MAPPING BIOENERGY RETROFITTING IN EUROPE'S INDUSTRY - BIOFIT FIRST RESULTS

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ABSTRACT: Bioenergy has evolved in the last decades from relatively simple heat and power production to a vast array of technologies for advanced biofuel production, intermediate bioenergy carriers, etc. Besides erecting entirely new bioenergy plants, retrofitting – which means replacing a part of a factory or installation with state-of-the-art equipment – is a good alternative to replace fossil fuels, upgrade outdated technology, or produce additional output from biomass. Bioenergy retrofitting provides significant benefits compared to building new plants, notably lower capital expenditure, shorter lead times, faster implementation, and less production time loss. The **BIOFIT** project (www.biofit-h2020.eu) is a Horizon 2020 project that aims to facilitate the market uptake of bioenergy retrofitting concepts in five specific industrial sectors in Europe, namely first-generation biofuels, pulp and paper, fossil refineries, fossil firing power and Combined Heat and Power (CHP) plants. First results show that the use of bioenergy is already widespread in the target sectors, that retrofitting is actually the dominant mode of implementation, and that there are large differences between countries. A wide spectrum of sector-specific retrofitting options exist and is being implemented, showing high interests in the opportunities from all stakeholders. BIOFIT facilitates this in a variety of ways.

Keywords: Bioenergy, Retrofitting, Market uptake, Industry, Industrial scale application

1 INTRODUCTION: THE BIOFIT PROJECT

Bioenergy is an essential form of renewable energy, providing an estimated 61% of EU's renewable energy production in 2018 [1]. In the future, bioenergy will remain important; in its 2017 Roadmap [2] the International Energy Agency (IEA) notes that bioenergy plays an essential role in its 2DS (2°C Scenario), providing almost 20% of the global cumulative CO_2 emission savings by 2060. Bioenergy is not without controversy. The sustainable use of bioenergy, which does not lead to loss of valuable arable land and/or biodiversity, and conforms to social and environmental standards, should be the norm. There is an increasing understanding that biomass is a finite resource, that needs to be supplied and used in a sustainable manner.

Retrofitting is the replacement of a part of a factory or installation with state-of-the-art equipment. Advantages of retrofitting instead of greenfield plants are that the capital expenditure can be lower, lead times can be shorter, implementation can be faster and consequently the loss of production time is less. All this means that technical and economic risks are lower.

The EU Horizon 2020 project BIOFIT – in full: Bioenergy Retrofits for Europe's Industry – has as central aim to facilitate the introduction bioenergy retrofitting in five industrial sectors, namely **first-generation biofuels, pulp and paper, fossil refineries, fossil firing power and Combined Heat and Power (CHP) plants**.

To ensure wider use of bioenergy retrofitting, BIOFIT implements a wide variety of actions: 1) *Develop concrete proposals (case studies) for bioenergy retrofitting* for each of the named industries. Currently 10 case studies – two per sector are being developed. 2) *Obtain an accurate and complete overview of options for bioenergy retrofitting* in said industries, as well as insight into the conditions under which each type of bioenergy retrofit is feasible and communicate this to the target groups. 3) *Involve, engage, and support stakeholders and market actors*, especially from industry, at several levels by i.a. communicating results, disseminating knowledge, providing opportunity for dialogue, and providing best practices and tools. 4) *Evaluate framework conditions* to identify – generic and industry-specific - barriers and enablers, and 5) *Provide advice to policy makers* at national and regional level to serve as input for more informed policy, market support and financial frameworks.

BIOFIT focuses mostly on the following **target countries:** Sweden, The Netherlands, Germany, Spain, Finland, Austria, Bosnia-Herzegovina, and Greece. In all these countries at least one BIOFIT project partner is located, ensuring access to in-depth knowledge about national framework conditions. In addition, one case study is implemented with an external company in Italy.

The BIOFIT project has a duration of 3 years and is now roughly half-way. The main emphasis of the project is now on the development of concrete case studies, which are all underway. Main activities that have been completed were the mapping of the opportunities for bioenergy retrofitting in the five selected industries. Via a variety of activities, such as an on-line map, fact sheets and a handbook, industry is informed on the many opportunities for retrofitting, the current status regarding retrofitting and in what framework these activities can take place.

In this publication, sector-specific options for retrofitting are discussed, and a short overview of the mapping activities of the BIOFIT project is given.

2 OPTIONS FOR RETROFITTING: SECTOR

OVERVIEW

For each sector there are different technical options based on their inputs, outputs, market environment and structure. This is reflected in the BIOFIT approach, and in the industry specific case studies that are being developed.

