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Bio-based economy: network, innovate, communicate

D2.1 Bio-based products and applications potential

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BIO-BASED INDUSTRIES Public-Private Partnership

Bio-based Industries Consortium

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1. Executive Summary

As the current model of production and consumption which largely relies on fossil-based resources impacts irreversibly on the environment and the availability of natural resources is approaching a peak soon, significant steps are being taken around the world to move from today's fossil based economy to a more sustainable economy based on biomass. A key factor in the realisation of a successful bio-based economy is the production of a range of bio-based products and bioenergy to substitute their fossil-derived equivalents by processing a wide variety of biological feedstock. The total European Bioeconomy amounts to a 2.1 trillion EUR turnover and provides 18.3 million jobs, which accounts for approximately 9% of the total EU workforce [1]. The EU has declared the bio-based products sector to be a priority area with high potential for future growth, reindustrialisation, and addressing societal challenges.

In this report, a review of the application areas and market penetration of the following bio-based market segments is attempted, along with an assessment of possible barriers to uptake and growth and future trends that characterize each specific sector:

- Bio-based chemicals and building blocks;
- Bioenergy and biofuels;
- Bioplastics/ biomaterials;
- Bio-based food and feed ingredients;
- Biosurfactants;
- Biolubricants.

This analysis was made following a review of relevant literature and based on several qualitative interviews with key stakeholders in the bio-based production domain. Additionally, information about the supply chains of bio-based products (relating to biomass feedstock used, processes and biorefineries) and about existing legislation and policy framework is presented.

Biomass feedstock and supply chains used in bio-based production

From a technical point of view a variety of feedstock can be converted to marketable bio-based products and bioenergy. Forestry, agriculture, waste (industrial and domestic) and aquaculture provide potential feedstock for bio-based production, which either constitute residues of other activities or are specifically produced as exploitable biomass (e.g. dedicated crops). An extensive list of biomass feedstock used for bio-based production is presented in Table 2. Overall:

- **Lignocellulosic biomass** is an abundant sustainable biomass source that can potentially provide a renewable feedstock for many next generation bio-products and bioenergy. Lignocellulosic biomass is already widely used for bioenergy and a small quantity for second generation biofuels. It can be chemically disrupted to isolate its component

[1] Piotrowski et al., 2016

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polymer materials, namely cellulose, lignin and hemicellulose, forming the base for the production of a wide range of chemical products or even broken down and used in the production of fuels and other chemicals. However, significant technical and economic barriers need to be overcome to maximise its potential. Recent studies indicate that the production of most bio-based products will still be non-lignocellulosic based by 2030 although the share using lignocellulosic biomass will reach at least 5%.[2,3] It is also expected that the growth of dedicated lignocellulosic crops will expand in the following years in the EU to be used for second generation biofuels production, as various thermochemical technologies for the production of biodiesel will also become commercial (biomass gasification to syngas and Fischer-Tropsch (FT) synthesis and Biomass to Liquids (BtL) process).

- Approximately 490 million tonnes of **forestry biomass** (dry mass) are currently exploited annually in Europe (including for pulp, paper and other traditional uses). An estimated 245 million tonnes of wood are used in the woodworking and pulp and paper industry annually and 240 million tonnes of wood are used for heat and power production. Forest based raw materials have high shares in the production of bio-based products and bioenergy, mainly via the lignin platform. At industrial scale, forest residues and waste wood can be converted to advanced biofuels or intermediates. However, sustainability considerations are very important as increasing the extraction of forest residues and biomass beyond a certain point will inevitably lead to trade-offs between productivity and environmental and economic sustainability. Beyond sustainability considerations, there are technical and economic limitations of forestry biomass used as feedstock.

- Regarding **agro-based biomass** used for bio-based products, the main feedstocks used are dedicated crops (mainly sugar, starch and oil) and farm and crop residues. Sugar and starch dedicated crops are used for the production of 1st generation bioethanol. Oil crops are mainly used for biodiesel production but also for other bio-based chemicals. Wet biomass like energy maize and maize residues are used for biogas production. It is estimated that at present there are approximately 5.5 million hectares of agricultural land on which bioenergy cropping takes place. Practically all of this land is used for biofuel cropping, mostly oil crops (82% of the land used for biomass production). These are processed into biodiesel; the remainder is used for the production of ethanol crops (11%), biogas (7%), and perennials go mostly into electricity and heat generation (1%).[4] Regarding agro-based crop residues, there potential to use a great quantity in the EU, which is currently being underutilized. Estimated quantities range from 139- 252 million tonnes in the 2030 timeframe in various studies.[5,6] The processing of these residues to produce advanced biofuels has

[2] S2BIOM D8.2, 2015
[3] Uslu and van Stralen, 2016
[4] BIOMASSFUTURES D3.3, 2012
[5] WASTED, 2014
[6] S2BIOM D8.2, 2015

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been identified as a great opportunity for local development and the reconversion of brownfields.[7]By far the largest source of crop residues is the straw and stover from grain crops (wheat, barley and maize). Again there are several technical and economic barriers to mobilising their wider use as bio-based production feedstock.

- **Waste biomass** also offers a potential route to bio-based production and there is growing recognition of the benefits of using wastes and residues as biomass feedstock. Used cooking oils or recycled vegetable oils were the second most important feedstock for biodiesel production in 2015 in the EU, with more than 1.1 million tonnes consumed in Europe in 2013[8]. Other plant origin oils used for biofuel production include tall oil, residue from the pulp industry, palm fatty acid distillate and by-products of the production of omega-3-fatty acids from fish oil. Regarding Municipal Solid Waste, the organic fraction consisting of food and garden waste may be converted into biogas via anaerobic digestion and the wood fraction that cannot be recycled can be combusted for bioenergy or advanced biofuels. Estimates of food waste are inherently difficult, counting for about 89 million tonnes in EU in 2010 and there are several technical, organizational and legislation difficulties in its use as feedstock. Estimates of wood fraction of MSW are in the range of 26-57 million tonnes per year.[9] Finally various other organic residues/ biological waste/by-products such as waste/by-products from beer production, bakeries, potato industry etc. have been studied or are in the phase of implementation as feedstock for bio-based production, usually following a biorefinery approach of simultaneous production of bioenergy and value-added products.

Bio-based products production processes

The various **processes** used to produce bio-based products from biomass belong in four main categories:

- **Mechanical or physical processes** (milling, separation, upgrading, dehydration etc.) are mainly used as biomass pre-treatments or in intermediate processing steps;
- **Chemical processes** (hydrolysis, oxidation etc.) are also mainly used as biomass pre-treatments or in intermediate processing steps;
- **Biochemical processes** (anaerobic digestion, fermentation, transesterification etc.). Overall, fermentation processes have been used since World War I for industrial production of energy carriers and chemicals and many bio-based chemicals are now produced by fermentation at an industrial scale, such as ethanol, lactate, amino acids and citric acid with the potential to produce many more. Apart from sugar and starch

[7] http://www.agenziacoesione.gov.it/opencms/export/sites/dps/it/documentazione/NEWS_2016/BIT/BIT_EN.pdf
[8] WASTED, 2014
[9] Kretschmer et al, 2013

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feedstock, lignocellulosic feedstock is also tested in more advanced fermentation systems. Anaerobic digestion is a well-established process for biogas production

- **Thermochemical** processes (combustion, gasification, pyrolysis etc.) are suitable for the conversion of lignocellulosic feedstock, such as wood. Combustion is the most widely used process to produce bioenergy for heat or power. Gasification technologies are under development and few large commercial units exist, mainly in areas with substantial forestry biomass capacity. Pyrolysis technologies are not yet fully commercially mature with a number of pilot plants in use worldwide and they can be economically efficient for Combined Heat and Power (CHP) only or in a biorefinery concept where both energy and other products of higher value are produced. Liquefaction and torrefaction of biomass are not as developed in commercial production and are expensive, although they have several potential applications.

Biorefining

Based on IEA Bioenergy Task 42 classification, many biorefinery types can derive, with different combinations and numbers of feedstock, platforms and products, as shown in Table 7. In the EU today, those types of biorefineries that are already state of the art and in commercial operation are the energy-driven ones, i.e. the biorefineries where the biomass is primarily used to produce biofuels and process residues are used either for heat and electricity or upgraded to bio-based products. There is only a limited number of product-driven biorefineries in commercial operation today in the EU and often their chain composing key technologies are still at an R&D or demonstration phase. New biorefinery types that will depend on lignin, organic solution and syngas platforms are mostly in the pilot or small-scale demonstration phase with limited commercialization in the medium term (2025). Nevertheless, they exhibit a high potential. High potential also exhibits the implementation of biorefineries in process industries, with the pulp and paper industry to be the key industry in such case studies with some highly innovative and diversified pulp mills that derive value from compounds extracted from wood.

Bio-based market sectors and market penetration

There is a long history of production for some **bio-based chemicals and building blocks**, such as citric acid, while others have been more recently introduced such as propylene glycol and some are still in the demonstration or development phase. Bioethanol dominates the market, followed by much smaller but still significant markets for n-butanol, acetic acid and lactic acid. Xylitol, sorbitol and furfural also show significant markets for chemical conversion of sugars, without petrochemical alternatives. Bio-based Furandicarboxylic acid (FDCA), levullinic acid and farnesene have the highest current prices and bio-based succinic acid has the fastest growing market at present. In the field of bio-based building blocks, the development stage ranges from proof of concept in the lab to full commercial production but only a few of them have reached commercially viable production compared to their fossil-fuel counterparts. The

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most dynamic developments are spearheaded by succinic acid and 1,4-BDO, with MEG as a distant runner-up. Bio-based MEG, L-lactic acid (L-LA), ethylene and epichlorohydrin are relatively well established on the market.

In 2014, 61% of all renewable energy that was consumed in the EU and 10% of the gross final consumption was accounted to **bioenergy**. In terms of sectors, 73% of bioenergy consumed in Europe was used in the heating sector (76.998 kTOE- Tonnes of Oil Equivalent) while 14% (14.349 kTOE) as bioelectricity.[10] The basic carriers of bioenergy are: solid biomass fuels, biogas and biofuels used for transportation purposes. The heating sector is the largest energy market for solid biomass fuels, used for residential consumption, industry and large-scale and district heating, with great differences in market penetration between different regions of the EU. Bioelectricity also represents 17.9% of the total renewable electricity with CHP plants dominating the relevant sector. The European biogas sector is very diverse is dependent on how each EU country sets up its biogas function in its area to favour different feedstock, i.e. whether biogas production is primarily seen as a means of waste management, as a means of generating renewable energy, or a combination of the two. According to data from 2014, Germany biogas production corresponds to the 65% of total EU production (higher), and is followed by Italy (14%), Czech Republic (5%), UK and Austria (3%).[11]

The most common **biofuel** is first generation bioethanol. Biodiesel is the second most common liquid biofuel and Europe is the biggest producer and consumer of biodiesel. In 2014, the EU consumed 134 million TOE of biodiesel for transportation uses.EU bioethanol production reached its highest level in 2014 – 5.3 billion litres – as the sector benefitted from low feedstock prices and the restrictive measures on bioethanol imports.[12] Advanced biofuels are also notably popular for research and for their widespread commercial use in Europe in the future. In Table 10 the most common biofuels (first generation and advanced) are presented along with current scales of production, related feedstock/ process and applications.

Bioplastics seem to have the best and longest market penetration compared to other bio-based sectors. A vast array of products derive from bioplastics using conventional plastic processing technologies with multiple applications, as shown in Table 11. Lignocellulosic polymers also exhibit great potential in high-value applications such as clothing fibres, films and filters. Bioplastics represent approximately 1% of the 300 million tons of plastic produced annually but there is notable growth in the market (20%-100% per year). The global production capacity of bioplastics is expected to reach 6.1 million tons in 2021, a significant increase from the 4.2 million tons that was produced in 2016.

Bio-based food and feed ingredients have numerous applications in various sectors of the food industry such as nutraceuticals, dairy products, beverages, oils and fats, animal feed, infant nutrition, snack foods and bakery goods etc., with probiotic and fructan market segments being dominant. Additionally, the multiple biomass feedstock that are being used for

[10] AEBIOM, 2016
[11] USDA Foreign Agricultural Service, 2016
[12] USDA Foreign Agricultural Service, 2016

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the production of second generation biofuels have introduced several co-products that can be used as livestock feed in the global market.

Biosurfactants can be found as components of various products which are used in many industries and for several applications such as household detergents, personal care, industrial cleaners, food processing, oleo field chemicals, agricultural chemicals etc. In 2012 the global demand for biosurfactants was 330,200 tonnes and this is expected to increase to 461,991.67 tons by 2020, growing at a Compound Annual Growth Rate (CAGR) of 4.3% from 2014 to 2020. [13] House hold detergent was the largest application of biosurfactants accounting for 44.6% of the market in 2013.

Biolubricants are used in a variety of applications and industries, commonly in machinery used in areas that are sensitive to pollution. Biolubricants are a very small part of the overall lubricant market, predominantly used in the US and Europe (accounting for 85-90% of the global market) as their high cost limits their appeal elsewhere. The two major user groups in the global biolubricants market are the automotive industry and industrial use, with the automotive industry using over 56% of the volume share of biolubricants in 2015. However, there has already been an increase in the market value of biolubricants up to 2015 and the market value is expected to grow at 5.4% CAGR from 2016 to 2024, owing to increasing application in the transportation and manufacturing industries due to environmental concerns.

Legislation and policy framework

Several EU policies – both implemented and under development – are already shaping the investment capabilities and decisions made by stakeholders in the bioeconomy, such as 2012's Europe's Bioeconomy Strategy, the 2030 Climate and Energy Framework, the Circular Economy Package and the Commission Expert Group for Bio-based products etc. An extensive list is presented in Table 16, whereas existing standards about bio-based products are presented in Table 17.

Barriers

There are various barriers to the development of sustainable levels of production and market exploitation of bio-based products. These are summarized below:

Barriers to sustainable production and market exploitation of bio-based products	
Feedstock- related barriers	• High costs of biomass feedstock produced in EU. • Inadequate availability of biomass feedstock at the required quality, quantity and price throughout the year • Seasonality in biomass feedstock production • Inefficient transport and distribution systems of several

[13] Grand View Research, 2015

Barriers to sustainable production and market exploitation of bio-based products	
	biomass feedstock types • Inefficient recovery systems for (bio)waste that could possibly be used as feedstock for bio-based products
Industry- related barriers	• Low technology readiness level and commercialization status for many bio-based products • Lack of cooperation between the stakeholders in the relevant value chains • Hurdles in establishing partnerships between academia and industry • Limited financial support for new production facilities • Lack of a trained workforce
Market- related barriers	• Low price of crude oil and natural gas that make the use of biomass feedstock and bio-based production processes economically unattractive • High cost of bio-based products compared to their fossil-fuel derived equivalents • Lower performance of many bio-based products compared to their fossil-fuel derived equivalents • No dedicated and detailed EU legislation framework, conflicts between sustainability goals and market needs, lack of uniform standardization and certified labelling for bio-based products • Gaps in the policy and subsidy framework • Intellectual property related barriers • Low public awareness of the benefits of using bio-based products • Lack of reliable and sufficient information about bio-based products

Drivers and future trends

The overall bio-based industry trend is to focus on delivering products with similar or even better performance and technical characteristics than the conventional, fossil- fuel derived products, to counterbalance their higher cost. In terms of biomass feedstock, there is a huge potential in waste deriving from the agri-food value chain that could be valorised for bio-based production and in organic waste in general. In the field of bio-based chemicals, the main market drivers are moving towards less petroleum dependency and feedstock diversification (multiple feedstock inputs) and aim to increase the environmental responsibility of the consumer, promote the idea of sustainability to manufacturers and offer innovative products. Regarding the bioplastics sector, several trends are identified, like the enhancement of

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compostable plastic materials applications in the packaging sector and the development of completely new materials. The basic future trend in the field of bioenergy, is towards the production of energy along with the production of other streams/ products of high- value in the biorefinery context. Also, the increase of short rotation coppice, the increase of imports of pellets to the EU, the future importance of saw mills as a provider of by-products both for the bioenergy and material sector, CHP and electricity production through gasification and pyrolysis and the production of second generation bioethanol are all future trends in the sector. In bio-based food and feed ingredients, it seems that there is significant potential for animal feed production, using agro-based waste or the by-products from biorefineries and in applications in the neutraceutic food sector. In general, it is concluded that to ensure that the bioeconomy reaches its expected potential, better cooperation between different sectors – agriculture, forestry, fisheries, food and aquaculture - must be achieved. The potential market will grow from cross-value chains and their development at the local level. Additionally, there needs to be a substantial change of mentality, not only in consumers but also in policy makers and industry if this market potential is to be reached.

