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Documentation of Study Tours

WP4: Industry Platform - Market uptake

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1 Introduction

The project partners organized several Study Tours as a part of BIOFIT Task 4.5 "Study tours for industry representatives to best practice examples". The objective of Task 4.5 and this deliverable is to collect and share experiences of retrofitting in different plants and industries, collected during the Study Tours. Study Tours included a wide variety of activities. In addition to visits to best practice examples, also different industry workshops and lab visits are documented in this deliverable. Most of the activities took place in conjunction with BIOFIT Progress meetings. Industrial stakeholders presented their solutions and were invited to participate workshops. The documented Study Tours and activities cover all the industry sectors addressed in BIOFIT project, namely first-generation biofuels (Biocarburantes de Castilla y León), pulp and paper (Äänekoski Bioproduct mill, Mörrum pulp mill, AustroCel Hallein), fossil refineries (Thessaloniki Refinery of HELPE), fossil firing power (Twence power plant, Drax power station), and combined heat and power (CHP) (Keljonlahti CHP plant).

Part of the activities were organized as virtual events due to prevailing Covid-19 pandemic. However, considerable space for industry to present their solutions and views was still ensured.

2 List of Study Tours

Table 1. List of Study Tours and related activities in BIOFIT project.

	Date	Name of the Study Tour	Occasion	# attendees
1.	31.10.2018	Excursion to Twence	BIOFIT Kick-off Meeting in Hengelo	21
2.	12.3.2019	Lab Tour to VTT's experimental facilities	BIOFIT 2nd Progress Meeting in Jyväskylä	19
3.	13.3.2019	Study Tour to Keljonlahti Power Plant	BIOFIT 2nd Progress Meeting in Jyväskylä	19
4.	13.3.2019	Seminar for fossil firing power and CHP	BIOFIT 2nd Progress Meeting in Jyväskylä	23
5.	14.3.2019	Study Tour to Äänekoski Bioproduct mill	BIOFIT 2nd Progress Meeting in Jyväskylä	20
6.	18.9.2019	Visit to Drax Power Station, Yorkshire	Bioenergy Europe	17 (2 from BIOFIT)
7.	24.9.2019	Tour of the CERTH facilities	BIOFIT 3rd Progress Meeting in Thessaloniki	24

8.	25.9.2019	Study Tour to the Thessaloniki refinery of HELPE	BIOFIT 3rd Progress Meeting in Thessaloniki	24
9.	25.9.2019	Industry Workshop with invited speakers from Greek industries/equipment manufacturers	BIOFIT 3rd Progress Meeting in Thessaloniki	29
10.	26.9.2019	Study visit at lignite mines restoration areas and overview of Ptolemaida V construction site	BIOFIT 3rd Progress Meeting in Thessaloniki	17
11.	26.9.2019	Study visit at Agios Dimitrios lignite-fired power plant	BIOFIT 3rd Progress Meeting in Thessaloniki	16
12.	4.3.2019	Study Tour to Södra Cell Mörrum pulp mill	BIOFIT 4th Progress Meeting in Karlshamn	19 + 2 from Södra Cell
13.	4.3.2019	Biomethanol production plant at Södra Cell Mönsterås pulp mill	BIOFIT 4th Progress Meeting in Karlshamn	19 + 2 from Södra Cell
14.	5.3.2019	Bioenergy retrofits in the Nordics for oil and gas boilers - Company presentation	BIOFIT 4th Progress Meeting in Karlshamn	19 + company representatives
15.	5.3.2019	Biogas production at Stora Enso Pulp and Paper Mill in Nymölla — Company presentation	BIOFIT 4th Progress Meeting in Karlshamn	19 + company representatives
16.	23.9.2020	Virtual Study Tour to Biocarburantes de Castilla y León (BCyL)	BIOFIT 5th Progress Meeting, virtual	26
17.	23.9.2020	Company presentations from the biofuels industry	BIOFIT 5th Progress Meeting, virtual	26
18.	23.9.2020	Workshop for biofuels sector - Recommendations for policy makers	BIOFIT 5th Progress Meeting, virtual	26
19.	24.3.2021	Presentations on “How to decarbonise refinery products” and Round-table on recommendations	BIOFIT 6th Progress Meeting, virtual	28

		to policy makers for the refinery sector in Europe		
20.	20.10.2021	Presentation: Retrofit of the AustroCel P&P plant	BIOFIT 7^{th} Progress Meeting, virtual	26

3 Excursion to Twence, 31.10.2018

A Study Tour to the Twence retrofitted biomass power plant and waste incineration plant in Hengelo, the Netherlands was organized during the BIOFIT Kick-off meeting on 31 October 2018. During the Study Tour, the project group with 21 people received a presentation of the Twence retrofit project BEC 2.0, in which BEC refers to Biomassa Elektriciteits Centrale. The BEC 2.0 objectives included optimum processing of the waste streams, and synergies between the two plants. The project was awarded with CEWEP innovation award due to reuse of CO_2 to produce sodium bicarbonate ($NaHCO_3$) that is used in the waste-to-energy plant for the cleaning of flue gases. The system is estimated to reduce CO_2 emissions by 3,000 tons per year.

Figure 1. BIOFIT partners arriving at Twence site.

In BEC project, the objective was to convert the electricity-only bioenergy plant to a combined heat and power plant. Today, after the retrofit the biomass power plant produces 73 MW heat and 20 MW electricity. The plant is fed with Dutch waste wood, called B-wood, which may contain small amounts of plastics. In the BEC project, a new turbine with controlled steam extraction for the heat supply was installed. The building, piping and other facilities were renovated to allow for the recovery of useable heat. The capacity of boiler was increased by 12%; this was mainly due to a new combustion control system. The air management in the furnace was improved. The air feed from the nozzles was modelled with CFD to find the optimal configuration. The air feed adjustment aimed also for an emission reduction since the plant had a serious CO emission problem. With the air adjustment, the CO emissions decreased by 50% and NO emissions by 15%. Concrete elements of the furnace and evaporator/membrane walls were replaced. In the retrofit, heat from the exhaust gas is captured and used to increase the heat supply further. Heat increase of 3 MW_{th} was obtained. The project also included new dashers, chutes, and crunchers for “bears” (deposits that fall down from the heat pipes). The cooling towers were relocated. New frequency inverters (VSD) and MCC were installed. The wood transportation system was revised and cyclone materials replaced.

Figure 2. Twence is in the scope of the BIOFIT project due to its BEC project.

The waste incineration plant handles yearly 1.0 million tons waste from 14 municipalities. Shareholders produce 25% of the waste and the rest is imported. The imported waste is mainly household waste from England. China’s decision to prohibit the plastics import in 2018 has not affected to waste quality.

At the site, there are also digesters that produce gas and heat. Gas is used for producing more electricity but it could also be fed to the grid. The Twence site will also be developed in the future by improving the plant efficiencies and including manure-based production and bioconversion. The entire site contributes to 344,000 tons of CO_2 reduction yearly and 187 million m^3 of CH_4 is produced. More investments related to biomass power plant are not needed or planned in the near future. Besides retrofitting, a new plant would have been a possibility, but it was seen as too expensive and time-consuming to build. The retrofit was completed in just seven weeks.

4 Study Tour to Keljonlahti Power Plant, 13.3.2019

Keljonlahti Power Plant in Jyväskylä, Finland is a combined heat and power (CHP) plant established in 2010. It produces electricity to leading power market in Europe (Nord Pool) and district heating to the City of Jyväskylä. Keljonlahti Power Plant is a typical large-scale CHP plant in Finland and in Nordic Countries. It produces ca. 250 MW_{th} district heat and ca. 210 MW_e electricity utilizing milled peat and energy wood. Peat improves the combustion, prevents corrosion and fouling, and balances the quality variation of wood. Both fuels are provincial energy resources and effect positively to regional economy. Keljonlahti Power Plant utilizes circulating fluidized bed combustion technology provided by Foster Wheeler Energy. The share of biomass has been step-by-step increased in energy production. Its effects have carefully been monitored.

Figure 3. Keljonlahti Power Plant on 13 March 2019.

BIOFIT project partners (17) and industrial advisory board members (2) were invited to see the fuel yard with fuel unloading, silos and fuel feeding equipment, and boiler and the turbine.

The sister plant (Rauhanlahti) commissioned in 1986 was originally designed for pulverized peat combustion, but retrofitted in 1993 to bubbling fluidized bed boiler in order to increase the biomass share in the energy production. It is included into BIOFIT Industry Map[1], but since the plant was not running during the BIOFIT 2nd Project Meeting, the Study Tour was redirected to Keljonlahti. The main motivation to retrofit at Rauhanlahti power plant were high maintenance costs of fuel system, continuous heavy oil support to stabilize the combustion process, high emissions, numerous dust explosions within peat milling system, willingness to diversify energy source to wood based biomass and agro biomass, and to increase the boiler output by 10%.

[1] www.biofit-h2020.eu/biofit-industry-map

Figure 4. Coal is used only if the peat and wood conveyors do not work.

4.1 Seminar for fossil firing power and CHP, 13.3.2019

After the Study Tour to Keljonlahti CHP plant, a seminar "Retrofit for fossil power and CHP, industry examples" was organized at VTT to facilitate the discussion on motivations, experiences and perceptions in retrofit projects. In the seminar, barriers related to Nordic heat and power production was raised by Jyväskylä Energy Group, and technology providers for energy production, Valmet[2] and Sumitomo SHI FW[3], gave valuable insights in retrofitting projects they have been involved in. Altogether, 23 participants attended the seminar, of which 7 participants were from industry.

Case examples from technology providers Valmet and Sumitomo displayed the technical options for CHP and fossil-firing power retrofits, which was especially beneficial for preparing the BIOFIT Handbook[4]. They highlighted the benefits and challenges of retrofitting CHP and fossil firing power. According to Valmet, benefits in retrofitting include:

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[2] www.valmet.com

[3] www.shi-fw.com

[4] www.biofit-h2020.eu/publications-reports/BioFitHandbook-2020-03-18.pdf

- 50-70% lower investment cost compared to new plant and possibility to utilize existing equipment,
- shorter project schedule (typically one year to commissioning),
- simpler permit process and faster project start, and
- familiar boiler to operators meaning less training required and less operation errors.