2.1 First Generation (1G) biofuels

The **first generation** (1G) biofuels sector in Europe involves the production of biodiesel (fatty acid methyl esters - FAME), hydrogenated vegetable oil (HVO) and bioethanol from various food crops. FAME and HVO are produced from oilseed crops such as rapeseed and sunflower. Bioethanol is produced from sugar or starch containing crops, such as sugar beet, grain and wheat. The main advantage of these fuels is that they can be blended with regular transport fuels.

For Europe, **biodiesel** production is more important than **bioethanol** production with a production of 11.5 million t/a of biodiesel in 2015, against 1.9 million m^3/a for bioethanol. These quantities are produced by numerous dedicated plants scattered across Europe. The production volume of biofuels, mainly biodiesel and bioethanol, has been stable in the last years in the European Union, after an increase in the years up to 2013. The support for biofuels from governments has decreased in recent years (e.g. Spain has decreased blending requirements). Uncertainties regarding the sustainability where addressed by the introduction of sustainability certification systems for biofuels, which can be seen as unprecedented models also for other sectors. However, uncertainties regarding the interactions of 1G biofuel production with the food production and land availability remain. A supplement and prospectively a replacement of 1G biofuels by 2G (**second generation**) biofuels is thus politically strongly desired, because the latter involve non-food crops such as lignocellulosic feedstocks and waste oils.

There are several *opportunities for retrofitting* in the 1G Biofuels sector:

1) **Cellulosic ethanol add-on to first generation bioethanol.** This involves the coupling of the 1G bioethanol with the 2G technologies that use lignocellulosic feedstock. Lignocellulosic biomass such as wood or straw mainly consist of cellulose, hemicellulose, and lignin components. The cellulose is also a biopolymer based on glucose monomers. However, cellulose is more difficult to saccharify and obtain a fermentable sugar solution. Current technologies for 2G bioethanol production usually use a thermal pre-treatment process like steam explosion to destruct the lignin – cellulose – hemicellulose composite. This pre-treatment has the goal to facilitate subsequent enzymatic saccharification of the cellulose. Again, ethanol is fermented from the sugar solution and purified similar to the downstream process in 1G ethanol production value chains. Different concepts for the integration of 2G ethanol into existing plants can be developed. Synergies could result from utilizing lignocellulosic parts of the starch crops (e.g. wheat bran), sharing parts of the downstream section, adapting the sugar contents of the fermentation by mixing of the mashes, sharing general infrastructure at the plant site or using lignin as a renewable fuel for heat provision. Within the BIOFIT project, the project partners Biocarburantes de Castilla y Leon and CIEMAT investigate the integration of the production of 30 million litres/year of 2G ethanol from unutilised components of the current feedstocks into the existing cereal-based ethanol production facility in Babilafuente, Spain.

2) **Alcohols for aviation (the ATJ process).** To add a further possibility of using bioethanol, aviation fuels can be produced from alcohol in a so-called alcohol-to-jet (ATJ) process. Within this process, short-chain alcohols (ethanol, propanol, or butanol) are converted to long-chain hydrocarbons and separated in various fuel fractions. The ATJ process starts with the purified alcohols. There are different processes for ATJ production, which vary slightly. The typical steps are illustrated in Figure 1. At high temperatures and under high pressure the OH groups of the alcohol molecules are dehydrated (removal of OH groups) and then converted into longer hydrocarbons (oligomerization). The resulting mixture of hydrocarbons of different lengths is distilled into desired fractions and remaining double bonds are saturated by using hydrogen [3].

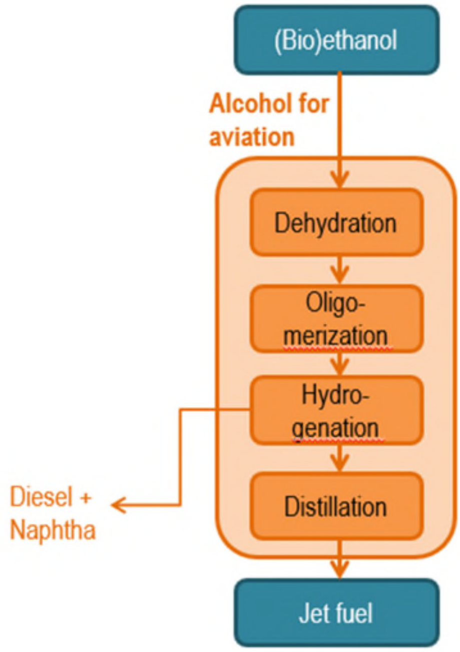

Figure 1: Schematic representation of the ATJ process

Depending on the processing parameters in the ATJ-process, kerosene fractions with and without aromatics can be produced. As by-products during distillation, biodiesel and naphtha fractions usually accrue. The conversion of the alcohols to kerosene in the ATJ process is not yet commercial, but demonstration plants are currently operated and flight tests with resulting kerosene have been made. Within the BIOFIT project a case study is conducted by DBFZ and Swedish Biofuels on the benefits of integrating the ATJ technology with existing 1G bioethanol plants.

