Standards and Regulations for the Bio-based Industry
STAR4BBI

Work Package 3

D3.1 Identification of technological trends in selected value chains

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Acronyms

AIEAA: Associazione Italiana di Economia Agraria e applicata
BTG: Biomass Technology Group
CAPEX: CAPital EXpenditures
CRISPR: Clustered regularly interspaced short palindromic repeats
DSS: Decision support systems
EASAC: European Academies’ Science Advisory Council
ECJ: European Courte of Justice
ECN: Energy Research Centre of the Netherlands
EFI: European Forest Institute
EPO: European Patent Office
FDCA: 2,5-Furandicarboxylic acid
FOAK: First-of-a-kind
GM: Genetic modified
GMO: Genetically modified organisms
HMF: 5-hydroxymethylfurfural
ICT: Information and Communication Technology
IEA: International Energy Agency
ILUC: Indirect land use change
INRA: Institut national de la recherche agronomique
JRC: Joint Research Centre
KET: Key Enabling Technologies
LTO: Land- en Tuinbouw Organisatie
MEG: Monoethylene glycol
NREL: National renewable energy laboratory
ODM: Oligo-nucleotide directed mutagenesis
OPEX: Operating expense
PEF: Polyethylene furanoate
PET: Polyethylene terephthalate
PHA: Polyhydroxyalkanoate
PLA: Polylactic acid
PTA: Terephthalate acid
RED II: Renewable Energy Directive
ROI: Return on Investments
SME: Small and medium size enterprises
SRES: Special Report on Emissions Scenarios
WOS: Web of science

Summary

The development of new biorefinering technologies to transform renewable resources into bio-based products and materials plays a crucial role in the transition away from a fossil-based society. Such a transition is expected to enable the European industry to deliver high-value products, which satisfy evolving consumer needs, create new commercial opportunities and reduce possible risks to the environment. Therefore, there is considerable economic and political pressure to ensure that novel technologies deliver innovation in line with societal priorities. Improved and systematic foresight investigations with a focus on technologies are needed for better decision-making in the future and for enabling the bio-based economy to timely tackle those challenges.

In this report, the results of the ex-ante analysis executed under the STAR4BBI project with the objective of identifying possible future technological developments, industry trends and innovations in selected value chains of the bio-based industries are presented. It aims at capturing the view of experts on anticipating future industry trends and innovations and identifying preliminary potential updates of the regulatory framework needed for supporting a full deployment of innovation potentials and therefore stimulating investments.

The principle of the cascading use of biomass, alternative innovative feedstocks (e.g. food waste and industrial waste), digitalization and, among others, cooperation agreements with farmers and forest owners, have been highlighted by the experts as pieces of innovation that will play an important role in upscaling the bio-based industry in the timeframe of 10 to15 years. In addition, different novel technologies for improving biomass cultivation efficiency (e.g. modern genome editing techniques) and efficiency in biorefineries (e.g. integrated biorefinery) have been indicated by the experts. However, there is a need to support the implementation of these innovative developments and technologies with the establishment of an innovation and investment friendly regulatory framework.

CRISPR related technologies, techniques for the valorisation of lignin and furan-based chemistry resulted as the three most promising technologies/innovations and were defined by the experts as potential drivers of change for the future of the European bioeconomy. As a result, these innovations and their full deployment are considered in this report, as a plausible description of how the industry might develop. However, the capacity for innovation and future development of these three breakthrough innovations/technologies depends on favourable regulatory and investments conditions. More specifically, for CRISPR related technologies updates in the current European regulatory framework are considered extremely important to fully deploy the potential and opportunities of this technological breakthrough. In the case of the valorisation of lignin and in furan-based chemistry to produce FDCA from sugars, experts referred mostly to technical barriers behind the development and adaptation of promising processes and technologies that should be addressed in order to fully exploit their potential. Specifically for the case of lignin, experts see the need for standards and of cross-sectorial partnership between biomass providers (forest and agro-based sectors) and industry involved in the development of technologies for the valorisation of lignin.

Table 1 (below) includes an overview of the main results, indicating which kind of intervention is imminent to fully deploy the potential and opportunities offered by the identified innovations/technological trends. For the purpose of this research, these interventions are classified as needed regulatory updates and support to investments.

Identified innovations/technological trends	**Intervention required**	
Trends in biomass cultivation efficiency	*Regulatory updates*	*Support to investments*
Cascading principle and circularity	X	
Genome editing techniques	X	
Digitalization in agriculture and forestry		X
Techniques for improving biomass cultivation efficiency	X	X
Cooperation agreements with farmers	X	X
Trends in processing and refining	*Regulatory updates*	*Support to investments*
Efficiency in plants	X	X
Integrated biorefineries	X	X
ICT and Industry 4.0		X
Innovations in biorefineries		X
Trends in vegetable oil biorefineries	*Regulatory updates*	*Support to investments*
Innovative extraction techniques		X
Innovative conversion techniques		X
Innovative applications		X
Product driven vegetable oil biorefineries		X
Trends in starch and sugar biorefineries	*Regulatory updates*	*Support to investments*
Production of bio-based products from 1st generation to 2nd generation sugars		X
Polyethylene furanoate (PEF) production to replace fossil-based polyethylene terephthalate (PET)		X
Trends in lignocellulosic biorefineries	*Regulatory updates*	*Support to investments*
Innovative pre-treatment technologies		X
Innovative conversion techniques		X
Product driven lignocellulosic biorefineries		X
Valorisation of lignocellulosic biomass	X	X
Identified potential "breakthrough" innovations / technologies	*Regulatory updates*	*Support to investments*
CRISPR technologies	X	X
Valorisation of lignin	X	X
Furan-based chemistry from sugars		X

Table 1 Overview of the main results

1. Introduction

This report presents the results of the ex-ante analysis executed under the STAR4BBI project with the objective of identifying possible future technological developments, industry trends and innovations in a horizon of 10 to 15 years in selected value chains of the bio-based economy (identified in an earlier phase of the project). It aims at capturing the view of experts on future industry trends and innovations and identifying updates of the regulatory framework that are likely to be needed for supporting a full deployment of innovation potentials (scenarios).

This report adopts the definition of scenario provided by the SRES report[i], which defines a scenario as a plausible description of how the future might develop. It does not aim at exploring alternative futures.

The remainder of the report is structured as follows: after providing an overview of relevant definitions, section 2 outlines the adopted methodology; section 3 provides a short overview of the studies analysed in the literature review; section 4 describes the results of identified trends that may improve efficiency both in biomass production and in processing and refining of biomass; section 5 describes potential innovations specific to selected value chains; section 6 contains specific information on the three most promising identified innovations/technologies and includes an analysis of the fluctuations of related patents and scientific publications; section 7 presents conclusions and next steps.

The results described in this report will represent the basis for preparing the questionnaire for a Delphi survey to be implemented within the framework of the project. The aim is to identify regulatory and standardization needs for enabling future investments and market developments of bio-based products in Europe. As part of the implementation of this project, recommendations for policy makers will be designed towards the establishment of an investment and regulatory friendly framework able to underpin the full deployment of the identified potential innovations.

2. Definitions and methodology

In the framework of this report, the identification of upcoming innovations and technological trends focuses on the concept of biorefineries, which represent a keystone for the establishment of the future bioeconomy[ii]. Objectives of the study are different feedstock biorefineries, including vegetable oils, sugar and starch, wood and agricultural/forest residues. This classification covers the STAR4BBI selected case studies, which are:

- PLA intermediates and foam for construction from sugar and starch
- Building blocks for bio-based plastics from vegetable oils
- Pine chemicals from wood and forestry by-products
- Succinic acid from starch
- Packaging based on wood and starch derivatives
- Cellulosic fibres into diverse lignin-based components
- Oleochemical products, mainly metal soaps for industrial applications

The forward-looking analysis presented in this report focuses on the identification of upcoming innovations and technological trends that could potentially improve efficiency both in biomass cultivation and in processing and refining steps (see figure 1).

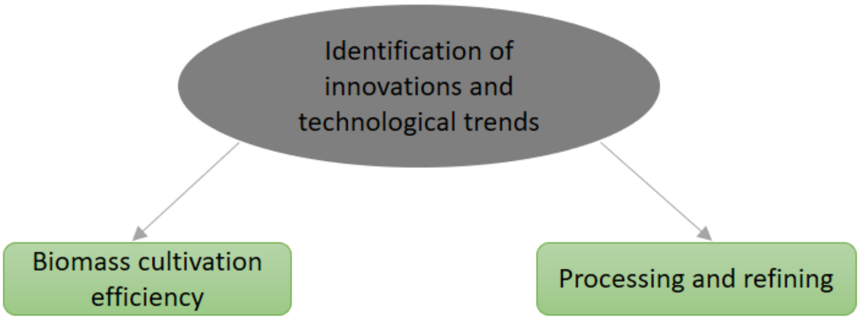

Figure 1 Focus of the forward-looking analysis

Biomass concept

Biomass is derived from organic materials such as trees, plants, as well as, agricultural and urban waste. Increasing the use of biomass in the EU can help diversify Europe's energy supply, create growth and jobs, and lower greenhouse gas emissions[iii]. Biomass resources include primary (biomass taken directly from the land, such as woody crops, the seeds of oil crops, residues resulting from the harvesting), secondary (biomass obtained after processing of primary biomass physically or chemically, such as wheat straw or corn stover), and tertiary (post-consumer residue streams, such as animal fats and greases, construction debris) sources of biomass.[iv] Depending on its origin, biomass can be classified as[v]:

- Biomass from agriculture: energy and agricultural crops and primary residues (sugar crops, starch crops, oil crops, etc.)

- Biomass from forestry: forestry biomass, primary forestry residues and secondary forestry residues
- Biomass from marine environment: fresh water plants, algal and aquatic biomass
- Biomass from waste: primary, secondary and tertiary residues and waste (municipal solid waste, non-hazardous commercial and industrial waste, oil-based residues, etc.)

According to the JRC, agriculture accounts for approximately 65% of the biomass supply sector in the EU-28, forestry accounts for 34%, and fisheries represent less than 1%. Over 60% of biomass is used for feed and food, with the remainder split evenly into bioenergy (biofuels) and biomaterials (mainly solid wood products).[vi]

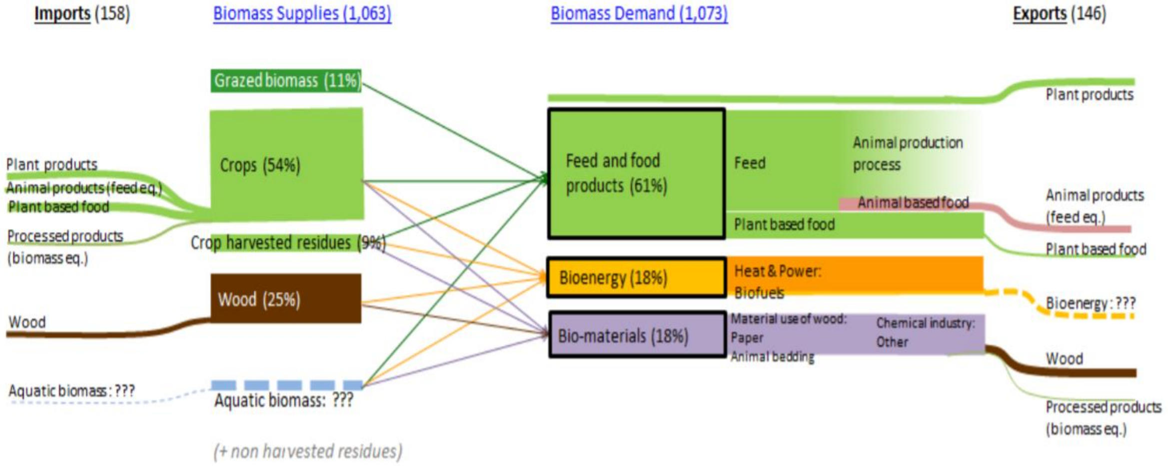

Figure 2 Biomass flows in the European Union. JRC. 2017

Biorefining concept

According to the NREL, a biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. A biorefinery can use all kinds of biomass ranging from agriculture and forestry to aquaculture and waste.

Following, in figure 3, a general graphical representation of the different processing and refining steps considered in the analysis is shown. In the biorefining stage, biomass may be separated into its different components (e.g. cellulose, starch, sugar, vegetable oil, etc.). This step usually includes the pre-treatment and conditioning of biomass, followed by component separation. Platform refers to the intermediate products that arise during biorefining and which serve as precursor for subsequent processes.

During the conversion process, the components may be transformed into intermediates or precursors and products through further conversion steps (raw materials are fully or partially processed into precursors or into more intermediate materials and afterwards, they are fully or partially refined into high-value products, including finished or semi-finished products).

Production processes belong to the following four main categories[vii]: mechanical or physical processes to achieve the size reduction and separation of the various components of the biomass (milling, separation, upgrading, etc.); chemical processes where chemical change in the substrate occurs (hydrolysis, oxidation, etc.); biochemical processes where microorganisms or enzymes are used (fermentation, transesterification, etc.); and thermochemical processes where feedstocks undergo extreme conditions (gasification, pyrolysis, etc.).

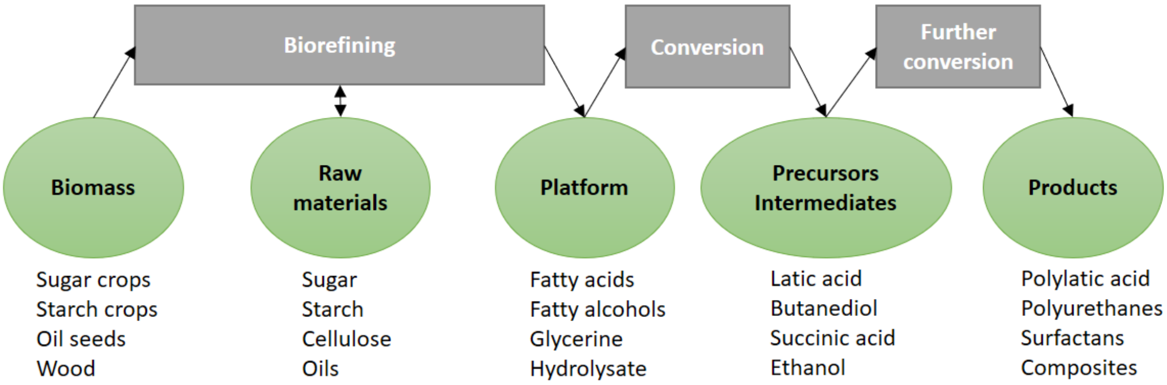

Figure 3 Processing and refining steps in biorefineries

Foresight analysis

The conducted foresight analysis includes the following main tasks: identification of potential innovation and technological trends (drivers of change), investigation of possible evolution pathways of identified innovative developments and preliminary identification of existing challenges.

As indicated in figure 4, the empirical analysis for the identification of potential drivers of change is based on an initial review of the literature, including foresight studies, academic literature, and grey literature. A list of the identified and analysed studies is included in section 3, and the results of the analysis are included in Annex I. The studies have been selected in order to cover the three value chains preselected as case studies: vegetable oil, starch and sugar and lignocellulosic biorefineries.

Figure 4 Different steps of the methodology

The results of the literature review have been used for the preparation of a questionnaire for conducting semi-structured interviews with technology experts in the field of biomass cultivation efficiency and biorefineries processes. The interviews aimed at capturing experts' view on possible emerging and breakthrough technologies that are likely to have the biggest future influence and the greatest potential to increase biomass cultivation and production efficiency in biorefineries, in the next 10 to 15 years, as well as, the related regulatory and investment barriers that could stop or delay these technological trends. Overall, 20 stakeholders have been interviewed, including 10 experts from industry and 10 experts from academia. Experts from the industry, include representatives of the STAR4BBI project selected case studies.

The questionnaire (included in Annex II) was structured in two main sections. The first section included different questions aimed at capturing the view of experts in the identification of potential innovations that could improve efficiency in biomass cultivation in the next 10 to 15 years. The second section included different questions aimed at capturing the view of experts in the identification of potential innovations that could improve efficiency in processing and refining steps in the next 10 to15 years. For both sections, generic and value chain specific questions were included.

The semi-structured interviews have been completed with an overview of the evolution of patents and scientific publications of the identified three breakthrough technologies/innovations identified on basis of the interviews. The patents were identified using the EPO database and the scientific publications using the WOS database.

3. Literature review

For the preparation of the experts' interviews template (see Annex II), different existing foresight studies have been identified and analysed.

In the following table, the selected studies are listed. On the right side of the table, studies are classified based on the focus related to biomass cultivation and/or production processes (PP). In addition, it is indicated to which value chain each study refers to (V: Vegetable oil / L: Lignocellulosic / S: Starch and sugar / G: General, applicable for all of them).

Name of the identified and analysed foresight studies	**Biomass**				**PP**
	V	**L**	**S**	**G**	
Biofuels in the European Union A vision for 2030 and beyond (Biofuels Research Advisory Council) (2006)	X	X	X	X	X
SCAR Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy: A Challenge for Europe (EC) (2015)	X	X	X	X	X
SUMFOREST Foresight Panel and Foresight Workshop Results on "Emerging Issues in European Forest-Based Sector and Research Priorities" (European Forest Institute) (2015)		X			
Global Food Security 2030 - Assessing trends with a view to guiding future EU policies (JRC) (2015)	X		X		X
A global view of bio-based industries: benchmarking and monitoring their economic importance and future developments (JRC) (2016)	X	X	X	X	X
Forest bioeconomy - a new scope for sustainability indicators (EFI) (2016)		X			X
EU commodity market development: Medium-term agricultural outlook (JRC) (2016)	X		X	X	
Agricultural knowledge and innovation systems towards the future (AKIS) (EC) (2016)				X	X
Teagasc Technology Foresight 2035 Report (2016)		X		X	X

Table 2 Identified and analysed foresight studies

The main results obtained in this analysis are presented in Annex I. In addition, in order to complement the results of the interviews, further studies were analysed[1].

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[1] See the list of references.

4. Innovations and technological trends and related regulatory and investment barriers

In this section, the main findings of the interviews with experts on general innovations and technological trends for both biomass cultivation and production processes are presented. In addition, a preliminary assessment of the related regulatory, investment and standardization challenges is included.