However, Valmet points out that there are many challenges related to retrofitting such as:

- fuel limitations of the original boiler (related to corrosion, fouling and emissions),
- reduced efficiency due to possibly higher flue gas exit temperature,
- limitations in boiler dimensions, layout and space,
- decrease in boiler capacity due to biomass, and
- no possibility to optimize the power plant process since fuels steam pressure and temperature will be the same as in the original boiler

4.2 Lab Tour to VTT's experimental facilities, 12.3.2019

BIOFIT project group (17 project members + 2 guides from VTT) visited VTT's experimental facilities: Pilot-scale test units for fluidized bed and grate firing and Foam forming platform for development of next generation fibre products.

The increasing need for utilization of renewable fuels to decrease CO_2 emissions leads exploiting more and more challenging fuels such as biomass, waste, low-grade coals, and industrial residues in CHP plants and fossil firing plants. VTT's pilot-scale combustion characterization test unit gives valuable information of fuel or fuel mixture combustion characteristics, all of which are critical parameters for boiler design. VTT's pilot test unit prevents the commercial scale boilers from surprises related to heat transfer, emissions and ash behavior, when changing to more challenging fuels.

VTT's Foam forming platform demonstrates the use of advanced bio-based raw materials in the products of pulp and paper industry.

5 Study Tour to Äänekoski Bioproduct Mill, 14.3.2019

Metsä Group's Bioproduct mill in Äänekoski, Finland is the largest wood-processing plant in the Northern Europe. It was constructed in the area of the previous Metsä Fibre's pulp mill.

Since the beginning of its operation in 2017, it has been called a bioproduct mill due to the wide portfolio with new products including bioenergy.

Figure 5. BIOFIT project members at Metsä Fibre's Pro Nemus visitor centre.

Metsä Fibre's Joutseno pulp mill is one of the BIOFIT best practice examples[5] due to replacing natural gas supply to the limekiln with renewable gas produced with gasification technology from residue feedstock. The Äänekoski Bioproduct mill utilizes the same gasification technology, although it has been used from the beginning of the operation. The Bioproduct mill was chosen as the Study Tour destination instead of Joutseno mill due to more central location and, since the mill exploits the latest technologies for bioenergy production at pulp and paper mill in larger extend and has larger bioproduct selection compared to Joutseno Mill.

The Study Tour at the Bioproduct Mill included general presentation of the site, cross-section to mills operations, products and opportunities at Pro Nemus visitor centre[6], presentation of

[5] www.biofit-h2020.eu/files/pdfs/190318%20-%20Biofit%20-%20Factsheet%20-%20Finland_Mets%C3%A4%20Fibre_low.pdf

[6] www.metsagroup.com/en/about-us/Pro%20Nemus/Pages/default.aspx

energy efficiency, and site tour with guidance. 20 project participants, from which one represented the Confederation of European Paper Industries, attended the Study Tour.

In energy efficiency presentation it was pointed out that Finnish forest owners own Metsä Group, Metsä aims at increasing the amount of carbon stored in the forests and into products, and the mills are fossil free and resource efficient.

6 Visit to Drax Power Station, 17.9.2019

A visit to the Drax power station in Selby, UK was attended by two (2) persons from the BIOFIT project, Manolis Karampinis / CERTH and Dino Tresnjo / EPBiH. The visit was organized by Bioenergy Europe and Drax on the occasion of a Bioenergy Europe board meeting and it was open for all interested participants.

Drax is the largest example of a coal-to-biomass conversion project in Europe and probably the most well-known; it is also the single largest renewable energy producer in the UK, generating in 2017 about 6% of Great Britain's electricity and 15 % of its renewable electricity. Originally a site of six coal-fired units (4 GW_e installed capacity in total), four of these have been converted gradually to biomass, from 2013 to 2018. Drax consumes more than 7 million tons of wood pellets per year, most of them originating from the USA and Canada.

During the visit, participants had the chance to hear more about the history of the conversion project, the logistics investments and operations performed and the Drax approach to sustainable biomass sourcing. A full tour of the facility also took place, including the new pilot unit for Bioenergy Carbon Capture and Storage (BECCS) installed in cooperation with C-Capture; the unit has the capacity to capture 1 t/day of CO_2 and is considered as the first step towards transforming Drax into a negative emissions emitter.

From the perspective of BIOFIT, the visit was very connected with the case study under development for Kakanj Unit 5[7] of EPBiH, for which a coal-to-biomass conversion (although of a much smaller scale) is being investigated.

[7] www.biofit-h2020.eu/elektroprivreda-bih-kakanj-bosnia-herzegovina-chp

Figure 6. Close-up of the biomass domes and train wagons used at Drax for wood pellet storage and transport respectively.

7 Study Tour to the Thessaloniki refinery of HELPE, 25.9.2019

A BIOFIT Case Study “Integration of HVO production in the Aspropyrgos refinery of Hellenic Petroleum in Greece”[8] investigates technical challenges associated with co-processing of used cooking oil along with conventional straight run LGO into existing Diesel Hydrotreater Unit at Thessaloniki refinery in Northern Greece. The unit is currently used to desulfurize the LGO stream coming from the CDU (Crude Distillation Unit) stripper column. UCO will consist of 5% volume of the processing mixture. As a result, the final product is expected to use 22,000 tonnes HVO (Hydrotreated Vegetable Oil) per year. HVO is characterized as a premium “drop-in fuel” that can replace diesel without modifications to existing refueling systems and/or vehicles. During the 3rd Progress meeting, BIOFIT project group (with 24 persons) had a bus trip around the Industrial Complex, in which the refinery is located. At the refinery, fuels and

[8] www.biofit-h2020.eu/hellenic-petroleum-greece-fossil-refineries

solvents are produced from crude oil, naphtha and off-spec gasoil and polypropylene out of propylene. In addition, PVC and NaOH are traded. The complex has capacity to treat 4,300,000 tons of crude per year. The polypropylene production factory located at the HELPE facilities has a capacity about 240,000 tons of polypropylene per year.

Figure 7. View to Thessaloniki refinery.

7.1 Industry Workshop with invited speakers from Greek industries / equipment manufacturers, 25.9.2019

Six (6) invited speakers gave their insights on bioenergy retrofitting at BIOFIT Industry Workshop on the second day of BIOFIT 3rd Progress meeting.

Mitsubitshi Hitachi Power Systems Europe (MHPSE) presented experience of coal to biomass retrofits. MHPSE is a technology provider of i.a. large-scale thermal power plants including coal- and gas-powered plants, boilers and generators. According to MHPSE, future energy system, however, does not include natural gas, fossil oil or coal at least without carbon capture and storage and thus, the company is providing biomass conversion technologies. The presentation focused on bioenergy retrofitting of coal firing and natural gas firing power plants. The company had experiences of retrofitting lignite firing power plants to combust woodchips and hard coal firing power plants to fire wood pellets. Example projects included i.e. Amer 9 (The Netherlands), Avedørewärket (Denmark) and Drax (United Kingdom). It was clear that technology for fore mentioned bioenergy retrofits does exist. Modifications needed for such a retrofit included an additional bunker or modification of bunker for biomass feeding, increased fuel flexibility due to less homogeneous feedstock, possibly also new grinding process and drying system for fuel. Modification in furnace depend on the needed changes; possible changes needed include changing the geometry of the furnace, new firing system (e.g. dual firing capacity) and dedicated biomass burners.

Philippopoulos Energy Technical S.A. presented the Atlas Tapes S.A.[9] success case. Philippopoulos S.A. is a Greek manufacturer of industrial plants for biomass and waste utilization (more than 100 references). The company supplied two biomass thermal oil heaters (10 MW each) and one biomass steam boiler (10 MW) to Atlas Tapes, which allowed the company to drastically reduce its fuel costs by switching from HFO to biomass. The accumulated savings are estimated at more than € 5.7 million per year. Key success factors were the long annual operation of the plant and the constant thermal consumption, as well as the high cost of the conventional fuel. However, drawbacks included increased installation, maintenance and supervision costs and uncertainties in biomass supply.

District Heating Company Amyndeo (DHCA) presented their company's transition to a completely different heating model. Due to EU's commitment to reduce CO_2 emissions, European environmental legislation for reduction of industrial emissions and CO_2 emissions price, lead to declining of coal use, which leads to closing down of Amindeo Power Station's production units, which have so far provided the district heat to DHCA. DHCA overcomes the challenge by the installation of a new thermal energy production unit combusting biomass (2 x 15 MW) with capacity to serve Amindeo's existing district heating system and future expansions. The target is to be able to produce thermal energy with as low an increase in the cost of heat to the final consumers as possible. The sourcing of different types of biomasses is being considered by DHCA; agricultural residues seem promising in terms of price comparison with lignite, however the challenge is to set-up their supply chains.

Grecian Magnesite[10] presented the H2020 BAMBOO project[11] in which heavy industry's innovative technologies are used to decrease the consumption and dependence on fossil fuels while improving energy saving. The main challenge in the Magnesite industry is high temperature (2,000 °C) required to produce dead-burnt magnesite, which causes both high fuel specific consumption and high NO_x emissions. Partial replacing of petcoke with a high-quality biomass was investigated in the project. This required modifications in existing

[9] www.atlas-tapes.gr
[10] www.grecianmagnesite.com
[11] www.bambooproject.eu

burners, improving monitoring and control of combustion parameters and adapting biomass handling e.g. milling and dosing.

CERTH gave a presentation of transportation fuels decarbonization. The presentation included examples of producing renewable transportation fuels directly from biomass feedstock as well as biomass (bio-crude) integration in petroleum refineries. It was concluded that it makes more economic sense to use existing hydroprocessing units for waste cooking oil than process it with separate unit. The required process changes induce emission reductions. In BIOMATES project[12], innovative non-food/non-feed biomass conversion technologies were investigated for bio-based refinery intermediates production.