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2. Introduction

This report was prepared under Task 2.1 “Review and assessment of the bio-based products current market uptake and applications and their future potential” of the BIOWAYS project (www.bioways.eu). The BIOWAYS project is funded by the Bio-based Industries Joint Undertaking (BBI-JU) under the EU’s Horizon 2020 Framework Programme (Grant Agreement No 760762). The aim of the project is to raise public awareness of bio-based products and to promote their applications and benefits to society at large as well as to highlight the role of the bio-based industries, using a variety of communication techniques, educational tools and materials.

The aim of the report is to provide insight into the current market situation and future trends of bio-based products and their applications by collecting evidence regarding the capabilities, benefits and potential risks associated with their usage, namely:

- The supply chains of bio-based products from feedstock to processing and biorefining;
- The application areas (market sectors) and functionalities of selected bio-based market segments: bio-based chemicals and building blocks, bioenergy, bioplastics/ biomaterials, bio-based food and feed ingredients, biosurfactants and biolubricants
- The penetration of bio-based products into the EU market and their future potential;
- The relevant existing EU legislation and policies;
- Case studies on practical examples covering as many market segments and value chains as possible.

The ultimate goal of the report is to provide BIOWAYS partners with a knowledge base for the development of information and training material as well the development of key communication messages and public engagement activities which are part of the project (under WP3 and WP4).

The analysis was conducted primarily through literature review of relevant studies, market reports, results and conclusions derived from EU-funded projects and other initiatives etc. The findings of the literature review were reinforced by qualitative interviews with key stakeholders of the bioeconomy domain which elicited their perception and concerns about the present and future of the market from their perspective. A name list of the interviewees is presented in Appendix A: List of Interviewees. A semi-structured qualitative questionnaire was used to help structure the interviews and this is available in Appendix B: Interview semi-structured questionnaire.

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3. Definitions

Bio-based products: products derived wholly or partly from biomass, such as plants, trees or animals. The biomass may have undergone physical, chemical or biological treatments.

Biomass: material of biological origin excluding material embedded in geological formations and/ or fossilized. Examples: (whole or parts of) plants, trees, algae, marine organisms, micro-organisms, animals etc.[14]

Bioeconomy: the set of economic activities relating to the invention, development, production and use of biological products and processes.[15]

Bioenergy: the conversion of biomass resources originating from agriculture, forests and biodegradable waste into useful energy carriers including heat, electricity and fuels for transport.

Lignocellulosic: fibrous, non-edible plant molecules/biomass containing cellulose, with varying amounts of lignin, chain length, and degrees of polymerization. This includes wood from forestry, short rotation coppice (SRC), and lignocellulosic energy crops, such as energy grasses and reeds.

Value chain: integrated process scheme, from feedstock to end products and markets

[14] CEN, 2014
[15] OECD, 2009

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4. Abbreviations

AD: Anaerobic Digestion

APG: Alkyl polyglycosides

BIC: Bio-based Industries Consortium

BLTC: Biomass Logistics and Trade Centers

BTD: Butanediol

BDO: Butanediol

BtL: Biomass to Liquid

CAGR: Compound Annual Growth Rate

CEN: European Committee for Standardization

CHP: Combined Heat and Power

DDGS: Distillers Dried Grain with Solubles

DG: Distillers Grain

DME: Dimethylether

EBTP: European Biofuels Technology Platform

EFSI: European Fund for Strategic Investments

EIP: European Innovation Partnerships

EMS: Emission Trading System

ETS: Emission Trading System

FAME: Fatty Acid Methyl Esters

FT: Fischer- Tropsch

HDRD: Hydrotreated Renewable Diesel

HEFA: Hydroprocessed Esters and Fatty acids

HRJ: Hydrotreated Renewable Jet

HVO: Hydrotreated Vegetable Oils

MEG: Mono Ethylene Glycol

MEL: Mannosylerythritol lipids

MSW: Municipal Solid Waste

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OECD: Organization for Economic Cooperation and Development

PA: Polyacryl

PBAT: Polybutylene adipate-co-terephthalate

PBS: Polybutylene Succinate

PBT: Polybutylene Terephthalate

PDO: Propanediol

PE: Polyethylene

PET: Polyethylene Terephthalate

PHA: Polyhydroxyalkanoate

PLA: Polylactic acid

PP: Polypropylene

PTT: Poly Trimethylene Terephthalate

PVC: Polyvynil Chloride

SFM: Sustainable Forest Management

SFMS: Sustainable Forest Management Systems

SRF: Soil Recovered Fuel

TCP: Thermoplastic Copolyester Elastomer

THF: Tetrahydrofurans

TOE: tonnes of oil equivalent

WDG: Wet distillers grain

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5. Introduction to the Bio-economy

By 2030, the global population is expected to increase by 28%, from 6.5 billion in 2005 to 8.3 billion. A larger population will increase the demand for essential natural resources: food, animal feed, fibre for clothing and housing, clean water, and energy. In less than 15 years, the world will need to produce around 50% more food and energy, together with 30% more fresh water. [16]

The current model of production and consumption, which largely relies on fossil-based resources, will impact irreversibly on the environment. While the global population and world economy continue to expand, society increasingly demands biological resources for food, energy and other uses and more sustainable production processes in industry, agriculture and fisheries. These sectors will need to produce, use and recycle biomass in a sustainable way, enabling a circular economy with optimal use of raw materials, side streams, by-products and waste. A sustainable, circular economy that avoids environmental degradation also implies substituting fossil based energy and fossil-based products (for instance plastics) by renewable energy and bio-based products. [17]

A sustainable development guarantees long-term maintenance of the factors that support life and human societies. This requires the long-term preservation, in good condition, of:

- environmental factors essential to life, such as biodiversity, clean fresh water, clean air, soil fertility, and an amenable climate;
- renewable resources such as water, timber, food, and fish; and
- the technological capabilities to develop alternatives to the depletion of non-renewable resources such as minerals, rock phosphate and petroleum, or to manage other challenges, such as climate change. [18]

[16] Population Institute , 2010
[17] Laroche, G., 2015
[18] OECD, 2009

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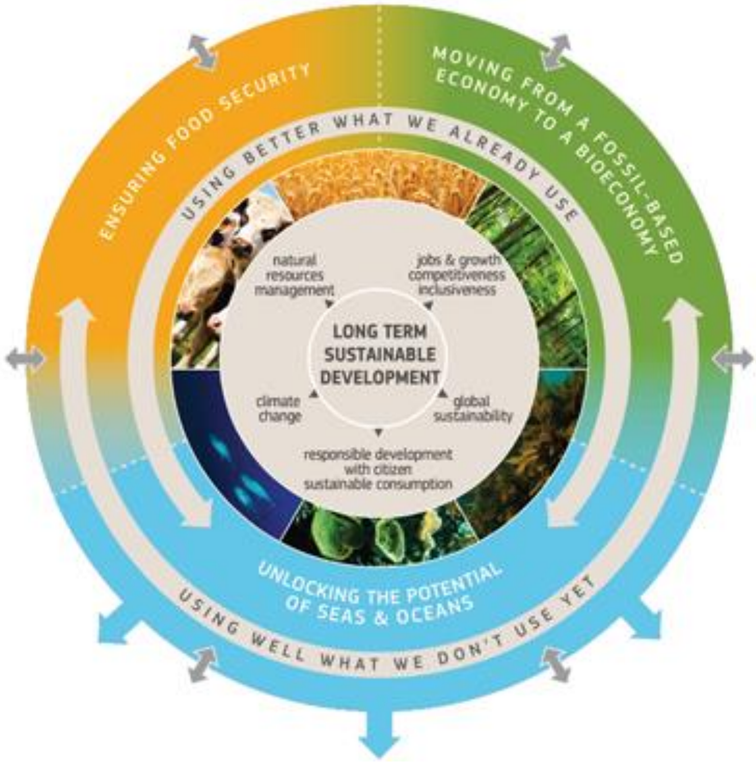

Figure 1: Long term sustainable development (EC) [19]

Bioeconomy is a new concept that officially came into light for discussion at the beginning of the 21st century. According to European Commission[20], "*The bioeconomy comprises those parts of the economy that use renewable biological resources from land and sea such as crops, forests, fish, animals and microorganisms to produce food, materials, and energy.*" According to the Innovation Policy Platform[21], the bioeconomy and biotechnologies can improve the supply and environmental sustainability of food, feed and fibre production, improve water quality, provide renewable energy, improve the health of animals and people, and help maintain biodiversity by detecting invasive species. OECD (Organization for Economic Cooperation and Development) defines the bioeconomy as "the set of economic activities relating to the invention, development, production and use of biological products and processes".[22]

The general idea of the bioeconomy is to develop energy, food and raw material supplies from renewable sources, moving away from our current dependency on fossil fuels and their derivatives. The bioeconomy can support sustainable development by improving the environmental efficiency of primary production and industrial processing and by helping to repair degraded oil and water.

[19] EU Bioecomony strategy, 2012
[20] https://ec.europa.eu/research/bioeconomy/index.cfm
[21] https://www.innovationpolicyplatform.org/content/biotechnology
[22] OECD, 2009

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The bioeconomy provides various societal, economic and environmental benefits (Table 1):

Table 1: Societal, economic and environmental benefits of bioeconomy

Societal benefits	Economic benefits	Environmental benefits
Ensuring food security and managing natural resources sustainably: More resource-efficient food supply chains, guaranteed food security, decreased use of chemical products in agriculture, reduced food waste, helping to meet rising food demand caused by rising global population.	**European competitiveness and sustainable economic growth:** Significant economic growth expected from new and expanding bio-based industries, from the adoption of innovative processes in existing organizations, and from the development of new markets operating with bio-based products.	**Reduction of the economy's dependence on fossil fuels** **Sustainable management of natural resources** **Pressure-relief on ecosystems** **Enhancement of recycling**
Quality of life and health benefits: Change of mentality towards a better lifestyle and environmental sensitivity, long- term positive effect addressing pressing environmental challenges (food, water, energy).	**New employment opportunities:** Green jobs created by the bioeconomy, particularly in rural, coastal and industrial areas. Multitude of new work possibilities and new high-skilled jobs and training options to meet labour demands in the diverse value chains of bio-based products.	
Challenges for Social Innovation: Changes in attitude (at individual and organizational level) to ways in which we re-use and recycle bio-based products, the treatment and valorization of waste and new forms of production and the distribution of products through the development of local networks. Huge potential		

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for social innovation in the areas of health, diet, education, and rural and coastal development.		

Systemic integration of social, environmental and economic sustainability into EU policies would help pave the way towards a more productive, competitive, and resource efficient bioeconomy. According to an extensive macro-economic study on the European Bioeconomy promoted by the Bio-based Industries Consortium (BIC) in March 2016[23], the total European Bioeconomy amounts to 2.1 trillion EUR turnover, with 18.3 million jobs accounting for approximately 9% of the total EU workforce, as shown in Figure 2 and Figure 3.[24]

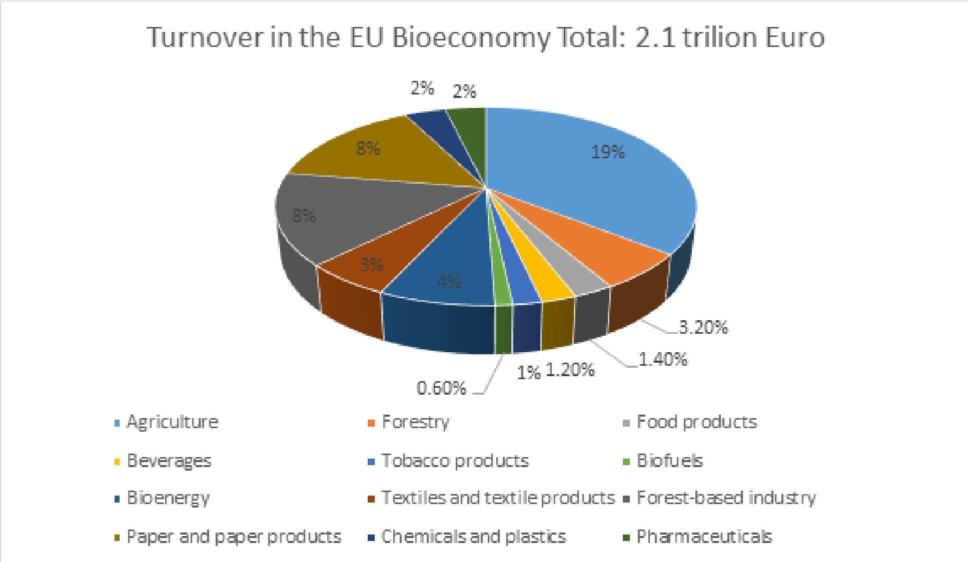

Figure 2: Turnover in the EU Bioeconomy (EU-28, 2013) Total: 2.1 trillion Euro[25]

[23] Piotrowski et al., 2016
[24] BECOTEPS, 2011
[25] Piotrowski et al., 2016

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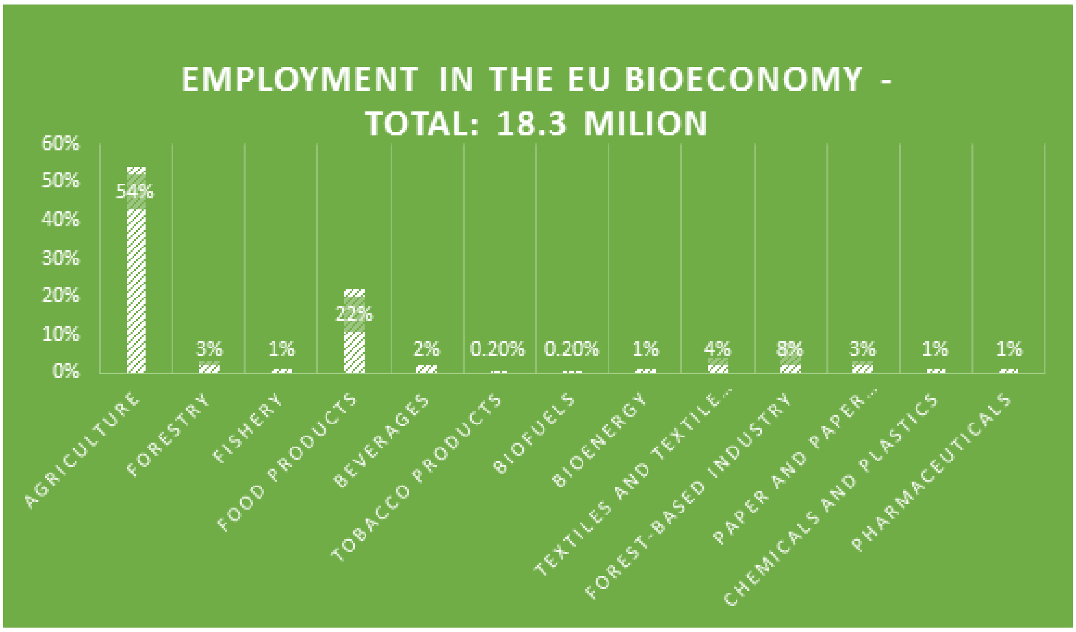

Figure 3: Employment in the EU Bioeconomy (EU-28, 2013) Total: 18.3 million[26]

In 2030, the biotechnology domain could contribute 2.7% to the GDP of OECD[27] countries, with the largest economic contribution of biotechnology in industry and in primary production, followed by health applications. Within this concept, the Europe 2020 Strategy identified in the bioeconomy a key element for smart and sustainable development and several EU policies – both implemented and under development – are already shaping the sector's investment capabilities and decisions. [28]

The most relevant are:

- the 2012 Europe's Bioeconomy Strategy that aims to ensure fossil materials are replaced with sustainable and renewable alternatives;
- the 2030 Climate and Energy Framework with new targets for emission reductions, renewable energy and energy efficiency and the related Emission Trading System (ETS);
- the EU framework programme for research Horizon 2020, including the Bio-based Industries Public Private Partnership;
- the Circular Economy Package, which would enhance recycling capabilities and offer more opportunities for bio-based products;
- the European Fund for Strategic Investments (EFSI), which, beyond its focus on infrastructure, may offer new funding opportunities for transformative investment[29].

