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The biogas value chains in the Swedish region of Skåne

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Preface

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Summary

Biogas systems are complex in the sense that they cut across several sectors, mainly agriculture, waste management and energy. Cooperation between actors in these sectors must work for biogas projects to be realised and successful.

The aim of this report is to describe the biogas systems in Skåne from a value chain perspective, including important development pathways. The different segments in the value chain are mapped with regard to actors, actors in supporting activities, technologies and institutions (mainly regulations). Skåne is a fairly small part of Sweden in terms of land area but it is the most important agricultural and food producing region in Sweden and comparatively densely populated. These characteristics explain why Skåne is an important (if not the most important) biogas region in Sweden.

The earliest applications of biogas were for the purpose of reducing the volume of sewage from waste water treatment plants. The biogas produced was used mainly for plant process needs and part of it was often flared. Much of the biogas today, from a variety of types of biogas plants, is upgraded and used for transport. The development towards transport applications can be traced back to the desire to reduce oil dependence and urban air pollution from diesel buses. Initially buses were converted to compressed natural gas, but with regional ambitions for fossil free public transport attention in recent years has turned to compressed biogas.

Biogas value chains have developed in response to sustainability concerns in energy and transport, sewage sludge and waste handling, and in agriculture. The development has generated new business opportunities, especially in the field of upgrading. The production of biogas, for transport fuel, waste handling and fertiliser, is expected to continue to grow in Skåne.

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1 Introduction

Biogas is a renewable fuel that can be produced from a variety of organic materials. Biogas is formed when organic materials are decomposed by microorganisms in the absence of oxygen, also called anaerobic digestion. The biogas produced consists mainly of methane (50-80 %) and carbon dioxide (20-50%). The biogas can be used directly for heat or combined heat and power (CHP) production. If the biogas is upgraded (CO₂ removal) it can be used as vehicle fuel or injected into the natural gas grid.

Biogas can also be produced through thermal gasification of biomass, but the fuel is then normally referred to as biomethane. Production of biomethane can be seen as a complementing technology to anaerobic digestion and is not addressed in any detail in this report.

Biogas systems are complex in the sense that they cut across several sectors, mainly agriculture, waste management and energy. Another characteristic is that the segments in the value chain involve different, often disparate actors. Important actors in the Swedish biogas value chain include farmers, energy companies and municipal waste management and wastewater treatment companies. Hence, the interplay and cooperation between these actors must work for a biogas project to be realised and successful. Also, profitability in each segment (for each actor) is important.

The aim of this report is to describe the biogas systems from a value chain perspective, including important development pathways. The different segments in the value chain are mapped with regard to actors, actors in supporting activities, technologies and institutions (mainly regulations). This knowledge is valuable for policymakers in order to design appropriate policies that support the development of the biogas systems. The geographical focus of this study is Skåne, the most southern county in Sweden. Skåne is a fairly small part of Sweden in terms of land area (Figure 1), but it is the most important agricultural and food producing region in Sweden and comparatively densely populated. These characteristics explain why Skåne is an important (if not the most important) biogas region in Sweden.

2 Biogas production and potentials

The biogas production in Skåne amounted to 288 GWh in 2010, corresponding to 21% of the Swedish production (SEA, 2011). Table 1 shows the distribution of biogas production and end uses/upgrading between different types of plants. In 2010 about 33 % of the biogas in Skåne was produced in *co-digestion plants* which mainly digest food waste from households and restaurants, organic waste from food-producing industries and manure and small amounts of energy crops from farmers (Paulsson, 2012). Most of the biogas produced in these plants is upgraded to be used as vehicle fuel.

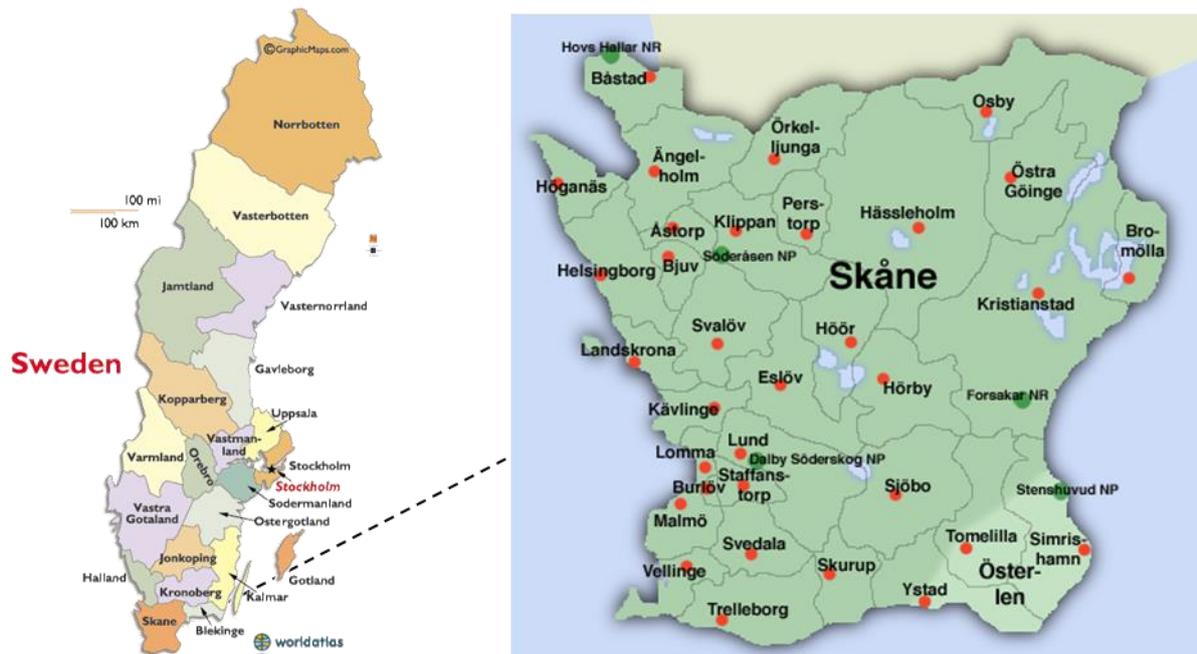


Figure 1: Map of Sweden (left) and Skåne (right). The maps were collected from Worldatlas (<http://www.worldatlas.com/webimage/countrys/europe/lcolor/secountries.gif>) and Naturproduktion Bengt Hedberg (<http://www.naturproduktion-bh.se/maps/skane.gif>).