Hellenic Petroleum presented the opportunities in retrofitting of fossil fuel refineries. In the presentation, the Future refinery was renamed as an Energy Hub due to different possibilities in the field of sustainable biofuels, power-to-liquids and heat recovery. Elefsina Refinery Upgrade Project was used as an example, since 5% of vegetable oil is proposed to be introduced in transportation fuel production. The Refinery Upgrade increases diesel and gasoline yield, but reduces fuel oil yield. Upgrading the process to allow heavier and cheaper feedstock requires investments to new equipment (hydrocracker, hydrotreater, upgrading the existing units), but enables easy supply chain adjustment to market volatility. Finally, the selected planned investments of the HELPE Group were presented, including the BIOFIT case study in this list.

7.2 Tour of the CERTH facilities, 24.9.2019

BIOFIT project group with twenty four (24) persons visited CERTH facilities. During the visit the group got a throughout presentation of Renewable hydrogen production station established in EU Life project BIOFUELS-2G[13] and Laboratory of Environmental Fuels and Hydrocarbons (LEFH)[14] of CERTH/CPERI. During the tour project group also saw the nZEB Smart House[15], which is a demonstration infrastructure used to exploring various innovative smart IoT-based technologies for domestic buildings. LEFH is a catalytic reaction engineering laboratory that carries out applied research in the area of refining/bio-refining technologies, new conventional fuels, renewable fuels and chemicals, new catalytic materials and environmental catalytic processes, such as $DeSO_x$, $DeNO_x$, from flue gases. LEFH provides technical support to refining and bio-refining industry and focuses on various processes and especially on Fluid Catalytic Cracking (FCC), Hydroprocessing Catalysts (HDS/HPC), Isomerization, Alkylation,

[12] www.biomates.eu

[13] www.ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3465

[14] www.lefh.cperi.certh.gr/

[15] https://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool/-/dih/1521/view

Reforming, Biomass Catalytic Pyrolysis, Bio-fuels upgrading, and Selective Catalytic Reduction (SCR).

Figure 8. Dr. Stella Bezergianni presents the products of different refining steps at LEFH.

8 Visit at restoration areas in lignite mines and overview of Ptolemaida V construction site, 26.9.2019

BIOFIT project group visited the Greek planting area of European Union LIFE program project called The Green Link[16], which was located next to Ptolemaida coal mines and Ptolemaida V construction site at former lignite mining area. During the Study visit, four representatives from the projects The Green Link and PPC presented the project results to 13 BIOFIT consortium partners. The aim of the project is to restore decertified areas with an innovative tree growing method across the Mediterranean border to increase resilience. In this area, around 4,000 trees were planted in all the demonstration plots, which all have different soil characteristics. With Cocoon planting technology[17] (see Figure 9), which is designed to support a seedling through its critical first year, 90% survival rate of trees is expected. In addition,

[16] www.thegreenlink.eu/en/home

[17] www.landlifecompany.com/technology

1,000 more trees were planted in the area of other stakeholders in Western Macedonia, including other exhausted lignite mines of PCC.

Figure 9. The Cocoon technology.

Figure 10. Visit at restoration areas in lignite mines in Ptolemais

From the planting area, there was a view to Ptolemaida V construction site (Figure 11). When completed in 2023, the plant will produce 615 MW_e (net) and will supply heat for the district heating system of the nearby city of Ptolemaida. The construction of the fifth coal-fired unit at the Ptolemaida aims at renewing the installed plants to reduce environmental footprint of the power production. Visit by BIOFIT project members took place just timely few days after the breaking news: Prime Minister Kyriakos Mitsotakis announced at the UN Climate Action Summit 2019 that by 2028 all Greek coal power plants should be shut down. That would be a great step against climate change. However, it became clear that uncertainty in the region is big in discussions with the workers at Ptolemaida.

Figure 11. Ptolemaida V construction site.

9 Study visit at Agios Dimitrios lignite-fired power plant, 26.9.2019

BIOFIT project group with 16 persons visited the Greece's largest power plant Agios Dimitrios. The power plant was established in 1984 and it has installed capacity of 1,600 MW_e (units:

2x300 MW, 2x310 MW and 1x365 MW). The plant also supplies 67+70 MW_{th} for the district heating system of Kozani.

Figure 12. BIOFIT project partners at Agios Dimitrios lignite-fired power plant.

10 Study Tour to Södra Cell Mörrum pulp mill, 4.3.2020

During the BIOFIT 4th Progress meeting in Karlshamn, Sweden a Study Tour to the Södra Cell pulp mill in Mörrum was organized. BIOFIT project group (with 19 people) and two persons from Södra Cell attended the Study Tour. During the tour, the guides showed the whole process line of the mill. The control rooms were not visited due to restrictions related to Covid-19 pandemic. The guides talked about the retrofits that had been made during the years at the mill. The largest bioenergy retrofit was related to changing fuel in the limekiln into biofuels.

Figure 13. The group at the roof of the recovery boiler at Södra Cell.

The tour to Södra Cell started with a company presentation. It was told that the forest owners in southern Sweden own Södra. The owners supply most of the raw material. Södra sees the forest as the raw material of tomorrow and one way to absorb the emitted CO_2.

Södra has three pulp mills in the south of Sweden. It produces e.g. paper pulp, sawn timber, tall oil, solid biofuels, electricity and district heating. The market is mostly in Europe (74%). Södra aims to be fossil free in energy by 2020 and in transportation by 2030. Fossil CO_2 emissions at Mörrum pulp mill have reduced almost to zero by 2019. Bark and wood residues are used for energy production. At Mörrum pulp mill, the last step is to replace the fossil start-up oil at the mill, which today accounts 0.8% of the mill's energy use. The largest reduction of emissions so far relates to the retrofit and change of fuel in the limekiln.

Södra is taking care of the environment, e.g. by using renewable resources, certified wood raw material, by making certificated products, and by environmental investments. For every tree they harvest, they plant three new ones; this has been the Swedish law since the beginning of the 1900s (The Swedish Forestry Act).

It was told the group that the consumers in northern Europe are asking for sustainable houses (wood based), textiles, packages, and transportation. In northern Europe, the consumers demand both sustainable forestry and no or low CO_2 emissions related to the production. The focus of customers in southern Europe is sustainable forestry but often no questions are asked regarding to emissions of the production.

The pulp mill in Mörrum is a medium size pulp mill with focus on special products. It was built in 1962 and employs 342 people. The plant produces pulp in two lines: dissolving/textile pulp (170,000 tons/year) from hardwood and paper pulp (270,000 tons/year) from softwood. In addition, 342 GWh electricity is generated and used at the mill and around 5 GWh of electricity is sold to the grid. Södra Cell Mörrum delivers 177 GWh district heating to the network in Karlshamn. Approximately 177 GWh of tall oil is sold for renewable diesel production (formerly to UPM to Finland, but now to Swedish company Sunpine). About 30 GWh of solid biofuels (e.g. bark) is sold to the markets. Södra is also demonstrating a textile recycling line; the aim is to get the process working.

Södra first started with pulp production solely, and then district heating production was included followed by green electricity production. Biofuels and chemicals production includes today bark and wood, tall oil and turpentine production. Next steps that are planned include lignin extraction, bio-chemicals' production and textile recycling.

10.1 Biomethanol production plant at Södra Cell Mönsterås pulp mill, 4.3.2019

Södra presented the means of Södra to become fossil fuel free at their sites during 2020. The long-term goal is to be fossil free also in all transportations by 2030. 80% of the products are sold abroad and thus, the tricky part to solve is to replace the fossil fuels in the transportation of the products. To reach the goals, Södra is working in different ways to increase biofuels' production. They produce tall oil to be processed to biodiesel by Sunpine/Preem and methanol production has started at the Mönsterås pulp mill. Södra is also investigating the possibility to produce bio-oil with HTC technology together with Norwegian company Statkraft. The collaboration is called Silva Green Fuel. A demonstration plant is supposed to be launched in 2021 at the Statkraft Tofte site in Norway.

Södra Cell Mönsterås is the first pulp mill in the world that upgrades the residue raw methanol into purified methanol. The process is up and running and will have an annual production of 5,000 tons. By using the produced biomethanol the GHG reductions are >95% compared to fossil methanol use. Today, the raw methanol is commonly used for energy production. The raw methanol upgrading process is more efficient compared to e-methanol production and CO_2 emissions can be captured earlier in the process. In e-methanol production, already emitted CO_2 is converted to methanol by combining it with H_2 from electrolysis. The first customer for Södra's biomethanol is Emmelev, a biodiesel producer, which uses the green methanol to create a more advanced fuel.

10.2 Bioenergy retrofits in the Nordics for oil and gas boilers — Company presentation, 5.3.2019

During second day of the 4th Progress meeting (5 March 2020), the Swedish company PetroBio[18] presented its company. PetroBio is an energy solution provider and expert within flame combustion. They deliver burners with control systems, fuel supply systems, flue gas and ash handling equipment, and full engineering, procurement and construction (EPC) deliveries for energy plants.

Background to the company complies with the Sweden story. In the 50s, Sweden started to shift from coal to oil and Petrobio started to work more with oil related technologies. In 1973/1979, during the oil crisis, Sweden started to convert from fossils to renewables due to political decision to become independent of foreign fuels. In 1991, Sweden introduced carbon tax for fossil fuels and tax exemption on renewable fuels, which again changed the marked away from fossils towards renewables.

PetroBio gave several examples on bioenergy retrofit projects where they have been involved. These included projects to convert fossil fuel boilers to be able to run on bio-oils in Kristianstad, at Karlshamn Energi and the hospital in Kristiandstad. They also gave two reference cases on retrofit from fossils to wood powder (at Göteborg Energi and at the asphalt company Skanska). Bio-oils generally have quite different characteristics to fossil oils (e.g. they have limited storage time, are not as lubricious, need pre-warming). Thus, special component such as burners, pumping units, pre-warming and flow control are needed.

Figure 14. PetroBio presents their company for the group.

