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Biojet Östersund – Supplementary studies and international cooperation

Supplementary studies to the project: Large scale Bio-Electro-Jet fuel production integration at CHP-plant in Östersund, Sweden

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In cooperation with Jämtkraft

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This report has been reviewed and approved in accordance with IVL's audited and approved management system.

Preface

This project is a follow-up study on the previously reported project *Large scale Bio-Electro-Jet fuel production integration at CHP plant in Östersund, Sweden*, which was an in-depth feasibility study on the establishment of a Bio-Electro-Jet fuel production plant at the suggested site. This follow-up project consists of two main parts: 1) Supplementary studies and 2) International outlook and cooperation. The first part contains supplementary studies to the previous project and mainly aims to provide information that is useful for possible investment decisions for a Bio-Electro-Jet fuel production plant. The second part includes the establishment of cooperation with relevant international actors and the development of opportunities to obtain EU funding. These two parts of the project have been conducted in parallel and the results have been synergistically integrated.

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Summary

The northern parts of Sweden have good access to large amounts of low-cost renewable electricity and biomass. Therefore, this area can be considered as suitable for production of electrofuels. This project is a follow-up study on the previously reported project *Large scale Bio-Electro-Jet fuel production integration at CHP plant in Östersund, Sweden*, which was an in-depth feasibility study on the establishment of a Bio-Electro-Jet fuel (BEJF) production plant at the suggested site. BEJF is an electrofuel, a fuel product in the jet-fuel range (C8-C16) produced from captured CO_2 of biogenic origin and H_2 from electrolysis of water using renewable electricity.

This study was performed with the ambition to clarify some of the findings from the previous project and also to address the possible hurdles and possibilities that exists for the implementation of an industrial BEJF production facility at the Lugnvik site in Östersund, Sweden. Also, the development of a roadmap for implementation of the concept is included in this study.

The study reports on the establishment of international consortia for both continued research and the realization of the full-scale facility. Hence, two parallel paths are described (research and full-scale) and a roadmap depicting possible ways forward for those paths during the upcoming 5 years is presented.

Many possible financing options (public national, private, EU-funding) are described for the two parallel, but interlinked, paths of full-scale industrial production, and research and development, including the identification of relevant upcoming calls within Horizon Europe. One important conclusion is that funding should be sourced separate for the two paths to prevent the implementation of the full-scale plant being dependent on research funding. However, the research path has great potential to provide valuable, knowledge also for the full-scale case.

One clarification from the previous study is the location and size of the carbon capture unit which has been addressed and determined. Another one is the development of an optimization tool for size and scale which has been discussed and, unfortunately dismissed due to complexity. Relevant regulations and permits linked to the construction and the operation of the plant has been described and discussed, and the certification for the operation and products as well as the quality concerns of those have been clarified.

Finally, market opportunities for by-products and the related quality requirements have been mapped, as well as other possible relevant inflows to the plant. The possibility of technology-transfer of the concept to another site is discussed and the work within a Master thesis for the optimization of policies related to sustainable aviation fuels have been connected to the scope of this study.

As a general next step, it is proposed that the roadmap developed within this project is followed for the upcoming five years. As a more specific next step, a follow up project in the form of a detailed pre-study is proposed that would enhance the possibility to go deeper into the concept.

Overall, the results highlight the feasibility of the concept addressed herein and a concrete plan towards its full-scale implementation is proposed.

Sammanfattning

De norra delarna av Sverige har god tillgång till stora mängder billig förnybar el och biomassa. Därför kan detta område anses vara lämpligt för produktion av elektrobränslen. Detta projekt är en uppföljningsstudie av det tidigare rapporterade projektet *Storskalig produktion av bioelektro-jet-bränsle vid kraftvärmeverk i Östersund, Sverige*, som var en djupgående genomförbarhetsstudie om inrättandet av en produktionsanläggning för bioelektro-jet-bränsle (BEJF). BEJF är ett elektrobränsle, en bränsleprodukt inom jetbränsleområdet (C8-C16) som framställts av infångad CO_2 av biogent ursprung och H_2 från elektrolys av vatten med förnybar elektricitet.

Denna studie genomfördes med ambitionen att klargöra några av resultaten från det föregående projektet och även utvärdera möjliga hinder och möjligheter som finns för implementeringen av konceptet för en industriell BEJF-produktionsanläggning vid Lugnvik-anläggningen i Östersund, Sverige. Utvecklingen av en färdplan för en möjlig väg framåt för konceptet ingår också i denna studie.

Studien inkluderar även en utvärdering av möjligheter för inrättandet av internationella konsortier för både fortsatt forskning och förverkligandet av fullskaleanläggningen. Därför beskrivs två parallella vägar (forskning och fullskala) och en färdplan som visar de möjliga vägarna framåt för dessa vägar under de kommande fem åren.

Många möjliga finansieringsalternativ (offentlig nationell, privat, EU-finansiering) beskrivs för de två parallella, men sammankopplade vägarna för fullskalig industriproduktion och forskning och utveckling, inklusive identifiering av relevanta kommande utlysningar inom Horisont Europa. En viktig slutsats är att finansiering ska anskaffas separat för de två vägarna för att förhindra att genomförandet av fullskaleanläggningen är beroende av forskningsfinansiering. Forskningen bedöms dock ha stor potential att tillhandahålla värdefull kunskap även för den industriella skalan.

Ett förtydligande från den tidigare studien är placeringen och storleken på koldioxidavskiljningsenheten som har behandlats och bestämts. En annan är utvecklingen av ett optimeringsverktyg för storlek och skala som har diskuterats och tyvärr avfärdats på grund av komplexitet. När det gäller möjliga hinder och möjligheter har relevanta föreskrifter och tillstånd kopplade till anläggningen och driften av anläggningen beskrivits och diskuterats, och certifieringen för driften och produkterna samt kvalitetskraven för dessa förtydligats.

Slutligen har marknadsmöjligheter för biprodukter och tillhörande kvalitetskrav kartlagts, liksom andra möjliga relevanta inflöden till anläggningen. Möjligheten för tekniköverföring av konceptet till en annan plats diskuteras. Resultat av en magisteruppsats för optimering av styrmedel relaterade till hållbara flygbränslen har kopplats till omfattningen av denna studie.

Som ett generellt nästa steg föreslås att den färdplan som utvecklats inom detta projekt följs de kommande fem åren. Som ett mer specifikt nästa steg föreslås ett uppföljningsprojekt i form av en detaljerad förstudie som skulle förbättra möjligheten att gå djupare in i konceptet.

Sammantaget framhäver de resultat som produceras inom detta projekt den goda genomförbarheten av det koncept som tas upp här och föreslår en konkret plan för dess genomförande i full skala.

1 Introduction

1.1 Purpose

This project is a follow-up study on the previously reported project *Large scale Bio-Electro-Jet fuel production integration at CHP plant in Östersund, Sweden*, which was an in-depth feasibility study on the establishment of a BEJF production plant at the suggested site. This follow-up project consists of two main parts: 1) Supplementary studies and 2) International outlook and cooperation. The first part contains supplementary studies to the previous project and mainly aims to produce information that is useful as basis for a possible investment decision in a BEJF production plant. The second part includes the establishment of cooperation with relevant international actors and the development of opportunities to produce applications for EU funding. These two project parts have been run in parallel during the project and the results of the two parts have been synergistically integrated. BEJF is an electrofuel, a fuel product in the jet-fuel range (C8-C16) produced from captured CO_2 of biogenic origin and H_2 from electrolysis of water using renewable electricity.

1.1.1 Supplementary studies

The supplementary studies presented in this report will be used to create a decision basis for investments and implementation of plans for hydrogen/aviation fuel production. Jämtkraft owns and operates the district heating network in the city of Östersund and has a CHP at the Lugnvik site to supply heat and power. Moreover, Jämtkraft also owns and operates both wind- and hydropower in the northern part of Sweden. Jämtkraft also have plans on constructing a new CHP-plant within the next 4-5 years. The studies within this project are carried out with Jämtkraft and the planned new CHP plant in focus, but methods and results are generalized and documented so that the results are useful for other actors and as a basis for international cooperation. The following supplementary studies have been performed within the project:

- A more detailed study of financing opportunities for the facility at organizational level (addressing the question on who may be able to contribute to the financing) including also public financing opportunities and loan guarantees at national and EU level.
- Analysis of suitable location and space requirements for CO_2 capture equipment in the new CHP plant (KVV).
- Analysis of the possibility to develop an excel-based tool to simulate material flows related to the BEJF production facility based on the local conditions in Östersund.
- Overview of relevant legislation and permits required for the construction and operation of the facility. Review of the locations of corresponding fuel production facilities in Sweden.
- Summary of the process around plant certification for aviation fuel production.
- Detailed mapping of other outlets related to outgoing end products from the process (petrol, diesel, wax, hydrogen, oxygen, carbon dioxide).
- Questions about quality and certification of by-products and flows for the overall business model.

- Questions concerning Tech transfer and knowledge transfer for other additional locations of the same concept, in Sweden, the Nordic countries, Europe and internationally.
- Compilation of other possible inflows (eg locally produced biogas, locally produced carbon dioxide and non-locally produced carbon dioxide).

1.1.2 Establishment of international cooperation

The establishment of international cooperation in this project includes mapping of actors and ongoing relevant research in the field as well as establishment of contacts and collaborative discussions for future applications to calls within the EU Green Deal and future ones within Horizon Europe. The aim of this part of the project was to:

- Identify and contact current international actors (energy, fuel companies, research providers, etc.) with relevant research and development on hydrogen and aviation fuels.
- Develop collaboration plans and proposals for the Green Deal and/or upcoming Horizon Europe programs.

1.2 Methodology and project implementation

The project has been led by IVL and has been carried out based on published literature and interviews as well as the results from the above-mentioned previous project. The input for the studies consists of data, results and conclusions from academic and popular science literature supplemented with interviews of national and international expertise within IVL's and working group participants' network of contacts.

The establishment of the international consortia are carried out through documentation of existing contacts and identification of new ones in collaboration with a selection of participants from the ongoing project *Large scale Bio-Electro-Jet fuel production integration at CHP plant in Östersund, Sweden* (Jämtkraft, Chalmers, Lund University, Fly Green Fund, Nordic Initiative for Sustainable Aviation, Power Region / Östersund Municipality). Only IVL's part of the work has been financed by this project.

Project manager at IVL has been Anton Fagerström. Internal and external resources have been allocated as needed within the project and the work has been reviewed internally within IVL. Project meetings have been held every 1-2 weeks during the project.

2 Background

Jämtkraft and IVL have, together with Chalmers, Lund University, Fly Green Fund, Nordic Initiative for Sustainable Aviation, Power Region / Östersund Municipality, carried out the previous project *Large scale Bio-Electro-Jet fuel production integration at CHP plant in Östersund, Sweden* funded by the Swedish Energy Agency, Jämtkraft's environmental fund and the IVL Foundation (SIVL). That project ran between June 2019 and December 2020.

In this previous project the possibility of producing electrofuels in the form of Bio electro jet fuel (BEJF) from renewable CO_2 and hydrogen (H_2) via two synthetic routes (F-T and AtJ) and the integration of these processes into a CHP plant were investigated under Swedish conditions. Both routes have shown comparable BEJF production costs of approximately EUR1.6/litreBEJF, with a slight increase of about 3% in the case of AtJ. It should, however, be noted that there is a significantly lower amount of jet fuel produced via the AtJ process compared to the F-T-route. A reduction of 78% in heating demands has been achieved in the F-T process through energy integration, which has also led to a significant increase in thermal efficiency of the process up to 39%, based on the F-T crude product. Both routes can be integrated with the CHP plant and the district heating network to achieve a better overall energy efficiency. Further research is required for the AtJ route in order to increase the hydrocarbon chain length in the product distribution, as well as for both routes to assess the effect of varying the capacity of biomass feed on the production cost of electrofuels.

The environmental impact for large scale production of electrofuels (in the form of BEJF) from the F-T pathway and the AtJ pathway was assessed using Life cycle assessment (LCA). The Global warming potential (GWP) of the studied fuels range between 11 and 19 g CO2 eq. per MJ BEJF produced, with the possibility for even lower emissions factors (9-16 g CO2 eq. per MJ BEJF) when co-products from the hydrogen production process are considered. The AtJ pathway resulted, for all studied impact categories, in slightly better environmental performance compared to the F-T pathway. In the absence of detailed data however, this pathway was modelled in a more simplified way compared to the F-T pathway which may explain some of the variations observed. According to the previous study it is indicated that the BEJFs can fulfil the emission reduction targets set by policy and provide a promising alternative for the aviation sector under the condition that renewable sources are used and that processes are highly integrated to take advantage of all possible synergies. It should be noted that results from LCAs in general, and of this study in particular, can be sensitive to the underlying assumptions and methodological choices performed. The outcome for example may differ for countries other than Sweden (or Nordic) and with a more carbon intense energy mix. To capture methodological variations, additional scenarios looking to other allocation approaches (for instance in relation to the CHP) or fuel related reporting frameworks (e.g. REDII) could be further investigated. Apart from the CHP, the remaining processes are based on simulations and experimental results indicating that the full integration potential and scale up effects are not considered in detail. Future assessments on a demo or full-scale fuel production facility may provide an even deeper understanding on the factors influencing the environmental performance of these fuels.