Table 1: Biogas production and end use/upgrading of biogas in different types of plants in Skåne in 2010 (SEA, 2011; Paulsson, 2012; Biogasportalen, 2012).

Type of plant	No. of plants	Biogas production (GWh)	Biogas utilisation (GWh)				
			Heat	Electricity	Upgrading	Flaring	Missing data
Municipal wastewater treatment plants	24	83.1	43.3	4.5	29.8	5.5	0
Co-fermentation plant	3	94.4	15.7	0	78.7	0	0
Farm-based plant	1	1.1	0.42	0.41	0	0	0.26
Industrial plant	1	23.4	18.8	3.9	0	0	0.71
Landfill plant	10	85.6	79.3	2.3	0	3.9	0
Total	39	288	158	11	109	9	1

Municipal wastewater treatment plants accounted for 29% of the biogas production in Skåne in 2010 (Paulsson, 2012). Biogas production from sewage sludge was introduced already in the 1960s in Sweden, primarily as a means to reduce the volume of sludge and to stabilise the sludge. Today, about half of the municipal wastewater treatment plants (the larger ones) in Skåne produce biogas from sewage sludge (Region Skåne, 2010). Sometimes the sewage sludge is co-digested with other substrates. The biogas is either upgraded or used in production of heat, and to a minor extent production of electricity.

For several years, until 2011, there was only one *farm-based plant* in Skåne (Hagavik) (Biogasportalen, 2012). The plant digests manure and organic waste from a food-producing industry. The produced biogas is used for production of heat that is used internally, and electricity, most of which is sold externally (SEPA, 2012). During 2012-13 another three farm-based plants were built and taken into operation in Skåne (Biogasportalen, 2013).

About 30 % of the biogas produced in Skåne originates from *landfills*. Almost all of this biogas was used in heat production (Paulsson, 2012). Biogas extracted from landfills typically contains a considerable amount of impurities something that complicates upgrading. The

extraction of biogas from landfills will gradually decrease due to the dramatic reduction in landfilling of organic waste. In 2010, only one percent of the municipal solid waste in Sweden was landfilled (Avfall Sverige, 2012). Due to the limited development potential, biogas from landfills will not be described or discussed further in this report.

The potential biogas production in Skåne was estimated to 2927 GWh/y by Björnsson et al. (2011) (Table 2). This estimate is based on the availability of different types of waste and residues, but include no energy crops. The largest (untapped) potential lies in manure and crop residues. A considerable part of the residues consists of straw, which, however, may be more suitable for direct combustion or thermal gasification. There is also considerable potential in expanding the use of industrial waste and food waste, while the untapped potential of sewage sludge is fairly small.

Biogas production in Sweden and Skåne has increased over the past 10-20 years. However, comprehensive biogas statistics is only available for 2005 and onwards. Before 2005, only sporadic data is available. Biogas production in Skåne, and Sweden as a whole, has increased to some extent since 2005 (SEA, 2011). However, the greatest change during 2005-2010 is that the upgrading of biogas in Sweden six-folded (ibid).

Table 2: The biogas production potential based on the estimated availability of different substrates in Skåne (Björnsson et al., 2011).

Substrate	Biogas production potential (GWh/y)
Sewage sludge	124
Food waste	182
Industrial waste	364
Wet manure	243
Solid manure	207
Crop residues (straw)	933
Crop residues (others)	874
Total	2927

3 The biogas value chain

3.1 Segments in the biogas value chain

Figure 2 shows the value chain for biogas and the co-product digestate (bio-fertiliser). The biogas value chain is of fairly local/regional character unlike those of fossil fuels and liquid biofuels. The segments in the value chain are generally located geographically close to each other since transportation of substrates and biogas over long distances is not economically viable. Upgraded biogas may however be transported over moderate distances by truck or through the natural gas grid, thus enabling end use to take place some distance from biogas production and upgrading.