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[18] www.petro.se

10.3 Biogas production at Stora Enso Pulp and Paper Mill in Nymölla — Company presentation, 5.3.2019

During the second day of the 4th Progress meeting (5 March 2020), Stora Enso presented the pulp and paper mill at Nymölla, which delivers district heat to Sölvesborg Energi (one of the BIOFIT Case Study companies). At Nymölla mill, Stora Enso produces pulp (340,000 t/a), paper (485,000 t/a), consumer board, packaging solutions, biomaterials and wood products. The pulp mill was established in 1962 and the paper mill in 1972. The mill employs approximately 545 persons. The market is mostly in Europe.

Nymölla is a medium size pulp mill with a sulphite process, which is today more rarely used than the sulphate/Kraft pulping process. The mill uses both hardwood and softwood as feedstock. The mill is an integrated mill and it is 85% energy self-sufficient. The mill delivers district heating to cities of Bromölla and Sölvesborg. The amount of excess heat to these cities is about 60% of the total heat production. Ash from the process is used to revitalize forestland. The turbines produce around 50% of the electricity demand of the pulp and paper mill and 5% of the fuel-use is still based on fossils. The goal is, anyhow, to go fossil free.

Gasum builds and will operate a biogas plant at Nymölla. The biogas plant will turn mill's wastewater effluent into renewable energy. The production will start in 2020. The production will be 75-80 GWh of liquefied biogas (LBG) yearly. All biogas will be sold to Gasum, not used onsite at Nymölla. The effluent water from Nymölla contains COD and is therefore suitable to extract biogas. Nymölla benefits from the retrofitting by reduced chemical and electricity consumption in the effluent treatment.

11 Virtual Tour to Biocarburantes de Castilla y León (BCyL), 23.9.2020

BIOFIT project partners had a virtual Study Tour to Biocarburantes de Castilla y León S.A. (BCyL) plant operated by the project partner Vertex Bioenergy and heard a presentation about the company as a part of the BIOFIT 5th Progress meeting on 23 September 2020. Altogether 26 persons, representing project partners, Industry Advisory Board members and Spanish companies virtually visited the plant. The main business of the Vertex Bioenergy[19] is to produce bioethanol. Vertex Bioenergy and the BCyL plant were owned by Trilantic until October 2020. Trilantic acquired four bioethanol plants from Abengoa Group due to its financial challenges three years ago, one of those plants being BCyL. BCyL was shut down in 2016 and was restarted again in June 2017. The total production capacity of the four state-of-

[19] www.vertexbioenergy.com/en/index.php

the-art bioethanol plants operated by Vertex Bioenergy (Figure 15) is 780 ML and they ran at full capacity. Each plant has around 70-75 employees. The plants in Spain produce surplus electricity, which is sold to the national power grid increasing the process profitability. Part of the CO_2 produced in Cartagena, Salamanca and Lacq in the grain to ethanol transformation process is sold to nearby facilities. The plants and their production are the followings:

- Cartagena, Spain: 113 ML bioethanol, 80,000 tons dried distillers grains with soluables (DDGS), 22 MW_e cogeneration capacity
- Coruña, Spain: 182 ML bioethanol, 118,000 tons DDGS, 26 MW_e cogeneration capacity
- Salamanca (BCyL), Spain: 249 ML bioethanol, 135,000 tons DDGS, 25 MW_e cogeneration capacity
- Lacq, France: 235 ML bioethanol, 143,000 tons DDGS

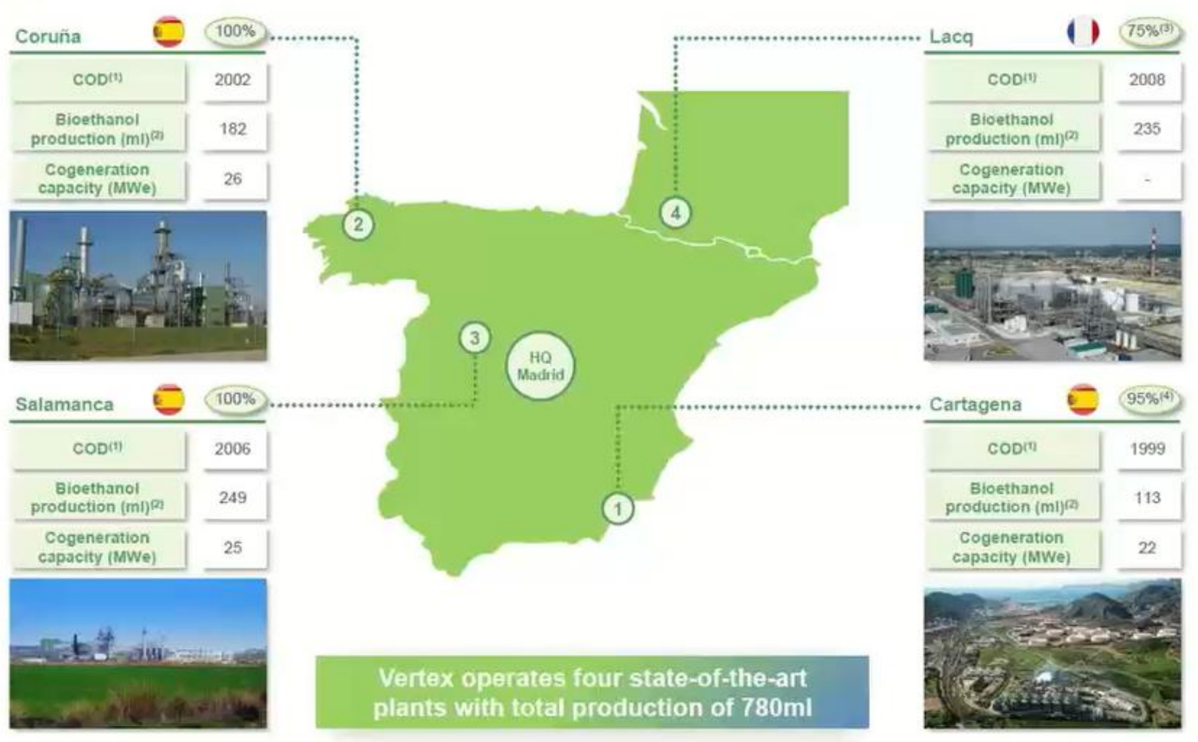

Figure 15. Bioethanol plants operated by Vertex Bioenergy (Figure: Vertex Bioenergy).

The BCyL plant differs from the others in the sense that the fermentation process is batch process (6 fermenters in 1G plant) instead of continuous process. Another difference between the BCyL plant and the other plants is that it has two different plants inside the installation:

1G plant ran since 2006 and 2G plant ran since 2009. The 1G plant is also one of the BIOFIT Case Studies[20].

The cereals to the 1G plant are received by train and truck mostly from central Spain. The plant includes intake, milling, storage, distillation, fermentation, DDGS, fresh water treatment plant, cooling towers to maintain the fermentation process in constant temperature, three boilers to produce steam mainly to distillation, gas turbine to produce electricity and exhaust gases for the drying process, and wastewater treatment plant. The plant can use different cereals, but it is mainly using corn, barley and wheat. The main raw material today is corn (annual input 553,000 tons). Operation with corn means easier production and less maintenance issues due to less abrasive cereal. Corn grain also includes less oil, which makes the operation easier due to lower viscosity. BCyL 1G plant produces 250,000 m^3 per year bioethanol, 142,000 tons per year as animal feed (DDGS), CO_2 of which 40,000 tons are sold to industry, and electricity from the gas turbine. Ethanol is separated according to different specifications. Ethanol is transported to local consumption, by train to a port in southern Spain and to northern Spain to be exported to other parts of Europe. DDGS is converted into pellets to improve the transportation in terms of volume reduction, though it consumes a lot of electricity. CO_2 is extracted from the fermentation stage and led to CO_2 scrubber (includes a lot of ethanol), where it is cleaned with water. Linde's installation further cleans and stores the CO_2.

The 2G plant is divided in two different plants (Figure 16). The biomass part was constructed in 2008 and it uses straw and corn stover as feedstock. The other part is operated with municipal residues to produce biofuels. The main product of both parts is ethanol.

[20] www.biofit-h2020.eu/biocarburantes-of-castilla-y-leon-spain-1g-biofuels

Figure 16. Two parts of the 2G plant in BCyL: biomass-to-ethanol plant and waste-to-biofuels plant (Figure: Vertex Bioenergy).

In the presentation by Vertex Bioenergy, it was talked about ethanol markets and explained that there are three different possibilities to enter the markets with ethanol. Ethanol can be directly mixed with gasoline to produce blendings E85 and E93, double counting bioethanol can be produced from wine alcohol (residues from alcohol plants), or E100 ethanol can be produced for Industrial Alcohols production or refineries. There is currently no market for double counted bioethanol in Spain, so the product eligible for that is mainly exported to France. In 2018, new European regulations on the labelling of fuels and vehicles (Directive 2014/94/EU) came into force, and now bioethanol blending is labelled as E5, E10 and E85. In Spain, E10 and E85 are not in use, only E5 is in use, and the E10 is approaching the markets.

In general, the ethanol market is created by the global consensus for the need to reduce GHG emissions. Transportation emissions contribute 27% of the EU's global total GHG emissions. Bioethanol is one of the only proven, cost efficient tools to reduce emissions in transport. Bioethanol can provide up to 70% GHG emissions savings and more compared to gasoline. Especially in France, the ethanol market is already quite large. France is going to E85, which requires a change in regular petrol cars (400-500 €/car) or use of flex-fuel vehicles. The growth in blends in France can be explained by favorable tax policies. The ethanol consumption in Spain is foreseen to be in the same range in 2030 than today, since the gasoline consumption will remain the same. The benefits of ethanol relate to reduction in CO_2 emissions and decreased dependency on fuel imports.

In REDII Directive, 10% renewable energy target is set for transport sector by 2020 and 14% by 2030. Spain targets 28% by 2030. 2G biofuel production is still rather small in Europe. Covid-19 pandemic complicated the bioethanol markets in Spain. Vertex Bioenergy had to drop their production by 30%. However, the plant produces ethanol also for other uses than transport such as sanitary hydroalcoholic gel.

Figure 17. Screenshot from virtual Study Tour held by Vertex Bioenergy.

11.1 Company presentations from the biofuels industry, 23.9.2020

Two company presentations were heard as a part of the BIOFIT Progress meeting; one by IMECAL about Perseo Biorefinery and one by ecoMotion.