In the previous study, business model aspects have been discussed assuming that electrofuels may in the future represent a renewable transport fuel with high GHG reduction potential. It is therefore crucial that the production plant is designed and operated in order to deliver a fuel with low climate impact. Other benefits and impact on sustainability to include in a sustainable business model are, for example, regional growth, job creation as well as social and gender equality. There will be several products generated from the process, such as e-jet, e-gasoline and e-diesel which are expected to contribute to the overall business model. Besides being sold to end customers these products could be sold to an intermediator, for example a refinery. Other by-products from the process to be considered in the business model include for example residual/surplus heat, oxygen and waxes where new or existing customers could be relevant.

In order to come closer to an investment decision for the proposed aviation fuel factory integrated with Lugnvik CHP in Östersund, it was proposed that a number of supplementary issues would be investigated in greater detail than what is included in the previous project. Furthermore, a number of research challenges are expected to remain in terms of scaling up new catalytic process steps for increased system efficiency in integration with existing infrastructure and international cooperation will be an important activity to quickly reach an implementation phase. The interest in international cooperation was also illustrated by the recently opened EU Horizon2020 call *Closing the industrial carbon cycle to combat climate change - Industrial feasibility of catalytic routes for sustainable alternatives to fossil resources* with high bearing on the previous project. With support from the EU, the opportunities are considered great for both support for the establishment of the proposed plant and for continued research and development of hydrogen and aviation fuel production in Sweden and the EU.

Against this background, IVL Swedish Environmental Institute proposed a supplementary project in the form of a collaboration with Jämtkraft to produce information useful for the basis for a possible investment decision. This collaboration project includes to, carry out the work of establishing European cooperation that is expected to lead to research proposals, map funding possibilities and perform some supplementary assessments. This project is part-financed by industrial funds from Jämtkraft, which are matched by SIVL, and intends to shed light on the additional opportunities and obstacles that exist for the construction of the aviation fuel factory. The main arguments for the funders to support the project is:

- The project is relevant for the industrial partner, Jämtkraft, and for the industry in that it produces previously unavailable results central to the construction of a Bio-electro-jet-fuel (BEJF) factory in direct connection to the company's facility.
- The project is relevant to IVL as it builds on its expertise in fuels and energy and has great potential to deepen the institute's research involvement in electro fuels, process integration and aviation.
- The project is relevant for the region as it has the potential to improve the opportunities for establishing sought after electricity-intensive industry.
- The project is relevant to Sweden's environmental and climate ambition as it has the potential to lead to a facility that can replace on the order of at least 10-15% of the annual consumption of fuel for domestic air transport in Sweden.
- The project has potential to strengthen Sweden’s competitiveness in the international arena as a producer of sustainable fuels. More “green” jobs can be created and new opportunities for cooperation between academia and the private sector can arise as a result from the project.
- The project has a research height in itself as completely new data is produced around a jet fuel plant's value chains as well as energy and material flows. Furthermore, the project leads to international cooperation with the aim of producing research proposals for EU funding.

- The planned international cooperation is expected to lead to continued research that increases the potential to streamline the production BEJF both in the planned facility, in Sweden and within the EU.

3 Establishment of international cooperation

One insight from the previous project *Large scale Bio-Electro-Jet fuel production integration at CHP plant in Östersund, Sweden* for the main involved stakeholders was that additional partners were needed to realize the plans for a full-scale production facility for BEJF. The reason for this conclusion was that linked to the realization specialized expertise would be needed in a number of areas related to the design and construction of the facility, and in downstream product testing, handling and distribution. Therefore, intensive work began by the project partners in forming a consortium capable of managing the tasks related to the realization of the BEJF plant.

Meanwhile, EU launched the Horizon 2020 Green Deal call *Closing the industrial carbon cycle to combat climate change - Industrial feasibility of catalytic routes for sustainable alternatives to fossil resources*, which was focused on the establishment of a demo-scale facility for synthetic fuels. Demo-scale in this case corresponds to an amount of synthetic fuel product of 4000 tonnes annually as compared to the size of the full-scale plant envisioned in the previous project of 80-100 000 tonnes yearly. This meant that two interconnected consortia were to be established: a smaller one with the focus on the full-scale plant, and a more populated one with a more explicit research focus.

The main partners of the full-scale consortium would be: Jämtkraft, one major conventional fuel producer, and an engineering company capable of constructing the facility. The partners of the research consortium would be more diverse and more tailored to meet the requirements in the specific call, at least for a start. The partners of the two consortia are listed in table 1 below. Partners contacted, but not part of either consortia are also listed in table 1 below. Partners not involved in the previous or the project at hand are kept anonymous.

Table 1. Partners of the two consortia formed within this project.

Participant	European region	Org. type	Consortia (Full scale, Research)
IVL Swedish Environmental Research Institute	Nordic	RTO	F, R
Jämtkraft	Nordic	Energy company	F, R
1	Nordic	Engineering company	F, R
2	Nordic	Fuel company	F, R
Power Region / Östersunds kommun	Nordic	Not for profit	F
Chalmers University	Nordic	University	R
Lund University	Nordic	University	R
Nordic Initiative for Sustainable Aviation	Nordic	Not for profit	R

3	West	Fuel company	R
4	South	RTO	R
5	South	RTO	R
6	West	Not for profit	R
7	Nordic	University	R
8	Nordic	Airport operator	R
9	Nordic	Airline	R
10	Central	Airplane company	R
11	South	Airport operator	R
12	South	Airline	R
13	East	University	R
X	West	Jet Engine company	Non
X	Nordic	Outdoor handheld machinery	Non
X	Nordic	Laboratory	Non
X	Nordic	Fuel company	Non
X	Nordic	Fuel company	Non
X	Nordic	Engineering firm	Non
X	Nordic	Engineering firm	Non
X	South	Engineering firm	Non

Each partner of the two consortia has their unique strengths, skills and fills specific rolls in the groups. The full-scale consortium was put together with the aim of getting an industrial scale plant up and running in the best way possible. The research consortium had the aim of creating a group with excellence in the areas needed to conduct ground-breaking research in the field of synthetic fuels and their incorporation into aviation. Their individual roles were:

- IVL Swedish Environmental Research Institute, has coordinated the work within this project, led the work in the previous project and the work with the application. IVL is determined to continue to have a role in both consortia, in order to facilitate the establishment of the full-scale plant, to develop the concept and technological steps through research and to be the bridge between the research and full-scale path.
- Chalmers University has been a research partner in the previous project and in the current research consortia with a focus on catalyst development for the AtJ (MeOH) synthesis pathway.
- Lund University has been a research partner in the previous project and in the current research consortia with a focus on process integration, CAPEX and OPEX. Also, a member in the research consortium on BEJF testing and air quality.
- Jämtkraft is an Energy company and a partner of this project, the previous project and the work ahead. Jämtkraft is dedicated to continue to have a role in both consortia. Jämtkraft owns the relevant CHP plant and the land for the facility to be constructed upon. Potential part-owner and operator of the BEJF facility.
- Power Region / Östersunds kommun is a partner of the ongoing project and a dedicated partner in realizing the concept at the site. Is, in a wider context, trying to attract energy-intensive industry to the region.
- Nordic Initiative for Sustainable Aviation is an NGO focused on promoting development in sustainable aviation.

4 Research proposal

Besides the establishment of international cooperation (reported above), there was also a more concrete goal about the development of collaboration plans and proposals for the Green Deal and/or upcoming Horizon Europe programs.

The research consortium described above was collated in order to establish international collaboration for the partners of this project. Explicitly however, the work revolved around the writing of an actual research proposal for the Horizon 2020 Green Deal call: Closing the industrial carbon cycle to combat climate change - Industrial feasibility of catalytic routes for sustainable alternatives to fossil resources, ID: LC-GD-3-1-2020, with application deadline 2020-01-26. Work commenced during early November 2020 and was carried out until late December when it finally was called off due to budget concerns. The call clearly requested the construction of a demonstration facility for the production of 4000 tonnes annually of synthetic fuels. The maximum amount of possible funding from the call was 40 MEUR. However, in a collaboration between LU, IVL and JK, the total cost of constructing such a facility was estimated to above 90 MEUR. The possibility to source the overshooting 50 MEUR during the course of a month was deemed highly unprobeable, and therefore the work on this specific proposal was cancelled.

The content of the proposal is summarised below:

The main objective is to demonstrate at TRL7 first of its kind advanced, modular and replicable solutions enabling the production of synthetic fuels and chemicals for use within different sectors (transport, working machines and as chemical feed stock). The solutions promote a cost-effective and technically viable decarbonisation of the current transport systems and unlock investments for the deployment of similar production facilities across the EU.

The project will focus on the production of synthetic transport fuels (electrofuels). Carbon dioxide (CO_2) will be captured from the flue gasses from a biomass (wood chips) fed combined heat and power plant (CHP). Renewable electricity (wind and hydropower) will be used to produce hydrogen (H_2) thought the electrolysis of water. CO_2 and H_2 will be catalytically converted to a hydrocarbon mixture (e-crude) which will be separated into discrete fuel fractions (e-jet, e-petrol, and e-diesel). The project will leverage the extensive knowledge acquired by the project consortium in the newly completed in-depth feasibility study *Large scale Bio-Electro-Jet fuel production integration at CHP plant in Östersund, Sweden*, where: i) the Best available technology for sub-processes and unit operations have been described and compared, ii) Integration design and total efficiency of the process for two alternative catalytic pathways (Fischer-Tropsch an modified Alcohol(methanol)-to-Jet) have been simulated, iii) CAPEX, OPEX and synthetic fuel production cost has been determined, iv) Life Cycle Assessments for synthetic fuel has been compared to other renewable options and, v) Sustainable business models have been evaluated involving stakeholders for the complete synthetic fuel value chain.

Starting from a comprehensive know-how, this project will: i) Develop, analyse and scale-up innovative recyclable catalytic material systems, ii) In detail design an integrated and modular system for synthetic fuel and chemicals production at a biomass fed CHP plant, iii) Analyse and work through the possible constraints for such a system, iv) Construct a demo facility to produce 4000 tonnes per annum of synthetic products in the form of fuels and chemicals, v) Demonstrate the complete value chain for several of those products, vi) Map the combustion pattern and emissions of those fuels, and vii) Validate their performance in Techno-economic evaluations and Life cycle assessments.

The knowledge generated in the Project will be exploited for replicability and generalization and promoted through a powerful dissemination and training strategy in order to encourage a rapid and widespread replication of the demonstrated solutions across the EU.

Even if the efforts on this particular proposal was cancelled, the ambition is still to use the network established within the scope of this project, in the form of the research consortium described above to form new project proposals and to submit those to suitable calls in the near future.

5 Financing possibilities

The concept of BEJF (or any synthetic fuel production for that matter) at Jämtkrafts Lungvik site in Östersund demands a large capital investment (CAPEX). Based on the previous report, an industrial full-scale plant with a production capacity of 80 – 100 kton electrofuel-product per year (corresponding to a 130 MW electrolyzer) would require an investment in the order of 135 MEUR. The rationale behind this estimate is described in the previous report. The electrolyzer cost assumed is taken from the lower end of the estimated interval in this case, around 500 EUR/kW. With higher electrolyzer costs, i.e.: 750 or 1000 EUR/kW, and 130 MW electrolyzer power, the corresponding CAPEX would be in the order of: 170 or 210 MEUR, respectively.

The proposed demo scale facility, which was the aim of the previously described work on a research proposal towards the EU H2020 Green deal call, was planned to have a production capacity of merely 4 kton, but with an associated CAPEX of above 90 MEUR. This number was reached in cooperation with an established engineering partner. Therefore, the establishment of a demo facility at the site is deemed unprobeable before there are an operational full-scale facility on the site. A demo plant would instead be possible as a bolt-on solution to an existing plant where only selected parts of the process could be developed and demonstrated. This solution would come at a significantly reduced cost as compared to starting with a demo before the full-scale plant is operational.