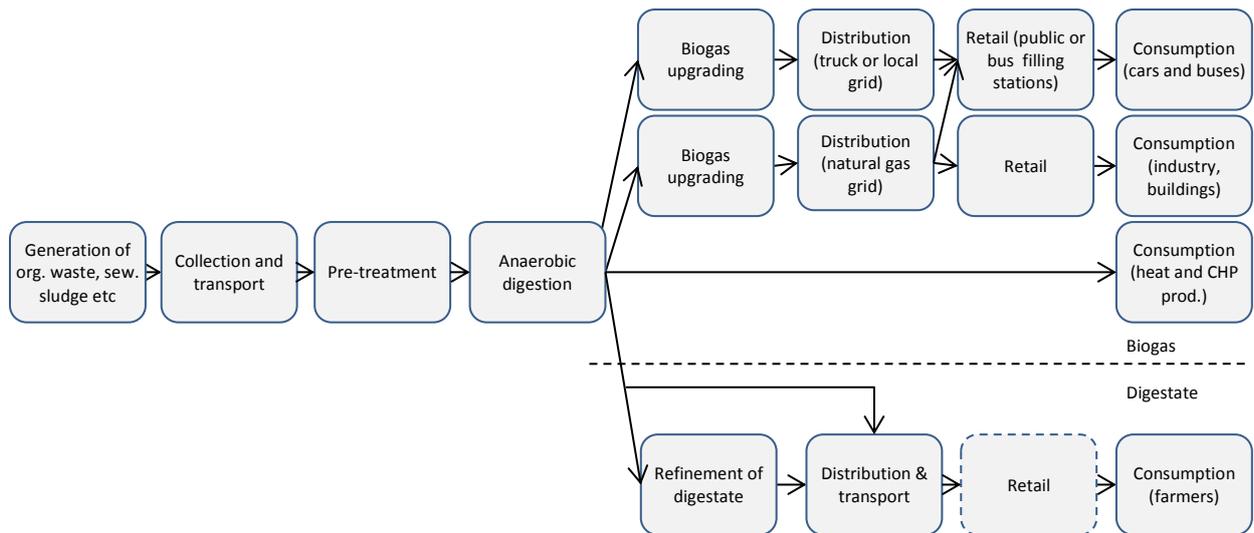


Figure 2: The biogas value chain.

The *generation of feedstock* mainly takes place within agriculture, households, service sector, industry and wastewater treatment plants. Important feedstocks (substrates) include sewage sludge, food waste, industrial organic waste, manure and crop residues. The need for *collection and transport* of the substrate varies between different substrates and the type of biogas plant. Biogas production from sewage sludge is normally located at the municipal wastewater treatment plant, while organic waste from industries and households need to be collected and transported to the biogas plant.

Before the substrate is fed into the biogas reactor it has often gone through some form of *pretreatment* at the biogas plant or somewhere else. The purpose of the pretreatment is usually to reduce the risk of operational disruptions and of contaminated biofertiliser. Depending on the substrate, pretreatment may involve for example size reduction of the material, removal of unwanted material (plastics, metals, etc.) and hygienization (heating of the substrate to kill bacteria).

After pretreatment, the substrate is fed into the biogas reactor (digester) which is the heart of the biogas plant. In the reactor the organic material in the substrate is decomposed by microorganisms in an oxygen free environment, i.e., *anaerobic digestion*, producing biogas and digestate, the residue. The reactors can be designed and operated differently; the anaerobic digestion may be carried out in a dry or wet process depending on the dry content of the substrates/substrate slurry. Furthermore, the digestion may involve one or several reactors that are run in batch or continuous mode, and that may be operated at different temperatures.

The produced biogas is then used in (on-site) *heat or CHP production* or upgraded to be used as vehicle fuel. Many biogas plants use at least a minor part of the biogas to produce heat required for heating the biogas reactor. Some biogas plants also produce heat for other internal/local demands at the farm, wastewater treatment plant, etc. However, local heat demand is often fairly limited unless it is possible to feed the heat into a district heating network.

The biogas must be upgraded in order to be used as transportation fuel or fed into the natural gas grid. The *upgrading*, i.e. cleaning of the biogas, should increase the methane content to at least 97 % by removing carbon dioxide, water vapour and different impurities.

The means of *distribution and transport* of the upgraded biogas differ depending on location. Part of the upgraded biogas that is produced along the west coast of Skåne is injected into the natural gas grid (In Sweden as a whole, 26 % of the upgraded biogas was injected the gas grid in 2011). The gas grid consists of one high-pressure grid and a number of low pressure grids to which most consumers such as filling stations are connected. Currently, (upgraded) biogas is only injected into these low pressure grids (Lantz, 2013). There are five injection points to the natural gas grid located in Skåne (SEA, 2011). Before upgraded biogas is injected into the natural gas grid, liquefied petroleum gas (LPG) is normally added to it in order to adjust the heating value so that it corresponds to that of natural gas. In mid and eastern Skåne the upgraded biogas may be fed into a local gas grid that supplies local filling stations with fuel. This is the case in for example Kristianstad (SEPA, 2012). Another option that is also applied is to compress and bottle the upgraded biogas in gas tubes (about 200 bars) and transport them by truck to filling stations.

In 2010, 94% of the upgraded biogas in Sweden was used for transportation (SEA, 2011). *Retail* of this biogas is done through filling stations that offer vehicle gas. The vehicle gas sold in Sweden generally consists of both upgraded biogas and natural gas. The exact composition varies depending on location and time of year ;in 2011 upgraded biogas accounted for 62% of the vehicle gas sold in Sweden (SEA, 2012). At the filling station the vehicle gas is compressed to 200-250 bars. There are essentially two types of vehicle gas filling stations, those available to the public and those dedicated for buses and other heavy vehicles. In 2012 there were 138 public filling stations for vehicle gas in Sweden, and in addition 57 non-public stations (Gasbilen, 2013a). These are located in mainly southern Sweden, not least in Skåne.

The *end use* of upgraded biogas is mainly as transportation fuel (94% of the upgraded biogas). In Skåne at least two thirds of the upgraded biogas is used in buses (Skånetrafiken, 2011), and the remaining part is used in passenger cars (private and municipal) and trucks (mainly municipal waste collection vehicles). The remaining 6% of the upgraded biogas was mainly used for heat purposes (SEA, 2011).

Apart from biogas, the anaerobic digestion produces a residue, the digestate. The digestate consists of the organic material that has not been decomposed in the digester, water and nutrients, mainly nitrogen, phosphorus and potassium. The digestate may therefore be used as fertiliser, thus closing the currently broken nutrient cycle. Nearly all digestate from co-digestion and farm-based plants, and about one quarter of the digestate from wastewater treatment plants, are used as fertilizer in Sweden (SEA, 2011).