The development of the bioeconomy can address many of the challenges that concern many stakeholders: consumers who get access to new sustainable products based on renewable

[26] Piotrowski et al., 2016
[27] OECD, 2009
[28] CEPI, 2017
[29] http://ec.europa.eu/environment/circular-economy/index_en.htm

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biological resources, bio-based industries that take technological and sustainability leadership and thereby build long-term competitive advantages; enhanced economic growth and new jobs in rural, coastal and industrial areas and new revenue streams for the EU-27 in the agriculture and forestry sectors.

Specific actions are needed to maximize the impact of bioeconomy research and innovation. In line with the recommendations of BIOWAYS's public consultation on the bioeconomy (D2.2), a more coherent policy framework, and increase in research investments, the development of bio-based markets and better communication with the public should all be prioritized. [30]

[30] EC, Directorate General for Research and Innovation- Food, Agriculture and Fisheries and Biotechnology, 2011

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6. Feedstock and Production processes

6.1. Feedstock

6.1.1. Introduction

A variety of feedstock can be converted to marketable bio-based products and bioenergy, as presented in Table 2. In terms of originating sector, biomass feedstock can be categorized in four major categories that could support further growth of the bio-based industries:

- From forestry;
- From agriculture;
- From waste (industrial such as process residues, by-products and wastes and domestic such as organic residues);
- From aquaculture.

A further distinction can be made between different biomass feedstocks to those that consist of **residues** of agricultural, forestry and industrial activities and to those that are **produced** specifically as exploitable biomasses (dedicated crops) from agriculture or in aquatic systems.

The basic components of biomass feedstock are cellulose, hemicellulose, lignin, starch, triglycerides, proteins and various chemical elements (C, O_2, H_2, S, N and ashes). Other important characteristics related to the performance of each feedstock are water content, heating value and specific volume.

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Table 2: Inventory of biomass feedstock used for bio-based products and bioenergy (adapted from [31] [32] [33][34])

ORIGIN	FEEDSTOCK	TYPE
Forestry	**Woody biomass residues:** Stem wood and primary forest residues, landscape residues: whole trees, timber, thinnings, branches, harvest losses (unmerchantable wood), stumps and coarse roots etc.	Residues
Forestry	**Woody biomass:** forests and other wooded land, including tree plantations and short rotation forests for stem wood production	Dedicated feedstock
Agriculture	**Lignocellulosic crops**: short rotation coppice (willow, poplar, eucalyptus etc.), red canary grass, miscanthus, giant reed, switch grass etc.	Dedicated feedstock
Agriculture	**Sugar crops**: sugar cane, sugar beet, sweet sorghum etc.	Dedicated feedstock
Agriculture	**Starch crops:** corn, wheat, industrial sweet potatoes, barley, rye, millet, rusby or virginia mallow, cassava etc.	Dedicated feedstock
Agriculture	**Oil crops**: coconut, palm, palm kernel, soybean, sunflower, linseed, rapeseed, castor etc.	Dedicated feedstock
Agriculture	**Grasses:** green plant materials, grass silage, immature cereals, plant shoots etc.	Dedicated feedstock
Agriculture	**Agricultural surplus**	Residues
Agriculture	**Animal manure** (wet and dry)	Residues
Agriculture	**Herbaceous residues**, partly now being left on the land or burned: wheat straw, bran, barley straw	Residues

[31] IEA Bioenergy- Task 42 Biorefinery, 2012
[32] BIOCHEM, 2010
[33] BACAS, 2011
[34] Biomassfutures, 2012

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ORIGIN	FEEDSTOCK	TYPE
Agriculture	**Grass** from permanent (semi-natural) grasslands	Residues
Agriculture	**Fruit and grain waste biomass:** olive stonnes, cherry pits, grape waste, nut shells, olive oil mill residues etc.	Residues
Process wastes Forestry	**Wood processing industry lignocellulosic by-products and residues**: sawdust, cutter savings, grinding powder, bark, woodchips, wood dust etc.	Residues
Process wastes Forestry	**Pulp and paper industry by-products and residues**: bark, black liquor and other sludges etc.	Residues
Process waste Agriculture	**Agro-industrial side-streams**: beet pulp, bagasse, corn cobs, corn stover, olive mill cakes, cassava waste water, palm oil mill effluent, groundnut waste, soybean waste, orange peel waste, potato peel waste	Residues
Organic waste	**Organic waste from industry and trade** (excluding agro-industrial and pulp and paper industry) including woody fractions such as bulk transport packaging, recovered demolition wood etc.	Residues
Organic waste	**Sewage sludge** (from industry and households)	Residues
Organic waste	**Oil-based residues:** animal fat from food industries, used cooking oil from restaurants, households and others etc.	Residues
Organic waste	**Municipal solid biodegradable waste** (from private households and gardens) including woody fractions such as food left overs, waste paper, discarded furniture etc.	Residues
Aquaculture	**Marine biomass:** micro and macro algae, seaweeds etc.	Dedicated feedstock

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6.1.2. Plant biomass potential

Lignocellulosic biomass is an abundant source that can potentially provide a renewable feedstock for many, next generation, bio-based products and bio-energy, with limited or no conflict with food and feed markets.

Lignocellulosic biomass originates mainly from forest residues such as stem wood and primary forest residues, landscape residues, wood processing industry by-products and residues, used wood, herbaceous residues etc. and dedicated lignocellulosic crops (woody and grassy perennials).

Currently, lignocellulosic biomass finds limited commercial exploitation in the production of bio-based products. Recent studies indicate that most bio-based production will still be non-lignocellulosic based by 2030 although the share of used lignocellulosic biomass will reach at least 5%. [35][36]Lignocellulosic biomass is already widely used for bioenergy (heat and electricity production) and a small quantity for advanced biofuels. The most common lignocellulosic feedstock currently used for heat production and electricity are wood chips (from primary forest residues), landscape care wood and agricultural prunnings.

In Figure 4, a comparative overview of various studies regarding sustainable lignocellulosic biomass potential to 2030 is presented. A great variance is observed, attributed to different baseline scenario assumptions, reference statistics etc. In most of the studies though, it is concluded that European potential for lignocellulosic biomass is significant. [37]

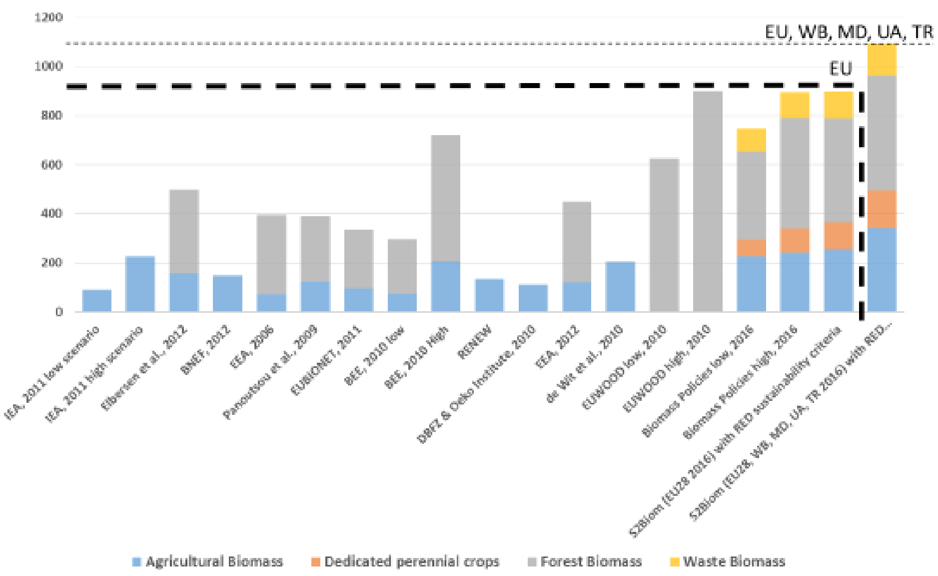

Figure 4: Estimated potential (thousand dry tonnes per year) for lignocellulosic biomass from agriculture, dedicated perennial crops, forest and waste activities in Europe[38]

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[35] S2BIOM D8.2, 2015
[36] Uslu and van Stralen, 2016
[37] S2BIOM D8.1, 2015
[38] S2BIOM D.8.2, 2015

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Lignocellulosic dedicated crops (woody and grassy perennials) are not widespread in most EU countries, with only some large cropping areas existing in Sweden, Poland and the UK. It is expected though that lignocellulosic dedicated crops will expand in the following years for the production of second generation biofuels, as various thermochemical technologies for the production of biodiesel will also become commercial (biomass gasification to syngas and Fischer-Tropsch (FT) synthesis and Biomass to Liquids (BtL) process). The future increase of dedicated lignocellulosic cropping will probably take place on land that is not needed for the production of food and feed or dedicated energy crops. [39]The most common lignocellulosic energy crops and their basic characteristics are presented in Table 3.

Table 3: Lignocellulosic energy crops (adapted from [40], [41])

Crop	Description	Main EU cropping areas
Miscanthus	Miscanthus is a promising lignocellulosic feedstock with various applications due to its rapid biomass accumulation in temperate climates. In Europe, there are presently an estimated 30,000 ha of miscanthus planted.	UK, France, Ireland
Short rotation coppice (willow, poplar)	Short rotation coppice has potential of providing feedstock for advanced biodiesel and drop-in biofuels (via thermochemical conversion) as well as for the production of 2nd generation ethanol (via biochemical conversion).	UK, Poland, Denmark, Italy, Germany
Giant reedgrass	Giant reedgrass (Spanish cane) is considered to be one of the most promising species for biomass production in Europe. It is cultivated as a feedstock for the commercial scale cellulosic ethanol plant Beta Renewables (see Case studies).	Mediterranean area
Reed canary grass	Reed canary grass provides good yields on poor soils and contaminated land and is thus an interesting candidate for bioremediation of brownfield sites as well as a source of biomass for bioenergy (typically as briquettes) or pulp. Is also considered a suitable feedstock for cellulosic ethanol production.	Finland, Sweden, Denmark
Switchgrass	Switchgrass has qualities that make it attractive as a biofuel source. Extensive research is being carried out into cultivation of Switchgrass as a biofuels feedstock in the US.	Negligible in present, apart from high estimate for Romania

[39] BIOMASSFUTURES D3.3, 2012
[40] http://www.biofuelstp.eu
[41] Erajää, S, 2015

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The forest-based pulp and paper industry has long experience on the logistics and use of woody and lignocellulosic biomass and it has a very good potential for the introduction of processes to convert woody biomass to second generation biofuels and or chemicals from syngas (see also 6.3.2 and Table 7). Agriculture can provide a range of residues and dedicated crops (short rotation coppice, dedicated energy crops, perennial grass etc.) to be processed in lignin-platform biorefineries, either as part of newly-developed industrial value chains or to provide additional raw material streams for C6 and C6/C5 platforms biorefineries.

Lignocellulosic biomass can be chemically disrupted to isolate its component polymer materials, namely cellulose, lignin and hemicellulose. These polymer products can be used to produce a wide range of chemical products or even broken down and used in the production of fuels and other chemicals. (see also 5.3.2 and Table 5) These range from high quality, high-value products in the case of cellulose, to low quality, low- value applications where the form, but not the quality is important in the case of lignin.[42]

While the use of lignocellulosic materials for the production of bio-based products seems attractive, significant technical and economic barriers need to be overcome, especially for a lignocellulosic waste and residues- to- chemicals capability. Examples of such issues are the heterogeneity of many wastes and residues, logistics and handling, market development etc.[43]

6.1.3. Forestry biomass potential

Approximately 490 million tonnes of forestry biomass (dry mass) are currently exploited annually in Europe (including pulp, paper and other traditional uses). An estimated 245 million tonnes of wood are used in the woodworking and pulp and paper industry annually and 240 million tonnes of wood are used for heat and power production. [44]

There are also the following types of forestry residues that have application in the production of bio-based products and bioenergy:

- Residues from harvest operations left in the forest after stem wood removal (branches, roots etc.);
- Complementary fellings (emerging from the difference between the maximum sustainable harvest level and the actual harvest quantities for round wood production);
- Wood wastes from a range of sources (e.g. construction or demolition wastes, waste from manufacturing of wood-based products).

According to the WASTED project study, it is estimated that around 80 million tonnes of forestry residues are produced annually in the EU. Given that not all forestry residues can be removed but some must be left in situ to provide ecological benefits (e.g. to provide habitat,

[42] Kretschmer et al., 2013
[43] Kretschmer et al., 2013
[44] S2BIOM, D8.1, 2015

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and improve soils), it is estimated that sustainable availability of forestry residues in 2030 will be at around 40 million tonnes per year. Estimates for total sustainable biomass from forestry in the same time frame range from 615 to 728 million tonnes[45].

Sustainability considerations are very important as increasing the extraction of forestry residues and biomass beyond a certain point will inevitably lead to trade-offs between productivity and environmental and economic sustainability. All potential approaches to increasing forestry biomass should respect the multifunctionality and sustainability of forests. Beyond sustainability considerations, there are technical and economic limitations of forestry biomass used as feedstock. The extraction costs are sometimes prohibitive and in many areas there is limited accessibility (sloping or wet ground or distance). Finally, the fragmented ownership of forests potentially may result in undermanagement. The improved organization and increased cooperation between forest owners could help also to overcome economic barriers as well as issues of fragmentation. Strengthening forestry biomass supply chains can also play an important role, for example via cooperative arrangements such as 'Biomass Trade Centres' (see Case studies) and public-private partnerships[46].

Forest based raw materials have high shares in bio-based products production and bioenergy, mainly via the lignin platform. Also wood wastes from various sources can potentially be used for bioenergy and biofuels production, as they are used already across the world as local fuel sources in wood burners or boilers. At the industrial scale, forestry residues and waste wood can be converted to advanced biofuels or intermediates, such as BioSNG, Biocrude, BtL, Methanol or BioDME, through various thermochemical pathways.[47]

6.1.4. Improved agro-based production

There are significant opportunities for agriculture in the deployment of sustainable bioenergy and bio-based product supply chains. The main feedstocks from agriculture are dedicated crops (mainly sugar, starch and oil) and farm and crop residues.

Sugar and starch dedicated crops are used for the production of 1st generation bioethanol. 7% of total sugar beet production was used for bioethanol production in the EU in 2014. Regarding starch crops, wheat and corn are the main feedstocks used in Europe for bioethanol production. 2,8 million metric tonnes of wheat and 5.2 million metric tonnes of corn were processed to bioethanol in 2014 in the EU. Other common starch crops used are barley (541,000 metric tonnes in the EU in 2014) and rye (846.000 metric tonnes in the EU in 2014). It is estimated that about 2.9% of total EU cereal production was used for bioethanol production in 2014. [48]

[45] S2BIOM, D8.1, 2015
[46] Kretschmer et al., 2013
[47] http://www.biofuelstp.eu
[48] USDA, 2016

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In general regarding bio-based production, the most promising species in the agricultural sector is wheat, with large arisings of 46million tonnes of bio-economic potential, which can be used without bothering the farmers. This is followed by maize stover, barley straw and rapeseed. In the last 15 years, the production of rapeseed has grown from around 10 mega tonnes to 25 mega tonnes. This 2.5 growth factor is due to the fact that rapeseed goes to the bio-energy sector and this is incentivised. In terms of areas where these materials are currently grown, France is very important in terms of wheat. The Czech Republic and Bulgaria follow. France, again, Italy and Romania are important areas for maize stover and the area of Paris and Spain are interesting concerning barley and rapeseed.

Oil crops are mainly used for biodiesel production but also for other bio-based chemicals. The most commonly used vegetable oils are rapeseed and palm, followed by coconut, soybean and castor. In Europe, rapeseed is the most common feedstock for biodiesel production, accounting for 49% of total biodiesel production in 2015. In the US, Argentina and Brazil, soybean oil is the most dominant biodiesel fuel feedstock. In Indonesia and Malaysia, palm oil is the main feedstock cultivated. Other common vegetable oils used in the EU for biodiesel production are palm oil, soybean oil and sunflower oil.

