REPORT f3 2016:09B

SYSTEMIC CONSTRAINTS AND DRIVERS FOR PRODUCTION OF FOREST-DERIVED TRANSPORT BIOFUELS IN SWEDEN

PART B: CASE STUDIES

Report from a project within the collaborative research program *Renewable transportation fuels and systems*

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THE SWEDISH KNOWLEDGE CENTRE FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This project is financed and carried out within the f3 and Swedish Energy Agency collaborative research program *Renewable transportation fuels and systems* (Förnybara drivmedel och system).

f3 Swedish Knowledge Centre for Renewable Transportation Fuels is a networking organization which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities
- Carries through system oriented research related to the entire renewable fuels value chain
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

The f3 centre is financed jointly by the centre partners and the region of Västra Götaland. f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020. Chalmers Industriteknik (CIT) functions as the host of the f3 organization (see www.f3centre.se).

Partners engaged in this project are IIIEE at Lund University, KTH Energy Processes, and IVL Swedish Environmental Research Institute. The project results are presented in a report in two parts, A and B.

This document, Part B, contains the following items:

- Case studies for a range of advanced biofuel projects in Sweden studied within the project *Systemic constraints and drivers for production of forest-derived transport biofuels in Sweden* [in Swedish: Analys av systembarriärer för produktion av skogsbaserade drivmedel].
- Case study analysis tables – i.e. analysis tables filled with data drawn from the case studies.

These materials have been utilised as the foundation for the Summary Analysis presented in Part A of the report. For an executive summary of the project, see Part A: Report.

The case studies and the key informants involved are summarised in the table below.

Table A. List of case studies, informants and input to study.

Case Study	Name, role	Organization	Input to study
GoBiGas	Lars Holmquist, Business Strategic Planner; Ingemar Gunnarsson, Development Engineer; Eric Zinn, Biogas Products Coordinator	Göteborg Energi	Case study interview: GoBiGas; Written input to webinar
Biorefinery Norrtorp	Göran Eriksson, Former President	Sekab	Case study interview: Biorefinery Norrtorp
VärmlandsMetanol	Björn Gillberg, President	VärmlandsMetanol	Case study interview: VärmlandsMetanol
Chemrec/Domsjö Fabriker	Jonas Rudberg, former CEO Chemrec; Max Jönsson CEO	Chemrec	Case study interviews: Chemrec plans at Domsjö Fabriker
E.ON	Björn Fredriksson Möller, Project Manager	E.ON	Case study interviews Bio2G
LTU Green fuels	Ingvar Landälv, Project Manager (former VP Technology at Chemrec)	Luleå University of Technology	Case study interview LTU Green fuels
Preem	Sören Eriksson, Product Developer; Åsa Håkansson, Business Developer	In person, 2015-12-10	Case study interview: Preem
RenFuel	Sven Löchen, CEO	RenFuel AB	Case study interview: Renfuel
SunPine/Södra	Gustav Tibblin (Chairman of the Board of SunPine)	Södra	Case study interview: SunPine

Portion B of the full report should be cited as:

Philip Peck, Grönkvist, S., Hansson, J., Lönnqvist, T. and Voytenko, Y. (2016) *Systemic constraints and drivers for production of forest-derived transport biofuels in Sweden – Part B: Case Studies*. Report No 2016:09B, f3 The Swedish Knowledge Centre for Renewable Transportation Fuels, Sweden – available at www.f3centre.se.

It constitutes an important support document to Part A (Peck, P. et al. (2016) *Systemic constraints and drivers for production of forest-derived transport biofuels in Sweden – Part A: Report*. Report No 2016:09A.

Both documents are available at www.f3centre.se.

CONTENTS

1 DETAIL CASE STUDIES

This section contains each case study in full. The phenomena described in each of these cases are then placed within the theory framework(s) in the next section of this document.

1.1 CHEMREC AND DOMSJÖ FABRIKER, ÖRNSKÖLDSVIK

Unless indicated/cited otherwise, the following section is based on an interview with Jonas Rudberg, Porcupine AB, CEO at Chemrec 2000-2008 (performed in September, 2015).

1.1.1 The technology system and localisation

This case study concerns the biofuels production project via gasification from sulphite liquor also called thick liquor at a full-scale (220 MW feedstock, 100 MW product) facility in Örnsköldsvik in connection to Domsjö Fabriker, based on the technology from Chemrec AB. Gasifier scale up is about 35 times the capacity of the LTU Green Fuels pilot plant in Piteå. The Domsjö plant was to have three gasifier trains each having a capacity of 50% of the thick liquor capacity meaning that the gasification plant would have 50% spare capacity. The planned production capacity corresponded to approximately 0.8 TWh/year in the form of 100 000 tonnes per year of DME or 140 000 tonnes methanol per year (Landälv, 2012, personal communication). Thick liquor gasification is performed in an entrained flow gasifier at a relatively high temperature for biomass gasification (1000 – 1100°C), providing a synthesis gas (syngas) for further processing to a fuel.

The reason for the plans to locate the facility at Domsjö Fabriker in Örnsköldsvik was largely due to the network of established contacts. When Chemrec searched for a suitable location of a full-scale facility, the network had good contacts with the owners of Domsjö Fabriker. Domsjö was also experienced in wood chemistry and open-minded for such ideas. But the key driver was the need for new recovery capacity because the existing recovery boilers are old, from around 1960.

The overall energy balance is presented in Table 1. The Chemrec concept represents a swap of major energy flows within the pulp mill. The thick liquor (in the Domsjö case, a sulphite process) is converted into a fuel, methanol, and the new combined plant is taking in more biomass to their existing biomass fed boilers to compensate for the energy loss for not burning the thick liquor.

Table 1. Envisioned production of the planned full-scale facility in Örnsköldsvik[1].

	Planned Production of methanol (tonnes per year)	Planned Production (GWh per year)	Feedstock liquor to gasifier (dry tonnes/d)	Feedstock liquor to gasifier (GWh per year)	Additional Biomass to the site for MeOH prod. (GWh per year)
Stream data	160 000	880	1100	1920	770

The overall conversion efficiency is therefore the quota between produced fuel and increased use of biomass in the system for methanol production. This quota is very much site specific and in the Domsjö case very attractive. The table shows that 770GWh/y of biomass was to be added to generate 880 GWh/y of methanol. On top of this biomass consumption, 360 GWh of biomass was to be added to reach balance in the combined energy system for the old and new plants. This resulted in

[1] Landälv, I. (2012). Personal communication: Ingvar Landälv, Chemrec AB (then), Luleå University of Technology (now) (with J. Hansson, IVL).

an increased power generation of 79 GWh/y compared with the case before introducing the gasification plant.

It is not obvious how to divide the total extra biomass usage (1130GWh/y) into use for heat/power or methanol production. Therefore the combined biomass to methanol and power efficiency can be expressed as (79 + 880)/(770+360)= 0.85 or 85%.

1.1.2 The proponent(s)/initiator and motivation factors for the initiative including partners and networks involved

Chemrec was the initiator of the full-scale facility in Örnsköldsvik. But there is a long history behind (30 year) including several engaged persons and experiences e.g., Stefan Jönsson, Ingvar Landälv, Jonas Rudberg, Jan-Erik Kignell, Ingemar Croon and Max Jönsson with different experiences from the oil industry, forest industry, petro chemistry, and from the plans to build an oil gasification plant in Nynäshamn. The main motivation factor is that black liquor gasification (or in this case thick liquor) is an interesting technique due to high conversion efficiency and the use of biomass flows in existing industry. A joint company owned by Jan-Erik Kignell and Ingemar Croon took the first patent on black liquor gasification in 1986.

Stefan Jönsson, Ingvar Landälv, Jonas Rudberg and later also Max Jönsson aimed at developing gasification in the case of renewable energy. First, focusing in electricity but then shifting to biofuels. Volvo and the American venture capital fond Vantage Point invested in Chemrec.

1.1.3 Reason behind project closure

In May 2012, the new owners of Domsjö Fabriker (Aditya Birla Group) decided to not continue with the project. The project closure depended on the lack of stable policy framework for biofuels for transport. The Swedish government and parliament did not provide any clear and stable long-term rules, which implied that the banks did not want to lend money to biofuel projects. In order to lend money to projects the banks require a so-called “letter of comfort” from the government. In this case, the “letter of comfort” did not include enough guaranties regarding the long-term value of biofuels in relation to fossil fuels. Everything else was settled. All risks except the political were addressed (see below) and the late change of owners of Domsjö Fabriker was not of decisive importance. Thus, by not understanding completely what it takes to finance a biofuel project, the Swedish government stopped the project.

1.1.4 Technical, financial/market-related and political/policy-related risks

All risks except the political had been addressed. The technique was ready for industrial up scaling and was considered mature by world leading EPCs (Engineering, Procurement & Construction companies) that offered to guarantee a functioning facility. All permits and the design were ready etc. The Swedish Energy Agency had decided to support the project with a grant (€55 million, approved by DG Competition). The mill and other involved actors were to provide €145 million but a loan of €150 million was needed.

As indicated above, the political risk (due to the lack of long term rules, CO_2 and energy tax exemption rules only known one year in advance at the time of the decision) influenced the owners’ possibility to continue with the project due to the influence on the possibility to borrow money from the bank. The political risk is the most complex risk to handle in a biofuel project and long-term rules for at least 13 years is needed according to Chemrec and other actors in the biofuels arena. Lack of long-term rules still holds back a number of second generation biofuels projects in Europe and the ambition by EU to support a number of such projects through the so called NER300 support scheme have all failed basically due to the same reason.

1.1.5 Policy instruments/interventions

The lack of long-term policies was crucial for the outcome of this project. According to Chemrec, general policies are not enough to realize new large-scale production of biofuels. Specific support is needed for the first production plants. Chemrec are strong advocates of the so-called price premium model (In Swedish: prispremium-modellen) for production support suggested in the Swedish FFF inquiry. The support model resembles a support model called contract for difference that is used to support investments in nuclear power in the United Kingdom by setting the price for electricity for many years ahead.

A quota system is not considered to provide enough clarity regarding the risk reduction, since a situation could appear when there is an over capacity in the production. Future policies should be designed with the help of experts from financial organisations such as EIB and the World Bank/IFC. These organisations could clarify what is needed from the government to secure bank loans for large biofuel production projects.

1.1.6 Future plans for the (envisioned) project

Chemrec is still investigating other cooperation possibilities.

1.2 LTU GREEN FUELS

The following section is based on an interview with Ingvar Landälv, Project Manager at Luleå University of Technology, formerly EVP Technology at Chemrec (performed in January, 2016).

1.2.1 The technology system

LTU Green fuels is today the name of the pilot plant (circa 3 MW_{th}) for the development of biofuels based on gasification of black liquor (BL) and other biomass-based feedstocks in Piteå utilizing the BLG technology developed by Chemrec. The BL has been retrieved from adjacent Kraft pulp mill since the start of operation in 2005 with synthesis gas (syngas) production and since 2011 with methanol/DME production. Initially focus was on the development of the gasification technology. After the addition of a methanol and DME synthesis plant, biofuels have been produced, with a production capacity of 4 tonnes DME per day see Table 2. The gasification is performed in an entrained flow gasifier at a relatively high temperature for biomass gasification (1000 – 1100°C), providing a syngas that can be used to produce different kinds of Smurfit Kappa biofuels.

The pilot plant has been running approximately 27 000 hours and has produced DME for about 11 000 h. The plant has produced over 1000 tonnes BioDME. The pulp mill started to blend fly ash in the black liquor and its specific energy content was thereby lower than initially planned (plant design was based on no blending of ash) reducing the syngas generation of the gasifier with about 20%. The planned production capacity of DME has achieved by buffering methanol in an intermediate storage.

Table 2. Schematic production and feedstock streams of the LTU Green fuel plant.[2]

	Planned Production, DME (tonnes per year)	Production of DME t/d	Feedstock	Feedstock input (dry tonnes of black liquor per day)	Feedstock input (MW_t)
Stream data	~750	4	Black liquor	20	~3

1.2.2 The proponent(s)/initiator and motivation factors for the initiative including partners and networks involved

Chemrec was the main initiator behind the pilot plant and had realized that the gas was suitable for syngas generation for further conversion to products in 2001. However, the initiative started already in the 1990s. Chemrec was owned by Kvaerner Pulping, who in 1997 received public funding (237 million SEK from the so called “Fabelprogrammet”) for construction of a BLG to Power and heat demonstration plant at the Assi Domän Kraftliner (today Smurfit Kappa) pulp and paper mill in Piteå. The grant also included construction of a pilot plant. The new pilot plant was supposed to be twice the size and to double the pressure compared to the previous gasification pilot plant at Skoghall pulp mill in Karlstad (1994 till 2000) which gasified 1.5 MW_{th} BL at 15 bar. Due to economic reasons the investment was not carried out and Chemrec was sold to a German company group (Babcock Borsig) that now owned the gasification technology. In 2001 Chemrec obtained a patent for a novel concept for production of biofuels from pulp mills. When Babcock Borsig was declared insolvent Nykomb Synergetics became main owner of Chemrec (in 2002).

In 2006, AB Volvo through its subsidiary company VTT (Volvo Technology Transfer) took over ownership together with the American cleantech investment fund Vantage Point. With approval from the Swedish Energy Agency, Chemrec could utilize money from the grant from the “Fabelprogrammet” together with approximately US$20 million in owners funding to build and operate the pilot plant in Piteå. Three subsequent research programs for black liquor gasification including many different partners were also linked to the pilot plant.

The selection of DME was due to the involvement of Volvo and the high conversion efficiency from biomass to methanol and DME. A DME-project (including Chemrec, Total, HaldorTopsoe, Preem and others) received funding from the EU, and the Swedish Energy Agency and was complemented by private funding (2008-2012). VTT, Vantage Point and Environmental Technologies Fund (ETF) invested further approximately US$10 million USD in Chemrec. The project produced BioDME used to fuel 10 Volvo trucks, totally driving about 1.5 million kilometres and was considered a “success story” by the responsible EU case officer.

Chemrec owned the plant until the end of 2012. Since 2013, activities at the pilot plant are led by Luleå Technical University through a holding company and have been financed by the Swedish Energy Agency and a range of other partners. In April 2016, it was announced that the pilot plant would close down due to lack of continued funding.

The three main reasons behind the pilot plant were: 1) to provide data for further up scaling, 2) to test equipment and construction materials, and 3) to test and validate different kinds of pulp mill liquor. The driving force has been to reach commercial scale. The main reasons behind the localization to Piteå were the size of the mill in Piteå combined with Assi Domän’s (today Smurfit

[2] *Ibid.*

Kappa's) and ETC's (today SP ETC) research facilities and the build up of long term experiences in field of wood-related sciences.

1.2.3 Technical, financial/market-related and political/policy-related risks

In order to prepare for up scaling, the gasification of sulphite thick liquor from Domsjö Fabriker (where a demonstration plant was planned) was tested in Piteå with successful result. When the Domsjö project was stopped (see the case study on Chemrec and Domsjö Fabriker) a new grant was approved by the Swedish Energy Agency for continued activities at the pilot plant until 2016. During this period co-gasification of black liquor and pyrolysis oil has been tested (Chemrec holds a patent).

There is a concern that if a full-scale demonstration project is further delayed, the competence will disappear and the patents are no longer valid, etc. Black liquor gasification implies a very drastic change for the pulp mills and competes with current technology and infrastructure. Future oriented mill owners and new strong suppliers are needed according to the interviewee in order for the technology to be chosen. The interviewee further means that the pulp mills are dependent on the suppliers of technology. If they are not in favour of new technologies it is difficult for the mills to invest in them. From a research point of view, gasification of black liquor is regarded as well researched already.

1.2.4 Policy instruments/interventions

In order to increase the scale of this technology there is a need for long-term policy support for second-generation biofuels. 1-2 plants are needed before the technology will be fully commercial. The so-called price premium model (In Swedish: prispremium-modellen) for production support suggested in the Swedish FFF inquiry is a good option. A quota system might work but then high quotas are needed and a market with an acceptable price for the produced biofuels must be guaranteed.

1.2.5 Future plans for the (envisioned) project

The next step for this technology is demonstration in a larger plant that has not been realized (see the case study on Chemrec and Domsjö Fabriker). There are on-going discussions with potential mills, for example Chemrec is still in contact with Domsjö Fabriker. The pilot plant can be further used for gasification of different raw materials. The top of the Chemrec gasifier could e.g. be changed out to an alternative design, which could be fed with solid feedstocks such as wood powder. This would be a cost effective way to develop and test such as system. The plant is also very well suited for development of alternative gas cleaning systems and synthesis processes as well as for test of so-called ”Power to Liquid concepts”.

1.3 BIOREFINERY NORRTORP

This case description is based on an interview with Göran Eriksson (GE), former president of Sekab. Tomas Lönnqvist, KTH, performed the interview via telephone 2015-09-22. A thorough pre-study providing technical data was also utilized.

The proposed project 'Biorefinery Norrtorp' was to produce up to 1.8 TWh_{pa} of methanol and/or methane from forest residues and round wood. The potential to utilize waste heat flows as a marketable by-product was also evaluated. A quite detailed feasibility study was produced that considers differing scenarios for production of methanol, liquefied methane, or a combination of both – the study however, yields no definitive recommendation regarding which scenario is most feasible. Informants to this case study did however indicate that the group slightly favoured methanol production.

1.3.1 The technology system (the initiative)

In general terms, the Biorefinery Norrtorp process is as follows: feedstock reception, drying of feedstock, production of oxygen and nitrogen, biomass gasification, CO conversion and cooling, gas cleaning, sulphur extraction, production of methanol, and production of bio-SNG. The gasification would be performed at high pressure (up to 33 bars) and high temperature (800 - 900°C).

The pre-study describes and evaluates several gasification technologies. One reason for this is that it keeps the choice of end product open (methane, methanol, or a combination of both). It states that if the facility were to produce methane designers and operators would opt for a lower temperature compared to methanol production. The principal gasification technology discussed is pressurized oxygen feed high temperature winkler gasifier, i.e. a modified version of circulating fluidized bed technology. Several technology providers are mentioned in the study. It is likely that a Thyssen-Krupp technology is the favoured choice. This is because of the project partner VärmlandsMetanol already has a working relationship with this technology provider. The anticipated process efficiency is about 65 % for combined methanol and methane production. The efficiency for methane production is similar but the efficiency for methanol production is lower at around 63%. These values are based on LHV and do not consider the use of heat for district heating – they do however include the use of by-product heat flows for internal process purposes.

Table 3 Envisioned production and feedstock streams[3]

Fuel output	Planned production (TWh_{pa})	By-product	Feedstock	Feedstock input (TWh_{pa})	Feedstock input
Methanol and/or methane	1.3 methanol + 0.48 methane	Heat to be used internally to dry feedstock	Forrest residues and round wood	2.8	1 067 000 ton/yr (50% moisture)

1.3.2 The proponents, partners and networks involved

The company Sakab and the Kumla municipality took the initiative. SAKAB[4] was a daughter company of E.ON Sweden, which also joined the project. The project involves (involved) many actors: SAKAB, E.ON Sweden, Kumla Municipality, VärmlandsMetanol, Structor,[5] and Peab.[6] The latter two had minor roles. The project members have been involved in three other methane and methanol projects, GoBiGas, Bio2G, and VärmlandsMetanol. This is because Sakab was a daughter company to E.ON Sweden. The interviewee, GE, also participated in the pre-study for the GoBiGas project on behalf of E.ON.

[3] Fredriksson Möller, B., Gillberg, B., Huhtala, R., Reinholdtzon, A., & Westlind, G. (2013). *Bioraffinaderi Norrtorp*.
[4] SAKAB AB was sold to Ekokem in 2012.
[5] A Swedish company with 400 employees dealing with civil, structural and environmental engineering, see www.structor.se
[6] A Swedish construction company, see www.PEAB.se

1.3.3 Motivating factors for initiative

Biorefinery Norrtorp gathers several actors. These can be assumed to have different motives for the project. The municipality is generally held to be motivated by the promise of regional development achievements. E.ON and VärmlandsMetanol were already involved in this type of projects; although other initiatives opted for different end products and different technologies, they started a cooperation based on the hypothesis that combined production may be more efficient, and this option was of interest. E.ON was also motivated to become familiar with the technology that VärmlandsMetanol had opted for. Sakab was interested in a new business opportunity.

1.3.4 Placement & existing infrastructure

One of the main actors Sakab is based in Kumla. The plant was to be located on their land close to their current activities in an industrial area some distance from the city. GE indicates that this project was to provide an additional income stream for Sakab on which they could spread their fixed costs. This is rather unexpected statement by the interviewee since the investment is very large. It might be explained by that Sakab did not have a major share of the investment. There are also other motives behind the location and one is that the area is an old industrial area with good access to infrastructure, not least railway terminals. There is also certain know-how in the area from previous gasification activities (Supra and Skifferoljebolaget), although GE stresses that this was not one of the major motivating factors since this knowledge is hard to exploit in this project.

The three business cases– production of methanol, methane or a combination of both – demonstrated similar economic performance. This is measured as cost per kWh by the gate. Since the site does not have access to a natural gas pipeline, methane would have to be liquefied to facilitate distribution. Liquefaction is an expensive and energy demanding process. If the same business case were considered for another site with a pipeline it is thus very likely that methane would have shown the best economic performance.

1.3.5 Feedstock/Raw materials supply chains

A combination of forest residues and round wood were considered as feedstock. A forest company, Sveaskog, investigated the possibilities to supply the plant with local feedstock on behalf of the project and concluded that there were insufficient residues in the area for the planned plant capacity. Thus, round wood was also considered. Another reason that this was considered as a feasible option is that Sveaskog expected the price on round wood to drop as the pulp & paper industry is experiencing problems.

1.3.6 Markets for products and waste heat/by-product flows

There is a developed market for methane and liquefied methane in the Swedish transport sector. Methanol however is a rather new product, although it has been used historically as a road transport fuel in Sweden. However, there is a demand for industrial processes and sea transport. There is also now a demand for bio-methanol as an input for the production of biodiesel (replacing fossil methanol). This provides an important pathway for biodiesel based on vegetable oils to lower its overall carbon dioxide footprint.[7]

Initially there were plans to sell excess process heat as district heating to Örebro[8]. GE was personally lobbying for this to happen. However, there was competition from another heat supplier in the municipality of Örebro. As a result, the project Biorefinery Norrtorp was planned with only the option to utilize such surplus heat to dry the incoming biomass.

On the one hand the proponents would like to keep the project within their municipality and on the land they own. On the other hand, they would like to obtain higher overall process energy efficiency, and a revenue stream, via delivery of excess heat to the district-heating grid. Although the interviewee did not mention it directly, there appears to be conflicting goals.

1.3.7 Risk

Multiple risks were recognized within the project. There is of course a technical risk since no gasification plant of this size has been built before. There is also a market risk, especially in the case of methanol as the markets mentioned above are a) under development, and b) subject to competition from established fossil sources, and c) subject to the price of oil and gas that have dropped markedly. There is also a significant risk perception that policy support might not materialize as expected. In addition, there may be political interests in the proponent municipality, Kumla, which can affect the project negatively.

1.3.7.1 Technical

The pre-study acknowledges that there is no experience from biomass gasification at this scale. In addition the end product is not even decided. Thus it cannot be determined which is the most appropriate technology.

1.3.7.2 Financial/Market-related

At the time of the pre-study the oil prices were also more than twice as high as when the interview was conducted (the pre-study is dated 2013-09-17 and the interview was conducted 2015-09-22) (Nasdaq, 2016).[9] The interviewee states that the natural gas price has fallen 40 % from the time of the pre-study until the time of the interview and that this had a strong influence on the decision (not to proceed). In the light of fossil fuel market dynamics over the past 2 years, perceptions of financial and market related risk can be considered higher now that at the time of the pre-study.

1.3.7.3 Political/Policy-related

GE considers the low predictability of policy instruments to be a more significant obstacle than the current period of low oil prices. The low predictability signifies "that it is not an issue of price any-

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[7] Lars Lind, Perstorp Bioproducts AB. *Sustainable biodiesel – Much better than its reputation: Examining feedstock supply and sustainability for biodiesel production,* presentation at Advanced Biofuels Conference, Stockholm Sept. 16, 2015.

[8] E.ON owns a heat and power plant in Örebro.

[9] Nasdaq, 2016. Crude Oil WTI (NYMEX) Price. Available at: http://www.nasdaq.com/markets/crude-oil.aspx?timeframe=3y [Accessed April 1, 2016].

more", according to GE. This comment is interpreted as if the changing possibilities due to policy instruments may completely change the conditions for a profitable production.

The interviewee (GE) stated that the predictability for policy instruments in Sweden is very low – too low to make any investment decisions. GE has the impression that policymakers are fond of supporting the "next thing", which right now is electric vehicles and to some extent also fuel cells. For this reason gasification of forest biomass does not receive the attention of policy makers any longer. The pre-study was made in September 2013. This is only two months before the results from the governmental inquiry regarding a vehicle fleet independent of fossil fuels (FFF) were presented. The interviewee mentions that there were great expectations on FFF and that this influenced their process.

1.3.8 Investment support

The group received financial support from SEA for the feasibility study.[10] As indicated earlier in this text, the project did not consider investment supports like NER 300 because it requires knowledge sharing. For the same reason they do not co-operate with academia. This is a rather remarkable statement given the size of the investment; the investment is estimated to between 6.6 and 6.8 billion SEK depending on if it is optimized for methane or methanol.

1.3.9 The most advantageous/desirable support model

The interviewee suggests a quota obligation that is guaranteed for a longer period of time, as long as 15 to 20 years. This decision should, according to GE, be taken by political parties from both blocks to guarantee stability. He believes that EU cannot consider it as state aid since it is the consumers that pay. According to him the green electricity certificates are an example of a quota obligation that works.[11]

1.3.10 Future plans for the (envisioned) project

The project Biorefinery Norrtorp is currently on hold and has not proceeded beyond the pre-study stage. A steering group has a meeting every second month to evaluate the situation.

The interviewee expressed scepticism towards the general possibilities of producing transport fuels from forest biomass in Sweden as well as towards the specific possibilities of realizing the plans of Biorefinery Norrtorp. GE considers the life-length of policies in Sweden as very short – too short for any investment decisions. GE returns to this topic throughout the interview. The FFF inquiry is mentioned as something they had expectations on and something that affected their process. Prior to the interview, he mentioned GoBiGas and that its value has been written down to zero.[12] As such, GE has interpreted this, and now communicates this is an example of how bad the possibilities are for transport fuels from forest biomass.

[10] Fredriksson Möller, B. et al., 2013. *Bioraffinaderi Norrtorp*

[11] GE is currently the president of Kumbro Vind, which deals with wind energy.

[12] http://www.kemivarldenbiotech.se/nyheter/GoBiGas-anlaggningens-varde-noll/

1.4 VÄRMLANDSMETANOL

VärmlandsMetanol aims at producing methanol from forest residues through gasification. The project concerns a large-scale process, 600 GWh_{pa}, from the commercial technology provider ThyssenKrupp industrial solution (TKIS). This case description is based on an interview with Björn Gillberg (BG), president of VärmlandsMetanol. Tomas Lönnqvist, KTH, performed the interview via telephone 2015-10-08.

1.4.1 The technology system (the initiative)

The process is based on circulating fluidized bed gasification. The interviewee states that the process is similar to the one considered in Biorefinery Norrtorp, but the scale is smaller[13]. Three separate lines for feedstock receptions are planned: round wood, twigs & tops, and wood chips. VärmlandsMetanol has made an EPC (engineering, procurement, and constructing) contract with the technology provider TKIS that guarantees a certain price and performance of the plant.

Table 4. Envisioned production and feedstock streams [14] [15] [16]

Fuel output	Planned production (GWh_{pa})	By-product: district heating (GWh_{pa})	Feedstock (changes over time)	Feedstock input (GWh_{pa})	Feedstock input
Methanol	600	10	Round wood, twigs & tops, and wood chips	900	1000 tons (wet weight) per day

1.4.2 The proponent

Björn Gillberg and the foundation Miljöcentrum took the initiative to VärmlandsMetanol.

1.4.3 Motivating factors for initiative

The interviewee states that only liquid fuels were considered since these may be used as drop-in fuels making use of the existing distribution infrastructure and vehicle fleet. Among the liquid fuels that may be produced from gasification of woody biomass, methanol production has the highest efficiency according to BG. These factors determined the choice to produce methanol.

1.4.4 Partners and networks involved

The actors involved in VärmlandsMetanol are Björn Gillberg, another major shareholder, around 1500 minor shareholders, and the technology provider TKIS. The company is not interested in cooperating with academia. BG states that universities often try to ”re-invent the wheel”. He underlines that a mature technology is available through their provider TKIS. TKIS is also protective about the technology, which may be an additional obstacle for cooperation with academia.

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[13] However the Norrtorp pre-study and the interview regarding Norrtorp says that methanol production was one of three options that were considered.

[14] Grahn, M. & Hansson, J., 2014. Prospects for domestic biofuels for transport in Sweden 2030 based on current production and future plans. *Wiley Interdisciplinary Reviews: Energy and Environment*, p.n/a–n/a. Available at: http://doi.wiley.com/10.1002/wene.138 [Accessed December 19, 2014].

[15] Börjesson, P. et al., 2013. *Present and future sustainable biofuels for transport (Dagens och framtidens hållbara biodrivmedel)*, Available at: https://pure.ltu.se/portal/files/76669144/f3_B_rjesson_et_al_Dagens_och_framtidens_h_llbara_biodrivmedel_Slutversion_rev_130620.pdf [Accessed December 19, 2014].

[16] Gillberg, B., 2008. *Memo regarding methanol plant in Hagfors*.

1.4.5 Placement & existing infrastructure

The project is located in Hagfors, in the southwest of Sweden because of feedstock availability and good road infrastructure, which serves both for obtaining feedstock and distributing the final product.

1.4.6 Feedstock/Raw materials supply chains

The facility considers three separate reception lines for round wood, twigs & tops, and wood chips. A reception area of 150 km around the facility is estimated. Possible feedstock providers are Mellanskog, Bergvik Skog, and Sveaskog. BG states the company would be able to compete with the pulp & paper industry for feedstock. This is because feedstock is not a large share of the costs; the company would rather be capital intensive, according to the interviewee.