Besides the capital investment, operational costs (OPEX) for this type of facility are also substantial, and in fact higher than the CAPEX based on the energy content of the fuel produced. The reason for this is mainly the very high electricity demand for the electrolyzers. The production cost per MWh of fuel produced in a full-scale facility is split around 16% originating from CAPEX, and 84% from OPEX. The electrolyzer CAPEX is hence not a main contributor to the production cost of the product.

However, as OPEX is very dominating, this is where one of the main advantages of the Lugnvik site in Sweden comes in to play: the very low predicted price for electricity up until at least 2040. In a European context, Sweden has the lowest price for electricity. Moreover, the area where Östersund and Lugnvik are located have among the lowest electricity prices in Sweden, and this electricity is of completely renewable origin. This area has an extensive production of renewable electricity, much more that it currently can use. Given the existing constraints in electricity transmission between the northern and southern parts of Sweden, and the losses associated with long-range electricity transmission, a case can be made that it is more rational to use the electricity closer to its origin of production.

There are thus substantial costs associated with constructing the BEJF facility. To find reliable and long-lasting partners to Jämtkraft for this endeavor has been one of the main aims of the present project. However, even after compiling possible partners (see the list of consortia members above) additional funding from other sources will also be needed for the project to be realized. Therefore, a possible way forward that takes funding into account have been proposed in this project, and is presented in chapter 6 below, both for the more commercially focused full-scale facility and for a possible researched-focused demo scale facility.

5.1 Specific sources of funding

There are a number of potential ways of co-funding the realization of the facility with external economic resources. It has been the aim of this study to map such opportunities in the Swedish and European arena, but as the international interest for green investments like this one grows - novel options constantly arise, and the list below is therefore not to be considered as completely comprehensive.

5.1.1 European investment bank

(European Investment Bank, 2021)

The European Investment Bank (EIB) is jointly owned by the EU countries. It seeks to:

- boost Europe's potential in terms of jobs & growth
- support action to mitigate climate change
- promote EU policies outside the EU

The Bank borrows money on capital markets and lends it on favourable terms to projects that support EU objectives. About 90 % of loans are made within the EU. None of the money comes from the EU budget.

The EIB provides 3 main types of products and services:

- lending – about 90 % of its total financial commitment. The Bank lends to clients of all sizes to support growth and jobs, and this support often helps to attract other investors
- 'blending' - allowing clients to combine EIB financing with additional investment
- advising and technical assistance - maximizing value for money

The EIB give out loans above EUR 25 million directly. Where smaller loans are involved, it opens credit lines for financial institutions that then lend funds to creditors.

All EU countries are shareholders in the EIB. Decisions are taken by the following bodies:

- the Board of Governors, comprising ministers (mostly finance ministers) from all EU countries. It defines general lending policy.
- the Board of Directors, chaired by the EIB President, which comprises 28 members appointed by the EU countries and one appointed by the European Commission. It approves lending and borrowing operations.

- the Management Committee, the Bank's executive body, which handles day-to-day business.

The Audit Committee checks that EIB operations are conducted in a proper manner. The Bank's departments implement management decisions.

EIB makes borrowing and lending decisions, based on the merits of each project and the opportunities offered by financial markets. Within the EU, it has specific lending priorities. Outside the EU, it supports the EU development and cooperation policies worldwide. As an independent body, the Bank takes its own borrowing and lending decisions. It cooperates with other EU institutions, especially the European Commission, the European Parliament, and the Council of the EU.

If one run a business or work in the public sector and have a project that could contribute to achieving EU policy objectives, one could be eligible for an EIB loan. To apply, contact the EIB by email, web form or through its offices, providing sufficient information to enable the Bank to judge whether the project meets its lending objectives and has a well-developed business plan.

The EIB is the majority shareholder of the European Investment Fund (EIF), which provides funding to small and medium-sized enterprises (SMEs) through venture capital and risk finance instruments. Other shareholders are the European Commission and financial institutions from across Europe. Established in 1994, the Fund is active in all EU countries, prospective member countries, Liechtenstein and Norway.

EIF products include:

- venture capital and micro-financing for SMEs, particularly new and innovative companies
- guarantees for financial institutions, to cover loans to SMEs
- help for EU countries and those in the process of joining the EU to develop their risk capital markets

EIB could co-finance the complete industrial full-scale facility.

5.1.2 EU Innovation Fund

The Innovation Fund is one of the world’s largest funding programmes for the demonstration of innovative low-carbon technologies. It will provide around EUR 10 billion of support over 2020-2030 for the commercial demonstration of innovative low-carbon technologies, aiming to bring to the market industrial solutions to decarbonise Europe and support its transition to climate neutrality. The goal is to help businesses invest in clean energy and industry to boost economic growth, create local future-proof jobs and reinforce European technological leadership on a global scale.

This is done through calls for large and small-scale projects focusing on:

- innovative low-carbon technologies and processes in energy-intensive industries, including products substituting carbon-intensive ones
- carbon capture and utilisation (CCU)
- construction and operation of carbon capture and storage (CCS)

- innovative renewable energy generation
- energy storage

The Innovation Fund is funded through the EU Emissions Trading System (EU ETS), the world's largest carbon pricing system, is providing the revenues for the Innovation Fund from the auctioning of 450 million allowances from 2020 to 2030, as well as any unspent funds from the NER300 programme. As the successor of the NER300 programme, the Innovation Fund improves the risk-sharing for projects by giving more funding in a more flexible way through a simpler selection process and is also open to projects from energy-intensive industries.

For the period 2020-2030, the Fund may amount to about EUR 10 billion, depending on the carbon price. In parallel to the Innovation Fund, the EU ETS provides the main long-term incentive for these technologies to be deployed. The Innovation Fund is a key funding instrument for delivering the EU's economy-wide commitments under the Paris Agreement and its objective to be climate neutral by 2050, as recognised in the European Green Deal Investment Plan.

The Innovation Fund focuses on highly innovative technologies and big flagship projects within Europe that can bring on significant emission reductions. It is about sharing the risk with project promoters to help with the demonstration of first-of-a-kind highly innovative projects.

It aims to finance a varied project pipeline achieving an optimal balance of a wide range of innovative technologies in all eligible sectors and Member States, Norway and Iceland. At the same time, the projects need to be sufficiently mature in terms of planning, business model as well as financial and legal structure. The fund supports cross-cutting projects on innovative low-carbon solutions that lead to emission reductions in multiple sectors, for example, through industrial symbiosis.

The Fund is also open to small-scale projects with total capital costs under €7.5 million.

EU Innovation Fund could co-finance the complete industrial full-scale facility.

5.1.3 InvestEU Programme

The InvestEU Programme builds on the successful model of the Investment Plan for Europe, the Juncker Plan. It will bring together, under one roof, the European Fund for Strategic Investments and 13 EU financial instruments currently available. Triggering at least €650 billion in additional investment, the Programme aims to give an additional boost to investment, innovation and job creation in Europe.

The InvestEU Programme consist of:

- The InvestEU Fund: Mobilising public and private investment using an EU budget guarantee
- The InvestEU Advisory Hub: Providing technical advice on investment projects needing financing.
- The InvestEU Portal: An easily accessible database that matches projects with potential investors worldwide.

The InvestEU Programme benefits:

- Simplified and streamlined investment support
- Just one set of rules and procedures and one point of contact for advice. InvestEU will make EU funding simpler to access and more effective.

InvestEU 2021-2027:

- Expanding the successful Juncker Plan model
  - By using an EU budget guarantee to crowd-in other investors, the InvestEU Fund will give an added boost to investment in the EU.
- Making EU funds go further
  - The EU budget guarantee can help public funds go further. InvestEU is expected to mobilise at least €650 billion in additional investment between 2021 and 2027.
- Targeting key areas
  - The InvestEU Fund will support four main policy areas: sustainable infrastructure; research, innovation and digitisation; small and medium businesses; and social investment and skills.
- Improving the investment environment in Europe
  - Like in the Juncker Plan, InvestEU will be a part of the Commission's economic policy mix of investment, structural reforms and fiscal responsibility, to ensure Europe remains an attractive place for businesses to settle and thrive.

InvestEU Programme could co-finance the complete industrial full-scale facility.

5.1.4 The Recovery and Resilience Facility

The Recovery and Resilience Facility (the Facility) will make €672.5 billion in loans and grants available to support reforms and investments undertaken by Member States. The aim is to mitigate the economic and social impact of the coronavirus pandemic and make European economies and societies more sustainable, resilient and better prepared for the challenges and opportunities of the green and digital transitions.

By offering large-scale financial support for investment and reforms, the Facility will better prepare Member States for a sustainable recovery.

The Commission proposed the Facility on 27 May 2020 as the centerpiece of NextGenerationEU, a temporary recovery instrument that allows the Commission to raise funds to help repair the immediate economic and social damage brought about by the coronavirus pandemic. The Facility is also closely aligned with the Commission’s priorities ensuring in the long-term a sustainable and inclusive recovery that promotes the green and digital transitions. On 21 July 2020, the European Council reached a political agreement on NextGenerationEU, including the Facility, and the 2021-2027 long-term EU budget.

Member States will prepare recovery and resilience plans that set out a coherent package of reforms and public investment projects. To benefit from the support of the Facility, these reforms and investments should be implemented by 2026.

Please observe, that the Swedish government intent to use this directed EU support for plans already incorporated in the national amending budgets of 2020. There is an ongoing debate on this issue and therefore, it is not yet clear if individual projects may be able to apply for these grants or if they will be incorporated directly in the national treasury to cover previous expenditures.

The Recovery and Resilience Facility could possibly co-finance the complete industrial full-scale facility or selected parts of it, given that the funds are made available for projects like this.

5.1.5 Bio-based Industries Joint Undertaking

The Bio-based Industries Joint Undertaking (BBI JU) is a €3.7 billion Public-Private Partnership between the European Union and the Bio-based Industries Consortium (BIC). Until today, BBI JU has funded 123 bio-based innovation projects involving 924 beneficiaries from 37 EU Member States and Associated Countries.

BBI JU is a €3.7 billion initiative providing funding for projects in the bio-based industries sector for the 2014-2020 period. The two founding partners contribute to the Joint Undertaking: €975 million in funding is provided by the Horizon 2020 programme of the European Union and €2.7 billion is contributed by the private sector, represented by BIC. By 2024, each euro of BBI JU funding is expected to have attracted a private contribution of €2.8.

There will be a successor to BBI JU announced Q1-Q2 2021.

The successor to BBI JU could be a source of getting in contact with possible sources of funding for the complete full-scale facility or selected parts of it.

5.1.6 Fuel cells and hydrogen joint undertaking

The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a unique public private partnership supporting research, technological development and demonstration (RTD) activities in fuel cell and hydrogen energy technologies in Europe. Its aim is to accelerate the market introduction of these technologies, realizing their potential as an instrument in achieving a carbon-clean energy system.

Fuel cells, as an efficient conversion technology, and hydrogen, as a clean energy carrier, have a great potential to help fight carbon dioxide emissions, to reduce dependence on hydrocarbons and to contribute to economic growth. The objective of the FCH JU is to bring these benefits to Europeans through a concentrated effort from all sectors.

The three members of the FCH JU are the European Commission, fuel cell and hydrogen industries represented by Hydrogen Europe and the research community represented by Hydrogen Europe Research.

FCH JU are working to facilitate the market introduction of FCH technologies in Europe and realize their potential in a carbon-clean energy system. This is done by implementing an optimal research and innovation (R&I) programme in order to develop a portfolio of clean, efficient solutions that exploit the properties of hydrogen as an energy carrier and fuel cells as energy converters, to the point of market readiness.

Figure 1. Fuel cells and hydrogen joint undertaking objectives.

There will be a new version of FCH JU announced Q1-Q2 2021.

The successor to FCH JU could be a source of getting in contact with possible sources of funding for the complete full-scale facility or selected parts of it, namely the electrolyser.

5.1.7 EU Taxonomy Regulation

At the end of November, the European Commission published two delegated acts to the EU Taxonomy Regulation for a sustainable financial sector, adopted in May 2020. The delegated acts provide technical definitions and reference points for the sustainability levels of different sectors, in two respective target areas: combating climate change and the construction of resilience to the effects of climate change. The two delegated acts are the first two target areas that receive definitions and reference points in order to be able to be assessed on the basis of taxonomy. In total, the taxonomy comprises six target areas, of which delegated acts for the remaining four areas will be published before the end of 2021. In total, the taxonomy will include reference targets and points for the areas:

- Counteracting climate change
- The construction of resilience to the effects of climate change
- Sustainable use and protection of water and marine resources
- Conversion to circular economy
- Emission reduction and control
- Protection and restoration of biodiversity and ecosystems.

