity, heating and digestate. Selling district heat to Vakka-Suomen Voima.	Mostly sales of biogas fuel for transport fuel. Also, local use by Knehtilä farm and in organic bakery that will be built in the future.	District heat is sold to Haukivuoren lämpö. Fuel is sold at the e-filling stations next to Biohauki and in Mikkeli.

Central Ostrobothnia Habitus project	Norrköping, Sweden Norrköping Industrial Symbiosis Network	Kankaanpää, Satakunta Industrial area of Kirkkokallio
Farm level decentralised	Industry level centralised	Industry level centralised
10-15 Nm^3/h per farm	Upgraded biogas to vehicle grade (~ 4.2 million Nm3/a).	Capacity: 60 000 t/a Biogas production: 35 GWh/a
Coordinated by the University of Applied Sciences Centria	Municipality of Norrköping, Händelöverket heat and power plant, Lantmännen Agroetanol bio-ethanol plant, Svensk Biogas biogas plant and Econova product producer from waste	Collaboration: Gasum, Honkajoki Oy, Vatajakosken Sähkö, Ownership: Gasum (sold by Honkajoen Biotehdas Ky).
Feedstock collected at multiple farms, processed locally into biogas and fertilizer.	Organic waste from farms, stillage from ethanol plant, organic waste from the city	It manages food industry feedstock including Honkajoki Oy, separately collected biowaste and packed biowaste
Biogas is transported by truck to a share liquification plant. The distance to the liquification plant should make sense to all members of the network Income from selling LBG and savings from processing digestate to use it as fertilizer.	Income from fuel, heat and electricity. Fuel is sold in Norrköping buses and cars. The digestate (~ 48 000 t/a) from biogas production is used by the regional farmers as organic fertilizer	The biogas produced is sold to a nearby energy company’s storage water heater and combined heat and power machine to create electricity, heat and process steam. The digestate is used in the agriculture. The excess water is reused to minimize the use of fresh water.

Vehmaa, Southwest Finland Industrial area of Vehmaa	Oulu, North Ostrobothnia Kiertokaari	Lahti, Päijänne Tavastia Kujala Waste Center
Industry level centralised	Municipal level centralised	Municipal & industrial level centralised
Capacity: 90 000 t/a Biogas production: 30 GWh/a	Capacity: 60 000 t/a Biogas production: 15 000 MWh/a.	Capacity: 80 000 t/a Biogas production: 50 000 MWh/a
Owner: Gasum Multiple industrial collaborators	Kiertokaari is co-owned by multiple municipalities: Hailuoto, Ii, Kempele, Lumijoki, Oulu, Pudasjärvi, Raahe, Siikajoki. Owner: Gasum (plant). Other collaborators: Oulun Energia and industrial players	Owner: LABIO Oy Collaborators: LABIO Oy biogas and composting plant, Tarpaper Recycling Finland Oy waste management plant, Gasum Oy biogas upgrading plant, NCC Roads Oy asphalt station and soil upgrade station
The plant mainly processes enzyme industry side streams, food industry side streams and pig farm sludge.	The plant uses sewage sludge, food industry side streams and household & other separately collected packed biowaste. Biogas is pumped to Kiertokaari from the Rusko waste management plant and Ruskotunturi.	biowaste: households, industry, shops and wholesalers, municipal utilities, farming and forestry, fisheries, horticulture sewage sludge
Biogas from the plant is used to generate electricity and heat with the plant's own CHP engines. Heat is used in the plant's own process and also sold to a nearby greenhouse.	The income from comes the industrial customers energy consumption as well as the fuel sold. Energy is also used by the waste management plant. The processed digestate is used in farming.	The biogas is processed by Gasum Oy which is responsible for the distribution and sale of swan-labelled gas. The digestate is composted to transform it into fertilizer or soil raw material.