1.4.7 Markets for products

Methanol has been used in Sweden as a transport fuel; a low blend-in into gasoline (M15) was used by 1000 vehicles between 1979 and 1982.[17] [18] Today Stena Line uses methanol in sea transport. This legitimizes the fuel according to BG, although Stena Line currently uses fossil methanol. The chemical industry uses methanol and there is an interest for green methanol, according to the interviewee. BG stresses the advantages of using methanol as a drop-in fuel in existing infrastructure. He further states that it is possible to use it in fuel cells in the future.

1.4.8 Markets for waste heat/by-product flows

About 10 GWh_{pa} of heat would be delivered as district heating locally in Hagfors. The rest would be used internally to dry incoming feedstock.

1.4.9 Risk

VärmlandsMetanol believes that they have minimized the technical risk through its cooperation with a commercial technology provider. However the company sees political risks, which may create market risks.

1.4.9.1 Technical

BG states that the technical risk has been minimized through the cooperation with TKIS which guarantees a certain price and performance.

1.4.9.2 Political/Policy-related

BG underlines that the tax on biofuels has been changed four times only since 2012 and that this affects the profitability of the project. He is positive to the recent news[19] that bio-methanol will be tax exempted from 2016-01-01, but the also says that is uncertain how long that will last.

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[17] Sterner, T., Johansson, B. & Johansson-Stenman, O., 1998. *Skall vi köra på sprit?*

[18] Ulmanen, J.H., Verbong, G.P.J. & Raven, R.P.J.M., 2009. Biofuel developments in Sweden and the Netherlands. *Renewable and Sustainable Energy Reviews*, 13(6-7), pp.1406–1417. Available at: http://www.sciencedirect.com/science/article/pii/S1364032108001718 [Accessed April 15, 2015].

[19] The news was recent at the time of the interview, 2015-10-08.

1.4.9.3 Policy instruments/interventions

BG makes the remarkable statement that long-term agreements such as public transport that buys biogas is probably to be considered as illegal state aid [*sic!*]. This statement should be interpreted in the context of that the EU commission considered a quota obligation combined with CO_2 in Sweden as illegal state aid. He also states that Swedish policy instruments have been unpredictable.

1.4.10 Investment support

The investment amounts 3.5 billion SEK. VärmlandsMetanol is not interested in the EU investment support NER 300. This is because NER 300 requires knowledge sharing which may be a problem for the technology provider TKIS. This statement may be recognized from the interview with Bio-refinery Norrtorp.

1.4.11 Taxation regimes

The interviewee comments that the project has been affected negatively by the taxation of biofuels from 2012 and onwards.

1.4.12 Carbon and energy prices

The oil price drop has of course affected the project negatively.

1.4.13 The most advantageous/desirable support model

BG suggests long-term taxes that guarantee that biofuels are a bit cheaper then fossil fuels. This may be achieved by a CO_2 tax exemption for biofuels combined with an increased CO_2 tax on fossil fuels. This must be guaranteed during a ”normal” payback period of 15 years. The system of green electricity certificates is also a good model according to the interviewee.

1.4.14 Future plans for the (envisioned) project

BG states that the project would need a guaranteed tax exemption for biofuels and oil price around 60 USD/barrel to be feasible. He also perceives that methanol is receiving attention and becoming “in” again. BG states that there is seven years of work in preparation for the project and that it would take an additional three years to realize it, once the right conditions are given.

1.5 GOBIGAS

The GoBiGas project utilizes forest biomass to produce biomethane and heat. The project thus far has achieved three of four steps: laboratory, pilot, and demonstration of the technology system. The fourth stage, a commercial plant is on hold. Currently the demonstration plant is proceeding with a sequence of commissioning phases. This is generally referred to as GoBiGas phase 1. The 20MW plant is connected to the natural gas grid and the district-heating grid. Unless otherwise cited, this case description is mainly based on an interview with Lars Holmquist (LH), business strategic planner, and Ingemar Gunnarsson (IG), development engineer at Göteborg Energi AB (GE). Tomas Lönnqvist of KTH conducted the interview, in the company’s facilities 2015-10-06.

1.5.1 The technology system (the initiative)

GoBiGas is based on a two-stage process: gasification and methanation. The process starts with thermal gasification to produce syngas that contains CO, H_2, H_20, CO_2, CH_4, H_2S, and tars such as

$C_{10}H_8$. Before methanation, the gas is cooled and passes through a cleaning process. The cleaning process consists of several steps. A gas filter removes particles. Tars are removed using an RME scrubber and an additional filter with activated carbon. An absorption vessel and an amine washer remove sulphur compounds. The methanation process also takes place at several stages – a shift reactor, a catalytic process, and an additional amine washer. In this process step, CO_2 is removed and CH_4 content is increased. This is because H_2 reacts with CO and CO_2 to form CH_4 and H_2O. The gas is then dried and pressurized to 35 bar before being injected into the natural gas transmission grid[20] The methane efficiency is around 65 % and the total efficiency, including heat, is expected to be over 90 %.[21] **Table 5** provides basic data about the plant.

Table 5. Production and feedstock streams at GoBiGas phase 1. Data for phase 2 is presented in parenthesis [22, 23, 24, 25]

Fuel output	Planned production (GWh_{pa})	Planned production (million Nm^3_{pa})	By-product: district heating (GWh_{pa})	Feedstock (changes over time)	Feedstock input (GWh_{pa})	Feedstock input
Methane	160 (800)	17.6 (88)	50 (250)	1) Pellets 2) chopped second quality round wood 3) twigs & tops	Biomass 250 (1250) Electricity 24 (120) RME 4 (20)	50 000 (250 000) tons of pellets (dry weight) or 90 000 (450 000) tons of branches & tops

1.5.2 The proponent(s)

GE Göteborg Energi AB commenced the GoBiGas initiative. E.ON Sverige joined the project at an early stage but left afterwards, partially because they decided to start their own gasification plant. Although E.ON has the same approach as GE there is currently not much cooperation between the projects. However personnel from E.ON has joined the GoBiGas project. The project started in 2005 and a preliminary decision was taken 2009 when SEA granted an investment support. A final decision was taken in 2010 when the EU commission approved the support as not being illegal state aid.

1.5.2.1 Motivating factors for initiative

GoBiGas is, among other things, an example of actions that can arise when Swedish municipalities move to reduce their carbon footprints. According to interviewees *"GoBiGas builds on a strong will to move forward and a belief that is possible to replace fossil fuels"*. GoBiGas was also seen as a business opportunity in line with the core business of GE. GoBiGas aims at producing a renewa-

[20] Göteborg Energi, 2016. GoBiGas process film. Available at: http://goteborgenergi.streamingbolaget.se/video/156153/link [Accessed April 1, 2016].

[21] Hedenskog, M., *The GoBiGas Project.* Presentation at Advanced Biofuels Conference, Stockholm Sept. 16, 2015.

[22] Börjesson, P. et al., 2013. *Present and future sustainable biofuels for transport (Dagens och framtidens hållbara biodrivmedel)*, Available at: https://pure.ltu.se/portal/files/76669144/f3_B_rjesson_et_al_Dagens_och_framtidens_h_llbara_biodrivmedel_Slutversion_rev_130620.pdf [Accessed December 19, 2014].

[23] Hedenskog, M., *The GoBiGas Project.* Presentation at Advanced Biofuels Conference, Stockholm Sept. 16, 2015.

[24] Grahn, M. & Hansson, J., 2014. Prospects for domestic biofuels for transport in Sweden 2030 based on current production and future plans. *Wiley Interdisciplinary Reviews: Energy and Environment*, p.n/a–n/a. Available at: http://doi.wiley.com/10.1002/wene.138 [Accessed December 19, 2014].

[25] Swedish Energy Agency, 2014. Press release: 1.9 billion SEK to Swedish bioenergy project. Available at: https://www.energimyndigheten.se/Press/Pressmeddelanden/19-miljarder-till-svenskt-bioenergiprojekt-/ [Accessed July 1, 2015].

ble vehicle fuel, vehicle gas. This fuel fits well into the core business of GE as a business with municipal ownership. The company has dealt with gas since the mid 19th century and it currently owns upgrading facilities for biogas from anaerobic digestion. In addition, they previously owned 50 % of the vehicle gas distribution company Fordonsgas Sverige – which they divested in 2014.

1.5.2.2 Partners and networks involved

GoBiGas represents a so-called triple helix cooperation between industry, government, and academia. GE cooperates with Chalmers University of Technology who operate the pilot plant. GE financed the pilot plant. It focuses on the gasification technology later used in the demonstration plant but it does not include the methanation process. GE also cooperates with Fordonsgas Sverige that is an important vehicle gas distributor. Pellets are received from the combined kraft pulp mill and sawmill Varö bruk. However there is no cooperation with the vehicle producers in the region.

1.5.3 Placement & Existing infrastructure

The primary reason for the location of the plant, in central Gothenburg, was access to infrastructure. GE considered a site that also would serve for Phase 2. The site provides access to railways, a good harbour, a pellets receiving terminal, the Swedish natural gas pipeline, the city's district heating grid, as well as proximity to vehicle gas and heat demand. In addition GE already owned the land and had environmental permits, which served to speed the process of approval and so forth.

1.5.4 Feedstock/Raw materials supply chains

Pellets are currently used as feedstock, but the company is in the process of switching to wood chips from low quality round wood (in Swedish: flisad sekundaved). Trials using wood chips started in March 2016 but have run into mechanical feed problems.[26] The plan is to eventually use forest slash/branches and tops (in Swedish: grenar och toppar, GROT). Two principal reasons for choosing pellets were that firstly it was expected to be easier to commission the plant using pellets (a reasonably homogeneous feedstock) but also because a pellets receiving terminal already existed on the site. A biomass receiving area of 100 – 150 km from Gothenburg is expected to be required for Phase 2. The interviewees perceive that it is now easier to obtain feedstock in comparison to the time when the project started.

1.5.5 Markets for waste heat/by-product flows

Heat is an important by-product and the immediate proximity of the district-heating grid influenced the location of the plant.

1.5.6 Risks

The project faces a suite of technical, financial, and policy related risks. The technical risk is has been ameliorated via the four stage process involved in the project – with each stage scaling up the technology. The current step, the demonstration plant, is not intended to be commercial but rather to prove that the technology works at a scale close to commercial viability. However, there is a financial risk and the final investment may differ from the original budget. However, financial and market related risks were significant – indeed the final investment required to deliver the plant

[26] Personal communication with T. Lönnqvist (Malin Hedenskog, 2 May 2016)

markedly exceeded the original budget (1500 MSEK compared to 1150 MSEK). Market related risks such as oil price changes,[27] are most relevant to the commercial plant, often referred to as Phase 2. Political risks, including changes in policy instruments, may also affect the commercial plant. The interviewees state that they did not base their investment decision on any specific policy instrument, however they did anticipate a rather stable, or even increasing oil price.

1.5.6.1 Technical

The interviewees express the view that "you take a risk when you build something no one has built before". This also turned out to be very true for the demonstration scale process. GE experienced serious technical difficulties related tars clogging the fluidised bed during commissioning operations. As result the facility had to be stopped repeatedly. After significant testing and research work together with the research partner (Chalmers University) they identified that olivine material (rich in Mg, Si, and Fe) in the bed was not being 'activated' – and tars were not being broken down as expected. Further testing successfully activated olivine adding K_2CO_3. The pellets have lower ash content and thus lower potassium content than the forest residues such as branches and tops that the process was designed for. Potassium is a catalyst that contributes bed properties that in turn support breakdown long hydrocarbon chains such as tars in the gasification process.

1.5.6.2 Financial/Market-related

By the end of 2010, when the decision to build GoBiGas phase 1 was taken, the oil price was circa $US90/bbl. During 2011 the price peaked at $US155/bbl (see Section 2.4 in Part A of this report for a discussion of oil price dynamics). By the time of the interview, October 2015, the price had dropped to $US48/bbl. At present (April 2016) the oil price has dropped further to $US38/bbl[28] (Nasdaq, 2016). GE did not foresee this development and its investment decisions were based on a higher oil price than now exists. This development implies that GoBiGas 2 would not be profitable at present. However, Phase 1 that has been built is a demonstration plant and not a commercial plant.

Furthermore although the investment in the demonstration plant was larger than expected (1500 MSEK instead of 1150 MSEK). The interviewees express that there has been a valuable learning-by-doing process and that they could construct a new plant of the same size for approximately 2/3 of the investment. In addition, when comparing Phase 1 and 2 there is clearly advantages related to economy of scale.

Although the project is focused on delivering vehicle fuel, the possibility to use methane in other applications – electricity generation, heat and power, and cooking gas – gives GE some flexibility and permits them to manage market related risks to some extent.

[27] It is important to note that the oil price dynamics are considered more important than gas price dynamics in cases where bio-SNG is produced for the transportation market. Gas in this case competes with petrol and diesel.

[28] Nasdaq, 2016. Crude Oil WTI (NYMEX) Price. Available at: http://www.nasdaq.com/markets/crude-oil.aspx?timeframe=3y [Accessed April 1, 2016].

1.5.7 Policy instruments/interventions

The interviewees state that their investment decision was not based on the expectation that a particular policy support would materialize. However they were counting on "fairly stable policy support". In this regard, policy developments in Sweden have been unstable from 2010, when the final decision was taken, up until the present. The so-called FFF investigation created expectations of policy instruments that would foster a vehicle fleet independent of fossil fuels, however, these expectations have not been met and some Swedish policies have been withdrawn, as they were not compatible with EU-legislation.

1.5.8 Investment support

One determining factor for the realization of phase 1 was an R&D support of SEK 222 million from SEA in 2009 (15 % of the total investment). The final decision was taken in 2010 when the European Commission approved the support as legal state aid. Phase 2 is also approved for a EU support mechanism called NER 300.

1.5.8.1 Taxation regimes

The interviewees mentioned several policy instruments that they perceive as important for the development of vehicle gas in Sweden. In this regard, it is important to notice that the interview was performed by the end of 2015 when the Swedish government had not yet received permission from the EU commission to continue its exemption of biofuels from energy and carbon tax. The interviewees mentioned this exemption as very important but also stressed that it was only guaranteed a few more months and stated, ”no investor would make a decision under these circumstances”.

Further, interviewees underlined the importance of support to vehicle gas end-users, e.g. reduced fringe benefit tax for gas vehicles and other cars defined as environmental cars. The interviewees perceive that this instrument are relevant to companies and other special segments that are in a position to afford the more expensive vehicles that use renewable fuels. Although these instruments, supporting the end-user, have been substantial they have also been unpredictable. One interviewee states that taxes are more predictable than support systems such as the environmental car premiums. He also adds "sticks are better than carrots". Furthermore the interviewees mention the importance of long-term agreements. As an example, an agreement with a local governmental body for gas use in public transport guarantees a demand for vehicle gas over time.

1.5.8.2 The most advantageous/desirable support model

The interviewees believe that a production support is more suited than an investment support to promote production of transport fuels from forest biomass in Sweden. This is because a production support reduces the risk for the producer and also because it "creates a market" by sending the right signals. They hold that the price-premium-model (as suggested by Thomas Kåberger in the FFF) is a well-designed production support.[29]. They also consider that the price-premium-model distributes the risks well. The model liberates the producer from the oil price risk and also from the effects from changes in the CO_2 tax. This is obtained by guaranteeing a premium to the producer. The premium is based on a reference price (for 2015: 12 SEK / litre diesel equivalent). The production

[29] Government of Sweden, 2013. *A vehicle fleet independent of fossil fuels [Fossilfrihet på väg]. SOU 2013:84*, Stockholm: Statens Offentliga Utredningar.

cost for diesel and CO_2 tax applied on diesel is later deducted from the premium. However the premium is only paid if the fuel is sold on the market and the producer thus has to assume the market risk. The price-premium would assure a production support to certain producers of renewable fuels, i.e. advanced or second generation biofuels.[30] The producer would receive a premium, which is financed by all fuel distributors. The fact that the government does not pay the premium should make it compatible with the EU legislation regarding state aid.[31]The interviewees believe that the model would fit the current situation well, considering the oil price fall and uncertainties regarding biofuels taxation. The quota obligation, on the other hand, is believed to mainly favour low percentage blends and thus not be very appropriate for producers of pure or high blend biofuels.

The interviewees also mention feed-in tariff systems and compare with the policies of Germany and France. They perceive the German and French support systems as stabile and predictable. However, in these countries, policy instruments for biogas are directed at electricity generation and thus the industry has opted for this end product.

1.5.9 Future plans for the (envisioned) project

As noted, the GoBiGas project is envisioned in four steps. The third and current step is the demonstration plant, which has a 20 MW methane production capacity. The demonstration plant is meant to show that the technology works and pave the way for GoBiGas Phase 2, a full-scale commercial plant of 100 MW methane output. According to the interviewees the critical determinant factors for the realization of Phase 2 are: a sufficient technical performance of the operations; a market for the product; the presence of beneficial policy instruments; and adequate financing. According to the interviewees, the last factor should not be problematic if the previous factors are in place.

Soon after the interview (2015-12-09) an, important press release was issued by GE. A motion was passed within the local government body that Phase 2 should be postponed. Further, the motion called for a full investigation of the costs of the current biogas production and it was decided to investigate the consequences if GE should withdraw from biogas operations altogether. GE underlines that no decisions have been made and that Phase 2 is not on the table – not least because it is not likely to be profitable given current conditions.

1.6 BIO2G

Unless otherwise cited, this case description is based on an in-depth interview and discussion with Björn Fredriksson Möller, Project Leader for Gasification Development at E.ON Sverige. Philip Peck and Yuliya Voytenko of IIIEE, Lund University, at the E.ON offices in Malmö on 2015-10-15, conducted the interview.

The E.ON Bio2G project has the aim to deliver a biomass gasification plant producing circa 1.6TW/yr of biogas synthetic natural gas (in this report: bio-SNG). Bio2G has been a high profile gasification project in the Swedish advanced fuel arena since circa 2007. Led by a division of the German utility E.ON in Malmö Sweden, the proposal encompasses a 200MW biomass gasification

[30] Second generation biofuels is sometimes defined as technologies using residues as feedstock. The definition used in FFF for which producers that would receive a premium includes gasification technologies but excludes e.g. biogas from anaerobic digestion, although it normally uses residues as feedstock.

[31] Government of Sweden, 2014. *Submission for comment; A vehicle fleet independent of fossil fuels; Reply from Preem*, Available at: http://www.regeringen.se/content/1/c6/24/09/47/8fb77f81.pdf.

plant to be located at a port location along the Swedish natural gas pipeline corridor in the Swedish southwest.[32]

With a planned bio-SNG production capacity of 200 MW (1.6TWh/yr), the proposed plant will require circa 1 million tonnes biomass per annum (fuel input ~325 MWth) and is projected to cost some €500 million (circa SEK4.3billion).

Bio2G is reliant upon consortium investment and biofuel technologies policy-support schemes for initial project viability. It has been identified at the EU level as a 'lighthouse' candidate for first-mover support via mechanisms such as NER300 (New Entrants Reserve)[33] and the EIBI (Implementation Plan of the European Industrial Bioenergy Initiative).[34] A successful NER300 application was made during 2012, this secured EU production support over 5 years that would total approximately €200million (SEK1.9 billion).

While not finalized, the location of the plant has generally been discussed in terms of a port city location (e.g. Malmö or Landskrona in the southwest of Sweden) or a pulp mill location (e.g. Varö, south of Gothenburg, again on the Swedish west coast). With strong support from local and regional actors, the project has been framed as offering significant partnering opportunities with local utilities, fuel suppliers, equipment suppliers and the forestry industry. An estimated 50-100 staff would be required for the plant.

Figure 1. Early 3D layout Bio2G.[35]

The Bio2G project commenced in 2007 and as of 2013 it has been held in 'waiting mode'. With regards to the envisioned project timeline indicated in **Figure 2** the project was placed on hold before handing in the permit application and launch of the FEED study.

[32] The Swedish natural gas market is very dependent on import from or through Denmark via one single pipeline (Dragör) Sweden is thus not directly linked to continental Europe but is, via Denmark, coupled to the European gas transmission system. The total import capacity of the Swedish gas transmission grid is currently approximately 22 TWh/year, while total consumption is in the range of circa 15 TWh/year. 3.5% of the total Swedish energy needs are covered by natural gas. However in those areas in Sweden where natural gas is established it covers approximately 20% of the energy needs. In Sweden approximately thirty municipalities, mainly situated at the West-Coast area and the Southern part of Sweden, have access to natural gas. Energimarknads Inspektion (2012) An overview of the Swedish natural gas market. PM2012:6 In Stockholm, natural gas is delivered as LNG. Both the city gas net and the vehicle gas net are suitable for biogas. As of 2016, circa 30% of the gas delivered is biogas. There is also a LNG harbor in Lysekil, north of Gothenburg.

[33] See http://ec.europa.eu/clima/policies/lowcarbon/ner300/index_en.htm

[34] See http://www.biofuelstp.eu/eibi.html

[35] Source: *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Dr. Björn Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013

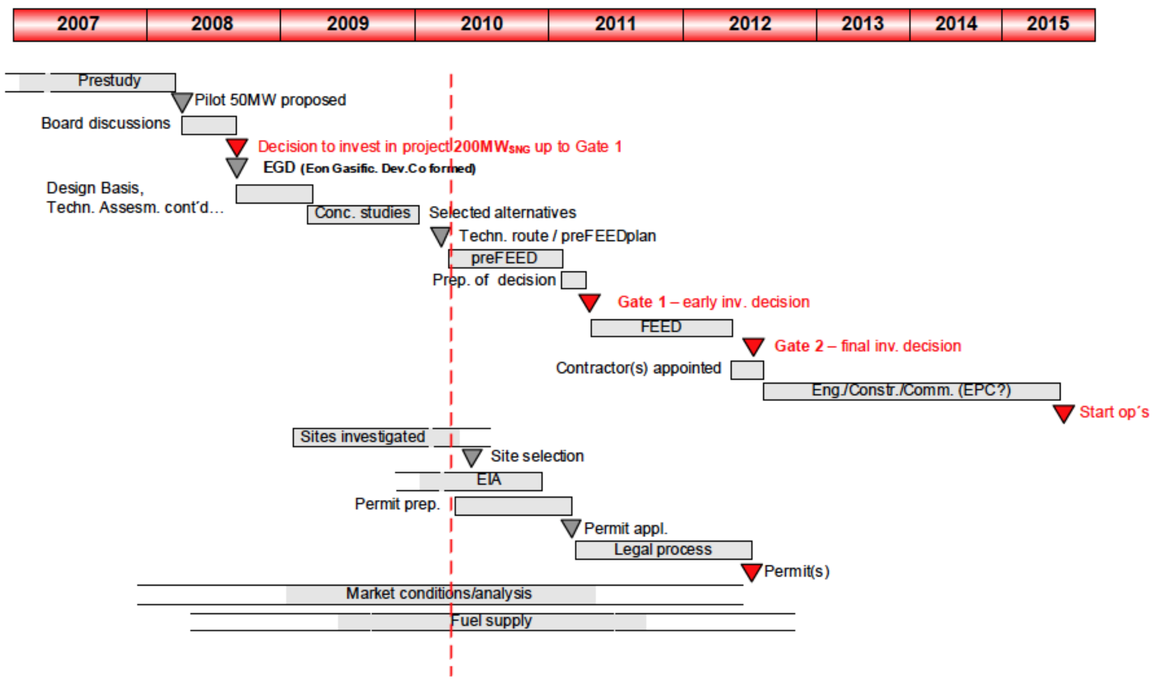

Figure 2. Envisaged project timeline as of 2010.[36]

1.6.1 The Initiative's technology system

The key parameters of the proposed Bio2G plant are shown in **Table 6**, **Figure 3**, and **Figure 4** below/overleaf. Additional process notes are included at the end of this sub-section.

Table 6. Bio2G Preliminary key parameters[37]

Fuel Input	Feedstock mass	Biogas production	Biogas annual	Biogas efficiency	Total efficiency	Heat
325 MWth	Circa 1Mtpa biomass (forest chips, slash)	200 MW ~ 21 000 m^3/h	Circa 1600 GWh	62-63% (excl. ASU)	70-80%	50*MW
Other products		10MW internal power potential for $N_{2liquid}$ potential biorefinery setup for CO & H_2				

***depending on feedstock moisture content.**

[36] Möller, B.F. (Nov 2010), *Gasification Development at E.ON*, (Eon101029_EGD@SGC_open) presented at the SGC International Seminar on Gasification, Svensk Gastekniskt CenterAB, 2010.

[37] *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Björn Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013

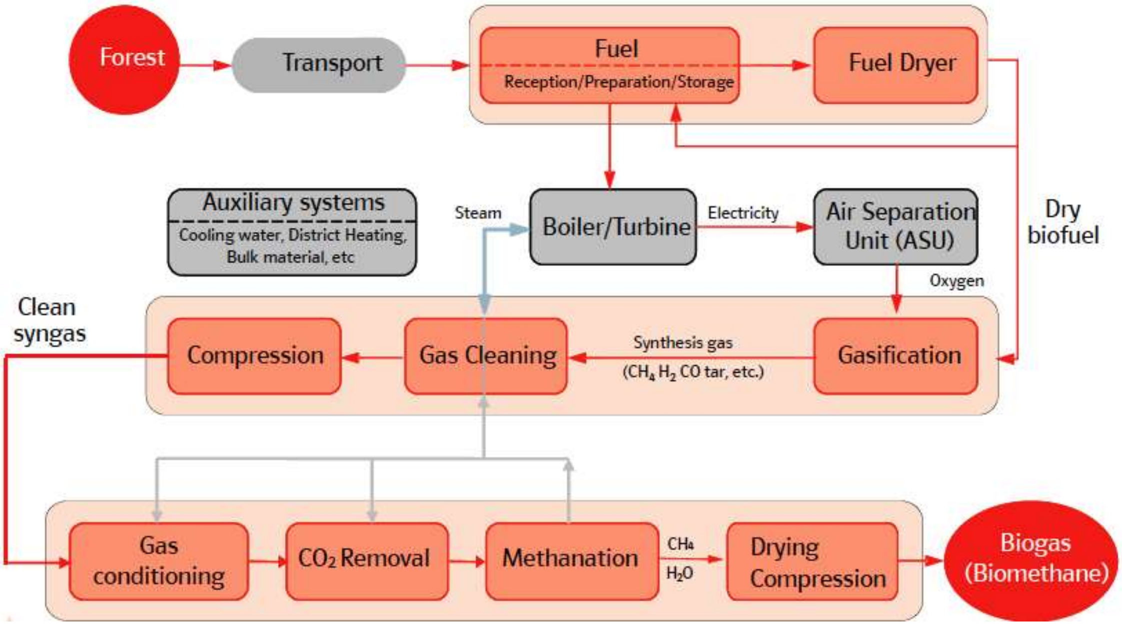

Figure 3. Process diagram Bio2G[38]

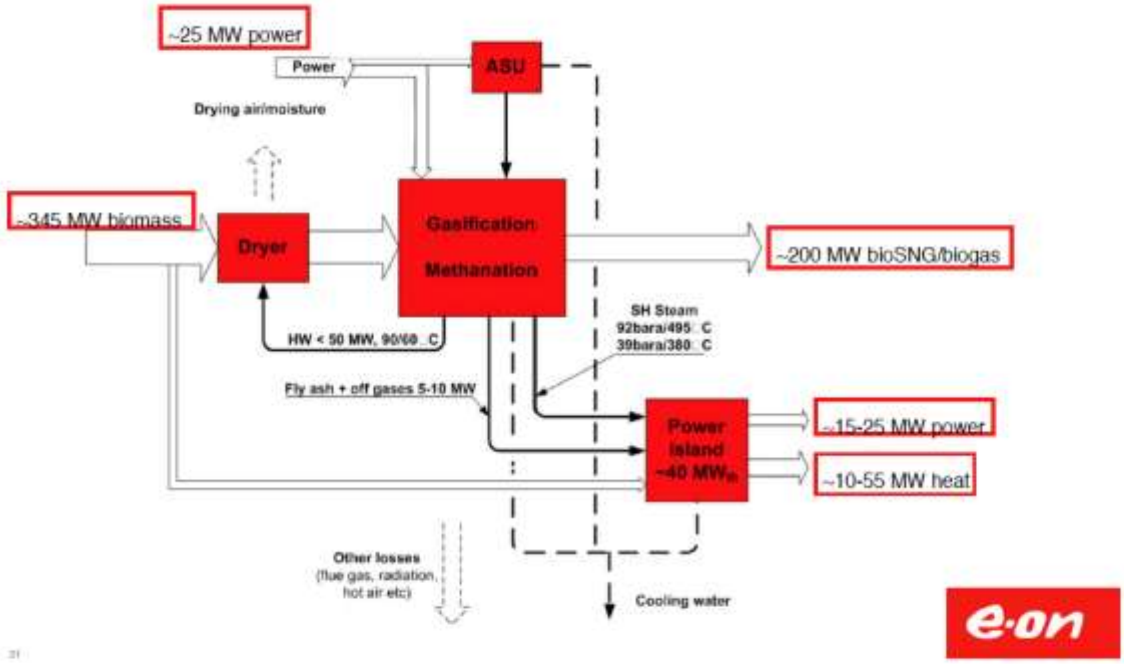

Figure 4. Indicative energy balance input/output[39]

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[38] *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Björn Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013

[39] Björn Fredriksson Möller, Bengt Ridell, (2013, June) *Case story: Vehicle gas in Sweden*. (p21). Available at: http://www.co2-electrofuels.org/Links/~/media/CO2_electrofuels/pdf/5_case_story_vehicle_gas_in_sweden.ashx (Accessed, April 20, 2016).

Additional process-related notes[40]

- Pressurised O_2-blown gasification using fluidized bed to achieve high methane yield; achieves higher efficiency than synthesis paths where CH_4 in producergas has to be converted to H_2 and CO.
- Flexible fuel utilization – supply chains from rail, road and sea, adjacent to gas pipeline.
- At the planning stage reached, the Bio2G design remained flexible – with details in the gas-cleaning set-up still evaluating different options.
- Catalytic tar conversion process – with selective non-conversion of CH_4
- Selective S and CO_2 removal without removal of CH_4.
- Hot gas filtering – aiming for the highest possible filtering temperature is intended to avoid reheating of clean gas, which consumes both oxygen and energy (producergas, CH_4) and to avoid tar condensation.
- Adiabatic methanation – with a highly exothermic reaction, the temperature rise is reduced when there is high inlet CH_4 content, thus removing need for recirculation, achieving better catalyst performance and less energy lost as heat.
- Simplified process scheme – no quench/heat-exchanger, no recycle gas etc.
- Heat integration with internal low temperature fuel drying, internal steam production where possible and electricity production.
- design prepared for addition of liquid biogas production and CO_2 reuse for Power-2-Gasboost, etc.
- Possibility for co-production of H_2 and CO in a biorefinery set-up.