In order to increase the quality of the digestate, *refining*, such as dewatering and the addition of micronutrients, could be applied. So far, such treatment is rarely (if at all) applied in Skåne. The digestate has high water content, something that constrains the reasonable distance for *transportation*. The digestate is generally transported from the biogas plants to farmers in the vicinity by road carriers and in at least one case (Helsingborg) by pipeline (SEPA, 2012). The lower use of digestate from sewage sludge as fertiliser can be explained by the fact that this digestate may contain various unwanted substances such as heavy metals, environmental toxins, and pharmaceutical compounds which should not be spread on agricultural land. Other uses of digestate include production of planting soil and as filling material at old landfills (Tamm and Fransson, 2011).

3.2 Actors and networks

3.2.1 The biogas value chain

The main actors in the biogas value chain are: i) farmers, ii) food-producing industries, iii) municipal waste management and wastewater treatment companies, iv) energy companies and v) municipalities and regional authorities. Appendix 1 summarises what segments the different types of actors are involved in and gives examples of actors in Skåne.

Farmers are so far mainly involved in the biogas value chain as feedstock suppliers and as end users of bio fertiliser. During the past 1-2 years, farmers have, however, also become increasingly involved in biogas production. Currently (in 2013) there are four farm-based biogas plants in Skåne (at the farms of Hagavik, Maglasäte, Norup, Edenberga and Skea), and more are being planned. Several biogas plants that are currently being planned in Skåne involve farmers as co-owners with energy companies, e.g. in Dalby (Lunds Energikoncernen) and Jordberga (E.ON).

Food producing industries are important suppliers of feedstock to biogas plants and their waste products are generally attractive substrate for anaerobic digestion. One example is the co-digestion plant in Bjuv that digests farm-based substrates and waste from Findus, a nearby food producing industry. The biogas plant is co-owned by a farm-based family company, Wrans Gunnarstorp Gods, E.ON and a Danish entrepreneur (SEPA, 2012).

In Sweden, the municipalities are responsible for wastewater treatment and waste management. *Municipal wastewater treatment and waste management companies* are important actors in several segments of the biogas value chain, especially collection and transport of substrate, biogas production and to some extent biogas upgrading. Only NSR, the waste management company in Helsingborg is active in retail of upgraded biogas. Sometimes, substrate collection, biogas production, upgrading and distribution are carried out by different subsidiary companies to the waste management company or wastewater treatment company. For example, in the municipality of Kristianstad (north-eastern part of Skåne), Kristianstad Renhållning takes care of collection and transport of waste (substrate) while its subsidiary Kristianstad Biogas is responsible for the co-digestion biogas plant. Kristianstad municipality is also involved in biogas production at the local wastewater treatment plant. In the west of Skåne, along the natural gas infrastructure, the municipal waste management and wastewater treatment companies are less involved in biogas upgrading, distribution and retail, segments that are instead handled by energy companies.

The natural gas grid in Skåne is owned by three *energy companies* (E.ON, Lunds Energikoncernen and Öresundskraft) which are important actors in the downstream segments of the biogas value chain, i.e., biogas upgrading, distribution and retail. Lunds Energikoncernen and Öresundskraft are owned by the municipalities of Lund and Helsingborg, while E.ON is a German private energy concern that operates internationally. With few exceptions, the public gas filling stations in Skåne are owned by one of these three energy companies. In a few cases the energy company owns the filling station jointly with an oil company. E.ON is also involved as co-owner of a biogas plant (with VASYD) and is investigating a number of new biogas plants that they would co-own. Also, Lunds Energikoncernen is investigating the opportunity of co-owning a biogas plant with farmers.

Municipalities and regional authorities are important consumers of upgraded biogas for their own vehicles fleets and public transportation. Skånetrafiken is a particularly important actor within public transportation in Skåne. Skånetrafiken is part of Region Skåne, a regional public body, and is responsible for public transport on city buses in 10 major cities, region buses and trains in Skåne. Skånetrafiken consumed about 15.2 million Nm³ of vehicle gas in their buses

in 2010, 49% of which was upgraded biogas, i.e., about 72 GWh of upgraded biogas (Skånetrafiken, 2011). Skånetrafiken hence consumes about two thirds of the upgraded biogas produced in Skåne, and their demand is likely to increase in the near future. Skånetrafiken aims to use upgraded biogas in all their buses and vehicles by 2020 and thus use no fossil fuels by that year (ibid).

In the future, companies that treat and refine the digestate may become another important group of actors in the biogas value chain. One company in Skåne (Ekobalans) that is trying to enter this market is developing technology for producing a more complete bio-fertiliser based on the digestate by for example adding various micro-nutrients.

3.2.2 The supporting activities

The functioning of the biogas value chain relies on a number of supporting activities carried out by actors such as equipment and gas vehicle manufacturers, plant engineering companies, municipalities and regional authorities, consultants, branch and lobby organisations.

Appendix 2 summarises the type of actors, including examples of actors, that are involved in supporting activities to the different segments of the biogas value chain.

The biogas plants are generally designed and built by plant engineering companies. These companies are often specialised on certain types of biogas plants with regard to substrates and capacity, for example small farm-based plants or biogas plants digesting sewage sludge. The plant engineering companies offer turnkey biogas plants, including pretreatment and anaerobic digestion, and equipment for either biogas upgrading or heat or CHP production. Some engineering companies manufacture some of the equipment and others rely mainly on external suppliers. Some important plant engineering companies that are based in Skåne include Purac Läckeby, Norups Gård and Malmberg Water.

The biogas value chain involves various equipment, some of which are fairly generic and some of which are custom-made for the biogas sector. Examples of equipment include pre-treatment and upgrading equipment, digesters, automation and software, and gas engines. Sweden has a strong position in developing and manufacturing biogas upgrading equipment. Some important companies are Malmberg Water, Purac Puregas, Cryo and Terracastus (the two former are based in Skåne).

