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Lignocellulosic biorefineries in Europe: current state and prospects

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Abstract:

Lignocellulosic biorefining processes plant-derived biomass into a range of bio-based products. Currently, more than 40 lignocellulosic biorefineries are operating across Europe. We address the challenges and future opportunities of this nascent industry by elucidating key elements of the biorefining sector, including feedstock sourcing, processing methods, and the bioproducts market.

Keywords: Bioeconomy; Sustainability; Biorefinery; Lignocellulose; Bioenergy; Bioproducts

1. The Biorefinery Industry in the EU

In 2012, the European Bioeconomy strategy was launched, defining the bioeconomy as "the production of renewable biological resources and the conversion of these resources and waste streams into value added products". This strategy and its action plans increased the turnover of the total bioeconomy in the EU from 2.09 trillion Euro in 2008 to 2.29 trillion in 2015 [1]. In the light of this development, the biorefinery is a vital component of the future bioeconomy defined by the International Energy Agency (IEA Bioenergy -Task 42, 2009) as "an integrated production plant using biomass feedstock to produce a range of value-added products". In 2017, there were 224 biorefineries operating across Europe, in addition to several currently under construction [2]. However, 181 of these commercial biorefineries are so-called first-generation facilities, which use feedstocks such as sugar, starch, oils and fats, and produce mainly biofuels and products of oleochemistry. Conversely, only 43 biorefineries are so-called second-generation facilities, which use more sustainable lignocellulosic feedstocks, such as non-food, non-energy crops and bio-waste, to produce biofuels, electricity, heat, bio-based chemicals and biomaterials. Fast-paced regulatory developments in the EU are accelerating the rate of lignocellulosic exploitation. For example, EU Directive 2015/1513 set out targets for a maximum of 7% share of biofuels to be derived from cereals, starch, sugars and oil-bearing crops by 2020 (including those grown for energy purposes on agricultural land). Additionally, in January 2018, the European parliament voted to limit its support for biofuels made from food crops, aiming to gradually reduce such fuels to 3.8% by 2030; ancillary measures seek to exclude palm oil-derived biofuels from the list of products that can count towards renewable targets by 2021, and to incentivize the use of lignocellulosic wastes in biofuel production. The EU has funded many projects under Horizon 2020 (the EU Research and Innovation programme that manages about €80 billion of research funding over the 7-year period from 2014 to 2020) to stimulate the use of various lignocellulosic feedstocks, with the aim of consolidating lignocellulosic-based biorefineries in Europe (Table 1). Therefore, a critical assessment of the future of the lignocellulosic biorefinery concept against a background of the current biorefining industry is especially timely.

2. The workflow of biorefining industry:

2.1. Lignocellulosic Feedstock Supply

Many different raw materials can be used as feedstocks for a lignocellulosic biorefinery, from residues derived from forestry or agriculture to agro-industrial wastes. The current annual consumption of lignocellulosic biomass in bio-based industries, as compared to total biomass availability, is relatively small. Even future projections, such as estimates outlined in the S2Biom project (which aims to predict the sustainable non-food biomass potential at the EU level), have predicted a maximum requirement of 476 million tons of lignocellulosic biomass to fulfil the needs of all bio-based industry in Europe by 2030. To put this into perspective, at least 1 billion tons of lignocellulosic biomass will be produced in Europe on an annual basis by 2030 [3]. Therefore, the challenge is not the availability of feedstock, but rather the logistical challenge surrounding the feedstock supply. The lignocellulosic feedstock supply chain may encompass collection, drying, densification, transport, and storage, and such processes will vary depending on biomass type and source [4-6]. Each supply chain stage faces formidable challenges, which can be summarized as follows:

Collection**:** The greatest challenges in the collection process are the marked decentralization of sources, the unpredictable fluctuations in quantity and quality, high moisture content (e.g. in case of agro-industrial waste) and possible contamination (e.g. soil pollution in agricultural residues). Collection, drying and densification are conducted in decentralized facilities prior to transportation to the biorefinery or centralized storage facility.

Drying**:** Lignocellulosic biomass derived from agro-industrial wastes/residues contains a high level of moisture, which may complicate biomass handling, size reduction and densification, as well as increasing the susceptibility of biomass to spoilage and a consequent rapid deterioration in quality. Drying processes may be natural (e.g. in the case of grasses) or conducted via conventional heating or microwaves.