1.6.2 *The project proponent(s)*

The project proponent is E.ON Sweden. In 2014 the company had a turnover of circa SEK 34 billion (€3.6 billion), employed around 3300 persons, and served a customer base of circa 1 million with electricity, biogas, natural gas, liquid petroleum gas (LPG), heat and energy from waste. E.ON Sverige AB was formed after a majority shareholding in Sydkraft AB was acquired in 2001 by E.ON AG, the large German utility, in a deal estimated at €7.3billion. In 2004, Sydkraft bought the Swedish energy company Graninge. In September 2005, Sydkraft changed its corporate name to E.ON Sverige (E.ON Sweden).

The Bio2G project leader is Dr. Björn Fredriksson Möller, of E.ON Gasification Development based in Malmö, Sweden's third largest city, in the far southwest of the country.

[40] *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Björn Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013 (Sept.) Available at: http://www.gastechnology.org/tcbiomass/tcb2013/04-Moller-tcbiomass2013-presentation-Wed.pdf (accessed 20 April, 2016)

1.6.3 Motivating factors for initiative

E.ON is a dominant actor in the Swedish biogas for vehicle transportation market. As of 2015 the company accounted for about 500 GWh of the circa 1700GWh fuel sold on the market. The Bio2G initiative can thus be seen as an important portion of E.ON's strategy to both grow its market, and maintain a dominant presence. Also, important to this case is that E.ON, via its central role in the natural gas sector, and connected to its fossil fuel (natural gas) fired cogeneration plant in Malmö (Öresundsverket – now owned by Uniper[41]), can be viewed as a major contributor to fossil carbon emissions in at least one of its key markets (i.e. the city of Malmö). All work that E.ON pursues that contribute to a reduction of greenhouse emissions, and a reduction of transportation-related fossil dependency, can thus be viewed as contributing to the overall legitimacy of the firm in Sweden.

A range of background conditions is brought forward by E.ON when communicating its reasons for pursuing biogas via woody biomass gasification. A number of these are outlined below.

- Denmark and Sweden have expressed goals to have 100% renewable gas by the year 2050 (Möller, 6/2013)[42] – as such, major gas grid actors presumably have a considerable incentive to commence the pursuit of technical pathways that prepare them for this potential future.
- Biogas can be pursued via digestion or via gasification. In 2015 biogas from small-to-medium sized production units (e.g. anaerobic digestion plants) supplied circa 1.7 TWh of energy. While the economic potential for digestion based biogas is estimated at 2-3 TWh, its technical potential is estimated to be circa 10 TWh.[43] The estimated potential via biomass gasification is however larger – with a range of technical and market potentials put forward – but generally in the 20TWh-to-2030 range.[44] Some potentials have be cited at more than 50 TWh.[45] 2020 visions for Sweden have called for 10TWh from digestion and 10TWh from gasification.[46]
- Electricity could supply ca. 15 TWh for the transportation sector. Considering energy efficiency improvements and use of electricity and biogas from anaerobic digestion in the transportation sector, there will still be a need of ca. 40-50TWh biogas from alternative sources in the longer term. These can be supplied through gasification.[47]

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[41] In a press release dated 1 April, 2016, E.ON announced the following: *E.ON successfully separated its operations from Uniper's effective January 1, 2016. From the new E.ON campus in Essen, the company will now focus on renewables, energy networks, and customer solutions. Uniper will operate independently from its headquarters in Düsseldorf. Uniper's businesses—conventional power generation (hydro, natural gas, coal) and global energy trading—remain essential for ensuring the security of the energy supply. E.ON has therefore reached another important milestone in the execution of its new strategy. The spinoff of Uniper is expected to take place later in 2016 following the approval of E.ON shareholders.* See http://www.eon.com/en/media/news/press-releases/2016/1/4/separation-of-eon-business-operations-completed-on-january-1-uniper-launched-on-schedule.html

[42] Björn Fredriksson Möller, Bengt Ridell, (2013, June) Case story: Vehicle gas in Sweden.

[43] Börjesson, Pål, Linda Tufvesson, and Mikael Lantz. "Livscykelanalys av svenska biodrivmedel." *Environmental and Energy System Studies report no. 70* (2010), and Möller *et al* (2013) *Bio2G…*

[44] Personal correspondence (email). Philip Peck with Björn Fredriksson Möller, E.ON.

[45] BioMil, A. B., and A. B. Envirum. "Den svenska biogaspotentialen från inhemska restprodukter." *Uppdragsgivare Avfall Sverige, Svenska Biogasföreningen, Svenska Gasföreningen och Svenskt Vatten* (2008).

[46] Möller *et al* (2013) *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Björn Fredriksson Möller, Anders Molin, Krister Ståhl, E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013. Available at: http://www.gastechnology.org/tcbiomass/tcb2013/04-Moller-tcbiomass2013-presentation-Wed.pdf (accessed 20 April, 2016)

[47] Interview with Björn Fredriksson Möller, (P. Peck, Y. Voytenko) 29 September 2015.

- Strategies to pursue digestion pathways in the future very often rely on dedicated crops as a significant source of substrate – indicating weaknesses when considering experiences with social and political opposition to first generation biofuels through to so called "ILUC-directive".

- Other strategies call for the building of significant infrastructure to support CNG/LNG, electricity and hydrogen for vehicles; these showing considerable compatibility with the development of biogas/bio-SNG for vehicles in Sweden.

- Profitability lies in the pursuit of gas for vehicular transportation (>50% renewable content). The market is fast growing and competing well against green alternatives. Very importantly, as it competes with transportation fuels, the oil price level applies as price base rather than gas (e.g. industrial or heating markets for gas are not nearly as attractive at current taxation levels).

Adding to the points above, communications issued from E.ON indicate historical links and accumulated company experiences from the Värnamo gasification project of the 1990s regarding technology systems (E.ON Sweden was formerly Sydkraft).[48] In the 1990s, Sydkraft AB built the world's first complete IGCC Power Plant that utilised wood as fuel. Located in Värnamo, Sweden, the technology used in the power plant was based on gasification in a pressurised circulating fluidised bed gasifier (note: a quite different technology than proposed for Bio2G). The gasification technology was developed in co-operation between Sydkraft AB and Foster Wheeler Energy International Inc. The accumulated operating experience in that project totalled more than 8500 hours of gasification runs and about 3500 hours of operation as a fully integrated plant. The plant operated successfully on a range of different wood fuels as well as on mixes of straw and wood.

Demonstrating their longer-term faith in gasification pathways to deliver a sound technical and economic platform for transportation biofuels, E.ON also presents the arguments shown in **Figure** 5 and **Table 7**. These portray that the company considers a) biogas as the top performing biofuel proposition from a well-to-wheel perspective; b) that bio-SNG (synthetic natural gas) outperforms comparable second generation biofuel systems when viewed from a cost perspective (normalised production and distributed costs).

[48] See: Möller, B.F. (Nov 2010), *Gasification Development at E.ON*, (Eon101029_EGD@SGC_open) presented at the SGC International Seminar on Gasification, Svensk Gastekniskt CenterAB, 2010, and http://www.vvbgc.se and 1999 Gasification Technologies Conference, San Francisco, California, October 17-20, 1999 Progress Report: Varnamo Biomass Gasification Plant, Krister Ståhl, Magnus Neergaard, Jorma Nieminen.

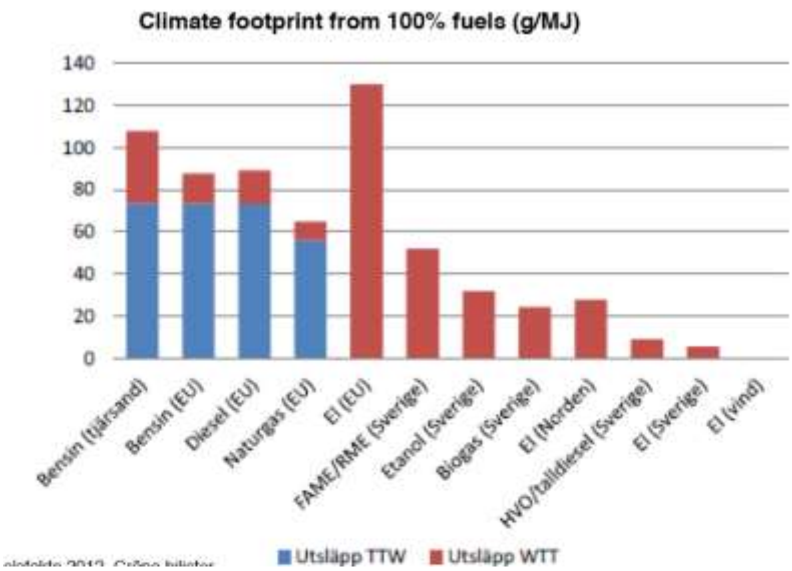

Figure 5. Comparative Tank and Wheel-to-Wheel emissions for 100% biofuels.[49]

Table 7. Bio2G Normalised costs for biofuel systems.[50]

Technology	Biogas (SNG)	Methanol	DME	FT-Diesel
Fuel input (MW)	300	300	300	300
Efficiency, total (%)	77	70	70	79
Efficiency, main product (%)	64	49	57	47 *
Prod.cost (normalized)	**100**	**136**	**121**	**173**
Equivalent cost incl. distribution (normalized)	100	111-120	107-118	135-141

Equivalent cost incl. distribution for ethanol is 124 and for FAME 119   * diesel+naphta

Using these background conditions as their point of departure, E.ON communicates that work required to reach visions involves *inter alia*: technology development to achieve more efficient digestion plants; the development of gasification into a commercial business, and to invest and build gasification plants – alone or with partners. The Bio2G project represents the operationalization of the latter two points.

Other work by E.ON as it expands its biogas network (e.g. via partnership with, or investment in digestion plants) contributes to the first point. As an example of this, E.ON is planning a biogas plant in Högbytorp, in the northwest of Stockholm County. The decision on the investment is to be

[49] Drivmedelsfakta 2012, Gröna bilister (Data sources) included in *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Dr. Björn Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013. Available at: http://www.gastechnology.org/tcbiomass/tcb2013/04-Moller-tcbiomass2013-presentation-Wed.pdf (accessed 20 April, 2016) Utsläpp=emission, TTW=Tank to wheel, WWT = Well to wheel.

[50] Grontmij (Data source) included in *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Dr. Björn Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013.

taken before the summer of 2016. E.ON is implementing a strategy where they first grow the market for vehicular gas, and then provide production capacity for biogas. E.ON is in the process of opening five refuelling stations in the general area – of which four are to be public stations. In contrast to areas in the southwest of the country where the gas pipeline can be used, this project requires that E.ON freights natural gas to the locations in the initial stage in order to build the market.[51]

1.6.4 Partners and networks involved

E.ON has been active in a suite of differing networks promoting biomass gasification since its entry to the Swedish market. It is observed that in essentially all communications related to the Bio2G project, E.ON highlights the importance of strong local support for E.ON Bio2G localisation in Malmö and Landskrona. Further, it stresses the importance of partnering opportunities with local utilities, fuel suppliers, equipment suppliers for reference plant technologies, and the forestry industry. This is demonstrated in the E.ON diagram shown as **Figure 6**.

As indicated in the previous Section, the company and the project also inherited networks from Sydkraft's previous significant gasification project at Värnamo.[52] The company has also been party to efforts (pre-2012) to launch new demonstration work at that (mothballed) plant with Vattenfall, AGA (Linde group) and SGC Energy.[53]

E.ON has a strong presence in the gaseous vehicle fuel industry and actively presents itself within bodies such as the Swedish *f3* network. The company has worked closely with municipal authorities such as Malmö and Landskrona while developing its strategies. Related to the presence of E.ON's 440MW$_e$ (250MW$_{th}$) gas fired in Malmö, E.ON's activities are also crucial to the realisation of the City of Malmö's climate goals – reflecting this, a continual dialogue with Malmö is maintained regarding fossil and renewable gas supply.

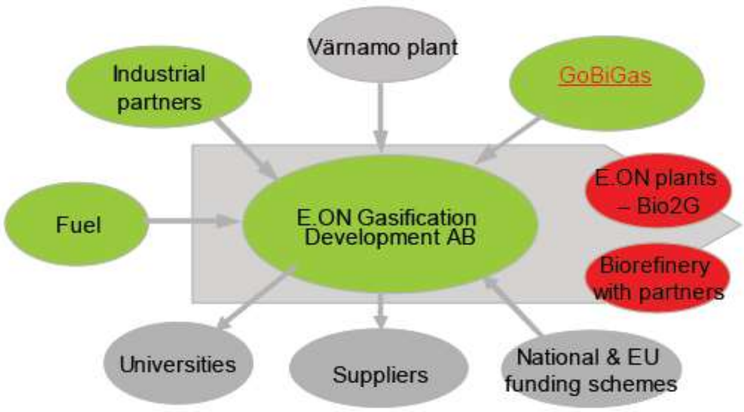

Figure 6. E.ON view of partnering and networks for Biogas SNG in Sweden[54].

[51] Interview: Tomas Lönnqvist (KTH) with Björn F. Möller (E.ON) 18 Nov. 2015.

[52] Among other things apparently related to equipment supply.

[53] The Industrial partners and Växjö Värnamo Biomass Gasification Centre (VBGC) planned a project with the main objective to rebuild the existing gasification plant to produce a synthesis gas from biomass suitable for the production of a number of different energy carriers, for electricity production and renewable transport fuels. See also: Möller, B.F. (Nov 2010), *Gasification Development at E.ON*, (Eon101029_EGD@SGC_open) presented at the SGC International Seminar on Gasification, Svensk Gastekniskt CenterAB, 2010

[54] Möller, B.F. (Nov 2010), *Gasification Development at E.ON*, (Eon101029_EGD@SGC_open) presented at the SGC International Seminar on Gasification, Svensk Gastekniskt CenterAB, 2010

While Bio2G was run as a consolidated project with 50% or more of the costs covered by E.ON in the early stages – there was no conclusive desire that E.ON be a dominant partner. To contrary, the company is clear that the active presence and investment of partners in an eventual project is a factor of critical importance if that can reduce project risk.[55]

E.ON has its own system for investment (Central Investment Programme) but access to such funds depends upon both assessment of project risk, and competition with other parts of E.ON for capital from the programme. Partnership is important to both of these factors.

While E.ON seek to avoid naming a number of potential partners (e.g. in interviews for this project for instance), some of these can be inferred from public information, or from previous project relationships. In both general and specific terms, interested parties delineated by E.ON.[56] include:

- local companies such as heat producers;
- distributors of vehicle gas (e.g. to gas pump);
- forest industry actors seeking new markets for biomass – in particular forest owners wishing to increase demand (thus ensure a reliable receiver) for their products;
- suppliers of equipment motivated to be involved in an important industry 'reference plant'.

1.6.5 Localisation: existing infrastructure and feedstock supply chains

The fundamental considerations for plant placement are: that it be adjacent to the natural gas grid; that location and logistics infrastructure facilitate fuel supply by ship, train and road transportation; that the site be an established industrial area, and that a sink for process heat to district heating is a possibility. In addition, it is required that the plant be close to key markets in the southern part of Sweden and close to areas with highest biomass supply. A central requirement for location is fuel flexibility – with the project requiring both endogenous (land transport) and exogenous (sea transport) fuel supply.

A location feasibility study performed by SWECO during 2010 identified six potential sites; four of these in the Öresund region. **Figure 7** below provides details of general locational preferences and relative availability of endogenous process feedstock. **Figure 8** provides a schematic view of in plant fuel logistics requirements.

Locations with a high profile in E.ON communications have been Landskrona and Malmö. Both of these cities have substantial port areas and significant levels of political support. However, waste heat from industry is relatively abundant in the region, and a Bio2G plant would create competition with existing infrastructure and investments. It is already clear that there is a higher willingness to accommodate residual heat from the plant in Landskrona than in Malmö. Indeed, in Malmö Bio2G would create competition with other E.ON plants. This noted, E.ON indicates that the City of Malmö is an important actor for the company (Malmö is a much larger city and hosts a much higher E.ON market presence). Related to the discussion presented in the previous section, another important factor is the willingness of a municipality to invest and the will of actors to help reduce the

[55] Interview with Björn Fredriksson Möller, (P. Peck, Y. Voytenko) 29 September 2015.
[56] *Ibid.*

(production) costs for energy. Finally, the existence of plentiful (excess to current demands) of biomass at one site (Varö) – is also an important factor that can be important for location.[57]

However, the requirement that a district heating system is present to act as an off take for process heat exists is not immutable. Comparisons between sites (e.g. Varö, Malmö, Landskrona) indicate that capital cost savings and other considerations at a pulp mill site (e.g. via reduced fuel storage and handling facilities) may compensate for reduced heat revenues. Fuel logistics are more complicated at an urban port than at a forest mill. The example is provided by E.ON that if a large shipment of biomass (e.g. for four weeks of biogas production) arrived from overseas (potentially North or South America), storage with a capacity for 6 weeks would reasonably required. Moreover, there are other risk factors that can affect costs – not least as chipped biomass fuels in particular have a number of health and safety implications. E.ON estimates that investment costs for such storage (including storage areas, safety, and other parameters) would represent some 10% of the total plant investment investment; i.e. SEK 400-500 million.

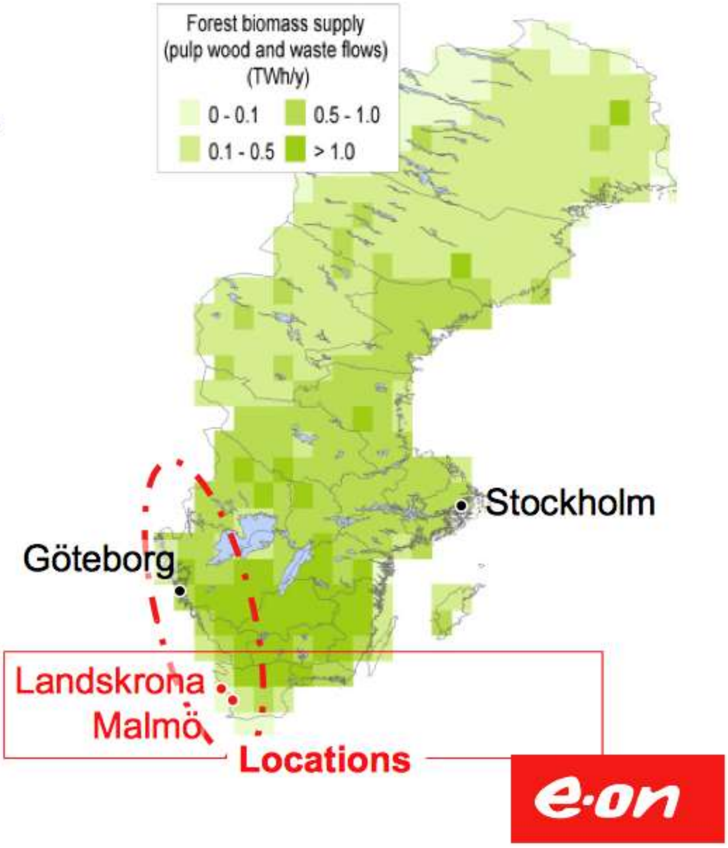

Figure 7. Location and biomass supply[58]

[57] *Ibid.*

[58] Möller *et al* (2013) *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Björn Fredriksson Möller, Anders Molin, Krister Ståhl, E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013. Available at: http://www.gastechnology.org/tcbiomass/tcb2013/04-Moller-tcbiomass2013-presentation-Wed.pdf (accessed 20 April, 2016)

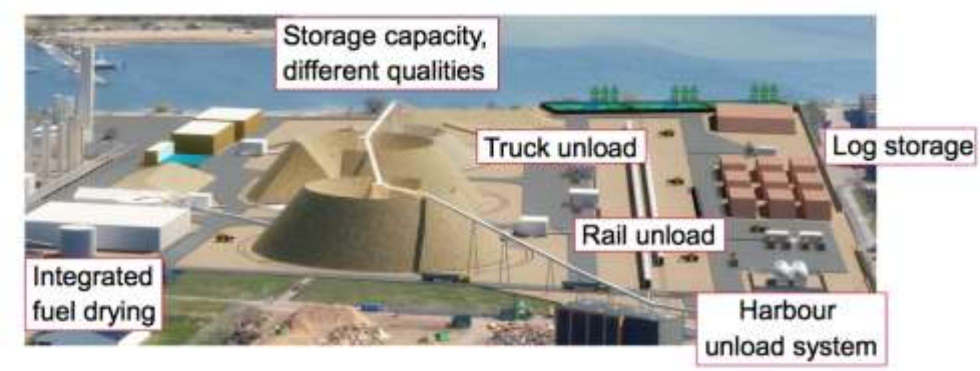

Figure 8. In plant fuel supply logistics requirements.[59]

1.6.6 Markets and distribution systems for biogas and biogas SNG

As noted in Section 1.6.3, Biogas SNG can be utilised in all (fossil) natural gas markets – but the vehicle gas market is crucial for economical viability of an initiative such as Bio2G under current market and taxation conditions. It is also important due to its potential for growth. Although taxation levels for natural gas remain favourable compared to oil-based products for industry and CHP, natural gas use in Sweden is relatively low. E.ON holds that project viability lies within the renewable transportation fuel field. The market has been fast growing and competing well against green alternatives. Very importantly, E.ON notes that as it competes with transportation fuels, the oil price level applies as price base rather than fossil gas (e.g. industrial or heating markets for gas are not as attractive).

Under the influence of policy support for the growth of biogas vehicle fleets[60] and municipal investments in gas fleets, the market grew steadily and at a slowly escalating rate in the period from the turn of the century to 2012/13. However, in the period since then a slowing of the gas vehicle market growth has been observed – largely related to uncertainty regarding on-going policy support for gas vehicles.[61] Growth trends for gas utilization (both fossil and biogas) and distribution infrastructure in Sweden are shown **Figure 9** and **Figure 10**. Delineation of tax exemption regimes and so forth are documented in Section.

For municipalities a number of drivers are important – factors such as making use of biogas from sewage sludge, meeting climate gas reduction goals, and enhancement of environmental profile are typical contributors. It is increasingly common that municipal bus fleets and/or waste collection fleets are run on biogas. For commercial actors, profitability lies with the achievement of growth in the market. This in turn requires the building of volume beyond the reach of the existing gas grid.

In this regard, E.ON indicates that vehicle gas can be distributed up to at least 400 km to a reasonable cost, but that the volumetric demand required for profitable operation of a fuelling station is roughly one million Nm^3/yr[62] or circa 10GWh (the corresponding volume for liquid fuels is 300

[59] *Ibid.*
[60] *Ibid.*
[61] Interview with Björn Fredriksson Möller, (P. Peck, Y. Voytenko) 29 September 2015.
[62] Björn Fredriksson Möller, Bengt Ridell, (2013, June) *Case story: Vehicle gas in Sweden*.

000m^3). While some refuelling points have been built for smaller volumes, the current growth rates for the Swedish market have required the building of around ten public filling stations per year.

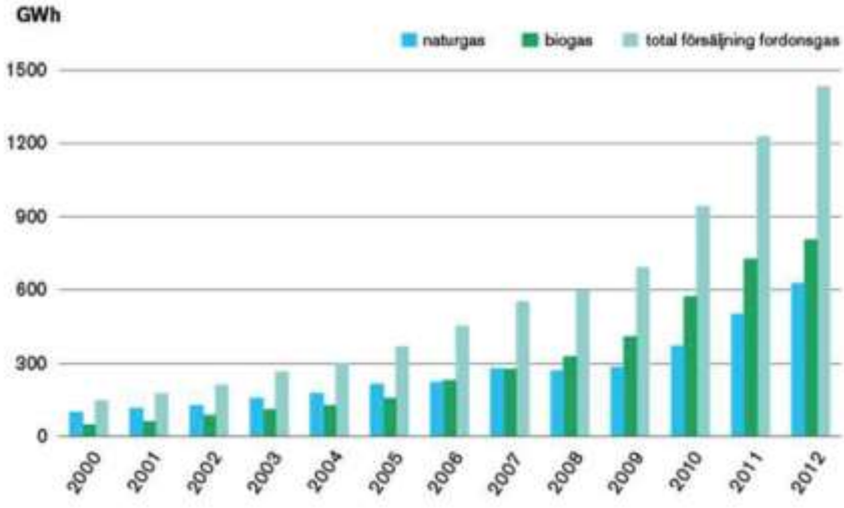

Figure 9. Market growth for gas utilization in vehicles.[63]

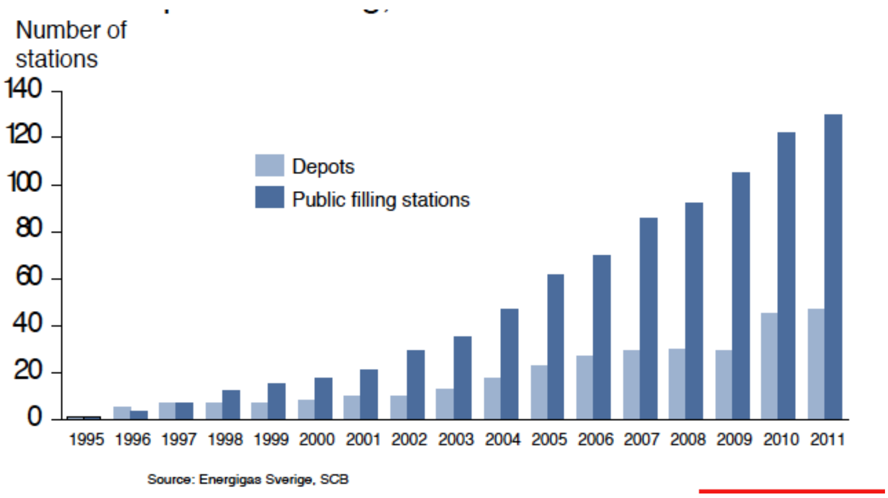

Figure 10. Growth in vehicular gas distribution infrastructure [Source: Möller June 2013].[64]

A growing range of vehicles that can utilize gas has complemented policy support and growing demand. While the market commenced with converted vehicles, there is now a suite of models constructed to suit gas. As of 2016, this includes models from Volkswagen (e.g. Passat, Up! and Touran), Mercedes (e.g. B180, E200), Subaru, Opel, Volvo, Fiat, Ford and Audi. Light trucks are available from VW, Opel and Mercedes, and heavy trucks are being introduced by Volvo to run on

[63] Möller *et al* (2013) *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Björn Fredriksson Möller, Anders Molin, Krister Ståhl, E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013. Available at: http://www.gastechnology.org/tcbiomass/tcb2013/04-Moller-tcbiomass2013-presentation-Wed.pdf (accessed 20 April, 2016) and Björn Fredriksson Möller, Bengt Ridell, (2013, June) *Case story: Vehicle gas in Sweden*. (p21). Available at: http://www.co2-electrofuels.org/Links/~/media/CO2_electrofuels/pdf/5_case_story_vehicle_gas_in_sweden.ashx (Accessed, April 20, 2016).

[64] *Ibid.*

methane-diesel operation. As noted, buses running on gas operate throughout Sweden – they are used in both local and regional fleets.

E.ON notes that in the past, there was a shortage of gas production. Now it is the market that is the bottleneck. “If one considers the 50% goal, then we have an oversupply of biogas”.[65] They indicate that from a purely economic viewpoint, it is advantageous for a distributor to lie at the level of 50% each biogas and fossil gas. As noted, vehicular applications remain the most profitable segment for biogas. In addition, there are a number of long-term agreements with producers and, for example, bus companies on the user side. The organisations that demand 100% biogas also contribute to ‘pulling up’ the statistics (for average biogas content in the grid). While E.ON does offer a product ‘biogas 100’ which costs a little extra (and is based on the promise that an equivalent amount of biogas is available in the gas grid), this is not a large product segment.

1.6.7 Risk and risk amelioration related to Bio2G

A range of risks are presented in relation to the project, however an item given overwhelming space within discussions of project related risk, is that of political uncertainty and biofuels-related policy volatility. By choice, this is presented later in this section – it is desired that other items be given space – not least so that policy related items could be placed in context relevant to these issues.

1.6.7.1 Technical risks

While technology related risks for a complex and ground-breaking project such as Bio2G are without doubt significant, they have been given relatively minor coverage in both literature and media examined in this case. It has not been a topic stressed by project proponents in discussions. The successful operation of the Värnamo gasification plant in the late 1990s (that Sydkraft was involved in, although having a different technical base) appears to contribute to the apparent high degree of confidence in the technologies.[66]

1.6.7.2 Financial/Market-related risks

The financial and market related risks are high. The project has not been progressed into the design and construct stage for the simple reasons that the financial performance of the project is inadequate without a healthy market for the bio-SNG and production support. The markets still do not have significant (growth) support via policy instruments.

A successful NER300 application during 2012 was explicitly pursued in order to decrease financial risk. However, NER300 production support to the order of circa 1.9 billion SEK (€204M) spread over the first five years of operation is insufficient to ameliorate market related risks to a point where the investment is viable. Further, the NER300 support is conditional upon a plant operation by 2018 – which is now impossible. However, the support can be extended to at least 2020 – a possible time frame if E.ON were to commence the project in 2016 (a situation that also appears unlikely). E.ON notes however that as there is a low uptake of approved NER300 support, this

[65] Interview: Tomas Lönnqvist (KTH) with Björn F. Möller (E.ON) 18 Nov. 2015.

[66] See for instance: Möller, B.F. (Nov 2010), *Gasification Development at E.ON*, (Eon101029_EGD@SGC_open) presented at the SGC International Seminar on Gasification, Svensk Gastekniskt CenterAB, 2010

creates a situation that should lead to a degree of flexibility on the side of the EU regarding further time extensions should the project be pursued.

E.ON has estimated, that with NER300 support, Bio2G can produce bio-SNG for some 60öre/KWh (7€cents/KWh) at the plant gate. This is competitive with the biogas production of today. In addition, there are also a proportion of green electricity certificates for the electricity that is produced in the plant and used internally.