R & D is a supporting activity that is carried out by actors in the biogas value chain as well as among supporting actors such as equipment and vehicle manufacturers, plant engineering companies, universities and research institutes.

Using upgraded biogas or vehicle gas requires adapted vehicles. The adapted passenger vehicles used in Sweden are typically bi-fuel vehicles with one fuel tank for vehicle gas and one for petrol. The bi-fuel passenger cars that are currently available on the Swedish market are by Volkswagen, Volvo, Fiat, Opel, Mercedes Benz, Ford, SAAB and Subaru (Gasbilen, 2013b).

Municipalities and regional county boards may play an important role in dissemination of knowledge and information and by creating networking opportunities for various actors. Other important supporting actors include banks and other financing institutions, consultants, and business associations.

In order to increase the confidence for digestate to be used as biofertiliser, thus increasing the value of this product, a number of biogas plants certify their digestate. Many food-producing industries require that their contracted farmers who use digestate only use certified digestate. The certification is carried out by SP Technical Research Institute of Sweden. There are three certification systems, one that applies to digestion of sewage sludge (REVAQ) and two for

plants that digest other substrates (SPCR 120 and KRAV). In 2010, 27 sewage sludge plants and 10 co-digestion plants in Sweden were certified (SEA 2011).

Several segments in the biogas value chain involve transportation services carried out by road carriers. For large biogas plants, road carriers often handle the transportation of substrate to the plant and that of bio fertiliser from the plant to the farmers. Road carriers are also sometimes used for transportation of upgraded biogas to filling stations.

3.2.3 Networks

Important networks for actors in the biogas value chain in Skåne include for example Biogas Syd and Sustainable Business Hub.

Biogas Syd started in 2005 and is a regional association for biogas stakeholders under the Skåne Association of Local Authorities. The association works with biogas issues in the field of business development, environment, technology, economics, agriculture and information but also links to research.

Sustainable Business Hub is a non-profit organisation dedicated to supporting the development and competitiveness of cleantech companies in southern Sweden. Sustainable Business Hub has about 85 members, most of which are private companies. Several members are engaged in the biogas sector.

3.3 Key technologies

Key technologies in the biogas value chain are found within pre-treatment, anaerobic digestion, biogas upgrading and end-use.

Although biogas production through anaerobic digestion in its simplest form is a very old technology, it is today not a fully mature technology. For example, there is still potential to develop technologies for handling and pre-treating substrates that do not digest easily, improve process control and get higher yields per unit of reactor volume, and to improve and develop new upgrading technologies.

The development of upgrading of biogas started later than that of biogas production. Still, some of the upgrading technologies have been applied and developed for about 20 years now and can be considered relatively mature. Three types of upgrading technologies were applied in Sweden in 2010: water scrubbers, pressure swing absorption and chemical absorption. Only the first two technologies were applied in biogas upgrading plants in Skåne (SEA, 2011). A “new” technology that is attracting interest is cryogenic separation in which the biogas is condensed to liquefied biogas (LBG). This technology is not completely new since it is widely applied on natural gas, but the scale is then much larger than what would be feasible with biogas. LBG is more than two times as dense in energy per volume as upgraded biogas (Bauer et al., 2013). The high energy density is advantageous with regard to transportation and distribution. Perhaps most importantly, this property makes LPG an attractive transportation fuel for heavy duty trucks and marine vessels. Today, only one upgrading plant in Sweden, in Lidköping, uses this technology (SEPA, 2012).

Within end-use of biogas, it is often possible to use an adapted form of technology and know-how from the natural gas sector (Lantz et al., 2007). For example, with no or minor adjustments biogas can be used for heat production in boilers developed for natural gas. Similarly, biogas benefits from the development of natural gas as transportation fuel and in CHP production.

There are several technologies available for CHP production from biogas. The maturity and appropriate application vary between technologies. Gas engines, based on Otto or diesel

engine technology are relatively mature technologies suitable for small-scale CHP production. Other technologies include Stirling engines, gas turbines, micro-turbines, and in the longer term, for example, fuel cells.

The current use of vehicle gas in Otto engines in passenger cars and buses can be seen as a mature technology. In the past decade more car models (bi-fuel) have gradually become available on the Swedish market. The bi-fuel cars have two separate fuel tanks and systems, one for petrol and one for vehicle gas, but only one engine, an Otto engine, that can run on either fuel. Buses and trucks, on the other hand, are built for using vehicle gas only. Unlike other heavy vehicles they use an Otto engine which has slightly lower efficiency than a diesel engine. The price of bi-fuel passenger cars is usually about 10% higher than that of a petrol-fuelled car.

In Sweden, the emergence of upgraded biogas/vehicle gas as fuel for buses is clearly linked to the development of natural gas. In 1988, three years after Sweden (Malmö) received its first natural gas by pipeline from Denmark, two buses fuelled by compressed natural gas (CNG) started running in Malmö (Sandén and Jonasson, 2005). Today, the buses in Malmö operated by Skånetrafiken run on vehicle gas (Skånetrafiken, 2011).

Ongoing technical development of so-called dual fuel technology could enable wider use of biogas/upgraded biogas or LBG in heavy vehicles. The dual fuel technology consists of a diesel engine and requires that the fuel mix contains at least 20% diesel apart from the biogas/upgraded biogas or LBG. This technology exists today but is not widely spread. Concerning heavy duty trucks (and marine vessels), main interest lies in using LBG mixed with diesel since this would increase the driving range considerably compared to using upgraded biogas. A very small number of such heavy trucks exist in Sweden today. In the future, LBG could potentially be used in ferries. There are some ferries abroad, e.g. in Norway, that currently use liquefied natural gas (LNG) (Region Skåne, 2011). There is ongoing technical development of dual fuel tractors that would use a mix of biogas (not upgraded) and diesel.