IMECAL delivers engineering and installations to energy and chemical industry. With Perseo Biorefinery[21] the company aims at turning organic waste into advanced biofuels, bioproducts and bioenergy. About 100 Mtons of municipal biowaste is generated annually in Europe. Only about a third (30 Mtons) of this waste is separately collected and composted and/or digested. A common EU target for recycling 65% of municipal solid organic waste (MSW) by 2035 (Directive 2018/851/EU), separate collection obligation of biowaste by the end of 2023 (Directive 2018/851/EU) and a target to reduce landfill of maximum of 10% of MSW by 2035 (Directive 2018/850/EU) are legislative drivers for IMECAL's solution.

[21] www.imecal.com/perseo/perseo-bioethanol-process/?lang=en

IMECAL has developed from lab to a semi-industrial plant with capacity of 25 tons/d in fermentation process. The plant has been in operation since 2007. The plant can produce bioethanol, solid organic fuel and bioenergy. The technology is based on simple biotechnological process, which is compatible with the existing MSW treatment facilities, but with better economical results. Perseo Biorefinery can be combined with anaerobic digestion, Waste-to-Energy plant and composting as a pre-treatment process in existing plants. The company promises up to 80% decrease in GHG emissions through production of 2G bioethanol.

ecoMotion's[22] presentation was about Retrofits & Biodiesel Industry in Spain. The company produced previously animal feed from Used Cooking Oil (UCO), but changes in legislation changed their business to produce biodiesel as a first company in Spain using only UCO as raw material in 2002. Later also animal fats were used for biodiesel production increasing the company's production capacity. According to EU, animal fat was double counted raw material in REDI, but Spain did not adapt that. In REDII, UCO and animal fats are not in the list of double counted raw materials. In 2019, double counted was implemented in Spain. Uncertainty in policy regulations has been a hurdle for the company. The company implemented retrofits to widen the raw material base to waste and residues.

11.2 Workshop for biofuels sector - Recommendations for policy makers, 23.9.2020

A workshop as part of the BIOFIT Progress meeting was held about Recommendations for policy makers in biofuels sector in Spain, including presentations by APPA Biocarburantes, MITECO and IDAE, and a round-table discussion.

A representative from APPA Biocarburantes[23] gave a presentation with topic "Present and future of biofuels in Spain". The Spanish association of biofuel producers aims at supporting the biofuels industry in Spain and giving impact on European legislation. Between 2005 and 2010 there were a lot of investments in biodiesel production in Spain due to high expectations, and the consumption saw an increase until 2012 due to high mandates and support from the government. However, changes in policies dropped the consumption in 2013 by more than 50%. The production capacity has steadily increased again from 2013 to 2018 due to mandates. Currently, there are 19 plants with an installed annual capacity of 3.2 Mtons (10 years ago there was more than 50 plants). Around 50% of the capacity is ran. For bioethanol industry the situation is different. The use of gasoline is much smaller compared to diesel in Spain. There are four bioethanol plants in Spain with installed capacity of 383,000 t, and the plants are running close to 100% capacity.

[22] www.ecomotion.de/en/eco/ecomotion-in-europe

[23] www.appa.es/appa-biocarburantes

Most of the renewable energy in the transport sector is from biofuels. The estimation is that EU's target of 10% by 2020 will not be met in Spain, but the share will be approx. 9.45%. Spanish target for renewable energy in transport sector is 28% by 2030. The absolute consumption of biofuels is foreseen to first increase from 2020 and then decrease by 2030 compared to 2020 level. This is due to problematic multipliers/double counting in REDII. Consequently, APPA proposes the following improvements for the NECP[24]:

- Increase the absolute targets for biofuels consumption planned for the period 2021-2030,
- Include concrete measures to ensure the consumption of E10, B10 and blends with higher biofuels contents (E85, B20, B30, B100),
- Set out specific targets for biofuel consumption in aviation and navigation, and
- Reduce or remove the multipliers provided in the Directive, and specify the energy consumption figures planned in accordance with the methodology of the Directive.

The priorities of the biofuels sector in Spain are, among others, to set growing obligations for the period 2021-2025 including separate targets for bioethanol and biodiesel, to incorporate into the Spanish legislation the objective of reducing the intensity of GHG emissions in transport sector (6% for 2020), to reinforce the resources of the biofuels certification entity, and to adopt measures for E10, B10 and blends with higher biofuels content.

A representative from MITECO[25] gave a presentation with topic "The role of biofuel in the Spanish NECP[24]". The objective of Spain is to reach carbon neutrality by 2050, with GHG emissions reduction of more than 90%. The reduction for transport sector is 34%. Energy efficiency plays a central role in the transport sector to achieve 2030 goals. Renewable energy target for transport sector is 28% and for power sector 100% by 2030. Several mechanisms are proposed to ensure sufficient amount of advanced biofuels in transport sector, such as general obligation, adaption of the certification system, aid programme for production facilities, and establishing specific consumption objectives for biofuels in aviation.

A representative from IDAE[26] talked about topic "Biofuels in Spain: Regulatory framework". The main policy instruments taking place in Spain regarding biofuels sector were presented. The regulatory framework is defined in EU level, the most important legislation being REDII Directive[27] and ILUC Directive for renewables, and directives concerning fuel quality and fuel

[24] National Energy and Climate Plan, ec.europa.eu/energy/sites/ener/files/documents/es_final_necp_main_en.pdf
[25] www.miteco.gob.es/es
[26] www.idae.es
[27] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

labelling. The biofuels obligation is set on national level. The main features of the biofuels obligation include reporting entity and certification entity.

In the round-table discussion, it was asked about feedstocks for 1G and 2G biofuels in Spain. It was explained that for 1G biofuels there are no problems with feedstock availability. For 2G advanced biofuels, the availability of waste residues is a limitation. The industry needs to do the necessary investments in order to be able to deal with the residues. Ability to work with different feedstock improves the potential.

It was asked if there is a level playing field for producers of biofuels and other forms of energy. It was commented that renewable electricity is now getting more support than other forms of energy. Renewable electricity is important to decarbonize e.g. the transport sector. Decarbonization is a huge task and the whole portfolio of technologies need to be used.

The presenters were also asked if significant investments in advanced biofuels are wanted and if the investments are foreseen to happen with the legislations presented. Investments in biofuels were foreseen since there needs to be a shift from 1G biofuels to 2G biofuels. It will be challenging, but all the technologies are needed to reach the 2030 targets. The situation is evolving and there has been seen during the last years a lot of changes in advanced biofuels sector. It is hard to say what the technology portfolio will be in 5-10 years' timeframe, but there is room for investments in technologies like cellulosic ethanol and biomethane in the short to medium term. A lot of money must be mobilized for demo and flagship plants. The experience of the industry in the last years has been confusing, since first there were high expectation on biofuels and a lot of investments in 1G biofuels were made, and now the production is wanted to be changed to 2G biofuels. Big investments for the industry are challenging with changing conditions and uncertainties.

12 Presentations on "How to decarbonise refinery products" and Round-table on recommendations to policy makers for the refinery sector in Europe, 24.3.2021

BIOFIT project partners gathered to BIOFIT 6th Progress meeting held on 23 and 24 March 2021. Altogether 28 persons participated the meeting, representing project partners, Industry Advisory Board members, and companies and associations giving presentations. The special focus of the meeting was on fossil refineries sector.

12.1 Industrial session on “How to decarbonise refinery products”, 24.3.2021

Science Executive from Concawe gave a presentation on topic “Refinery 2050: Opportunities and challenges for the refining industry”[28]. Concawe[29] represents 41 member companies and is open for companies owning refining capacity in the EU. Concawe’s mission is to conduct research to provide impartial scientific information.

European Union aims to have net zero emissions in 2050. According to PRIMES Impact Assessment model, fuels in transport (incl. aviation and maritime) in 2050 include electricity, hydrogen, e-gas, biogas, natural gas, liquid biofuels, e-liquids and oil products. The total use drops compared to 2030 due to efficiency measures. The fuel base will diversify from the current one. The key questions are how to satisfy the future need for products and fuels in a low GHG intensive manner and what is the role of refineries. Multiple pathways need to be integrated in a holistic view (well-to-wheels). There are many alternatives due to multiple combinations of resources, conversion technologies and powertrains. Over 250 ways to produce the fuels and more than 60 powertrain combinations lead to over 1,500 possible pathways. The source of electricity used in the production of biofuels and e-fuels plays a role from the GHG reduction perspective. More information: JEC Well-to-Wheels report v5[30].

Concawe’s Vision 2050 sees the refinery as an energy hub within an industrial cluster (Figure 18). The vision includes two parts: refining system, and low-carbon feedstock and advanced fuels. Concawe has defined three steps for the transformation towards low CO_2 economy. First step (early-stage) means high efficiency operation, and includes integration of green hydrogen, CCS, process electrification, energy efficiency measures and integration of biogas into the processes. Second step (evolution) means progressive introduction of low-emission components and low-carbon feedstocks, incl. negative emissions through BECCS. Step 3 is named as hub for production and distribution of low-emission energy products and raw materials.