Wet biomass like energy maize and maize residues are used for biogas production. It is estimated that at present there are approximately 5.5 million hectares of agricultural land on which bioenergy cropping takes place in the EU. This amounts to 3.2% of the total cropping area (and around 1% of the utilized agricultural area) in the EU. Practically all of this land is used for biofuel cropping, mostly oil crops (82% of the land used for biomass production). These are processed into biodiesel; the remainder is used for the production of ethanol crops (11%), biogas (7%), and perennials go mostly into electricity and heat generation (1%).[49] At present bioenergy cropping is important in some EU countries like France and Germany while significant oil crops for biodiesel are also found in the UK, Poland and Romania. Dedicated cropping with perennials is still taking place at a very small scale, with Finland, Sweden, UK and Poland having the largest areas.

Manure is a by-product of agricultural activities that is mainly used for the production of biogas to serve local energy needs.

Regarding crop residues, considerable volumes of stems, leaves, wheat straw, bran, barley straw, husks, chaff, cobs etc. are produced in the EU and are currently underutilized. The processing of such residuals to produce advanced biofuels has been identified as a great opportunity for local development and the reconversion of brownfields.[50] By far the largest source of crop residues is the straw and stover from grain crops (wheat, barley and maize). Estimates of the potential available for bio-based production and bioenergy varies significantly. Based on the assumption that one-third of residues must remain in the largest source of crop field to maintain soil quality and one third must be left for existing uses, the

[49] BIOMASSFUTURES D3.3, 2012
[50] http://www.agenziacoesione.gov.it/opencms/export/sites/dps/it/documentazione/NEWS_2016/BIT/BIT_EN.pdf

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WASTED project study[51] estimates that around 122 million tonnes of agricultural residues are currently sustainably available with 139 million tonnes estimated for 2030. Other studies, with not so strict restrictions on collection of agricultural waste, for reasons related to soil fertility protection, estimate quantities from 186 to 252 million tonnes in the 2030 timeframe. [52]

There are several barriers to the mobilization of crop residues to be used as feedstock for bio-based products and bioenergy: [53]

- Agricultural residues are highly dispersed, making their collection and transport feasible over relatively short distances only (low energy density), demanding a careful location of processing plants;
- Existing uses and established practices dictate that a certain share should be left in situ, for soil quality maintenance purposes, limiting the available potential for bio-based production and constituting a possible barrier to the mobilization of the residues as farmers may be unaware of the sustainable extraction rates or reluctant to give up old practices;
- There is lack of suitable machinery for collection and harvesting crop residues at farm level, as it is unfavourable economically.

It is estimated that the cost of harvesting crop residues is four times the price bioenergy plants are willing to pay, making the certain biomass feedstock more suitable for biorefineries that produce higher value products such as platform chemicals than for bioenergy plants. It is estimated that EU's agricultural residue potential will remain heavily underutilized up to 2020 and 2030 with only about 11% of it being used. [54]

6.1.5. Waste valorization

Bioeconomy offers an opportunity to transform the waste from a cost into a resource. Waste biomass offers a potential route to overcome the concerns over using food materials for non food purposes regarding bio-based production and there is growing recognition of the benefits of using wastes and residues as feedstock.

Used cooking oils (UCO) or recycled vegetable oils were the second most important feedstock for biodiesel production in 2015 in the EU, with the Netherlands, the UK and Germany being the largest EU producers of biodiesel produced from used cooking oils. It has attracted a significant interest for aviation biofuels production. Industry analysts estimate that more than 1.1 million tonnes of UCO was consumed in Europe in 2013. Of this volume, about 700.000 tonnes are estimated to come from within the EU, as there are substantial imports of used cooking oils, largely coming from the US. Increased collection in the future, maybe with the

[51] WASTED, 2014
[52] S2BIOM D8.2, 2015
[53]Kretschmer et al., 2013
[54] Kretschmer et al., 2013

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introduction of home collection, is likely. [55] Other plant origin oils used for biofuels production include tall oil, residue from pulp industry, palm fatty acid distillate and by-products of the production of Omega-3-fatty acids from fish oil. Finally, waste from potato processing industries (potato peel) has attracted interest in being used as a bioethanol feedstock in the last years.[56]

Waste animal fat is also used for biodiesel production in multi-feedstock production facilities of small and medium-scale, named Animal Fatty Acids Methyl Esters (FAME), which exhibits better engine performance than conventional biodiesel according to recent studies.[57]

Municipal Solid Waste (MSW) can also be converted into liquid biofuels or used for heat and power generation. European households dispose of around 110-150 million tonnes of biogenic material annually.[58][59] The different MSW streams are as follows:

- Recyclable materials (metals, paper and plastics): used for manufacture of recycled products;
- Organic fraction (putrescible food waste, garden waste): may be converted to biogas via anaerobic digestion. It is estimated that around 44 million tonnes of household and garden waste will be available in 2030.[60] Estimates of food waste quantities are inherently difficult. European Commission estimated a total of 89 million tonnes of food waste produced in 2010 in the EU, including manufacturing food waste (35 million tonnes), household food waste (38 million tonnes), retail/ wholesale food waste (4 million tonnes) and food service/ catering food waste (12 million tonnes); [61]
- Solid Recovered Fuel (SRF) (the fraction of MSW that cannot be recycled e.g. shredded textiles, wood, paper, card and plastics): SRF can be combusted or converted to syngas, and then be use for bioenergy or be processed into advanced biofuels. Estimates of the wood fraction of MSW are in the range of 26-57 million tonnes per year. Of this, around 40 % is recycled into other products and around 50 % is burned for energy, leaving just under 10 % available as potential feedstock for advanced biofuels. [62]

Food waste is not suited for direct energy generation through conventional combustion processes, because it has high moisture content. Biological technologies such as anaerobic digestion (AD) are more suitable, and there is the technical possibility of co-digestion with other substrates such as manure and slurry. But even in this case the processing is costly and technically complex due to the heterogeneity of food waste originating from diffuse sources and the need of separation/ pretreatment. The diffuse sources of food waste and the fact that

[55] WASTED, 2014
[56] Arapoglou et al., 2010
[57] http://www.biofuelstp.eu
[58] WASTED, 2014
[59] S2BIOM D8.1, 2015
[60] WASTED, 2014
[61] Kretschmer et al., 2013
[62] WASTED, 2014

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in most cases food waste is mixed with other types of waste from households constitute a great challenge with respect to collecting, transporting and separating this waste stream, as well as to locating possible processing plants. Source separation and separate collection of food waste would provide the greatest potential for its use. Finally, a further potential barrier to the mobilization of food waste as a source of energy is the fact that increasing legislation and policy efforts are being made in the EU to prevent and reduce food waste. This may inhibit possible investments in relevant process infrastructure and technologies.[63]

Finally, any organic residues / biological waste materials can potentially be converted to advanced biofuels by thermochemical, biochemical or chemical processes. Examples of such biomass feedstock include waste from beer and other beverage production and waste from bakeries etc. The facilities that use this kind of feedstock follow a biorefinery approach maximizing the conversion of biomass and waste streams into products and energy.

6.2. PROCESSES

The various processes used to produce bio-based products from biomass fall into four main subgroups: [64]

- **Mechanical or physical processes** which achieve a size reduction or a separation of the various components and do not change the chemical structure of the biomass used;
- **Biochemical processes** which occur with the use of microorganisms or enzymes in mild conditions (temperature, pressure);
- **Chemical processes** where a chemical change in the substrate occurs;
- **Thermochemical processes** where feedstock undergoes extreme conditions (high temperature and/ or pressure with or without a catalyst).

Table 4: Bio-based products related processes

Mechanical/ Physical processes	Biochemical processes	Chemical processes	Thermochemical processes
Pressing	Anaerobic digestion	Hydrolysis	Combustion
Milling	Aerobic/ Anaerobic fermentation	Oxidation	Gasification
Separation	Enzymatic conversion	Pulping	Pyrolysis
Fiber separation	Transesterification		Hydrothermal upgrading

[63] Kretschmer et al., 2013
[64] Cherubini et al., 2009

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Upgrading			Torrefaction
Fractionation			Liquefaction
Extraction			Hydrogenation

Starch and sugar biomass feedstock as well as those containing cellulose and hemicellulose are usually treated via the biochemical route, mainly with fermentation. Thermochemical processes are suitable for the conversion of lignocellulosic feedstock, such as wood, as the contained lignin cannot be treated via the fermentation route.

6.2.1. Thermochemical processes

The principal focus of thermochemical processes has been on developing diesel and kerosene replacements for the road and aviation sector, although the production of gasoline and other chemicals is also possible. [65]

Combustion is the most widely used route to turn biomass into energy (heat and power), accounting for 90% of all energy recovered from biomass worldwide. The biomass boiler is the heart of the biomass combustion system, and there are many different types and models. These are usually classified by the type of biomass they are suitable for use with (e.g. dry woodchip, wet woodchip, pellet, log, bale, etc.); by the type of combustion grate (moving grate, plane grate, stoker, batch-fired); and by their rated thermal output. They vary from manually fed, generally small, boilers with few controls, through to fully automatically fed boilers with automatic ignition and full remote monitoring and control systems. Moving grate systems are generally more common in large-scale applications of 300kW-1MW and exhibit a wide tolerance of fuel type, moisture content and particle size. Plane grate systems tend to be more common in the 25-300kW range and can use both pellets and woodchips. In the same output range stoker systems are also used and they are generally cheaper and less sophisticated. Finally, batch-fired systems constitute a simple and cost-effective solution but with a high level of labour and biomass material quality required. For power generation with combustion technology, grate furnaces are used. Heat is transformed into steam, which passes through a turbine connected to a power generator. The typical electric efficiency of modern plants of such technological equipment is 40-45%.

In biomass gasification, biomass is not directly burnt but it is first gasified at temperatures of 800-1100°C with the presence of a gasification agent such as oxygen, steam and air. Biomass is converted into a gas mixture containing mainly carbon monoxide and hydrogen called bio-syngas. This is then used for building new more complex molecules for use as fuels, chemicals or materials (hydrogen, methanol, methane and dimethyl ether are typical end products of gasification). In general, biomass gasification requires a relatively dry feedstock such as straw, wood, black liquor etc. but a range of different biomass feedstock including low-cost mixed

[65] Kretschmer et al., 2013

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MSW, wood and residues and pyrolysis oil can also be used.[66] A pretreatment with physical or chemical methods is usually necessary to improve the conversion of lignocellulosic biomass and the product gas needs cleaning and conditioning before synthesis. Gasification technologies are under development and few large commercial units exist. In general, gasification appears more appropriate for power and bio-based chemicals generation than for heat generation.

Pyrolysis is the thermal degradation process that occurs in the absence of oxygen, which produces a variety of products such as fuel gas, pyrolysis oil and tars. These products can be used as input for secondary processes such as hydrogenation, fractionation and gasification (after upgrading) or combusted directly in co-combustion plants or in diesel engines. Most pyrolysis processes are only suitable for dry feedstock with limited variability such as low cost lignocellulosic materials and wastes[67]Pyrolysis technologies are not yet fully commercially mature. Currently a number of pilot plants are in use worldwide but the technology is ready for further up scaling. Pyrolysis processes can be economically efficient for Combined Heat and Power (CHP) only or in a biorefinery concept where both energy and other products of higher value are produced. For example, the pulp and paper industry can use it to convert by-products into bio-oil and the oil-refining industry to produce bio-based diesel through hydrotreating or cracking. Pyrolysis products may be used in the iron and steel industry.[68]

Liquefaction converts solid biomass feedstock into liquid under high pressure at low temperature in the presence of hydrogen and a catalyst. This technology requires high reactor complexity and is not as developed as pyrolysis due to high costs. Torrefaction is a mild thermal treatment of biomass under low-oxygen conditions which results in a homogeneous fuel with improved grinding quality, a higher energy density and fewer impurities. Torrified biomass can be densified through palletization, resulting in a more energy-dense product. Several torrefaction technologies are developed, with some of them to have reached commercial production. Torrified biomass has several potential applications, with the main of them being for co-firing and combustion. For torrified biomass combustion, boilers that also use wood pellets or chips are available for this application, with a high market potential.

Finally, hydrogenation is a process which converts vegetable and animal oils into a high quality product which can be directly used as fossil fuel substitute, such as Hydrotreated Vegetable Oils (HVO), also known as Hydrotreated Renewable Jet (HRJ), Hydrotreated Renewable Diesel (HDRD) etc.

6.2.2. Biochemical processes

A major focus of biochemical processes has been on developing alcohols such as ethanol and butanol for biofuels, bio-based chemicals and bioplastics.

[66]Kretschmer et al., 2013
[67] Kretschmer et al., 2013
[68] Sanden and Pettersson, 2014

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Fermentation processes have been used since World War I for industrial production of energy carriers and chemicals. The basic principle of fermentation is the use of microorganisms that convert the biomass containing sugars into a specific product or a range of products. The last years' development in biotechnology has further advanced the possibility to design microorganisms for production of selected chemicals that cannot be produced efficiently by microorganisms found in nature. From the bio-based production perspective, many bio-based chemicals are now produced by fermentation in industrial scale such as ethanol, lactate, amino acids and citric acid with a potential to produce a large range of platform chemicals by this route.

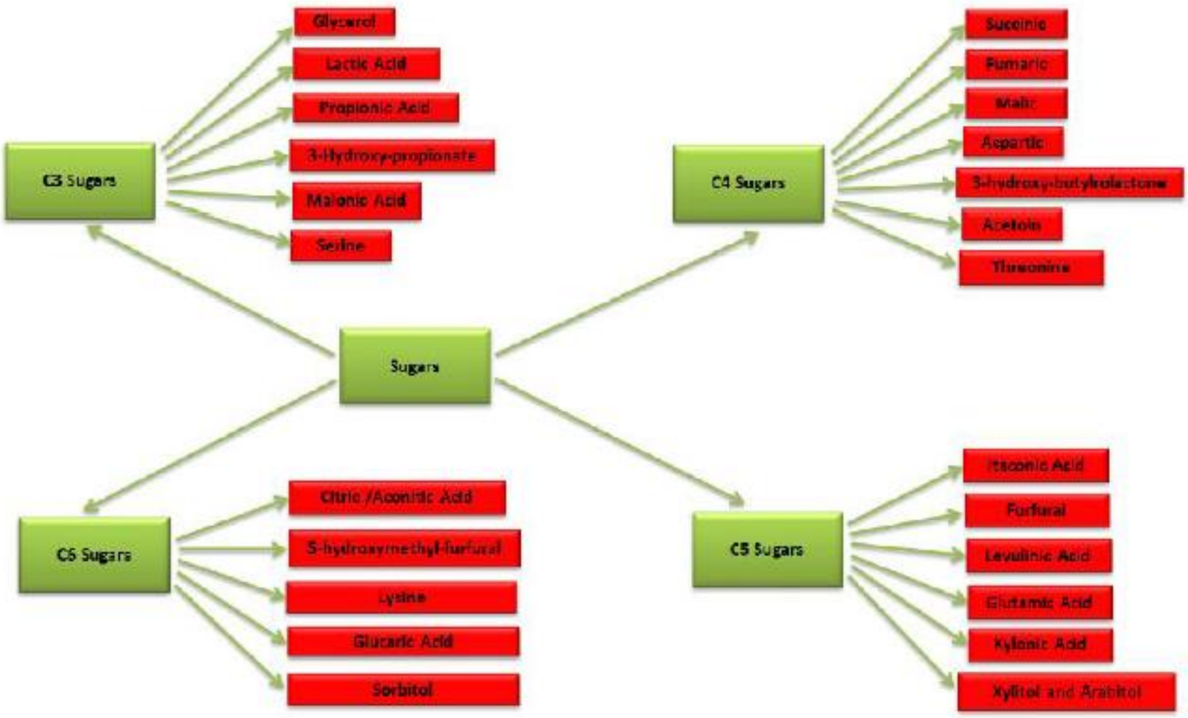

Figure 5: Chemicals derived from fermentation of sugars[69]

Apart from sugar and starch biomass feedstock that are easily fermented with traditional methods, lignocellulosic feedstock can also be used in more advanced fermentation systems, with alternated lignocellulosic residues and dedicated crops grown especially for this purpose. Major efforts have been made in developing bioethanol production via the fermentation route, as shown in Figure 6.