4.1 Achievements to increase biomass cultivation efficiency

Cascading principle and circularity

The majority of the experts mentioned the principle of cascading use of biomass as a way to maximise resource efficiency. According to the European Commission, cascading use can be defined as the efficient utilisation of resources by using residues and recycled materials to extend total biomass availability within a given system[viii]. In other words, the cascading use of biomass is understood as the sustainable use of all biomass streams including waste (comprehensive raw material use). Sustainable use requires that minerals and carbon content in the soil should be maintained at an acceptable level, which means that they have to be brought back to the field in sufficient quantities. Another approach differentiates between 'cascading use' in terms of a vertical use hierarchy (a product is manufactured and after its end of life, a new product is made from it, e.g. through recycling) and of 'coupled or co-production' in terms of a horizontal use hierarchy, which means the utilisation of side streams and residues (e.g. Vis et al. 2014). By applying the principle of cascading use of biomass, the recycling of bio-based products and multiple uses of the same feedstock are encouraged, increasing overall feedstock efficiency. Increased coupled production – which in this context is subsumed under the term "cascading use" – will open the pathway to alternative feedstock use in production processes, including food waste, agricultural and forest residues.

To date, the potentials of biomass cascades have been largely ignored[ix], and the realization of cascade potentials is still minor. Indeed, nowadays, residues (such as lignocellulosic biomass of sunflower and cardoon) are mostly used for energy generation. However, applied research on the valorisation of biomass residues to high-value products such as lactic acid and other biochemicals is increasing. Different biorefineries in Europe have been utilising for decades all fractions of the biomass in order to maximize the economic output, including UPM, Borregaard and British sugar. In addition, the BBI JU project AgriChemWhey (2018-2021) can be cited as an example for proposing the development of the first world integrated biorefinery for converting food-processing residues to bio-based chemicals. The project is working towards the establishment of a dedicated plant in Ireland.

The use of 2nd and 3rd generation agro-industrial residues (such as sugarcane bagasse or side-streams of dairy processing), following an industrial symbiosis model has also been mentioned as an emerging trend that provides an opportunity for more resource efficiency. Industrial symbiosis is the exchange of materials or waste streams between companies, so that one company's waste becomes another company's raw materials[x].

On the other hand, nowadays, large amounts of solid food wastes are buried in landfills, while liquid food wastes are released into public sewer systems. High transport and landfill costs and strict governmental regulations have led to the development of alternative utilization options of food processing wastes. The selection of an appropriate process to recover materials and energy from food waste largely depends on the characteristics of the waste, the desired forms of bioenergy and bio-based products to be produced, and the economic feasibility.[xi] Incorporation of price-advantaged feedstocks like organic, municipal, and wet-waste materials has been highlighted by the experts as upcoming innovations that could have an added benefit of solving local and regional waste disposal related issues. However, other experts also pointed out that market mechanisms are volatile and hard to predict. As soon as a market exists for such feedstocks, it is difficult to say how price structures will develop and whether they will still provide an advantage. Currently, the valorisation of organic waste into fertilisers is endorsed by EU fertiliser regulation, in which common rules about the conversion of bio-waste into raw materials that can be used to manufacture fertilisers[xii] are provided.

The production of sustainable non-food crops (hemp, cardoon, mischanthus, etc.) on marginal lands (those that cannot be used for growing food crops, including contaminated land) as alternative feedstock was also mentioned. In this respect, contrasting opinions were given. On the one hand, non-food crops that can stay for a longer time with less fertilizers improving soil quality are seen as an interesting prospect for avoiding the global competition for land. In addition, some of these non-food crops, like miscanthus and hemp are relatively under-exploited, even though it is stated that they could offer an interesting business opportunity for farmers and industry. However, this promise should be regarded with some caution, since research in both, miscanthus and hemp, has been going on for decades and its implementation instead is still lacking – if the business case were that good, more farmers would have gotten on the proverbial train already. One reason for the non-implementation is that perennial crops constitute a much larger risk for farmers, since they cannot decide from year to year which crops they will cultivate – often missing out on rising prices and therefore revenues for other certain crop in the next year. Another reason is that the term “marginal land” by definition means a piece of land that is not economically feasible to use for a given purpose. Without subsidies or other incentives, it is highly unlikely that farmers will start cultivating such areas[xiii].

The appropriateness and potential of using marginal lands for cultivating several non-food industrial crops as a source of biomass is being analysed by different research projects, such as GRACE (2017-2022) and MAGIC (2017-2021), both financed by the BBI JU.

Multi-cropping systems where more than one crop are grown on the same field during the season with annual rotation, can be considered as a solution to improve harvesting by moving away from dominant monocultures, which reduce biodiversity and soil quality. Multi-cropping systems and short rotations have the potential to increase the yields per hectare, instead of increasing the yields of a single oil crop, but also pose severe challenges. On the one hand, ideally the different crops should have similar properties if they are intended to be used for the same purposes. On the other hand, this may involve costly changes in today’s fully automated agriculture planting and harvesting machinery.

An important and critical trend is the development of high-value products from lignin (selected as a breakthrough innovation and further analysed in the section 6.2) as a side-stream from lignocellulosic value chain. Early biorefinery models based on lignocellulosic plants focused on the extraction of sugars and their conversion into platform chemicals, assuming that lignin residues would be burned to produce steam and power. However, several economic analyses[xiv][xv] clearly show that at least a portion of the lignin residue must be converted to high-value products in order to have an economically viable biorefinery.

Finally, experts recognize that there is a need to develop Decision Support Systems (DSS) for optimizing the supply chain management, including the use of the cascade principle. DSS are information system that supports business or organizational decision-making activities.

Genome editing techniques

Experts recognize the relevant and increasing role that modern genome editing technologies[2] play in further development of the bioeconomy industries. They were mentioned as technologies that could potentially:

- Increase productivity and robustness of crops as well as strengthen resilience to volatile temperatures and diseases
- Improve quality of plants (e.g. oleic content in the case of sunflower and cardoon).
- Optimize the biomass composition for specific technical applications toward the development of non-food crops (e.g. non-food oil crops jatropha, crambe, camelina, guayule, etc.), or making easier transformation into bio-based products when plants already have a preferred chemical structure (e.g. high linoleic, oleic content).

Among genome editing technology, CRISPR technologies were identified as the most relevant to be used for technical applications by the majority of experts. For this reason, CRISPR technologies have been selected as promising breakthrough technologies and further analysed in the section 6.1.

Digitalization in agriculture and forestry

The use of ICTs has a great potential for improving biomass cultivation efficiency. In the coming years, ICTs will be used to screen the quality of the biomass with sensors between the harvest and the biorefining stage to fine-tune the processes. This could help to identify the quality of the biomass in terms of purity and moisture content. Indeed, digitalization can support the design of new biomass value chains and measure the quality control (infrared technologies) by improving biomass production through reliable, high resolution and up-to-date information. Precision farming will enable to respond much more rapidly and effectively to problems related to climate change, logistics and transportation, as well as, resource efficiency. In fact, according to some experts, ICT will change the agricultural sector more than other technologies will.

Several BBI research project are making substantial efforts to integrate the use of ICT in agriculture in order to improve biomass cultivation efficiency. For example, the EFFORTE

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[2] New forms of genetic modification that do not involve the introduction of genes from other species.

project (BBI JU project, 2016-2019) aims at achieving substantial influence on the implementation and improved use of Big Data within forestry increasing cost-efficiency and boosting new business opportunities to SME in the bioeconomy. The TECH4EFFECT (BBI JU project, 2016-2020) project focuses on increasing access to wood resources through data and knowledge-based forest management, increasing efficiency in forest harvesting and collection, and reducing soil impact from forest operations.

Even if the use of ICT could have a high return on investments (ROI), it is important to consider that digitalization is cost intensive. Therefore, mainly for small farmers and forest owner the cost for acquiring and adopting these technologies represents a barrier.

Experts suggested that technical assistance and education on new machineries and cultivation equipment could be provided to farmers. Developments in the education approach of farmers will help to close yield gaps between European countries. Matrìca (Italy), is actually providing farmers with full technical assistance for new technologies, therefore according to most of the experts interviewed, it is a model to be followed and replicated. Another solution would be to establish a network or cooperative of farmers, agroindustry and biorefinery stakeholders in order to share knowledge and information (see below, Cooperation agreements with farmers and forest owners).

Other technologies for improving biomass cultivation efficiency

Improvement of land use techniques

With regard to the improvement of the land use techniques, special attention has been paid to the use of fertilizers. Currently used fertilizers are made with phosphorous, which in addition to be a limited resource[xvi], is imported[xvii], has a high carbon footprint and reduces soil quality in the long-term. Therefore, research efforts are aimed at finding a substitution or even recovery methods. The substitution of mineral fertilizers could be accomplished using other products, derived for example from farm residues, such as struvite, which is a recycled source of phosphorous extracted from wastewater and an effective alternative to maintain the agricultural production systems[xviii].

Innovative harvesting, separation and storage

Decentralization and pre-processing could be a solution to reduce storage and transport requirements, e.g. wood could be pyrolysed to produce an energy dense bio-oil in a pre-processing plant, which then can be transported and upgraded to biochemicals. In the same way, beets could be processed locally to produce a storable dense sugar, reducing transport costs and redistribution of beet process residues, which is easily transportable to a fermentation facility. In general, biorefineries should be near the fields otherwise the transportation costs are too high.

Innovative cultivation and growing systems to improve yields

A solution for improving the efficiency of the yields could be to improve the photosynthesis of plants. Crop leaves in full sunlight, dissipate damaging excess absorbed light energy as heat. When leaves are shaded, this protective dissipation continues for many minutes and reduces photosynthesis. Predictions have suggested that the efficiency of the photosynthetic process could improve crop yields.[xix]

Multiple targets have been identified that could be manipulated to increase crop photosynthesis. The most important target is Rubisco because it catalyses both carboxylation and oxygenation reactions and the majority of responses of photosynthesis to light, CO_2, and temperature are reflected in its kinetic properties[xx]. In addition, photosynthesis of plants can be also improved through genome editing techniques (see 6.1 CRISPR related technologies).

Cooperation agreements with farmers and forest owners

To promote biomass availability in a sustainable manner, cooperatives and cooperation between biomass producers should be promoted[xxi]. Already implemented examples of this business model are the companies Novamont (Italy) and Pomacle Bazancourt (France). The recently growing number of sugar platform biorefineries, which focus on bio-based products, could also be considered in this regard. Avantium, Reverdia and GFB chemicals are examples of multi-actor innovation partnership networks with farmers and biomass producers that are being developed in order to valorise and exploit side-stream biomass resources from agriculture and forestry.

The establishment of programs to increase the skills and knowledge base of farmers, as well as, to offer them full technical assistance is considered a way to stimulate the use of locally produced feedstocks in biorefineries, potentially reducing the acquisition of feedstocks in the world market. In specific cases like in the Netherlands, these agreements might be not so important, since farmers are highly qualified and invest in their own specialization. In fact, farmers are in most of the cases co-owners of biorefineries. Examples of agro-industrial cooperatives in the Netherlands are the following: Royal Cosun (converting sugar beets, potatoes, chicory and vegetables and fruits into a wide range of products), Avebe (converting potatoes into wide range of starch-based products) FrieslandCampina (milk) and Agrifirm (wide variety of feed).

Experts highlighted that a dedicated network is needed to link the biorefinery stakeholders in Europe.

4.2 Achievements regarding the production processes

Efficiency in conversion and production plants

One way of achieving efficiency in conversion and production plants is the adoption of a **multipurpose-plant** model, in which biorefinery processes are integrated in existing infrastructures. This strategy can be adopted by oil refineries with a vision of transferring traditional oil refineries to biorefineries (e.g. Preem in Sweden). Another interesting model is the production of biodiesel and chemicals as by products. These kinds of plants combine both, thermochemical processes and biochemistry. This will also facilitate the use of all biomass streams in a circular economy optic.

In addition, **material-driven biorefineries** that primarily generate bio-based products, such as bio-based materials and chemicals are another way to make the plant more efficient since high-valuable products are produced first. According to several experts, material-driven biorefineries will mature and reach commercial scale in the next years. However, bio-fuels will continue to be produced because the transportation sector is still very important (at least until the electric car gains the highest market share). In any case, experts retained that both material and energy driven biorefineries are needed, although materials create higher value. According to another expert, efficiency can also be increased by optimizing the quality of products for specific uses, especially the quality of intermediates.

Integrated biorefineries

The concept of integrated biorefineries in which fuels, heat and power and co-products are produced from diverse forms of regional biomass, promoting local and regional economic development and energy security, plays an important role in this study. The idea is not to replicate existing industries but to develop a new bioeconomy approach integrating innovative technologies in biorefineries within rural communities and therefore, promoting rural development. According to an expert, integrated biorefineries model will also facilitate the conversion of alternative feedstocks (such as lignocellulose) in existing biorefineries.

Integrated biorefineries that use all the biomass streams (including waste) and production processes according to the cascading approach is considered an optimal strategy. In the BALI project (see Figure 5) co-production of lignosulfonates and sugars has been implemented. BALI technology involves converting the cellulose fibres in biomass to sugars that can be used for the production of 2nd generation bioethanol, while other components of the biomass (lignin) can be used to produce advanced bio-chemicals (high-value products).

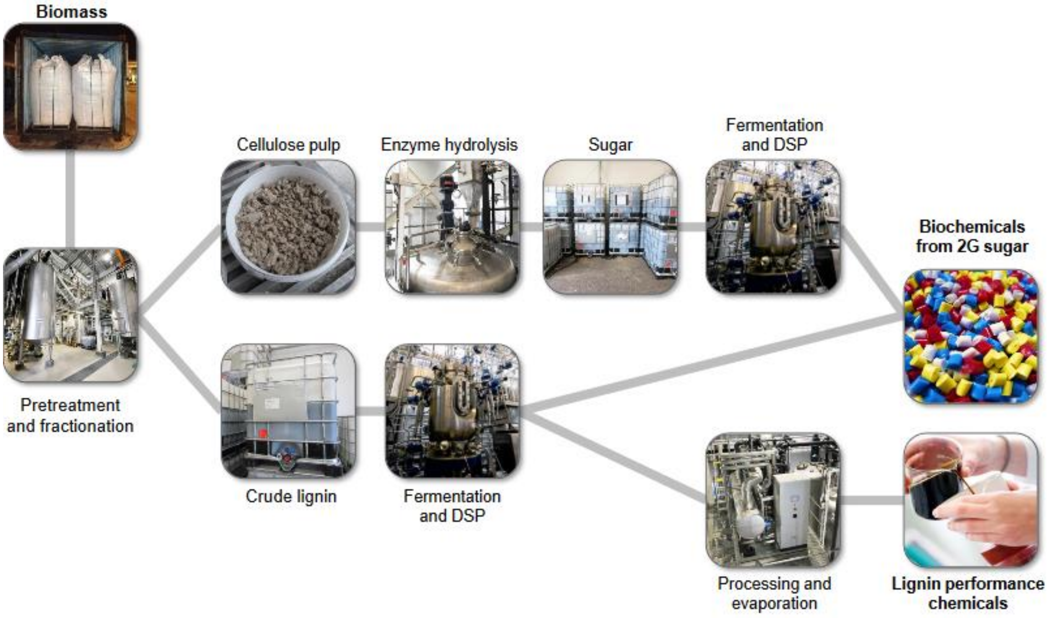

Figure 5 BALI Project. Borregaard

Developments of integrated innovative models of biorefineries such as Matrìca in Italy, which produces new bio-based products with extra functionalities, in demonstration plants, will reach a commercial scale for more applications. Most experts agreed that Matrìca will be standard model for biorefineries to follow in the future.

Digitalization and industry 4.0

Experts recognize the role of digitalization and the use of ICT tools in significantly improving logistical issues such as biomass supply, collection and storage and the preparatory steps towards biorefining. The revolution 4.0, defined as the introduction of automation, digitalization and data exchange in manufacturing technologies, is considered an innovation that can contribute towards achieving an increased efficiency in biorefineries manufacturing processes.

In addition, with the adoption of new digital developments, such as robotics, bio-based production processes can be easily supervised and the process of collecting and storing data is facilitated. It is expected that digitalization will support the sharing of data between industry and policy makers and therefore, it will improve the process of monitoring the impact of the bio-based economy.

There are a number of ways that digitalisation can influence production processes, such as:

- Tracking the composition and quality of the ingredients in a feed material to separate the usable and unusable streams of the feed material
- Digital networks for connecting actors from supply chain across sectors
- Automatized real-time monitoring systems provided by digitally connected entities of machines or databases that centralise data processing
- Automatized communication between production entities and optimisation of the system.

These and a number of other technological developments are meant to bring large improvements and cost efficiency in bio-based products. However, these are related to high investment costs, which is a limitation for a number of small companies.

There are already many companies introducing novel digital applications in their production processes, such as Borregaard biorefinery that changed its process controlling system from 15 control rooms to 1, running the whole plant with 4 consoles.

Potential innovation in the different biorefinery steps

In the following section, identified potential innovations applicable to the different steps of all the value chains are included, namely extraction, pre-treatment and biorefining. Specific innovations related to each of the selected value chains are presented in the section 5.

More efficient extraction techniques

More efficient extraction techniques comparing to those that are currently in used, include: supercritical fluid extraction, liquid extraction, partitioning, acid-based extractions, ultrasound extractions and microwave assisted extractions. As of now, these are mainly used in laboratories and not on a large scale. Enzyme technologies with nanotechnologies and combinations will also have a huge potential.

More efficient extraction means also using better bio-based solvents. New techniques will potentially substitute current solvent extraction with fossil-based hexane, which is very cheap and also safe, but not environmentally friendly. Selected value chains that currently use both, pressing techniques and solvent extraction techniques (hexane) are aiming to use only pressing techniques.

Improved refining

According to experts, the following improved pre-treatment technologies and enabling technologies are expected:

- Near Infrared spectroscopy models to identify biomass characteristics in an early stage. In this regard, microwave frequency could be a potential technology but is still in a research phase
- Enzymatic pre-treatments especially when combined with crude enzymes for on-site production via solid-state fermentation processes
- Techniques to reduce inhibitors for enzymatic hydrolysis and subsequent fermentation.

Improved conversion techniques from biomass into high-value bio-based products

Within conversion processes, the use of thermochemical processes for the production of innovative products are still in a research stage and according to several experts, they seem to have a long way to go. Thermochemistry benefits from about 150 years of technology development for efficiently converting these feedstocks to energy, fuel and chemical products, and the integration of a conventional or modified thermochemical conversion step to upgrade a bio-based feedstock or a product from a bio-based process[xxii]. Thermochemical processes depend on the final product (biofuel, bio-based chemicals, etc.) and therefore, different grades of purification are required, but a higher purification also means a higher cost. In contrast, the biochemical pathway is soon to be commercialized. However, according to one expert, effective biorefineries will use multiple conversion pathways, such as thermochemical, biochemical, chemo-catalytic, extraction, etc.