Densification**:** Densification (compaction), carried out by means of stacking, baling, briquetting, or pelletizing, is an essential pre-processing step to increase the bulk density of lignocellulosic materials. These steps permit efficient transport and storage operations and achieve standard sizes and weights for each unit of feedstock. Before the compacting process, mechanical processing may be required to reduce size by shredding and grinding. While existing equipment used in agriculture could be employed in moderate-scale biomass compacting and size reduction, new technologies are required to handle large amounts of biomass for industrial scale processing.

Transport**:** Economically, transportation efficiency is increased when the collection area is closer to the processing/storage facility. Existing transportation systems employed for moving woodchips or lignocellulosic wastes may prove inefficient due to the low density of lignocellulosic wastes and transportation energy costs.

***Storage*:** Variations in quantity and seasonal availability of agricultural residues or agro-industrial waste, as well as in the location of sources, all combine to create the need for long-term storage facilities. However, this requirement presents challenges in terms of maintaining biomass quality at a high capacity and at a low cost. Additionally, there may be significant health and safety aspects of biomass storage that can complicate operations [7].

To address these challenges in supply chain logistics, several strategic research initiatives have been recommended by The European Biorefinery Joint Strategic Research Roadmap for 2020, with a view to achieving the European Biorefinery 2030 vision [8]. Such recommendations include the development of integrated logistical models to remove supply chain bottlenecks, the availability of machinery which is capable of handling large amounts of feedstock, the mapping of biomass inventories, and the establishment of a centralized regional hub for biomass collection and storage.

These efforts are expected to decrease logistical costs, which in turn may reduce biorefinery production costs. However, for long-term commercial success, economies of scale in terms of biorefinery size are also vital in the goal to achieve economically acceptable conversion processes [9]. Thus, logistics costs and operational complexity increase as processing capacity or lignocellulosic feedstock collection/storage radius increase. Accordingly, smaller-scale integrated biorefinery units are being studied for suitability in small rural-urban areas in Europe to address these challenges [10].

2.2. Processing of Lignocellulosic Feedstock:

Current lignocellulose pretreatment approaches: Lignocellulosic biomass is a complex matrix that is relatively refractory to degradation. Sugars are locked in a recalcitrant structure that requires a pretreatment step to release them. Many conventional methods (e.g. chemical, physical, and biological methods) are used for pretreating lignocellulosic biomass. However, achieving a workable balance between pretreatment efficacy, cost and environmental sustainability is difficult [11]. Therefore, even combinations of these methods have not been deployed effectively at the required scale of an integrated biorefinery that utilizes multiple feedstocks.

Current lignocellulose utilization technologies: The current mainstream lignocellulose disruption technologies that are employed in a typical biorefinery depend both on the specific lignocellulosic feedstock and the value of the final product. Such technologies may be classified as either biochemical [12] or thermochemical [13], and key challenges relate to scalability and flexibility to sustainably optimize the production process (against a background of diverse feedstocks, variable market demand and fluctuating economics). Hence, integrating the biorefinery concept with existing industrial processing methods has been identified as a potential solution to address these challenges. For example, the most common proposed model cited is an integrated biorefinery-pulp/paper plant that can produce chemicals, fuels, or electric power, along with conventional wood, pulp, and paper products. However, in reality, aspects such as the separation and purification of products, as well as ensuring quality and standardization, add additional challenges to the industrialization process.

2.3. Biobased products market

Examples of potential bio-based products include biofuels (e.g. bioethanol, biodiesel, and biogas), biochemicals (e.g. industrial enzymes, and nutraceuticals), and biomaterials (e.g. biodegradable plastics) [14]. However, supported by specific EU policies (Fig. 1), bioenergy and biofuels have received greater attention. By the year 2030, the EU aims to provide 25%

of its transportation energy via biofuels derived from advanced biorefineries (2nd generation biorefineries). By this time, it also intends to replace 30% of oil-based chemicals by bio-based chemicals, and supplant non-degradable materials with degradable materials. Interestingly, 80% of the EU bio-based infrastructure will be in rural areas, which are expected to support community development programs. However, developing sustainable markets for bio-based products, and raising the public awareness of this area will still be a challenge. Even so, it is expected that evolving market demand, combined with further EU policies acting to spur public awareness, will accelerate product development and encourage private sector investment. International experts foresee that at least 15 advanced biorefineries will be launched by 2024 [15].

3. Conclusion

The lignocellulosic biorefinery represents an important component of the future European bioeconomy. While this nascent industry faces significant challenges, such as feedstock logistics, limitations of conventional processing technologies and uncertain market economics, such challenges are being countered by ambitious EU policies that are aimed at supporting this industry to achieve climate and bioenergy goals.