3) Multi-feedstock biodiesel add-ons. Biodiesel plants built for processing vegetable oils can be retrofitted to multi-feedstock biodiesel plants that can also process used cooking oil (UCO) and waste animal fats. Compared to rapeseed oil, these feedstock types have a more inhomogeneous composition with varying levels of triglycerides, a higher proportion of free fatty acids (FFA), as well as increased levels of impurities like plastics, Phosphorous, Nitrogen and Sulfur components.

For this reason, it is impossible to process UCO and waste animal fats in biodiesel plants which were built for plant oils without changing the components. Therefore, pre-treatment steps to separate impurities in these waste fat feedstock types must be added to the process. Furthermore, additional esterification reactors – e.g. with an acid catalyst like Sulfuric acid – decreasing the high content of FFA must be integrated in the biodiesel production system.

Figure 2: Biodiesel, biodiesel blend and fossil diesel (Source: DBFZ)

After the esterification reaction, the separation of the raw biodiesel and the glycerol phase is carried out by sedimentation or centrifugation. The separated phases can then be integrated into the existing process. It might also be necessary to retrofit distillation columns for waste-based biodiesel to be able to meet the quality criteria of the EN14214 (European biodiesel fuel quality standard).

2.2 Pulp and Paper

The number of pulp, paper and board mills in Europe (CEPI countries) has steadily decreased since the 1990's, while the production volume has remained relatively stable. In 2018, 151 pulp mills and 746 paper and board mills were located in Europe. The total pulp production volume was 38 million tons and paper and board production volume 92 million tons. Majority of the pulp produced today is sulphate pulp with 68% share [4].

The pulp and paper industry is the fourth largest industrial energy consumer in Europe [5]. The industry has reduced its carbon emissions by 26% since 2005 by using solid by-streams for energy purposes [6]. In 2017, the biomass consumption in pulp and paper industry was 710 PJ, which is nearly 60% of fuels consumption. Largest fossil source was natural gas with 392 PJ consumption. (CEPI, 2019) In northern Europe, namely Sweden and Finland, pulp and paper production relies on virgin wood as raw material and mills are largely self-sufficient in energy and often provide energy also outside the mill. The sector development includes increase in energy efficiency and transition from integrated P&P mills to separate sites and thus, the energy requirements in the pulp mills' are lower than before. At the same time, there is an ample interest in added-value bio-based products, such as biofuels, bio-composites, and bio-based plastics.

The countries using mainly recycled fibers as domestic raw material for paper production typically have only a small forestry resources. These countries typically use natural gas as an energy source in paper industry. Although the use of natural gas is not a precondition for paper recycling it is often used due to cost-efficiency, lack of viable alternatives and national energy policies. (CEPI, 2018)

There are several *opportunities for retrofitting* in the pulp and paper sector:

1) **Ethanol production from brown liquor**. In the acidic sulphite pulping process, the hemicellulose part from the wood is converted into simple sugars also called monomeric sugars. Monomeric sugars can be directly fermented into ethanol by yeast or digested to produce biogas. Currently, ethanol is produced in several old sulphite pulp mills, such as at Domsjö mill in Örnsköldsvik, Sweden and Borregaard, Norway. However, most pulp mills today employ Kraft pulping process, which limits the possibilities for ethanol production. In BIOFIT, project partner BEST studies fermentation of liquor at the AustroCel Hallein pulp mill in Austria for the production of advanced bioethanol.

2) **Raw methanol purification and black liquor gasification to DME.** In the Kraft pulping process, a small amount of methanol is produced and can be separated from foul condensates of black liquor evaporation. This way the substance that would otherwise be considered as waste stream to be disposed or treated with effluent system can be purified to transportation fuel additive. A raw methanol purification plant is under construction at Södra Cell's mill in Mönsterås, Sweden (**Error! Reference source not found.**) with annual production capacity of 5,000 t/a.

Figure 3: Methanol plant at Södra Cell's mill in Mönsterås, Sweden. (Photo: Södra Cell)

Furthermore, dimethyl ether can be produced either through methanol dehydration or through direct synthesis. Black liquor by-product from evaporation can be gasified into synthesis gas, which can be further converted into biofuels suitable for transportation, such as Fischer Tropsch (FT)-diesel, methanol or DME. Chemrec demonstrated black liquor gasification to DME in Luleå, Sweden.