In addition, the interest for the following production processes is increasing: chemo-catalytic conversion of cellulosic biomass; biotechnological conversion for succinic and lactic acid, as well, as other organic acids; biochemistry and fermentation techniques; continuous fermentation processing (possibility with integrated hydrolysis) with an increasing circulation of inputs (e.g. nutrients, etc.) and biochemistry through enzymatic processes (Cargill, Dupont, Novamont); and esterification, a non-innovative biochemical process that is being improved to make it more efficient.

In general, for conversion processes, a decrease of the operational costs must be achieved, for example, in the catalyst operation operational costs can be improved by using iron instead of cobalt. In addition, according to several experts, once the processes are optimized, costs can be reduced by increasing the production volume and expanding it to other markets. In this direction, companies should be able to provide continuously innovative products that satisfy the latest needs of consumers. One possible strategy suggested by the interviewed companies is to acquire markets by sending samples of products worldwide and finding improved new applications for existing intermediate products.

4.3 Needed regulatory and investment updates

Needed general regulatory updates

The lack of a European level playing field between bio-based products and bioenergy and between bio-based and fossil-based products has been mentioned by the majority of the experts as barrier that hampers the potential deployment of innovations and technological trends in the European bio-based industry. According to one expert, nowadays, the global subsides to biofuels are 6 times higher than the combined subsidies to all bio-based products.

In order to support the production of bio-based products, experts provided different solutions: the implementation of a carbon tax to all products and the introduction of quotas in the currently discussed future Renewable Energy Directive (RED II) for promoting bio-based materials and products, where there is already implemented a blending mandate for biofuels. However, such quota regulations are often heavily protected by bio-based industries themselves, and therefore, a quick solution is not expected.

The availability of clear criteria for assessing the sustainability of bio-based products has also been mentioned as extremely important for the future development of the industry. Stakeholders need to come together to agree on a methodology, and this methodology could be included for example, according to several experts, within the Circular Economy Package of the European Commission.

Needed general investment updates

The experts mentioned different barriers linked to investments that need to be overcome. One of them is the volatile profitability and cash flow generation of bio-based products, because their market development is affected by volatilities in volumes and prices of both feedstocks and products. Another cited financial issue that could potentially lead to liquidity problems is linked to the large size of initial capital needed at early stage for producing bio-based products. Indeed, bio-based industries are usually cost intensive and financial resources are needed for moving from demonstration to FOAK and industrial scale projects[xxiii]. Although BBI JU is providing some good help in this respect, the European bio-based industry faces issues accessing private capital.

Regulatory framework conditions were also cited as challenges for investments. Experts referred to existing regulations that imply additional investment costs. For example, the regulatory requirements needed for the introduction of genetic modified crops in the EU market implies higher investment costs. In this regards, experts also cited the REACH regulation and the fact that its related registration obligations are costly and time intensive and therefore represent a burden for some innovative bio-based products.

On the other hand, regulation framework conditions are also considered important drivers towards the development of the bio-based economy. In fact, a recent report came to the conclusion that REACH may actually be an opportunity for the bio-based economy because it offers opportunities for producers to provide safe bio-based alternatives for substances of very high concern[xxiv]. In any case, strict chemicals safety regulation is often perceived as a plus by consumers and should be judged carefully.

Regulatory and investment barriers on biomass cultivation efficiency

Experts highlighted the lack of a consistent and standardized definition of the term cascading use as a major barrier. At the EU level there are several documents addressing the issue to encourage the cascading use of biomass: EU Bioeconomy strategy (2012), EU Forest Strategy (2013), Circular Economy Package (2014-2015) and RED/iLUC directives. Most of these, however, have guideline character and do not provide concrete regulation supporting the enforcement and implementation of the policy. In fact, the RED and iLUC directives provide incentives for direct incineration of biomass in heat and power plants, undermining the objective of making the most value of biomass and keeping it in the circle as long as possible (see also[xxv]), directly counteracting the goals of cascading use.

In addition, the integration of the principle of cascading use of biomass into existing legislature differs widely among individual countries[xxvi]. For example, in Germany the policies having a considerable impact on the end-of-life management of wood waste are the ordinances on wood waste and the circular economy law (AltholzV/KrWG), while the biowaste ordinance and the circular economy law determine the treatment of organic waste (BioAbfV/KrWG). Although both waste treatment ordinances introduce regulations on collection quotas and recycling targets, they do not address the routes of use of the collected biomass, and do not provide any preference for either energy or material uses (in practice often supporting the direct energy use of waste wood).[xxvii] Another example is Flanders where the electricity producers can use wood only if the wood stream is not used as an industrial resource. This system is meant to support the creation of the cascading hierarchy of materials over energy applications of the biomass.[xxviii]

Furthermore, some experts recognize the existing European waste regulation as a barrier towards the development of the bio-based economy. The fact that waste is mostly undefined makes the process more difficult due to the different compositions and qualities (waste may contain heavy metals, etc.).

Besides, there is no harmonized system in the EU to classify alternative feedstocks, such as food waste, agricultural and forest residues. Some countries such as Finland, the Netherlands or Germany, have established systems of wood classification for recycling, but these are not consistent and not implemented everywhere. Regarding other feedstocks, such as food waste or agricultural residues, the “end of waste” criteria stemming from the Waste Framework Directive should be guiding in classifying feedstocks, but they are not easy to implement and not always unambiguous.

With regard to multi-cropping biorefineries, they could improve the biodiversity but this will take more than 15 years. The main problem is that this needs to deal with the seasonal variation in the production of different feedstocks, and therefore, quality might be affected. In this respect, the programme Horizon 2020 and other agricultural policies should focus not only on monoculture hindering innovation-farming methods such as agroforestry. In addition, the system is currently overregulated, so less regulation in this area would help farmers experiment more, thus creating a market for new technologies and investment opportunities. In addition, the introduction of multi-cropping system means the introduction of different harvesting techniques, which require innovation, and therefore more investment costs.

To conclude, several experts pointed out the problem of logistics. Biomass often has a strong seasonality, and logistics is a major obstacle for many feedstocks. Biomass yards and logistic trade centres should be developed as intermediate collection points, since residues can be pre-processed at farms and then transported to larger biorefineries.

Regulatory and investment barriers on genome editing techniques

In general, Europe is being very slow in deciding the regulatory status of crops resulting from genome editing techniques and currently a European decision whether regulations for GMO apply to plants is lacking. For the specific case of CRISPR techniques, there is a big discussion whether it should be regulated as a GM technique or as new breeding technology (see section 6.1). The majority agrees that the use of genome editing techniques should not be regulated as GMO; however, this should depend on the sector of application of the final product. Some experts recognize the importance of the use of GMO, in addition to gene-edited crops, for specific technical applications (such as fuels and chemicals) but not for food.

Regulatory and investment barrier on the use of ICT

The main problem when implementing ICT in farms and industries is related to investments. In most of the cases, ICTs are cost intensive and there is need to ensure that these technologies are implemented without losing jobs. The implementation of ICTs in industries like online analytics (real-time connexion between laboratory and plant) is costly and especially for small plants this can represent an unaffordable cost since there is no financial support. In addition, support is needed to develop new skills and competences to operate the smart factories of the future.

Also relevant are the data ownership and data security issues. Farmers increasingly have to reveal confidential farm details to gain access to the benefits of ICT technologies. This issue must be regulated in order this information not to fall under the control of the market speculation.

Another topic related to data security is the lack of regulation on the ownership of the data gathered by drones. Drones are used to increase yields and reduce crop damage, providing farmers weekly/daily/hourly information on crops to analyse irrigation problems, soil variation and pest or fungal infestations, and multispectral images that highlight differences between healthy and distressed plants.

Regulatory and investment barriers linked to efficiency in plants

Biorefineries must comply with several regulations in most of the cases slowing down the production process. Among these regulations, we can find: processes regulation (e.g. specific authorization for higher volume plants, in the case of switching from batch to continuous processes); compliance with product related regulations that might differ with regulations at a national level (e.g. plastics used in food packaging need to comply with the related regulation, REACH regulation in case of using chemicals); and compliance with sustainability requirements (for instance bio-based lubricants that aimed at acquiring the EU Eco-label, or the regulation around palm oil). In addition, companies have to comply with sustainability requirements set by consumers.

On the other hand, for achieving plant efficiency, new investments are needed. The limited funding opportunities and the administrative difficulties linked to the acquisition of funds are considered important investment barriers. Consequently, stakeholders are not convinced to invest in a highly risky market such as the bio-based products market.

Incentives for research and development exist, however, incentives for technology push and market introduction/uptake are still missing (valley of death between product development and commercialisation). Experts also see a decrease in the policy support in comparison with the previous ten years.

5. Innovation and technological trends in the selected value chains

In this section, innovations and technological trends in selected value chains (vegetable oil, starch and sugar and lignocellulosic biorefineries) are presented. See Annex III for detailed graphical representations of the different value chains.

5.1 Vegetable oil biorefinery

Regarding the biorefining stage on vegetable oil biorefineries, the expectations about technological developments vary between the interviewed experts.

A few experts said that since the oilseed industry has existed for such a long time, technologies to separate the components of oil crops and the following extraction steps are already mature and well integrated. Nowadays, it is easy to stick to organic solvents extraction mostly using hexane due to economic and technical reasons. Experts agree that there is a need to change to alternative solvents in order to replace organic solvents. In this sense, alternatives to the environmentally unfriendly solvent extraction of vegetable oils are being researched, because the extraction is a key process that will entail a strong impact on the resulting oil characteristics and quality. Technologies such as ultrasound-assisted extraction, supercritical fluid extraction or the use of less hazardous solvents can replace the organic solvent extraction step. They represent an interesting alternative, generally safer and more sustainable. However, this would be very difficult to implement due to the current maturity and low-cost of organic solvents.

Depending on the final application different conversion processes could be adopted, including industrial biotechnology, chemical and thermochemical conversion processes or a combinations of these. Technological trends in these conversion processes vary depending on the sector of application of the final product. Experts agreed that the thermochemical conversion has more potential for vegetable oil biorefineries than the biochemical conversion.

In addition, a high interest exists in Europe with respect to the conversion of oil crops into polymer building blocks. According to some experts, traditional and new technologies will be implemented in the market to produce new bio-based products, such as biopolymers. These are already quite mature, but more and wider applications in final products will occur based on intermediate chemical building blocks in the coming years. However, there were also adverse opinions due to the higher costs of biopolymers compared to fossil-based plastics, which represents a huge market. Especially the current low crude oil price and weaker marketing effects of “green” plastics may shift the industry back to fossil-based polymers.

Other innovative trends cited by the experts are the following: the conversion of fatty acids to high-valuable products (there is a large portfolio of fatty acids, ranging from C8 to C22, each of them with different properties); and the production of ester alcohol from glycerol (by-product from biodiesel production).

The expectations regarding the use of residues showed different opinions among experts. Some experts said that the high priority in the use of waste streams is in the fuel production, while other experts said that this focus would shift in the next years to material applications (such as production of lactic acid from vegetable oils residues (2nd generation lactic acid)). Personal research or economic interests can explain such differences in opinions.

To conclude, current vegetable oil biorefineries are mostly “energy driven” biorefineries using transesterification/hydroprocessing to produce biodiesel. However, according to the experts, in a few years these will be focused on adding value to side streams (e.g. glycerol in the case of transesterification) to produce bio-based products (e.g. PHA). In this sense, there will be a transition to product-driven vegetable oil biorefineries following the model adopted by Novamont (producing first high-value products and then lower value products such as biofuels from residues).

5.2 Starch and sugar biorefinery

A change from 1st generation to 2nd generation of sugars as feedstock for both fuels and chemicals is technically possible. Nowadays, sugar-based products are mainly produced from sugar beets and sugar cane (1st generation biomass) but companies are striving to produce these products on a basis of 2nd generation biomass (such as lignocellulosic feedstocks). Despite this, from an economic point of view, it is highly unlikely that there will be complete switch, since the routes needed for the production of 2nd generation sugars are much more complicated, implying higher costs for the production process.

Technologies for large-scale purification processes (such as chromatographic processes) already in use for the traditional 1st generation sugar industry, are being adapted to separation and purification processes of new sugar streams. The purification process (mainly using distillation and crystallization) of intermediate products is very important in order to obtain high quality in bio-based products.

Bioethanol produced from 2nd generation biomass (such as cellulose) has been a research goal in the last decade but is still struggling to reach a mature stage, and some plants that were operative have stopped producing. In respect of using cellulose to produce other bio-based products, there were two different opinions. Some experts stressed that technologies to convert cellulose into bio-based products would still need 10 to 15 years to mature. Others focused more on the fact that this will not happen because the costs to produce sugars from lignocellulose are still very high and will never be lower than the costs from 1st generation sugars and starches.

Several experts also commented the importance of the production of furans from sugars for the material and energy sector. For example, PEF produced via furan chemistry, could replace fossil-based PET used in the manufacturing of plastic bottles (this innovation has been selected a breakthrough technology that has been further analysed the section 6.3).

Further, improvements in biochemical processes such as more efficient fermentation processes or selection of more efficient enzymes are expected to be achieved (e.g. advanced membrane technologies can improve the recirculation of water, nutrients and microbes in the fermentation process (e.g., Reverse Osmosis, Electro dialysis)).

5.3 Lignocellulosic biorefinery

Several experts agreed that lignocellulosic biorefineries will shift to material approaches in the future, because of the higher value of material applications such as fine chemicals and polymers. Usually, sawmill residues and similar low-value fractions of the wood are burnt for energy purposes. In the future a shift to more complex chemical application will happen. Different examples of potential innovations were cited by the experts, including: the conversion of lignocellulose residues into single cell protein for food and feed using microorganisms[xxix]; bio-chemicals and plastics from hydrolysed cellulose and hemicellulose; and the use of microorganisms to produce oils[xxxxxxi].

With respect to specific production processes, new pre-treatment technologies will result in maximum material use of lignocellulosic feedstocks. For example, the organosolv pre-treatment method can be applied to extract sugars and lignin from lignocellulosic biomass with alcohol and water. Pre-treatment adjustments will allow using lignin stream in a further conversion downstream process to produce bio-based products (e.g. polymers). Organosolv pre-treatment efficiently removes lignin from lignocellulosic materials and solubilises most of the hemicellulose sugars.[xxxii] The CAPEX/OPEX of an organosolv plant is relatively high to such an extent that the realisation of a plant is certainly not expected for the next years.

Most of the experts agreed that depending on the final applications, different conversion processes will be selected in a given biorefinery, including industrial biotechnology, chemical and thermochemical conversion processes or combinations of these. Therefore, technological trends in conversion processes vary depending which intermediate product or final product is being targeted. According to some experts, thermochemical pathways (gasification, pyrolysis) still have long ways to go, while biochemical pathways (2nd generation bioethanol) would be most probably commercialized soon.

Another approach is to valorise the different lignocellulosic biomass streams (lignin, cellulose, and hemicellulose) into bio-based products, currently used only to generate energy. Several experts agreed on the importance of using lignin to produce high-value products (this innovation has been selected a breakthrough technology that has been further analysed the section 6.2) and turn the cellulose into sugars converting them into material applications.

To conclude, several experts commented that the logistic costs associated with the lignocellulosic biomass are still underestimated. Biorefineries do not need to be always fully integrated where all parts of the biomass are valorised at one plant. The valorisation of residues can be pre-processed near collection fields and then transported to biorefineries, improving transport efficiency.

6. Analysis of promising technologies and innovative developments

This section of the report describes the three promising technologies and innovative developments indicated by the interviewees as potential drivers of change for the future of the European bioeconomy. It includes a description of the importance of these technologies/innovations for the bio-based economy and provides a preliminary assessment of the related regulatory and standardization challenges that are considered by the experts as potential barriers that should be overcome in order to guarantee their full deployment.

With the aim of providing scientific evidence of the experts' opinion, the evolution of the published scientific publications and patents of the identified technologies and innovations are included in this report.

6.1 CRISPR related technologies

The utilization of enzyme-based genome editing technologies like CRISPR/Cas, zinc fingers, and TALENs CRISPR based technologies have been indicated by the experts as promising innovations that can potentially revolutionize the future production of bio-based products. The scientific audience recognizes these potential and the number of scientific publications and filled patents related to CRISPR related technologies has increased drastically over the last years (see section 6.1.1).

Gene editing technologies allow adding, removing and modifying genetic material at particular locations in the genome. Among different genome editing methods, CRISPR/Cas9 (associated protein 9) is becoming very popular among the scientific audience, because it is faster, cheaper, more accurate, more efficient and therefore more user-friendly than traditional gene editing techniques. CRISPR technologies are used to create a modified RNA, which includes a short guide sequence that attaches to a specific target sequence of DNA in a genome and the Cas9 enzyme. The modified RNA is used to recognize the DNA sequence, and the Cas9 enzyme cuts the DNA at the targeted location. Although Cas9 is the enzyme that is used most often, other enzymes (for example CPF1 o CAS 12) can also be used. Once the DNA is cut, researchers use the cell's own DNA repair machinery to add or delete pieces of genetic material, or to make changes to the DNA by replacing an existing segment with a customized DNA sequence[xxxiii].

In the contrary to most genetic modified techniques, CRISPR/Cas does not change many parts of the DNA by using chemicals or radiation. CRISPR/Cas can modify specific parts of the DNA or can delete specific targeted parts of it to create new crops for specific purposes. It is hardly possible to detect the differences between CRISPR/Cas modified plants and conventional modified plants.

The EASAC defines genome editing as the intentional alteration of a targeted DNA sequence in a cell, using site-specific DNA nuclease enzymes[xxxiv]. Therefore, genome editing is different from transgenic technologies, where genes from other species are introduced.

Modern genome editing technologies has allowed far more efficient gene modification and can be used in different application sectors related to the bio-based economy, including:

- Plant breeding, by increasing the production, composition, yield and disease resistance of agricultural crops.
- Industrial biotechnology processes: industrial microbial biotechnology and genome editing in microorganisms, bacteria and yeast to generate biofuels, pharmaceuticals and other high-value chemicals.
- Synthetic biology by improving the creation of strains.
- Photosynthesis of plants: by modifying the genome of the plant, it is possible to improve the efficiency of the conversion of light into crop mass (currently, photosynthesis in plants is still relatively inefficient).

Challenges of this technology

Regulation, ethical concerns and social acceptance are the key constraints that are preventing for taking advantage of modern genome editing technologies. The EU regulatory and legislative framework on genome editing technologies is currently fragmented and often not harmonized among different member states. For example, in Germany it is still not clear whether gene-edited plants should be regulated as GM or not. France regulates in the same way all organisms created through all methods of mutagenesis, including classical methods. They argued that easy-to-use, modern gene-editing tools will encourage large numbers of new plants to be created whose environmental impacts are uncertain. Sweden and Finland decided in favour of non-regulation and have promised to check their position if the EU decides to regulate it. Netherlands, considers the exclusion of most forms of gene editing from the genome editing regulation. Other countries are waiting for a decision of the ECJ. As can be observed, at the European level there are different opinions and different existing regulations, creating a regulatory gap.