The Taxonomy Regulation aims to create an EU-wide assessment basis for sustainability and sustainability work that will be relevant by requiring all financial products (B2B as well as end-customer products) to report what proportion of their content is in line with the taxonomy rules. To achieve effect, the taxonomy interacts with several other regulations, such as the regulations on eco-design and ecolabelling, as well as the regulations on sustainability reporting in the financial sector and transparency and sustainability reporting in the non-financial sector. (ELS Analys, 2020)

Expected overall effects of the Taxonomy Regulation can be summarized as:

- The Taxonomy Regulation has been added to steer capital flows in the EU towards sustainability and thus speed up the combat on climate change. Various opinion polls have shown that the EU population tends to classify the climate as the greatest individual threat to the EU and its Member States, and the proportion of the population who consider the climate threat to be one of the most time-critical challenges affecting the individual in the coming years is often as high as within the range 60-75%. Therefore, it can be assumed that when each financial product and institution is required to report to what extent it is in line with the taxonomy's sustainability criteria, greener products and institutions will have a competitive advantage.
- Although difficult to quantify, it has been estimated that up to 50% of capital under management will live up to ESG (Environmental, Social and Governance) rules, of which taxonomy rules will be fundamental in the EU, around 2025 by PwC. According to the study, around 77% of institutional investors surveyed planned to stop buying products that were not classified according to ESG requirements as early as 2022. However, only 14% of institutional investors planned to stop issuing products without complying with ESG classification in the same year, which rather underlines the uncertainty in the reasoning. It is clear, however, that a strong shift is on the way and will have two main effects on the financial market for non-financial companies: changed assets, and pricing of capital.
- Lenders will move towards increasing the proportion of their loan stock that goes to green companies and green projects. It will increase competitiveness for borrowers who have high green values based on their CAPEX and OPEX and reduce competitiveness for companies that have a lower valuation based on the taxonomy and thus "reduce" the lender's average green value on both the loan stock and for the player as a whole. In other words, more and more money will chase green values in the market, while loans and investments in non-green companies and businesses will be considered a potential and, in a few years, probably also a real burden.
- Banks and financial institutions will increasingly have access to capital from central banks with green earmarking, which will also in the long run reduce the supply of capital for companies and businesses that are not in line with the taxonomy.
- More directly, mutual funds and PE companies will reduce and rebalance their assets in line with the taxonomy, which means that sectors and companies that can no longer move in line with the taxonomy will see more and more investors passing them by. For listed companies, this can become visible as a price discount, as they are weighted in portfolios by institutional investors. For all companies with a low taxonomy ranking, the number of investors and lenders will decrease, and a discount or premium will de facto grow on financial products aimed at them.

In context of the current concept of BEJF-production in Östersund, this means that investments for the facility will become increasingly available in the upcoming few-years, in general. And for foresighted investors, the opportunity of investing in a facility like this could already be very attractive.

5.1.8 Venture capital

One form of possible financing for the project is venture capital. Meaning that a financier, with the motivation of making profit over a certain time-period, would invest in a particular project. The time-period may differ between various venture capitalists, but profit is always their rational for investing. Therefore, a strong business case and business plan is key in attracting venture capital. In Sweden, a large number of venture capitalists exist, and it is important to find a good match between their particular line of interest and the project to be financed. Some of the largest venture capitalists include, but are not limited to the following:

- Alfvén & Didrikson
- Altor
- Atomico
- Carl Bennet AB
- Creandum
- EQT
- Fouriertransform
- Healthcap
- IK Investment Partners
- Industrifonden
- Inlandsinnovation
- KTH Chalmers Capital
- Neqst
- Nordic Capital
- Northzone
- Ratos
- Saminvest
- SEB Venture Capital
- Segulah
- Svensk Exportkredit
- Swedfund
- Triton

Venture capital is diverse and if a good match is found between the interests of the investors and a specific part of the full-scale facility, i.e. the CC-equipment, the electrolyser, or the synthesis step, this can be a good source of funding for a specific part of the facility. Venture capital may also join the proposed Joint Venture discussed below for the complete facility.

5.1.9 Climate bonds

Climate bonds (also known as green bonds) are fixed-income financial instruments (bonds) that have positive environmental and/or climate benefits. They follow the Green Bond Principles stated by the International Capital Market Association (ICMA), and they proceeds from the issuance of which are to be used for the pre-specified types of projects. They differ from sustainability bonds in that the latter also needs to have a positive social outcome, besides simply having a positive impact on the environment.

Climate bonds are issued in order to raise finance for climate change solutions: climate change mitigation or adaptation related projects or programs. These might be greenhouse gas emission reduction projects ranging from clean energy to energy efficiency, or climate change adaptation projects ranging from building Nile delta flood defenses or helping the Great Barrier Reef adapt to warming waters. Like normal bonds, climate bonds can be issued by governments, multi-national banks or corporations. The issuing entity guarantees to repay the bond over a certain period of time, plus either a fixed or variable rate of return.

Most climate bonds are asset-backed, or ringfenced, with investors being promised that all funds raised will only go to specified climate-related programs or assets, such as renewable energy plants or climate mitigation focused funding programs.

Climate bonds are theme bonds, similar in principle to a railway bond of the 19th century, the war bonds of the early 20th century or the highway bond of the 1960s. Theme bonds are designed to:

- Allow institutional capital - pension, government, insurance and sovereign wealth funds - to invest in areas seen as politically important to their stakeholders that have the same credit risk and returns profile as standards bonds.
- Provide a means for governments to direct funding to climate change mitigation. For example, this might be done by choosing to privilege qualifying bonds with preferential tax treatments.
- Send a political signal to other stakeholders.

Otherwise, for operational purposes, theme bonds largely function as conventional debt instruments. They are risk-weighted, and credit rated in the usual way based on the creditworthiness of the issuer, and tradable, market conditions permitting, in international secondary bond markets. These instruments can theoretically be issued at all levels of the fixed income market, from sovereigns to corporate.

Climate bonds can fill a similar role as venture capital for the full-scale facility. The main difference is that the bonds may require additional administration, as more small entities will be involved. On the other hand, control will not have to be distributed in the same way as with venture capital.

5.1.10 Horizon Europe

Horizon Europe (HE), is the EU's next funding programme for research and innovation, succeeding Horizon 2020, which ended in 2020 with a number of large Green Deal calls. HE will run from 2021 to 2027 with a proposed budget of €100 billion.

HE will support European partnerships with EU countries, the private sector, foundations and other stakeholders. The aim is to deliver on global challenges and industrial modernization through concerted research and innovation efforts.

HE is structured in three-pillars, as per the illustration below

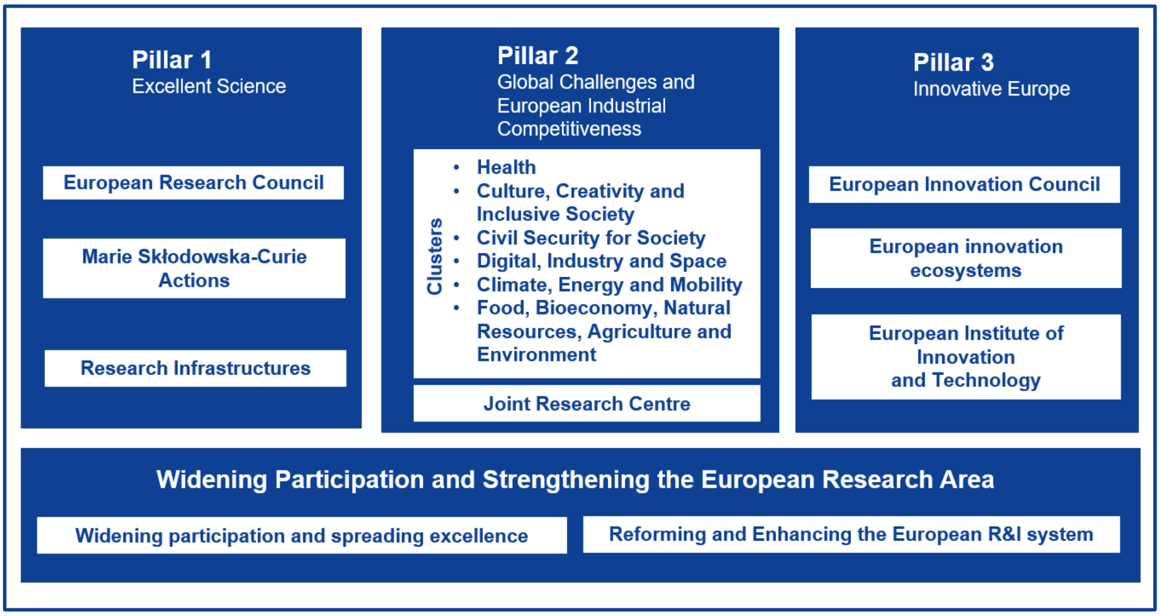

Figure 2. The three pillars of Horizon Europe

The first calls originating from HE is expected to be launched in Q1 of 2021. Through its European research network, and through the work in the consortium established within this project, IVL has gotten access to several drafts for the upcoming calls during 2021 and 2022. Many of these calls are strongly aimed at research from relatively low Technology readiness levels (TRL 3-5), but a few of the upcoming calls are also more applicable to the concept of BEFJ production in Östersund, or parts of the facility, see table 2 for details.

Table 2. Upcoming calls within Horizon Europe with bearing on the concept.

Call	Name	Open	Close	Approx budget	Comment
HORIZON-CL5-2021-D3-01-15	Cost reduction of CO_2 capture (new or improved technologies)	2021-04-15	2021-10-19	10-15 MEUR	Funds for development of CC-technologies
HORIZON-CL5-2022-D3-01-15	Decarbonising industry with CCUS	2021-10-15	2022-02-23	29 MEUR	Possibility to apply for funds for implementation of CC
HORIZON-CL5-2022-D3-03-07	Development of algal and renewable fuels of non-biological origin	2022-09-06	2023-01-10	5 MEUR	Good call for WP2 and 3 from previous proposal, lab-pilot scale. Synthetic fuels included, H2 as final product excluded.
TWIN-TRANSITION-50-2022	Hydrogen as chemical feedstock in process industries (IA)			N/A	Possibility to go deeper into the concept. A development from the recently finished project. Could be focused on optimization of F-T and development of AtJ(MeOH), could also highlight MeOH as intermediary for logistical purposes.

HORIZON-CL5-2022-D3-02-05	Renewable energy carriers from variable renewable electricity surplus and carbon emissions from energy consuming sectors	2022-05-26	2022-10-27	9 MEUR	Good call to get funding for bolt-on Demo on a presumed already existing industrial plant.
HORIZON-CL5-2022-D3-01-01	Demonstration of cost-effective advanced biofuel technologies utilizing existing industrial plants	2021-04-15	2021-08-26	15 MEUR	About re-fitting factories, possibly CHPs, to new facilities for production of advanced renewable fuels.
HORIZON-CL5-2022-D3-02-08	Demonstration of complete value chains for advanced biofuel and non-biological renewable fuel production	2022-05-26	2022-10-27	10 MEUR	Good match for WP5 from previous proposal.

5.1.11 Swedish Energy Agency

The Swedish Energy Agency (STEM) was the main financier, together with Jämtkraft and SIVL, for the previous project that investigated the feasibility of the BEJF concept at the Lungvik site from a number of aspects, as well as led up to this project. STEM has several calls on a regular basis that relates to this concept and project. Some of which are more research-oriented and some which provide specific support for the construction of facilities.

5.1.11.1 Pilot and demonstration project for energy and climate change

Projects that can take innovations from research to the market can receive support. The call is aimed at pilot and demonstration projects aimed at energy and climate change and include all areas of the Swedish Energy Agency's research and innovation. Product, service and production demonstrations can be supported. System demonstrations that include, for example, economic, infrastructural, regulatory and political conditions are also covered by the call. (Swedish Energy Agency, 2021)

The call is aimed at major pilot and demonstration projects and normally the total eligible costs for projects within this call are from SEK 5,000,000 and up. The project will mainly concern experimental development. The aid intensity can thus be a maximum of 25% of the project's eligible costs in cases where the beneficiary is a large company. Small and medium-sized enterprises can receive a supplement of 20 and 10 percentage points, respectively. A small part of the project activities can consist of research that can justify a higher level of support for these activities. Projects must be in one of the following three different categories, or a combination of these:

- Product or prototype demonstrations
- Production demonstration

- System demonstration

There would be possible to apply to this call for a bolt-on demo solution as described above. This demonstration facility would be interlinked with a full-scale facility and focus on the demonstration of research specifically within the synthesis unit operation of the plant.