3) **Kraft lignin extraction from black liquor.** Lignin is usually dissolved in black liquor, which is combusted in the recovery boiler to produce heat and power. Another option is to extract it from the black liquor, which enables decreasing the recovery boiler load. Lignin is an easily transportable energy carrier and can be used as a bioenergy product e.g. as fuel in the lime kiln or converted into advanced biofuel. LignoBoost lignin separation technology developed by Valmet is used at full scale at

Stora Enso's mill in Sunila, Finland and in pilot scale in Bäckhammar, Sweden.

4) **Renewable diesel from tall oil.** Crude tall oil (CTO) is obtained in separation of the soap in the Kraft pulping process. The soap is acidified in order to separate out the CTO. The CTO can further undergo purification, hydrogenation treatment and fractionation based on different boiling points. Tall oil is an attractive feedstock for biofuels production due to its low oxygen content. UPM and SunPine are the only companies that use CTO for renewable diesel production. UPM produces renewable diesel BioVerno and naphtha in its Biorefinery (**Error! Reference source not found.Error! Reference source not found.**) in Lappeenranta, Finland. SunPine in Sweden esterifies tall oil with methyl ester and the product is further converted into transportation fuels at the Preem's refinery.

Figure 4: UPM's Biorefinery in Lappeenranta, Finland produces 120 million litres of renewable diesel and naphtha per year. (Photo: UPM)

5) **Hydrothermal liquefaction (HTL) of black liquor and lignin.** HTL is an attractive process to increase the energy content of wet organic containing streams without drying, producing bio-oil. The product biocrude can be further refined to biofuels, although the quality of the product is significantly lower compared to fossil crude oil. Renfuel produces a biocrude product called Lignol via a catalyst process from lignin at a demonstration plant in Bäckhammar, Sweden. Another plant is under construction in Vallvik, Sweden. Also Silva Green is building a demonstration plant in Tofte, Norway to convert woody residues into biocrude.

6) **Bark gasification.** Bark is produced as a by-product of debarking at pulp mills, and typically combusted to produce additional heat and power. In many pulp mills, lime kiln is the only part using fossil fuels, mainly natural gas and oil. Lately, the fossil fuels have been replaced by renewable ones. One possibility is to use bark via gasification. A bark gasifier installed in 1987 at Södra Cell's Värö mill, Sweden offers over 30 years of experience of retrofitting lime kiln from oil to gasifier gas. Recent gasifier investments have been made at Metsä Fiber's pulp mill in Joutseno, Finland and Bioproduct mill in Äänekoski, Finland.

7) **Hydrothermal carbonization (HTC) of sludge.** HTC is a process to separate water and produce a coal like product, biocoal, from wet lignocellulosic biomass feedstock. A demonstration plant has been implemented first time to pulp and paper mill at Stora Enso's Heinola fluting mill, Finland to process wastewater treatment plant's sludge. In BIOFIT, project partner VTT studies HTC of pulp mill wastewater sludge with the C-Green's innovative OxyPower HTC technology at a Nordic pulp mill for sludge disposal and production of HTC biocoal.

8) **Anaerobic digestion of sludge.** Another option to treat the sludge from wastewater treatment plant is anaerobic digestion, which produces biogas while reducing the amount of sludge. Typically, the sludge from different pulp and paper making process stages is combined, dewatered, and disposed through incineration, and the treatment has aimed at sludge reduction. Since the wastewater includes large amounts of organic matter the biogas potential is substantial. Several pulp and paper mills in Europe have already implemented anaerobic digestion for biogas production, such as several Norske Skog's mills. Strategies to valorize the biogas include selling it to external markets e.g. for transportation use and using it at the mill to replace fossil fuels.

9) **Replacing fossil fuels at paper mills' energy production.** Paper mills in Central and Southern Europe are to large extent dependent on natural gas and also coal as an energy source. Although increasing the share of biomass is technically feasible option at paper mills, the further increase in biomass use is marginal; the mills have limited access to biomass feedstock, lack in storage facilities and logistics constraints. Biogas produced on-site from wastewater treatment plant's sludge could account for 10% of paper mill's energy consumption. (CEPI, 2018)

2.3 Fossil refineries

Fossil fuel refineries convert crude oils into finished products by breaking them down and processing them to new products such as fuels for transport. **Crude oil** is extracted from the earth. There are many types of crude oils, with many different components. Most of these components are hydrocarbons (molecules consisting of the elements carbon and hydrogen). Other components in crude oils consist of a combination of hydrocarbons and small amounts of other elements, such as sulphur, nitrogen and metals. Refineries are large and capital-intensive installations that convert crude oil into **final products**. In European refineries about 65% of the products are transport fuels, such as diesel, gasoline, kerosene, heavy oil and liquid gas. 25% of the products are made for other applications, such as bitumen, lubricants, heating oil and oil coke. 10% of the products are petrochemical feedstock used in chemicals, synthetic rubber, and a variety of plastics.