In general, plant scientists argue that new editing tools, such as CRISPR technologies represent precisely small targeted changes to a gene that are indistinguishable from natural mutations. This aspect was highlighted by the interviewed experts that recalled the need to clarify the differences between older genetic engineering techniques and modern genome editing techniques, in which the resulting crops are non-transgenic (i.e. they do not contain any foreign gene). Experts recognize the need to provide transparency with regard to GMO practices in order to be accepted by the society. Indeed, organisms can be genetically modified without inserting foreign DNA into a crop. The best example is mutagenesis by radiation or by chemicals (without using enzymes) which is not subject to European GMO regulations and has been standard practice for the past 150 years. For instance, Sweden, Germany and the UK have categorised ODM[3], one of the simpler methods that does not employ enzymes, as mutagenesis, which is not subject to European GMO regulations.

European scientists must also compete with countries, like the US, where gene-edited products are not regarded as genetically modified organisms. Continued legal limbo on gene editing tech in Europe is holding up the introduction of such technologies.

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[3] ODM has been used by companies like Californian Cibus to develop herbicide-tolerant canola, flax, and rice, as well as a Phytophora--resistant potato.

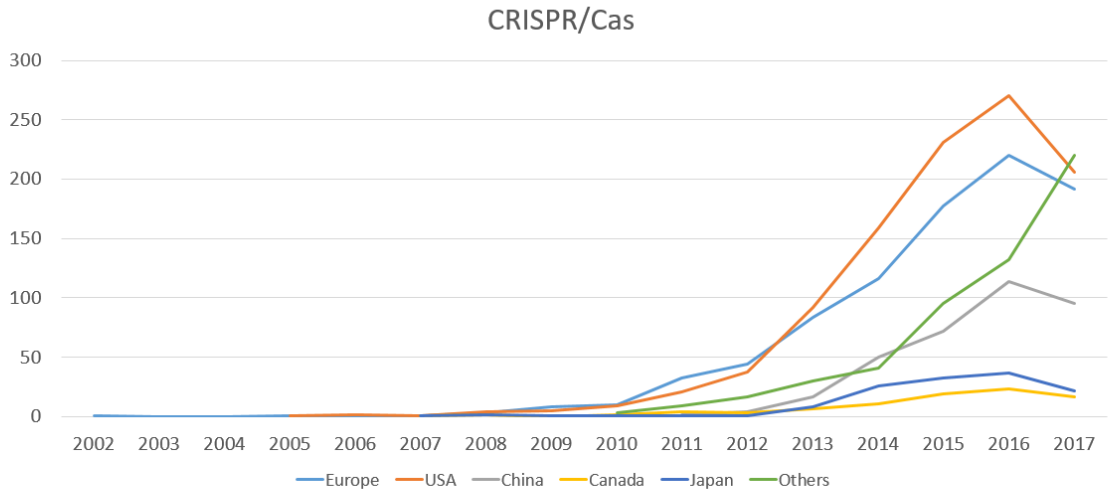
In addition, usually the concerns of the public (such as transfer of toxins and allergens into another plant affecting also the human heath) are related to the different applications of genome editing, rather than the technology itself. NGOs are also sceptical about genome editing and make pressure among consumers. For consumer products, the future will depend very much on consumer acceptance and on regulatory landscape.

6.1.1 Overview of scientific publications and patents

Scientific publications

Research papers in the field of genome editing were collected from the WOS database, with the search formulas = CRISPR Cas, CRISPR Cas 9 and CRISPR CSF1 (this last one also known as CRISPR Cas12). The retrieval time is from 2002 to 2017 (since CRISPR was officially named in 2002). The publications include articles and reviews and the language is limited to English.

The results obtained show that many experts are dedicating time and resources to explore new scientific advancements and opportunities of CRISPR-Cas related technologies. As shown in the graphs below, in the last six years, published scientific publications for the three research terms have increased considerably, mainly in the US and in Europe. More specifically, for the terms CRISPR/Cas the number of published scientific publications have increased from 38 to 206 and from 44 to 192, respectively in the US and in Europe. For the term CRISPR/Cas9, the results show an increase from 21 to 814 and from 7 to 639 respectively in the US and in Europe. For the search formula CRISPR/CSF less publications were identified, nonetheless, there is a rising trend, in particular in Europe.



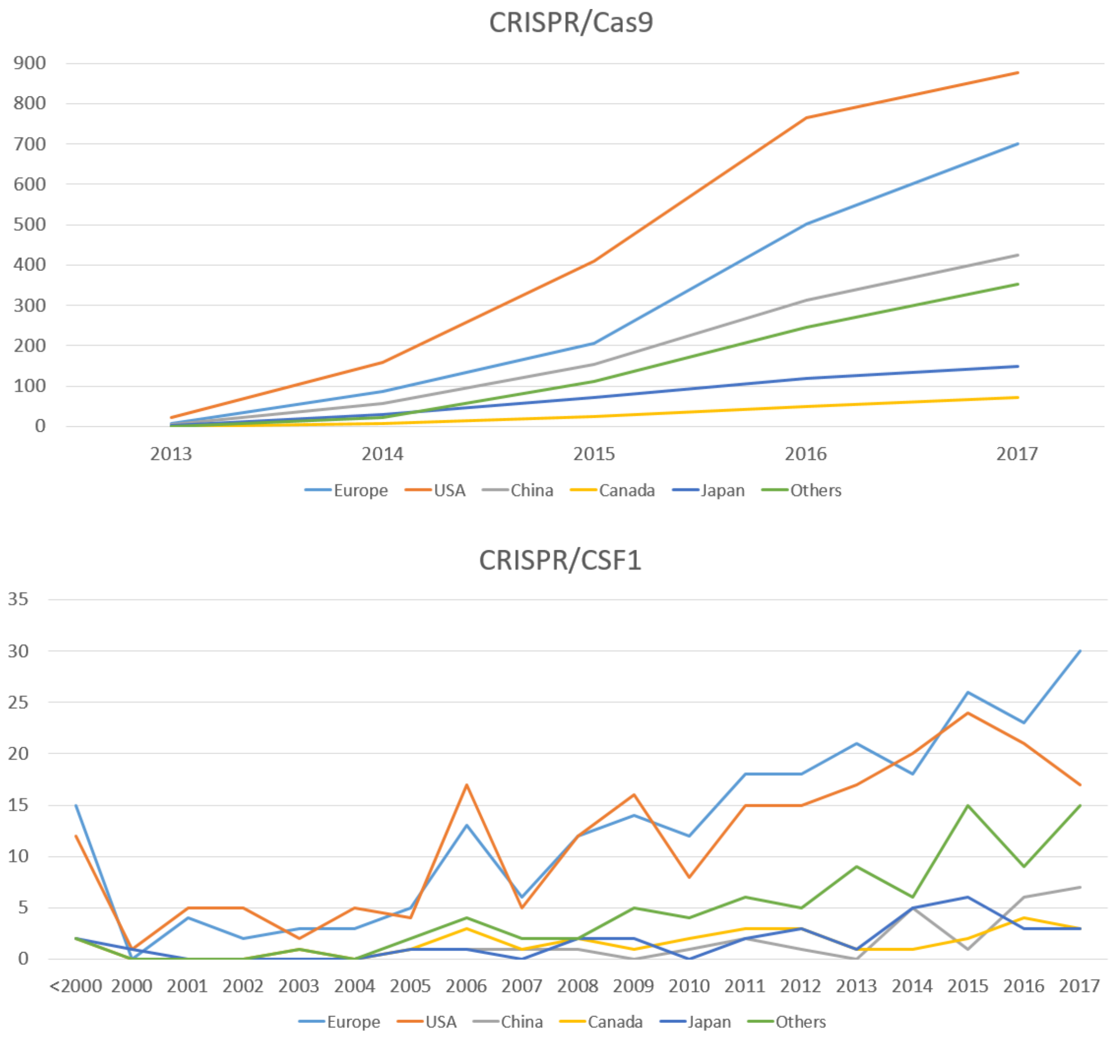


Figure 6 Fluctuation of scientific publications on CRISPR technologies

<u>Patents</u>

Patents were identified in the EPO database, using the keywords CRISPR Cas, CRISPR Cas 9 and CRISPR CSF1. In case of CRISPR Cas and CRISPR CSF1 the retrieval time is from 2007 to 2017, and for CRISPR/Cas 9 is from 2012 to 2017.

For the three variations of CRISPR technologies a rising trend can be observed (see graphs below). Nonetheless, most of the patents have been issued in USA (138 for CRISPR/Cas, 111 for CRISPR/Cas9 and 11 for CRISPR/CSF1) while in Europe the progress is slow and limited (28 for CRISPR/Cas, 26 for CRISPR/Cas9 and 8 for CRISPR/CSF1). It is expected that this divergence is due to the existing regulatory problems on genome editing technologies in Europe.

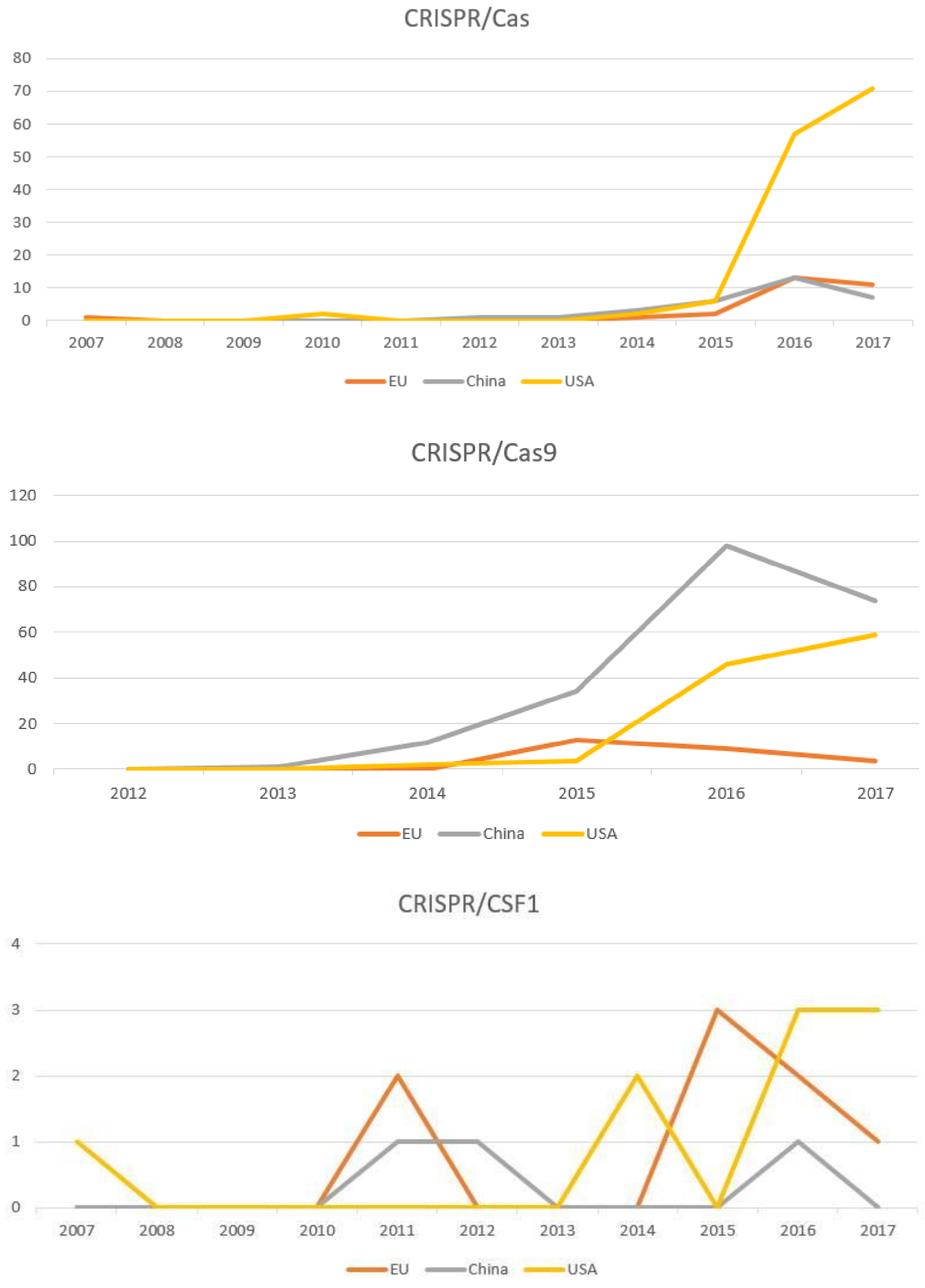


Figure 7 Fluctuation of patents on CRISPR technologies

6.2 Valorisation of lignin into high valuable products

The world's most abundant renewable resource is forest biomass, of which the three main components are cellulose, hemicellulose, and lignin.[xxxv] Lignin is a major component of woody biomass and a significant by-product of wood fractionation along with cellulose and hemicellulose[xxxvi]. It represents the second most abundant natural polymer after cellulose[xxxvii] (lignin present currently 300 billion tonnes and annually increases by around 20 billion tonnes[xxxviii]).

Currently, operating biorefineries receive and process enormous quantities of biomass, and whereas cellulose and hemicellulose are used in the paper industry and fermentation processes, lignin is considered a waste product and burned for heat and power[xxxix]. In the future, it is expected that lignin will become an abundant and inexpensive new feedstock for chemicals and fuel production, and in particular a renewable source for aromatic compounds[xl]. In the ideal situation, an integrated process must be established in a biorefinery, where all the fractions are valorised.[xli]

Lignin has unique properties including its highly aromatic nature and lower oxygen content compared to polysaccharides (polymeric carbohydrate molecules, another component of wood fibres), making it highly interesting biopolymer to be converted into chemical building blocks, bio-fuels and bio-based materials[xlii]. According to several experts, the valorisation of this component is crucial for the economic profitability of biorefineries[xliii]. Nonetheless, it cannot be ignored the importance of lignin in power generation, and according to one expert, it is important that lignin will still be used for on-site power supply in biorefineries in order to avoid fossil-based power sources.

In this sense, different BBI projects are currently exploring the use of lignin as a biomass. For example, the project SmartLi (2015-2018) will develop new valorisation routes for lignin to create bio-based products, such as composites, plasticisers and different types of resins. Besides, the project ValChem (2015-2019) wants to demonstrate the viability (both technically and economically) of producing lignin-based chemicals.

According to a study carried out by the ECN together with Wageningen UR of the Netherlands, organosolv lignin is the most promising technical lignin for further processing into high-value products, such as chemicals[xliv]. In this sense, the EU project BIOCORE (FP7, 2007-2013) coordinated by INRA (France), researched on several value-added products from organosolv lignin, such as phenol replacement in phenol-formaldehyde resins. Within this project, a biorefinery approach (LIBRA) in which lignin pre-treatment, pryrolysis and upgrading into different bio-based products was carried out.

Figure 8 shows an example of potential value chain for the valorisation of lignin. Almost any type of lignocellulosic biomass (wood, wood waste, sunflower, etc.) can be pyrolysed (other possible processes that are being researched: Moghi Technology to produce phenolic oil from lignin (Biochemtex), hydrothermal conversion of lignin (VTT and Thunen Institute)) to obtain a pyrolysed lignin oil. This oil can be converted to several bio-based products (polymers, cement, carbon fibres, agrochemical applications, resins, coatings, aromatics, etc.[xlv]) through different conversion processes. The produced gas and char during the fast pyrolysis will be also valorised to obtain on-site heat and power.

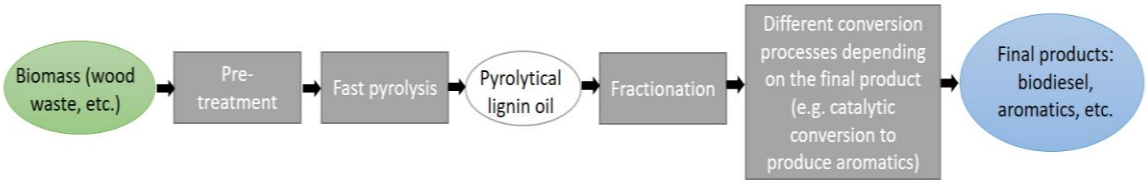


Figure 8 Example of valorisation of lignin

These processes shown above are not innovative itself. For example, fast pyrolysis is an old process; in fact, the valorisation of lignocellulosic through fast pyrolysis is already at commercial stage. However, the fast pyrolysis of the lignin is still at research level and is considered by the experts as a promising future development. In this direction, BTG is actively exploring and developing different new products by using pyrolysis oil from lignin as the raw material (e.g. as a substitute for fossil phenol in phenol-formaldehyde resins and as a replacement for fossil bitumen in asphalt).

Taking into account the importance of lignin valorisation, following the most innovative processes cited by the interviewed experts are presented. These processes belong to different stages of the above presented value chain:

1. **Fast pyrolysis:** Among the primary thermochemical conversion routes (i.e. gasification and fast pyrolysis), the fast pyrolysis is the most economically feasible way to convert biomass into liquid fuels, and therefore has attracted a great deal of research over the past two decades.[xlvi] Fast pyrolysis is a process in which biomass are rapidly heated to 450 - 600 °C in the absence of air. Under these conditions, organic vapours, pyrolysis gases and charcoal are produced. The vapours are condensed to bio-oil (typically, 60-75 wt. % of the feedstock).[xlvii] With this process, a pyrolysed oil is produced as an intermediate suitable for a wide variety of applications. Fast pyrolysis for liquids production is currently of interest as the liquid can be stored and transported[xlviii].

   Several initiatives are working on the introduction of existing fast pyrolysis processes into an innovative process to valorise lignin. The project Empyro (the Netherlands, started in January 2014) is a pyrolysis oil production plant for the pyrolysis of all fractions of lignocellulose, including lignin.

2. **Catalytic conversion to produce aromatics:** Once the biomass is pyrolysed and the lignin oil is obtained, several conversion processes can be adopted to convert the pyrolysed lignin oil into bio-based products.

   The realization of biorefinery schemes with fully integrated lignin valorisation processes requires the development of catalytic technology to perform the desired depolymerisation of lignin. Lignin is the largest reservoir of aromatic compounds on earth and has great potential to be used in many industrial applications[xlix], but above all, lignin is the most obvious candidate to become the major aromatic resource of a future bio-based economy[l].