[28] https://www.biofit-h2020.eu/news-and-events/concawe-bdi-and-btg-bioliquids-at-6th-biofit-meeting-24-march-2021/Concawe_Biofit_ProjectMeeting_24032021.pdf

[29] https://www.concawe.eu/

[30] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jec-well-wheels-report-v5

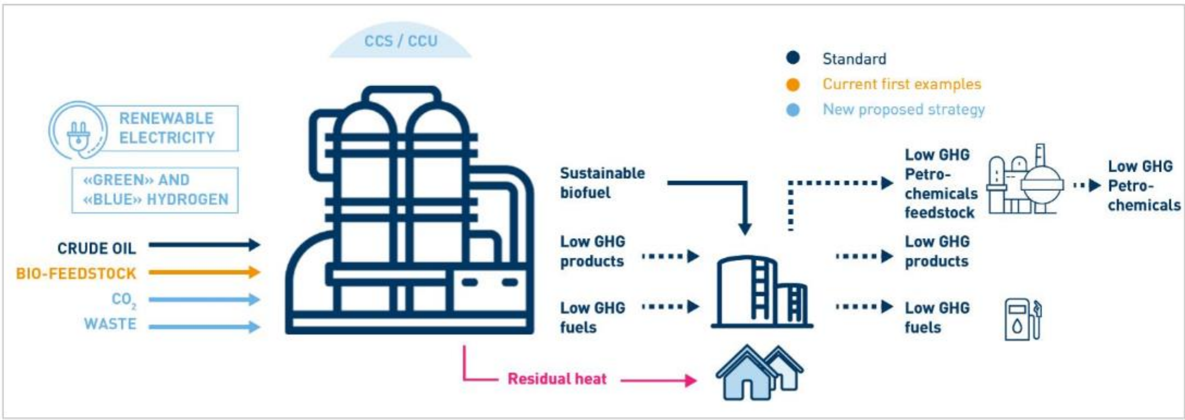

Figure 18. Concawe's vision 2050 of the refinery as an energy hub within an industrial cluster. (Figure: Concawe).

According to Concawe's Clean Fuels for All Strategy, demo and scale-up activities are needed. First-of-a-Kind plants together with supply chain development and market creation is the key. The strategy (Figure 19) foresees First-of-a-Kind BTL plants and refining with CCS and green hydrogen in the early 2020s and First-of-a-Kind e-fuel plants a couple of years later. R&D, cross-sectoral collaboration and policy framework are considered as the key success factors for market uptake. The challenge in bioenergy-based technologies is that they are CAPEX intensive.

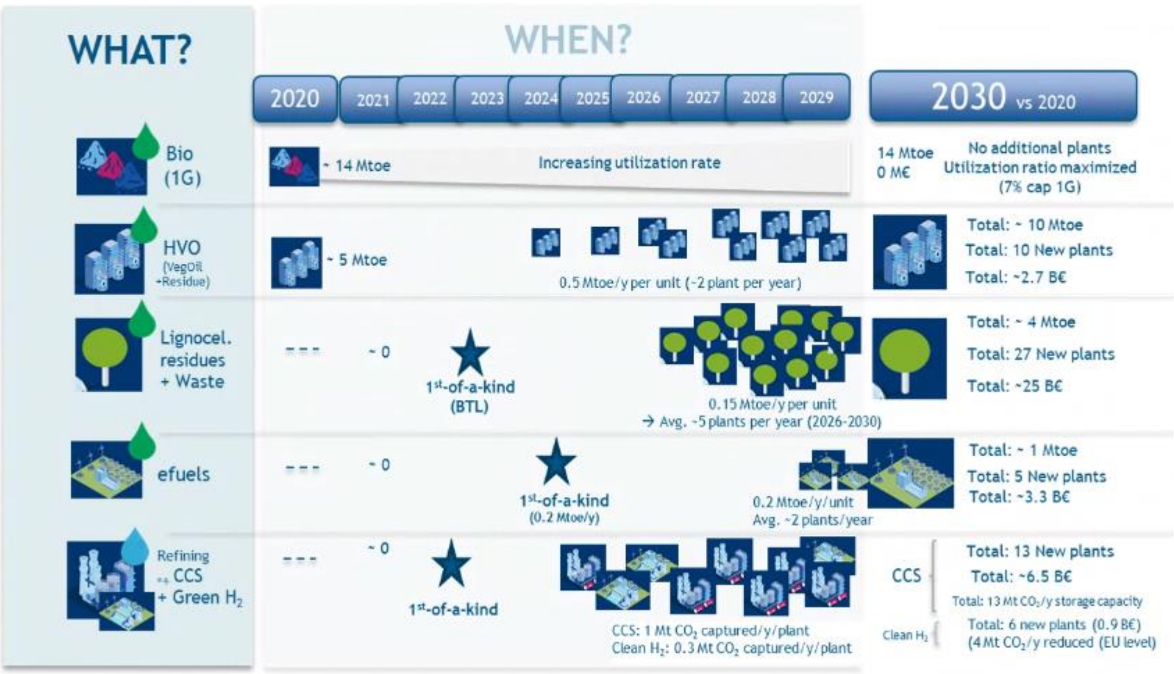

Figure 19. Vision for demo and scale-up activities according to Concawe's Clean Fuels for All Strategy. (Figure: Concawe).

BDI BioEnergy International gave a presentation on topic The bioCRACK Process – a refinery integrated BtL-concept[31]. BDI[32] is an Austrian based, highly specialised plant engineering and construction company, which provides turn-key EPC solutions. The company is expertised in industrial BioDiesel and BtL multi-feedstock technologies.

BioCRACK process is a new, patented BtL process, as add-on technology to existing mineral oil refinery (not a stand-alone process). Motivation for the technology development at BDI include:

- Growing renewable energy share in transport sector through mandates for biofuel portion in RED II (post 2020)
- Strong demand for 2nd generation biofuels (no competition with food production)
- Continuous development of benchmark technologies for biofuel production at BDI

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[31] https://www.biofit-h2020.eu/news-and-events/concawe-bdi-and-btg-bioliquids-at-6th-biofit-meeting-24-march-2021/07c2-2021-03-24_BioFit-ProgressMeeting_BDI_bioCRACK_fin_web.pdf

[32] https://www.bdi-bioenergy.com/en/start

- Conversion of biogenic waste and residues from "non-food" areas into high-quality biofuel

The goals of the bioCRACK project include: simple process technology, final fuel product's compliance with current fuel quality standards, usable side-products (no waste streams), fit in with conventional process of mineral oi refining, liquid phase pyrolysis (liquefaction of solid biomass), and co-processing of intermediate product in refinery (heavy ends) and solid biomass.

Ideal biomass for bioCRACK process is renewable lignocelluloses, such as wood chips, forest residues and chopped straw/agricultural residues. The outputs from the process are biochar, raw fuel for upgrading to diesel with renewable content, pyrolysis oil and gas. The refinery integration is presented in Figure 20.

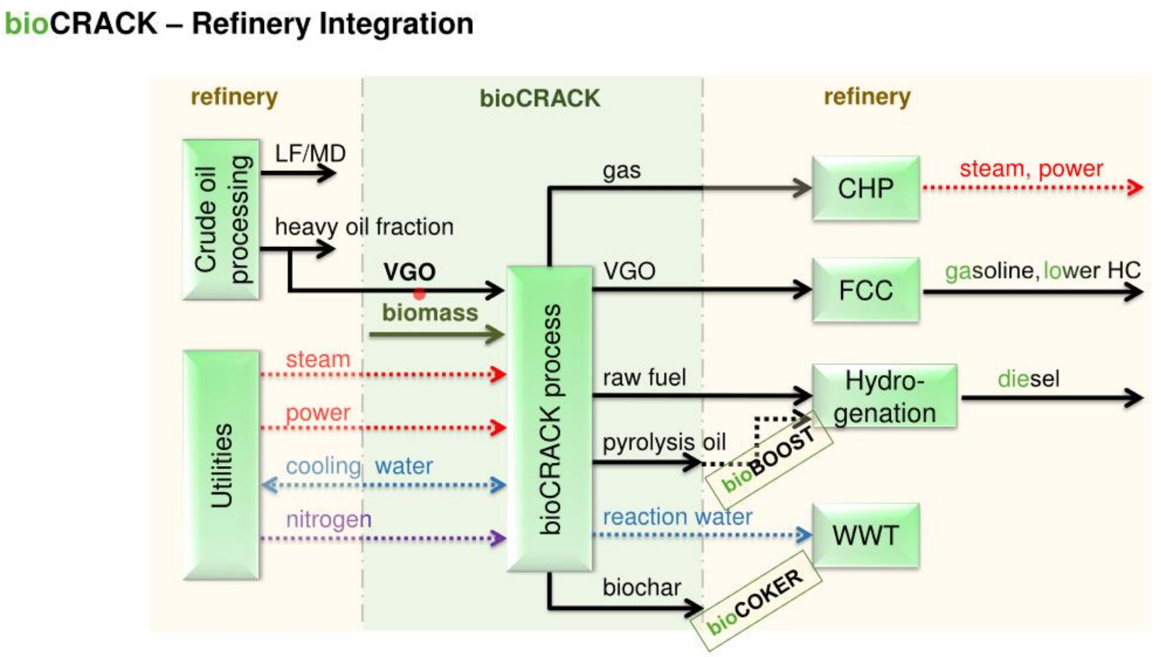

Figure 20. BioCRACK is not a stand-alone process but integrated to existing mineral oil refineries. (Picture: BDI).

BDI has constructed an integrated pilot plant at the OMV refinery in Schwechat, Austria with capacity of 1,000 tons biomass/yr. The pilot scale testing has lasted for two years. The produced raw diesel can be upgraded to EN590 diesel through standard hydrogenation. The integration led to overall increase in fuel production from VGO by +5%. The fuel distribution shifted from petrol (-11%) to diesel (+25%) and kerosene (+15%).

GHG saving potential for biofuels from bioCRACK (wood) (according to RED) is calculated to be 84%. Estimated CapEx for industrial scale facility using 400,000 tons biomass/yr and producing 60,000 tons/yr biofuels is estimated to be 200-300 M€.

BioCRACK process produces pyrolysis oil as a side product. It differs from fast pyrolysis oil in terms of having lower molecular size distribution, higher water content and lower viscosity. One option of add value for pyrolysis oil is hydrodeoxygenation (HDO) treatment. BDI's bioBOOST process aims at increasing biogenic carbon transfer, preferably into fuel. Results from the project show successful HDO of pyrolysis oil from bioCRACK process, using low-pressure/-temperature hydrocracking parameters. The end-product complies with fuel specification. BioBOOST process in combination with bioCRACK process could increase the yield of production of biogenic fuel portion and GHG saving potential up to 86%. The combination of processes is called BiomassPyrolysisRefinery (Figure 21).