It is – also within the sector itself - accepted that a main challenge of the refining sector is how to manage the transition to a low-carbon economy. The European platform organisation of refineries, FuelsEurope, has issued its own vision document "Vision 2050" in 2018 [7], in which they lay out their vision for a low-carbon future for the refining industry. They foresee the increased use of new feedstocks, such as renewables, waste and captured CO2 in a very efficient manufacturing centre in synergy with other sectors, such as chemicals, district-heating.

Main *opportunities for retrofitting* in refinery sector are:

1) Hydroprocessing of renewable liquid oils. This is the main technology for achieving the goal of integrating the production of renewable biofuels in existing refineries. Renewable liquid oils, such as palm oil and used cooking oil are upgraded to renewable transport fuels such as HVO (Hydrogenated Vegetable Oils), or HEFA (hydroprocessed esters and fatty acids). The production is carried out by conversion of the oils and fats to paraffins (straight hydrocarbon chains), after which the paraffins are cracked and isomerised so that the green diesel (main product) meets the required cold property requirements. By-products are green naphtha and green jet fuel. The production of HVO is commercially proven, and there are several companies which license the technology, such as Axens IFP (Vegan), Honeywell UOP (Green Diesel), Neste (NextBTL), Haldor Topsoe (Hydroflex) and ENI (Ecofining). Table 1 provides an overview on current refineries where HVO is produced.

Table 1: Overview of current refineries where HVO is produced, including HVO capacity

Operator	Location	Status	Capacity (t/year)
BP	Castellon (Spain)	Operational	80.000
Repsol	various (Spain)	Operational	200.000
Cepsa	La Rabida (Spain)	Operational	43.000
Cepsa	San Roque (Spain	Operational	43.000
ENI	Venice (Italy)	Operational	300.000
ENI	Gela (Italy)	Operational	600.000
Total	La Mede (France)	Operational	500.000
Total operational production in refineries			1.766.000

Within the BIOFIT project partners Hellenic Petroleum, CERTH and TFMC will investigate the integration of new equipment to produce hydrotreated vegetable oil (HVO) into the Thessaloniki refinery of Hellenic Petroleum in Greece. The expected production capacity is 25,000 tons of biofuel.

2) Pyrolysis oil integration into refineries. Pyrolysis is a process in which biomass is heated in the absence of air/oxygen. Under these conditions the organic material decomposes, forming vapours, permanent gases and charcoal. The vapours can be condensed to form the main product: pyrolysis liquid. In order to maximize the liquid production, the biomass heating, as well as the vapor condensing needs to be done quickly. Hence the name fast pyrolysis. Pyrolysis oil is a relatively homogeneous bioliquid that can be produced from a variety of solid (lignocellulosic) biomass types. Hence it is in principle suitable for co-feeding in refineries, because refineries are used to liquids, and because refineries are large scale facilities that require large quantities of input. For normal bulky biomass this imposes logistical challenges, but the pyrolysis oil energy density is such that transport over larger distances becomes economical. Co-feeding of pyrolysis oil can be done in the FCC (Fluid Catalytic Cracker) of a refinery. After earlier experiements on pilot scale by Petrobras in Brazil, oil company PREEM will now be the first one to co-feed pyrolysis oil in their refinery in Lysekil (Sweden). The required pyrolysis oil will be produced by Pyrocell, a Joint Venture of PREEM and Setra. Co-feeding can commence in 2021, when pyrocell has completed the construction of their pyrolysis plant. Within the BIOFIT project the co-feeding of pyrolysis oil in the FCC (Fluid Catalytic Cracker) of Total will be investigated.

Figure 6: Pyrolysis oil

2.4 Fossil fired power and combined heat and power.

Fossil fuels contributed to 65.1% of the world's gross electricity production in 2016; coal alone amounted to 38.3% of the total amount [8]. Mostly due to the huge growth in China and India, the installed capacity of coal fired power plants has exceeded 2,000 GW, more than double than the capacity in 2000 [9].

Figure 5: The Ptolemaida V 615 MWe lignite-fired power plant (under construction). Due to the 2028 Greek Coal phase-out, a bioenergy retrofit is one of the options considered for keeping the plant operational.

Thanks to a set of policies pushing for wide decarbonization of the energy sector, the situation in Europe is quite different from the global perspective. Still, 19.2% of power production in EU-28 is coming from hard coal and lignite [10]. As for 2018, the installed power capacity of operating coal-fired power plants in the EU-28 was almost 155 GW (CarbonBrief, 2019); the largest coal power plant fleet is located in Germany (48 GW), followed by Poland (30 GW). Several EU member states – Austria, Denmark, Finland, France, Greece, Hungary, Ireland, Italy, Netherlands, Portugal, Slovakia, and Sweden – have pledged a coal phase-out till 2030 or earlier. The decarbonization efforts are going to be challenging since about 40% of Europe's current operational coal fleet is in these countries.