Challenges of these technologies

1. **Lignin fast pyrolysis**: Efforts on the fast pyrolysis of lignin are scarce compared to fast pyrolysis on non-fractionated biomass and cellulose, most likely due to the difficulties in feeding lignin into a reactor: lignin has low melting point and can easily agglomerate, creating heat transfer challenges. Therefore, temperature, feed rate, and residence time must be optimized for each type of lignin[li]. In addition, current burner designs are quite sensitive to changes in the quality of the bio-oil, which may cause problems in ignition, flame detection and flame stabilization. In consequence, combustion applications should be standardized, and consequently standards, norms, specifications and guidelines should be defined and created urgently.[lii]

   According to one expert, fast pyrolysis is very energy intensive and not cost efficient yet, therefore, as long as it is not cost-competitive to crude oil it will not be successfully implemented. In addition, according to another expert, lignin is not an ideal feedstock for fast pyrolysis since the obtained lignin oil is low quality oil. According to this expert, this makes lignin currently interesting only to produce heat and power.

2. **Catalytic lignin conversion to produce aromatics**: In contrast to cellulose, which consists of a single type of monomer and one type of linkage, lignin is heterogeneous. The structure of lignin depends on its origin, external conditions during growth and the isolation and pre-treatment technology applied to isolate the lignin, thus affecting the final product[liii]. This is a problem for keeping intact the aromaticity[liv].

Besides, there are several challenges that concern the whole strategy of valorisation of lignin.

On the one hand, as already mentioned, the structure of the lignin is heterogeneous. Apart from this, there are many types of lignin and there is not enough knowledge about their detailed structure (physical and chemical properties and effects of pre-treatment technologies on their structure and properties). A possible solution that would increase the chances for successful lignin-based value chains will be the creation of a databank containing fingerprints of all kind of lignins (i.e. different kinds of origin, availability and the effect of external conditions and pre-treatment processes).[lv] However, another expert commented that it is not even possible to know all the components of the lignin.

On the other hand, the currently existing pre-treatment methods (acidic pulping, alkaline pulping, Bergius-Rheinau process, steam explosion, organosolv pulping, hydrolysis and pre-treatment methods with ionic liquids (still in pilot phase)) in order to separate lignocellulosic in its different fractions lead to molecular structures alterations of lignin, making lignin more chemically recalcitrant to valorisation. Currently, lignin is isolated as a valuable fraction, but if such an approach of maximizing the value of lignin is adopted, new pre-treatment methods could be developed that the lignin structure is preserved more.[lvi]

In addition, standards of biodegradability and compostability of products (such as EN13432, EN14995, EN14046, ISO18644 and ISO14855) are demanding degradation to CO2, water, methane, biomass and minerals within a certain time (typically 3months, 6 months, etc.). These requirements cannot be met by product made out of lignin, and lignin constitutes 1/3 of every plant. When a plant is degraded in soil, the polysaccharides are degraded to CO2 and water fast, while the last 30% of the plant, the lignin, is converted to soil organic matter (humins, humic acid) which is essential for soil to be productive. According to an expert, due to the requirements for products (such as plastics, packaging, fertilizer coatings, soil conditioners, etc.) to be biodegradable in accordance with standards, and since lignin is highly resistant to biodegradation, lignin-based products will often not be accepted, even though this is what nature needs and is used to.

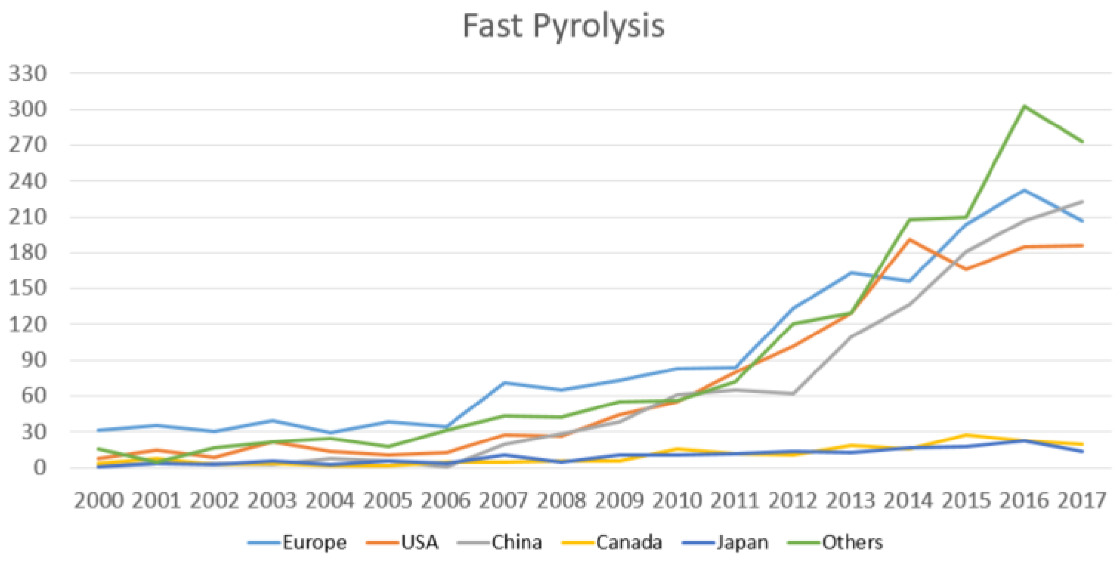
Research into lignin valorisation requires insight in the whole value chain[lvii]. Moreover, full valorisation strategies require cross-sectoral partnerships between the forest-based sector, agro sector, and the frontrunners of the chemical industry. Only then sound cascading approaches can be developed that lead to an optimal valorisation of both the cellulose/hemicellulose fraction and the lignin fraction of the lignocellulosic biomass.[lviii]

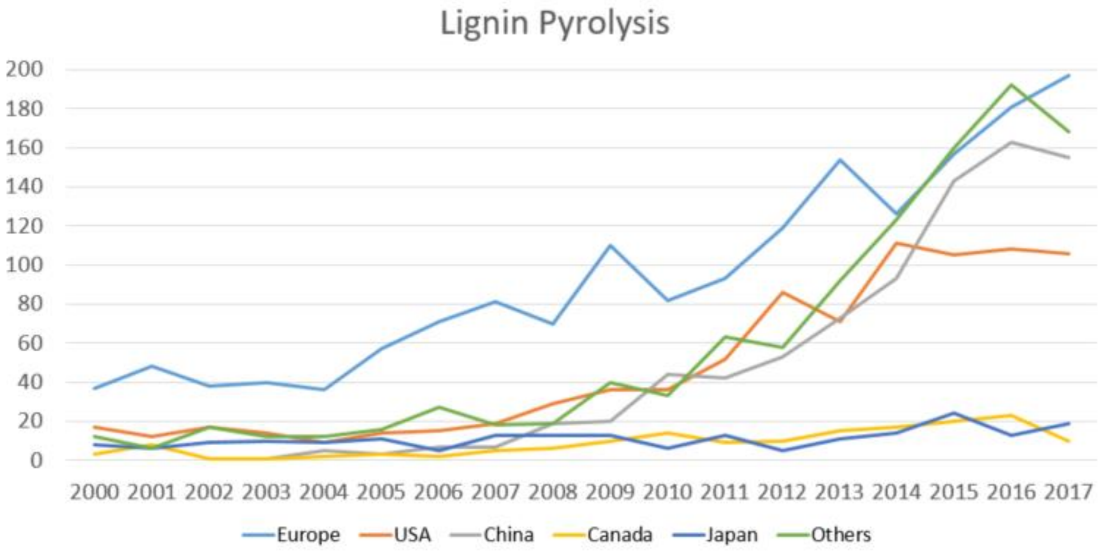
6.2.1 Overview of scientific publications and patents

Scientific publications

Research papers in the field of lignin valorisation were collected again from the WOS. The used keywords in this case were: lignin pyrolysis, fast pyrolysis and catalytic lignin conversion. The retrieval time is from 2000 to 2017 for all the terms and the language is limited to English.

The valorisation of lignin into high-value products is very important for a biorefinery in order to be economically competitive. In the following graphs, the increasing interest of experts on the topic can be observed. According to the graphs, the most of the scientific publications on fast pyrolysis and lignin pyrolysis have been published in Europe (1707 out of 6130 for fast pyrolysis and 1697 out of 4812 for lignin pyrolysis) while for the catalytic lignin conversion is China the country with the largest number of publications (279 out of 1091). In addition, since the year 2000, the publications on lignin pyrolysis in Europe have increased from 37 to 197, on fast pyrolysis from 31 to 207 and on catalytic conversion from 2 to 63.





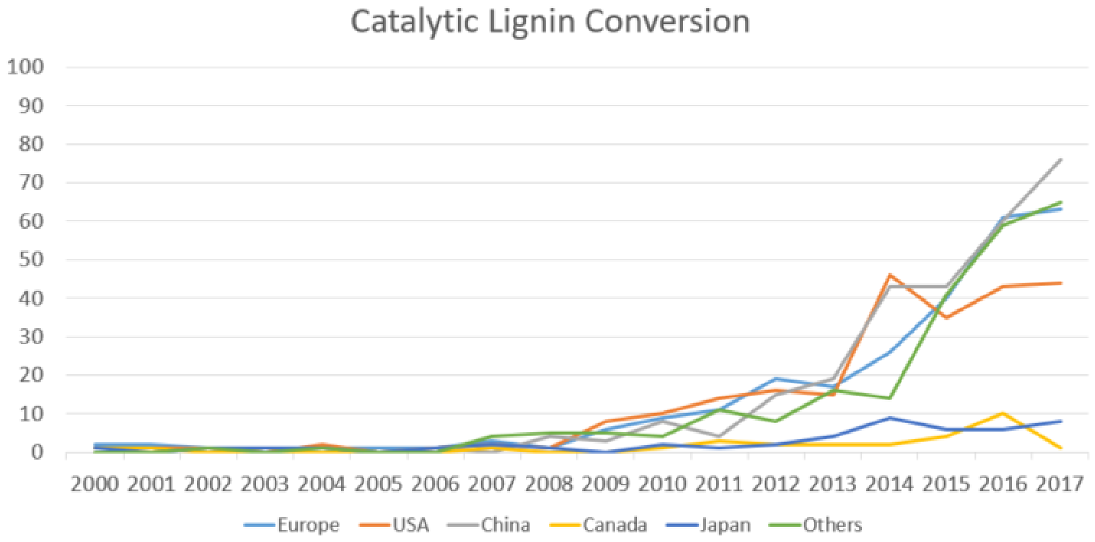


Figure 9 Fluctuation of scientific publications on valorisation of lignin technologies

Patents

With regard to the patents, the website of the EPO has been used for the analysis. Keywords were lignin pyrolysis, fast pyrolysis and catalytic lignin conversion. The retrieval time is from 2000 to 2017 for all the terms.

In the same way as the scientific publications, the tendency of patents shows an increase in the interest on the topics over the years. Although the most of the scientific publications have been published in Europe, with regard to the patents is China the country with the largest number of issued patents (284 out of 381 for fast pyrolysis, 46 out of 80 for lignin pyrolysis and 29 out of 50 for catalytic lignin conversion).

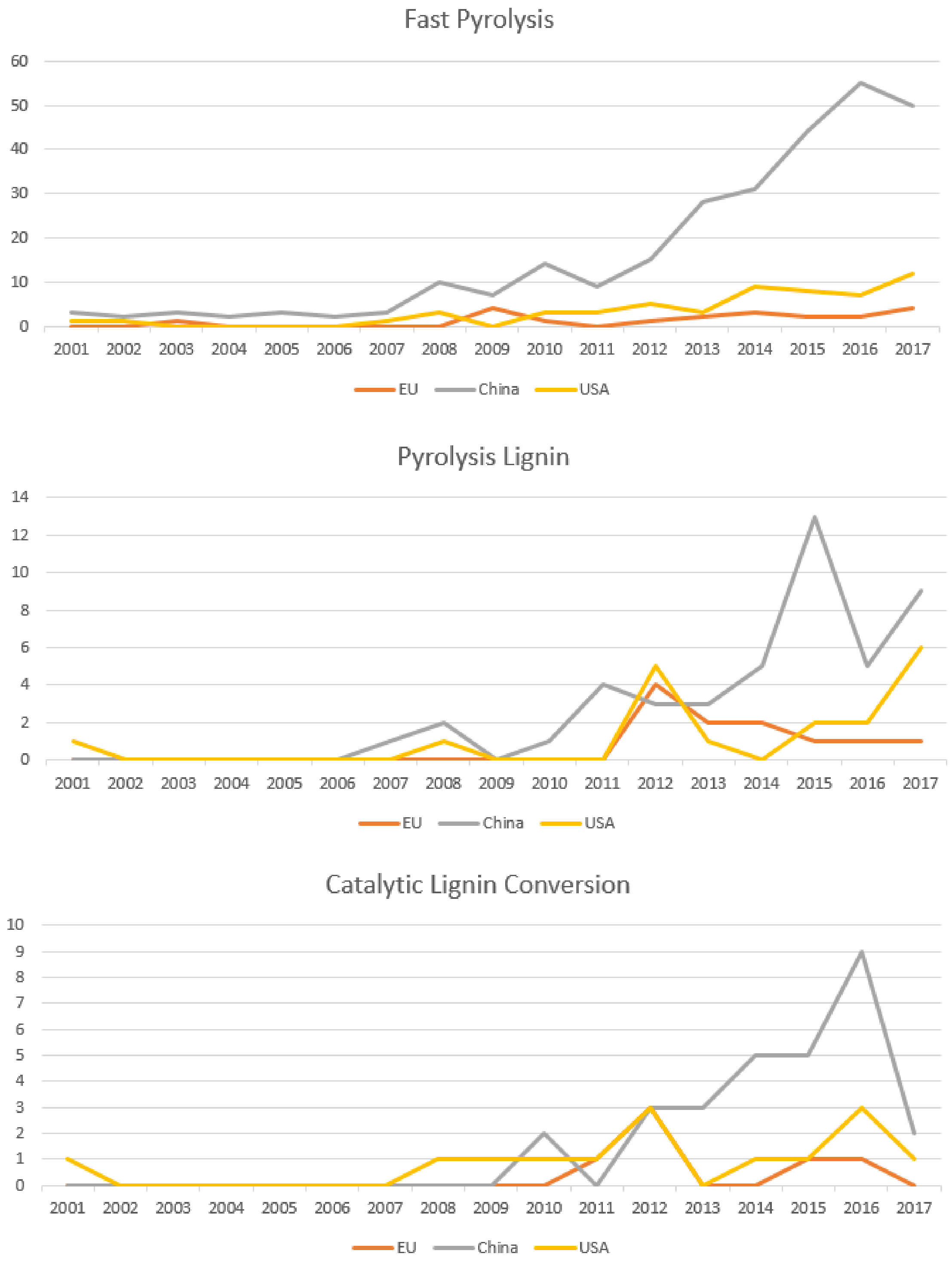


Figure 10 Fluctuation of patents on valorisation of lignin technologies

6.3 Furan-based chemistry to produce FDCA from sugars

FDCA is a highly promising bio-based building block for producing resins and polymers. FDCA is advocated as a green replacement for PTA (fossil-based) a predominant compound in polymer and resin manufacture today.[lix]

FDCA can be polymerized into PEF making use of existing polyester infrastructure. PEF is recyclable which offers converters and brand owners the opportunity of a closed loop product lifecycle. It gives improved finished product performance, due to better barrier, thermal and mechanical properties when compared to PET. At the same time, it improves packaging sustainability, since PEF produced from FDCA is 100% bio-based when bio-based MEG is used[lx].

In the following figure, the different pathways to obtain FDCA using different biomass feedstocks are shown:

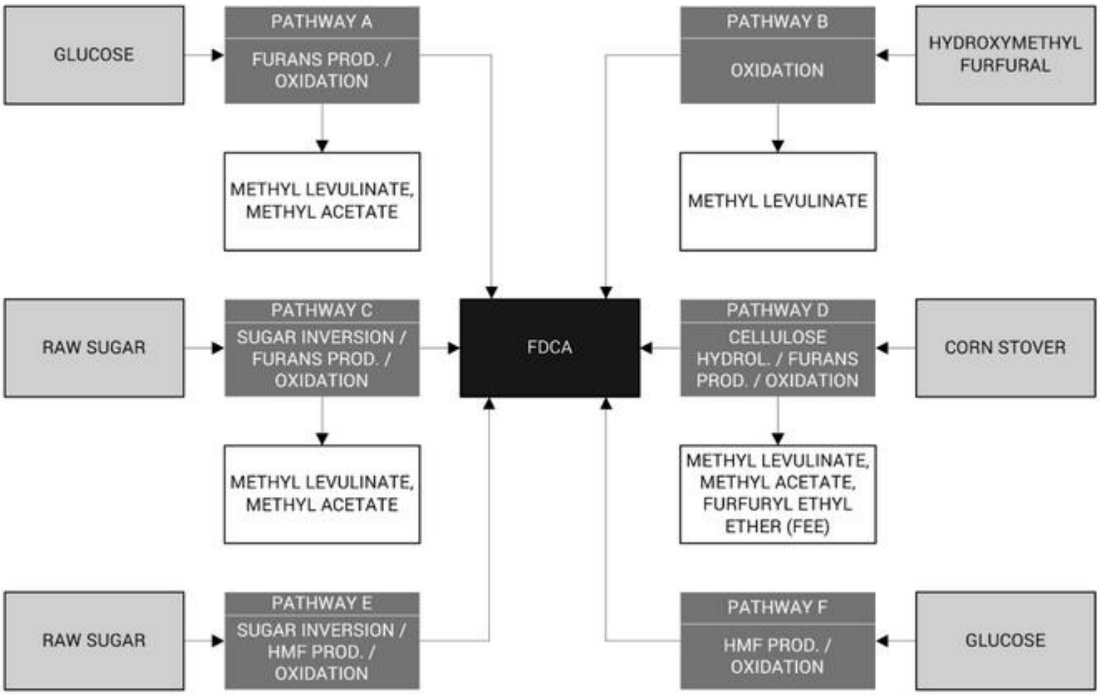


Figure 11 Different production pathways to obtain FDCA[lxi]

Avantium is one of the main companies producing FDCA. In this case, biomass is converted into HMF and this chemical compound can be converted into FDCA by bacteria through fermentation (pathway F in the picture above)[lxii].