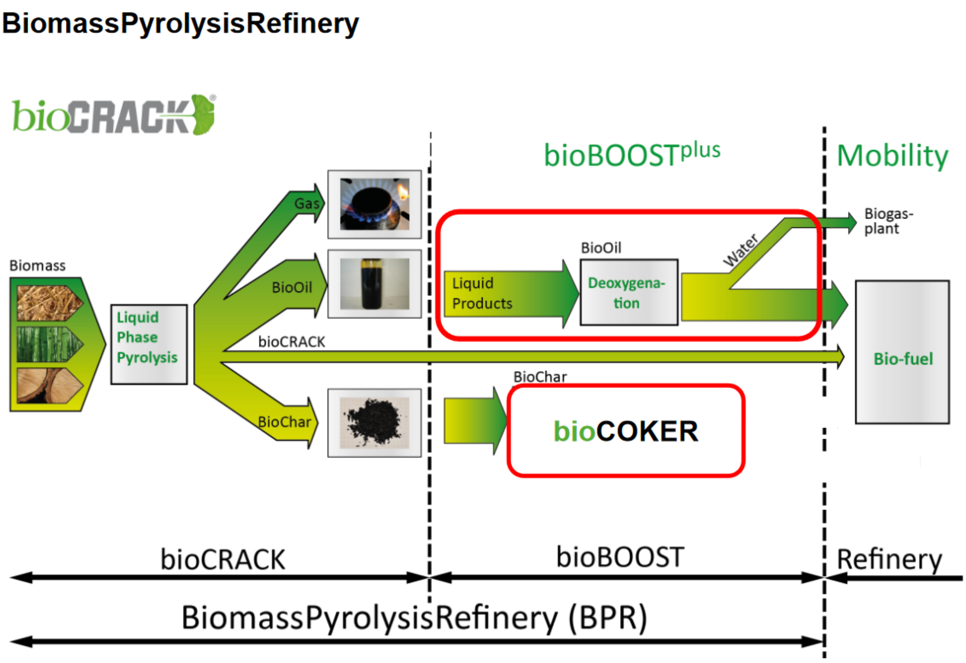

Figure 21. BiomassPyrolysisRefinery integrates bioCRACK and bioBOOST processes to an existing mineral oil refinery. (Picture: BDI).

The challenge in retrofitting refineries with bioCRACK process is that all the refineries are different and thus retrofitting is always case-specific. Also, scaling-up and investment environment create a challenge.

BTG Bioliquids gave a presentation on Advanced Biofuels from co-processing Fast Pyrolysis Bio-Oil[33]. BTG Bioliquids[34] is a technology provider for fast pyrolysis technology, which converts sustainable biomass residues into fast pyrolysis bio-oil (FPBO) through rapid heating (450-600 °C) in absence of oxygen. The company was established in 2008 by BTG, which was started in 1987 as a spin-off from the University of Twence. In 2015, BTG Bioliquids started up commercial Empyro plant in the Netherlands. The plant was later sold to Twence. Other commercial plants include Green Fuel Nordic's plant in Lieksa, Finland, which was started up in 2020, and Pyrocell plant, which is under construction in Gävle, Sweden (start-up in 2021).

Co-processing of FPBO in an existing refinery uses existing infrastructure, which potentially leads to low CapEx, short time to market and fast GHG reduction. Figure 22 shows different routes from FPBO to transport fuels in an integrated refinery. Fluid catalytic cracker (FCC) unit, which is present in existing fossil refineries, is the gateway for FPBO into a refinery. FPBO is injected into the FCC via separate nozzles. Biomolecules are cracked together with the regular FCC feed and the green content is distributed across the different products. Operability has been proven for 5 wt-% FPBO at commercial scale and for 10 wt-% at pilot scale. The challenge in feeding FPBO into the FCC is how to track the green content of the products. FPBO co-processing has shown to have little impact on overall FCC product yields.

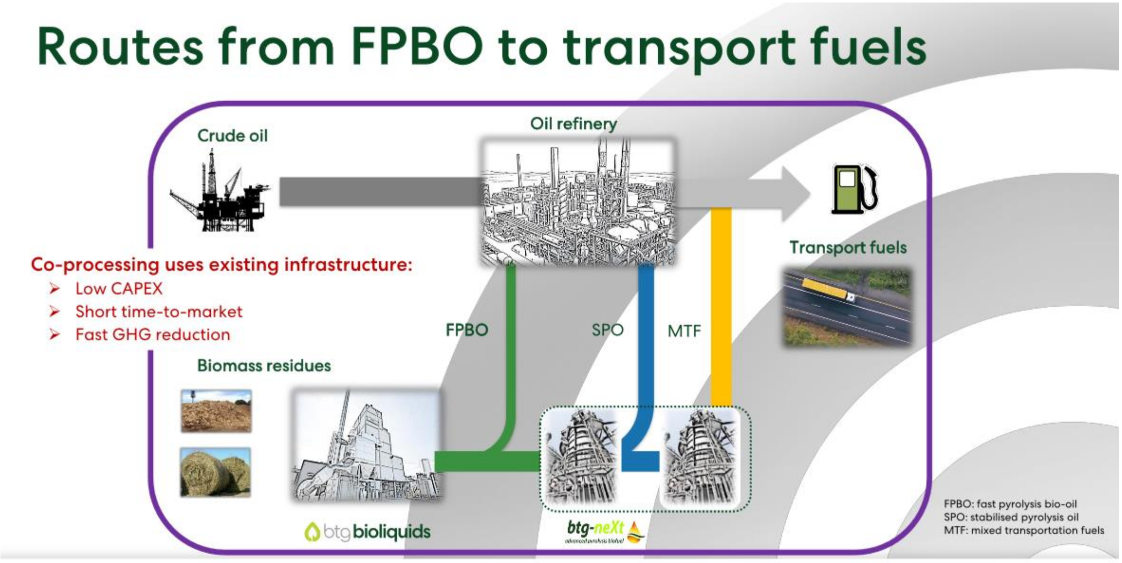

Figure 22. Routes from FPBO to transport fuels in an integrated refinery. (Picture: BTG Bioliquids).

[33] https://www.biofit-h2020.eu/news-and-events/concawe-bdi-and-btg-bioliquids-at-6th-biofit-meeting-24-march-2021/BTG-Bioliquids_BioFIT_AdvancedBiofuelsfromFPBO_web.pdf

[34] https://www.btg-bioliquids.com/

Tracing biogenic content through a supply chain is easy and well-established for products that have a high biogenic content. Existing certification systems rely either on radiocarbon determination (“^{14}C) or bookkeeping methods based on e.g. mass or energy balance. However, radiocarbon analysis is shown to be unfeasible for low co-processing percentages (<10 wt-% FPBO).The challenges in applying the radiocarbon analysis include scale difference between a FP plant and FCC unit (1:100), limited co-processing percentages of FPBO (around 5 wt-%) and the distribution of green content across many refinery products.

Possible bookkeeping methods include observed yields, energy balance, mass balance and free attribution, in which operator can choose to which product the bio-fraction is allocated. Bookkeeping methods have their limitations, but they are appropriate for the purpose. A bookkeeping case study has shown that among the mentioned methods, observed yields and energy balance methods strike a good balance between implementability and accuracy. Free attribution method is straightforward and easy to implement, but its fairness is questionable.

12.2 Round-table on recommendations to policy makers for the refinery sector in Europe, 24.3.2021

A round-table for all the meeting participants for arranged as a part of the 6th Progress meeting programme. The participants were divided in four separate groups to discuss the questions below, after which the discussions were summarised in a plenary session.

Questions

1. Which technologies are most promising for short-term and long-term decarbonisation of the fossil refinery sector?
2. What barriers are there towards decarbonisation in the fossil refinery sector?
3. What would the fossil refinery sector need to decarbonise?
4. How can the transition towards decarbonisation be stimulated:
    - As it is now, via minimum mandates
    - Via a cap on the production of fossil fuels
    - Via some other means?

Questions 1: Which technologies are most promising for short-term and long-term decarbonisation of the fossil refinery sector?

- Short-term solutions:
    - Co-processing/co-refining vegetable oils, HVO or HEFA is a low hanging fruit
    - Conversion of fossil refineries to biorefineries
    - Waste heat utilisation
- Long-term solutions:

- Green hydrogen (electrolyser infrastructure). It has to be noted that electrification may decrease the need for e-fuels (lower efficiency).
- Pyrolysis oils
- Carbon Capture and Storage/Utilisation (CCS/U)
- Very long-term solutions may include plastics and electric transportation

Question 2: What barriers are there towards decarbonisation in the fossil refinery sector?

- Refineries are different and thus, there are not standardised solutions available.
- Existing refineries should be linked with biogenic value chains, refineries need to look outside the box and learn new things.
- Large amount of electricity is needed for decarbonisation of refineries. The question is where will this electricity come from. The same question concerns also other energy intensive industries.
- Refineries operate at highly global field, and level playing field has to be ensured for all regions, e.g. through carbon tax.
- Biomass availability in terms of local vs global availability and the location of the refinery vs location of the feedstock. Usually, conversion process takes place close to the feedstock, while refineries are usually close to harbours and industry. This might become an issue. It is also difficult to find common solutions for many types of refineries.
- Co-processing, and in general many different ways of using biomass, is important, since fast transition to biorefineries is needed. Availability and quality of the feedstock are important. Availability and the price of the biomass affect the technology choice.
- Competition of feedstock with other industries, e.g. of waste oils with biodiesel industry, and with pulp and paper sector.
- Policies are striving for increased use of electrical vehicles, which will affect the development of the fossil refinery sector.
- Fossil fuels are too cheap and biomass refineries have high CapEx.
- Public acceptance is very important. It must be taken care of that refineries are not seen as green washing but wanting to take responsibility and contributing to decarbonisation. Sustainability information might be hard to understand for the customers.

Question 3: What would the fossil refinery sector need to decarbonise?

- Technological possibilities (co-feeding can only make up to approx. 5%)
- Decreasing the amount of crude oil that is processed. Shut down of existing fossil refineries could be an opportunity for biorefineries.