5.1.11.2 The industrial leap (Industriklivet)

Sweden's Parliament has adopted the climate target that Sweden will have no net emissions of greenhouse gases into the atmosphere by 2045 and thereafter achieve negative emissions. To support the change, the government has decided on the long-term initiative Industriklivet. (Swedish Energy Agency, 2020)

Achieving the climate goals will require extensive investments in new technology that is often not commercialized. The road to net zero emissions requires investments in innovative and technology-changing solutions. Industry is playing a major role in the transition to a circular and bio-based economy. Both by reducing their own emissions and by contributing to climate change in society through their products.

Within Industriklivet, grants can be given for feasibility studies, research, pilot and demonstration projects as well as investments for:

- Measures that help reduce industry's greenhouse gas emissions. Greenhouse gas emissions from industry refer to process-related emissions according to climate reporting as well as certain combustion emissions and diffuse emissions linked to the process-related emissions. This also refers to emissions that arise from the combustion of residual products from fossil raw materials in manufacturing processes, such as flaring of industrial residual gases. Emissions from purchased fuels that are burned only to extract energy are only included in cases where a reduction in direct emissions from processes is also included in the project or when they involve a technological leap for industry. This means that conventional fuel changes are not included. The area is aimed at industries with process-related greenhouse gas emissions, primarily in the iron and steel, chemical and mineral and cement industries.
- Measures that contribute to permanent negative emissions. Permanent negative greenhouse gas emissions are achieved, for example, through the separation, transport and geological storage of greenhouse gases of biogenic origin or from the atmosphere. The area of negative emissions does not include the use of carbon dioxide of biogenic origin (CCU) or projects concerning biochar such as production and use. The area is primarily aimed at companies with biogenic emissions of greenhouse gases in, for example, the pulp and paper industry and combined heat and power plants.
- Strategically important initiatives in industry that contribute to climate change in the rest of society. Strategically important initiatives mean the application of new technology or other innovative solutions in industry that in a significant way contribute to reducing greenhouse gas emissions in society. These can be, for example, new solutions in the areas of battery production, biofuels, plastic return refineries, hydrogen or recycling plants. The area is aimed at industries that can make

a significant contribution to society's climate change by applying new technology or other innovative solutions.

Industrilivet comprises a total of approximately SEK 750 million in 2021 and can finance projects that run until and including 2028, where the annual budget is decided in connection with the budget bill. Through the Regulatory Letter for 2018, the Swedish Energy Agency was commissioned to be responsible for Industrial Life. From 2019, it will be possible within Industriklivet to contribute to measures to achieve negative emissions. For 2021, Industriklivet will be further broadened and provide the opportunity for grants for strategically important initiatives.

Industriklivet is a possible source of funding for the full-scale facility ~~of~~ for selected parts of it. Specifically, the CC-equipment or the synthesis equipment could be co-financed from this programme.

5.1.11.3 Fossil free aviation 2045

The purpose of the call is to contribute to fossil-free aviation. The investment covers all sustainable renewable fuels.

The projects will focus on the following:

- Sustainable renewable fuels for aviation
- Electric flight
- Flights with hydrogen operation

Research, development and innovation around refueling, and charging infrastructure are also included.

The project can start no earlier than 1 July 2021 and last until 31 December 2022.

There are plans to submit an application to this call. The project would enhance the possibility to go deeper into the concept. And be a development from the recently finished project. This application could be focused on optimization of F-T and development of AtJ(MeOH), could also highlight MeOH as intermediary for logistical purposes.

5.1.11.4 Other national support for PtL

In discussions within the consortia described above, the probability for a focused call for Power-to-Liquids has been brought up a number of times. There seems to be rather vague indications that such a call may be realized some time during 2021 or 2022. Although, official confirmation for this being true is currently lacking. Nevertheless, the rationale seems logic from a Swedish national perspective. PtL, and hence also BEJF, produced in Sweden from Swedish renewable raw materials is a very attractive option in terms of meeting the climate goals for hard-to-electrify transport sectors, from a security of supply point of view and from a national competitiveness standpoint. Therefore, it is deemed not unlikely that such a specified call will be announced in the future.

It is still too early to estimate exactly in which way this kind of call could benefit the project. However, the presumptive call is deemed highly interested to the research part of the concept.

6 A plan ahead

6.1 Full scale industrial facility

One of the aims of this study has been to identify a way forward where the establishment of a commercial Full-Scale plant is as independent as possible of the research path. However, off course, there will always be a strong link between the two. Nevertheless, the construction of the full-scale plant should not be dependent on if research funds are granted or not.

The main stakeholders for the full scale BEJF facility at the Lugnvik site could be Jämtkraft together with a fuel production partner. Regardless of the efforts and success at receiving possible future external funding, the stakeholders themselves will have to commit time, effort and economic resources towards the realization of the project. If the partnership is sincere, it is suggested that plans for the formation of a Joint-Venture (JV) in a separate financial entity are made as soon as possible. The formation of a JV would show the commitment of the partners and clarify the role of each partner under the roof of the JV. Moreover, financial risk would transfer away from Jämtkraft and the partner to the JV and external funding directed towards a JV focused on the realization of the plant are deemed to be administratively more manageable as well as possibly also more successful.

After the JV is formed it is suggested that a more detailed pre-study is performed. To pick up where the previous feasibility study left off in terms of the full-scale facility. This proposed project would include a determination of scale and the effects that would have, a more detailed study on CAPEX and OPEX and sensibility analysis of the two, the development of a clear and motivated business case, and the development of a business plan to lay as a foundation for attracting investors to the construction and ownership of the full-scale facility.

The next natural step is a dedicated effort to source funding for the full-scale facility. This could be in the form of loans from the European investment bank or other banks who are keen to invest in large sustainability projects or in the form of Climate bonds, in the form of grants from EU Innovation Fund, InvestEU Programme, the Swedish Energy Agency, or possibly the Recovery and Resilience Facility, in the form of cooperative investments from Venture Capital or other presumptive private partners.

After the funding of the project is secure, detailed design of the facility will have to be performed. Thereafter the construction can commence, and once finished the plant can be commissioned and begin operation.

6.2 Research path

The research path is interconnected with the full-scale facility to some extent, at least when it comes to the demonstration and piloting of technologies. As mentioned above, research can continue at the simulation and lab-scale as of now. But for a demo facility to be financially feasible it needs to be interlinked as a bolt-on part to an existing operational full-scale facility. Therefore, it is suggested that funding is sought for the former type of research projects up until funding is secured for the full-scale facility and design of that facility has begun. Thereafter, funding for a dedicated bolt-on demonstration or pilot plant can be applied for. The rationale behind this reasoning is that it will be needed to be able to prove that the infrastructure for a demonstration facility will be operational at the time the demo will be built. And the only way to prove this is through the full funding of the full-scale facility and its planned constructional timeline.

Taking the above into consideration, there is still plenty of research options available that is closely tied to the concept of this study. Below is a suggested time plan for how the full-scale facility and the research path could look like in the upcoming years and their interdependencies.

6.3 Proposed plan ahead

An outline of a plan ahead for the concept of BEJF production at the Lugnvik site in Östersund is depicted in figure 3. The plan contains a section on the full-scale facility with the aim of commercial production and based on available technologies. This section is divided in a pre-commercial and a commercial phase. The plan also contains a section on the research path with the aim of developing new technologies and solutions and is focused around bench/lab/pilot/demo-scale. This section is also divided into two phases, the first is on R&D on bench and in lab and is correlated in time with the pre-commercial phase for the full-scale plant. The second phase for the research path is more focused on demonstration and is correlated in time with the commercial phase of the full-scale plant.

The pre-commercial phase, for the full-scale plant, starts with the formation of a Joint Venture described above. Thereafter, a period of intense efforts for fund sourcing is commenced, led by the JV. In parallel to these activities the detailed pre-study described above is suggested to be performed, this study can be linked with the application for a project from STEM FFF 2045, also described above.

The commercial phase of the full-scale facility is rather straight forward in this plan and contains, in consecutive order: Plant design, Plant construction and commissioning, and finally, Plant operations. There exist several possible links to research for these different sub-phases which are described, and depicted, below.

The research path is dependent on available calls and awarded grants from those calls. It needs to be stressed that the full plan ahead cannot be dependent on such grants for its fulfillment, instead the possible research projects linked to this concept at this site should be seen as a possible additional bonus which may help in achieving additional objectives beneficial, but not detrimental, to the final overall objective.

It is suggested that an application to the STEM call Fossil free aviation 2045 is submitted at the end of March 2021. This proposed project would enhance the possibility to go deeper into the concept and be a development from the recently finished project. This application could be focused on optimization of F-T and development of AtJ(MeOH), could also highlight MeOH as intermediary for logistical purposes. It is also possible to look into the application of specific CC-technologies into this concept and how they could be optimized for this purpose. Interlinked to this proposed project is the more detailed pre-study suggested above. This call is suggested to be prioritized.

The upcoming Horizon Europe calls depicted in figure 3 below and table 2 above all have bearing on the concept and would provide valuable knowledge for the overall concept, and in some cases also funds directly applicable to the full-scale facility.

HORIZON-CL5-2022-D3-01-01, Demonstration of cost-effective advanced biofuel technologies utilizing existing industrial plants, is the first of the applicable calls to open and close. The call is about re-fitting factories, possibly CHPs, to new facilities for production of advanced renewable fuels. The match with the concept in this study is not perfect but if successful, a grant from this call could possibly be used as part-financing for the full-scale facility.

HORIZON-CL5-2021-D3-01-15, Cost reduction of CO2 capture (new or improved technologies), is a technology development call. This could be used for development of improved CC-technology which can feed into another Horizon project. There is no direct link between this call and the full-scale facility.

HORIZON-CL5-2022-D3-01-15, Decarbonizing industry with CCUS, is a better match, and also has a larger budget. Results from the above-mentioned project could possibly be fed into this project. This call provides the opportunity for projects, like the full-scale facility, to get part-funding for implementation of CC-technology. This call is suggested to be prioritized.

HORIZON-CL5-2022-D3-02-05, Renewable energy carriers from variable renewable electricity surplus and carbon emissions from energy consuming sectors. This call is suggested to be a good way to get funding for a bolt-on demo on a presumed already funded industrial plant. If this is sought and granted the demo-facility may be included already in the design phase of the full-scale facility. This call is suggested to be prioritized.

HORIZON-CL5-2022-D3-02-08, Demonstration of complete value chains for advanced biofuel and non-biological renewable fuel production, is deemed to be a very good match for the contents of WP5 from the Green deal proposal. This project, if granted, can run in parallel with the construction, commission and operation of the full-scale facility. This call is suggested to be prioritized.

Horizon Europe will announce many more additional calls during the depicted period in figure 3.