A potential production chain produce FDCA can be observed in the following figure:

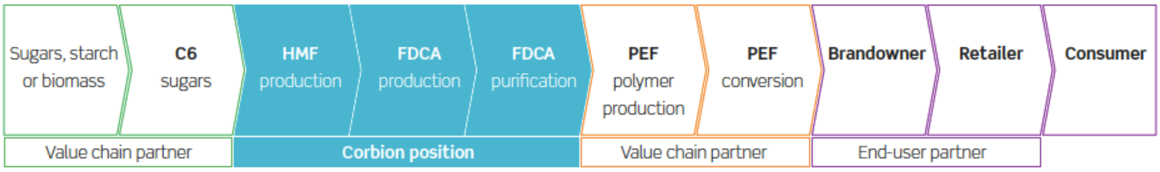


Figure 12 Potential production chain of FDCA in Corbion

Wageningen University for Food and Bio-based research is currently working in a process to convert agricultural biomass feedstock into HMF. This chemical compound can be converted into FDCA, again by bacteria through fermentation and can replace terephthalate. Avantium is also developing a next generation bioplastics based on FDCA, called "YXY building blocks", which can be produced based on sugars and other non-food carbohydrates.

In addition, BASF and Avantium have established a Joint venture called Synvina for the production and marketing of FDCA. In addition, the BBI JU has recently granted 25 million euro to PEFerence (2017-2022) a consortium of eleven companies. The grant supports the establishment of an innovative value chain for bio-based raw materials, as well as, chemicals and materials based on PEF. It includes the intended construction of a 50,000 tons FDCA reference plant.

Challenges of this technology

FDCA can replace fossil-based terephthalate used in the production of PET bottles. However, the main problem is the difficulty to produce high purity FDCA, making the price unacceptable.

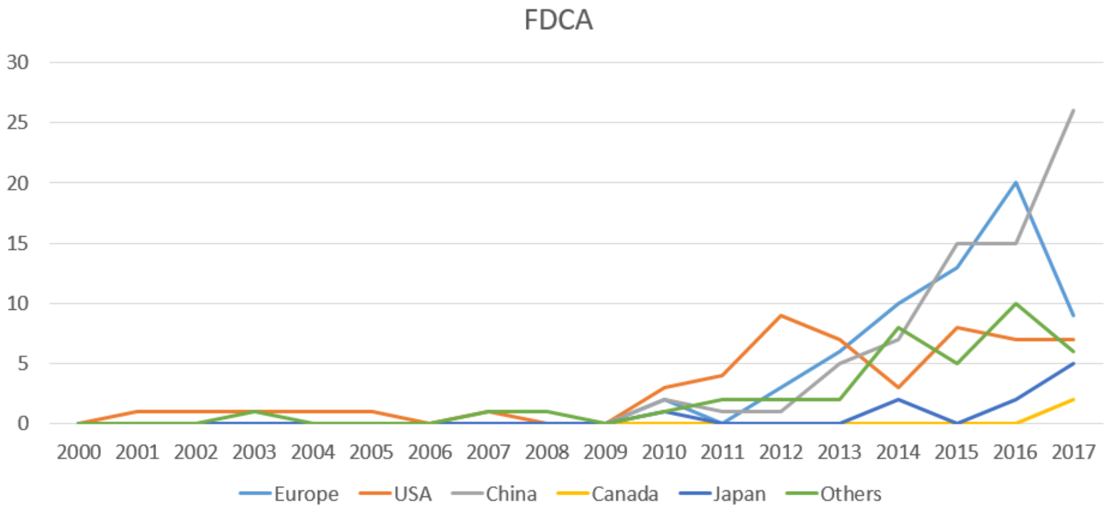
The investigation of the synthesis and modification of PEF, PPF, and PBF has become an important topic in both the industrial and academic communities[lxiii]. In fact, the project "YXY building blocks" from Avantium, presented above, is trying to produce high purity FDCA in a reasonable price.

6.3.1 Overview of scientific publications and patents

Scientific publications

Scientific publications on the production of FDCA from sugars were collected from the WOS webpage. The used keywords were FDCA and Furandicarboxylic acid. The retrieval time is from 2000 to 2017 for both terms and the language is limited to English.

According to the following graphs, the production of PEF through the building block FDCA is of great interest among academia and industry experts. For both terms, China is the country with most publications (26 for FDCA and 44 for Furandicarboxylic acid). In the case of the term Furandicarboxylic acid, Europe has also published a high number of publications (36).



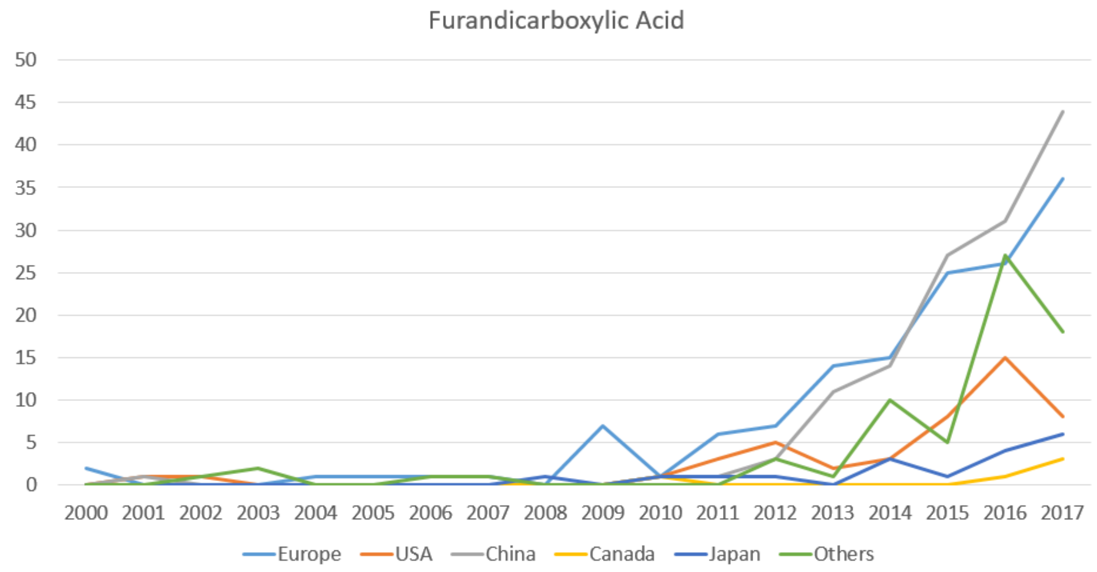
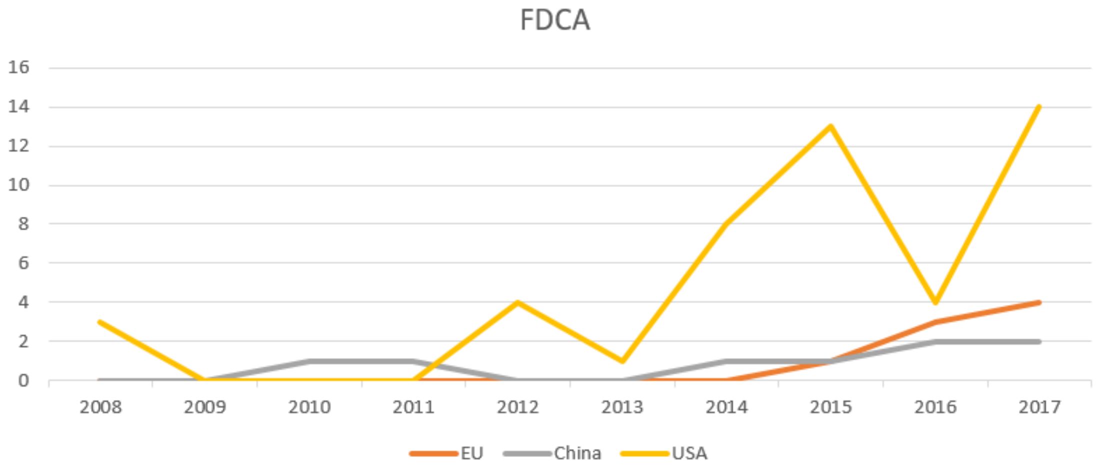


Figure 13 Fluctuation of scientific publications on FDCA from sugars

<u>Patents</u>

For collecting the patents, the website of the EPO has been used, with the keywords FDCA and Furandicarboxylic acid. The retrieval time is from 2008 to 2017 for both terms.

The USA is the country that has issued most patents (in total 48), with an enormous difference comparing the patents issued in Europe (8) and China (8). However, for the term Furandicarboxylic acid is China the country with the highest number of issued patents, followed by Europe (37), very close to USA (36).



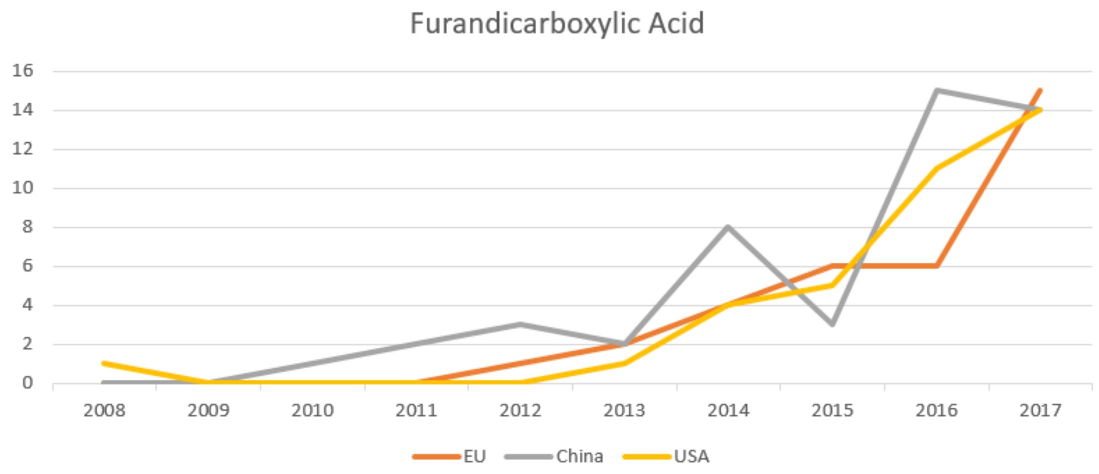


Figure 14 Fluctuation of patents on FDCA from sugars

6.4 Summary of promising technologies

The rising trends of the evolution of scientific publications and patents (shown in the graphs included in section 6.3) reflect the fact that the scientific audience and industry is allocating resources to the early development and further exploitation of the three selected technologies and innovative developments. However, these achievements in the research and development phase should be further supported by creating the right framework conditions in which technologies can further develop and be scaled-up.

Indeed, the potential of three innovations (defined in this report as drivers of changes) for the further development of the European bioeconomy should be facilitated by the establishment of a supportive and investment friendly regulatory framework, that finds a solution to existing and potential challenges linked to the technologies.

In the case of CRISPR technologies, the main challenge is the lack of a supportive regulatory and legislative framework on genome editing technologies, currently fragmented and not harmonized among different member states. Ethical concerns and social non-acceptance are delaying its development and it is increasingly necessary in order to be competitive with countries such as USA.

Regarding valorisation of lignin and furan-based chemistry from sugars, the barriers are mostly technical. Support on investments on those technologies are therefore needed to be able to improve these technologies at competitive prices.

In further analysis of the project, experts' opinion on the specific elements to be included in such standardization and policy framework will be compiled. These elements will help supporting the development of the selected promising industrial value chains and technologies/innovations, and therefore, the European bio-based economy.

7. Conclusion

In this report, a collection of experts' opinions was carried out regarding upcoming innovation that could be implemented in the next 10 to15 years with positive impacts in terms of improving biomass availability and production processes in biorefineries in general (see section 4) and particularly in the selected value chains (see section 5). Three different technologies and innovative developments have been selected as the most promising trends to be developed in the indicated timeframe and of which a deeper analysis has been accomplished (see section 6). Special attention has been paid to the existing regulatory and investment barriers that could delay or stop these technological developments and that should be removed in order to support the promotion of a cutting-edge European bio-based economy.

The principle of the cascading use of biomass, alternative innovative feedstocks (e.g. food waste and industrial waste), digitalization and, among others, cooperation agreements with farmers and forest owners, have been highlighted by the experts as drivers of innovation that will play an important role in upscaling the bio-based industry in the previously specified timeframe of 10 to 15 years. In addition, different novel technologies for improving biomass cultivation efficiency (e.g. modern genome editing techniques) and process innovation for improving efficiency in biorefineries (e.g. integrated biorefinery) have been indicated by the experts. However, there is a need to support the implementation of these innovative developments and technologies with the establishment of an innovation and investment friendly regulatory framework.

CRISPR related technologies, techniques for the valorisation of lignin and furan-based chemistry resulted as the three most promising technologies/innovations and were defined by the experts as potential drivers of change for the future of the European bioeconomy. The capacity for innovation of these three breakthrough innovations/technologies depends on favourable regulatory and investments conditions. More specifically, for CRISPR related technologies updates in the current European regulatory framework are considered extremely important to fully deploy the potential and opportunities of this technological breakthrough. In the case of the valorisation of lignin and in the furan-based chemistry to produce FDCA from sugars, experts referred mostly to technical barriers behind the development and adaptation of promising processes and technologies that should be addressed in order to fully exploit their potential. Specifically for the case of lignin, experts see the need for standards and cross-sectorial partnership between biomass providers (forest and agro-based sectors) and industry involved in the development of technologies for the valorisation of lignin.

The resulting preliminary assessment on promising technologies and related regulatory and investment opportunities will be the basis for further project activities, in which a two rounds Delphi survey will be implemented. The outcome will be specific recommendations for the establishment of innovation-friendly regulatory framework needed for promoting investments in bio-based markets in general and technological developments in the selected value chains in particular.

Annex I: Results of the foresight studies analysis

Table 3 Results of the foresight studies analysis

Identified technological trends in biomass production
Foresight study: Biofuels in the European Union A vision for 2030 and beyond (Biofuels Research Advisory Council) ✓ Reach clean and CO2-efficient biofuels using a wide range of biomass resources, based on sustainable and innovative technologies. ✓ Increase domestic biofuel production, by investing in biomass production, harvesting, distribution and processing, as well as, developing agreed biofuel and biofuel-blend standards. ✓ For the supply of the biomass feedstock, sustainable land strategies must be created that are compatible with the climatic, environmental and socio-economic conditions prevailing in each region. ✓ Different sectors compete for biomass from agriculture and forestry. Planning efforts should focus on choosing the best available cropping solutions for each region and land type. ✓ Genetics can be used to improve the quality characteristics of the crops.
Foresight study: SCAR Sustainable Agriculture, Forestry and Fisheries in the Bio-economy: A Challenge for Europe (EC) ✓ The biomass potential can be upgraded by introducing new and improved extraction and processing technologies, by increasing current yields by closing yield gaps, increasing productive land, introducing new or improved species that may or may not be generated by various biotechnological advances. ✓ There is a need to grant access to sustainable raw materials at world market prices for the production of bio-based products. This will require the application of the cascade principle in the use of biomass and eliminating any possible distortions in the allocation of biomass for alternative uses that might result from aid and other mechanisms that favour the use of biomass for other purposes. ✓ It is required an integrated biomass harvesting and processing to address scale, transport cost and low biomass densities, and these processes must have a high energy / material conversion yield in order to be competitive. ✓ Future needs are an increase in yield and value from the same amount of raw material. ✓ The major target is an effective destruction and separation of biomass of various origins into the major building blocks to allow a further conversion into chemicals and products, fuels and energy. Emphasis is currently placed on low-cost technologies and utilization of fewer chemicals. ✓ The lignin challenge: Most of the lignin separated today in pulp mills is used to satisfy the energy demand for the overall wood separation and recovery process for chemicals. About 15 %+ of the lignin can be immediately removed from a classical mill scenario and used for different applications. In future scenarios, lignin as fuel should be completely avoided, as lignin offers in principle multiple ways to serve as biopolymer and starting compound for platform chemicals.

- ✓ By 2050, the percentage of cereals, vegetable oils and sugar used for bio-fuel production is projected to at least double: 6.1 %, 10.3 % and 1.8 % of the fuel produced respectively.

Foresight study: SUMFOREST Foresight Panel and Foresight Workshop Results on “Emerging Issues in European Forest-Based Sector and Research Priorities” (European Forest Institute)

- ✓ There is a need to develop decision support systems for optimized supply chain management, including cascade use of wood, fibres and biomass, linked to forest planning tools for multifunctional forest management.
- ✓ There is a need to improve the land use: zoning, super-efficient biomass production, urban fringes, recreation and environmental protection.
- ✓ New forest management methods and genetically improved trees, combined with climate change mitigation, pose new challenges to forest management. The research should develop novel and cost-efficient methods for obtaining reliable, high resolution, and up-to-date information on current biomass resources as well as on genetically-improved wood properties. Combining genomic information with tree breeding and effective propagation methods will enable possibilities to enhance growth as well as grow trees with specific wood properties (chemical, physical).
- ✓ There is also a need to develop models and decision tools for assessing the quantity and properties of raw material, economic performance, and environmental effects associated with enhanced biomass production chains.

Foresight study: A global view of bio-based industries: benchmarking and monitoring their economic importance and future developments (JRC)

- ✓ There is a lack of data regarding the use of biomass beyond the traditional sectors (food and animal feed, energy, textiles, etc.) and on the potential of waste as biomass source.
- ✓ Biomass should be processed in biorefineries that apply a cascading approach where high-value products are extracted first, followed by less-valuable products, in a very effective way, ending with high volume low value products (e.g. fuels).
- ✓ Recommendations: improve opportunities for feedstock producers within the bio-economy and investigate the scope for using novel biomass.

Foresight study: Forest bio-economy - a new scope for sustainability indicators (European Forest Institute (EFI))

- ✓ Utilisation of forests to create products and services that help economies to replace fossil-based raw materials, products and services. This list of opportunities is long, including bioenergy, wood construction, packaging products, chemicals, textiles, etc.
- ✓ There is a need to measure the entire forest value chains for solid wood products, wood-based materials and bioenergy production, fully accounting for woody biomass flows, trading, cascading and recycling needs.
- ✓ Push the boundaries of the forest sector and its self-perception. It requires going beyond the traditional forest sector framework and moving towards diversified and cross-sectoral approaches.