Fermentation is also used to produce second generation biosurfactants. Microorganisms are grown on water miscible or oily substrates, and the produced biosurfactants either remain adherent to microbial cell surfaces or are secreted in the medium. A variety of microorganisms among bacteria, yeasts and fungi are capable of producing biosurfactants with different

[69] Kretschmer et al., 2013

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molecular structures. Some of the most commonly investigated microorganisms along with substrates used and biosurfactants types produced are presented in Table 5.

Table 5: Biomass substrates used to produce a number of commercial biosurfactants (adapted from [70])

Biomass substrate	Microorganism	Biosurfactant
Fermented distillery and whey waste Molasses Oil waste Rapeseed oil Soybean oil refinery wastes Sunflower oil Vegetable oil Whey	*Pseudomonas* spp.	Rhamnolipid
Lubricating oil Molasses Peat hydrolysates Potato waste Wheat bran	*Bacillus* spp.	Surfactin/ Lipopetide
Canola oil Oil refinery waste Soil molasses-based medium Soybean oil	*Candida* spp.	Glycolipids Shophorolipid Mannosyl Erithritol lipid (MAL)

[70] Satpute et al., 2017

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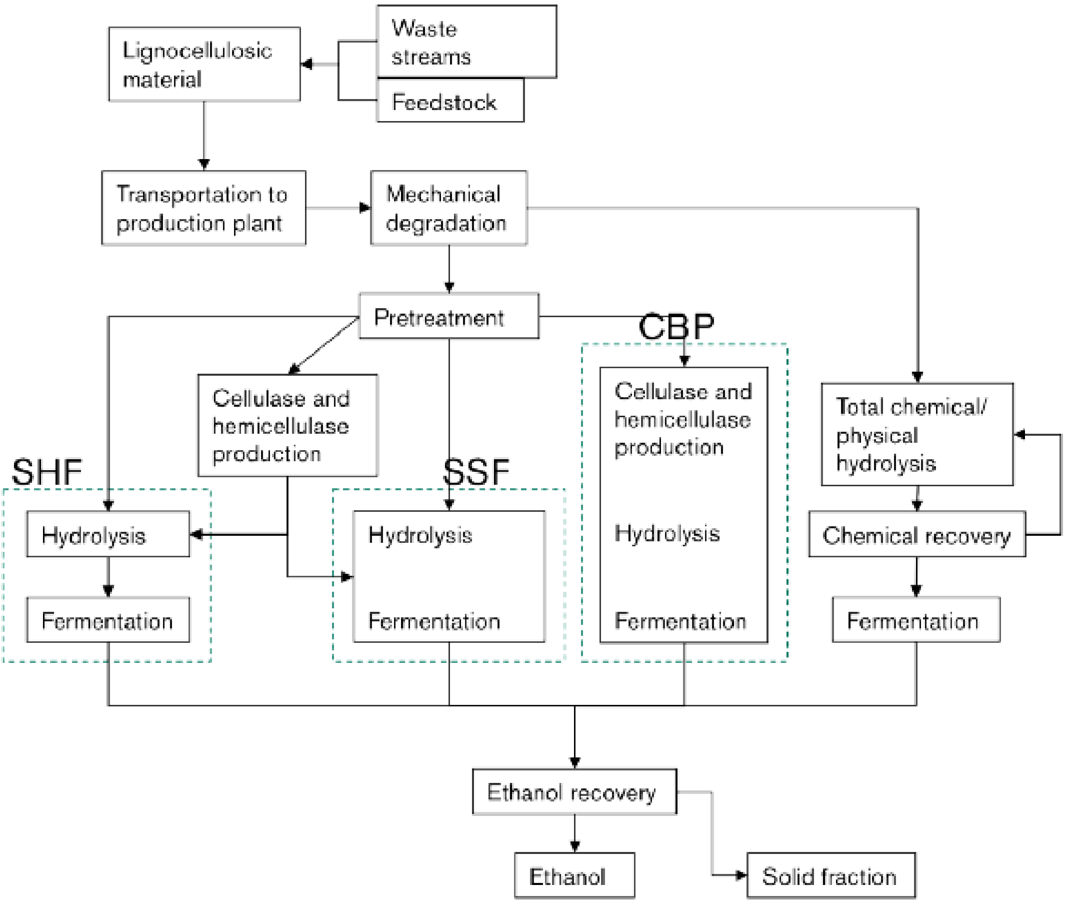

Figure 6: Examples of fermentation routes for the production of bioethanol from lignocellulosic materials

SHF= Separate hydrolysis and fermentation,
SSF= Simultaneous saccharification and fermentation,
CPB= Consolidated bioprocessing[71]

Anaerobic digestion is the microbiological process of decomposition of organic matter in the absence of oxygen in airproof reactor tanks (digesters). The process includes three main stages: hydrolysis, acidogenesis and methanogenesis that are characterized by different microbial activities, which are strongly dependent upon each other. The process results in two main end-products: biogas and digestate. The digestate is usable as fertilizer, as it is rich in nutrients. Composition and properties of biogas obtained depend on the input feedstock, type of digester and operational factors. Digesters can work in continuous or batch flow and in single- or multi-steps. Continuous flow digesters have lower operating costs and multiple digesters enable higher efficiencies but have higher investment costs. The main digester types are covered lagoon, upflow sludge blanket, fixed film, complete mix and plug flow. The feedstock needs to be checked accurately, and usually requires pre-treatments (either

[71] Sanden and Pettersson, 2014

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separation or mixing) to ensure the appropriate composition before entering the digester. Co-digestion of multiple types of feedstock is a common practice for achieving the best balance between biogas yield and process stability, especially in medium- to large-scale AD plants.

Biogas can also be recovered from landfills, where a passive (natural) anaerobic digestion occurs. The recovery of biogas from landfill is limited, particularly in developing countries and the relevant recovery techniques vary widely as a function of waste and landfill characteristics.

6.3. Biorefineries

6.3.1. Bio-based products and the biorefinery concept

In a biorefinery, biomass is processed to be upgraded to one or more valuable products such as biofuels, bio-based chemicals, energy (electricity and heat). The biorefinery concept connotes the efficient upgrading of biomass and the generation of valuable products in an economic, social and environmentallysustainable way. The term does not apply to a specific process industry or system but in fact covers a broad range of technical systems. A biorefinery can be anything from one single machine for conversion of biomass up to a complex polygeneration plant integrated with other industries and energy systems, refining different kinds of biomass feedstock into one or many products using chemical, biochemical and thermochemical transformations.

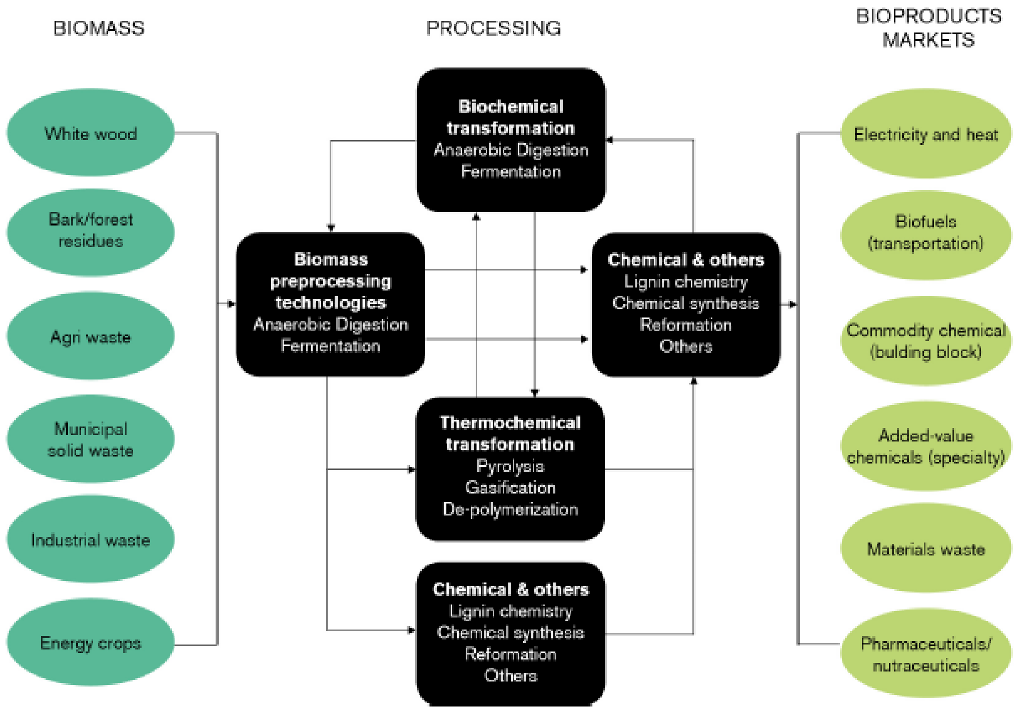

Figure 7: Biorefinery feedstock, technologies and product markets[72]

[72] Sanden and Pettersson, 2014

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IEA Bioenergy Task 42 has classified biorefineries based on their key characteristics (listed in order of importance):

- Platform
- Products
- Feedstock
- Processes

With the combination of these four features, different biorefinery configurations can be described in a consistent manner. The platforms are intermediates from which final products are derived, in a concept like that used in petrochemical industry, where crude oil is fractionated into many intermediate technological bases and from each of them a product family. The platforms may be reached via different conversion processes applied to various feedstocks and may lead to a variety of marketable products via multiple processes. The number of involved platforms in a biorefinery is an indicator of system complexity.

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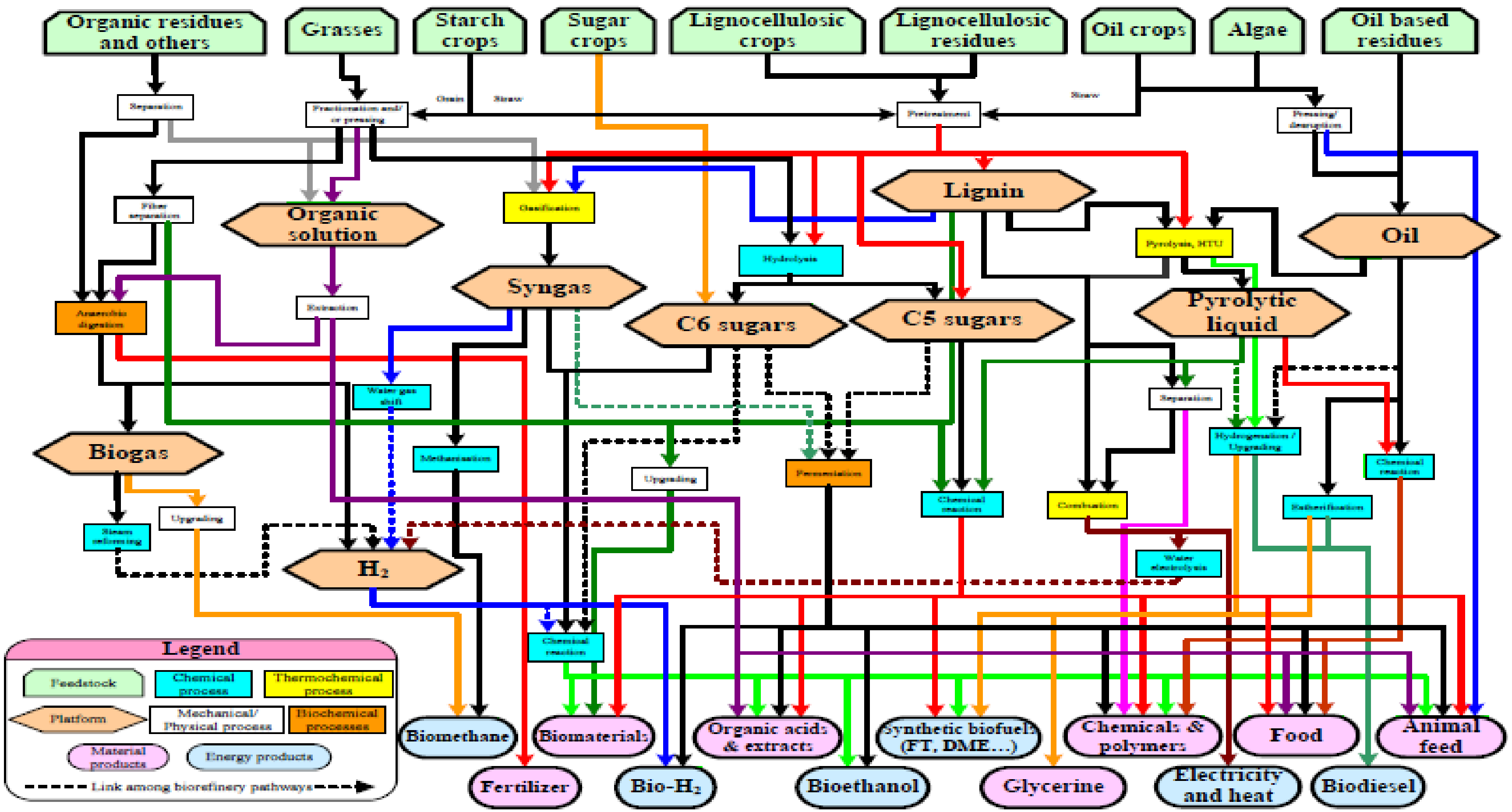

Figure 8: Biorefineries classification system[73]

[73] IEA Bioenergy- Task 42 Biorefinery, 2012

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Based on this classification, many biorefinery concepts can derive, with different combinations and numbers of feedstock, platforms and products used. In the EU today, as shown in Table 6, those types of biorefineries that are already state of the art and in commercial operation are the simpler ones, using one feedstock and producing two or three products (based largely on either sugar or starch and vegetable oils) and the energy-driven ones, i.e. the biorefineries where the biomass is primarily used to produce biofuels and process residues are used either for heat and electricity or upgraded to bio-based products. Also much of the existing biorefinery network has a strong link to biofuel production, as shown in Table 6.

These biorefineries usually use the infrastructure of power plants, digestion plants or biofuel plants as well as relevant available feedstock. But they exhibit a questionable profitability and often financial support from the government and/or a regulated market is necessary for their sustainable operation. Integration of primary and secondary processing of the raw materials remains limited. Some integration of biomass primary processing with chemicals manufacture is emerging with the diversification of product streams from some agro-industries (e.g. starch producers) towards chemical intermediates (lactic acid, succinic acid etc.) and specialty chemicals (e.g. polyols). Upgrading of the existing plants and the development of value chains to multi-product biorefineries is needed to improve full value chain sustainability.

Table 6: Energy-driven biorefineries types of commercial technological status[74]

Platform	Feedstock	Products
Oil	Oilseed crops Oil seed residues	Biodiesel, glycerol, animal feed (Distillers Dried Grain with Solubles-DDGS), oleochemicals
C6 sugars	Sugar & starch crops	Bioethanol, feed
C6 sugars	Sugar crops	Bioethanol, electricity, heat, sugar, fertilizer

There are only limited product-driven biorefineries in commercial operation today in the EU and often their chain- composing key technologies are still at an R&D or demonstration phase. Nevertheless, they exhibit a high potential deploying new high efficient sustainable biorefinery-based value chains co-producing fuels, high-value bio-based products and bioenergy. New biorefinery types that will depend on lignin, organic solution and syngas platforms are mostly in the pilot or small-scale demonstration phase with limited commercialization in the medium term (2025). In Table 7 the various biorefinery platforms, along with related products of commercial interest and pathways are presented.