- Clear and stable political framework, e.g. CO_2 price or tax, legislation, and investment environment are important factors for decarbonisation of the fossil refinery sector. Sustainable business case is always more challenging than the existing fossil based, and thus, influence from the governments is needed. Global nature of the sector means also different legislations, which is a challenge for operating in the field.
- Subsidies are needed for many First-of-a-Kind plants, and minimising the risks is important. Lack of incentives hinders the investments.
- The scale of activities in the refinery sector is large and a lot of raw material is needed. Feedstock prices are increasing. Reliability of the feedstock supply needs to be secured.
- EU taxonomy may help for the sustainability issues in EU.
- Demand for alternative products.

13 Presentation: Retrofit to the AustroCel P&P plant, 20.10.2021

In BIOFIT 7th Project Meeting on October 20th 2021, AustroCel presented the retrofit of the AustroCel Hallein pulp plant to produce lignocellulosic bioethanol. Altogether 26 listeners attended the meeting during the presentation. As common in the pulp and paper industry, many retrofits have been done in AustroCel during its history. One of the biggest changes was the end of the paper production in 2009, and transition to viscose pulp production in a refinery-type of business. From the beginning of the year 2021, AustroCel has been producing 20-25 Mio l/a ethanol. AustroCel sells ethanol to OMV (only fossil refiner in Austria) for blending with gasoline. The use of ethanol is part of the national transport fuel blending obligation, which is based on the requirements of the EU Renewable Energy Directive. The ethanol produced at AustroCel qualifies as advanced biofuel, and the amount produced is sufficient to substitute up to 1% of Austrian gasoline demand.

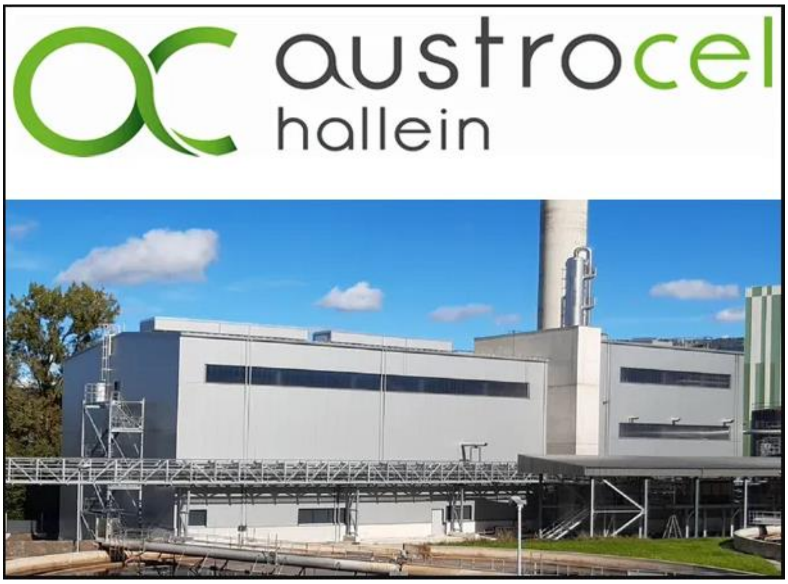

Figure 23. The bioethanol production plant (Picture: AustroCel Hallein).

In Austria, wood can be collected sustainably; more wood is growing than is harvested. The spruce wood used by AustroCel originates mainly from Austria and Germany and is certified with PEFC. Around 95% of the quantity are sawmill residues (wood chips) and only about 5% are wood logs. AustroCel produces 420 t/d of pulp for textiles and cellulose specialities. The textile fibre market is increasing globally.

Since wood consists of cellulose, hemicelluloses, and lignin, only about 40% of the raw material ends up as pulp. AustroCel Hallein utilizes side streams from the cooking and washing process, e.g. filtrates are used to produce biogas (2.000 m³/h) from which electricity is generated. The site also has a CHP plant to produce process and district heat and electricity out of internal residues, sludge and energy wood. The heat that is not used for the production processes (more than 100 GWh/a), is delivered as district heat to households in Hallein and Salzburg. Produced green power is fed into the grid.

Converting the site from paper production to dissolving pulp production in 2011 opened the opportunity for ethanol production. In the dissolving pulp production process, after the cooking, a solution that contains lignin and sugars remain. This brown liquor is concentrated in the evaporation plant and burned in the recovery boiler for energy production and recovery of chemicals. Due to the conversion to dissolving pulp production, the amount of liquor and its sugar content increased, allowing for higher possible ethanol yields. Thus, the retrofitting to ethanol production became an interesting option. In this case, retrofitting was very attractive, since the feedstock for the ethanol process is a side stream of the original process (i.e. free of charge). AustroCels yeast is very well adapted to the medium that they are using. Due to the well-adapted yeast, purification (filtering) is not needed before the fermentation, only pre-concentration, which also decreases the costs. However, the possibilities of similar retrofits in general depend of the quality/purity of pulp the plant is producing and the resulting amount of sugar in the brown liquor.

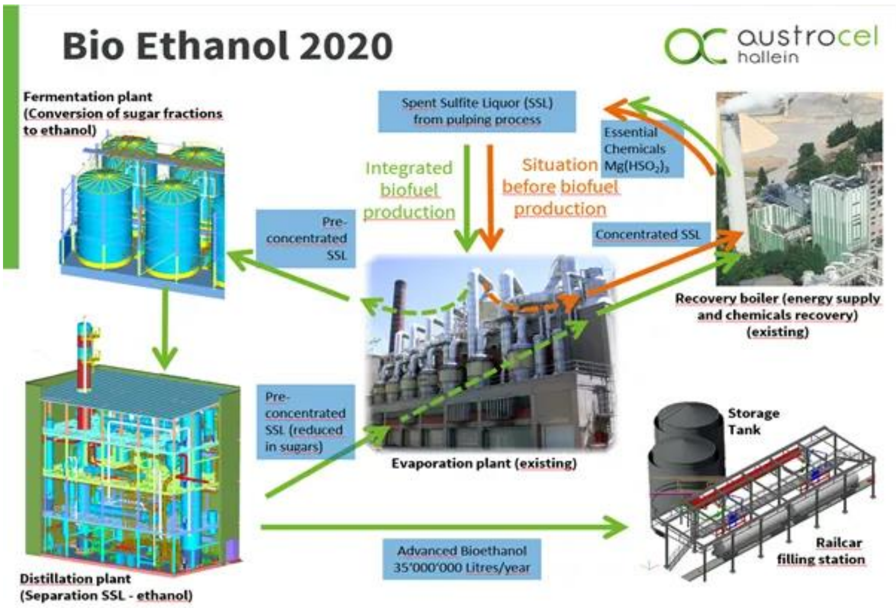

Figure 24. Process steps of bioethanol production (Picture: AustroCel Hallein).

Investment to ethanol production process was about 42 million euros with an annual capacity of up to 35 million litres of ethanol. AustroCel had already earlier produced ethanol from brown liquor in Hallein (1941 to 1988). Thus, calculable technological risk was known by former experience. In the retrofit, the brown liquor is taken out of the evaporation unit after a first pre-concentration and then sent to the fermentation process. The fermentation results in ethanol containing fermented slurry, which is sent to a distiller to concentrate the ethanol. After distilling off the ethanol, the remaining slurry is sent back to the evaporation unit. All the processes at the site are interconnected.

AustroCel is committed to further R&D activities. Interesting topics include utilization of C5 sugars on top of C6 sugars, which would lead to a higher ethanol yield, or filtering the lignosulfonates for further use. A big part of the lignosulfonates is burned in the form of concentrated liquor because of energy production needs, but a significant part of the concentrated liquor is also sold out. It could be more profitable if lignosulfonates filtered from concentrated liquor were sold instead of concentrated liquor itself. In addition, anaerobic fermentation produces very clean CO_2 that can be used for other applications without much purification effort.

14 Summary and Lessons learned

Several Study Tours and related activities, such as workshops and lab visits, were organized in the course of the BIOFIT project by several project partners. Study Tours covered all the industry sectors addressed in the project, namely first-generation biofuels, pulp and paper, fossil refineries, fossil firing power, and combined heat and power (CHP). The key goal of the Study Tours was to collect experiences of bioenergy retrofitting from different industries and to give space for industry to present their solutions, and drivers and barriers for retrofitting. The objective of this deliverable is to document the key activities and findings from the Study Tours. Sectors covered in BIOFIT are very different, but some general lessons learned can be derived.

General lessons learned from the Study Tours:

- The visits to different bioenergy retrofit plants show that there are a high number of options how bioenergy can support different industries in their decarbonisation goals. The role of bioenergy varies depending on the application and industry; it can e.g. substitute fossil counterpart, top up the fossil production or be a new bioenergy product in the industry.
- There are already many different technologies available in the markets for bioenergy retrofitting, provided by a wide variety of companies and proven in operation. In addition, technologies are under development at different stages. Some of the technologies, either on markets or under development, were presented as a part of BIOFIT Study Tour activities.
- Several presentations were heard and discussions held with industry representatives, both plant owners and technology suppliers, who gave valuable insights in retrofitting based on their experiences. This kind of information exchange is important to enhance the research and development.
- Retrofits seem to be part of the long-term strategy of the companies investing in those. Retrofits often comprise of series of actions towards a certain goal and are considered as learning processes. The process requires investing both money and time, continuous learning (e.g. about supply chain, biomass characteristics, technical issues, markets and policies) and flexibility to react on the prevailing circumstances.
- Drivers for bioenergy retrofitting are very case specific, varying in different applications, countries and markets. Some identified ones are for example associated to lower cost and shorter implementation compared to building a greenfield plant, widening the feedstock base and thus lowering the risk in changes of feedstock

availability or policies, producing higher-value products and diversifying the product portfolio, demand from customer and market side, and legislation.

- Several barriers, case specific like drivers, were also mentioned. These can relate e.g. to technical issues or restrictions associated to utilization of old infrastructure, feedstock availability, and policies. Plants are typically large in scale and different also within a certain sector, which means that there is not a standard retrofit solution available, but a tailor-made solution and case-specific feasibility analysis are needed.
- There are both supporting and restricting legislation in place. However, particular emphasis was placed on the need for stable and long-term policies and investment environment to encourage industry to invest and mobilise resources.
- One important question in bioenergy retrofit investments is the feedstock availability and the price of biomass. Possibility to operate with wide feedstock base lowers the risk.

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