Foresight study: EU commodity market development: Medium-term agricultural outlook (JRC)

- ✓ Utilized agricultural area (UAA) in the EU is expected to decrease at a slower pace than in the previous decade, from 177 million hectares (2016) to 173 million hectares (2026). In absolute terms, the largest decrease is projected for arable crops (2 million hectares) whereas in relative terms for fallow land (14%) and oilseeds (9%), the latter being driven by slowing biofuel demand.
- ✓ Higher annual yield growth is foreseen for maize (1.5%), which is mainly used as animal feed, while rice is the only crop for which yield is expected to slip back (-0.09%).
- ✓ Harvested area in the EU is generally projected to decline except for soybean (0.2%), common wheat (0.15%), and maize (0.07%).
- ✓ Oil meals will become relatively more important in the EU oilseed complex as domestic meat production is increasing.
- ✓ Oilseed prices are assumed to recover in the medium term mainly due to increasing production costs.
- ✓ EU sugar production is expected to increase. The abolition of sugar quotas (2017) will happen in a moment where farmers have incentives to continue producing due to low commodity prices for alternative crops.
- ✓ Over the 2016-2026 period, the rising ethanol consumption will translate into an intensified use of maize for biofuels.

Foresight study: Agricultural knowledge and innovation systems towards the future (AKIS) (EC)

- ✓ ICTs will change the way farms are operated and managed and it will change the farm structure as well as the food chain in unexplored ways:
    - The incorporation of Farm Management and Information System (FMIS) and decision support system (DSSs) in web-based approaches is a particularly important aim;
    - Controlled-traffic farming (CTF) enables the geo-positional control of field traffic in order to optimise yields and inputs and reduce negative environmental impacts; Precision livestock farming is based on sensor measurements;
    - Advances in robotic engineering must be applied in the agricultural sphere in order to step up innovation.

These new methods will enable practitioners to respond much more rapidly and effectively to problems such as extreme weather, pests or climate change, leading to a more reliable food supply for all.

Foresight study: Teagasc Technology Foresight 2035 Report

- ✓ Biomass potential is under-exploited, because many waste streams are not used in an optimal way. More material and energy can be extracted from these streams. It can be enhanced by raising current yields and developing new and improved extraction and processing technologies.
- ✓ New value chains from (organic) waste problems to economic opportunities by realising sustainable technologies to convert waste into valuable products.
- ✓ Enhance education services to help increase the skills and knowledge base of farmers and food producers.
- ✓ The development of new tools for monitoring the environment based on satellites, sensor networks, smart connected farm machinery and drones, suggest that it will become

increasingly possible to monitor the environment and quantify the provision of public goods to the extent that it will be possible for farmers to charge fees for the public goods provided.

- ✓ The application of the tools used to monitor and manipulate the microbiota will also be applied to the food chain where they will be used to provide microbiology process maps, identify high-risk areas leading to contamination or for the rapid and real-time identification of pathogens and spoilage organisms.

Identified investment and regulatory barriers in biomass production

Foresight study: A global view of bio-based industries: benchmarking and monitoring their economic importance and future developments (JRC)

- ✓ Enhancement of markets and competitiveness in bio-economy sectors, including a better understanding of biomass availability, support to markets through standardisation, labelling, public procurements and the provision of better information to consumers.
- ✓ More possibilities should be explored to increase biomass availability, while guaranteeing sustainability. The green growth can then be realised by stimulating higher CO2 prices (through ETS (emissions trading systems) or other solutions), improved regulations, research & innovation (R&I) activities and by establishing partnership between governments and other EU players.
- ✓ Introduction of regulatory policies implies an increase in investment costs. For example, when introducing a new GM crops into the EU market, several regulatory requirements must be complied with, which affect investment costs and the optimal timing to reach the market. The fact that the industry is affected by these regulatory hurdles is demonstrated by the decreasing number of biotechnology patents filed in the EU since 2000 (OECD, 2016), which also affects the bio-based economy. Certain standard models do not consider these elements of uncertainty and irreversibility, and therefore underestimate the implications of this type of regulation on the investment behaviour of the industry.
- ✓ The cost of feedstock, infrastructure logistics and transport, trade barriers (e.g. for importing feedstock for ethanol), seasonality of feedstock production and quality of the raw material.

Identified technological trends in production processes

Foresight study: Biofuels in the European Union A vision for 2030 and beyond (Biofuels Research Advisory Council)

- ✓ New catalytic processes such as those based on heterogeneous catalysis could be used to increase the yield and economics.
- ✓ The co-production of fuels, heat & power and co-products in integrated biorefineries will enhance the overall economy and competitiveness of biofuels.
- ✓ Further progress is required to improve the energy and therefore carbon balance of existing technologies innovative processes for biomass conversion and fractionation of products. New developments in the areas of catalytic and separation processes (such as membranes, new adsorbents, ionic liquids or supercritical extraction) can lead to improved energy efficiency and better thermal integration.

✓ The quality of by-products is also an important factor. Improving the purity of glycerol can improve significantly the competitiveness of FAME (fatty acid methyl esters) production. The optimal use of by-products as intermediates for the production of fine chemicals or pharmaceuticals should also be considered. ✓ Diesel fuel can also be produced by hydro- treatment of vegetable oil and animal greases. The technology has reached the demonstration stage. ✓ The acquisition of thermodynamic, fluid dynamic and kinetic data is required for optimisation of existing and the development of new processes.
Foresight study: SCAR Sustainable Agriculture, Forestry and Fisheries in the Bio-economy: A Challenge for Europe (EC) ✓ In order to transform the available biomass, cost effective fractionation and conversion technologies are needed on large scale to feed the demand. ✓ Industrial biotechnology has a special importance for the future bio-based economy as an innovative field with a great number of opportunities to produce platform chemicals, building blocks for a variety of polymers as well as molecules for fine chemistry and pharmacy. “Green” and “white” biotechnologies have already clearly demonstrated their innovation potential. ✓ The conversion of already existing pulp mills into advanced biorefineries means making use of existing infrastructure, expertise and permits, and hence investment costs are lower compared to emerging technologies. ✓ Sensor technology, remote sensing, etc. contributing to precision techniques in the primary sectors have great potential to improve resource efficiency.
Foresight study: Global Food Security 2030 - Assessing trends with a view to guiding future EU policies (JRC) ✓ Sustainable intensification of smallholder agriculture through technology transfer and adaptation.
Foresight study: A global view of bio-based industries: benchmarking and monitoring their economic importance and future developments (JRC) ✓ Regarding research and innovation, a climate of investment and access to funding is a key issue for the EC. ✓ Enhance production, mainly focusing on the need to increase yield productivity and robustness, the need to find properties of some bio-based products that fit the consumers, for example speciality products and the possibilities of scale-up.
Foresight study: Forest bio-economy - a new scope for sustainability indicators (European Forest Institute (EFI)) ✓ New challenges for data and monitoring.
Foresight study: Teagasc Technology Foresight 2035 Report ✓ Integrated energy, pulp and chemicals biorefineries realising sustainable bio-energy production, by backwards integration with biorefinery operations isolating higher added value components. ✓ There is also a role for publicly funded research in devising standards and protocols for data collection and interoperability, and in researching issues around data ownership and privacy.

- Other promising new biotechnologies: Cloning/Reproductive technologies, Genome engineering, Epigenetic technologies, Metagenomics, Next-Generation Sequencing, Functional Genomics and Systems Biology.
- Genome sequencing and genotyping platforms will capture genetic data from plants, animals and even whole ecologies. This will facilitate breeding programmes to deliver multi-objective strategies that aim to simultaneously improve the production efficiency, functional differentiation and protection of natural capital of primary production, especially in the dairy, beef, sheep, pigs and crops sectors.

Identified investment and regulatory barriers in production processes

Foresight study: A global view of bio-based industries: benchmarking and monitoring their economic importance and future developments (JRC)

- Recommendations: develop a workforce that can maintain Europe’s competitiveness in industrial biotechnology; introduce a long-term, stable and transparent policy and incentive framework to promote the bio-economy; improve public perception and awareness of industrial biotechnology and bio- based products; identify, provide leverage and build upon EU capabilities for pilot and demonstration facilities; promote the use of co-products; improve the bioconversion and downstream processing steps; improve access to financing for large-scale biorefinery projects; develop stronger relationships between conventional and non-conventional players in the value chain
- Access to finance, particularly for upscaling (i.e. from pilot to ‘demo’ plants) to demonstrate the proof of concept in order to capture the interest of investors, and also for new production plants.
- The cost of patents and intellectual property legislation, demo and flagship support, collaboration between industry and academia and training.
- The blending mandate forces the use of biomass for bioenergy production, thus displacing it from chemical production, which means that its effect on the biochemical sector is very negative.

Foresight study: Agricultural knowledge and innovation systems towards the future (AKIS) (EC)

- The issue of ICT and agricultural research and innovation is complex. There are many ICT developments that will benefit agriculture and the food chain. Some will be disruptive and call for social innovation. Promoting such innovations is a challenging task for governments.
- The rapid development of technologies places high demands on the education and training of farmers.
- Lack of reliable and fast internet connections are crucial barriers for virtual collaboration and innovation. This barrier may be reduced by rural development funding of broadband infrastructure in regions with no or slow access to the internet.
- The price of hardware and broadband subscription may also be an obstacle in poor regions, but rural funding programmes may also assist here.
- Also cultural aspects may also be a barrier, almost one-third of EU farmers are above 65 years of age and probably not familiar with PCs, smartphones and ICT tools. Promotion of easy access ICT tools, courses and demonstration of good examples may reduce the problem. Another cultural barrier is the lack of engagement of researchers in social media for farmers. A change in the system for rewarding researchers may

solve this problem. Risk of overload and misinformation of farmers, participating in multi-actor social media platforms may also be a barrier. Use of Twitter for following reliable experts may be used as a filter for overload and misinformation or it may be built into the software tools used for the virtual networking. ✓ The lack of maintenance of networks beyond research project periods is a barrier for the establishment of stable and lasting collaborative networks within different fields of the agricultural sector. Increased use of already established ICT tools and well-established virtual social networks such as AgChat may change that.
Foresight study: Teagasc Technology Foresight 2035 Report ✓ The introduction of new technologies may have implications for public engagement and science communication, as consumer acceptance of such solutions will depend on the perception of consumers and their ability to make sense of such technologies. ✓ Low profitability at primary production, climate change, water quality, biodiversity loss, antimicrobial resistance, food innovation, food safety and rural. ✓ New technologies will also require more expertise from the staff. ✓ New policy instruments and delivery mechanisms will be required, as well as, new tools for monitoring and decision support.

Annex II: Template of the experts’ interviews

Aim of the interview

The aim of the following interview is to collect data on possible technological and innovative trends in the next 10 to15 years in biorefineries. The interview will try to capture experts’ views about available, emerging and breakthrough technologies that are likely to have the biggest future influence and the greatest potential to increase production efficiency in biorefineries. A preliminary assessment of possible regulatory barriers and hurdles and existing funding gaps that are hampering investments in the bio-based economy will be part of the discussion. For the purpose of this project, only technological developments and innovations linked to biomass and production processes will be considered (from feedstock to final product). The use and post-use of the product is beyond the scope of this interview.

Table 4 Template of the experts’ interviews

General questions about the company

Do you consider yourself an expert in the field of biorefineries?	
Are you an expert specifically in the field of vegetable oil, lignocellulosic or starch/sugar biorefineries?	
What type of organization do you work for (e.g. business, NGO, industry association, public organization, university, research institution, etc.)? How many workers does your organization employ?	
What country do you work in?	
What does your organization do? What are some of its specific activities? What kind of bio-based products does your organization produce?	

Technological and innovation trends / regulatory and investment barriers

Production processes in biorefineries	
Technological and innovation trends	**Answer**
What technological trends/innovations in biorefinery production do you think could happen/be implemented in the next 10 to15 years?	
Do you consider any of the following technological trends feasible and/or potentially likely to occur? *(if not mentioned)*	
More efficient extraction techniques of raw materials/feedstock (e.g. liquid-solid extraction, liquid-liquid extraction, partitioning, acid-base extractions, ultrasound extraction (UE), microwave assisted extraction (MAE))	
Improved refining or obtaining a raw material stream with desired specifications for the subsequent production stage (pretreatment + primary separation/fractionation).	

Improve the purity of raw material (through techniques like fractionation, separation, conversion - e.g. via advanced chromatography technologies). Each product needs a different purity of biomass	
Improved conversion techniques from biomass into high-value bio-products: Thermochemical: pre-treatment (i.e. drying, size reduction), feeding, conversion (e.g. gasification, pyrolysis), product clean up and conditioning and product end-use Biochemical: converting biomass (using enzymes) to sugar or other fermentation feedstock, fermenting these biomass intermediates using biocatalysts and processing the fermentation product to bio-products *Requirement: selection of one main product in order to minimize the design of different process flow sheets* *Effective biorefineries will use multiple conversion pathways: thermal, biochemical, chemocatalytic, extraction etc.*	
Integrated biorefineries: produce fuels, chemicals, and power from diverse forms of regional biomass, promoting local and regional economic development and energy security.	
Use of the cascade principle in the use of biomass (use of all biomass streams including waste) and production processes (where high-value products are extracted first, followed by less-valuable products, ending with high volume low value products)	
Closed-Loop Cycle (energy recovery for using it in production processes)	
Integration of biorefinery processes in existing infrastructures to reduce costs	
Usage of ICTs (Information and communications technologies) in the production processes	
Regulatory and investment barriers	**Answer**
Regulatory barriers	
What regulatory barriers could delay or stop the technological development of production processes in biorefineries? *E.g. Lack of standards and certification schemes with regard to bio-based products (with the exception of biofuels)* *Lack of policies supporting bio-based products* *Or existence of policies supporting bio-energy: Renewable Energy Directive D2009/28/EC and the Fuel Quality Directive D2009/30/EC*	

Lack of National policies supporting bio-based products (natural conservation policies, climate change policies, agricultural policies, etc.) *REACH (or any other regulation) regulation for chemicals*	
How do you think these barriers could be overcome?	
Which stakeholders would be key in overcoming these/this barrier(s)?	
Investment barriers	
What investment barriers could delay or stop these technological developments of production processes? *E.g. volatile profitability and cash flow generation due to the volatilities in volumes and prices of products/outputs.* *Large size of capital expenditures required (liquidity issues).* *Difficult access to finance or Lack of public funding for demonstration and commercialization phases (demonstration, flagship and industrial-scale)* *Complicated and long application procedures for public funding*	
How do you think these barriers can be overcome?	
Which stakeholders would be key in overcoming these/this barrier(s)?	
Standards	
What standards do you use at the moment? What product standards or specifications do your customers require? What standards are currently missing or should be rewritten to stimulate further investments and developments in the production processes in biorefineries?	
What certificates or process declarations do you currently use? Do your customers require certificates and if so on what topics? What trend do you see in relation to certification/certificates?	
Have you ever experienced problems with definitions / common understanding/language when talking about bio-based processes within your organization or with clients? Do you expect any challenges around terminology in the future?	
Biomass / feedstock production	
Technological and innovation trends	**Answer**
In your view, what innovations and technological trends will most likely occur in biomass production in the next 10 to 15 years?	

Do you consider any of the following technological trends feasible and/or potentially likely to occur? *(if not mentioned)*	
Improvement of the land use techniques (without competing with food or feed) (e.g. precision farming, improved water and fertilizer management)	
Innovative harvesting, separation and storage techniques (e.g. improved machineries) Development of new protocols for the optimization of harvesting, separation and storage	
New cooperative agreements with the agricultural sector Development of new agronomic protocols for the optimization of biomass cultivation Establishment of programs to increase the skills and knowledge base of farmers in order to be able to enhance the biomass cultivation	
Combination of different feedstocks (e.g. vegetable oil + waste oil) = Multi-feedstock biorefinery	
Use of innovative cultivation techniques and growing systems to improve yields (e.g. efficient machineries, improve the input of oil crops, new fertilization techniques e.g. bio-stimulants - biologically derived fertilizer additives used in crop production to enhance plant nutrition, health, growth and productivity)	
Use of genetic modification or other technologies (e.g. genome editing, mutation technologies, advanced breeding technologies): to increase productivity and robustness (e.g. production on less arable land) to optimize the biomass composition to development of non-food crops (e.g. non-food oil crops jatropha, crambe, camelina, guayule)	
Use of ICT in agriculture (e-agriculture) (e.g. weed control, cloud seeding, planting seeds, harvesting, environmental monitoring, efficient farm management)	
Establishment of programs to increase the skills and knowledge of farmers with regard to ICT	
Regulatory and investment barriers	**Answer**
Regulatory barriers	
Which regulatory barriers/hurdles could delay or stop technological developments and innovations in biomass production? *E.g. Lack of incentives for the production of biomass for bio-based materials and chemicals*	

Complicate procedure to use GMO in Europe (applicants can apply for GMO authorisations by submitting a dossier with experimental data and a risk assessment) *Lack of standards and policies*	
How do you think these barriers could be overcome?	
Which stakeholders would be key in overcoming these/this barrier(s)?	
Investment barriers	
Which investment barriers could delay or stop the technological development of biomass production? *E.g. volatile profitability and cash flow generation due to the volatilities in volumes and prices of inputs/feedstocks* *Innovative techniques costs (e.g. new growing systems, new fertilization techniques - e.g. bio-stimulants (biologically derived fertilizer additives used in crop production to enhance plant nutrition, health, growth and productivity)* *Innovative technology costs (e.g. efficient machinery, ICT)* *Costs of research (e.g. GM, ICT)*	
How do you think these barriers could be overcome?	
Which stakeholders would be key in overcoming these/this barrier(s)?	
Standards	
What standards do you use at the moment? What standards are currently missing or should be rewritten to stimulate further investments and developments in the biomass production in your value chain?	
What certificates do you currently use? Do your customers require the biomass to be validated and certified? What trend do you see in relation to certification/certificates?	
Have you ever experienced problems with definitions around bio-based/ common understanding/language when talking about bio-based products? Do you expect any challenges around terminology in the future?	