An issue that many biogas producers and other stakeholders identify as important for future development is how to increase the market value of the digestate as biofertiliser (cf Region Skåne, 2011; SEA, 2010). Today, the digestate often lacks market value and is given for free to farmers. One approach to solving this dilemma is certification of the digestate, which is becoming increasingly common. Another approach is to develop technologies for improving the quality of the digestate. This can be achieved by for example adding various micronutrients to the digestate, thus producing a more complete bio fertiliser. Research in this area also involves the development of cleaning technologies for removing heavy metals and other undesired substances. This would enable more digestate from sewage sludge to be used as fertiliser.

3.4 Prices and economic transactions in the value chain

The supply of substrate to a biogas plant generally involves a contract over several years between the supplier and biogas producer (Fagerström, 2010). The price of substrate and the responsibility for transportation of the substrate vary between substrates depending on its alternative uses (opportunity cost) and its attractiveness as substrate in biogas production. The willingness to pay for a substrate is influenced by for example the energy content per tonne of substrate and the need for pretreatment. In areas with more than one biogas producer, competition for substrate may also influence prices. In the case of municipal organic waste (food waste), the biogas plants so far charge a gate fee for taking care of the waste and the

municipal waste management companies take responsibility for transportation (ibid). In the case of a more attractive substrate such as slaughterhouse waste, biogas producers sometimes pay for this substrate, and in other cases the plant receives a small gate fee. In either case the biogas plant organises the transportation of the slaughterhouse waste (ibid). Biogas plants that use manure generally collect the manure for free at the farms that they have signed a contract with (ibid). Often, the biogas producer also returns the digestate for free to the contracted farmers.

For upgraded biogas to be used as transportation fuel, the price of petrol is an important determinant of the overall profitability of the biogas production, as well as the economic margins in the different segments in the biogas value chain. According to an informal agreement between gas distributors and retailers, the price of vehicle gas, i.e. compressed natural gas and biogas, is set 20% lower (based on energy content) than the price of petrol at public filling stations (SEA, 2010). The rationale for pricing it cheaper than petrol is the lower availability of vehicle gas and higher price of bi-fuel vehicles. This price model is, however, likely to change in the near future since upgraded biogas is increasingly competing with diesel rather than petrol.

4 Institutional setting

4.1 Regulative institutions

Biogas production is affected by institutions that concerns agricultural practices, waste management, energy and transportation. There are thus many regulative institutions that shape the condition for biogas production and use in Skåne. All of them will not be mentioned here, but we have tried to capture the most important ones. See Appendix 3 for a summary.

The prospects for biogas production from various types of organic waste are greatly influenced by regulations concerning waste and waste management. In 1999 the EU directive on landfilling was enacted and since 2005 it is illegal to landfill organic waste in Sweden (SFS 2001:512), something that promotes other waste management methods. Digestion of the organic waste (for production of biogas) is one available option; two other alternatives are incineration (for energy recovery) and composting. So far, incineration of waste (MSW) has seen the largest absolute increase (Avfall Sverige, 2012). In order to favour the biological treatment methods, Sweden imposed a tax on incineration of waste in 2006. This tax was, however, considered to be ineffective and was abolished in 2010 (Avfall Sverige, 2012).

The biological treatment methods (digestion and composting) are furthermore supported by the Swedish environmental objectives (Prop. 2000/01: 130) that specify goals on increased recycling of organic materials through composting or digestion. For example, one goal is that by 2015 at least 60% of the phosphorous in the sewage should be returned to productive land, at least half of which should be arable land. No specific policy instruments have, however, been adopted in order to meet the goals on recycling of organic materials.

Two investment programs, the local investment programme (LIP) that ran in 1998-2002 and the climate investment programme (KLIMP) that ran in 2003-2008 have been of great importance for the realisation of biogas projects. Both programs targeted local actors such as municipalities, who could receive grants for long term investments that should, in the case of LIP, benefit the environment, and in the case of KLIMP reduce greenhouse gas emissions. Almost one third of the KLIMP grants were given to biogas related projects which could consist of building a biogas plant or filling station or the purchase of bi-fuel vehicles (Tamm and Fransson, 2011). The subsidies were given to municipalities and bigger companies, and

not to individual farmers. Both programs were managed by the Swedish Environmental Protection Agency.

Since 2009 there is an investment subsidy that targets biogas plants that use manure as main feedstock. The investment subsidy is funded within the Rural Development Programme and is available to farmers only.

The utilisation of biogas is supported by a number of EU and national goals and policy instruments. For example, in 2009 the EU adopted the Renewable Energy Directive which set the target of achieving at least 20% renewable energy sources in the EU gross energy consumption by 2020, as well as 10% of renewable energy in the transportation sector by 2020 (EC, 2009). The former target is broken down and differs between the member states; Sweden should achieve 49% of RES in the gross energy consumption by 2020.

In Sweden biogas and other biofuels (solid, liquid and gaseous) are exempt from energy and carbon taxes regardless if they are used as transportation fuel or in heat production (SEA, 2012). Fuels used in electricity production are not taxed; instead electricity consumption is taxed. Since 2003, electricity production from biogas and other renewable sources is promoted through a quota obligation scheme with tradable renewable electricity certificates. (SFS 2003:113). Since only a small part of the biogas produced in Sweden is used in electricity production, the quota obligation scheme seems to have had limited effect on the biogas development.