While, as noted earlier in this text, the project exists in a period of policy instability and lack of clarity, there are more factors at play. E.ON presents views that the existing market is unlikely to be enough to underpin such an investment (this should also be viewed in the light that E.ON does not see Bio2G as just a 'one off' plant, but rather the first in a series of such). Simply put, the current market is entirely insufficient to absorb the production of a facility such as Bio2G. They indicate both a need for a new segment, or new segments of gas buyers on the transportation market, and more considered growth of existing segments.

1.6.8 Considered growth of existing segments

As indicated earlier in this case, biogas fuelled busses are common throughout Sweden. While both local and regional fleets do have biogas buses, this is more common in the local fleets. Overall, however, the total proportion of biogas buses is relatively small. Further, there is now a developing trend to replace buses, including biogas buses (local) with electrical buses. In some instances, such activities are taking place instead of a change-out of regional buses from diesel to biogas.

In a related manner, the market for biogas-fuelled cars is also being affected by growing attention on electrical vehicles, particularly in the media where these are 'hyped'. E.ON indicates concern that as an option that is 'exactly as a normal car', the public is not aware of the economical or environmental benefits of a gas vehicle and that a more balanced coverage is required to prevent an overall reduction in the market growth as attention is diverted to less functional (range, fuelling) and more expensive electrical vehicles. E.ON also perceives that there is also an important lack of differentiation between so-called 'environmental vehicles' – they consider that it is quite unreasonable that a biogas vehicle is categorised essentially the same as a fuel-efficient diesel vehicle. The fundamental difference that there exists the possibility to choose an entirely renewable fuel option, and moreover avoid other health endangering emissions. [67]

At present, electricity and gas fleets are growing at a rate of around 500 vehicles per month each. However, the gas fleet is much larger – some 50 000 vehicles compared to 10 000 electrical vehicles. E.ON considers that while there is lot of discussion surrounding electrical vehicles, not as much is happening in that area compared to gas.

1.6.8.1 New segments and growth segments

At present the major users of biogas remain as municipalities, company work vehicles, and taxis. E.ON considers however, that these segments will be 'eroded somewhat at the edges' as electrical fleets grow. While periods of healthy growth have been observed in vehicle fleets, and more biogas vehicles are made available by manufacturers, a prime bottleneck for biogas remains demand for

[67] Interview: Tomas Lönnqvist (KTH) with Björn F. Möller (E.ON) 18 Nov. 2015.

vehicle gas and fleet expansion is required to provide such demand. New user groups are required to provide such demand, and E.ON perceives that they must include both private/domestic vehicle owners, and even heavy goods fleets. E.ON perceives opportunities to significantly grow markets in a number of areas, these include *inter alia*:

- Existing but limited segments
    - Taxis
    - Company cars ('förmånsbilar'/'Fringe-benefit vehicle')
    - Business cars ("företagsbilar" - a large segment)

- New segments
    - Private drivers and heavy transport (distribution trucks)
    - Heavy trucks / distribution trucks
    - Business bi-fuel utilities – (e.g. a Volkswagen Caddy)
    - Trucks without trailer (12 m) that can operate over shorter distances (e.g. in the cities, between storages, to railway etc.), while LNG (liquid biogas) would be applied for long distances. Both Scania and Volvo supply engines to support these moves.
    - Maritime transport is also a potential market – with promising volumes should it arise.

1.6.9 Political Issues

This category seeks to focus upon political actors rather than policy. A recurring theme in interviews and discussions with E.ON in this regard is that political attention spans are short, and political actors experience great difficulty in understanding "which pathway to choose" – "there are many stakeholders and it is difficult to know". However, the media plays an extremely important role exacerbating such challenges and serves to divert attention from a complex field of technologies (where biogas is one platform) to items that fall in a different category. In short, they hold that the media wants to have something like: "here is the winner, this is best".[68] There are advocates for different solutions, and also advantages and disadvantages of different pathways. While such challenges are recognised and worked upon by actors such as the European Biofuels Technology Platform, E.ON believes that a "balanced opinion is required for politicians – one must start with everything, not just the cheapest alternative". [69] Seen together with the manner in which media portrays different solutions, E.ON believes this hinders development in general, and development of their biogas and bio-SNG markets in particular.

1.6.10 Policy instruments/interventions

The existing taxation regime for biogas is that there is a tax reduction of 100% of energy tax and 100% of carbon dioxide tax for biogas used or sold as motor fuel. In December 2015, this exemption was approved by the EC until 2019.

A common theme regarding this project is a lack of certainty (low 'foreseeability') regarding policy instruments affecting biofuels in Sweden. While a suite of policy instruments has supported biogas, their time horizons have been short, and they have been surrounded by uncertainty. It is held by

[68] Interview with Björn Fredriksson Möller, (P. Peck, Y. Voytenko) 29 September 2015.
[69] *Ibid.*

project proponents, that to underpin investment decisions, a time horizon of significantly longer than 3 years (roughly the current best situation) is required. Policy instability affects the growth of the vehicle gas market – which in turn delivers uncertainty for any investment in biogas or bio-SNG production.

In this regard, E.ON provides an example regarding the process of confirming a reduced 'fringe benefits tax' related to company vehicles. This is decided for only three years at a time. The decision and announcement of extension is taken late each time – and thus decision-makers that choose an environmental vehicle as a company car are only guaranteed the advantage for a reduced time period. Another example can be found in the process of extending the tax exemption of biofuels. The renewed exemption (from 2016 to 2020) was only decided at the end of 2015.[70] E.ON sums this up as follows when discussing the hypothetical situation that they should commence the Bio2G project at this time -- *"we do not know, how the rules will look like, when the plant is in operation in 2020 – [that is] a huge uncertainty, that is in simple terms the dilemma that we deal with today"*.[71]

Reflecting challenges in policy regimes and market growth in Sweden, E.ON is still growing its involvement in production. During 2015/16 the company is involved in the building of a 200MW facility in Denmark. This is significantly larger than the aforementioned Högbytorp facility. In Denmark there is fiscal support for the feed-in of gas to the grid. The support is formed to suit meat producers, as it requires the inclusion of animal manure in the substrate mix. After this point, the biogas is treated identically to fossil gas in the utilisation market. The import of biogas to Sweden from Denmark is then taxed as fossil gas – it is not possible to receive a double policy support.

1.6.11 Workable policy regimes

In discussions of potential policy regimes that could support the following morphologies were presented by E.ON in general terms: [72]

- A modest energy taxation on all fuels (as in the EU), with a significant CO_2 taxation that is based well to wheel emissions of carbon;
- The introduction of a 15-20% quota obligation, which will allow for more certainty on how much fuel should be in the transportation mix. This would be developed with time (e.g. by 2030 have 80% of all transport run on biofuels). A quota obligation should include both high and low percentage blends. It should be set relatively (sufficiently) high to demand action, and allow trade between segments (as sketched out in Sweden's FFF investigation). E.ON considers that the obligation would need to be placed on distributors. However, E.ON also recognises that an obligation format may not aid the vehicular vehicle gas market – there being a risk that the system would result in a high volume of low blend fuels and leave niches such as biogas out. As such, a system may need special clauses to also promote biogas.

[70] Interview: Tomas Lönnqvist (KTH) with Björn F. Möller (E.ON) 18 Nov. 2015.
[71] Interview with Björn Fredriksson Möller, (P. Peck, Y. Voytenko) 29 September 2015.
[72] *Ibid.*

- A combination of a permanent taxation exemption 100%, and a market share quota (a permanent tax exemption of 100% and allocated quota obligations) would be advantageous (but it is recognised that the EC does not want to introduce permanent tax exemption). As there is no CO_2 tax in the EU, one needs to extract energy taxes. One can apply for an exemption (dispens) for a maximum 10 years.

- Bonus/malus (e.g. a system that provides a bonus for environmental cars, which in turn is balanced by disincentives or malus for non-environmental cars) has been debated, both positively and negatively, by biofuel proponents.[73] Regarding this system, E.ON indicates uncertainty how such a system would affect biogas after 2017. For them, an important discussion is however, that a bonus malus system could be spread over several years so that the relative advantage can move with the vehicle. For example so that it follows a company vehicle status to a private vehicle status via the second hand market. This in recognition that the re-sale value of a vehicle is an important factor in a decision calculus.

- E.ON has indicated that a body such as *f3* could generate a proposal for fuel mix together with intermediary goals, and how one should progress on each of the goals. A prime objective would need to be to ameliorate situations where the *f3* community is counter-productively criticising each other – but where progress towards ‘advanced biofuels’ is stimulated. While fuels such as HVO (hydrogenated vegetable oils), and methanol are sold on the market, a proportion of these are not “advanced biofuels”. In contrast, in Sweden 97% of methane produced for transport is based on the residues – as such, most of the Swedish effort in this area fulfils the criteria for advanced biofuels.

1.6.12 Investment support

As noted earlier in this report, investment by partners is important for the Bio2G project progression. E.ON indicates that circa 25% of the total project cost should be seen as a minimum. While investment support from the Swedish government has been put into larger advanced biofuel projects (e.g. GoBiGas and Chemrec), the timing of these initiatives was too early for Bio2G.

1.6.13 Future plans for the (envisioned) project[74]

As has been indicated, E.ON handles some 500 GWh gas in the transportation sector in Sweden (circa 1/3 of the whole market). By 2020 a reasonable corporate goal is considered to be to double this. Stockholm has natural gas supply (via LNG), and fuelling stations for natural gas where a station is generally profitable from around 10 GWh/yr capacity. Thus, significant expansion is expected in that market. Further, the company has also invested in refuelling stations in Denmark – and in production capacity. E.ON is involved in a collaborative project in Sønderjysk that will produce 200 GWh biogas per year. In Sweden the biggest plant so far is in Jordberga at 109 GWh. In the absence of the Bio2G project, the company can transport biogas from Denmark to Sweden – currently however, these volumes are not counted as biogas in Sweden. Rather, they are offset on

[73] See for example: http://www.gronabilister.se/arkiv/pressmeddelanden/18-4-grona-bilister-sa-utformas-robin-hood-skatt-for-bilar-regeringen (accessed 26 April 2016)

[74] Interview with Björn Fredriksson Möller, (P. Peck, Y. Voytenko) 29 September 2015.

other markets (in this case the Danish) and pay the same tax as natural gas in Sweden. The expansion of biogas is expected to continue with a focus on transportation use; as industry pays a low tax on natural gas this is little or no incentive to switch to biogas.

In discussions, it has been made clear that the E.ON model for expansion can generally be summarised as follows *'we need to create the market for the gas before we build the production plant where the gas produced'*. This situation is possible as there is currently more than adequate biogas available for sale. The company believes that if taxation regimes remain in similar forms to today, then an extra 1.5 TWh will be expected by 2025. By that time there will clearly be a need for other types of gas production plants such as Bio2G.

1.7 RENFUEL

The following section is based on an interview with Sven Löchen, CEO at RenFuel AB (performed in March, 2016).

1.7.1 The technology system

Renfuel will build a pilot plant that in industrial scale converts lignin, which is extracted from a kraft pulp mill, into a liquid renewable carbon and hydrogen based lignin oil (catalytic lignin oil, called Lignol). The catalytic process decomposes the lignin (which is blended with oil) at atmospheric pressure, below the boiling point. One tonne of lignin is converted to one cubic meter of lignin oil. The lignin oil can be refined to renewable petrol and diesel and has the same characteristics as fossil oil and can be used as drop-in fuel at different levels. During the production of lignin oil oxygen is removed. To what extent will depend on the cost-effectiveness of removing oxygen in the Renfuel process compared to removing it in the subsequent refinery process.

The planned size of the pilot plant corresponds to a few thousand tonnes of lignin oil per year (see Table 1). The pilot plant will be located in connection to Nordic Papers pulp mill in Bäckhammar, Värmland, Sweden. The Renfuel pilot project runs from October 2015 to 2018. When all agreements and design specifications are in place, the constructions phase continues during 2016. The plant will be in operation during 2017 and will be evaluated and plans will be made for a commercial plant during 2018.

Table 8. Envisioned production and feedstock streams of the planned Renfuel pilot plant[75] (Löchen, 2016).

	Planned Production (tonnes)	Planned Production (GWh)	Feedstock	Feedstock input (tonnes)	Feedstock input (GWh)
Fuel output (lignin oil)	In the range 1-9000	?	Lignin	?	?
By-product output	No biomass based by-products	-	-	-	-

1.7.2 The proponent(s)/initiator and motivation factors for the initiative

Renfuel is the subsequent result of a case within a mentor program (Mentor for research) by The Royal Swedish Academy of Engineering Sciences (IngenjörsVetenskapsAkademien). In the mentor

[75] Löchen, S. (2016). Personal communication: RenFuel AB, Sven Löchen, CEO at RenFuel AB, 8 March (with J. Hansson, IVL).

program (during 2009-2010) the scientist Joseph Samec from Uppsala University was matched with Sven Löchen from the industry. Initially Joseph Samec wanted to convert cellulose to liquid fuel but in order to not compete with the forest industry they chose to focus on lignin instead.

At kraft pulp mills using forest biomass lignin is considered a by-product that is part of the black liquor. Based on experiences from earlier domestic biofuel production projects, Samec/Löchen realised that it is crucial to find a raw material with a large supply, low competition, existing infrastructure and that is non-controversial from an environmental and political point of view. They also realised that in order to succeed it is crucial to focus on a specific link of the biofuel production chain and reach a relatively low CAPEX (Capital Expenditures).

The research was moved to the company KAT2BIZ that holds the patents. In 2012, Renfuel was formed with KAT2BIZ as main owner. The purpose of Renfuel is to materialise the business model and reach industrial scale. The aim is a scale that reduces the technical risk of the future transition to commercial scale.

1.7.3 Partners and networks involved

The involved parties include financiers and risk capital actors, forest industry and refinery actors, and companies interested in constructing these plants in the future. Renfuel have access to extensive knowledge about the forest industry and refinery technology but due to business reasons, refineries are not included in the company.

1.7.4 Feedstock/raw materials supply chains and market

The catalytic lignin oil is produced from lignin that is obtained from the black liquor from pulp mills. Besides lignin, the Renfuel process needs oil. The oil can be either fossil based or renewable based. For example, domestically produced rape oil or the raw tall diesel from SunPine could be used in the future.

By removing lignin from the pulp mill, by time it might be possible to expand the capacity of the pulp mill. The reduced pressure on the recovery boiler might make it possible to convert more wood, in its turn increasing the possible level of lignin withdrawal. For pulp mills that need to reduce the pressure on the recovery boiler due to age, the withdrawal of lignin is also interesting.

If the future domestic prerequisites are not sufficient the lignol product can be sold to other nations with better policy set-ups. Since, it in practice is the regulations that influences the development, the current relatively low oil price is not that important from the perspective of Renfuel.

1.7.5 Technical, financial/market-related and political/policy-related risks

Renfuel handle the different risks by using an abundant non-controversial raw material with existing infrastructure, by protecting the “Renfuel process” with several patents, by focusing on the described specific link of the chain for producing transport fuels (i.e., they leave the final delivery step to more experienced actors), and by obtaining a relatively low CAPEX. The planned size of the pilot plant is chosen in order to reduce the technical risk of the future transition to commercial scale. The Renfuel process will be adapted in order to make it possible for refineries to use the lignol with minor modifications in existing infrastructure. In general, the risks, and how to avoid them, have been identified by Renfuel based on the experiences from earlier Swedish biofuel production projects.

1.7.6 Policy instruments/interventions

Renfuel has received investment support. The total budget of the entire pilot initiative amounts to 140 million SEK and the Swedish Energy Agency is the main economic contributor (slightly over 100 million SEK in total). The rest is provided by existing owners (also including in-kind).

The development of national policies is naturally important for Renfuel that believes that a quota system for biofuels for transport is the most important required national policy measure. Renfuel has not been significantly impacted by the competition from other forest based transport fuels under development.

1.7.7 Future plans for the (envisioned) project

The size of future commercial plants depend on the amount of lignin that is possible to extract at a specific mill or if several mills will deliver lignin to one lignol plant. A first commercial lignol plant is expected to be in the size of 50-200 000 tonne lignol per year.

1.8 SUNPINE

The following section is based on an interview with Gustav Tibblin, Södra and chairman of the board of SunPine (performed in October, 2015), complemented by information from the SunPine webpage (www.SunPine.se).

1.8.1 The technology system and localisation

At the SunPine facility in Piteå, raw tall diesel is separated from raw tall oil, a by-product from the pulp and paper industry. The raw tall diesel is then processed further to HVO diesel fuel, by treatment with hydrogen gas under high pressure, by Preem at the refinery in Göteborg. The SunPine facility in Piteå (since 2010) is the first facility of this kind in the world and the unique steps are the fractionation of the raw tall oil and the treatment to high quality diesel. The current production capacity for raw tall diesel is 100 000 m^3 per year. Gustav Tibblin did not reveal the conversion efficiency from raw tall oil to raw tall diesel due to the "refinery" structure of SunPine producing several products including tall oil pitch and resin (that they aim to develop further).

There are three main reasons behind the localization in Piteå. Firstly, there is a lot of tall oil in that region and plenty of industries. Secondly, Solanders Science Center, which operates a demonstration plant for gasification, as well as other development of forest based process technologies, is located in Piteå and the innovator Lars Stigsson had experiences from this location earlier. Thirdly, Piteå is considered to be one of the best municipalities in Sweden to realize new industries with a relatively smooth and not to time-consuming process (an industry friendly municipality).

Table 9. Envisioned production and feedstock streams of the SunPine facility[76].

	Production (m^3 per year)	Production (GWh)	Feedstock	Feedstock input (tons)	Feedstock input (GWh)
Fuel output (raw tall diesel)	100 000	-	Raw tall oil	na	na

[76] Tibblin, G. (2015). Personal communication: Gustav Tibblin, Södra and chairman of the board of SunPine, 1 October (with J Hansson, IVL).

1.8.2 The proponent(s)/initiator and motivation factors for the initiative and the partners and networks involved

Lars Stigsson, Kiram, is the innovator behind the idea to extract diesel from raw tall oil. In 2006, a theoretical description of the process was available and Stigsson contacted several companies in order to find interested parties. SunPine was formed and is owned by Preem (25%), Sveaskog (25%), Södra skogsägarna (25%), KIRAM (15%), and Lawter (10%; Lawter joined in 2014).

There are three main reasons why Södra decided to join this project. Firstly, Södra is a significant producer of tall oil and the market for tall oil was not working well with few actors and a low demand. Secondly, Södra is in favour of innovation and in processes replacing fossil fuels with biomass. Thirdly, pure economical reason since this was considered a profitable project.

1.8.3 Feedstock/raw materials supply chains and market

As indicated above the tall oil market represented an oligopoly with few actors and low demand. Both producers of tall oil and producers of diesel were part of the SunPine company and this has facilitated supply chains, and market related issues.

1.8.4 Technical, financial/market-related and political/policy-related risks

Strong owners that invested equity and facilitated bank loans reduced the financial risk. Patents reduced technical risks but this also implied that they had to be in charge of the construction process themselves. The first facility did not work immediately and was rebuilt so it took at few years before the production reached targeted level and was profitable.

Regarding polices SunPine was a bit naive in believing that stable and long-term policies were to be implemented. Since this was not the case, the uncertainties have had negative impact and the owners of SunPine have put large resources in trying to influence policy makers. Due to good luck and skill it has worked out in the end. However, they indicate that if they had known what they know today about the policies it is uncertain if the companies would have invested in SunPine.

1.8.5 Policy instruments/interventions

The exemptions from CO_2 and energy tax have been decisive for the project and are considered as important policy measures. SunPine have not had any significant investment support. For Södra, it is not particularly important exactly which policy instrument that is implemented as long as the policies are foreseeable and trustworthy over time.

1.8.6 Future plans for the (envisioned) project

There are no plans for similar additional plants at the moment. SunPine are focusing on the by-products at present and have started producing resin.

1.8.7 Other plans for Södra

Södra did also plan for a demonstration plant for lignoboost in Mörrum. Lignoboost is a technology for extracting high quality lignin from a kraft pulp mill. By implementing the lignoboost process it is possible to expand the capacity of a pulp mill without increasing the capacity of the recovery boiler (which is often the bottleneck) and the lignin can provide revenue if used. The reason behind the plan of Södra was the interest in innovation, in processes replacing fossil fuels with biomass and the possibility to increase revenues. The EU had approved a grant from the Swedish Energy

Agency. The technical risk was an issue when the project was stopped due to the unproven technology and related to the development of lignin as product. But also the economical and political risk due to uncertain future conditions.

At present, Södra in cooperation with Statkraft (Norway) is involved in Silva Green Fuel AS with the aim to produce forest-based biofuels. The plan is to evaluate different technologies and if judged possible they will jointly build a demonstration plant (most likely in Norway). Results will be presented in a few years.

1.9 PREEM

The information about the context of Preem's involvement in biofuel production below and above was gathered in an interview with Sören Eriksson and Åsa Håkansson at Preem in Stockholm 10 December 2015.

1.9.1 The technology system (the initiative)

Preem is a leading Swedish petrochemical refiner with two of Sweden's three refineries for transportation fuels and about 80% of the total refinery capacity in Sweden.[77] St1 operates the third refinery. The total refinery capacity in Sweden corresponds to about twice the domestic consumption, which makes Sweden more important as an oil product country than may be expected if one considers that there are no domestic oil resources. The refineries are situated in Lysekil and Gothenburg and the former is about twice the size of the latter. Investments to produce transportation fuels from biomass have until present time (April 2016) only been carried out in Gothenburg, but there are plans for similar solutions in Lysekil.

Preem's production of biofuel has been ramped up since the production of hydro-treated vegetable oil, HVO, started in 2010. The capacity at start-up in 2010 was 100 000 m^3 per year while the present annual capacity is now more than 160 000 m^3 HVO after investments in 2015. The capacity could theoretically be up to 300 000 m^3 per year, but this is currently limited by the hydrogen capacity at the refinery.

HVO is interchangeable with conventional diesel and is presently mixed with FAME so that the product Preem Evolution Diesel sold in Sweden now contains up to 50% renewables.[78] Previously, the blending of HVO into conventional diesel fuels was limited by the cold flow properties of the straight carbon chains of the HVO. The blend was thereby lower in the winter qualities in comparison to the summer quality fuels. This has been technically resolved by an isomerization step adopted from Neste in which the straight carbon chains are made more branched. The so-called cloud point temperature of the HVO is thereby lowered.

The feedstock for the HVO is crude tall oil (CTO) from Kraft pulp mills that is processed to crude tall diesel at SunPine in Piteå. CTO is a product, or by-product (depending on the context) that is split in two fractions by distillation, crude tall diesel and tall oil pitch. The plant in Piteå also has an esterification step, intended to be used to produce esters instead of fatty acids. However, this step

[77] Preem, 2016. About Preem – Refineries. https://www.preem.se/en/in-english/about/refineries/ (accessed 28 April 2016)

[78] Preem, 2016. A Unique Swedish Transportation Fuel [Ett unikt svenskt drivmedel]. http://preem.se/om-preem/hallbarhet/evolution-drivmedel/evolution-diesel/ (accessed 28 April 2016)

has never been used and one reason for this is that the methanol that should have been used in the esterification was of fossil origin. The crude tall diesel shipped to Gothenburg hence consists of fatty acids. More than half of the CTO becomes crude tall diesel in the SunPine process.[79] The crude tall diesel contains some sulphur from the Kraft pulp process together with a substantial amount of oxygen and both are removed at Preem in a process called the green hydro treater process (GHT). This step used to be a mild hydro cracker that was redesigned to the GHT and, as the name indicates, hydrogen is needed in the GHT. The hydrogen used in the process is taken from the catalytic reformer at the refinery, a process step in which naphtha is converted to petrol, and the amount of produced hydrogen is still enough for the GHT. This is even so despite a worldwide trend in refineries where the demand for hydrogen in other unit operations at refineries has increased due to stricter environmental demands and poorer qualities of crude oil, i.e. heavier crudes that contain more sulphur. The refinery in Lysekil has a hydrogen plant to cover increased hydrogen demand, thus it is possible to refine pure high sulphur Russian crudes. The hydrogen surplus in Gothenburg is maintained via the processing of lighter low sulphur crudes that are refined at this site, normally North Sea crudes, i.e. Brent.

1.9.2 The proponent

Lars Stigsson at Kiram AB who contacted the corporate management at Preem took the initiative for that which later became the HVO production at Preem in Gothenburg. SunPine AB was founded in 2006 with Kiram as the sole owner and in 2008 Preem AB joined together with Sveaskog and Södra Skogsägarna.

The Finnish refiner Neste has been the world leading producer of HVO at commercial scale since 2007[80] and as the interviewees pointed out that it has been natural to look at this example as a basis for HVO production. Neste's total capacity today is about 2.1 million tonnes at their refineries in Singapore, Rotterdam and Porvoo; i.e. more than ten times the capacity of Preem. The main feedstock for the HVO production at these refineries is palm oil. Recently, this has also been diversified to use a combination with technical corn oil, FAME, and animal fats. Another difference between Preem and Neste is that the latter uses dedicated production lines for HVO. This makes the investment cost approximately ten times higher than the integrated approach to introduce HVO in existing production lines used by Preem. According to Preem, this usually means that most of the equipment could be the same with modifications such as material changes and ceramic lining to withstand the more aggressive fluids in the bioprocess. This has been an important factor in the decision process for Preem. As pointed out above, the isomerization process to improve the cold flow properties was not introduced until recently in Gothenburg. The reason for this was a legal process about the patent rights to carry out these steps, a situation that subsequently was solved financially with Neste. Thus, it is clear that Neste has been a source of inspiration for the production of HVO, but also that Preem have decided to follow a different path for both the feedstock and production technology.

The decision to invest in the HVO line in Gothenburg was made by Preem while the investment for the crude tall diesel plant in Piteå was a joint decision by the owners. Preem invested circa

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[79] SunPine, 2011. Biorefinery – Second generation biofuel. http://www.ieatask33.org/app/webroot/files/file/minutes_and_presentations/Pitea_Oct2011/Site%20visits/SunPine%20presentation_eng.pdf (accessed 28 April 2016)

[80] Neste Oil, 2014. Hydrotreated vegetable oil (HVO) - premium renewable biofuel for diesel engines, Neste Oil Proprietary publication.

SEK100 million in Piteå, thereby presently (April 2016) owning about 25 % of SunPine where the total investment has been somewhat above SEK 400 million.[81] Another SEK300 million was invested at the refinery in Gothenburg. Both plants started their operation in 2010. Preem subsequently invested SEK350 million in the isomerization step and the capacity increase in Gothenburg (to more than 160 000 m^3 of HVO). Both these updates were in operation by the autumn of 2015. Since the capacity of crude tall diesel in Piteå is still 100 000 m^3 per year, the remaining part has to be filled with another feedstock and the main additional feedstocks, as early 2016, animal fats and rape seed oil. In the GHT, the triglycerides in the rapeseed oil are split into propane and three hydrocarbon chains. At present, this propane is presently not marketed as renewable.

1.9.3 Motivating factors for initiative

The main financial motive for the investment decisions in 2008 was the tax alleviations for renewable transportation fuels available in Sweden. Preem emphasize that they never have received investment supports for their investments. During the interview, the interviewees pointed out that there were sever factors that they considered to be very strong drivers for investment decisions, e.g. expected market development, expected policy instruments (i.e. that the tax alleviation should remain or be replaced by a quota system), experiences from other plants, present distribution infrastructure, match with the present core business, and environmental properties.[82] Issues such as in-house know-how and the possibilities for synergies and co-operations with other organisations were not considered to be as important. Preem noted that as part-owners of SunPine, they have some interests in the extraction of resin acids and other valuable products like athraquinone and phytosterols from the CTO and since these are valuable products for other purposes than transportation fuels, it might be considered as an important synergy for SunPine. Since the initial investments, the investments for the extraction and further processing of resin acids have also been made in cooperation with the chemical company Lawter, which added an owner to the list of owners of SunPine.[83]

1.9.4 Placement/Localisation

During the interview, two factors that were identified as the most important for the localization of the production were the present infrastructure for the distribution of the transportation fuels and, naturally, the existing refineries. Hence, the localization of the final steps for the production of transportation biofuels was not a difficult question; the biofuel processing should be performed at one of the present refineries in Gothenburg or Lysekil.

The localization of the SunPine plant was described as something that was presented to Preem in the concept laid out by Kiram. The major reasons to place SunPine at a port close to Piteå was the vicinity to several Kraft pulp mills that could deliver CTO, the good harbour and a number of available cisterns/storage tanks that were already in place.

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[81] This investment figure includes additional investments made for extractions of tall oil resin acids. Present ownership is: Preem 25%, Sveaskog 25%, Södra 25%, Kiram 15%, Lawter 10%.

[82] The interviewees also identified these as particularly relevant items within the interview guide (distributed to them prior to the interview situation).

[83] SunPine, 2014. Press release: SunPine and Lawter expands [SunPine och Lawther expanderar], 15 July 2014. http://www.SunPine.se/pressmeddelanden/SunPine-och-lawter-bygger-ut/ (accessed 28 April 2016)

1.9.5 Feedstock/Raw materials supply chains

The investments for HVO production at the refinery in Gothenburg would not have been carried out without a reliable supply of feedstock, which in this case was crude tall diesel, and vice versa for the investments at SunPine. The investment decisions relied on each other.

When presented with a list of potential factors of importance (via the interview guide) Preem rated almost all the factors mentioned under the arguments for the chosen feedstock as very strong. These were: the supply of feedstock, the technical possibilities to use it in present processes, the policy instruments connected to the feedstock, possibilities for cooperation, the opinion about the feedstock among the citizens and in the supply chain, and the environmental performance of the feedstock. The only factor that was rated as neutral was the price for the feedstock. They do not consider this to be low and the comment about this was that it is also true for other possible feedstocks that will complement the CTO during the on-going expansion. Further, the case with tall oil is special since it is a limited resource that had a limited market prior to the use as a feedstock for transportation fuels. In the past, Kraft pulp mills sold the CTO to one company in Sweden, Arizona Chemicals. They fractionated (distilled) it for a variety of products while some part of the fractionated CTO still ended up as tall oil pitch that mainly is used as a fuel oil. There are also plants for CTO fractionation in Finland. The limited market made the market survey relatively easy. For the on-going expansion with alternative feedstock, such as, animal fats, fish oil, jatropha oil, used cooking oil, and technical corn oil, the interviewees mention that there is a more normal buyer/seller market with several actors involved in each case.