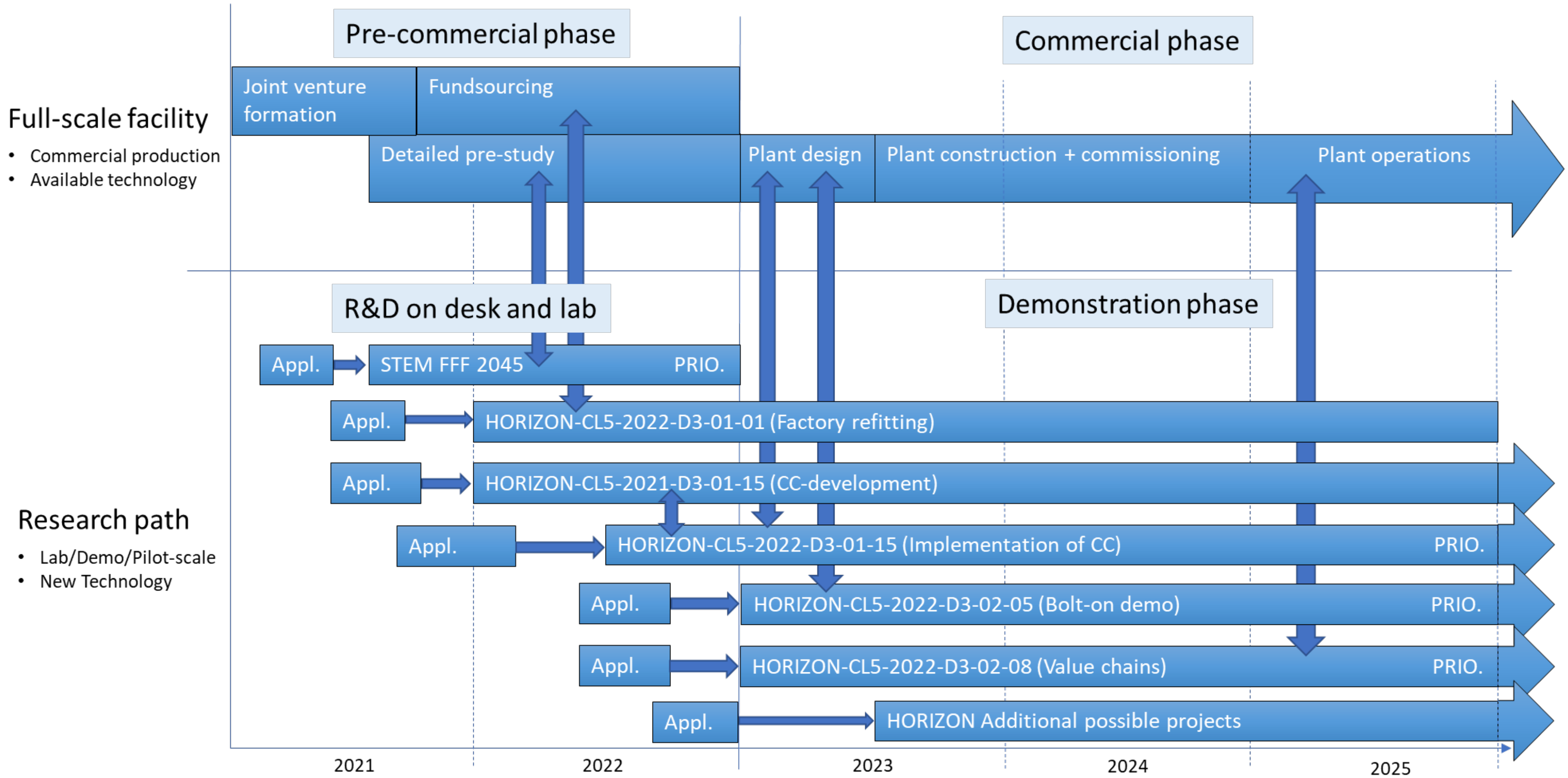

Figure 3. A plan ahead for the implementation of the concept of BEJF production at the Jämtkraft Lugnvik site in Östersund.

7 Carbon dioxide capture location

The equipment needed to capture CO_2 from the flue gas stream needs to be incorporated as close to the chimney of the CHP, and to the synthesis equipment as possible to avoid unwanted excess piping for the transport of mass and energy flows. This holds true whether the existing CHP or the new ditto are considered for integration with the BEJF production facility. There are benefits with incorporating the CC-equipment already at the design and construction phase as oppose to retrofitting an existing plant with the unit. Regardless which plant is considered, a certain area and volume will be occupied by the CC-equipment and its immediate accessories. The CC-equipment itself consists of two columns, a capture- and a stripper column, of equal height but different width due to the difference in mass flow between the two. The capture column captures the CO_2 from the flue gas into a liquid medium consisting of an amine-mixture, please see the previous report for details on this technology. The stripper column then dissolves the CO_2 from the liquid medium to create a gas stream rich in CO_2.

Based on the calculations performed in the previously reported project the flue gas molar weight is determined to be 29 kg/kmol. The flue gas mass flow is 97 000 kg/h, which corresponds to 3344 kmol/h or 74924 Nm^3/h or 20.8 Nm^3/s. A flow speed of 1 m/s corresponds to 60 % of capture column flooding. This gives a needed area of 21 m^2, which correspond to a capture column diameter of 5.2 m. The outgoing gas flow from the stripper is around 60% of the ingoing gas flow to the capture column which results in a stripper column diameter of 3.1 m. The height is set to between 6 and 7 meters. Hence, a volume of approximately 10x10x10 meters would be able to house both columns and its auxiliary equipment.

8 Development of excel tool

In the previous project, the research partner Lund University used specialised software, Aspen, to model and simulate the material and energy flows within the interconnected CHP-BEJF production facility. This was done in detail for one scale of production volumes of BEJF product. The interplays between different parts of the system are intricate, which is why a specialized software is used for these types of calculations. Downstream, including synthesis, the system scales relatively linearly within the ranges considered in this project. However, upstream there are several complicated both positive and negative feedback-loops that renders the interpolation between scales unsuitable.

One example of such a feedback-loop is the one between the carbon capture unit, the electrolyser, the district heating network and the CHP boiler. The CC unit can be designed to a certain flue gas flow and to capture a certain amount of CO_2 out of that flow, i.e. lowering the CO_2 concentration of the flue gasses and creating a CO_2 rich side stream. If one decides to increase the amount of CO_2 captured from the same amount of flue gas, this would not affect the amount of biomass burned directly. However, more H_2 would need to be produced by the electrolyser to match the increased amount of CO_2. This would, in turn, increase the amount of residual heat from the electrolyser. That heat would need to be incorporated in the DH-network which would result in a lesser need for heat from the boiler. Less heat from the boiler would mean a smaller flue gas flow. Hence a negative feedback loop. This is just one example out of many that pinpoints the complexity of the integrated system.

Due to the complexity of creating an accurate tool to be able to scale the mass and energy balances of the whole integrated system, excel is not a suitable tool. It is doable to perform this type of modelling, but it would require a larger and more focused project, specialized software and dedicated modelling specialists.

9 Relevant regulation and permits

This section summarizes the findings on regulation and permits that are of relevance for the construction and operation of the CHP-BEJF production facility. Information in relation to this topic has been collected through literature search but mostly through personal communication and interviews with relevant actors in Sweden.

The facility that needs to be established to produce the desired fuels and chemicals consists of different operation units as already mentioned above. In summary the project focuses on construction of the carbon capture unit, the hydrogen production unit (electrolyser) and the fuel synthesis unit all of which are plant to be integrated in the existing or the one under development CHP unit. These are considered for a demo but also full-scale production facility.

A natural step after compiling the relevant permits and regulations would be to conduct a detailed time plan considering prioritization, required time and relevant actors for the preparation and application process as well as waiting time until decision. This is, however, out of the scope of this project and more relevant to be performed by specialized consultants.

9.1 Permits related to construction

Every municipality plans on how land areas are divided and where appropriate sites for residential areas, manufacturing facilities or other industrial activities can be located. The corresponding municipality in this case and for the development and construction of the CHP-BEJF plant is Östersund, in the County of Jämtland.

Construction activities including the construction of new buildings is administrated by Boverket – the Swedish National Board of Housing, Building and Planning. Boverket provides the frameworks and regulations to be followed. Building permits are required for new construction, extensions or for certain types of alterations to an existing building. The related regulations to be followed are within the Planning and Building Act (2010:900) and Planning and Building Ordinance (2011:338).

In addition to Boverket, the Municipal Building committee is also responsible for construction activities. Building permit (bygglov) applications must be sent to the municipal building committee and granted before any construction work can be started (Business Sweden, 2020).

A building permit in this case may be also needed for storage tanks or other installations that may contain hazardous materials. As stated by Boverket: *"A building permit is required to set up, move or substantially alter certain fixed tanks and other fixed facilities. A building permit is required if the tank or facility is for chemical products that are hazardous to health and the environment. The same applies if it is for* *goods that can cause a fire or other accidents"* (Boverket - Bygglov för anläggningar: Fasta cistern, 2018).

An environmental impact assessment (miljökonsekvensbeskrivning, MKB) is often part of the permit application process for property developments, infrastructure and similar projects. The assessment must identify and describe the environmental impact of the project. It should also include measures taken to reduce negative environmental impact.

9.2 Regulation and permits in relation to Environmental hazardous activities and health protection

The Swedish Environmental Code was adopted in 1998 and entered into force 1 January 1999 (Miljöbalken (1998:808)). The Code contains 33 chapters comprising almost 500 sections. However, it is only the fundamental environmental rules that are included in the Environmental Code.

Chapter 9 regulates the permit and notification requirements for environmentally hazardous activities. The definition of the so called environmental hazardous activities includes use of land or buildings that entails a risk to effect human health or the environment due to discharges or emissions onto land or into water areas or groundwater.

Examination of permits for environmentally hazardous activities is handled by the County Administrative Board but is then handed over for final assessment and decision to a so-called environmental assessment delegation that is appointed within each county administrative board. The operator/applicant must send the application documents together with an attached environmental impact assessment (EIA). Prior to the establishment of an EIA, the operator/applicant is obliged to consult with the authorities and individuals who may be affected by the activities.

9.3 Regulation and permits in relation to flammable and hazardous materials

The production facility concerned in this project will produce, handle and potentially store and transfer flammable materials both in liquid and gas form. These include among others hydrogen, diesel, jet fuel and gasoline. Moreover, chemicals and other potentially hazardous materials can be used and stored. The four major regulatory schemes that are of relevance for this project are:

- The Regulation for flammable and explosive materials (2010:1011) and (SFS 2020:903) (in Swedish: Lagen om brandfarliga och explosiva varor (LBE))
- The Seveso directive
- The Work Environment Act or "Arbetsmiljölagen"
- Regulation on transport of hazardous materials (in Swedish: Lag om transport av farligt gods (2006:263).

All are briefly described below while further guidance and details can be found in the respective references given throughout the text.

Flammable materials in Sweden are listed under LBE, the Regulation for flammable and explosive materials (2010:1011) and (SFS 2020:903) and by the Swedish Civil Contingencies Agency (in Swedish: Myndigheten för samhällsskydd och beredskap (MSB)) (Myndigheten för samhällsskydd och Beredskap, Tillstånd för brandfarliga och explosiva varor, 2021).

LBE, aims to prevent and limit accidents and associated damage to life, health, environment and property that may be caused from fires or explosions of flammable materials. A definition of what is considered as flammable and explosive material is provided in MSBFS 2020:1 (*Myndigheten för samhällsskydd och beredskaps föreskrifter om vilka varor som ska anses utgöra brandfarliga eller explosiva varor*) (Myndigheten för samhällsskydd och Beredskap, 2020). LBE, defines among other things the precautionary measures that need to be taken in order to prevent accidents but also the requirements on how to import, export, manage or store and transfer such materials. According to LBE, in order to handle flammable or explosive materials a specific permit may be necessary. That permit depends on the amounts of materials that will be handled.

Permits on flammable materials are administrated by the licencing authority (tillståndsmyndigheten) at the municipality that is mostly concerned and affected although there might be cases where several authorities are involved (Myndigheten för samhällsskydd och Beredskap , 2017). In many municipalities application for permit can be done at the Rescue Service (räddningstjänsten).

The maximum levels of flammable liquids or gases that can be handled without permit requirements are shown in Table 3 as defined in chapter 2-4 §§ MSBFS 2013:3. Diesel or gasoline are considered under flammable liquids while hydrogen under flammable gases (Myndigheten för samhällsskydd och Beredskap , 2017).

Table 3 Amounts of flammable materials that can be handled without permit (Myndigheten för samhällsskydd och Beredskap , 2017).

		Volume (in litters)		
	Flammable gases	Extreme flammable or flammable aerosols[1]	Flammable liquids with maximum flash-point 60°C	Flammable liquids with flash-point more than 60°C but less than 100°C[1]
Professional public operation	Indoors:2 Outdoors: 60	100	100	10 000
Professional, non-public operation - indoors	250	500	500	10 000
Professional, non-public operation – outdoors[2]	1 000	3 000	3 000	50 000

[1]This also includes gas oils, diesel and light fuel oils with a flash point of 55–60 ° C.

[2] Outdoors also considers buried tanks and pipelines.

A special note is made on major industries where several facilities, departments or processes handle flammable goods. If they are technically independent of each other, it can be practical to share the permit. The departments and manufacturing processes are then described separately in the application, as well as different managers as assigned for the different parts. However, it is the core business that holds the permit.

During the permit application process, the licensing authority has the opportunity to investigate whether the regulatory requirements are met and whether the protection measures against fire and explosion are sufficient, before the facility is built. The decision on the acceptance of the permit can take up to three months from the time the licensing authority receives the application. More information on the application process and all associated documents that need to be delivered can be found in (Myndigheten för samhällsskydd och Beredskap , 2017).

In addition to the above-mentioned regulations specific guidelines and rules are available for industries that use significant amounts of chemicals or other potentially hazardous materials. The Seveso directive focuses on *"the prevention of major accidents which might result from certain industrial activities and with the limitation of their consequences for man and the environment"* (European Commission, 2012). It was first introduced in 1982 and concerns industrial activities that handle or store significant amounts of chemicals and other potentially hazardous materials.

The Seveso directive has been adopted and integrated in the Swedish law in SFS 2015:236 (Sveriges Riksdag, 2015) and SFS 2018:1847 (Sveriges Riksdag, Förordning om ändring i förordningen (2015:236) om åtgärder för att förebygga och begränsa följderna av allvarliga kemikalieolyckor. SFS 2018:1847, 2018). There are two classification levels which define also the level of requirements for the industrial activity. In the lower level, the respective industry would only need to report its activities to the associated authority (County Administrative Board), (Jämtlands County Administrative Board, 2021) while for the higher level, a permit as well as a safety report are necessary. In both levels, information shall be open to the public. The application process and related documentation can be found in (Myndigheten för samhällsskydd och Beredskap, Anmälan enligt Seveso, 2021) and (Jämtlands County Administrative Board, 2021) .