74 https://www.iea-bioenergy.task42-biorefineries.com/upload_mm/c/3/5/5a89df61-57c8-4f73-9b8e-16e5775c1a4c_Jungmeier%20Long%20Version_CEBC14.pdf

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Table 7: Biorefinery platforms and related bio-based products (adapted from [75,76])

PLATFORM	DESCRIPTION	PRODUCTS
Syngas	Syngas is a mixture of mainly carbon monoxide and hydrogen produced by biomass gasification. Energy-driven biorefineries in demonstration scale use syngas to produce power, Fischer-Tropsch (FT) diesel, hydrogen, carbon dioxide and heat. Syngas can also be fermented to lower alcohols and ammonia.	Methanol Dimethylether (DME) Ethanol FT diesel Hydrogen Carbon dioxide
Biogas	Biogas is mainly produced by the anaerobic digestion of high moisture content biomass (manure, agro-industrial waste, municipal organic waste). A future perspective is the increase of biogas production from energy crops and from more by-products from agricultural, food and energy industry. Biogas production can be part of sustainable biochemical and bio-fuels biorefinery concepts as it can derive from wet streams. Value can be increased by optimizing methane yield and deriving nutrient value from the digestate streams.	Biogas Methane
C6 C6/C5	Feedstock used for these platforms are starch and sugar crops. Molasses from the refining process are currently mainly used to produce bioethanol (first generation), organic acids and starch-derived C6 sugars, while residue of sugar beet pulp is used for animal feed and food additives. A variety of important chemical blocks can also derive from C6 sugar platform via biological fermentation and chemical transformation and new processes of this kind are becoming available and competitive. Mixed C5/C5 platforms derive from the hydrolysis of hemicelluloses from lignocellulosic feedstock. The processes used are selective dehydration, hydrogenation and oxygenation as	Traditional: Ethanol, lactic acid Innovative: Succinic acid, itaconic acid, adipic acid, 3-hydroxypropionic acid/ aldehyde, isoprene/farnesene glutamic acid, aspartic acid, sorbitol, levulinic acid, glucaric acid, hydroxymethylfurfural, p-

[75] IAE Biooenergy- Task 42 Biorefinery, 2012
[76] S2BIOM D8.1, 2015

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PLATFORM	DESCRIPTION	PRODUCTS
	fermentation of these carbohydrate streams still faces important technical, biological and economical barriers. It is expected that existing sugar/ starch biorefineries will progressively use these platforms with first integrating cereal straw into the supply chain followed using dedicated lignocellulosic crops to produce second generation bioethanol and other fermentation products.	xylene
Plant-based oil	The oleochemical industry is a major producer of biodiesel, glycerol and other bio-based products. Biodiesel production is based in palm, rapeseed and soy oils and has increased significantly in recent years. Chemical and enzymatic modification of vegetable oils derives fatty acids, alcohols, fatty esters, ketones, dimer acids and glycerol. Most fatty acid derivatives are used as surfactants in soaps, detergents and personal care products and originate from coconut, palm and palm kernel oil. Soybean, sunflower and linseed oils are used to produce alkyd resins, linoleum and epoxidized oils. Rapeseed oil is used for Biolubricants and hydraulic fluids. Also, some building blocks for bio-based plastics derive from castor oil. Given advances in plant genetics and oil processing, there is considerable interest in developing processes for the manufacture of polymers such as polyurethanes, polyamides and epoxy resins from plant oils. Glycerol is an important co-product of fatty acid/ alcohol production and biodiesel production that encounters a variety of uses. There is considerable effort from chemical producers to look at technology for its conversion to chemical building blocks, via fermentation, anaerobic digestion or chemical conversion. Finally there is an important subcategory of plants that produce natural waxes (jojoba seeds, carnuba palm and other desert shrubs), which are used in specialized high-value applications such as cosmetics. With decreasing financial support for biofuels, it is expected that small-scale production of biodiesel from plant-oil based platform will be reduced while medium/ large- scale production will increasingly focus on the abovementioned higher added-value applications.	Biodiesel Biosurfactants Alkyd resins Linoleum Biolubricants Glycerol Promising glycerol derived chemicals: propylene glycol, epichlorohydrin, acrylic acid, propylene

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PLATFORM	DESCRIPTION	PRODUCTS
Algae oil	Algae biomass can be a sustainable renewable resource for chemicals and energy. Compared to plants, algae have a higher productivity, they can be cultivated in water or non-arable land thus not competing for resources with conventional agriculture, the essential elements that they need can be found in residual streams and the biomass produced has characteristics that facilitate its further process. Microalgae have been grown for decades at small-scale for high- value compounds for food and feed applications, especially in Asia and North America but the production capacity is very limited compared to land-based energy crops. A leap in the development of microalgae technology (both cultivation and biorefinery) is required for the production of biofuels and bulk chemicals.	High value-added compounds in food and feed applications
Organic solutions	This biorefinery concept is also called "the green biorefinery" processing fresh biomass such as grass, clover, alfalfa or immature cereals. Dewatering of wet biomass derives a nutrient-rich juice (organic solutions platform) and a fibre-rich lignocellulosic press cake, which both lead to various valorization pathways. The pressed juiced residues can finally be used to produce biogas. In the following years it is expected that these smaller scale biorefineries can be set up as new industrial value chains are established in regions that traditionally produce high quantities of wet biomass, such as grassland areas.	Lactic acid and derivatives Proteins Amino-acids Bioethanol Biogas Grass fiber products (insulation materials)
Lignin	Lignin is expected to play a significant role as a new chemical feedstock particularly in the formation of supramolecular materials and aromatic chemicals. There are two primary process routes: the thermochemical that uses heat to convert lignocellulosic feedstock to syngas which is later used to produce biofuels and chemicals and the biochemical approach that fractionates lignocellulosic raw material into cellulose, hemicellulose and lignin to be later converted into value-added bio-products. Up to now the clear majority of industrial applications have been developed for lignosulfonates, which are used in a wide range of lower value applications where the form but not the quality is important (dispersant applications, binder and adhesive	Potential products: syngas products (methanol, DME, ethanol etc.), hydrocarbons (benzene, toluene, xylene etc.), phenols (catechols, phenol, cresols etc.), oxidized products, (vanillin, vanillic acid, DMSO, aromatic acids etc.)

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PLATFORM	DESCRIPTION	PRODUCTS
	applications). The use of lignin for chemical production is so far limited except for limited production of vanillin from lignosulfonates. Also Kraft lignin is produced as a commercial product in small quantities. New extraction technologies developed in Sweden will lead to an increase in Kraft lignin production. The production of bioethanol from lignocellulosic feedstock could also result in new forms of higher quality lignin available for chemical applications. The production of more value-added chemicals from lignin (resins, composites and polymers, aromatic compounds etc.) is viewed as a medium to long term opportunity.	macromolecules (carbon fibre fillers, polymer extenders, substituted lignins, adhesives, binders etc.)
Pyrolysis oil	A biorefinery based on pyrolysis oil could offer the possibility of decentralized production of the oil in regions where abundant biomass is readily available. The basis for creating high- value compounds is the cost-effective fractionation of the pyrolysis oil, which will result in various qualities of oil needed for further upgrading to chemicals, petrochemicals, automotive fuels and energy.	Foreseen: Phenols, organic acids, furfural, HMF and levoglucosan

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The value of biorefinery products is strongly dependent on the volume that is produced: commodities (i.e. cellulose- based fibre, ethanol) have typically lower prices than added-value chemicals (vanillin, aldehydes) and pharmaceuticals.

In order to overcome feedstock availability costs, bio-refineries should be localised where the utilized feedstock is available and cheap. In this way, the whole territory becomes valorized and this is the case in several agricultural areas. For such examples of biorefineries developed on a local level, please check Paragraph 10.

6.3.2. The integrated energy, pulp and chemicals biorefineries

In many cases biorefining would benefit from being integrated with a processing industry, to improve the overall profitability and productivity of energy-related products. Implemented biorefineries in process industries are very rare. There are though some case studies from the pulp and paper industry with some highly innovative and diversified pulp mills that derive value from compounds extracted from wood, creating higher value from what were previously "energy-side" streams, like the spent cooking liquor in Kraft pulp mills that today is used for electricity and steam production. Examples of such projects are extraction of hemicelluloses and lignin in the pulping process, extraction of bioactive substances or other soluble components (such as tannins) from wood or bark, production of specialty cellulose products, isolation of essential oils from different tree species, black liquor gasification, biomass gasification and ethanol production as part of the pulping process.

Hemicelluloses can lead to a wide range of value-added products (e.g. ethanol, butanol, xylitol, lactic acid, fibre additives, hydrogels etc.) while extracted lignin can be used as a solid fuel either within the mill replacing fossil fuel or externally, e.g. in CHP plants. Black liquor gasification generates syngas that can be used as a feedstock for production of biofuels (dimethyl ether, methanol, FT fuels, hydrogen) or as a fuel for electricity generation in CHP units. Several black liquor gasification technologies have been under development during the past thirty years. In this pulp mill biorefinery context, there is also the possibility to make use of low-quality forestry biomass residues.

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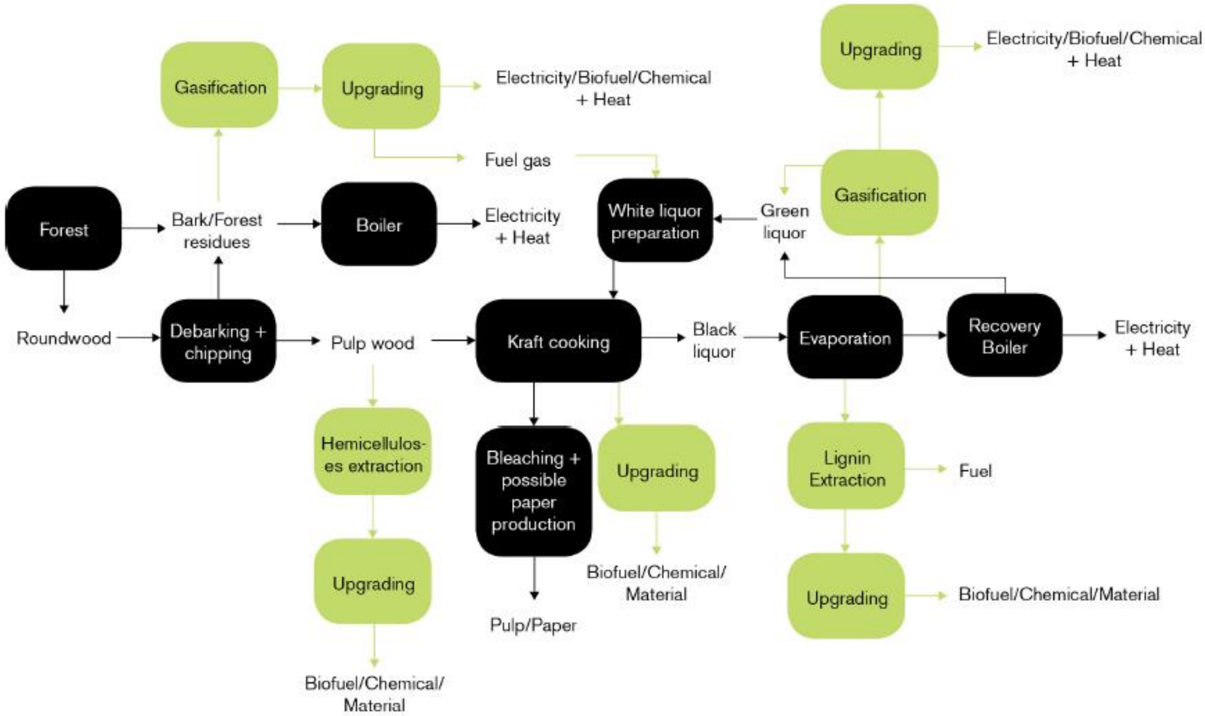

Figure 9: Example of biorefinery concepts and products that could be implemented at a Kraft pulp mill (conventional process units are black colored)[77]

Another type of biorefinery, not directly utilizing the process streams from the kraft process, can be created when a mill and another consumer, or producer, of heat are integrated to achieve synergistic effects such as heat cascading. In this concept, mills with a heat surplus can be integrated with processes such as lignocellulosic ethanol production, district heating systems or several types of biomass upgrading, for example drying, torrefaction or pyrolysis that require heat.

The pulp mills have good prerequisites to become future biorefineries, as the scale of industry permits economies of scale, some product by-streams such as black liquor are already partly processed and excellent process integration opportunities exist such as common waste and effluent handling, water, logistics, heat sources etc.

Other industries that could benefit from integrating biorefining steps are the iron and steel-making industry and oil refineries.

[77] Sanden and Pettersson, 2014

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7. PRODUCTS, APPLICATION AREAS AND MARKET ANALYSIS

7.1. BIO-BASED BASE CHEMICALS AND BUILDING BLOCKS.

In this category of bio-based products, chemicals are considered that derive from biomass feedstock through chemical or biological conversions and are used either as base chemicals in industrial manufacturing processes or as building blocks to be transformed into new families of useful molecules, leading to high-value bio-based chemicals or materials.

The great number of biomass feedstocks that can be used combined with the numerous possible pathways leads to a great number of possible derivatives as shown in Figure 10. Some of them have a long history of bio-based production such as citric acid, others are recently introduced such as propylene glycol and some of them are in the demonstration or development phase. A number of bio-based building blocks and base chemicals is outlined in Table 8 with the potential of growth and supporting industry interest.

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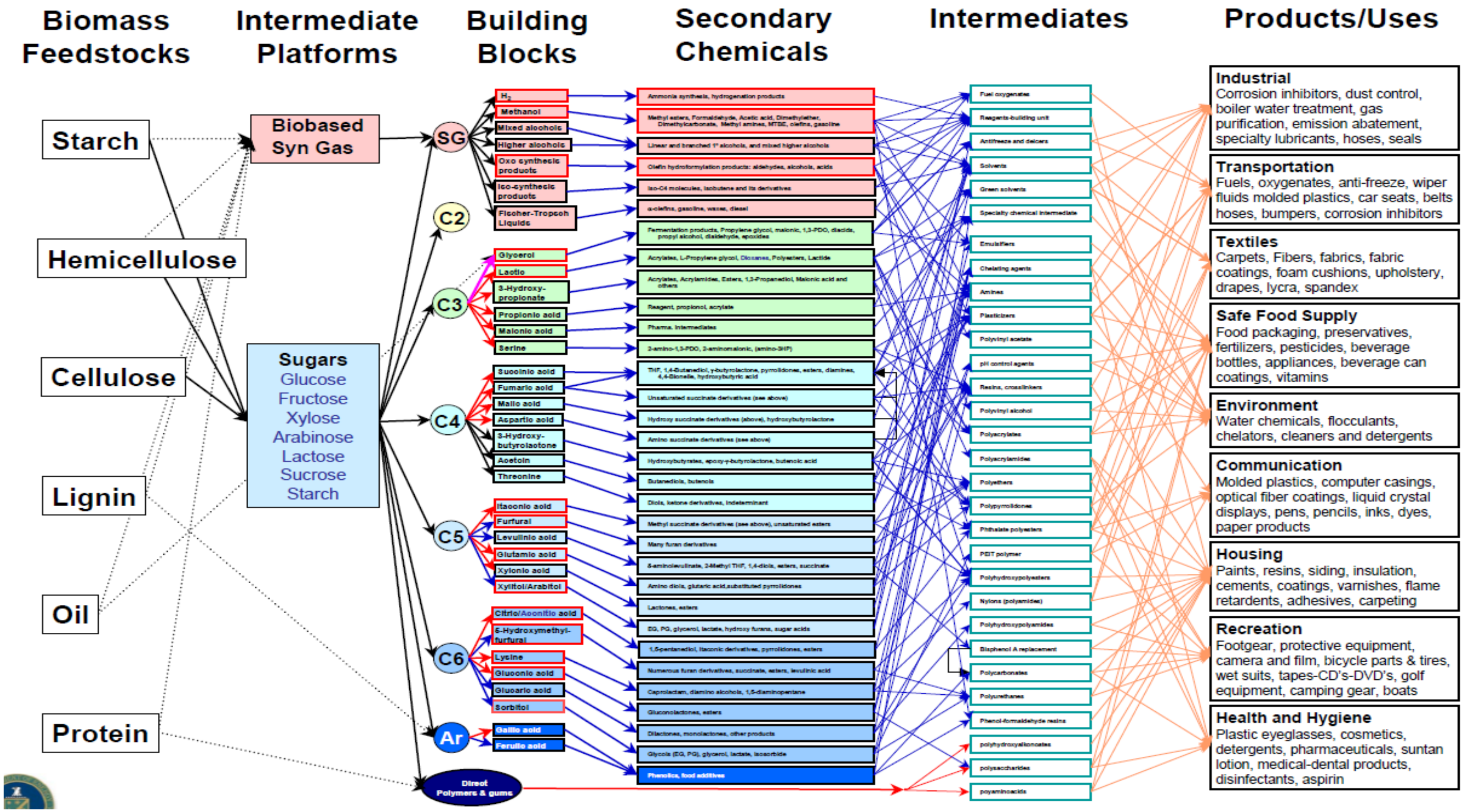