The utilisation of biogas for transportation purposes has probably been indirectly supported by the lower taxes applied on natural gas when used as transportation fuel (no energy tax and reduced carbon tax) since vehicle gas is a mixture of natural gas and upgraded biogas. Furthermore, owners of bi-fuel vehicles and other vehicles that meet certain GHG emission requirements are exempt from vehicle tax for the first five years. During 2007-2009, it was possible to receive investment support for the purchase of bi-fuel vehicles (through the so-called "miljöbilspremier"). In 2009, the GHG emission requirements attached to this support was lowered considerably and bi-fuel vehicles are no longer eligible for this support.

Since 2006 large filling stations are required by law (SFS 2005:1248) to provide at least one of renewable fuel. This law has in practice mainly supported the use of ethanol, since such pumps are less expensive to install than pumps for vehicle gas. Since this was expected, the law was complemented by a special investment subsidy for investments in vehicle gas filling stations. The subsidy was introduced in 2006 and available until 2009.

A Swedish standard for the use of biogas as a vehicle fuel was developed in 1999 but a European or international standard may be on its way (SGC, 2011). Certification of both digestate and biogas is not mandatory but can be issued by a number of organisations, such as SP and SGC.

Until 2009 there was a tax on nitrogen in mineral fertilizers, something that promoted the use of digestate as fertiliser.

4.2 Cognitive institutions

The emissions target set by the Swedish government is set to zero net emissions of greenhouse gases by 2050 (prop. 2008/2009:162). Biogas can play a small but important role in fulfilling this target. In 2010 Skåne was appointed pilot county for green development, and biogas was set out to be a particularly important energy carrier to foster (Ministry of Environment, 2010). In 2011 a biogas roadmap for Skåne was launched by Region Skåne (Region Skåne, 2011).

The biogas roadmap sets ambitious goals concerning the development of biogas production and utilisation for 2020 and biogas is considered to be important to enable the reduction of eutrophication, increase competitiveness and knowledge building in the region. Focus is on using biogas as a transport fuel, why upgrading must be supported (Region Skåne, 2011). Innovation strategies and knowledge building is deemed important and one specific goal is that Skåne is to be the world leading region when it comes to education and conferences on biogas. Public procurement and expansions of the gas grid are short run solutions suggested to reach the goal of making biogas available in all of Skåne. Public procurement is supposed to be one of the ways to further promote biogas (ibid).

5 Development pathways¹

As noted initially, biogas cuts across the sectors of energy, waste and agriculture and it is therefore relevant to include all these sectors in an overview of important development pathways. The use of upgraded biogas for cars and buses is relatively unique to Sweden and Skåne. This development can be traced back to the oil-crises when the search for alternative fuels started. After natural gas had been introduced in Sweden (1985/1986 along the southern west coast) it took only three years before CNG buses were introduced in Malmö. CNG was seen as a better alternative for transport than diesel, resulting in less dependence on oil and lower emissions of air-pollutants. Somewhat later, upgraded biogas became recognised as a better and greener alternative than CNG. In that sense, natural gas has paved the way for biogas. However, in another Swedish city, Linköping, upgraded biogas buses were introduced without being preceded by CNG buses (again motivated by oil dependence and environmental concerns).²

Waste handling and wastewater treatment, as noted earlier, has been important drivers of the development. In the early phases, digestion was applied to sewage sludge in order to reduce weight and volume. Biogas was a by-product and it was sometimes flared when there was no obvious use for it in, or near, the wastewater treatment plant. Producing gas for transport or other uses was not a key objective. In the case of wet organic waste from households and industry, for a time during 1980s composting was seen as the main option for handling this waste fraction. The potential for energy, through biogas production, was not widely recognized as an option. But during the 1990s, interest in digesting organic waste for biogas increased, partly driven through new waste legislation and supported through the LIP/KLIMP programs the market started to build.

Driving forces have so far been weaker in agriculture. There was a heated debate in the 1990s and early 2000s on the pros and cons of spreading sewage sludge on farmland, with contamination risks and heavy metals. This may have helped spur attention to risks and the subsequent development of certification schemes and treatment methods also for digestates from fermentation of organic waste and co-digestion plants. Efforts to develop more sustainable agricultural practices and reduce the use of mineral fertilisers in the future may very well become an important motivation for further development of biogas systems.

¹ This section is based on interviews with Göran Strandberg and Liisa Fransson of Lunds Energikoncernen, Pål Börjesson and Lovisa Björnsson of Lund University, Johan Möllerström of Malmberg Water, and Carl Lilliehöök, a currently independent consultant with long experience from biogas projects. Much of the results are also supported in a forthcoming paper by Martin and Coenen (2013) on “Geography of transitions and cluster innovations: the emerging biomass based industry in Southern Sweden”.

² But also in Linköping the initial interest was spurred by the expected introduction of natural gas though plans for a pipeline that were eventually abandoned (UNEP, 2013).

Malmberg Water, a company with a long history of drilling wells for water, and more recently for geoenery, as well as water treatment technology is an interesting example of how a new business may develop. In 1997 the city of Kristianstad wanted to procure biogas upgrading. Malmberg Water decided to make a bid, and won the contract. Although they had no previous experience in this particular application they were well established in water treatment and had process technology expertise. A scrubber was thereafter developed and successfully deployed in Kristianstad in 1999. The upgrading business was initially quite slow, with about 1.5 upgrading units sold per year in Sweden, until around 2007 when a contract was won for a container based turn-key upgrading unit for the German market. Since then, more than 30 plants have been delivered to the German market, mainly to upgrade for injection to the gas grid (in total there are 60 Malmberg plants operating in Europe as of 2013).