The levels for lower or higher requirements for selected fuels that can related to this production facility can be found in the following table. The complete list is available in the respective law SFS 2015:236 (Sveriges Riksdag, 2015).

Table 4. Levels for lower or higher requirements within the Seveso directive for selected fuels

Category /sections/ product	Demand for Lower level (ton)	Demand for Higher level (ton)
Del 1 **Section P - Physical hazards**		
P2 Flammable gases category 1 or 2	10	50
P5a flammable liquids	10	50

category 1, category 2 or 3 maintained at a temperature above its boiling point, or other liquids with flash point 60oC which is kept in temperature above its boiling point		
P5b flammable liquids of category 2 or 3 where special process conditions, such as high pressure or high temperature, can give risk of serious accident, or other liquids with flash point 60 ° C where special process conditions, such as high pressure or high temperature, may give rise to danger for serious accident.	50	200
P5c flammable liquids of category 2 or 3 that are not included in P5a or P5b	5 000	50 000
Del 2 Named dangerous substances		
34. Petroleum products and alternative fuels		
a) Gasoline and naphtha b) Kerosene (including aviation fuels) c) Gas oils (including diesel fuels, light fuel oils and mixed components for gas oils) d) Heavy fuel oils e) Alternative fuels with the same use and similar properties in question of fire and environmental hazards such as those products referred to in a – d	2 500	25 000

The investigations and discussion within this project have been focusing on the production, handling and potential storage of hydrogen. This was mainly due to the fact that less information on big scale hydrogen production is available at the moment while regulations around production and management of flammable liquids such as diesel are well known.

The demo facility aims to produce 4 000 tonnes of synthetic products annually while the full-scale plant could produce 80 000 – 100 000 tonnes. Based on the mass and energy balance calculations that were performed in the previous project that would correspond to a rough annual demand of 2 100 tonnes hydrogen for the demo plant, to 52 000-64 000 tonnes for the full scale facility . Hydrogen in this specific concept and facility will be produced via water electrolysis using easily accessible renewable electricity.

Safety aspects are crucial and need to be considered as hydrogen is an easy ignitable and extremely inflammable material. The properties of hydrogen gas are quite different from those of other gases. Being the lightest gas hydrogen can easily diffuse through materials and through time affect their properties. Hydrogen accidents are initiated by a release of hydrogen from pipes, valves or containers which are typically operated at pressures above atmospheric pressure. These accidents can vary in intensity and severity. Given that, hydrogen is also treated as flammable material and included in the aforementioned Swedish Regulation for flammable and explosive materials the by MSB.

It was discussed during the interviews that dedicated regulation on large scale hydrogen production is currently missing. While specific guidelines can be found for different types of flammable materials (both liquid and gases (e.g., natural gas)), very little information is available on large scale hydrogen production specifically. There are certain cases where hydrogen production is mentioned, at least for refuelling stations and vehicle use (Myndigheten för samhällsskydd och Beredskap, 2020). Developments however are ongoing.

Based on the above, an additional group of rules that need to be taken into consideration concern rules on work environment and health and safety of the employees. The Swedish Work Environment Authority (Arbetsmiljö Verket) publishes provisions and guidelines on how to ensure a healthy and safe working environment. The overarching rules are under the Work Environment Act or Arbetsmijlölagen SFS 1977:1160 (Sveriges Riksdag, 1977)**.** For specific information on gases for example one can refer to the AFS 1997:7 (Arbetsmiljöverket, Gaser (AFS 1997:7), föreskrifter, 1997). Morever, AFS 1999:5 concerns the implementation of the Seveso directive mentioned about in the area of health and safety at work (Arbetsmiljöverket, 1999). For the usage of pressure vessel containing gas there are specific instructions from the Swedish Work Environment Authority in (AFS 2017:3) *Use and control of pressurized devices* and in (AFS 2016:1) *Pressure-bearing devices.*

Many of the materials may be handled, transferred and stored in the production facility. However, the products and co products of the process (bioliquids for example) may need to be transferred and distributed to other locations by means of road or other transport. Such transport activities are included and administrated by the law for transport of potentially hazardous materials (Lag om transport av farligt gods in Swedish (SFS 2006:263) and SFS 2019:45 (Regeringskansliet, 2006) the associated Acts (2006:311)**.** Specific permits for the transport activities may be needed. The responsible authority for the case of road transport is MSB while several authorities can be responsible for different areas and operations (e.g. the police department and more). The regulation suggests that a safety manager needs to be appointed who has the responsibility to support and ensure that specific requirements in relation to transport of hazardous materials are met.

10 Plant and fuel certification

According to information collected through interviews with experts in fuel production, there is currently no need for certification of the production plant. However, in the proposed new law for a reduction obligation quota for jet fuel, which will enter into force 1st July 2021, the fuel supplier will need to fulfil the requirements of the Sustainability Act. Suppliers of jet fuel will need to apply for a sustainability notice (in Swedish: Hållbarhetsbesked) in accordance with the Sustainability Act (2010: 598) on sustainability criteria for biofuels and liquids biofuels. In addition, the plants that produce the fuel may need a plant notice (in Swedish: Anläggningsbesked). Both a sustainability notice and a plant notice are needed to be able to deduct energy and carbon dioxide tax for biofuels. Both these notices are applied for at the Swedish Energy Agency. However, the plant notice does not necessarily apply to a specific facility. For a fuel supplier who purchases biofuels from several different plants, the plant notice can cover all these suppliers.

In addition, the fuel production pathway needs to be certified and quality certificates are requested for each produced batch of fuel. These certifications are described in the following sub chapters.

10.1 Certification of the fuel production pathway

New jet fuels must be certified according to the standard ASTM D7566 in order to be used within aviation. The organisation ASTM International (American Society for Testing Materials) has developed this standard, specifying technical requirement for the fuel when it is mixed with petroleum-based fuel. The specification dictates heating value, fuel density, freezing point, fluidity, aromatic content and thermal stability. Seven renewable jet fuels have been produced and certified according to the standard, see Table 5.

Table 5 Drop-in alternative jet fuels that have gone through the D4054 process and are qualified for commercial use (Commercial Aviation Alternative Fuels Initiative, 2021)

Production pathway	Maximum blending level	Feedstock
Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)	50%	Lipids that come from plant and animal fats, oils, and greases.
Fischer-Tropsch kerosene with aromatics (F-T - SPK/A)	50%	Biomass
Fischer-Tropsch kerosene without aromatics (F-T - SPK)	50%	Biomass
Hydro-processing of Fermented sugars – Synthetic Iso-Paraffinic kerosene (HFS-SIP)	10%	Sugars
Alcohol-to-jet Synthetic Paraffinic Kerosene (ATJ-SPK)	50%	Ethanol and isobutanol, from fermentation of starches/sugars or biochemical conversion of other forms of hydrogen and carbon.
Catalytic Hydrothermolysis Synthesized Kerosene (CH-SK, or CHJ)	50%	Lipids that come from plant and animal fats, oils and greases.

Hydroprocessed Hydrocarbons, Esters and Fatty Acids Synthetic Paraffinic Kerosene (HHC-SPK or HC-HEFA-SPK)	10%	Bio-derived hydrocarbons, at present only tri-terpenes produced by the *Botryococcus braunii* species of algae.

In addition, co-processing up to 5% by volume of renewable content in petroleum refineries has been approved. This includes:

- Lipids (plant oils and animal fats)
- Fischer-Tropsch Biocrude (unrefined hydrocarbon content coming from an F-T reactor)

Furthermore, there are several pathways in the testing process.

Important for the case of Östersund is that Fischer-Tropsch is a certified process. Lately, the maximum blending level has been increased from 30% to 50%. This improves the opportunities for F-T-fuels.

Also, the co-processing pathway may be important for the Östersund case. It opens the alternative to deliver F-T biocrude to a refinery instead of upgrading it to final product.

However, the alcohol-to-jet kerosene production pathway is only certified for certain alcohols as raw material, such as iso-butanol and ethanol. In the case of Östersund, the alcohol-to-jet kerosene would be produced from methanol, which is not a certified raw material. In order to obtain certificate, a process which takes between two and five years needs to be carried out. There are three phases in the process: Initial Screening, Follow-on Testing and Balloting and Approval.

The Initial Screening includes sending a minor amount of the fuel for screening by ASTM International. About 40 litre fuel is required for the first tests. This costs about 5,000 USD. The purpose of the screening is to prove that is technically possible to obtain the right length of the carbon chains with the new production pathway. Testing results are compiled into a Phase 1 Research Report and submitted to participating Original Equipment Manufacturers (OEMs) for review. OEM review is necessary to determine if the proposed Sustainable Aviation Fuel (SAF) is fit for purpose for use on aircraft and engines, and to identify the Phase 2 testing requirements (Commercial Aviation Alternative Fuels Initiative, 2021).

For Tier 2 testing, between 40 and 400 litres fuel are required. For Tier 3, between 1000 and 40,000 litres are required, and for Tier 4 up to 850,000 litres fuel.

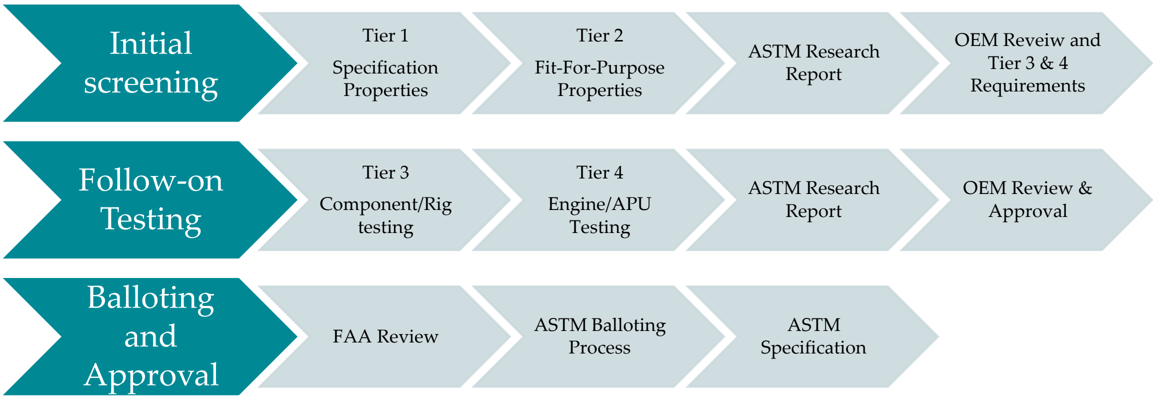

Figure 4. ASTM D4054 Evaluation process (Commercial Aviation Alternative Fuels Initiative, 2021)

10.2 Quality certification

In addition to certification of the fuel production pathway, there are guidance documents with recommended practices to ensure the quality of the jet fuel as it moves along the supply chain. Each produced batch of fuel needs a Certification of Quality (CQ). The CQ needs to follow the batch from producer to end-user. For a minor fuel producer, it is most suitable to send fuel batch samples for external analysis. The cost for a CQ analysis is about 25,000 SEK.

The CQ is required for all fuels, not only jet fuel. The gasoline and diesel fractions will require CQs as well.

11 Market opportunities for by products

In addition to jet-fuel, several by products will be generated during the fuel distillation step but also during electrolysis. The main by products will be gasoline and diesel, but some amounts of waxes, hydrogen, oxygen and CO_2 will be generated as well. In this section the market opportunities for these by products are described. Information has been collected mostly from personal communication with relevant stakeholders in Sweden.

The different by products that are generated at the distillation stage can be sold directly to end costumers (e.g., through fuel distributors) or as intermediate products to a refinery for example. Both options have advantages and disadvantages. Selling a ready to use and certified product may increase profits but requires significant administrative work as well as additional process and testing steps. Selling an intermediate product, although at lower price it may broaden the scope of potential buyers thus increase market opportunities.

Gasoline is a mix of between 5 to 12 components and it has to fulfil the standard for motor fuels (EN228). Hence it is complicated to produce the right mix to fulfil the requirements of the standard. The most viable alternative in this case is to focus on selling the electro-gasoline as a good mixing component to a refinery.