1.9.6 Markets for products

Sweden was – and is – seen by Preem as the natural market for the biofuel blends. For other products, Preem exports about two thirds of the production from the two refineries. The markets for transportation biofuels are, with some exceptions, relatively national. The foundation for the belief in the Swedish market is the belief in the Swedish policy instruments, which for Preem is equivalent to the total alleviation of energy and carbon dioxide taxes on HVO.

The ratings of the factors that have influenced the decision to invest in production of HVO are discussed in the preceding sub-section.

1.9.7 Markets for waste heat/by-product flows

Except for the necessary synergy between SunPine and the refinery in Gothenburg and the possibility to get access to crude tall oil, there are no obvious synergies that have influenced the localization of the plants. No excess heat is delivered from SunPine in Piteå and the GHT in Gothenburg does not influence the already significant deliveries of waste heat to the district heating net in Gothenburg.

At SunPine, there is an on-going development of possibilities to extract other valuable products from the tall oil pitch that presently is used as a fuel oil in limekilns at pulp mills and in district heating plants. These products are phytosterols and some resin acids that are used by the food and chemical industries. In Finland, Neste have announced that they have started to produce transportation fuels from the tall oil pitch itself[84], which is promoted in the current EU legislation. However, Preem have not mention any plans of doing the same in Sweden. In one proposal by the European Commission from 2012[85], tall oil pitch was explicitly mentioned as a feedstock from which transportation fuels should be calculated as four times their energy content in fulfilling the target for renewable transportation fuels as set by the renewable energy directive (RES), i.e. a very strong incentive for a member state to put in a policy instrument to support its utilisation. However, this never materialized – and the fuel produced from tall oil pitch is together with transportation fuels from a number of different specified biomass waste streams, black liquor, bark, tall oil, branches, animal manure, straw, algae, etc., currently calculated as twice their energy content in fulfilling the targets as set by the RES.[86] Tall oil pitch is thereby not more promoted as a feedstock for transportation fuels than other components of crude tall oil by the EU.

1.9.8 Technical Risks

Preem did not see any apparent technical risks with the investments made since they both had a full-scale example in the Neste production facilities and also based the production line in Gothenburg on modified existing process steps such as the mild hydro treater that became the GHT. The SunPine plant in Piteå is based on some conventional separation steps, i.e. not any revolutionary technical solutions. Thus, the process in Piteå was also seen as a relatively low risk investment considering the technology. The SunPine plant had to shut down the operation in the end of 2010 to deal with some problems during the start of operation, but this is very common in the start-up phase of a new plant.

1.9.9 Financial/Market-related risks

Preem believed that the market for biofuels and especially biofuels that could be used in the present distribution infrastructure and conventional vehicles would grow significantly and they have been correct in their assumption. The market for HVO has grown tremendously. In 2014, the total volume sold in Sweden was 439 000 m^3 and in 2015, this figure was 655 000 m^3.[87] The renewable part of transportation fuels was in total 14.7% of total amount of transportation fuels in Sweden in 2015, calculated according to the (amended) biofuel directive – and the share for HVO alone was 7%.[88] Preem strongly believe that the market for renewable transportation fuels will grow as long as there is a political interest for it to do so. As they have not used a feedstock that has been portrayed negatively by the media, the risk that HVO will encounter the same market failure as ethanol is considered small. The previously discussed alternatives to the present feedstock also indicates that Preem

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[84] Neste, 2013. Press release**:** Neste Oil uses tall oil pitch to produce traffic fuel. https://www.neste.com/en/neste-oil-uses-tall-oil-pitch-produce-traffic-fuel (accessed 27 April 2016)

[85] European Commission (2012). Proposal for a directive of the European parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources, Brussels, 17.10.2012, COM(2012) 595 final, 2012/0288 (COD).

[86] DIRECTIVE (EU) 2015/1513 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

[87] SPBI, 2016. Press release: Renewable transportation fuels in Sweden increased to 14.7% in 2015 [Förnybara drivmedel i Sverige 2015 ökade till 14,7 %], 16 March 2016. http://spbi.se/blog/2016/03/16/fornybara-drivmedel-i-sverige-2015-okade-till-147/ (accessed 28 April 2016)

[88] DIRECTIVE (EU) 2015/1513 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources.

are very aware of the risk that if their fuel were to be portrayed by critical stakeholders as unsustainable, they that could lead to a failure of the market. The oft-debated palm oil was never mentioned as an alternative during the interview.

1.9.10 Political/Policy-related risks

Early in the interview, Preem mentioned that a risk-reducing factor for them during the years of investment in HVO production has been the lasting full alleviation of energy and carbon dioxide taxes for HVO in Sweden. There have been discussions about changing the tax alleviations, but this has not yet happened. The interviewees revealed that they do not believe that the alleviations will be changed unless there are is another powerful policy instrument presently under formulation as a replacement. Hence, the political risk is seen as relatively low in Sweden while they consider the EU legislation as simply a framework that sets the limits of the political effort possible to pursue in each member state.

1.9.11 Policy instruments

When Preem rates different policy instruments, a clear picture appears. The alleviations of energy and carbon dioxide taxes have been instrumental for all decisions about HVO and are therefore regarded as very important for the development of the production. The only other policy instruments that are thought to have affected the decision process are public procurement and long-term contracts. More specifically, those interviewed mean that the role of municipalities to promote biofuels by public procurement or contracts with service providers have been important for the general consumption of renewable fuels. For the future development of other production pathways, Preem also mention that the information exchange with universities and education centres are important.

The policy instruments that are rated as unimportant for the decisions taken are the direct support for research and development to the producer, investment support, support to consumers, information from public authorities, and laws and regulations (other than tax alleviations). Preem points out that they never have received an investment support for their investments in Piteå and Gothenburg. A remark from one of the interviewees that says a lot is that *"all others* [in Sweden] *received investment support, but we were the ones that invested"*.

1.9.12 Investment support

As pointed out above, no investment support was received for SunPine or the GHT in Gothenburg. Generally, Preem points out that investment support is a weak policy instrument while an operational support as tax alleviation has a strong impact on the decision. A summary of the investments in biofuel production units in Sweden supports a view that they are correct in this general observation.

1.9.13 Taxation regimes

As has been described above, the tax alleviations have been very strong tools for the development of the HVO production in Sweden, i.e. for the investments made foremost by Preem. It is also pointed out that tax alleviations are a simple instrument to handle administratively by the companies. However, the interviewees both believe in the realization and support the idea of a future Swedish quota system for renewable transportation fuels. Their reasoning for supporting such a development is that the growth is so strong, and has to be even stronger, if the political visions for the Swedish transportation sector should be met. With this development there will be a tipping point when it will be too costly for the Swedish state to keep the tax alleviations.

A quota system that affects all transportation fuels will be even more effective to promote the growth of renewable transportation fuels according to Preem and explicitly they mention a quota system that resembles the system for green certificates in the Swedish and Norwegian electricity market. Preem also believes that independent of the policy instrument(s) that will be the preferred choice in Sweden, the changes that will occur will affect the prospects for production of renewable transportation fuels positively. The believe that it is possible to reach the political visions of a transportation sector that is independent of fossil fuels by 2030 according to the interviewees.

1.9.14 The most advantageous/desirable support model

Most of the reflections from Preem about policy instruments have been discussed in the previous sections, but some additional remarks may be added. In the rating of investment support versus operation support, the interviewees considered the first as a weak policy instrument while the latter was considered as very powerful. This is not surprising, since they have based all their previous investments on the tax alleviations without any investment supports at all. A comment is that investment supports may be better adapted for small operators; in this context, the interviewees also consider the price premium model as suggested by Tomas Kåberger in the FFF inquiry[89] as an investment support.

The continuing investments in increased production also reveal that Preem believes in a continued support and they perceive that the stability of the Swedish policy instruments as sufficient. They believe that the political will to promote renewable transportation fuels in Sweden is strong enough for them to be willing to continue the investments. The perceived long-term stability has had a strong positive effect on the investment in the Gothenburg refinery as well as on the investments and agreements with SunPine as the feedstock supplier.

1.9.15 Future plans for the (envisioned) project

The interviewees at Preem reveal several future possibilities to increase the production of renewable transportation fuels in their refineries. There are serious plans to start producing HVO at the refinery in Lysekil while there are a number of on-going activities to increase the production of HVO in Gothenburg. They have to expand the feedstock base to meet the increased production capacity of more than 160 000 m^3 of HVO. Among the alternatives envisaged are also the possibilities to receive bio oils from new biomass conversion concepts out in the countryside. Examples that are discussed are to receive oils from processed lignin extracted at Kraft pulp mills, (see the Renfuel project case in Section 1.7), and pyrolysis oils for the conversion to green petrol and/or diesel. There are however technical challenges to be overcome with the conversion of both these oils and probably more so for pyrolysis oils than for lignin oils. The pyrolysis oils probably need to be cracked, which is not the case for the vegetable fatty acids, thus the pyrolysis oils have to be fed to

[89] Government of Sweden, 2013. Fossil free road transport [Fossilfrihet på väg]. SOU 2013:84,[3] Stockholm: Statens Offentliga Utredningar. Basis report 24 [Underlagsrapport 24].

another part of the process than the fatty acids used today. There are also other problems with pyrolysis oils; they contain sugars, tars and a lot of oxygen that consume considerable amounts of hydrogen in the process steps to produce useful hydrocarbons.

The origin of the hydrogen has this far been rather subordinate for the sustainable criteria used to evaluate the transportation fuels, but this may change if pyrolysis oil is starting to become a major feedstock for the biofuels. Pyrolysis oils contain much more oxygen and hence demand much more hydrogen in the processing. An alternative is to use pyrolysis oil for the hydrogen production itself. Steam reforming of hydrocarbons is the dominating process for hydrogen production globally, but it is normally not performed for heavier hydrocarbon than naphtha. However, to use pyrolysis oil for hydrogen production has been thoroughly investigated in several cases.[90,91,92]

Preem have also considered the conversion of solid biomass to hydrocarbons in a slurry hydrocracker and to upgrade green crude oils from hydrothermal liquefaction (HTL) to green petrol and/or diesel.[93] A slurry hydrocracker is a unit that is commercially used by refineries to upgrade heavy residues to transportation fuels and it was originally developed almost a century ago to liquefy coal to produce distillates (diesel fuels).[94] This is why a slurry hydrocracker is believed to be useful for the conversion of solid biomass to liquid fuels as well. HTL is a technology in which biomass may be converted to a bio crude oil in a reactor with water and catalysts under elevated temperatures and very high pressures. A lot of research is being carried out surrounding HTLs and the possibility to co-process the bio-crude in refinery has also been studied.[95,96] All Preem's present and future concepts are therefore based on "liquid in – liquid out" with one exception, the slurry hydrocracker.

The interviewees point out that almost all of the considered future options are based on co-processing of bio oils produced somewhere else in the present refineries. They also point out that this is a worldwide trend in the refineries, despite the leading role that Neste have created with their biodiesel production in dedicated lines. Preem also emphasize that if we are to see a major shift toward renewable transportation fuels globally, the refineries will be the key element. Some stand-alone plants will exist in various places, but the large volumes have to be produced by the refineries.

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[90] Bleeker, M., Gorter, S., Kersten, S., van der Ham, L., van den Berg, H., Veringa, H., 2010. Hydrogen production from pyrolysis oil using the steam-iron process: a process design study. Clean Technologies and Environmental Policy, 12 (2), pp 125-135

[91] Sarkar, S., Kumar A., 2010. Large-scale biohydrogen production from bio-oil, Bioresource Technology, 101 (19), pp 7350-7361.

[92] Lea-Langton, A., Zin, R. M., Dupont, Martyn V. Twigg, M.V., 2012. Biomass pyrolysis oils for hydrogen production using chemical looping reforming. Int. J. of Hydrogen Energy, 37 (2), pp 2037–2043.

[93] Nyström, S., Lind Grennfelt, E., 2016. The future, our most important market – Renewable transportation fuels from Preem. Presentation at Preem in Gothenburg, 3 February 2016.

[94] Gillis, D., VanWees, M., Zimmerman, P. 2009. Upgrading Residues to Maximize Distillate Yields. UOP LLC, Des Plaines, Illinois, USA.

[95] Uhrenholt Jensen, C., Hoffmann, J., Rosendahl, L.A. 2016. Co-processing potential of HTL bio-crude at petroleum refineries – Part 1: Fractional distillation and characterization. 165, pp 526-535.

[96] Uhrenholt Jensen, C., Hoffmann, J., Rosendahl, L.A. 2016. Co-processing potential of HTL bio-crude at petroleum refineries. Part 2: A parametric hydrotreating study. 165, pp 536-543.

2 CASE STUDY ANALYSIS TABLES

This section of the report contains analysis tables for each of the biofuels production-related cases undertaken in the study.

2.1 LTU GREEN FUELS AND CHEMREC AND DOMSJÖ FABRIKER, ÖRNSKÖLDSVIK

2.1.1 Niche phenomena, LTU Green Fuels and Chemrec and Domsjö Fabriker, Örnsköldsvik.

Level of Analysis	Underlying phenomena	Parameters of particular interest in this study	Examples of anticipated information from case studies
Niche (location/situations/properties) *LTU Green fuels is a pilot plant for the production of biofuels (mainly DME) based on gasification of black liquor and other biomass based products in Piteå.* *In order to demonstrate the gasification technology developed by Chemrec and tested in the now called LTU Green Fuels pilot plant in Piteå, there were plans for biofuels production via black liquor gasification at a full-scale facility in Örnsköldsvik in connection to Domsjö Fabriker (approximately 100 MWfuel).*	A location for a learning process (a niche) A distinct/special/novel socio-technical offering (a niche offering)	Distinct place or situation where an innovation is hosted, tested or applied The form and novelty of the innovation	Description of the nature and elements of the innovation and how it differs from established systems. Description of the 'business ecosystems' forming around the system and influencing the business model, including collaborators and others that benefit. Boundaries of the system and relevant actors.
Describe the niches relevant to case study.	**Describe location** **Describe offering**	**Describe how it is hosted, tested or applied.** **Describe novelty.**	**Specific examples or anecdotes from case.**
Black liquor gasification – pilot scale	LTU Green fuels, Piteå. Pilot plant for the production of biofuels (mainly DME and methanol) based on gasification of black liquor and other biomass based products in Piteå (in operation 2010-2016). Based on the technology developed by Chemrec (entrained flow biomass gasification). Production capacity of 6 GWh fuel/ year (4 tonnes DME per day). Black liquor gasification results in a synthesis gas suitable for further processing to transport fuel.	Chemrec was the main initiator behind the pilot plant (with a long history, see case study description in Appendix). Hosted and tested with significant Swedish government support (e.g. Swedish Energy Agency) and EU support but also supported by Volvo and an American cleantech investment company. Contributing to building of technical networks, identification of key techno-economic development pathways. Black liquor gasification implies a very drastic change for the pulp mills and is perceived to compete with current technology and infrastructure. Therefore, questioned by the major part of the forestry sector. Considered a successful technology case by the EU. The pilot plant has been used to 1) provide data for further up scaling, 2) to test equipment and construction materials, and 3) to test and validate different kinds of pulp mill liquor. The main reasons behind the localization in Piteå were the size of the mill in Piteå and the existing industrial area with experiences, research tradition and infrastructure. Future oriented mill owners and new strong suppliers are needed according to the interviewee in order for the technology to be chosen. In April 2016, it was announced that the pilot plant would close down.	

<table>
<tr><th>Describe the niches relevant to case study.</th><th>Describe location

Describe offering</th><th>Describe how it is hosted, tested or applied.

Describe novelty.</th><th>Specific examples or anecdotes from case.</th></tr>
<tr><td>Black liquor gasification – full scale</td><td>In order to demonstrate the gasification technology developed by Chemrec (entrained flow biomass gasification) in larger scale there were plans for production of DME or methanol via black liquor gasification at a full-scale facility in Örnsköldsvik in connection to Domsjö Fabriker (approximately 100 MWfuel). The planned production capacity corresponded to approximately 0.8 TWhfuel/year (DME or methanol) and about 35 times the capacity of the LTU Green Fuels pilot plant in Piteå.

Not realized.</td><td colspan="2">Chemrec was the initiator of the full-scale facility in Örnsköldsvik. But there is a long history behind (30 year) including several engaged persons with different experiences from e.g., the oil industry, forest industry, and petrochemistry.

The planned location in connection to Domsjö Fabriker in Örnsköldsvik depended on the associated network of engaged contacts.

Not realized despite the approved government support (via the Swedish Energy Agency), the successful testing of the technology in the pilot plant and technical guaranties. However, no governmental guarantees about continued policy support.

The technique was ready for industrial up-scaling and was considered mature by world leading EPCs (Engineering, Procurement & Construction companies). All permits and the design were ready etc.

The project closure depended on the lack of stable policy framework for biofuels for transport (CO_2 and energy tax exemption rules only known one year in advance). The Swedish government and parliament did not provide clear and stable long-term rules (e.g., in the required “letter of comfort”), which implied that the banks did not want to lend money to biofuel projects. All risks except the political were addressed.</td></tr>
<tr><td>DME/methanol production and distribution systems</td><td>In the pilot plant focus on DME due to the involvement of Volvo and EU project related demands. Total production at approximately 1000 tonnes of DME. Distribution linked to the Volvo trucks testing the fuel.

Market demand to decide if DME or methanol from full scale plant.

Historical experiences of low blend-in (M15) and pure methanol (M100) in Sweden (but very limited number of vehicles).</td><td colspan="2">DME require new infrastructure since it cannot be blended into conventional diesel

Renewable methanol may be distributed through trucks (liquid fuel) and blended-in to gasoline or used as pure biofuel.</td></tr>
<tr><td>Fleet and vehicle niches</td><td>The DME produced in the pilot plant was tested in 10 Volvo trucks (novel testing).</td><td colspan="2">Stimulated by the growing market demand for truck fleets with lower CO_2 emissions.

For the pilot plant secured market for the produced DME that was successfully tested in the 10 Volvo trucks.

DME can be used in modified diesel engines thus requiring new modified diesel vehicles.

Currently Stena Line uses methanol (produced from natural gas) in sea transport, which may legitimize the fuel/make the fuel known as an alternative that meets the new environmental demands in the Baltic Sea (sulphur emissions).</td></tr>
</table>

2.1.2 Niche-transition phenomena, LTU Green Fuels and Chemrec and Domsjö Fabriker, Örnsköldsvik.

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study**	**Examples of anticipated information from case studies**
Niche – to – regime (locations and processes)	Co-evolution of new technologies, markets, and user preferences Formation of market spaces that are protected or insulated from 'normal' market selection in the regime	Synergies with new markets and user preferences and parallel evolution of differing parts of the technology system Examples of learning by doing, learning by using and learning by interacting Evidence of protected spaces – 'incubation rooms' for new technology system that rely on a special technical application, geographical situation, social context, subsidy regime, etc. Spaces where social networks to support the innovations arise: e.g. supply chains, user–producer relationships	Research and R&D history and development Funding provided for the innovation, why given, and where in the process. Description of critical phases perceived for the innovation emergence and anticipated scale(s). Role of incumbents vs. new entrants (synergistic, antagonistic, parasitic) Policies that have helped the innovation forward. Policies that can help them to scale up. Trends to a dominant design among (similar) innovations
Niche to regime phenomena	**Insulated market spaces**		**Co-evolution of technologies, markets and preferences**
Black liquor gasification	Gasification available for black liquor (100-150 MW) and pyrolysis oil. Replacement of recovery boiler.		Based on domestic raw material (by-product). Successful technology development verified in pilot scale. The pilot plant also used for testing different raw material, for developing gas cleaning process and the synthesis process and suitable for testing the "Power to Liquid concept". Black liquor gasification implies a very drastic change for the pulp mills and competes with current technology and infrastructure. Therefore, questioned by the major part of the forestry sector and considered a high risk project. In order to scale up, need for long term policy support (at least 13 years) for second generation biofuels. General policies not considered enough for realization. Specific support is needed for the first production plants. The so called price premium model (In Swedish: prispremium-modellen) for production support suggested in the Swedish FFF inquiry is the preferable option. Future policies should be designed with the help of experts from financial organisations like EIB and the World Bank/IFC.
DME/methanol production, distribution systems and fleet and vehicle niches	The DME produced in the pilot plant tested in 10 Volvo trucks (novel testing). Demands on low sulphur emissions have incentivized Stena Line to use the methanol (based on fossil fuels).		Further market expansion needed in the case of demonstration/full scale plant.

2.1.3 *Regime phenomena, LTU Green Fuels and Chemrec and Domsjö Fabriker, Örnsköldsvik.*

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study**	**Examples of anticipated information from case studies**
Regime (Conditions – precursors for drivers & constraints) Here regime conditions focus on the semi-coherent set of rules carried by different social groups.	Constraints (and drivers) arising because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology.	**Constraints:** Mismatch with one or more of the (seven) dimensions in the incumbent sociotechnical regime: • technology, • user practices and application domains (markets), • symbolic meaning of technology, • infrastructure, • industry structure, • policy, and • techno-scientific knowledge **Drivers:** Supportive situation(s) and synergies with incumbent regime dimensions.	Limitations/opportunities posed by the current established systems Social, regulatory and market barriers and opportunities Specific Policies and regulations, clashes between policies, clarity and stability of policy interventions. Collaboration with established sectors/regimes Impacts and benefits associated with material flows and benefit accrual (e.g. fossil- to bio)
Black liquor gasification	Technologies, operations and maintenance networks – Limitations posed by the current established forestry sector. Technology system perceived to compromise or threatens pulp and paper production infrastructure/investments. Difficult to convince the forestry sector due to the competition with current technology and infrastructure and the technical and economic risk is considered high. Symbolic meaning of technology – Success story at pilot plant level but no large-scale applications yet. Somewhat negative picture around gasification in the society today due to the spreading of unsuccessful stories which influence policy makers. Announced closure of the pilot plant may also have a negative impact on the reputation of advanced gasification. Infrastructure – Linked to the forestry sector and pulp and paper mill infrastructure. Policy –The initiative is in line with national and EU goals for independence from fossil fuels. Pilot plant supported by Swedish governmental and EU funding. The full-scale plant stopped due to lack of national stable policy framework for biofuels. In order to scale up, need for long term policy support for second generation biofuels. The so called price premium model (In Swedish: prispremium-modellen) for production support suggested in the Swedish FFF inquiry is the preferable option but quota system believed to possibly work. Techno-scientific knowledge – Gasification available for black liquor (100-150 MW) and pyrolysis oil.		
DME/methanol production, distribution systems and fleet and vehicle niches	Collaboration with established regimes: engine and vehicle development regime (Volvo) in the case of pilot plant User practices and application domains (markets) – DME requiring new vehicles, distribution systems and actions by vehicle users. Methanol may be blended-in to gasoline like ethanol. Possible competitor to E5? Infrastructure – requiring changes to existing infrastructure Industry structure – Part of engine and vehicle development regime involved (Volvo) in the case of pilot plant Policy – Further policies needed Techno-scientific knowledge – Appears functionally adequate.		

2.1.4 Landscape phenomena, LTU Green Fuels and Chemrec and Domsjö Fabriker, Örnsköldsvik.

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study**	**Examples of anticipated information from case studies**
Landscape (conditions) *Here landscape conditions focus on heterogeneous factors including oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, and environmental problems.*	On-going processes, or disruptions, at the landscape level – and between regime and landscape – change conditions that are central to the progress or success of the new technology.	**Constraints**: Reversals in progress as a result of new conditions disadvantageous to the technology **Drivers**: Windows of opportunity for breakout (from niche level) related to special conditions advantageous to the new technology	Effects of structural shifts in forestry industry Impact of oil prices on development Influence of the political economy of biofuels (all generations) Escalating environmental concerns and drivers.
	Constraints		**Drivers**
Black liquor gasification	Low fossil fuel prices may influence further expansion. The development of other biofuels might also influence negatively		Expanding global climate discourse, increasing evidence of (catastrophic) climate change effects and progress with intergovernmental rulemaking increases the demand for renewable based transport fuels. Limited global biomass supply and problems associated with agricultural crops increase the attractiveness of forest based transport fuels. Global economic trends encourage forest sector interest (diversification, waste valorisation). ILUC debate underpins technologies not relying on crops or agriculture.
DME/methanol production, distribution systems and fleet and vehicle niches	Electric car revolution might reduce the interest.		Dominant paradigm of diesel/petrol engines dominates Growing socio-political awareness of multi-negatives of existing fuel systems (e.g. health and climate) opens opportunities for clean fuel systems. New requirements in the shipping sector may increase the demand for DME and methanol.

2.1.5 Proponent Strategies to Promote Innovation Development

Level of Analysis	**Cognitive Legitimacy**	**Sociopolitical Legitimacy**	**Examples of anticipated information from case studies**
Organizational	Develop knowledge base via symbolic language and behav-iours (key theme of **knowledge**)	Develop trust in new activity by maintaining internally consistent stories (Key theme of **trust**)	Consistent details of how their system contributes to environment and society How this innovation builds upon track record, trust etc. Symbolic framing of the technology system
Cognitive legit. Project proponents represent experienced actors with considerable scientific knowledge and large networks. DME/methanol from black liquor gasifica-tion presented as renewable, climate friendly, based on by-products from Swedish forestry. Project proponents active in the public debate, in forming national and interna-tional collaboration with industry and in informing policy makers.		**Sociopolitical legit.** The production process attractive to policy makers but difficult to convince the forestry sector due to the perceived competition with current technology and infrastructure and due to that the technical and economic risk is considered high. Pilot plat and related projects linked to national university.	
Intraindustry	Develop knowledge base by encouraging convergence around a dominant design	Develop perceptions of reliability by mobilizing to take collective action	Activities across the industry to build common industry knowledge base Convergence around a dominant design/technology plat-form, performance standards Development of industry organisation, collective lobby group, etc. Stable and reliable sequences of interaction with other actors in industry
Cognitive and Sociopolitical legit. Extensive activities (including different partners and forestry industries) at the pilot plant securing considerable knowledge base. Involvement of current engine and vehicle regime (Volvo) at the pilot plant level. All technical and economic risks addressed except the political risk.		**Sociopolitical legit.** Chemrec and Domsjö Fabriker jointly worked for realizing the full scale plant.	
Interindustry	Develop knowledge base by promoting activity through third-party actors	Develop reputation of new activity as a reality by negotiating and compromising with other industries	Evidence of cooperation, negotiation or compromise with other industries where there is competition for resources, markets etc. Promotion of their new activity through third-party actors (e.g. third party testing, pilots, etc.)
Cognitive legit. Enabling for large incumbents (forestry sector) to further develop the renewable sector.		**Sociopolitical legit.**	

Table 14, continued.

Institutional	Develop knowledge base by creating linkages with established educational curricula	Develop legitimacy by organizing collective marketing and lobbying efforts	Evidence of broader public/political knowledge and awareness of the innovation and its importance How and why other actors have joined to build up much of the trust and reliability of the new activities Established activities of industry councils, alliances, and other affiliations that perform collective marketing and lobbying efforts. Linkages with established educational curricula at universities etc.
<u>Cognitive legit.</u> Contribute to knowledge sharing between different industries.		**<u>Sociopolitical legit.</u>** Well aligned with national discourse regarding bio-economy. As part of bioeconomy, initiative contributes to diversification of forest sector. Free of land use issues (e.g. ILUC). Contributes to reduced national energy dependence. Key solution for achievement of national climate goals and visions of fossil free transport sector.	

2.2 BIOREFINERY NORRTORP AND VÄRMLANDSMETANOL

As a result of the distinct overlap between these two projects, they have been combined within this analysis process.

2.2.1 Niche phenomena, Biorefinery Norrtorp (BN) and Värmlandsmetanol (VM).

Level of Analysis	Underlying phenomena	Parameters of particular interest in this study (Examples)	Specific information that interviewees may take up (Examples)
Niche (location/situations/properties) The analysis concerns both VM and BN. Both projects aim at producing methanol from forest residues and round wood through gasification. The main proponent of VM is also involved in BN that considers using the same technology. If nothing else stated below the information refers to both projects. One difference between the two projects is that BN evaluated production of methanol, methane or a combination of both. However, the project group leaned towards methanol production. BN is also a larger project than VM (1800 and 600 GWh_{pa} respectively).	A location for a learning process (a niche) A distinct/special/novel socio-technical offering (a niche offering)	Distinct place or situation where an innovation is hosted, tested or applied The form and novelty of the innovation	Description of the nature and elements of the innovation and how it differs from established systems. Description of the 'business ecosystems' forming around the system and influencing the business model, including collaborators and others that benefit. Boundaries of the system and relevant actors.
Methanol projects	No large-scale production of renewable methane has been performed in Sweden.	Commercial technology is readily available from ThyssenKrupp industrial solutions (TKIS). According to the interviewee the provider guarantees a certain performance and price.	
Fleet and vehicle niches	Historical experiences of low blend-in (M15) and pure methanol (M100) in Sweden (not so well-known!). Around 1000 vehicles between 1979 and 1982. M15 infrastructure covered large parts of Sweden (and neighbouring countries)	Currently Stena Line uses methanol (produced from natural gas) in sea transport, which may legitimize the fuel/make the fuel known as an alternative that meets the new environmental demands in the Baltic Sea (sulphur emissions).	
Methanol production and distribution systems		Renewable methanol may be distributed through trucks (liquid fuel) and blended-in to gasoline or used as pure biofuel.	

2.2.2 Niche-transition phenomena, Biorefinery Norrtorp (BN) and Värmlandsmetanol (VM).

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study (Examples)**	**Specific information that interviewees may take up (Examples)**
Niche – to – regime (locations and processes)	Co-evolution of new technologies, markets, and user preferences Formation of market spaces that are protected or insulated from 'normal' market selection in the regime	Synergies with new markets and user preferences and parallel evolution of differing parts of the technology system Examples of learning by doing, learning by using and learning by interacting Evidence of protected spaces – 'incubation rooms' for new technology system that rely on a special technical application, geographical situation, social context, subsidy regime, etc. Spaces where social networks to support the innovations arise: e.g. supply chains, user–producer relationships	Research and R&D history and development Funding provided for the innovation, why given, and where in the process. Description of critical phases perceived for the innovation emergence and anticipated scale(s). Role of incumbents vs. new entrants (synergistic, antagonistic, parasitic) Policies that have helped the innovation forward. Policies that can help them to scale up. Trends to a dominant design among (similar) innovations
Methanol technologies		Technology from TKIS is readily available and commercially developed. Thus, no need for research cooperation with academia (according to interviewees). No interest of NER 300 investment support since this would require knowledge sharing (again, according to the interviewees). Interviewees are very sceptical to current policy framework and its predictability, particularly the tax exemption. A guaranteed tax exemption during 15 years would be sufficient (combined with a higher oil price, see landscape).	
Fleet and vehicle systems		Methanol is not used today in Swedish road transport. However, methanol could be used as low-blend-in to gasoline. Demands on low sulphur emissions have incentivized Stena Line to use the fuel (sea transport). Methanol is a bulk chemical, which is demanded by industry (not only a transport fuel). One example of this is in FAME production. Thus several alternative uses to road transport.	
Methanol production and distribution systems		The localisation of the plants (Hagfors for VM and Kumla for BN) appears to be based upon feedstock availability, infrastructure for feedstock supply, and in connection to current activities (in the case of BN). The demand for fuel and heat as well as infrastructure for fuel and heat does not appear to have as prioritized. As a result there is no (BN) or little (VM) demand for the surplus heat and it is planned to use it to dry incoming feedstock. BN received funding for a pre-study from SEA.	