Combined Heat and Power (CHP) plants produce both heat and electricity at the same time, thereby reaching higher total efficiencies and exhibiting a better use of energy resources compared to heat-only or electricity-only installations due to primary energy savings. In several Nordic EU countries – Sweden, Denmark, Lithuania – extensive retrofitting of fossil-fuel fired CHPs to (solid) biomass CHPs is (or has) taking place. For example, the main fuel in Swedish CHP systems is biomass, and Lithuania is expected to follow in a few years. Other opportunities for retrofitting are the replacement of fossil oil with liquid biofuels. An example is the Lantmannen Reppe (Sweden) retrofit.

Main *opportunities for retrofitting* in the Power/CHP sectors are:

1) Co-firing of biomass. The coal industry has already a lot of experience with co-firing of biomass, because of relatively low CAPEX requirements, scalable solutions, and various technical options to implement co-firing. The IEA Bioenergy Task 32 database [11] lists hundreds of industrial co-firing cases from Europe and around the world. Co-firing can be done with a large variety of biomass types and in many technical configurations. **Direct co-firing** is the most common and economic solution. However, it poses several limitations on the

Figure 7: The Kakanj CHP plant of BIOFIT project partner Elektroprivreda BiH

range of fuels and thermal shares. **Parallel** and **indirect co-firing** schemes are more suitable for biomass fuels containing problematic compounds or when the ash quality is of importance for sub-sequent sale or disposal. Generally, as the process complexity and investment costs rise, the biomass thermal share can be increased, and the more 'difficult' biomass types can be co-fired. In the BIOFIT Handbook [12], all relevant types of co-firing are explained in more detail.

Within the BIOFIT project, partners Elektroprivreda BiH and CERTH investigate the options for applying direct co-firing at Unit 6 (223 MWe) of the Tuzla thermal power plant, using a variety of locally available biomass resources (woody residues, agroresidues, energy crops) at a maximum of 30 % mass substitution rate.

2) Biomass repowering (full bioenergy retrofitting). Biomass repowering is the evolution of direct co-firing to very high shares of biomass in the fuel mixture, often up to 100%. This option requires the change of the fuel feeding, milling and burning system to something suitable for biomass. One of the earliest examples of a 100 % retrofit to biomass is Rodenhuize 4 in Belgium. The conversion was implemented with a series of successive steps, starting from installation of transport, storage, handling, and milling infrastructure for wood pellets and the conversion of a single burner row in 2005. Other burner rows followed later, and in 2011 the full conversion was completed. There are several other examples of coal-fired power or CHP plants that have been converted from coal to biomass; in the BIOFIT Handbook, a list of 21 units – several belonging to the same power station – is given. Most conversions have been implemented in pulverized fuel boilers, in which the retrofits where related to the milling and feeding system, along with the logistics infrastructure for biomass sourcing (e.g. storage, port facilities, etc.). However, there are examples of more extensive retrofits, such as the Polaniec Green Unit in Poland, where the older pulverized fuel boiler was replaced with a state-of-the-art CFB boiler and the steam turbine was retrofitted as well. A key challenge in such retrofits is biomass sourcing; the volumes required are very high and, in most cases, they must be supplied from the global market. This is one of the main reasons why wood pellets are the most used biomass fuel in such retrofits; their relatively high energy density and standardized properties allows them to be traded over large distances. Another reason for choosing wood pellets over other biomass fuels is their fuel properties; they have relatively low ash content (< 2-3 % weight on dry basis) and low concentrations of chlorine and alkalis which can create problems of corrosion and fouling in power production applications. Wood chips are also occasionally used. Interesting new opportunities are the use of thermally treated biomass. With technologies like torrefaction, steam explosion and hydrothermal carbonization biomass can be pre-treated so that existing infrastructure and equipment of power stations can be used, lowering investment costs. Various trials have been performed or are on-going, such as the ARBAFLAME project.

Within the BIOFIT project two industrial case studies aim for a full biomass repowering of existing coal plants, namely the Kakanj Unit 5, a 118 MW_e CHP plant of Elektroprivreda BiH, which is considered for repowering using locally available woody biomass resources, e.g. wood chips, sawdust, etc. The other case study relates to Fiume Santo Unit 4 (320 MW_e) power plant of EP Produzione. The plant is located on the northwest of Sardinia; along with the BIOFIT project partners, the company is investigating its conversion into a biomass power plant using imported wood pellets as the main fuel.