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Table 1. Funded projects by the EU for utilizing Lignocellulosic feedstock in Biorefinery industry.

Project name	Biorefinery Feedstock	Coordinated in	Period	Total Cost (EUR)
AgriChemWhey	By-products from dairy processing	Ireland	2018-2021	29 949 323
GRACE	*Miscanthus* or hemp varieties from marginal lands	Germany	2017-2022	15 000 851,21
SmartLi	Kraft lignins, lignosulphonates and bleaching effluents	Finland	2015-2019	2 407 461,25
BIOSKOH	Lignocellulosic feedstock	Italy	2016-2021	30 122 313,75
BARBARA	Agri and food waste	Spain	2017-2020	2 711 375
AgriMax	Agri and food waste	Spain	2016-2020	15 543 494,56
PULP2VALUE	Sugarbeet Pulp	Netherlands	2015-2019	11 428 347,50
GreenSolRes	Lignocellulosic residues or wastes	Netherlands	2016-2020	10 609 637,01
Dendromass4Europe	Dendromass on marginal land	Germany	2017-2022	20 442 318,75
SYLFEED	Wood residues	France	2017-2020	14 976 590
GreenProtein	Vegetable residues from the packed salad processing	Netherlands	2016-2021	5 546 519,99
PROMINENT	Cereal processing side streams.	Finland	2015-2018	3 103 897,50
FIRST2RUN	Cardoon from marginal lands	Italy	2015-2019	25 022 688,75
Zelcor	Lignocellulosic residues from ethanol production, lignins dissolved during pulping process and lignin-like humins formed by sugars conversion	France	2016-2020	6 710 012,50
STAR4BBI	Lignocellulosic feedstocks from forests, and agriculture	Netherlands	2016-2019	995 877,50
BIOrescue	Wheat straw and agri-industrial waste	Spain	2016-2019	3 767 587,50
OPTISOCHEM	Residual wheat straw	France	2017-2021	16 376 816,83
US4GREENCHEM	Lignocellulosic feedstock	Germany	2015-2019	3 803 925
FUNGUSCHAIN	Mushroom (*Agaricus bisporus*) farming residues	Netherlands	2016-2020	8 143 661,25
POLYBIOSKIN	Food waste	Spain	2017-2020	4 058 359,38
ValChem	Woody feedstock	Finland	2015-2019	18 502 703,25
LIBBIO	Andes Lupin from marginal lands	Iceland	2016-2020	4 923 750
LIGNOFLAG	Straw	Germany	2017-2022	34 969 215

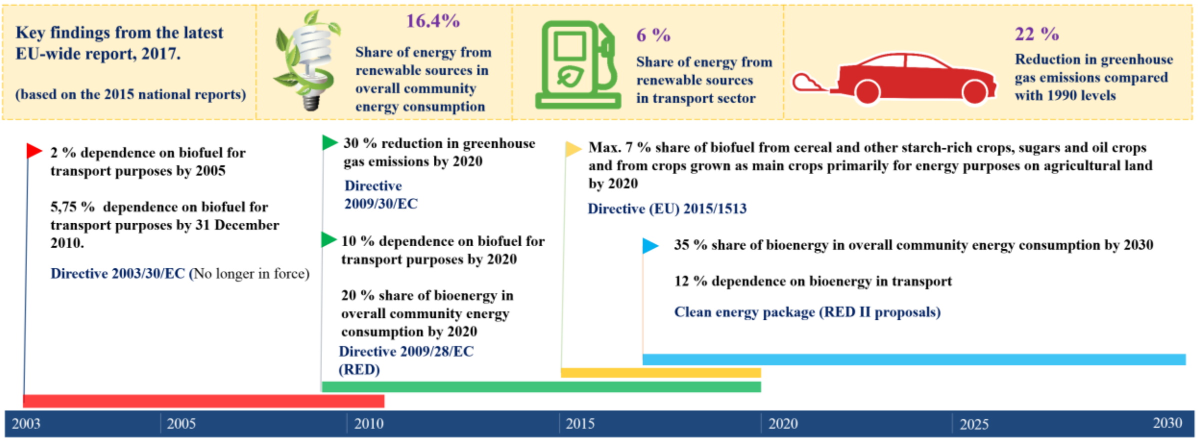

Figure 1. Biofuel Policy and Targets from 2003 to 2018; Road map for 2020 and beyond