2.2.3 Regime phenomena, Biorefinery Norrtorp (BN) and Värmlandsmetanol (VM).

Level of Analysis	Underlying phenomena	Parameters of particular interest in this study (Examples)	Specific information that interviewees may take up (Examples)
Regime (Conditions – precursors for drivers & constraints) Here regime conditions focus on the semi-coherent set of rules carried by different social groups.	Constraints (and drivers) arising because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology.	**Constraints:** Mismatch with one or more of the (seven) dimensions in the incumbent sociotechnical regime: • technology, • user practices and application domains (markets), • symbolic meaning of technology, • infrastructure, • industry structure, • policy, and • techno-scientific knowledge **Drivers:** Supportive situation(s) and synergies with incumbent regime dimensions.	Limitations/opportunities posed by the current established systems Social, regulatory and market barriers and opportunities Specific Policies and regulations, clashes between policies, clarity and stability of policy interventions. Collaboration with established sectors/regimes Impacts and benefits associated with material flows and benefit accrual (e.g. fossil- to bio)
Methanol technologies	Plant would use not only residues but also round wood and thus compete for feedstock with pulp & paper industry. Technological risk reduced through cooperation with TKIS.		
Fleet and vehicle systems	Methanol may be blended-in to gasoline as ethanol is. It may be a competitor to E5. Methanol may also be used in fuel cells (although hydrogen is more likely). Methanol is also a bulk chemical demanded by industry.		
Methanol production and distribution systems	Current policy framework is perceived as not sufficiently predictable by the proponents (VM and BN). Most important/desired is a tax exemption over a long period of time (15 years). VM proponent perceives that methanol is receiving increasing attention as a promising transport fuel. BN interviewee expresses that the project had great expectations that policy support as described in the FFF investigation would materialize.		

2.2.4 Landscape phenomena, Biorefinery Norrtorp (BN) and Värmlandsmetanol (VM).

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study (Examples)**	**Specific information that interviewees may take up (anticipated examples)**
Landscape (conditions) Here landscape conditions focus on heterogeneous factors including oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, and environmental problems.	On-going processes, or disruptions, at the landscape level – and between regime and landscape – change conditions that are central to the progress or success of the new technology.	**Constraints**: Reversals in progress as a result of new conditions disadvantageous to the technology **Drivers**: Windows of opportunity for breakout (from niche level) related to special conditions advantageous to the new technology	Effects of structural shifts in forestry industry Impact of oil prices on development Influence of the political economy of biofuels (all generations) Escalating environmental concerns and drivers.
	Current **low oil price** make the projects not profitable. VM would need an oil price around 60 USD/barrel and a tax exemption during the investment period (approximately 15 years).		

2.2.5 Proponent Strategies to Promote Innovation Development, Biorefinery Norrtorp (BN) and Värmlandsmetanol (VM).

Level of Analysis	**Cognitive Legitimacy**	**Sociopolitical Legitimacy**	**Specific information that interviewees may take up (Examples)**
Organizational	Develop knowledge base via symbolic language and behaviours	Develop trust in new activity by maintaining internally consistent stories	Consistent details of how their system contributes to environment and society How this innovation builds upon track record, trust etc. Symbolic framing of the technology system
			"Story telling": VM and its proponent are well known in Sweden for environmental work, although not related to renewable transport fuels.
Intraindustry	Develop knowledge base by encouraging convergence around a dominant design	Develop perceptions of reliability by mobilizing to take collective action	Activities across the industry to build common industry knowledge base Convergence around a dominant design/technology platform, performance standards Development of industry organisation, collective lobby group, etc. Stable and reliable sequences of interaction with other actors in industry
			VM and BN build on the same idea, technology, and, partially, the same proponent. BN has chosen a site where there is SOME know-how from previous gasification projects and which is also an industrial area with access to good infrastructure.
Interindustry	Develop knowledge base by promoting activity through third-party actors	Develop reputation of new activity as a reality by negotiating and compromising with other industries	Evidence of cooperation, negotiation or compromise with other industries where there is completion for resources, markets etc. Promotion of their new activity through third-party actors (e.g. third party testing, pilots, etc.)
			Both projects have cooperation with technology provider. In addition, BN consists of a fairly large network including other potential biofuel producers, e.g. E.ON, VM, Sekab, and a municipality. A forest company also surveyed the feedstock possibilities in the proximity of BN. Less developed cooperation for making use of heat (although this is due the locations). No cooperation for research and development other than with TKIS
Institutional	Develop knowledge base by creating linkages with established educational curricula	Develop legitimacy by organizing collective marketing and lobbying efforts	Evidence of broader public/political knowledge and awareness of the innovation and its importance How and why other actors have joined to build up much of the trust and reliability of the new activities Established activities of industry councils, alliances, and other affiliations that perform collective marketing and lobbying efforts. Linkages with established educational curricula at universities etc.

2.3 GOBIGAS

2.3.1 Niche phenomena, GoBiGas

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study (Examples)**	**Specific information that interviewees may take up (Examples)**
Niche (location/situations/properties) The GoBiGas project is designed in four phases: laboratory, pilot, demonstration, and commercial plant. The project is currently com-missioning the demonstration plant and the commercial plant has been postponed. Methane and heat is produced from forest residues and the demonstration plant may deliver 160 GWHpa methane. The commercial plant, if realized, would deliver 800 GWHpa methane.	A location for a learning process (a niche) A distinct/ special/novel socio-technical offering (a niche offering)	Distinct place or situation where an innovation is hosted, tested or applied The form and novelty of the innovation	Description of the nature and elements of the innovation and how it differs from established systems. Description of the 'business ecosys-tems' forming around the system and influencing the business model, including collaborators and others that benefit. Boundaries of the system and relevant actors.
Bio-SNG pilot projects	Previous experiences from Güssingen in Austria for gasification part (not methanation).	The project has received support from SEA for demon-stration plant and been approved for support from NER 300 for commercial plant. Large network with collaborations, e.g. Chalmers university and the vehicle gas distributor Fordonsgas Sverige. Initially also with E.ON. However, no colla-boration with vehicle manufacturers. The collaboration with Chalmers permitted solving unexpected technical problems during commissioning phase.	
Fleet and vehicle niches	In line with municipal and national GHG mitigation efforts.	Vehicle gas market has grown quickly in Sweden (in percentage although still small in absolute numbers) supported by municipal initiatives and national policy instruments. However the demand remained constant during 2015. Public transport and taxis are large vehi-cle gas consumers. Taxi has been incentivized by e.g. preferential treatment at Arlanda Airport. Public transport has made long term agreement guaranteeing a demand over a period of time.	
Biogas production and distribution niches	Three main geographical areas with different prerequisites to develop biogas: along the natural gas grid, Stockholm area with local grid, and other municipalities outside of the grid. GoBiGas is located in the first area	Vehicle gas development started with natural gas and upgraded biogas came later. Areas without access to natural gas (previously the case in Stockholm) have suffered from unstable supply, which has affected the users' perception of the fuel.	

2.3.2 *Niche-transition phenomena, GoBiGas*

Level of Analysis	Underlying phenomena	Parameters of particular interest in this study (Examples)	Specific information that interviewees may take up (Examples)
Niche – to – regime (locations and processes)	Co-evolution of new technologies, markets, and user preferences Formation of market spaces that are protect-ted or insulated from 'normal' market selection in the regime	Synergies with new markets and user preferences and parallel evolution of differing parts of the technology system Examples of learning by doing, learning by using and learning by interacting Evidence of protected spaces – 'incubation rooms' for new technology system that rely on a special technical application, geographical situation, social context, subsidy regime, etc. Spaces where social networks to support the innovations arise: e.g. supply chains, user–producer relationships	R&D history Funding provided for the innovation, why given, and where in the process. Description of critical phases perceived for the innovation emergence and anticipated scale(s). Role of incumbents vs. new entrants (synergistic, antagonistic, parasitic) Policies that have helped the innovation forward. Policies that can help them to scale up. Trends to a dominant design among (similar) innovations
Niche to regime phenomena			
Advanced bio-SNG technologies	KLIMP and other investment support programs have incentivized biogas production in Sweden.		The project is designed in four phases: laboratory, pilot, demonstra-tion, and commercial plant. Laboratory and pilot plant at Chalmers. Also current phase, demonstration plant, is commissioned in col-laboration with Chalmers. SEA supported demonstration plant and NER 300 funding is approved for comercial plant. Critical problems were experienced during commissioning phase since the process clogged. This problem was not foreseen and the technology pro-vider could not facilitate a so-lution. Chalmers researchers sugges-ted adding K_2CO_3 to acti-vate the olivine, a solution that worked. Thus a significant portion of learning-by-doing. Heavy negative media attention during 2015 "technical problems", "not profitable" & "local politicians will close the project". Göte-borg Energi has issued a statement on their home-page to nuance the debate; technical challenges could be ex-pected, as GoBiGas is the first of its kind. The demonstration plant was never meant to be profitable but to demonstrate that it works. The commercial plant is put on hold, not only because of a political decision but also because the conditions (oil price) are not fulfilled. Thus the only political decision with effect is the one to review the company's biogas activities and the possible effects of a (not decided) closure. However the revision concerns all biogas activities in the company and not only GoBiGas.

Niche transformation phenomena, GoBiGas, continued.

Fleet and vehicle systems	A number of policy instruments have affected the biogas in transport development, mainly on the national level: tax exemption (although perceived as uncertain if it would be prolonged 2016-2020 or not), environmental car premiums (applied for gas vehicles until 2009), 5-year exemption from vehicle tax (2010-), exemption from congestion fees (in Stockholm until 2009), exemption from parking fees in various municipalities (Stockholm 2005-2008, Gothenburg 1998-2015)	Biogas is well known due to its use in public transport and taxi. Private vehicle owners are however not yet adopting gas vehicles. National symbol for biogas launched end of 2015. May be used through out the chain – from waste collection to gas vehicles – to increase awareness.
Biogas production and distribution systems	Obligation to provide “alternative fuel” at refuelling stations combined with investment support for infrastructure (other than ethanol). Voluntary agreement to keep minimum share 50 % biogas in vehicle gas. The agreement is vague and also not very relevant presently since the total share is about 74 %.	GoBiGas (bio-SNG) is synergistic with biogas from anaerobic digestion. Göteborg Energi has also been granted access to the natural gas grid (alike other biogas producers) and may inject methane to the grid. This influenced the location of the plant. In addition GoBiGas may take advantage of the district-heating grid making use of surplus heat.

2.3.3 Regime phenomena, GoBiGas

<table>
<tr><th>Level of Analysis</th><th>Underlying phenomena</th><th>Parameters of particular interest in this study (Examples)</th><th>Specific information that interviewees may take up (Examples)</th></tr>
<tr><td>Regime
(Conditions – precursors for drivers & constraints)
Here regime conditions focus on the semi-coherent set of rules carried by different social groups.</td><td>Constraints (and drivers) arising because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology.</td><td>Constraints:
Mismatch with one or more of the (seven) dimensions in the incumbent sociotechnical regime:
• technology,
• user practices and application domains (markets),
• symbolic meaning of technology,
• infrastructure,
• industry structure,
• policy, and
• techno-scientific knowledge
Drivers: Supportive situation(s) and synergies with incumbent regime dimensions.</td><td>Limitations/opportunities posed by the current established systems
Social, regulatory and market barriers and opportunities
Specific Policies and regulations, clashes between policies, clarity and stability of policy interventions.
Collaboration with established sectors/regimes
Impacts and benefits associated with material flows and benefit accrual (e.g. fossil- to bio)</td></tr>
<tr><td>Advanced bio-SNG technologies</td><td colspan="3">Many actors observe the GoBiGas project as it is the first of its kind. There are many gasification plans in Sweden (and elsewhere) that have not materialized. The current vehicle gas market is quite small (1550 GWhpa) for such a project (commercial plant would provide 800 GWhpa). In addition the vehicle gas market remained constant during 2015 (while the production of upgraded biogas for transport remained constant). The location of the GoBiGas site was chosen because of good infrastructure: railroad, natural gas pipeline, district heating grid, pellets receiving terminal, chimney etc. In addition the company owned the land and had environmental permits approved. Good collaboration with industry does not only include gas and heat infrastructure, universities and technology providers but also biomass providers (Varö bruk provides pellets).
Although the project has received policy support (investment support) the uncertainty of the tax exemption for biogas in transport has affected the biogas sector and thus the project negatively.</td></tr>
<tr><td>Fleet and vehicle systems</td><td colspan="3">The national biogas strategy from 2015(proposed by “the biogas lobby”) includes premium for “environmental” trucks alike the previous premium for purchase of “environmental” cars. This is because new user segments are needed.
Vehicle gas replaces diesel and gasoline and must be competitive with these fuels. Gas vehicles are generally more expensive than diesel and gasoline cars. Furthermore, the infrastructure for vehicle gas is much less extended than the one for conventional (fossil) fuels; there are 163 public and 63 non-public refuelling stations. This can be compared with totally 2670 refuelling stations in Sweden.</td></tr>
<tr><td>Biogas production and distribution systems</td><td colspan="3">See infrastructure above.
Biogas production is conducted at 277 facilities in Sweden, mainly co-digestion plants and sewage treatment plants. The technology is well established at the regime level and the municipalities have supported this development.</td></tr>
</table>

2.3.4 Landscape phenomena, GoBiGas

<table>
<tr><th>Level of Analysis</th><th>Underlying phenomena</th><th>Parameters of particular interest in this study (Examples)</th><th>Specific information that interviewees may take up (anticipated examples)</th></tr>
<tr><td>Landscape (conditions)
Here landscape conditions focus on heterogeneous factors including oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, and environmental problems.</td><td>On-going processes, or disruptions, at the landscape level – and between regime and landscape – change conditions that are central to the progress or success of the new technology.</td><td>Constraints: Reversals in progress as a result of new conditions disadvantageous to the technology
Drivers: Windows of opportunity for breakout (from niche level) related to special conditions advantageous to the new technology</td><td>Effects of structural shifts in forestry industry
Impact of oil prices on development
Influence of the political economy of biofuels (all generations)
Escalating environmental concerns and drivers.</td></tr>
<tr><td>Landscape phenomena</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="3">When the decision to build the GoBiGas demonstration plant was taken in 2010 the oil price was about 90 USD/barrel. There was an expectation that the oil price would remain at this level that would imply that the commercial plant would be profitable. During the following year the oil price increased and reached a peak at 155 USD/barrel. However, the present oil price (42 USD/barrel 2016-04-20) implies that the plans for a commercial plant have been postponed.
There were expectations on resolute policies from the government that would mitigate climate change and benefit projects like GoBiGas. However, Göteborg Energi did not take any specific policy instrument for granted and did not base their investment decisions on any governmental support or policies (other than the granted investment support).</td></tr>
</table>

2.3.5 Proponent Strategies to Promote Innovation Development, GoBiGas

Level of Analysis	Cognitive Legitimacy	Sociopolitical Legitimacy	Specific information that interviewees may take up (Examples)
Organizational	Develop knowledge base via symbolic language and behaviours	Develop trust in new activity by maintaining internally consistent stories	Consistent details of how their system contributes to environment and society How this innovation builds upon track record, trust etc. Symbolic framing of the technology system
			Göteborg Energi has been working with gas since the 19th century. The company has also been involved in biogas production and upgrading and previously co-owned a distribution company (Fordonsgas Sverige). GoBiGas is thus in line with the companies core business.
Intraindustry	Develop knowledge base by encouraging convergence around a dominant design	Develop perceptions of reliability by mobilizing to take collective action	Activities across the industry to build common industry knowledge base Convergence around a dominant design/technology platform, performance standards Development of industry organisation, collective lobby group, etc. Stable and reliable sequences of interaction with other actors in industry
Interindustry	Develop knowledge base by promoting activity through third-party actors	Develop reputation of new activity as a reality by negotiating and compromising with other industries	Evidence of cooperation, negotiation or compromise with other industries where there is competition for resources, markets etc. Promotion of their new activity through third-party actors (e.g. third party testing, pilots, etc.)
			Göteborg Energi has a large network of co-operations with infrastructure providers (natural gas, heat), feedstock providers, vehicle gas distributors, research networks (e.g. *f3*), and the local university Chalmers.
Institutional	Develop knowledge base by creating linkages with established educational curricula	Develop legitimacy by organizing collective marketing and lobbying efforts	Evidence of broader public/political knowledge and awareness of the innovation and its importance How and why other actors have joined to build up much of the trust and reliability of the new activities Established activities of industry councils, alliances, and other affiliations that perform collective marketing and lobbying efforts. Linkages with established educational curricula at universities etc.

2.4 BIO2G

2.4.1 Niche phenomena, Bio2G

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study**	**Examples of anticipated information from case studies**
Niche (location/situations/properties) *The Bio2Gas project represents a full scale project that could facilitate the shift from biogas-vehicle fuel from an extended network of niche applicati-ons to a mainstream regime status.* *Discussion of niches in this case focus on the learning and market building spaces provided in the build up of the biogas for transport market.*	A location for a learning process (a niche) A distinct/special/ novel socio-technical offering (a niche offering)	Distinct place or situation where an innovation is hosted, tested or applied The form and novelty of the innovation	Description of the nature and ele-ments of the innovation and how it differs from established systems. Description of the ‘business ecosystems’ forming around the system and influencing the business model, including collaborators and others that benefit. Boundaries of the system and relevant actors.
Describe the niches relevant to case study.	**Describe location** **Describe offering**	**Describe how it is hosted, test-ed or applied. Describe novelty.**	**Specific examples or anecdotes from case.**
Bio-SNG pilot projects	GoBiGas – Gothenburg: Demonstration plant that demonstrated the feasibility of large scale gasification. Also supporting SE tra-dition of novel demonstration (Värnamo)	Expanding upon Güssing plant experience and demonstrating large scale production viability on forest chips/pellets. A long sequence of pilots at different scales led to GoBiGas demonstration. Hosted and tested with significant Swedish government support (e.g. Swedish Energy Agency). Contributing to building of technical networks, identification of key techno-economic development pathways Linked to existing pipeline and large-scale user of gas and heat energy.	
Fleet and vehicle niches	In municipalities. Hosted as part of CO_2 reduction strategies. Offering clean, low noise. In some businesses and private uses. Hosted for ‘image’ enhancement or ‘environmental behaviour’ (low carbon, particulates, noise.)	Taxi fleets, bus fleets and municipal fleets have formed basis of a market to sell gas. Hosted and supported by local and national government support systems. Swedish vehicle manufacturers supported initial engine supply for gas vehicles. Both personal transport and freight engines. Slow but steady market growth to circa 2% of Swedish road fleet consumption. Technical potential lies in range 50%+ of future fleet requirements. Stimulated by purchasing mandates and fleet investment (municipalities) Stimulated by national environmental vehicle support (policy) Niche expansion required to support Bio2G type projects. New markets (moving into new commercial transport fleets) are required to accelerate gas demand (create significant market)	

Niche phenomena, Bio2G, continued.

Biogas production & distribution system niches	Key initial locations: a) along Swedish gas pipeline b) in towns with biogas production Key offerings: mixed fossil/biogas systems and 'island' systems around Sweden distant from gas pipeline. Stockholm provide key niche: existing 'town gas' system converted to natural gas in recent years. Expansion of system with both fossil and renewable gas.	Novelty related to manner proponents combine socio-economic co-benefits within production/waste management systems; how 'island' gas systems have been built distant from the Swedish gas grid; how gas pipelines are used to facilitate 'fossil/biogas mix'. Steady growth of vehicle gas distribution system range and volume. Production grown as a "Swedish model" for utilisation of WWTP gas sludge digestion expands over a >30 year period. Expanding fleets allow expansion of gas production system. Fleets expansion facilitated by development of distribution and refuelling up to 400km from gas pipeline.

2.4.2 Niche-transition phenomena, Bio2G

Level of Analysis	Underlying phenomena	Parameters of particular interest in this study	Examples of anticipated information from case studies
Niche – to – regime (locations and processes) *Locations and processes aiding migration from niche to regime for key niche items associated with Bio2G project.*	Co-evolution of new technologies, markets, and user preferences Formation of market spaces that are protected or insulated from 'normal' market selection in the regime	Synergies with new markets and user preferences and parallel evolution of differing parts of the technology system Examples of learning by doing, learning by using and learning by interacting Evidence of protected spaces – 'incubation rooms' for new technology system that rely on a special technical application, geographical situation, social context, subsidy regime, etc. Spaces where social networks to support the innovations arise: e.g. supply chains, user–producer relationships	Research and R&D history and development Funding provided for the innovation, why given, and where in the process. Description of critical phases perceived for the innovation emergence and anticipated scale(s). Role of incumbents vs. new entrants (synergistic, antagonistic, parasitic) Policies that have helped the innovation forward. Policies that can help them to scale up. Trends to a dominant design among (similar) innovations
Niche to regime phenomena	**Insulated market spaces**		**Co-evolution of technologies, markets and preferences**
Advanced bio-SNG technologies	National goals to achieve 10TWh biogas provide minimum indications of market, and clear need for gasification NER300 operational funding for 'lighthouse' project Göteborg Energi/Gothenburg support and physical hosting for GoBiGas pilot National funding for GoBiGas project		(+) GoBiGas - further establishment of 'technical validity' of biogas-sng production as a large scale renewable fuel system Experience building via experimentation/challenges with pellets and forest chips.
Fleet and vehicle systems	100% energy and carbon tax exemptions Sweden underpin biogas market. Double(+) counting rules for biogas applications (EU climate reduction goals). National policies for tax reductions (vehicles and fuels). Local government initiatives promoting biogas fleets Contractual demands for clean fuels in inner city areas (e.g. waste management fleets) Climate goal pledges by towns and cities open market spaces Privileged access to city centre (trucks) and cars (tolls/parking) Adoption by leading taxi companies (image/branding) Preferential treatment in taxi-queue systems (e.g. airports)		High visibility of biogas bus and truck fleets establishes relevance, sense of normality and expectations of function. Active branch organisations and third parties that support (e.g. Energigas Sverige, Biogasportalen.se, BiogasSyd, BiogasÖst, Svenskt Gastekniskt Center, Energiforsk, Gasbilen.se, Grönabilister,….) Early taxi fleets in Stockholm etc. spread norms and expectations of function. Bus fleets etc. stimulate engine and fuel system development from major engine system manufacturers. Growing availability of gas vehicles across manufacturers reinforces consumer confidence Emergent fleets form both a market and the legitimacy of the technology systems.
Biogas production & distribution systems	West coast design - >50% biogas in grid (open access for biogas), seamless fit with fossil gas (bio-SNG). Island systems with transported gas supported by incumbent gas players to grow niche. Co-benefits associated with utilisation of energy from waste systems underpin expansion of gas production from digestion, incl. expansion to food waste etc. – existence of municipal fleets provides immediate 'self-demand' Increased utilisation of capital resources invested in digestion/waste collection reinforces niche stability. Biogas utilisation in transport a high priority when municipalities seek to meet their climate gas goals.		Formation and collaboration of biogas 'branch organisations' Full engagement of pipeline controllers as a legitimacy function – encouraging access from biogas Development of distribution fleets and systems etc. spread beyond gas grid Proof of concept to multiple social actors – gas grid enabled systems and island systems deliver reliable gas for transport.

2.4.3 Regime phenomena, Bio2G

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study**	**Examples of anticipated information from case studies**
Regime (conditions – precursors for drivers & constraints) Here regime conditions focus on the semi-coherent set of rules carried by different social groups.	Constraints (and drivers) arising because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology.	**Constraints:** Mismatch with one or more of the (seven) dimensions in the incumbent sociotechnical regime: • technology, • user practices and application domains (markets), • symbolic meaning of technology, • infrastructure, • industry structure, • policy, and • techno-scientific knowledge **Drivers:** Supportive situation(s) and synergies with incumbent regime dimensions.	Limitations/opportunities posed by the current established systems Social, regulatory and market barriers and opportunities Specific Policies and regulations, clashes between policies, clarity and stability of policy interventions. Collaboration with established sectors/regimes Impacts and benefits associated with material flows and benefit accrual (e.g. fossil- to bio)
Advanced biogas-sng technologies	Technologies, operations and maintenance networks – moderate to high technical risk remains with technologies and their systems of provisions. The plant would operate as an important reference plant to build such. User practices and application domains (markets) – market size/application domains remain insufficient for expansion with large-scale gasification projects. Larger fleets of larger vehicles required to meet produced gas. Symbolic meaning of technology – large-scale applications unknown. Reputation of technology field impaired by experiences and communications surrounding GoBiGas. Erosion of faith in system related to communication of technical challenges, funding management and fossil fuel price reductions under demonstration period (this could be on next page). Recent closure of black liquor gasification pilot may also have potential to impair reputation of advanced gasification. Infrastructure – facilitating infrastructure present and available in Sweden. Port locations located adjacent to gas pipeline with access to biomass feedstocks via road, rail and sea, plus heat sinks. Large-scale project could facilitate expansion of distribution networks (establishing political legitimacy that is lacking for fossil gas). Industry structure – while the industry is to be established, ownership from within the existing fossil gas industry Policy – the initiative is in line with national and EU goals for independence from fossil fuels. As such, policy support appears soundly anchored beyond 2030. Techno-scientific knowledge – Gasification pilots in Sweden have established a foundational base – this project would serve as a basis for expansion of knowledge ('Lighthouse' project status).		
Fleet and vehicle systems	Technologies, operations and maintenance networks – with expansion of vehicle availability from multiple manufacturers, these systems appear functionally established for small vehicle fleets. Limited presence for commercial goods fleets. User practices and application domains (markets) – expansion into transportation (regional buses, light truck fleets, business fleets, etc. required to underpin market). Entirely new market groups and applications involved. Existing protected niches do not cover such categories. Symbolic meaning of technology – much of potential market remains ill informed of climate and environmental performance of gas vehicles. Media and policy makers shift focus confusing messages to public, to investors, and to markets. Infrastructure – distribution infrastructure has successfully grown with market. Island and grid solutions. Expectations are that this factor is challenging but not a major bottleneck. Industry structure – existing and potential fleet structure and markets are disjointed, multi-sectorial and cover all B2B, B2C etc. categories. Different market and policy drivers affect each market. Policy – policy regimes have been short term, unclear, and dynamic. Techno-scientific knowledge – appears functionally adequate. Active technology development underway in heavy goods motor systems.		

Regime phenomena, Bio2G, continued.

Biogas production & distribution systems	Technologies, operations and maintenance networks – appear functionally adequate for digestion based systems User practices and application domains (markets) – see industry structure below. Symbolic meaning of technology – existing system largely perceived as an increasingly functional component of a responsible "green" waste management systems. Rule making such as climate gas counting rules reinforce such. Infrastructure – locality specific to digestible waste production or accumulation points. Local network infrastructure unless location adjacent to fossil gas distribution pipeline. Pipeline is a collaborative facilitator of biogas distribution/storage if it is upgraded. Industry structure – existing system involves multiple waste-based municipal systems (small-moderate) that have been grown organically; these are increasingly supplemented by commercial waste/crop fed systems at larger scale (100+GWh/yr capacity). No large gasification projects exist. Policy – current policy regimes supportive of biogas production but not specifically focused on distribution grid/network. Also policy insecurity in vehicle sector retards explanation of both production and distribution systems. Techno-scientific knowledge – appears functionally adequate.

Landscape phenomena, Bio2G

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study**	**Examples of anticipated information from case studies**
Landscape (conditions) *Here landscape conditions focus on heterogeneous factors including oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, and environmental problems.*	On-going processes, or disruptions, at the landscape level – and between regime and landscape – change conditions that are central to the progress or success of the new technology.	**Constraints**: Reversals in progress as a result of new conditions disadvantageous to the technology **Drivers**: Windows of opportunity for breakout (from niche level) related to special conditions advantageous to the new technology	Effects of structural shifts in forestry industry Impact of oil prices on development Influence of the political economy of biofuels (all generations) Escalating environmental concerns and drivers.
	Constraints		**Drivers**
Advanced biogas-sng technologies	Low fossil fuel prices and stagnant economic growth inhibit investment. Energigewende effects in Germany challenges investment in higher risk projects such as Bio2G from German utilities. Public discourse shift to PV power serves to shift or dilute focus from gas and other biofuels.		Expanding global climate discourse, increasing evidence of (catastrophic) climate change effects and progress with intergovernmental rulemaking increases imperative for gasification technologies. Opening opportunities for 'lighthouse' renewable projects as major European utilities redefine business models. Global economic trends encourages forest sector interest (diversification, waste valorisation). ILUC debate underpins technologies not relying on crops or agriculture.
Fleet and vehicle systems	Dominant paradigm of diesel/petrol engines dominate. Electric car revolution removes or makes diffuse focus on gas-fuelled vehicles.		Growing socio-political awareness of multi-negatives of existing fuel systems (e.g. health and climate) open opportunities for clean fuel systems.
Biogas production & distribution systems	Low fossil fuel prices and stagnant economic growth inhibit investment.		Circular economy and resource efficiency imperatives underpin waste to gas initiatives in general. The political economy of CO_2 reduction goals within Swedish cities opens up regime structure for renewable gas production systems.