Figure 10: Model of a bio-based product flow-chart from biomass feedstock[78]

[78] Werby, T. and Petersen, G. 2004

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Table 8: Bio-based chemical building blocks and base chemicals

Building block/ Chemical	End product applications
Methane	Chemical industry
Carbon monoxide	FT fuels
Methanol	Chemical industry
Ethylene	Bio-based Polyethylene (PE), Mono ethylene glycol (MEG), Polyvinil Chloride (PVC)
Mono Ethylene Glycol (MEG)	Production of bio-based Polyethylene Terephthalate (PET) (plastic bottles, textile fibres)
Lactic acid	Food and beverage sector, personal care products, Polylactic Acid (PLA) (food packaging- rigid containers, shrink wrap, short shelf-life trays, mulch films, rubbish bags)
Ethyl lactate	Solvents
Propylene glycol	Industrial applications (polyester resins, coolants, anti-freeze, hydraulic and brake fluids, aircraft de-icing fluid, heat transfer fluids, paints, coatings), fragrance, cosmetics and personal care applications, food industry (flavourings), animal feed (pharmaceutical formulations)
1,3 Propanediol (PDO)	Personal care applications, fibres, polyurethans
Epicholorohydrin	Epoxy resins, paper reinforcement in specific applications (tea bags, coffee filters etc.)
Propylene	Polypropylene, propylene oxide, acrylonitrile, acrylic acid, butanol
Acrylic acid	Coatings, adhesives, superabsorbent polymers, detergent polymers
Acrylonitrile	Acrylic fibers (carpets, clothing), acrylonitrile polymers (pipes and fittings, automobiles, furniture, packaging),
Acrylamide	Resins
Butanol	Solvents, paints, butyl rubber, PET, fuels
Adipic acid	Nylons, resins, polyurethanes
Succinic acid	Butanediol (BTD), Polybutylene succinate (PBS), Polybutylene terephthalate (PBT), tetrahydrofurans (THF) (solvents, polyurethane polymers), fibers such as lycra, de-icers
Isoprene	Rubber (surgical gloves, car tyres etc.)
Furans	Polysters, polyurethane, fuels

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Building block/ Chemical	End product applications
Furandicarboxylic acid (FDCA)	
Farnesene	Lubricants, additives to cosmetic products, flavour and fragrances, polymer additives
Terapthalic acid	PET, plasticizers
3-Hydroxypropionic acid (HPA)	Sorona fibre, contact lenses, diapers (super absorbent polymers)
Aspartic acid	Substitutes of Polyacryl (PA) and polycarboxylates (detergents, water treatment systems, corrosion inhibition, super-absorbent polymers)
Glucaric acid	Solvents, nylons of different properties (i.e. Kevlar vs. carpet fibre)
Glutamic acid	Monomers for polyesters and polyamides
Levullinic acid	Fuel oxygenates, solvents
Polyhydroxyalkanoates	Plastics

The development stage ranges from laboratory scale to full- scale production.

As far as it concerns the market potential of the bio-based base chemicals and building blocks, Europe holds the highest percentage (29%) in terms of production comparing to the rest markets of the world, as shown in Figure 11.

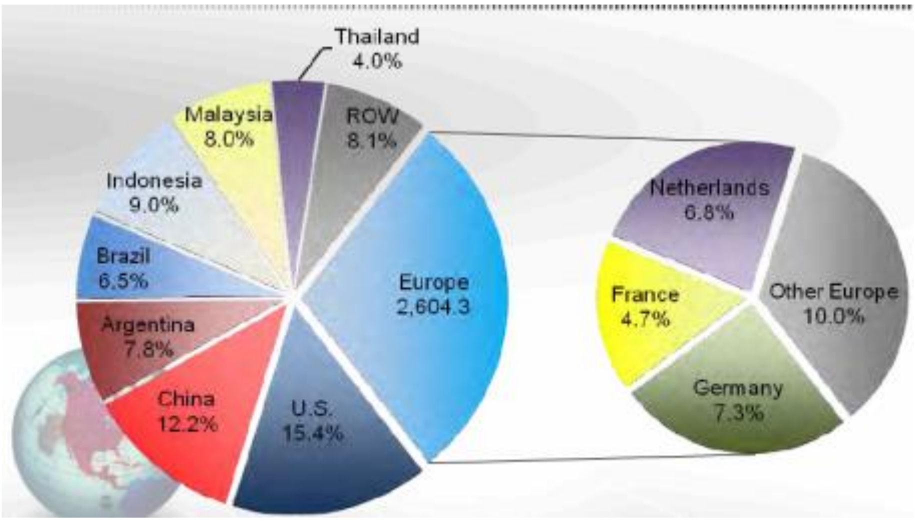

Figure 11: Where are bio-based chemicals being produced? [79]

[79]Deschamps, N., 2013

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Table 9 shows that bio-ethanol dominates at $58 billion a year, followed by much smaller, but still significant, markets for n-butanol, acetic acid and lactic acid. Xylitol, sorbitol and furfural also show significant markets for chemical conversion of sugars, without petrochemical alternatives. The smallest bio-based markets are those of the earliest stage products, such as 3-hydroxypropionic acid, acrylic acid, isoprene, adipic acid and 5-hydroxymethylfurfural (HMF). Bio-based Furandicarboxylic acid (FDCA), levullinic acid and farnesene have the highest current prices, but could be expected to drop to around $1,000/tonne (the indicative future bio-based production cost being targeted by several companies) once the relevant conversion technologies have been successfully commercialised.

Bio-based succinic acid has the fastest growing market at present, due to the level and breadth of industry activity in the product. In many cases, if economically competitive, bio-based products could easily overtake their fossil based alternatives, and expand into new non drop-in markets – they are not necessarily limited by the current demand in the total (bio+fossil) drop-in replacement market. Many bio-based products will however be struggling to compete economically due to significantly lower crude oil prices in recent months. Indeed, note that most of the source data is from 2013 or 2014, so the dramatic drop (>50%) in crude oil prices experienced globally is not reflected. Some of the fossil-derived comparators may now be significantly cheaper than listed in Table 9.

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Table 9: Estimated prices and volumes for bio-based and total product markets[80]

Product	Bio-based market				Total market (bio+fossil)		
	Price ($/t)	Volume (ktpa)	Sales (m$/y)	% of total market	Price ($/t)	Volume (ktpa)	Sales (m$/y)
Acetic acid	617	1,357	837	10%	617	13,570	8,373
Ethylene	1,300-2,000	200	260-400	0.2%	1,100-1,600	127,000	140,000-203,000
Ethylene glycol	1,300-1,500	425	553-638	1.5%	900-1,100	28,000	25,200-30,800
Ethanol	815	71,310	58,141	93%	823	76,677	63,141
3-HPA	1,100	0.04	0.04	assumed 100%	1,100	0.04	0.04
Acetone	1,400	174	244	3.2%	1,400	5,500	7,700
Acrylic acid	2,688	0.3	0.9	0.01%	2,469	5,210	12,863
Lactic acid	1,450	472	684	100%	1,450	472	684
PDO	1,760	128	225	100%	1,760	128	225
BDO	>3,000	3.0	9	0.1%	1,800-3,200	2,500	4,500-8,000
Isobutanol	1,721	105	181	21%	1,721	500	860
n-butanol	1,890	590	1,115	20%	1,250-1,550	3,000	3,750-4,650
Iso-butene	>>1,850	0.01	0.02	0.00006%	1,850	15,000	27,750
Succinic acid	2,940	38	111	49%	2,500	76	191
Furfural	1,000-1,450	300-700	300-1,015	assumed 100%	1,000-1,450	300-700	300-1,015
Isoprene	>2,000	0.02	0.04	0.002%	2,000	850	1,700
Itaconic acid	1,900	41	79	assumed 100%	1,900	41.4	79
Levulinic acid	6,500	3.0	20	assumed 100%	6,500	3.0	20
Xylitol	3,900	160	624	assumed 100%	3,900	160	624
FDCA	NA (high)	0.045	~10	assumed 100%	NA (high)	0.045	~10
5-HMF	>2,655	0.02	0.05	20%	2,655	0.1	0.27
Adipic acid	2,150	0.001	0.002	0.00003%	1,850-2,300	3,019	5,600-6,900
Sorbitol	650	164	107	assumed 100%	650	164	107
p-xylene	1,415	1.5	2.1	0.004%	1,350-1,450	35,925	48,500-52,100
Farnesene	5,581	12	68	assumed 100%	5,581	12.2	68
Algal lipids	>>1,000	122	>122	assumed 100%	>>1,000	122	>122
PHAs	6,500	17	111	assumed 100%	6,500	17	111

In the field of bio-based building blocks, major developments have been made in the recent years. The development stage of bio-based building blocks ranges from proof-of-concept in the laboratory to full commercial production, but as of 2013, only a few bio-based building blocks have reached economically favourable production compared to their oil-based counterparts. The EU demand that can currently be produced by fermentation is estimated at less than 700 million euro in 2013, representing approximately 35% of global production and an average CAGR of roughly 10% from 2008 to 2013. Hence, the EU is one of the major consuming regions

[80] E4tech, RE-CORD and WUR, 2015

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of fermentation-based building blocks. Although the EU is investing heavily in the research and development of fermentation-based building blocks, the majority of new facilities are built outside Europe, mainly in Asia and Brazil because of the availability of low cost sugars, lower operating costs (namely energy and labour), and the global nature of chemical markets.

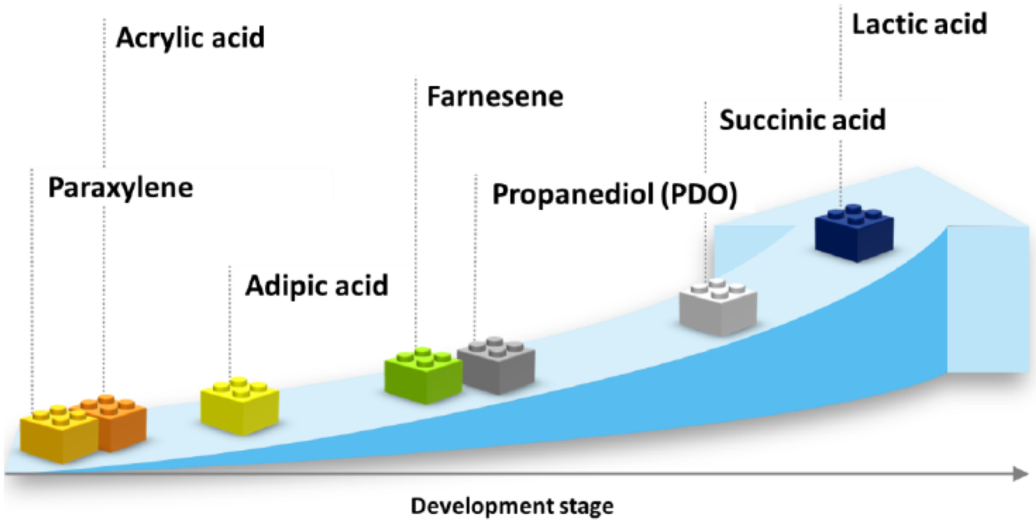

Figure 12 - Development stage of selected bio-based chemical building blocks[81]

In 2016, the total production capacity of the bio-based building blocks reviewed in literature is 2.4 million tonnes and is expected to reach 3.5 million tonnes in 2021, which means a CAGR of 8%.

The bio-based building block annual capacity growth rate is twice as high as the bio-based polymer annual capacity growth rate. The most dynamic developments are spearheaded by succinic acid and 1,4-BDO, with MEG as a distant runner-up. Bio-based MEG, L-lactic acid (L-LA), ethylene and epichlorohydrin are relatively well established on the market.

These bio-based building blocks cover most of the total production capacity. They are expected to keep on growing, especially bio-based MEG, whereas L-LA, bio-based ethylene and epichlorohydrin are projected to grow at lower rate or even to stagnate. However, the most dynamic developments are spearheaded by succinic acid and 1,4-BDO. Both drop-in bio-based building blocks are brand new on the market. The first facilities are currently running and more will be built in the coming years.

[81]BIO-TIC, 2015

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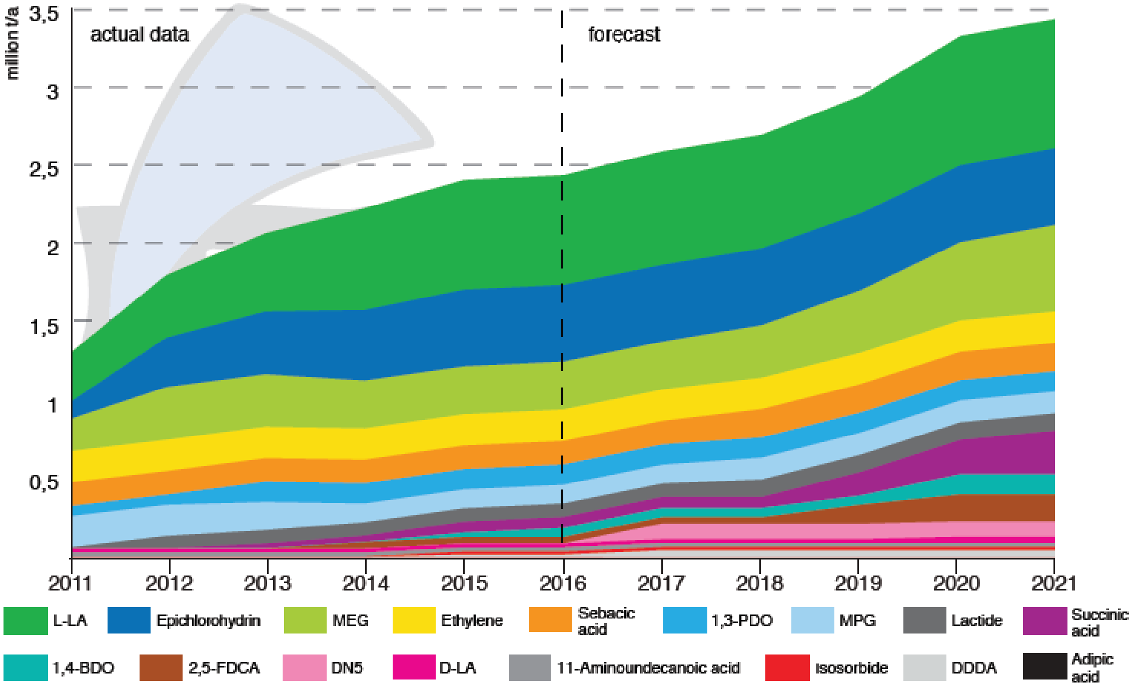

Figure 13: Selected bio-based building blocks: Evolution worldwide production capacities from 2011 to 2021[82]-

7.2. BIOENERGY

Bioenergy is the conversion of biomass resources originating from agriculture, forests and biodegradable waste into useful energy carriers including heat, electricity and fuels for transport.

In 2014, the average EU-28 energy dependency was estimated up to 53.4%, with oil import dependency to be the highest (87.4%), followed by natural gas (67.2%) and solid fossil fuels (45.6%)[83]. Within this concept, European Commission strategy considers bioenergy and renewables as the solution in reducing EU energy dependency. In the field of European bioenergy consumption, only the 4.4% corresponds to biomass imports. The rest 95.6% relies on the biomass, which is harvested and transformed in rural areas, for heating and electricity, contributing to the development of local economies[84].

In 2014, 61% of all renewable energy that was consumed in the EU and the 10% of the gross final consumption was accounted on bioenergy. The level of bioenergy consumption that year (2014) was more than double the consumption in year 2000 and in terms of sectors, 73% of bioenergy consumed in Europe was used in the heating sector (76.998 ktoe) while 14% (14.349 ktoe) as bioelectricity. [85].