Annex III: Value chains steps

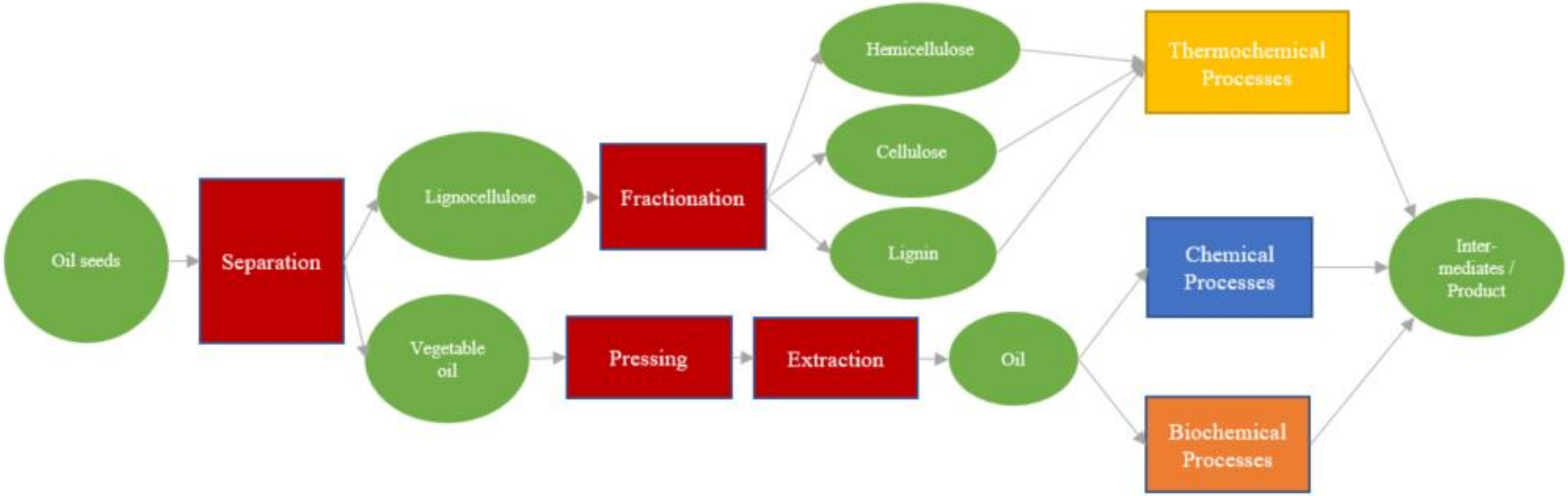


Figure 15 Value chain steps in vegetable oil biorefineries[lxiv]

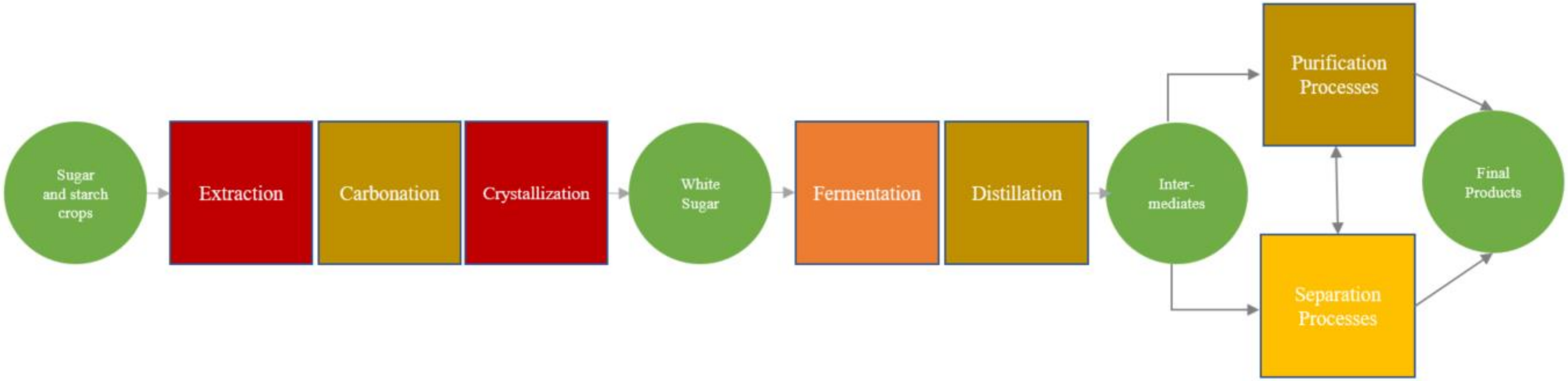


Figure 16 Value chain steps in starch and sugar biorefineries[lxv]

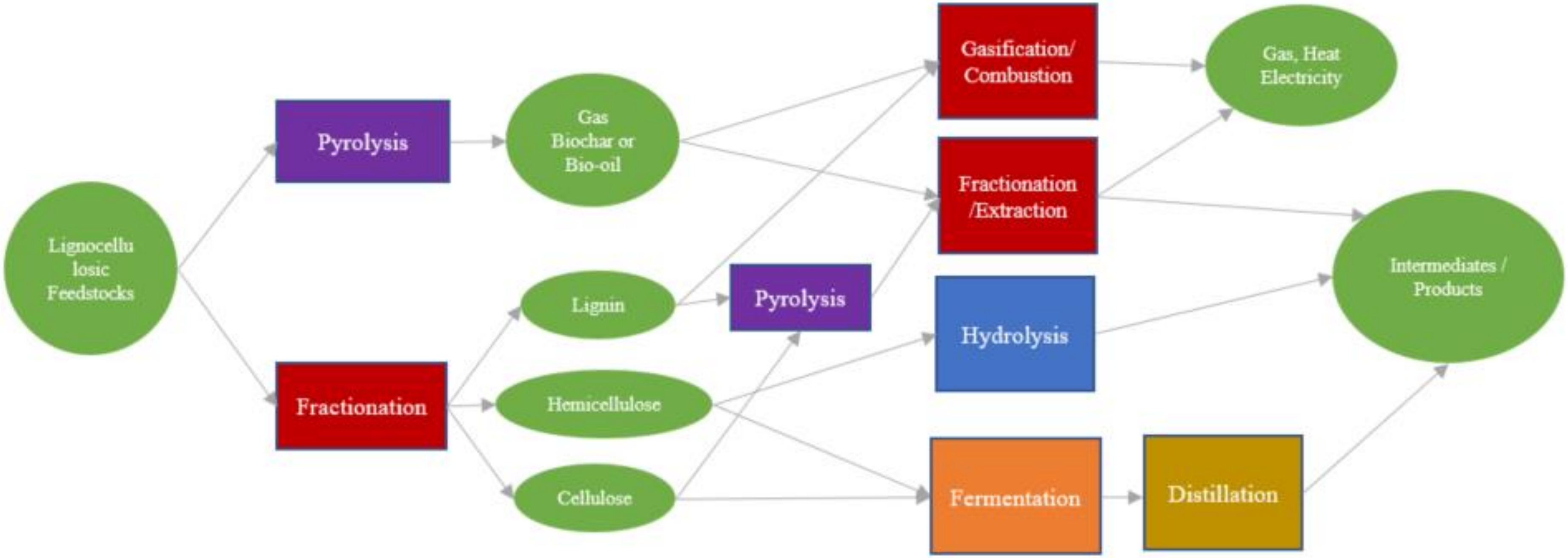


Figure 17 Value chain steps in lignocellulosic biorefineries[lxvi]

Contact

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References

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[i] N. Nakicenovic et al., Intergovernmental Panel on climate change, Emission scenarios, 2000 (Available at: https://www.ipcc.ch/pdf/special-reports/emissions_scenarios.pdf)

[ii] P.Schieb, H.Lescieux-Katir, M.Thénot, B.Clément-Larosière, Biorefinery 2030: Future Prospects for the Bioeconomy, 2015

[iii] https://ec.europa.eu/energy/en/topics/renewable-energy/biomass

[iv] United Nations Foundation, International Bioenergy Initiative. Biomass conversion technologies (2008) (Available at: http://www.globalproblems-globalsolutions-files.org/gpgs_files/pdf/UNF_Bioenergy/UNF_Bioenergy_5.pdf)

[v] L. Ladu, R. Quitzow, Bio-based economy: policy framework and foresight thinking, in: P. Morone, F. Papendiek (Eds.), Food Waste Reduction and Valorisation, Springer International Publishing, 2017

[vi] JRC of the European Commission, Biomass flows in the European Union (2017) (Available at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC106502/kjna28565enn.pdf)

[vii] D2.1. Bio-based products and application potential, 2017, Bioways bio-based economy: network, innovate, communicate. Bio-based industries, Horizon 2020 project.

[viii] European Commission, Study on the Optimised Cascading Use of Wood, 2016 (Available at: https://publications.europa.eu/en/publication-detail/-/publication/04c3a181-4e3d-11e6-89bd-01aa75ed71a1)

[ix] Umwelt Bundesamt, Biomass Cascades, increasing resource efficiency by cascading use of biomass – from theory to practice (2017) (Available at: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-06-13_texte_53-2017_biokaskaden_summary.pdf)

[x] Ellen MacArthur Foundation, Effective industrial symbiosis, 2017

[xi] L.Wang, Production of Bioenergy and Bioproducts from Food Processing Wastes: A Review, American Society of Agricultural and Biological Engineers (ASABE), 2013

[xii] https://www.seipasa.com/en/blog/regulations-eu-fertilizers-organic-waste/

[xiii] Dammer, L. et al. 2017: Sustainable First and Second Generation Bioethanol for Europe. Hürth 2017.

[xiv] A.Mabrouk et al., Techno-Economic Evaluation for Feasibility of Lignin Valorisation Process for the Production of Bio-Based Chemicals, The Italian Association of chemical engineering (AIDIC), 2017 (Available at: http://www.aidic.it/cet/17/61/069.pdf)

[xv] BG. Hermann, M. Patel, Today's and tomorrow's bio-based bulk chemicals from white biotechnology: A techno-economic analysis, Applied biochemistry and biotechnology, 2007

[xvi] L.Egle et al., Phosphorus recovery from municipal wastewater: An integrated comparative technological, environmental and economic assessment of P recovery technologies, Science of the total environment, 2016 (Available at: https://ac.els-cdn.com/S0048969716314656/1-s2.0-S0048969716314656-main.pdf?_tid=548abe96-00f5-11e8-9fcb-00000aab0f6c&acdnat=1516791612_da85b91c7ca7553d1c86863278fd360e)

[xvii] European Commission, Circular economy action plan, 2015

[xviii] Md.Mukhlesur Rahman et al., Production of slow release crystal fertilizer from wastewaters through struvite crystallization – A review,Arabian Journal of Chemistry (Available at: https://ac.els-cdn.com/S187853521300347X/1-s2.0-S187853521300347X-main.pdf?_tid=spdf-75922790-0afc-4b76-92af-206b0617b4b1&acdnat=1519837807_ad3f0ed5bb089e26285016f6856543ac)

[xix] J.Kromdijk et al., Improving photosynthesis and crop productivity by accelerating recovery from photoprotection, Science, 2016 (Available at: http://science.sciencemag.org/content/354/6314/857.full)

[xx] J.R.Evans, Improving photosynthesis, Plant phycology – The American association of plant biologists, 2013 (Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3729760/)

[xxi] Bioeconomy Stakeholders Panel, European Bioeconomy Stakeholder MANIFESTO, 2017

[xxii] M. Schultz, Classical chemical technology wins role in bioprocessing, PTI Global solutions, 2017

[xxiii] European Investment Bank, Access-to-finance conditions for Investments in Bio-Based Industries and the Blue Economy, 2017

[xxiv] RIVM Letter report, REACHing out to the bio-based economy - Perspectives and challenges of EU chemicals legislation, 2016 (Available at: https://www.rivm.nl/dsresource?objectid=5cb9674b-ef4d-4dc8-8bd2-731d804114c2&type=org&disposition=inline)

[xxv] http://www.euractiv.com/section/circular-economy/opinion/why-the-eus-renewable-energy-proposal-subverts-the-circular-economy/

[xxvi] Dammer et al., Mapping study on Cascading use of wood products, WWF, 2016 (Available at: https://mobil.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/WWF-Study_Cascading_Use_of_Wood_Products.pdf)

[xxvii] IEA Bioenergy, Cascading of woody biomass: definitions, policies and effects on international trade (2016) (Available at: http://task40.ieabioenergy.com/wp-content/uploads/2013/09/t40-cascading-2016.pdf)

[xxviii] Birdlife Europe and the European Environmental Bureau, Cascading use of biomass: opportunities and obstacles in EU policies (Available at: http://www.birdlife.org/sites/default/files/attachments/cascading_use_memo_final.pdf)

[xxix] P. Bajpai, Single Cell Protein Production from Lignocellulosic Biomass, 2017

[xxx] G. Christophe et al., Recent developments in microbial oils production: a possible alternative to vegetable oils for biodiesel without competition with human food?, 2012 (Available at: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-89132012000100004)

[xxxi] K. Ochsenreither et al., Production Strategies and Applications of Microbial Single Cell Oils, 2016 (Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5050229/)

[xxxii] D.K.Sidiras et al., Organosolv pretreatment as a major step for lignocellulosic biomass refining, ECI Digital Archives, 2015 (Available at: http://dc.engconfintl.org/cgi/viewcontent.cgi?article=1013&context=biorefinery_I)

[xxxiii] Genetics home reference, What are genome editing and CRISPR-Cas9? (Available at: https://ghr.nlm.nih.gov/primer/genomicresearch/genomeediting)

[xxxiv] EASAC, Genome editing: scientific opportunities, public interest and policy options in the European Union, 2017 (Available: https://www.easac.eu/fileadmin/PDF_s/reports_statements/Genome_Editing/EASAC_Report_31_on_Genome_Editing.pdf)

xxxv T. Aro and P. Fatehi, Production and Application of Lignosulfonates and Sulfonated Lignin, Chemsuschem, 2017 (Available at: http://onlinelibrary.wiley.com/doi/10.1002/cssc.201700082/full)

[xxxvi] T.Shui, Fractionation of cornstalk into cellulose and lignin for the production of sodium carboxymethyl cellulose, 2016, The University of Western Ontario (Available at: https://ir.lib.uwo.ca/cgi/viewcontent.cgi?referer=https://www.google.de/&httpsredir=1&article=5627&context=etd)

[xxxvii] H. Chen, Chemical Composition and Structure of Natural Lignocellulose, 2014, Biotechnology of lignocellulose

[xxxviii] P. Bruijnincx et at. (Utrecht University), Lignin valorisation - The importance of a full value chain approach, 2016

[xxxix] Beis et al., Fast pyrolysis of lignins, 2010 (Available at: https://bioresources.cnr.ncsu.edu/BioRes_05/BioRes_05_3_1408_Beis_MHJBJSWFHBD_Fast_Pyrolysis_Lignins_896.pdf)

[xl] Beis et al., Fast pyrolysis of lignins, 2010 (Available at: https://bioresources.cnr.ncsu.edu/BioRes_05/BioRes_05_3_1408_Beis_MHJBJSWFHBD_Fast_Pyrolysis_Lignins_896.pdf)

[xli] P. Bruijnincx et at. (Utrecht University), Lignin valorisation - The importance of a full value chain approach, 2016

[xlii] P. Bruijnincx et at. (Utrecht University), Lignin valorisation - The importance of a full value chain approach, 2016

[xliii] Anna Louise Jongerius, Catalytic Conversion of Lignin for the Production of Aromatics, Smart Mix Program of the Netherlands Ministry of Economic Affairs and the Netherlands Ministry of Economic affairs and the Netherlands Ministry of education, 2013

[xliv] P.D.De Wild et al., Lignin pyrolysis for profitable lignocellulosic biorefineries, Biofpr, 2014 (Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.893.2114&rep=rep1&type=pdf)

[xlv] P.D.De Wild et al., Lignin pyrolysis for profitable lignocellulosic biorefineries, Biofpr, 2014 (Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.893.2114&rep=rep1&type=pdf)

[xlvi] L. Changjun et al., Catalytic Fast Pyrolysis of Lignocellulosic Biomass, Chemical Society Reviews, 2014 (Available at: http://pubs.rsc.org/en/content/getauthorversionpdf/c3cs60414d)

[xlvii] Biomass technology group, Fast pyrolysis (Available at: http://www.btg-world.com/en/rtd/technologies/fast-pyrolysis)

[xlviii] A.V.Bridgwater, Biomass and Bioenergy, Review of fast pyrolysis of biomass and product upgrading, 2012 (Available at: http://www.sciencedirect.com/science/article/pii/S0961953411000638)

[xlix] T. Aro and P. Fatehi, Production and Application of Lignosulfonates and Sulfonated Lignin, ChemSusChem, 2017

[l] A.L.Jongerius, Catalytic Conversion of Lignin for the Production of Aromatics, Smart Mix Program of the Netherlands Ministry of Economic Affairs and the Netherlands Ministry of Economic affairs and the Netherlands Ministry of education, 2013 (Available at: https://dspace.library.uu.nl/bitstream/handle/1874/280975/jongerius.pdf)

[li] Beis et al., Fast pyrolysis of lignins, 2010 (Available at: https://bioresources.cnr.ncsu.edu/BioRes_05/BioRes_05_3_1408_Beis_MHJBJSWFHBD_Fast_Pyrolysis_Lignins_896.pdf)

[lii] VTT, Fuel oil quality and combustion of fast pyrolysis bio-oils, 2013, (Available at:http://www.vtt.fi/Documents/T87.pdf)

[liii] P. Bruijnincx et at. (Utrecht University), Lignin valorisation - The importance of a full value chain approach, 2016

[liv] A.L.Jongerius, Catalytic Conversion of Lignin for the Production of Aromatics, Smart Mix Program of the Netherlands Ministry of Economic Affairs and the Netherlands Ministry of Economic affairs and the Netherlands Ministry of education, 2013 (Available at: https://dspace.library.uu.nl/bitstream/handle/1874/280975/jongerius.pdf)

[lv] P. Bruijnincx et at. (Utrecht University), Lignin valorisation - The importance of a full value chain approach, 2016

[lvi] P. Bruijnincx et at. (Utrecht University), Lignin valorisation - The importance of a full value chain approach, 2016

[lvii] P. Bruijnincx et at. (Utrecht University), Lignin valorisation - The importance of a full value chain approach, 2016

[lviii] P. Bruijnincx et at. (Utrecht University), Lignin valorisation - The importance of a full value chain approach, 2016

[lix] Project: FDCA production from renewable biomass. Partners: Wageningen Food & Biobased, Bird Engineering, TU-Delft, DSM, University Groningen Research. Duration: 2011-2014 (Available at: https://www.wur.nl/en/show/FDCA-production-from-renewable-biomass.htm)

[lx] Corbion, Bioplastics, creating a more sustainable future (Available at: http://www.corbion.com/bioplastics)

[lxi] FDCA Production from Glucose - Cost Analysis | FDCA E11A. Furanix Technologies B.V. 2016

[lxii] Project: FDCA production from renewable biomass. Partners: Wageningen Food & Biobased, Bird Engineering, TU-Delft, DSM, University Groningen Research. Duration: 2011-2014 (Available at: https://www.wur.nl/en/show/FDCA-production-from-renewable-biomass.htm)

[lxiii] J.Wang et al., Copolyesters Based on 2,5-Furandicarboxylic Acid (FDCA): Effect of 2,2,4,4-Tetramethyl-1,3-Cyclobutanediol Units on Their Properties, Polymers, 2017

[lxiv] A. Pandey et al., Industrial Biorefineries and White Biotechnology, 2015

[lxv] A. Pandey et al., Industrial Biorefineries and White Biotechnology, 2015

[lxvi] A. Pandey et al., Industrial Biorefineries and White Biotechnology, 2015