2.4.4 Proponent Strategies to Promote Innovation Development, Bio2G

<table>
<tr><th>Level of Analysis</th><th>Cognitive Legitimacy</th><th>Sociopolitical Legitimacy</th><th>Examples of anticipated information from case studies</th></tr>
<tr><td>Organizational</td><td>Develop knowledge base via symbolic language and behaviours (key theme of knowledge)</td><td>Develop trust in new activity by maintaining internally consistent stories
(key theme of trust)</td><td>Consistent details of how their system contributes to environment and society
How this innovation builds upon track record, trust etc.
Symbolic framing of the technology system</td></tr>
<tr><td colspan="2"><u>Cognitive legit.</u>
Project proponents have maintained clear message of ‘in line with national visions’ and ‘climate imperative’.
Extensive web and market presence reinforce knowledge of vehicle gas offering and reliability.
E.ON seeks to frame Bio-SNG and biogas as ‘clean, climate effective, eco-efficient, in line with waste hierarchy, land-use issue free …’ (-) limited success in this area is related.</td><td colspan="2"><u>Sociopolitical legit.</u>
Proponent story telling consistent and ‘diplomatic’ across extended period of years.
High coherency regarding offering: pollutant emission free, good climate performance, avoiding ILUC concerns, etc.
Increasingly visible symbolic framing – “the market is growing beyond economic potential of digestion – imperative for large gasification’
Organization has avoided ‘over-discussion’ of technical complexity and risk. Consistent message of ‘essentially all proven technologies’ to be applied in Bio2G</td></tr>
<tr><td>Intraindustry</td><td>Develop knowledge base by encouraging convergence around a dominant design</td><td>Develop perceptions of reliability by mobilizing to take collective action</td><td>Activities across the industry to build common industry knowledge base
Convergence around a dominant design/technology platform, performance standards
Development of industry organisation, collective lobby group, etc.
Stable and reliable sequences of interaction with other actors in industry</td></tr>
<tr><td colspan="2"><u>Cognitive legit.</u>
Well aligned with existing and future ‘product-service designs’ for gas vehicles and transportation solutions – including hydrogen, LNG economies.
Information from collective actions from throughout the industry contributes to improved knowledge of vehicle gas offerings, gas production etc. (e.g. Energigas Sverige, Biogasportalen.se, BiogasSyd, BiogasÖst, Svenskt Gastekniskt Center, Energiforsk, Gasbilen.se, Gröna bilister)
Many collaborations across renewable transportation fuel fields (e.g. Bioraff. Norrtorp, GoBiGas, etc.)
E.ON participation in a broad range of networks; f3, renewable fuels, etc. Reliability reinforced by major player status, significant investment, and broad support of industry.
Clear knowledge of gas function – all gas complies with fossil gas standards.</td><td colspan="2"><u>Sociopolitical legit.</u>
E.ON centrally involved in building out distribution network and function. Controlling one third of the market, proponent dominates market. Network and demand is built in advance of gas production efforts with reliability of supply as a central (trust-related) theme.
Minimal visibility of competing systems.
Collective action and coalitions from throughout the industry strengthens social and political trust in system. Clear policy support results (e.g. tax exemptions for gas transport fuels)
E.ON has dominant market presence and visibility. ‘Island’ and grid based systems both pursued, and accommodated.
Clear standard (min 50% biogas) for gas supply in Sweden provides both flexibility and ‘standardisation’ for both grid and ‘island’ supply models.
Partnership and presence in a broad range of overlapping or related technology initiatives within vehicle gas field. (e.g. GoBiGas, waste digestion projects, ….)</td></tr>
</table>

Proponent Strategies to Promote Innovation Development, Bio2G, continued.

Interindustry	Develop knowledge base by promoting activity through third-party actors	Develop reputation of new activity as a reality by negotiating and compromising with other industries	Evidence of cooperation, negotiation or compromise with other industries where there is competition for resources, markets etc. Promotion of their new activity through third-party actors (e.g. third party testing, pilots, etc.)
<u>Cognitive legit.</u> Absence of threat to fossil fuel industry. Rather biogas and bio-SNG are enablers for large incumbents (e.g. E.ON) to move into renewable sector. Evidence of good fit with vehicle and engine manufacturers. Growing range of gas vehicles. Absence of 'poor biofuel quality' scandals. Technology system does not compromise or threaten pulp and paper production infrastructure/investments.		**<u>Sociopolitical legit.</u>** Partnership and presence in a broad range of overlapping or related technology initiatives beyond vehicle gas field. (e.g. Biorefinery Norrtorp) Stable and reliable interactions with cities, harbours. Poses minimum threat to sunk costs in forestry and initiative based on forest wastes. Offers improved utilisation of forestry logistics infrastructure. Active engagement of municipalities, large taxi fleets etc. in demonstrating feasibility of gas-vehicle mobility.	
Institutional	Develop knowledge base by creating linkages with established educational curricula	Develop legitimacy by organizing collective marketing and lobbying efforts	Evidence of broader public/political knowledge and awareness of the innovation and its importance How and why other actors have joined to build up much of the trust and reliability of the new activities Established activities of industry councils, alliances, and other affiliations that perform collective marketing and lobbying efforts. Linkages with established educational curricula at universities etc.
<u>Cognitive legit.</u> E.ON highly supportive of research community. Strong links to tertiary education systems through biogas and thermo-chemical research. In past, there has been significant marketing and education interaction (e.g. school, university visit centre at Öresundsverket in Malmö).		**<u>Sociopolitical legit.</u>** E.ON present with a number of significant collective actions from throughout the industry contributes to trust and knowledge (e.g. Energigas Sverige, Biogasportalen.se, BiogasSyd, BiogasÖst, Svenskt Gastekniskt Center, Energiforsk, Gasbilen.se) Well aligned with national discourse regarding bio-economy, circular economies, and waste management hierarchies. As part of bioeconomy, initiative contributes to diversification of forest sector. Free of land use issues (e.g. ILUC). Contributes to reduced national energy dependence. Key solution for achievement of national climate goals, visions of fossil free transport sector, fossil free industry, …	

2.5 RENFUEL

2.5.1 Niche phenomena, RenFuel

Level of Analysis	Underlying phenomena	Parameters of particular interest in this study	Examples of anticipated information from case studies
Niche (location/situations/ properties) *Renfuel will build a pilot plant that in a catalytic process of industrial scale converts lignin into catalytic lignin oil. The lignin oil can then be refined to renewable petrol and diesel.*	A location for a learning process (a niche) A distinct/special/novel socio-technical offering (a niche offering)	Distinct place or situation where an innovation is hosted, tested or applied The form and novelty of the innovation	Description of the nature and elements of the innovation and how it differs from established systems. Description of the 'business ecosystems' forming around the system and influencing the business model, including collaborators and others that benefit. Boundaries of the system and relevant actors.
Describe the niches relevant to case study.	**Describe location** **Describe offering**	**Describe how it is hosted, tested or applied.** **Describe novelty.**	**Specific examples or anecdotes from case.**
Catalytic processes for converting lignin into lignin oil	Relevant catalytic processes for con-verting lignin into liquid lignin oil developed and tested at laboratory level in Uppsala and Södertälje. The aim is to make the lignin oil suitable for further hydrogenation processes.	Renfuel is the result of a case within a mentor program by the Royal Swedish Academy of Engineering Sciences (Ingen-jörsVetenskapsAkademien). Tested with significant Swedish government support (e.g., Swedish Energy Agency). Contributing to building of technical and commercial networks. Linked to existing biochemical research, pharmaceutical industry and pulp mills.	
Pilot plant for lignin oil production	To be realized in connection to Nordic Papers pulp mill in Bäckhammar, Värmland. Planned to be in operation in 2017. The plant will produce lignin oil (that is suitable for further hydrogenation processes) from lignin from a kraft pulp mill.	The Renfuel pilot plant is the result of col-laboration within the mentor program mentioned above. Hosted and to be realized and tested with significant Swedish government support (Swedish Energy Agency) and other funding. Represent the first pilot plant for this catalytic process. Two processes for removing the lignin from the black liquor (complementary to lignoboost) will also be tested. Renfuel focus on a specific link of the chain for producing transport fuels (using a non-controversial raw material, reaching relatively low CAPEX (Capital Expenditures), and leaving the final delivery step to more experienced actors. Renfuel have access to extensive knowledge about the forest industry and refinery technology.	

Niche phenomena, RenFuel, continued.

Lignoboost and other processes for lignin removal	Lignoboost is a commercial technology for extracting high quality lignin from a kraft pulp mill (developed by Innventia). The LignoBoost technology is owned and commercialized by Valmet. Two commercial plants (Domtar, USA and Stora Enso, Finland) are presently running. By lignin removal it is possible to expand the capacity of a pulp mill without increasing the capacity of the recovery boiler (which is often the bottleneck) and the lignin can be used.	In the Renfuel pilot plant two processes for removing the lignin from the black liquor (complementary to lignoboost) will also be tested. Södra did plan for a demonstration plant for lignoboost in Mörrum with significant Swedish government support (Swedish Energy Agency) but the project was abandoned.
Hydrogenation process niche	The lignin oil produced by Renfuel could be further processed in a hydrogenation process at a refinery resulting in renewable petrol and diesel. Hydrogenation process is integrated in existing refinery infrastructure, i.e., in production of fossil fuel based transport fuels and represents an addition to the incumbent petrochemical regime.	There is a promising market for the lignin oil. Petrochemical industry for example, Preem is very interested. Renfuel have access to extensive knowledge about the forest industry and refinery technology but due to business reasons, refineries are not included in the company Steady growth of HVO use in Sweden (also from other raw materials).
Vehicle and distribution system niches	The final transport fuel can be used as drop in fuel i.e., use existing vehicle and distribution systems.	The final transport fuel can be blended with fossil diesel and gasoline having the same characteristics, requiring minor changes in existing distribution and infrastructure (including vehicles).

2.5.2 Niche-transition phenomena, RenFuel

Level of Analysis	Underlying phenomena	Parameters of particular interest in this study	Examples of anticipated information from case studies
Niche – to – regime (locations and processes) *The Renfuel pilot plant has not progressed into an operational niche yet.*	Co-evolution of new technologies, markets, and user preferences Formation of market spaces that are protected or insulated from 'normal' market selection in the regime	Synergies with new markets and user preferences and parallel evolution of differing parts of the technology system Examples of learning by doing, learning by using and learning by interacting Evidence of protected spaces – 'incubation rooms' for new technology system that rely on a special technical application, geographical situation, social context, subsidy regime, etc. Spaces where social networks to support the innovations arise: e.g. supply chains, user–producer relationships	Research and R&D history and development Funding provided for the innovation, why given, and where in the process. Description of critical phases perceived for the innovation emergence and anticipated scale(s). Role of incumbents vs. new entrants (syn-ergistic, antagonistic, parasitic) Policies that have helped the innovation forward. Policies that can help them to scale up. Trends to a dominant design among (similar) innovations
Niche to regime phenomena	**Insulated market spaces**		**Co-evolution of technologies, markets and preferences**
Catalytic processes for converting lignin into lignin oil	Relevant catalytic processes for converting lignin into liquid lignin oil developed and tested at laboratory level. The aim is to make the lignin oil suitable for further hydrogenation processes.		Based on non-controversial domestic raw material (by-product). Further development in larger scale requires lignin removal processes. It is also likely to require minor hydrogenation process devel-opment. Require collaboration with forest industries and petro-chemical industry.
Pilot plant for lignin oil production	The Renfuel pilot plant has not progressed into an operational niche yet.		Based on non-controversial domestic raw material (by-product). Large-scale lignin oil production requires lignin removal processes. It is also likely to require minor hydrogenation process devel-opment. Require collaboration with forest industries and petro-chemical industry. Potentially successful inter-industry collabo-ration.
Lignoboost and other processes for lignin removal	Lignoboost is commercial technology (2 plants in operation). Other processes are under development potentially providing lignin removal processes with better characteristics.		Based on non-controversial domestic raw material (by-product). Increasing market demand for lignin removal for different purposes. Further development, testing and technical validity is needed for lignin removal processes.
Hydrogenation process niche	Hydrogenation process technologies are approaching regime status		Linked to renewable oil markets and the development of raw tall diesel, lignin oil etc. Preem is searching for other raw material for increased HVO production. Linked to refinery development.
Vehicle and distribution system niches	To be included in existing distribution and infrastructure for fossil based diesel and gasoline.		Potentially increasing the market for renew-able transport fuels.

2.5.3 Regime phenomena, RenFuel

<table>
<tr><th>Level of Analysis</th><th>Underlying phenomena</th><th>Parameters of particular interest in this study</th><th>Examples of anticipated information from case studies</th></tr>
<tr><td>Regime
(conditions – precursors for drivers & constraints)
Here regime conditions focus on the semi-coherent set of rules carried by different social groups.</td><td>Constraints (and drivers) arising because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology.</td><td>Constraints:
Mismatch with one or more of the (seven) dimensions in the incumbent sociotechnical regime:
• technology,
• user practices and application domains (markets),
• symbolic meaning of technology,
• infrastructure,
• industry structure,
• policy, and
• techno-scientific knowledge
Drivers: Supportive situation(s) and synergies with incumbent regime dimensions.</td><td>Limitations/opportunities posed by the current established systems
Social, regulatory and market barriers and opportunities
Specific Policies and regulations, clashes between policies, clarity and stability of policy interventions.
Collaboration with established sectors/regimes
Impacts and benefits associated with material flows and benefit accrual (e.g. fossil- to bio)</td></tr>
<tr><td>Catalytic processes for converting lignin into lignin oil</td><td colspan="3">Not in regime phase yet.
Technologies, operations and maintenance networks - Forestry sector providing the raw material.
User practices and application domains (markets) – Secured market for the lignin by the collaboration with the forestry sector.
Symbolic meaning of technology – Based on non-controversial domestic raw material (by-product).
Infrastructure – To be developed but made available through the related network of actors.
Industry structure – see Technologies... above.
Policy – Stimulated by existing policies and specific policy support given.
Techno-scientific knowledge – Under development.</td></tr>
<tr><td>Pilot plant for lignin oil production</td><td colspan="3">Not in regime phase yet.
Technologies, operations and maintenance networks - Forestry sector providing the raw material and planned collaboration with petrochemical regime for further processing of the product to transport fuel
User practices and application domains (markets) – Secured market for the lignin by the collaboration with the forestry sector and for the lignin oil due to the interest from petrochemical industry (e.g., Preem).
Symbolic meaning of technology – Based on non-controversial domestic raw material (by-product). First pilot plant to demonstrate this technology.
Infrastructure – Made available through the related network of actors.
Industry structure – see Technologies... above.
Policy – Stimulated by existing policies and specific policy support given.
Techno-scientific knowledge – Under development.</td></tr>
<tr><td>Lignoboost and other processes for lignin removal</td><td colspan="3">Technologies, operations and maintenance networks – Lignin removal currently not used for most mills. Lignoboost commercial, others under development.
User practices and application domains (markets) – Under development.
Symbolic meaning of technology – Represent possibility to improve mill capacity.
Infrastructure – Lignin removal process needed but linked to mill infrastructure.
Industry structure –Linked to mill development. Lignin removal currently not used for most mills. Lignoboost commercial, others under development.
Policy – Stimulated by current policy regimes.
Techno-scientific knowledge – Under development.</td></tr>
</table>

Regime phenomena, RenFuel, continued.

Hydrogenation process niche	Technologies, operations and maintenance networks – only minor adjustment expected Collaboration with established regimes –Petrochemical regime and current production of fossil based diesel and gasoline User practices and application domains (markets) – Not requiring actions by vehicle users, included in existing markets. Symbolic meaning of technology – The current production of HVO might facilitate for the development of renewable gasoline, represent development of the refineries and possibility to enter into the renewable transport fuel market Infrastructure – Requiring only minor changes to existing infrastructure Industry structure – Providing development possibilities for existing industry structure Policy – Stimulated by existing policies Techno-scientific knowledge – Further development expected.
Vehicle and distribution system niches	Collaboration with established regimes: petrochemical regime and current vehicle producer regime User practices and application domains (markets) – not requiring actions by vehicle users, included in existing markets and existing distribution systems. Symbolic meaning of technology – no particular impact Infrastructure – requiring only minor changes to existing infrastructure Industry structure – Not requiring any major changes for existing industry Policy – No particular policies needed Techno-scientific knowledge – Appears functionally adequate.

2.5.4 Landscape phenomena, RenFuel

Level of Analysis	Underlying phenomena	Parameters of particular interest in this study	Examples of anticipated information from case studies
Landscape (conditions) *Here landscape conditions focus on heterogeneous factors including oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, and environmental problems.*	On-going processes, or disruptions, at the landscape level – and between regime and landscape – change conditions that are central to the progress or success of the new technology.	**Constraints**: Reversals in progress as a result of new conditions disadvantageous to the technology **Drivers**: Windows of opportunity for breakout (from niche level) related to special conditions advantageous to the new technology	Effects of structural shifts in forestry industry Impact of oil prices on development Influence of the political economy of biofuels (all generations) Escalating environmental concerns and drivers.
	Constraints		**Drivers**
Catalytic processes for converting lignin into lignin oil + **Pilot plant for lignin oil production**	Potential up-scaling problems might hinder technology development. Low fossil fuel prices may influence the development. Access to further funding might be crucial.		Expanding global climate discourse, increasing evidence of (catastrophic) climate change effects and progress with intergovernmental rulemaking increases the demand for renewable based transport fuels. Limited global biomass supply and problems associated with agricultural crops increase the attractiveness of forest based transport fuels. Global economic trends encourage forest sector interest (diversification, waste valorisation). ILUC debate underpins technologies not relying on crops or agriculture.
Lignoboost and other processes for lignin removal	Problems related to technology development. Access to funding is crucial. Low fossil fuel prices may influence the interest at least temporarily.		Increased marked demand for lignin for different purposes is expected. The possibility provided by lignin removal to expand the capacity of a pulp mill without increasing the capacity of the recovery boiler or reducing the pressure on the recovery boiler.
Hydrogenation process niche	Low fossil fuel prices may influence further development		Expanding global climate discourse, increasing evidence of (catastrophic) climate change effects and progress with intergovernmental rulemaking increases the interest in hydrogenation technologies The need for refinery and the petrochemical regime to adapt to future demands for renewable based transport fuels.
Vehicle and distribution system niches	Electric car revolution might reduce the interest		Dominant paradigm of diesel/petrol engines dominates Growing socio-political awareness of multi-negatives of existing fuel systems (e.g. health and climate) opens opportunities for clean fuel systems.

2.5.5 Proponent Strategies to Promote Innovation Development, RenFuel

<table>
<tr><th>Level of Analysis</th><th>Cognitive Legitimacy</th><th>Sociopolitical Legitimacy</th><th>Examples of anticipated information from case studies</th></tr>
<tr><td>Organizational</td><td>Develop knowledge base via symbolic language and behaviours (key theme of knowledge)</td><td>Develop trust in new activity by maintaining internally consistent stories
(key theme of trust)</td><td>Consistent details of how their system contributes to environment and society
How this innovation builds upon track record, trust etc.
Symbolic framing of the technology system</td></tr>
<tr><td colspan="2"><u>Cognitive legit.</u>
Technology process to be up scaled and further developed.
Project proponents include actors with extensive knowledge about the forest industry and refinery technology representing a considerable knowledge base.
Major skilled player will handle marketing of the final product, in order to increase reliability.
Lignin oil presented as renewable, climate friendly, based on by-products from Swedish forestry, possible to blend with fossil diesel and gasoline to high levels.</td><td colspan="2"><u>Sociopolitical legit.</u>
The idea/innovation was presented for the right investor.
High coherency regarding offering: pollutant emission free, good climate performance, avoiding ILUC concerns, domestic raw material in the form of a by-product etc.
Drop in fuel concept easy to communicate and attractive for policy makers and the public.</td></tr>
<tr><td>Intraindustry</td><td>Develop knowledge base by encouraging convergence around a dominant design</td><td>Develop perceptions of reliability by mobilizing to take collective action</td><td>Activities across the industry to build common industry knowledge base
Convergence around a dominant design/technology platform, performance standards
Development of industry organisation, collective lobby group, etc.
Stable and reliable sequences of interaction with other actors in industry</td></tr>
<tr><td colspan="2"><u>Cognitive legit.</u>
Collaboration with key actors is under development. The technology is under development.</td><td colspan="2"><u>Sociopolitical legit.</u>
To be developed.</td></tr>
<tr><td>Interindustry</td><td>Develop knowledge base by promoting activity through third-party actors</td><td>Develop reputation of new activity as a reality by negotiating and compromising with other industries</td><td>Evidence of cooperation, negotiation or compromise with other industries where there is competition for resources, markets etc.
Promotion of their new activity through third-party actors (e.g. third party testing, pilots, etc.</td></tr>
<tr><td colspan="2"><u>Cognitive legit.</u>
Absence of threat to fossil fuel industry. Rather enabling for large incumbents (e.g. Preem) to increase its production of renewable transport fuels.
No new demands for vehicle and engine manufacturers. Technology system does not compromise or threaten pulp and paper production infrastructure/investments.</td><td colspan="2"><u>Sociopolitical legit.</u>
Creation of trust is under development. Strategic network created. Smooth introduction expected since there are no new demands for vehicle and engine manufacturers.</td></tr>
</table>

Proponent Strategies to Promote Innovation Development, RenFuel, continued.

Institutional	Develop knowledge base by creating linkages with established educational curricula	Develop legitimacy by organizing collective marketing and lobbying efforts	Evidence of broader public/political knowledge and awareness of the innovation and its importance How and why other actors have joined to build up much of the trust and reliability of the new activities Established activities of industry councils, alliances, and other affiliations that perform collective marketing and lobbying efforts. Linkages with established educational curricula at universities etc.
Cognitive legit. Contribute to knowledge sharing between different industries.		**Sociopolitical legit.** Well aligned with national discourse regarding bio-economy. As part of bioeconomy, initiative contributes to diversification of forest sector. Free of land use issues (e.g. ILUC). Contributes to reduced national energy dependence. Key solution for achievement of national climate goals and visions of fossil free transport sector.	

2.6 SUNPINE

2.6.1 *Niche phenomena, Sunpine*

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study**	**Examples of anticipated information from case studies**
Niche (location/situations/ properties) *The SunPine facility in Piteå represents the first commercial full scale plant that produces raw tall diesel from raw tall oil, which is a by-product from the pulp and paper industry. The current production capacity for raw tall diesel is 100 000 m³ per year.*	A location for a learning process (a niche) A distinct/special/novel socio-technical offering (a niche offering)	Distinct place or situation where an innovation is hosted, tested or applied The form and novelty of the innovation	Description of the nature and elements of the innovation and how it differs from established systems. Description of the 'business ecosystems' forming around the system and influencing the business model, including collaborators and others that benefit. Boundaries of the system and relevant actors.
Describe the niches relevant to case study.	**Describe location** **Describe offering**	**Describe how it is hosted, tested or applied.** **Describe novelty.**	**Specific examples or anecdotes from case.**
Raw tall diesel production	SunPine, Piteå: Commercial full scale plant that produces raw tall diesel from raw tall oil by fractionation of the raw tall oil (that is a by-product from the pulp and paper industry). Realized by the formation of a new business ecosystem.	Based on an idea by the innovator Lars Stigsson, Kiram, the full scale plant was realized in 2010. Not preceded by any pilot or demonstration plants. Formation of a new innovative business ecosystem: The innovator built strategically the necessary networks for realizing the plant including tall oil producers and refinery (i.e., Preem, Sveaskog, Södra skogsägarna, Kiram, and Lawter). This powerful consortium of actors facilitated supply chains and market related issues. Piteå chosen due to vast access of talloil, existence of other forest based process technologies and due to it representing a truly industry friendly municipality. No specific governmental support. Strong owners that invested equity and facilitated bank loans reduced the financial risk. Patents reduced technical risks.	
Hydrogenation process niche	The raw tall diesel produced in the SunPine facility is processed further to HVO diesel fuel by Preem at the refinery in Göteborg. Hydrogenation process is integrated in existing refinery infrastructure, i.e., in production of fossil fuel based transport fuels. Trial of the full concept in Sweden (including raw tall diesel production and hydrogenation processes)	Secured market for the raw tall diesel. Preem is one of the owners of SunPine. Steady growth of HVO use in Sweden (also from other raw materials).	
Vehicle and distribution niche	Drop in fuel. HVO blend-ed in diesel, represents a more renewable fuel with lower fossil CO2 emissions that can be used in existing diesel vehicles.	Stimulated by an increased use of diesel engines in general and the growing market of truck fleets with lower CO2 emissions. The HVO is blended with fossil diesel having the same characteristics, requiring minor changes in existing distribution and infrastructure (including vehicles).	

2.6.2 Niche-transition phenomena, Sunpine

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study**	**Examples of anticipated information from case studies**
Niche – to – regime (locations and processes)	Co-evolution of new technologies, markets, and user preferences Formation of market spaces that are protected or insulated from 'normal' market selection in the regime	Synergies with new markets and user preferences and parallel evolution of differing parts of the technology system Examples of learning by doing, learning by using and learning by interacting Evidence of protected spaces – 'incubation rooms' for new technology system that rely on a special technical application, geographical situation, social context, subsidy regime, etc. Spaces where social networks to support the innovations arise: e.g. supply chains, user–producer relationships	Research and R&D history and development Funding provided for the innovation, why given, and where in the process. Description of critical phases perceived for the innovation emergence and anticipated scale(s). Role of incumbents vs. new entrants (synergistic, antagonistic, parasitic) Policies that have helped the innovation forward. Policies that can help them to scale up. Trends to a dominant design among (similar) innovations

Niche to regime phenomena	**Insulated market spaces**	**Co-evolution of technologies, markets and preferences**
Raw tall diesel production	Powerful consortium of actors linked to SunPine. The development of raw tall diesel production at SunPine was linked to the development of hydrogenation processes at Preem. Increased national demand for diesel likely to have spurred this development.	Based on domestic raw material (by-product). SunPine is owned by Preem (25%) Sveaskog (25%), Södra skogsägarna (25%), KIRAM (15%) and Lawter (10%). Attractive for forestry companies due to new business area increasing the value of raw tall oil, the oligopoly structure of the tall oil market, and for other economic reasons. Attractive for Preem since it represents a way to increase its portfolio, enter the renewable fuel market, and enhance the public image. Successful technology development leading to increased use of HVO in Sweden (also from other raw materials, partly imported). Representing successful inter-industry collaboration.
Hydrogenation process technologies	Hydrogenation process technologies are approaching regime status	The production of HVO based on talloil linked to steady growth of HVO use in Sweden (also from other raw materials, partly imported). Preem searching for other raw material for increased HVO production.
Vehicle and distribution niche	Included in existing distribution and infrastructure for fossil based diesel.	Expanding market demand (from a niche to mainstream demand) due to increased environmental concern and the possibility to use larger share of renewable transport fuels in existing mainstream vehicles. Potentially improving the public opinion on diesel vehicles as considered even more environmental friendly than gasoline vehicles.

2.6.3 Regime phenomena, Sunpine

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Here regime conditions focus on the semi-coherent set of rules carried by different social groups.</td><td>Constraints (and drivers) arising because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology.</td><td>Constraints:
Mismatch with one or more of the (seven) dimensions in the incumbent sociotechnical regime:
• technology,
• user practices and application domains (markets),
• symbolic meaning of technology,
• infrastructure,
• industry structure,
• policy, and
• techno-scientific knowledge
Drivers: Supportive situation(s) and synergies with incumbent regime dimensions.</td><td>Limitations/opportunities posed by the current established systems
Social, regulatory and market barriers and opportunities
Specific Policies and regulations, clashes between policies, clarity and stability of policy interventions.
Collaboration with established sectors/regimes
Impacts and benefits associated with material flows and benefit accrual (e.g. fossil- to bio)</td></tr>
<tr><td>Raw tall diesel production</td><td colspan="3">Collaboration with established sectors - forestry sector providing the raw material and petrochemical regime further processing the product to transport fuel
User practices and application domains (markets) – Secured market for the raw tall diesel by Preem being one of the owners of SunPine. Secured market for the raw tall oil by Södra and Sveaskog being part of the owners of SunPine.
Symbolic meaning of technology – success story, might facilitate for the development of renewable gasoline
Infrastructure – made available through the related network of actors
Industry structure – Representing successful inter-industry collaboration
Policy – Stimulated by existing policies but supplementary policies expected
Techno-scientific knowledge – Current focus on the by-products. Further projects may follow.</td></tr>
<tr><td>Hydrogenation process technologies</td><td colspan="3">Collaboration with established regimes - petrochemical regime and current production of fossil based diesel
User practices and application domains (markets) – not requiring actions by vehicle users, included in existing markets.
Symbolic meaning of technology – might facilitate for the development of renewable gasoline
Infrastructure – requiring only minor changes to existing infrastructure
Industry structure – Providing development possibilities for existing industry structure
Policy – Stimulated by existing policies
Techno-scientific knowledge – Further development expected.</td></tr>
<tr><td>Vehicle and distribution niche</td><td colspan="3">Collaboration with established regimes: petrochemical regime and current vehicle producer regime
User practices and application domains (markets) – not requiring actions by vehicle users, included in existing markets and existing distribution systems.
Symbolic meaning of technology – no particular impact
Infrastructure – requiring only minor changes to existing infrastructure
Industry structure – Not requiring any major changes for existing industry
Policy – No particular policies needed
Techno-scientific knowledge – Appears functionally adequate.</td></tr>
</table>

2.6.4 Landscape phenomena, Sunpine

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study**	**Examples of anticipated information from case studies**
Landscape (conditions) *Here landscape conditions focus on heterogeneous factors including oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, and environmental problems.*	On-going processes, or disruptions, at the landscape level – and between regime and landscape – change conditions that are central to the progress or success of the new technology.	**Constraints**: Reversals in progress as a result of new conditions disadvantageous to the technology **Drivers**: Windows of opportunity for breakout (from niche level) related to special conditions advantageous to the new technology	Effects of structural shifts in forestry industry Impact of oil prices on development Influence of the political economy of biofuels (all generations) Escalating environmental concerns and drivers.
	Constraints		**Drivers**
Raw tall diesel production	Limited supply of domestic raw material limit expansion Low fossil fuel prices may influence further expansion		Expanding global climate discourse, increasing evidence of (catastrophic) climate change effects and progress with intergovernmental rulemaking increases the demand for renewable based transport fuels. Limited global biomass supply and problems associated with agricultural crops increase the attractiveness of forest based transport fuels. Global economic trends encourages forest sector interest (diversification, waste valorisation). ILUC debate underpins technologies not relying on crops or agriculture.
Hydrogenation process technologies	Low fossil fuel prices may influence further development		Expanding global climate discourse, increasing evidence of (catastrophic) climate change effects and progress with intergovernmental rulemaking increases the interest in hydrogenation technologies. The need for refinery and the petrochemical regime to adapt to future demands for renewable based transport fuels.
Vehicle and distribution niche	Electric car revolution might reduce the interest		Dominant paradigm of diesel/petrol engines dominates Growing socio-political awareness of multi-negatives of existing fuel systems (e.g. health and climate) open opportunities for clean fuel systems.