3 BIOFIT ACTIVITIES AND OUTPUTS

The goal of BIOFIT is to facilitate the introduction of bioenergy retrofitting in the earlier mentioned industries. To this end, in the first phase of the project an overview has been made of existing options for bioenergy retrofitting. Tangible outcomes of this work are the following:

- An **interactive map of retrofitted installations** in Europe is online (https://www.biofit-h2020.eu/biofit-industry-map/). In this map a graphical representation of succesfull bioenergy retrofits is given. The map can be viewed as such, but it is also possible to zoom in and look at individual retrofits.
- **Nine fact sheets of succesfull bioenergy retrofits** have been produced so far and are accessible via the BIOFIT website. The fact sheets contain information on the situation before the retrofits, the rationale of the retrofits and the benefits of the retrofits.
- An **Industry Survey** to discern the motivations, experiences and perceptions of companies that had completed bioenergy retrofitting. This survey consisted of a combination of an on-line survey and a number of in-depth interviews Interestingly, the results revealed more benefits of retrofitting than barriers. Benefits, such as compliance with regulations, low emission, corporate social responsibility, sustainable business model, clean energy production, and competitive advantage are the most popular benefits. Furthermore, lower capital investments, increased production volume, end-user satisfaction, and minimal investments in infrastructure have been stimulation factors for companies to retrofit. Furthermore, important factors turned out to be being part of a network of innovative companies, and cooperation with universities and knowledge centers

was also considered critical by many.

- A **Handbook** has been published in which the technical options for retrofitting for all target sectors are detailed. The handbook includes arguments for retrofitting, describes the retrofitting process and its impact on public perception, summarizes the European biomass potential and logistics of biomass, provides an overview on biomass conversion pathways, and finally, explains technical retrofitting solutions for industries. The handbook is available in English at the BIOFIT website, and is currently translated in Bosnian, Dutch, German, Greek, and Spanish.

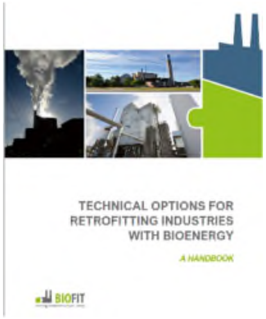

Figure 8: The BIOFIT handbook

- An overview of legal, institutional, and political **framework conditions** in Europe and the BIOFIT target countries (Austria, Bosnia and Herzegovina, Finland, Germany, Greece, The Netherlands, Spain, Sweden) for retrofitting in the five selected industrial sectors has been drafted. The overview shows that, it is stated that all target countries have introduced different policies and legislations that positively or negatively affect biomass integration into the considered industries. However, it must be noted that the ambitions of most policies need to be much higher in order to reach the goals of the Paris Agreement on Climate Change mitigation.
- In a concise **Summary for policy makers** an analysis on the challenges, barriers and technical solutions for the addressed sectors was made and recommendations for the policy makers elaborated. This Summary reflects the current ongoing discussions within the project consortium and with stakeholders. It is a snapshot after one year of project implementation. The content of this summary paper will be taken up to formulate more extended recommendations at the end of the BIOFIT project.
- BIOFIT develops **interactive Digital Support Tools (DST)** for five studied sectors. DSTs are targeted for industries to determine the benefits of retrofitting based on a few criteria, such as CAPEX and emissions reductions. The first tool has been lately published for CHP sector.

Besides the above-summarized work on the mapping of bioenergy retrofitting, many other activities have been carried out under the flag of BIOFIT, most notably the regular, sector specific industrial fora meetings and webinars. A visit to the BIOFIT website gives a more complete overview of the whole project and show when and how stakeholders can participate.

4 RESULTS AND CONCLUSION

The BIOFIT mapping work characterizing existing options for bioenergy retrofitting has shown that all five sectors are quite different from another.

The retrofitting of the **first-generation biofuels industry** with second generation biofuel technologies is needed to further develop the overall biofuels market in Europe. Although it is expected that electromobility will play a key role in the future transport sector, biofuels will be important to cover niche applications such as heavy duty transport or for the aviation sector. In addition, also first generation biofuels still have their justification and their use may be extended. This applies for instance to the small-scale production and use of pure plant oils and biodiesel for powering heavy machinery in the agricultural sector. Improved waste fat collection (with the appropriate regulations in place) could help generate more sustainable feedstock for biofuel production.

The **pulp and paper industry** already uses biomass for their main products. A distinction in the sector must be made in companies that only produce pulp, in companies that buy the pulp from other companies to produce paper products, and in companies that produce both, pulp and paper. Depending on this, biomass and waste products can be already used in some plants as process energy or even sold. In the Nordic pulp and paper industry, which utilizes virgin wood feedstock, there is an ample interest in more efficient use of bio-based residues for added-value products. As paper products will be needed in the long-term, the full retrofitting of the whole sector is sustainable and should be a political priority, with specific attention to non-pulp producing plants.