Renewable diesel that is produced via F-T synthesis is generally considered a product of very good quality and of significant benefits in relation to its fossil or even biogenic counterparts (e.g. FAME fuels). It has low aromatic compounds, high cetane number and almost zero sulfur content. It is generally considered a compound that can be easily used or mixed with fossil diesel. However, quality would still need to be investigated as well as the ability to fulfill the diesel market standards.

Due to the reduction obligation quota for both gasoline and diesel, several refineries in Sweden could be interested in buying renewable gasoline or diesel as intermediate components.

During water electrolysis (where the hydrogen needed during the fuel synthesis step is produced) a significant amount of oxygen is also obtained. There are examples around Sweden that heavy industries such as steel manufacturing have shown interest in using excess oxygen from electrolysis in their own processes (e.g. in blast furnaces or electric arc furnaces). However, such an industry is not located in the proximity of the BJET facility. Other alternatives where the excess oxygen could be use, is for medical purposes in the local hospital, at the dairy factory in the area, or other small local industries.

11.1 Quality requirements for by products

Depending on the by product and end use target there are certain quality aspects that need to be considered and potentially fulfilled. Tests on the different fuel fractions (bio jet, renewable gasoline or diesel for example) are performed at dedicated laboratories in order to investigate their quality against a specific standard or quality specification.

During our interview with a representative from such laboratory, it was mentioned that tests are performed according to the end use and end use specifications. For example, quality requirements from the use of renewable diesel in machines may differ from the quality requirements of ICE motors.

12 Technology transfer

The potential for jet fuel production in Östersund, can only cover a minor share of the Swedish demand for jet fuel. However, the technologies have potential to be used at several locations both in Sweden and other countries, as long as they meet certain requirements.

In order to obtain good environmental performance and a low fuel production cost, some specific prerequisites are required. These requirements will narrow down the possibilities of technology transfer (tech transfer) to locations which fulfil them. The most important prerequisites are: all feedstock sources are available at the site, electricity and CO_2 has 100% non-fossil origin, and not the least that heat integration is possible to a high extent, e.g. as in the case of Östersund where excess heat from the fuel production processes can be used for district heating.

In Sweden, these prerequisites can be found at several locations. As presented in Hanson et al, 2017, most of the high concentrated biogenic CO_2 sources, e.g. from biogas upgrading, are found in the southern, most populated, parts of Sweden (Hansson, Hackl, Taljegard, Brynolf, & Grahn, 2017). However, the greatest sources are the pulp and paper industries and biomass CHP plants. The CO_2 streams are less concentrated, but still possible to use. Due to large scale hydro power, the electricity price is found in northern Sweden. Combined with the vast expansion of wind power in northern Sweden, the most advantageous sites for electro-fuel production should be found in there too. Especially at locations close to cities with district heating networks are preferable, since the excess heat from the fuel production could be used for district heating. To summarise, northern cities with district heating, a close-by pulp and paper mill and/or a biomass CHP plant should be the most advantageous locations.

Looking outside Sweden, there are several locations with good prerequisites for the technology. The most apparent locations are close to cities with district heating, located in regions with high share of wind power and/or hydropower. However, a biogenic CO_2 source is required as well, which may narrow down the opportunities. In many EU countries, apart from Sweden and Finland, the use of biomass for energy purposes and/or pulp mills is less common. In Germany, France, Italy, Spain, Romania, Poland, Austria and Latvia it is somewhat more common (Eurostat, 2021). Of these, there are some countries with large expansion of district heating networks, e.g. Poland, Romania, Germany, France and Latvia. Out of these, especially Germany has a high amount of installed wind power, but also France and Poland have significant amounts (WindEurope, 2021). By combining maps of locations of district heating networks, locations of wind power and biomass use in these three countries, a first list of interesting sites for bio-electro-jet production may be obtained.

13 Optimization model

During late autumn 2020, IVL was contacted by a master student at KTH, who wanted to discuss possible options for her thesis work. The work is performed at KTH by the student Jenny Trinh, and co-supervised by Julia Hansson and Anton Fagerström at IVL. The full report of the thesis will become available during Q2 2021. Below is a description of the content of the work.

13.1 Research objective and questions

The objective of the thesis is to investigate the different pathways with alternative fuels for the aviation industry. The thesis aims to investigate and compare the different pathways based on factors such as availability, economic feasibility and GHG-emissions as well as the ability to meet Sweden and EU’s set climate targets. The investigation also includes building an understanding of potential barriers and possibilities for supply and demand of alternative aviation fuel options. Furthermore, the objective is to investigate how different policies could affect the integration of and the economic perspective of alternative fuel options and help make them competitive against fossil jet fuel.

The following research questions will be explored and answered:

1. Which is the optimal alternative jet fuel option to help reduce the GHG-emissions from the aviation industry?
2. How can policy instruments help the integration of alternative jet fuels and make them economically feasible?

13.2 Methodology and limitations

A literature review will be conducted in order to obtain an understanding of the current situation of renewable energy in the aviation industry. Based on the literature study, the alternative fuel options and technologies that are most promising in terms of technical maturity and availability will be chosen and compared in the thesis. The scope of the thesis will be limited to studying domestic aviation in Sweden. A geographical boundary will be set on the supply chain of the alternative aviation fuels, which will be limited to Sweden as well. The investigation on the supply chain will be exploring the resources, production and transport of the fuels to make the chosen options comparable. As for the biomass-based fuels the type of feedstock used will be limited to those currently used or available in Sweden for biofuel production, as well as limited to the process methods that are certified for aviation jet fuel by ASTM.

A mixed-integer linear programming optimisation model will be created in Python, in order to optimise the identified options based on factors such as emissions, availability and economic feasibility. The optimisation will be made in combination with a scenario analysis to investigate different pathways in which alternative fuel options and technologies could be made feasible for implementation in the aviation industry. The scenario analysis will include a business-as-usual scenario with the current jet fuel demand from Swedish airports, in which conventional jet fuel will help meet demand if the production of alternative jet fuel is insufficient. Furthermore, different policy options (i.e. aviation tax, blending mandate, emissions trading etc.) will be explored in the scenario analysis to investigate their effect on the integration of different alternative jet fuel options. The emission targets that will be included in the study are limited to the targets set by Sweden and EU. The literature review on policy frameworks will therefore focus on Sweden and EU.

13.3 Technology choice

From the literature study six technology options were chosen for comparison in this thesis. For the biomass-based fuels the selection was limited to the process pathways that had been approved by the standard ASTM D7566 Drop-In Fuel Specification, following which factors such as their technical maturity and feedstock used in the process, were evaluated. An investigation was also conducted on which alternatives the aviation industry considers to be of interest as well as which options were considered to have potential to meet jet fuel demands in both short and long-term. Based on these factors, the following technologies were chosen:

- Hydroprocessed Esters and Fatty Acids (HEFA)
- Fischer-Tropsch (F-T)
- Hydrothermal liquefaction (HTL)
- Electrofuels
- Hydrogen propulsion technology

14 Other inflows

In addition to the CO_2 that could be captured from the CHP plants, existing and planned, in Östersund, there are other renewable CO_2 sources in the region that could be of interest to use as inflow to the bio-electro-fuel production. These are of interest to investigate since they could help to even out the variation around the year in CO_2 captured from the CHP plants. There are higher volumes in winter and lower in summer. Thereby, a continuous fuel production can be obtained throughout the year.

Currently, the municipality of Östersund has one biogas plant, at the wastewater treatment plant. The biogas is upgraded by scrubbing, which means that the biomethane is separated from the carbon dioxide. The carbon dioxide stream is relatively clean but contains steam which needs to be removed if the CO_2 should be possible to transport and use elsewhere. Approximately 6 GWh biomethane is produced, corresponding to 900,000 Nm^3 gas. The gas contains about 60% biomethane and 40% CO_2. However, not all the gas is upgraded since part of it is used internally for heat and electricity generation and a small part is flared. In year 2019, 447,000 Nm^3 upgraded biogas was produced (SCB, 2021).

Except the biogas production at the wastewater treatment plant, there are plans for a food waste digestion plant in Östersund. According to the plans, 17 GWh biomethane would be produced from year 2025, which correspond to 1,7 million Nm^3 gas. With the upgrading technology that is suggested for the new plant, the CO_2 stream will be very clean. Also, the plant is planned to be built close to the site that is suggested for location of the bio-electro-jet production. Due to the small distance, about five kilometers, a gas pipe would be possible to connect the plants.

One option for the biogas, is to transform it to hydrogen with help from electricity. Particularly, this is interesting if it shows to be difficult to sell the biogas as fuel, due to low demand or high competition. The methane to hydrogen transformation is an efficient process which demand much less electricity compared to an electrolyzer. In addition, more CO_2 will be obtained. To summarise, the potential from the existing and planned biogas plants in Östersund could contribute by approximately 2,000 tonnes CO_2 per year, which can be related to the monthly production of CO_2 from the existing CHP plant which is 5,000 tonnes/month in the summer and 37,000 tonnes/month in the winter. Producing hydrogen from the biogas could contribute by approximately 17 GWh H_2, or 0.6 tonnes per year. This can be related to the total hydrogen production in the full-scale plant which is between 52,000 to 65,000 tonnes/year. Hence, the biogas can contribute with only a very minor part.

In addition to the biogenic CO_2 sources in the Östersund region, it may be considered to use CO_2 from more remote sources. One alternative could be to access CO_2 produced in other CHP plants with carbon capture. For example, according to the discussions that were initiated in the earlier study, Stockholm Exergi is positive to reusing the captured CO_2 from their pilot facility. This facility can produce from around 700 kg up to 2 tons CO_2 daily. If larger quantities are needed, CO_2 can also be accessed from their other production sites, such as Brista which has, at the lowest production, 20,000 ton/month. Stockholm Exergi's total CO_2 production is, calculated at the minimal production, 100,000 ton/month (if requested, but can also be zero). At maximal capacity, the biogenic CO_2 production reaches 166,667 ton/month.

15 Conclusions

The present study was performed with the ambition to clarify some of the findings from the previous project *Large scale Bio-Electro-Jet fuel production integration at CHP plant in Östersund, Sweden* and also to address the possible hurdles and possibilities that exists for the implementation of the concept of an industrial BEJF production facility at the Lugnvik site in Östersund, Sweden.

The study reports on the establishment of international consortia for both continued research and the realization of the full-scale facility. Hence, two parallel paths are described (research and full-scale) and a roadmap depicting the possible ways forward for those paths during the upcoming 5 years is suggested and motivated.

Many possible financing options (public national, private, EU-funding) are described for the two parallel, but interlinked, paths of full-scale industrial production, and research and development, including the identification of relevant upcoming calls within Horizon Europe. One important conclusion is that funding should be sourced separate for the two paths to prevent the implementation of the full-scale plant being dependent on research funding. However, the research path has great potential to provide valuable, knowledge also for the full-scale case.

One clarification from the previous study is the location and size of the carbon capture unit which has been addressed and determined. Another one is the development of an optimization tool for size and scale which has been discussed and, unfortunately dismissed due to complexity. Regarding possible hurdles and possibilities, relevant regulations and permits linked to the construction and the operation of the plant has been described and discussed, and the certification for the operation and products as well as the quality concerns of those have been clarified.

Finally, market opportunities for by-products and the related quality requirements have been mapped, as well as other possible relevant inflows to the plant. The possibility of technology-transfer of the concept to another site is discussed and the work within a Master thesis for the optimization of policies related to sustainable aviation fuels have been connected to the scope of this study.

As a general next step, it is proposed that the roadmap developed within this project is followed for the upcoming five years. As more specific next steps, the formation of a Joint Venture is suggested, and a follow up project in the form of a detailed pre-study is proposed that would enhance the possibility to go deeper into the concept. This project would both be a continuation of the recently finished project in terms of technical development and pick up where the previous feasibility study left off in terms of the full-scale facility. It is suggested that this is performed as a joint project between the stakeholders from the previously finished project and that an application is submitted to the Swedish Energy Agency for such a project during spring of 2021. Such an application could include subjects such as: i) Optimization of F-T, ii) Development of AtJ(MeOH), iii) Highlight MeOH as intermediary and/or final product for logistical and/or technical purposes, iv) Look into the application of specific CC-technologies into this concept and how they could be optimized for this purpose, v) BEJF-production integration with CHP and DH, effectiveness of integration at various scales and loads, vi) Determination of scale and the effects that would have, vii) A more detailed study on CAPEX (based on inquiries) and OPEX and sensibility analysis of the two, viii) A more detailed LCA for the determined scale and options for end-products, ix) Development of a clear and motivated business case, x) Development of a business plan to lay as a foundation for attracting investors to the construction and ownership of the full-scale facility, and xi) Communication activities.

Overall, the results produced within this project highlights the good feasibility of the concept addressed herein and proposes a concrete plan ahead towards its full-scale implementation.

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