The interviews show that there are some interesting pathways for the biogas developments in Skåne. But except for the established use of methane (natural gas) as a vehicle fuel, and perhaps the gas grid on the west coast, there are no notably strong path dependencies (in terms of lock-ins or pathways created by e.g., capital investments, standards, and legislation). Biogas has rather been challenging the existing regimes with, for example, lock-in of transport fuels to petrol and diesel, large investments made in waste incinerators, or established agricultural practices of spreading manure and commercial fertilisers. But sustainability concerns in energy and transport, waste handling, and agriculture have slowly worked in a direction where biogas (for fuel, waste handling and fertiliser) is becoming an increasingly important technology.

Appendix 1 Actors in the biogas value chain, excluding the segment of heat and electricity production from biogas.

Feedstock production	Collection and transport (supply of substrate)	Pretreatment and anaerobic digestion	Biogas upgrading	Distribution of upgraded biogas	Retail	End-use of upgraded biogas
<p>Farmers</p> <p>Municipal waste water treatment VASYD, NSVA, Kristianstad mun.</p> <p>Industry (food processors etc) Findus, Örtofta, Procordia, Scan etc</p> <p>Households and service sector (restaurants etc)</p>	<p>Farmers</p> <p>Municipal waste management comp. VASYD, Kristianstad renhållning, NSR</p> <p>Municipal waste water treatment VASYD, NSVA, Kristianstad mun.</p>	<p>Farmer Hagavik</p> <p>Municipal waste management comp SYSAV Biotec 2012; Kristianstad biogas; NSR</p> <p>Municipal waste water treatment VASYD, NSVA, Kristianstad mun.</p> <p>Energy company E.ON</p> <p>Industry Örtofta Nordic Sugar</p> <p>Entrepreneurs Söderåsen Bioenergi</p>	<p>Municipal waste management comp. Kristianstad biogas; NSR</p> <p>Municipal waste water treatment VASYD, NSVA, Kristianstad mun.</p> <p>Energy companies Lunds Energi, E.ON</p>	<p>Municipal waste management comp. Kristianstad biogas; NSR</p> <p>Municipal waste water treatment VASYD, NSVA</p> <p>Energy companies Lunds Energi, E.ON, Öresundskraft</p> <p>Oil companies (upgraded biogas) OKQ8, Shell</p>	<p>Municipal waste management comp. NSR</p> <p>Energy companies Lunds Energi, E.ON, Öresundskraft</p> <p>Oil companies (upgraded biogas) OKQ8, Shell</p>	<p>Private vehicle owners</p> <p>Public buses Skånetrafiken, Veolia</p> <p>Municipal vehicle fleets</p> <p>Housing companies</p> <p>Industry Scan</p>

VA SYD is a municipal joint authority formed by the water and sewage departments of Burlöv, Eslöv, Lund and Malmö.

Appendix 2: supporting activities to the biogas (and bio fertiliser) value chain.

Feedstock production	Collection and transport	Pre-treatment	Anaerobic digestion	Secondary processing	Distribution and transport	Retail	End-use
Farm equipment	Road carriers	Plant engineering companies <i>Norups Gård; Purac</i>	Plant engineering companies <i>Norups Gård; Purac Läckeby</i>	Plant engineering companies <i>Norups Gård; Purac Läckeby</i>		Filling stations	Bi-fuel vehicles <i>Volvo, Volkswagen, Fiat, Mercedes, Opel</i>
Source separated waste collection equipment <i>WTM AB</i>	Waste collection vehicles	Pre-treatment equipment <i>BioPreplant; MSI Teknik AB; Xylem; Spirac; Läckeby Products</i>	Automation, software (Bioprocess control)	Biogas upgrading equipment <i>Malmberg Water; Terracastus Technologies, Cryo; Purac Puregas</i>		Gas filling station equipment	Vehicle gas buses <i>Volvo, Scania</i>
	Storage of substrate <i>MPG Miljöprodukter</i>			Storage of digestate <i>MPG Miljöprodukter</i>			LBG trucks <i>Volvo</i>
			Bio fertiliser certification <i>SP Sveriges tekniska forskningsinstitut</i>	Bio fertiliser upgrading technology <i>Ekobalans</i>			Gas engines and gas turbines <i>Compower</i>
Consultants	Consultants	Consultants	Consultants	Consultants	Consultants	Consultants	Consultants

Appendix 3: Policies and institutions relevant for the biogas value chain.

Feedstock production (supply of substrate)	Collection and transport	Pre-treatment, primary processing and secondary processing	Distribution and transport	Retail	Consumption
<p>Agricultural policy</p> <p>Waste management policy -Ban on land filling of organic waste -Tax on incineration of MSW (2006- 2010)</p>	<p>-Voluntary municipal collection of food waste</p>	<p>Environmental code -environmental permit Health regulation (if using animal byproducts; hygienization required)</p> <p>Plan and building act</p> <p>Investment subsidies -LIP (1998-2002) -KLIMP (2003-2008) -Rural Development Programme - Swedish Energy Agency investment support</p>	<p>Environmental code</p> <p>Investment subsidies: KLIMP (2003-2008)</p>	<p>Exemption from energy tax Carbon tax on fossil fuels</p> <p>Law on supply of renewable fuels at large filling stations (2006-) EU fuel quality directive</p> <p>Investment subsidies: -KLIMP (2003-2008) SEPA investment support for building of gas filling stations (2006-2010)</p> <p>RES directive and sustainability criteria for bioliquids (and soon? Diogas)</p> <p>Certification of digestate</p>	<p>No vehicle tax first five years (2010-)</p> <p>Free or beneficial parking Vehicle investment subsidy “miljöbilspremie” (2007- 2009)</p> <p>environmentally driven public procurement</p> <p>Exemption from energy tax Carbon tax on fossil fuels ETS</p> <p>Renewable electricity certificates</p>

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