2.6.5 Proponent Strategies to Promote Innovation Development, Sunpine

Level of Analysis	**Cognitive Legitimacy**	**Sociopolitical Legitimacy**	**Examples of anticipated information from case studies**
Organizational	Develop knowledge base via symbolic language and behaviours (key theme of **knowledge**)	Develop trust in new activity by maintaining internally consistent stories (key theme of **trust**)	Consistent details of how their system contributes to environment and society How this innovation builds upon track record, trust etc. Symbolic framing of the technology system
<u>Cognitive and Sociopolitical legit.</u> Project proponents represent key sectors securing considerable knowledge base. Major skilled player handled marketing of the final product, in order to increase reliability. HVO based on talloil presented as renewable, climate friendly, based on by-products from Swedish forestry, possible to blend with fossil diesel to high levels.		**<u>Sociopolitical legit.</u>** The idea/innovation was presented for investor right in time and for the right investor. High coherency regarding offering: pollutant emission free, good climate performance, avoiding ILUC concerns, domestic raw material in the form of a by-product etc. Drop in fuel concept easy to communicate and attractive for policy makers and the public.	
Intraindustry	Develop knowledge base by encouraging convergence around a dominant design	Develop perceptions of reliability by mobilizing to take collective action	Activities across the industry to build common industry knowledge base Convergence around a dominant design/technology platform, performance standards Development of industry organisation, collective lobby group, etc. Stable and reliable sequences of interaction with other actors in industry
<u>Cognitive and Sociopolitical legit.</u> Realized by strong collaboration between key actors including forestry and petrochemical sectors with considerable relevant knowledge and that participate in a broad range of networks.		**<u>Sociopolitical legit.</u>** Created by the strong collaboration between key actors including forestry and petrochemical sectors with relevant knowledge. Reliability reinforced by major player status, and significant own investments. Strengthened by the use of existing distribution and infrastructure. Collective action and coalitions from throughout the industry strengthens social and political trust in system.	
Interindustry	Develop knowledge base by promoting activity through third-party actors	Develop reputation of new activity as a reality by negotiating and compromising with other industries	Evidence of cooperation, negotiation or compromise with other industries where there is competition for resources, markets etc. Promotion of their new activity through third-party actors (e.g. third party testing, pilots, etc.)

Proponent Strategies to Promote Innovation Development, Sunpine, Sunpine, continued.

<u>Cognitive and Sociopolitical legit.</u> Absence of threat to fossil fuel industry since Preem involved. Enabling for large incumbents (e.g. Preem and Södra) to move into renewable sector or further develop this sector. No new demands for vehicle and engine manufacturers. Technology system does not compromise or threaten pulp and paper production infrastructure/investments.		**<u>Cognitive and Sociopolitical legit.</u>** Trust created by commercial produced by the large incumbents (e.g. Preem and Södra) showing that they to move into re-newable sector or further develop this sector. Smooth introduction since there are no new demands for vehicle and engine manufacturers.	
Institutional	Develop knowledge base by creating linkages with established educational curricula	Develop legitimacy by organizing collective marketing and lobbying efforts	Evidence of broader public/political knowledge and awareness of the innovation and its importance How and why other actors have joined to build up much of the trust and reliability of the new activities Established activities of industry councils, alliances, and other affiliations that perform collective marketing and lobbying efforts. Linkages with established educational curricula at universities etc.
<u>Cognitive and Sociopolitical legit.</u> Contribute to knowledge sharing between different indus-tries.		**<u>Cognitive and Sociopolitical legit.</u>** Well aligned with national discourse regarding bio-economy. As part of bioeconomy, initiative contributes to diversification of forest sector. Free of land use issues (e.g. ILUC). Contributes to reduced national energy dependence. Key solution for achievement of national climate goals and visions of fossil free transport sector.	

2.7 PREEM

Analysis tables for the Preem case are provided overleaf.

2.7.1 Niche phenomena, Preem

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study (Examples)**	**Specific information that interviewees may take up (Examples)**
Niche (location/situations/properties) *The co-production of hydro treated vegetable oil and conventional diesel at Preem's refinery in Gothenburg represent the first facility for HVO production in Sweden and one of a few using a feedstock originating from the pulp industry. It is the second step in a production chain utilising crude tall oil as a feedstock, SunPine in Piteå being the first.*	A location for a learning process (a niche) A distinct/special/ novel socio-technical offering (a niche offering).	Distinct place or situation where an innovation is hosted, tested or applied The form and novelty of the innovation	Description of the nature and elements of the innovation and how it differs from established systems. Description of the 'business ecosystems' forming around the system and influencing the business model, including collaborators and others that benefit. Boundaries of the system and relevant actors.
Raw tall diesel production	SunPine, Piteå Commercial full scale plant that produces raw tall diesel from raw tall oil by fractionation of the raw tall oil (that is a by-product from the pulp and paper industry). This is the first step to produce blend-in HVO from crude tall oil.	The original idea to produce HVO from crude tall diesel came from the innovator Lars Stigsson, Kiram The idea was presented to Preem and this was the spark that triggered the HVO production at the refinery in Gothenburg together with the crude tall diesel production from crude tall oil at SunPine in Piteå. However, it is a mutual dependency, the SunPine process also relied on a safe customer for the crude tall diesel. The first step production chain in full scale was entirely new, but Preem found inspiration for the HVO production in Neste in Finland. The innovator built strategically the necessary networks for realizing the plant including tall oil producers and refinery. This facilitated supply chains and market related issues. SunPine is owned by Preem (25%) Sveaskog (25%), Södra skogsägarna (25%), KIRAM (15%) and Lawter (10%). Attractive for pulp companies due to the oligopoly structure of the tall oil market. Piteå chosen due to access of crude tall oil, a good harbour and access to storage for feedstock and interim products in cisterns already in place. No investment support from the government. Strong owners that invested equity and facilitated bank loans that reduced the financial risk. Technical risks were reduced by patents.	
Hydrogenation process niche	The raw tall diesel produced in the SunPine facility is processed further to HVO diesel fuel by Preem at the refinery in Göteborg. Hydrogenation process is integrated in existing refinery infrastructure, i.e., in production of fossil fuel-based transport fuels.	A mild hydro treater that could be converted to a green hydro treater was already available at the refinery in Gothenburg. The co-production of HVO and diesel in existing production lines made the specific investments ten times lower than in comparable dedicated lines. This lowered the financial risk. Diesel demand in the Swedish market was clearly on the way up and the investments in a fuel that could be mixed in diesel at any extent and for which there was no domestic production thereby filled a gap. Preem had already entered the track to build up their environmental image, e.g. with an ultra low sulphur level in diesel, and they were also convinced that the government would continue on the climate-track, which in this case means that they believed that the tax exemptions would last. Investment made simultaneously to the SunPine investment, thus a reliable feedstock provider was secured.	

Niche phenomena, Preem, continued.

Vehicle and distribution niche	Drop-in fuel. HVO blended in diesel, represents a more renewable fuel with lower fossil CO_2 emissions that can be used in existing diesel vehicles. Initially the HVO had limitations in the mixing (blending) properties, but the more established FAME is much more limited if not used in dedicated vehicles. The HVO product has been developed with an isomeriza-tion step that allows the HVO to be mixed at any propor-tions.	Stimulated by an increased consumption of diesel in main markets and, at the time of the investment, also in Sweden. Growing environmental concerns among customers that could choose a less environmentally harmful product in the present vehicles without any additional costs. Unlike other products from Preem, the HVO is directed towards the Swedish market due to the favourable tax exemptions and the best possibilities to develop the environmental image though the visible Swedish distribution infrastructure. The initial HVO produced at Preem is less restrained than the more established FAME in the possibilities to blend in conventional diesel. The blend-in HVO requires no changes in existing distribution and infrastructure (including vehicles).

2.7.2 Niche-transition phenomena, Preem

Level of Analysis	Underlying phenomena	Parameters of particular interest in this study (Examples)	Specific information that interviewees may take up (Examples)
Niche – to – regime (locations and processes)	Co-evolution of new technologies, markets, and user preferences Formation of market spaces that are protected or insulated from 'normal' market selection in the regime	Synergies with new markets and user preferences and parallel evolution of differing parts of the technology system Examples of learning by doing, learning by using and learning by interacting Evidence of protected spaces – 'incubation rooms' for new technology system that rely on a special technical application, geographical situation, social context, sub-sidy regime, etc. Spaces where social networks to support the innovations arise: e.g. supply chains, user–producer relationships	Research and R&D history and development Funding provided for the innovation, why given, and where in the process. Description of critical phases perceived for the innovation emergence and anticipated scale(s). Role of incumbents vs. new entrants (synergistic, antagonistic, parasitic) Policies that have helped the innovation forward. Policies that can help them to scale up. Trends to a dominant design among (similar) innovations
Upgrade of the production ca-pacity including an isomerization step that makes the HVO techni-cally comparable to conventional diesel. *Since the current production capacity at the refinery in Gothenburg is more than 160 000 tonnes per year, it exceeds the production capacity in Piteå. Hence, other feedstock, such as animal fats and rapeseed oil are used for the HVO produc-tion.*	Sweden is an attractive market for HVO be-cause of the tax exemptions and the market is expanding more rapidly than the production capacity at Preem. The market share of HVO is presently at a scale that has reached regime status on the Swedish market for transportation fuels. The feedstock from SunPine is no longer sufficient as a feedstock and Preem has already diversified the feedstock but are diversifying it further. Since the current tax exemptions is sufficient to cover the costs and there are no limits in the blend-in volumes, there are no limits for the market space of HVO.	The initial HVO was limited in the blend-in share by its flow properties in a winter climate but the isomeri-zation step ena-bled mixing in diesel at any extent (no blending walls), without modification of the distribution infrastructure and vehicle fleet. This has fully opened up the established market for transporta-tion fuels. Neste has a patent on the isomerization and Preem has to pay licences to use the technology. Preem, as an established refiner and transportation fuel distrib-utor, had direct access to the distribution infrastructure and thereby the market for HVO.	The feedstock base must be increased since the production of crude tall diesel is limited by the capacity at SunPine. The environmental image of Preem has improved with the HVO. The company will not risk this new image by using the most used feedstock for HVO globally, the highly controversial palm oil that is used by the main forerunner and competitor Neste.
Vehicle and distribution niche	Included in existing distribution and infrastruc-ture for fossil based diesel.	The significant improvement in fuel efficiency has together with particulate filters and reduced sulphur levels in diesel fuels changed the public opinion about diesel vehicles from being very environmentally harmful. This, together with the attractive specific fuel costs, has led to a major shift towards diesel vehi-cles in Europe and successively also in Sweden. The possibility to combine these positive factors with an even less environmentally harmful fuel at no additional cost has led to market space for HVO that has been hard to fill for Preem. Bad publicity could be very damaging for the market. An ex-ample in hand is the Swedish ethanol E85 boom and (bust) decline case.	Policies have not restrained the use of HVO as a blend-in in conventional diesel and the Swedish government have kept the tax exemptions over time, which has enabled the expansion.

2.7.3 Regime phenomena, Preem.

<table>
<tr><th>Level of Analysis</th><th>Underlying phenomena</th><th>Parameters of particular interest in this study (Examples)</th><th>Specific information that interviewees may take up (Examples)</th></tr>
<tr><td>Regime
(conditions – pre-cursors for drivers & constraints)
Here regime conditions focus on the semi-coherent set of rules carried by different social groups.</td><td>Constraints (and drivers) arising because regulations, infrastructure, user practices, maintenance networks are aligned to the existing technology.</td><td>Constraints:
Mismatch with one or more of the (seven) dimensions in the incumbent sociotechnical regime:
• technology,
• user practices and application domains (markets),
• symbolic meaning of technology,
• infrastructure,
• industry structure,
• policy, and
• techno-scientific knowledge
Drivers: Supportive situation(s) and synergies with incumbent regime dimensions.</td><td>Limitations/opportunities posed by the current established systems
Social, regulatory and market barriers and opportunities
Specific Policies and regulations, clashes between policies, clarity and stability of policy interventions.
Collaboration with established sectors/regimes
Impacts and benefits associated with material flows and benefit accrual (e.g. fossil to bio)</td></tr>
<tr><td>HVO production</td><td colspan="3">Collaboration with established sectors – forest industry providing the raw material and petrochemical regime further processing the product to transport fuel. The feedstock is the limiting factor with current policy framework. Preem use animal fats and rapeseed oil as complements to the crude tall diesel at the current production rates and are exploring different types of feedstock for future expansions. The main feedstock for HVO globally – the much debated palm oil, is not on the list. There is awareness that bad publicity can be detrimental for the whole production, as for the rise and fall of Swedish ethanol, and Preem are not willing to take the risk with palm oil. They are hence looking at other options and collaboration with different sectors.
User practices and application domains (markets) – rapid growth of HVO use in Sweden (also from other types of feedstock than crude tall diesel). The HVO production has, contrary to other production methods for forest-derived biofuels, no constraints on the market side for the product. Since the product is co-processed with the conventional product in the production lines of the largest refiner in the Nordic countries, there are no incumbent players to compete with. The market can swallow all produced HVO.
Symbolic meaning of technology – a success story that may inspire others to invest in biofuel production as well as broadening the renewable products and feedstock base for Swedish refineries.
Infrastructure – requiring only minor changes to existing infrastructure.
Industry structure – providing development possibilities for existing industry structure and representing successful inter-industry collaboration. The main barriers for the further expansion is on the feedstock side since the HVO production demands a liquid feedstock.
Policy – the current policy instrument (tax exemptions) is stimulating and not putting any constraints on the production. Preem are convinced that the current Swedish shares of biofuels in general and HVO in particular will bring about a shift towards quota obligations. This may put a constraint on the share if biofuels, but Preem are still advocates of such a solution. The market is likely to collapse in the absence of a policy framework that do not promote the HVO production in a way that resembles the tax exemptions or a sufficient quota obligation.
Techno-scientific knowledge – current focus is on expansion and further projects may follow. Since the hydrogenation process requires a liquid feedstock, Preem are very interested in the development of technologies that converts solid biomass to bio oils. A number of such conversion technologies have reached relatively far in the development towards commercial units, e.g. pyrolysis, lignin oil production, and hydrothermal liquefaction. Preem see themselves as natural receivers and upgraders of bio oils from a large number of smaller conversion units, i.e. to continue the path with inter-industrial solutions that started with SunPine. The product focus is not entirely on HVO, since the path lignin oils may result in renewable petrol.</td></tr>
</table>

Regime phenomena, Preem, continued.

Vehicle and distribution niche	Collaboration with established regimes – petrochemical regime and current vehicle producer regime. The current distribution system and vehicle fleet pose no technical constraints to a further expansion of the HVO market in Sweden. User practices and application domains (markets) – not requiring actions by vehicle users, included in existing markets and existing distribution systems. A perception among customers that HVO represents something bad is a real threat for the market as is a change of policy in to a system that will make the product more expensive than the conventional fuels. Symbolic meaning of technology – Demonstration of the usefulness of the distribution infrastructure and vehicle fleet in the transition to a larger share of renewables. Infrastructure – requiring only minor changes to existing infrastructure. Industry structure – Not requiring any major changes for existing industry. Policy – No particular policies needed. Techno-scientific knowledge – Appears functionally adequate.

2.7.4 Landscape phenomena, Preem

Level of Analysis	**Underlying phenomena**	**Parameters of particular interest in this study (Examples)**	**Specific information that interviewees may take up (anticipated examples)**
Landscape (conditions) Here landscape conditions focus on heterogeneous factors including oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems.	On-going processes, or disruptions, at the landscape level – and between regime and landscape – change conditions that are central to the progress or success of the new technology.	**Constraints**: Reversals in progress as a result of new conditions disadvantageous to the technology **Drivers**: Windows of opportunity for breakout (from niche level) related to special conditions advantageous to the new technology	Effects of structural shifts in forestry industry Impact of oil prices on development Influence of the political economy of biofuels (all generations) Escalating environmental concerns and drivers.

Landscape phenomena, Preem, continued.

Hydrogenation process technologies	An increasing awareness of climate change and the political response to this is the foundation for the attempts to reduce the impacts for different societal sectors. The EU has a strong focus on the transport sector, since it is a sector from which the climate impacts have been difficult to decrease. Low fossil fuel prices may influence further development	**Drivers:** The policy framework in response to climate change in synergy with a public awareness are the main driving factors for the increasing shares of biofuel in the Swedish transportation sector. HVO has been the main contributor in recent years. Limited global feedstock supply for first generation Biofuels as well as an increased awareness that all options for biofuel feedstock were not good options gave a massive response in customer preferences and policy support through the ILUC debate and sustainability criteria. Crude tall oil was not part of this debate and hence fitted well into the policy framework as well as in general marketing. **Constraints:** The recent years' low crude oil prices have reduced the general interest in biofuel investments, but HVO seems untouched by the development. The feedstock base is a severe limitation for HVO, since the feedstock either has to be planted/farmed or converted to a liquid of a solid biomass is used. Land-use practises may thus become a much more debated issue to deal with for the HVO industry in the relatively near future since the industry is rapidly expanding.	The forest industry as a whole wanted a more diversified market for one of their by-products. The high oil between price between 2011 and 2014 suited the development generally for renewable transportation fuels. The large increase in HVO consumption in Sweden since the onset in 2011 seem to be relatively untouched by the shift in oil prices. The general policy framework at EU level is supportive of biofuels produced with the HVO feedstocks used in Sweden, but to different extents. All feedstock qualifies under the sustainability criteria while some qualify for the double counting in fulfilment of the RES targets. The refinery industry do not see themselves as an industry suffering from societal demands but rather as leaders in the shaping of a new landscape allowing a renewable transportation fuel-regime.
Vehicle and distribution niche	Most biofuels need adaptation of the distribution infrastructure and the vehicle fleet. This is not the case for HVO where very little has to be changed, i.e. no obstacles at the landscape level.		

2.7.5 Proponent Strategies to Promote Innovation Development, Preem

Level of Analysis	Cognitive Legitimacy	Sociopolitical Legitimacy	Specific information that interviewees may take up (Examples)
Organizational	Develop knowledge base via symbolic language and behaviours	Develop trust in new activity by maintaining internally consistent stories	Consistent details of how their system contributes to environment and society How this innovation builds upon track record, trust etc. Symbolic framing of the technology system
	Cognitive and sociopolitical legitimacy: Product chain represent key sectors securing considerable knowledge base from feedstock supply till fuel distribution and marketing. Preem has promoted the product consistently. HVO based on talloil is presented as renewable, climate friendly, based on by-products from Swedish forestry, possible to blend with fossil diesel to high levels. Marketing have also been focusing on how policy instruments should encourage a higher share of renewables in the conven-tional fuels, thus emphasising that the company takes on social and environmental responsibilities.		Cognitive and sociopolitical legitimacy: The idea was presented to Preem by the inventor in a way that suited the company's profile. High coherency regarding offering: pollutant emission free, good climate performance, avoiding ILUC concerns, domestic raw material in the form of a by-product etc. Drop in fuel concept easy to communi-cate and attractive for policy makers and the public.
Intraindustry	Develop knowledge base by encouraging convergence around a dominant design	Develop perceptions of reliability by mobilizing to take collective action	Activities across the industry to build common industry knowledge base Convergence around a dominant design/technology platform, perfor-mance standards Development of industry organisation, collective lobby group, etc. Stable and reliable sequences of interaction with other actors in industry
	Preem is very active in networks that focus on renewable transportation fuel chains and show an interest for actors that represent their own fuel chain. Communicates the rationality in using the existing production lines, distribution infrastructure and vehicle fleet in the shift towards more renewables in the transportation sector. Emphasising the core role of the refiners in the shift to a renewable energy future, thereby positioning themselves against other production and distribution chains such as gasification routes.	Reliability in their fuel chain is enforced by strong collaboration between key actors including forest industry. The reliability is strengthened by major player status, significant own investments and by the use of exis-ting production and dis-tribution infrastruc-ture.	
Interindustry	Develop knowledge base by promoting activity through third-party actors	Develop reputation of new activity as a reality by negotiating and compromising with other industries	Evidence of cooperation, negotiation or compromise with other industries where there is competition for resources, markets etc. Promotion of their new activity through third-party actors (e.g. third party testing, pilots, etc.)

Proponent Strategies to Promote Innovation Development, Preem, continued.

	See Intraindustry above, but no positioning against in cases where other actors represent links in fuel chains that may be valuable in future systems including refineries and conventional fuel distribution system for liquid fuels. No new demands for vehicle and engine manufacturers. Technology system does not compromise or threaten pulp and paper production infrastructure/ investments.	Preem reveals a strong interest in future possible feed-stock providers as part of the vision to have refineries as the core in a transformation towards a larger share of renewable transporttation fuels. Preem are open about on-going discussions with other actors.	For the limited resource crude tall oil, there is an obvious competition with the industry that uses it for other products. There are no obvious signs of negotia-tions and compromise with this industry.
Institutional	Develop knowledge base by creating linkages with estab-lished educational curricula	Develop legitimacy by organizing collective marketing and lobby-ing efforts	Evidence of broader public/political knowledge and awareness of the inno-vation and its importance How and why other actors have joined to build up much of the trust and relia-bility of the new activities Established activities of industry coun-cils, alliances, and other affiliations that perform collective marketing and lobby-ing efforts. Linkages with established educational curricula at universities etc.
	Preem has an active and long-lasting cooperation with Chalmers University of Technol-ogy.	Well aligned with national discourse regarding bioecono-my. As part of bio-economy, Preem are active in initiatives that contribute to the diversification of the forest industry. Preem are sending the message that they represent a key solution for achieve-ment of national RES targets and, in the long run, the Swedish vision of a fossil free transport sector and the national climate goals.	

3 REFERENCES/FOOTNOTES

References have been provided throughout the document using footnotes. These footnotes are also presented below as end notes in order to increase readability.

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2. *Ibid.*
3. Fredriksson Möller, B., Gillberg, B., Huhtala, R., Reinholdtzon, A., & Westlind, G. (2013). *Bioraffinaderi Norrtorp*.
4. SAKAB AB was sold to Ekokem in 2012.
5. A Swedish company with 400 employees dealing with civil, structural and environmental engineering, see www.structor.se
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18. Ulmanen, J.H., Verbong, G.P.J. & Raven, R.P.J.M., 2009. Biofuel developments in Sweden and the Netherlands. *Renewable and Sustainable Energy Reviews*, 13(6-7), pp.1406–1417. Available at: http://www.sciencedirect.com/science/article/pii/S1364032108001718 [Accessed April 15, 2015].

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21. Hedenskog, M., *The GoBiGas Project.* Presentation at Advanced Biofuels Conference, Stockholm Sept. 16, 2015.

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24. Grahn, M. & Hansson, J., 2014. Prospects for domestic biofuels for transport in Sweden 2030 based on current production and future plans. *Wiley Interdisciplinary Reviews: Energy and Environment*, p.n/a–n/a. Available at: http://doi.wiley.com/10.1002/wene.138 [Accessed December 19, 2014].

25. Swedish Energy Agency, 2014. Press release: 1.9 billion SEK to Swedish bioenergy project. Available at: https://www.energimyndigheten.se/Press/Pressmeddelanden/19-miljarder-till-svenskt-bioenergiprojekt-/ [Accessed July 1, 2015].

26. Personal communication with T. Lönnqvist (Malin Hedenskog, 2 May 2016)

27. It is important to note that the oil price dynamics are considered more important than gas price dynamics in cases where bio-SNG is produced for the transportation market. Gas in this case competes with petrol and diesel.

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29. Government of Sweden, 2013. *A vehicle fleet independent of fossil fuels [Fossilfrihet på väg]. SOU 2013:84*, Stockholm: Statens Offentliga Utredningar.

30. Second generation biofuels is sometimes defined as technologies using residues as feedstock. The definition used in FFF for which producers that would receive a premium includes gasification technologies but excludes e.g. biogas from anaerobic digestion, although it normally uses residues as feedstock.

31. Government of Sweden, 2014. *Submission for comment; A vehicle fleet independent of fossil fuels; Reply from Preem*, Available at: http://www.regeringen.se/content/1/c6/24/09/47/8fb77f81.pdf.

32. The Swedish natural gas market is very dependent on import from or through Denmark via one single pipeline (Dragör) Sweden is thus not directly linked to continental Europe but is, via Denmark, coupled to the European gas transmission system. The total import capacity of the Swedish gas transmission grid is currently approximately 22 TWh/year, while total consumption is in the range of circa 15 TWh/year. 3.5% of the total Swedish energy needs are covered by natural gas. However in those areas in Sweden where natural gas is established it covers approximately 20% of the energy needs. In Sweden approximately thirty municipalities, mainly situated at the West-Coast area and the Southern part of Sweden, have access to natural gas. Energimarknads Inspektion (2012) An overview of the Swedish natural gas market. PM2012:6 In Stockholm, natural gas is delivered as LNG. Both the city gas net and the vehicle gas net are suitable for biogas. As of 2016, circa 30% of the gas delivered is biogas. There is also a LNG harbor in Lysekil, north of Gothenborg.

33. See http://ec.europa.eu/clima/policies/lowcarbon/ner300/index_en.htm

34. See http://www.biofuelstp.eu/eibi.html

35. Source: *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Dr. Björn Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013

36. Möller, B.F. (Nov 2010), *Gasification Development at E.ON*, (Eon101029_EGD@SGC_open) presented at the SGC International Seminar on Gasification, Svensk Gastekniskt CenterAB, 2010.

37. *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Björn Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013

38. *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Björn Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013

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41. In a press release dated 1 April, 2016, E.ON announced the following: *E.ON successfully separated its operations from Uniper's effective January 1, 2016. From the new E.ON campus in Essen, the company will now focus on renewables, energy networks, and customer solutions. Uniper will operate independently from its headquarters in Düsseldorf. Uniper's businesses—conventional power generation (hydro, natural gas, coal) and global energy trading—remain essential for ensuring the security of the energy supply. E.ON has therefore reached another important milestone in the execution of its new strategy. The spinoff of Uniper is expected to take place later in 2016 following the approval of E.ON shareholders.* See http://www.eon.com/en/media/news/press-releases/2016/1/4/separation-of-eon-business-operations-completed-on-january-1-uniper-launched-on-schedule.html
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47. Interview with Björn Fredriksson Möller, (P. Peck, Y. Voytenko) 29 September 2015.
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50. Grontmij (Data source) included in *Bio2G – A full-scale reference plant in Sweden for production of bio-SNG (biomethane) based on thermal gasification of biomass*, Dr. Björn

Fredriksson Möller, Anders Molin, Krister Ståhl E.ON Gasification Development. The International Conference of Thermochemical Conversion Science, 2013.

51. Interview: Tomas Lönnqvist (KTH) with Björn F. Möller (E.ON) 18 Nov. 2015.

52. Among other things apparently related to equipment supply.

53. The Industrial partners and Växjö Värnamo Biomass Gasification Centre (VBGC) planned a project with the main objective to rebuild the existing gasification plant to produce a synthesis gas from biomass suitable for the production of a number of different energy carriers, for electricity production and renewable transport fuels. See also: Möller, B.F. (Nov 2010), *Gasification Development at E.ON*, (Eon101029_EGD@SGC_open) presented at the SGC International Seminar on Gasification, Svensk Gastekniskt CenterAB, 2010

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62. Björn Fredriksson Möller, Bengt Ridell, (2013, June) *Case story: Vehicle gas in Sweden*.

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64. *Ibid.*

65. Interview: Tomas Lönnqvist (KTH) with Björn F. Möller (E.ON) 18 Nov. 2015.

66. See for instance: Möller, B.F. (Nov 2010), *Gasification Development at E.ON*, (Eon101029_EGD@SGC_open) presented at the SGC International Seminar on Gasification, Svensk Gastekniskt CenterAB, 2010

67. Interview: Tomas Lönnqvist (KTH) with Björn F. Möller (E.ON) 18 Nov. 2015.

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4 APPENDIX: RESEARCH INTERACTIONS/INFORMANTS

Organization	Name, role	Communication channel, date	Input to study
Göteborg Energi	Lars Holmquist, Business Strategic Planner; Ingemar Gunnarsson, Development Engineer; Eric Zinn, Biogas Products Coordinator	In person, 2015-10-06; Email 2016-04-26	Case study interview: GoBiGas; Written input to webinar
Sekab	Göran Eriksson, Former President	Via telephone, 2015-09-22	Case study interview: Biorefinery Norrtorp
VärmlandsMetanol	Björn Gillberg, President	Via telephone, 2015-10-08	Case study interview
Chemrec	Jonas Rudberg, former CEO; Max Jönsson CEO	In person, September 2015	Case study interview
E.ON	Björn Fredriksson Möller, Project Manager	In person, 2015-9-25; Webinar 2016-04-25	Case study interview: Bio2G; Webinar participation
Luleå University of Technology	Ingvar Landälv, Project Manager (former VP Technology at Chemrec)	Via telephone, January 2016	Case study interview: LTU Green fuels
Preem	Sören Eriksson, product Developer; Åsa Håkansson, business developer	In person, 2015-12-10	Case study interview
RenFuel AB	Sven Löchen, CEO	In person, March 2016	Case study interview
Södra/SunPine	Gustav Tibblin (Chairman of the board of SunPine)	Via telephone, October 2015, Webinar 2016-04-25	Case study interview: SunPine; Webinar participation
2030 secretariat, Equest AB	Jacob Lagercrantz, Co-founder, Managing Director	Webinar 2016-04-25	Webinar participation
LTU	Elisabeth Wetterlund, Associate Senior Lecturer	Webinar 2016-04-25	Webinar participation
Chalmers	Hans Hellmark, Senior Researcher	Email 2016-04-22	Written input to webinar
SEA, Chalmers	Tomas Kåberger, Former General Director, Swedish Energy Agency, Professor	Via telephone, 2016-04-25	Input to webinar (telephone mini-interview)
LTU	Patrik Söderholm, Professor	Email 2016-04-26	Written input to webinar
Lantmännen Agroetanol	Andreas Gundberg, Technology Manager	Via telephone, 2016-04-26	Input to webinar (telephone mini-interview)

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