Fossil refineries still supplies the whole transport sector with energy, today, as fossil fuels are still the dominant energy source in the sector. However, policies on the decarbonisation of the energy sector will have a huge impact on fossil refineries and may lead to radical change of the industry. Partial retrofitting of refineries with biomass is an intermediate step in the short to medium term. In the very long-term, the refining of crude oil into various products will be non-existent as such or at least have only a very marginal role. Opportunities exist, however, if today's refineries are transferred into installations with different roles, services, and products. Thereby, the full conversion into biorefineries and the use of new technologies such as Power-to-X and Synthesis processes can open up future windows for the refinery sector.

The **fossil power generation** sector is based on the large-scale use of coal, oil and natural gas. Similar to the fossil refinery sector, it faces the overall challenge of the decarbonisation targets. There exist several retrofitting options with bioenergy, including biomass repowering that allows for a complete fossil fuel phase-out. A key challenge is such retrofits is the supply of large volumes of biomass, which require the application of robust sustainability criteria and the establishment of technical limitations; such measures are already considered in EU legislation, e.g. in REDII. A potential role of large-scale biomass power plants in the future is the application of BECCS (Bio-energy with carbon capture and storage) solutions. The Drax biomass power plant in the UK is already implementing these technologies in pilot scale [13], aiming to become a world leader in negative carbon emissions by 2030.

The **combined heat and power (CHP)** sector includes small to large scale installations that are fueled by fossil fuels, biomass and/or waste. For the larger scale CHP units that are fueled with fossil fuels, the retrofitting options are very similar to those of the fossil power generation sector. For both, the fossil power and the large-scale CHP sectors, a general challenge is the centralized location of the installations. In the future, it may be required to give up the central locations of large-scale units and to install more decentralized units which are located closer to the heat demand. This may be needed, due to the challenge of biomass logistics and to increase the fuel efficiency of biomass. The installation of several smaller new installations has the advantage of being more suitable to balance intermittent power sources, such as solar and wind. Another challenge of both sectors, in case of installations fueled with coal, is related to the phase-out of coal and its social challenges for the coal regions in transition. For these regions, coal to biomass retrofitting can be a supporting measure for the short to medium term.

Even though the five sectors have quite different characteristics and bioenergy retrofitting options vary, two general observations can be made: (1) biomass availability and mobilization play an important role in all sectors and require due attention, (2) there are many new technological opportunities for bioenergy retrofitting, leading to a wide spectrum of, high-value products, higher efficiencies and lower cost, which justifies continued support for RD&D as well as dedicated policy development.

5 REFERENCES

[1] http://www.europeanbioenergyday.eu/

[2] IEA Technology Roadmap Delivering Sustainable Bioenergy, 2017.

[3] Diederichs, Gabriel W., Mohsen Ali Mandegari, Somayeh Farzad, and Johann F. Görgens (2016). Techno-economic comparison of biojet fuel production from lignocellulose, vegetable oil and sugar cane juice. Bioresource technology, 216, 331–39.

[4] CEPI, (2019). CEPI Key Statistics 2018.

[5] Chan, Y. & Kantamaneni, R., (2015). Study on Energy Efficiency and Energy Saving Potential in Industry and on Possible Policy Mechanisms. A report submitted by ICF Consulting Limited. Available at: https://ec.europa.eu/energy/studies/study-energy-efficiency-and-energy-saving-potential-industry-and-possible-policy-mechanisms_en?redir=1

[6] CEPI, (2018). The challenge: decarbonizing whilst being recycling pioneer, summary for policy makers

[7] https://www.fuelseurope.eu/clean-fuels-for-all/vision-2050/

[8] CEPI, Key statistics 2017 European pulp and paper industry

[5] Bioenergy Europe Statistical Report 2019

[6] Climate Analytics (2017). A stress test for coal in Europe under the Paris Agreement.

[7] https://www.fuelseurope.eu/clean-fuels-for-all/vision-2050/

[8] CarbonBrief (2019) Mapped: The world's coal power plants. - https://www.carbonbrief.org/mapped-worlds-coal-power-plants [26.10.2019]

[9] IEA (2019) Electricity Statistics

[10] Agora Energiewende and Sandbag (2019): The European Power Sector in 2018. Up-to-date analysis on the electricity transition. https://sandbag.org.uk/wp-content/uploads/2019/01/The-European-Power-Sector-in-2018-1.pdf

[11] http://task32.ieabioenergy.com/database-biomass-cofiring-initiatives/

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

[13] www.drax.com/about-us/our-projects/bioenergy-carbon-capture-use-and-storage-beccs/

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Bioenergy Retrofits for Europe's Industry

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7 PROJECT PARTNERS