[82] European Bioplastics and Nova Institute, 2016
[83] AEBIOM, 2016
[84] AEBIOM, 2016
[85] AEBIOM, 2016

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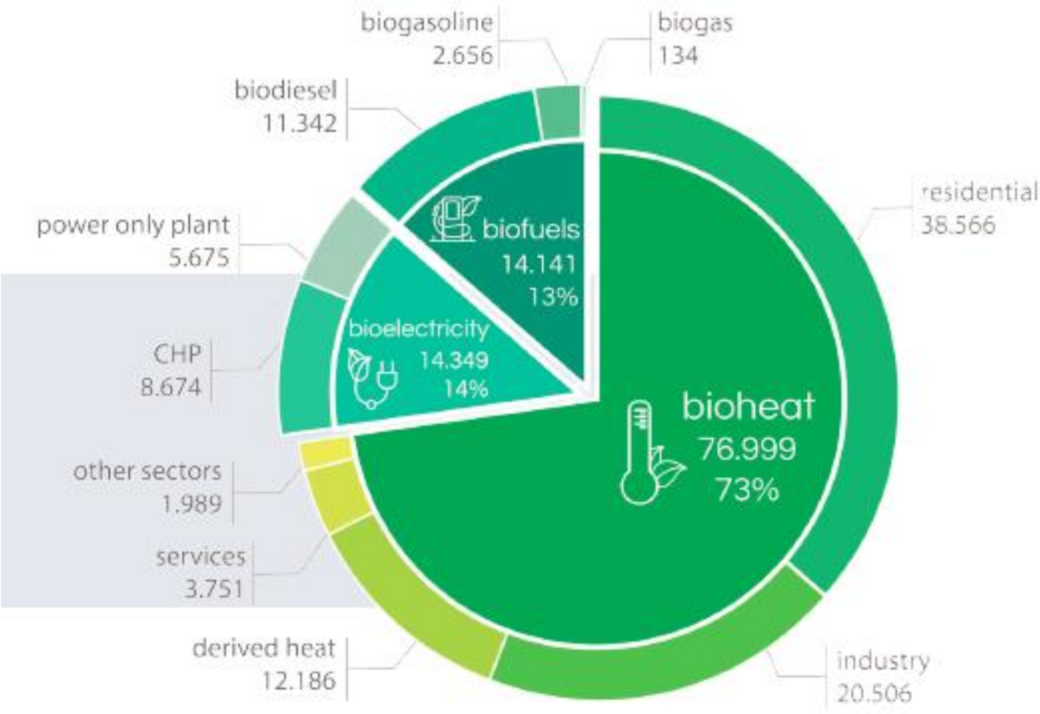

Figure 14: EU-28 gross final energy consumption of bioenergy per market segment[86]

The basic carriers of bioenergy are: solid biomass fuels, biogas and biofuels used for transportation purposes.

7.2.1. Solid biomass fuels

Woody biomass can be used as a fuel in different forms, each of them with different characteristics for a given situation. The simplest form of woodfuel, requiring little specialist equipment to prepare is logs and firewood. Logs may be sold directly to domestic consumers as fire- wood logs to be burned in an open fire or log burner. They are not suitable for an automated heating system. Wood chips are chopped woody material (whole trees of soft wood, short-rotation forestry, branches, tops etc.) with usual particle size of 5-60mm. Wood chips can be fed automatically into a boiler. This makes them suitable for larger boilers, however they are a relatively bulky fuel so require a large fuel store. By the term wood powder, the shredding of various wood biomass under 3mm, usually by milling various woody residual materials is depicted. It has limited direct application in practice, only in some industrial-scale facilities. Pellets and briquets are produced by forcing wood powder through a matrix under high pressure followed by cooling down for durability and stability. Pellets length is normally 10-30mm at 8-12mm of diameter, briquettes are of 10-40cm at 2-12cm of diameter. Pellets possess high energy density and standardized characteristics. They can be used in fully automatic heating systems. Both pellets and briquets are appropriate for small-scale simplifying heating systems (households) and for larger systems. Briquettes seem

[86] AEBIOM, 2016

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particularly suitable to replace firewood. Pellets of low quality, which do not meet the requirements of the small-scale heating systems can be employed for industrial use. For large-scale applications, wood chips from short-rotation forestry and residual wood appear to be the best options, followed by pellets and wood powder. Fuel pellets and briquettes can also be made from a number of other forms of biomass, including Miscanthus, straw, and various forms of biomass residues. Although these are all perfectly acceptable types of biomass fuel pellet, they have different properties, especially combustion properties, and require suitable, specialist combustion equipment to burn them safely and efficiently.

The heating sector appears to be the largest energy market for solid biomass fuels. Biomass heating systems are used at almost any scale, from domestic (about 10kWth) through to light commercial (about 50KWth to several hundreds) to industrial or district heating units (up to hundreds of MWth). But bioenergy used for heating entails a complex energy system, from the technoeconomic point of view, since it depends on the simultaneous nearby availability of heat consumers and biomass feedstock. The efficient heat generation also requires an optimum combination between combustion technology and fuel properties. In this context, there is an inverse correlation between the quality of fuels and the level of sophistication of combustion systems.

Residential consumption (including hot water supply for household use) accounts for half of total consumption of bioenergy. Medium scale applications of bioheating include agricultural heating for greenhouses, schools, hospitals, multi-family houses and hotels. All heat-producing installations of this scale are decentralized, meaning that they are not connected to a grid. This sector consists of individual heating appliances such as stoves and boilers using pellets, woodchips or wood logs. The small-scale facilities are less efficient than the large-scale systems, due to economy of scale. The automatic stoves using pellets and in fewer cases-straw are the efficiency leaders in the small-scale sector. Also, the performance of conventional manually-filled stoves on firewood or briquettes has also improved significantly in the recent years.

Industry and large- scale heat represent together about 40% of solid biomass fuel consumption in the heat sector. The most important applications of bioenergy heat generation at a large-scale level include:

- Single large building heating (flat blocks, business centres, airport terminals etc.);
- District heating;
- Industrial steam (with a steam temperature above 140^{o}C).

District heating is the use of a centralized installation to provide heat for a number of buildings, through a grid. District heating makes use of these cost advantages, as well as the administrative benefits of using a single boiler installation to provide heat several buildings. These might be a number of individual houses, blocks of social housing, local council offices, a school, etc. Boilers to burn woodfuels are economically attractive, especially for installations of the scale of a few hundred kW. Also, municipal solid waste incineration or biogas installations are used for district heating. District heating is common in some European countries such as Denmark.

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Large heating plants for district heating or industrial use have capacities in the range of 1MW up to 500MW and are capable of using a variety of feedstock from wood-chips to miscanthus. For large-scale applications, the travelling grate technology using wood chips, pellets or straw appears to be the preferred choice for burning solid biomass, followed by other grate modifications- fixed inclined grate, vibrating grate or underfeed stokers. The batch combustion of biomass is generally not regarded as a suitable large-scale option, although the cigar-type burner of whole straw bales is viable.[87]

Bioelectricity represents 17.9% of the total renewable electricity in the EU. It is usually generated from solid biomass and biogas installations. The most usual are large coal biomass co-firing plants and biogas installations based on anaerobic digestion of agricultural waste and energy crops. The technologies used range from mature solutions to emerging technologies that have not been yet deployed on a large-scale (for example co-firing with torrefied biomass). Direct co-firing with up to 10% biomass (measured on an energy basis) in pulverised-fuel and fluidised-bed boilers is successfully demonstrated and commercially available.

The secure, long-term supply of low-cost, sustainably sourced feedstock is critical to the economics of biomass power plants. Usual feedstock includes agricultural residues, and by-products such as black liquor from paper industry or bagasse at sugar mills. Feedstock costs may very modest in these cases, given that their collection is easy and they are transported over short distances. As the distances involved become bigger, the feedstock costs may become significant, as many biomass feedstocks have relatively low energy density values and are therefore bulky and expensive to transport.

The combined heat and power generation from biomass is an option for power plants whose energy efficiency could be increased by the useful utilization of the residual steam for heating purposes. In Europe, the largest part of bioelectricity produced is generated in combined heat and power plants. There are substantial benefits from the use of biomass for CHP rather than simply to provide power alone. For CHP, the overall energy efficiency is typically 70-90% compared to an average of 30-35% in dedicated biomass plants for power alone.

CHP plants have substantially higher capital costs than heat-only installations of the same scale and at smaller scales (below 10MW) the electric efficiency of the plant is much lower. It is therefore important for a CHP plant to operate smoothly and successfully the nearby existence of sufficient and stable heat demand that will ensure the economic viability of the investment. For biomass CHP plants, there is an additional important factor- the nearby availability of sufficient biomass resource in terms of quantity and quality. Hence, as the most suitable applications of bio-based CHP plants appear to be factories which might generate biomass as a by-product or as residues from a core activity and also have a constant heat demand to use in the production purposes– agricultural farms, sawmills, pulp and paper industries etc. Biomass CHP plants for district heating are common in Northern and Eastern Europe where an extensive district heating network combined with relatively high heat demand during winter season and an established resource supply coexist.

[87] Kavalov and Petenez, 2005

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There are great differences in the market penetration of bioenergy between the different regions of the EU. Some countries like Italy, present a pellet heating development for both residential or industry purposes, other countries, such as Lithuania, advance in building new large-scale CHP plants and big cities like Paris and Copenhagen turn to use biomass for district heating. Germany is the biggest producer of bioheat in Europe with 14%, followed by Sweden and France which represent the 11% each and Finland and Italy with 9% each. [88]

According to S2Biom project results, the total demand for electricity from biomass resources followed an increase of more than 250% between 2005-2015. [89] This increment is attributed mostly to the increase of biomass electricity in Germany the last decade. The same period, a steady growth in biomass electricity was observed in countries such as Austria, Spain, Italy and Sweden, whereas in other countries such as Greece, Lithuania, Luxembourg and Slovakia the consumption of electricity from biomass resources begun lately. [90]

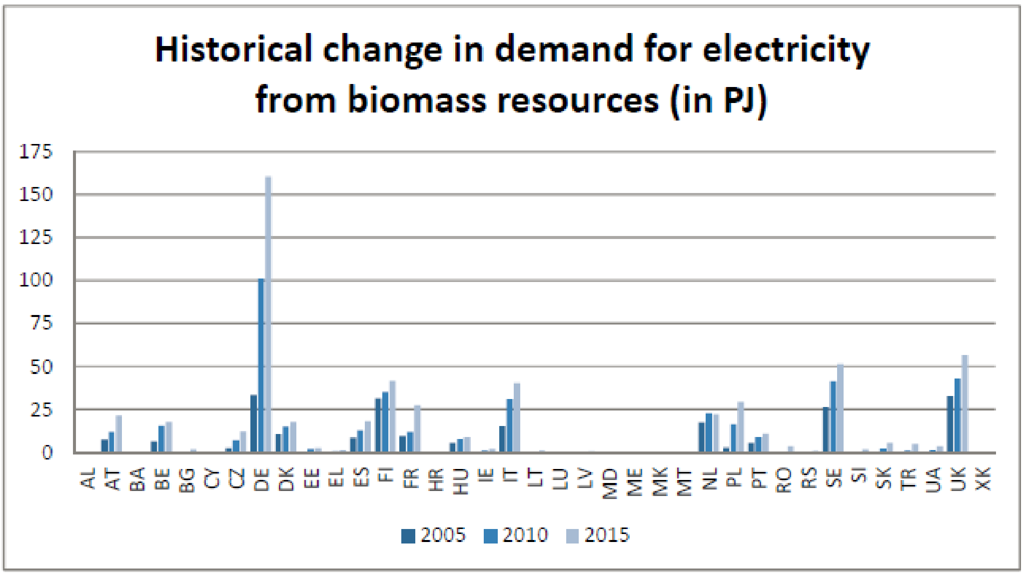

Figure 15:Historical change in demand of electricity from biomass resources[91]

The top 5 countries of the EU where bioelectricity generation accounted for a total of 66.8% are Germany (30%), United Kingdom (14%), Italy (11%), Poland and Sweden (6%).[92]

7.2.2. Biogas

Biogas is a mix that consists of methane (50-75%), carbon dioxide (25-45%), small amounts of water (2-7%) and trace gases such as hydrogen sulphide, oxygen, nitrogen, ammonia, hydrogen. The feedstock used describes and characterizes the biogas production. Accordingly, the following biogas types may be distinguished:

[88] AEBIOM, 2016
[89] S2Biom D7.2a, 2015
[90] S2Biom D7.2a, 2015
[91] S2BIOM D7.2a, 2015
[92] AEBIOM, 2016

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- Landfill biogas, which is the biogas captured from urban or industrial landfills;
- Sewage sludge biogas, generated in wastewater treatment plants;
- Biogas produced from various types of organic waste (animal slurry, farming waste, green waste, food processing waste) and from dedicated energy crops such as maize, sugar beet or wheat.

Currently biogas production is mainly done by the anaerobic digestion of high moisture content biomass in digesters or landfills and it is a commercially well-established process. Also, biogas can be produced by thermal gasification of woody biomass (bio-syngas) but this process is less mature.

Biogas can be combusted directly for heat and power or upgraded to biomethane to be fed into natural gas grid as a direct substitute of natural gas for district heating or used for power production. Applications may serve the domestic, agricultural and or industrial sector. Applications of biogas for transportation purposes are discussed in Paragraph 7.2.3

Biogas is also ideal for generation of electric power or CHP. Various gas-based approaches exist operating on a mix of natural gas and biogas, including biomethane, more commonly based on internal combustion. These plants require higher investments than biomass CHP plants but have lower operating costs and higher efficiencies. The electricity produced can be fed into the public grid or used as an independent power supply for industrial, agricultural or commercial applications or rural settlements that are off the grid. The waste heat can be utilized in downstream systems for additional power generation, but also for use in heating, drying or the operation of refrigeration machines. An interesting option is biogas fermenters that use straw with liquid manure that could boost biogas-based energy output, especially in regions with large manure and straw surpluses.

The European biogas sector is very diverse and depends on how each EU country sets the role of biogas in its area in order to favour different kinds of feedstock i.e. whether biogas production is primarily seen as a means of waste management, as a means of generating renewable energy, or a combination of the two. As an example, Germany generates 93% of its biogas from the fermentation of agricultural crops and crop residues, whereas UK, Greece, Estonia, Ireland and Portugal rely on landfill and sewage sludge gas and other countries use a variety of feedstock combinations. According to data from 2014, Germany biogas production corresponds to the 65% of total EU production (higher), and follow Italy (14%), Czech Republic (5%), UK and Austria (3%). [93]

7.2.3. Biofuels

Liquid biofuels used for transportation purposes are divided in three main categories based on the type of biomass feedstock used to produce them:

[93] USDA Foreign Agricultural Service, 2016

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- **First-generation or conventional biofuels:** where dedicated food crops are used for their production (sugar crops, starch crops, oil crops such as palm, rapeseed, soy, beets and cereals);
- **Second-generation or advanced biofuels**: which are produced from feedstock that does not compete directly with food and feed crops, such as wastes and residues (agricultural, forestry, wood, municipal solid waste etc.), non-food dedicated crops grown on marginal land (miscanthus, short rotation coppice etc.) and novel feedstock such as aquatic plants, macroalgae etc. Often the term refers to biofuels produced from lignocellulosic or cellulosic biomass;
- **Third generation:** which are produced from aquatic autotrophic organisms (e.g. algae).

Table 10: Bio-fuels (adapted from [94], [95])

Fuel	Feedstock/ Process	Scale of production	Uses
First generation			
Bioethanol	Sugar and starch from agricultural crops (sugar cane, cereals, sugar beets (fermentation)	Industrial	Petrol substitute Petrol blend component Feedstock for petrol additive ETBE
Bio-ETBE	Bioethanol and isobutylene (Catalysis)	Industrial	Blend with petrol, in conventional vehicles and fuel distribution systems
Biodiesel (FAME)	Oil crops (rape, palm, soy etc.), Jatropha, new oil crops (Camelina, *Salicornia bigelovii*) (transesterification)	Industrial	Substitute diesel, transportation fuel, power generation fuel
Straight vegetable oils (SVO) Pure vegetable oils (PPO)	Canola, rapeseed, sunflower	Demonstration Small scale	Diesel engines (machinery, vehicles
Bioethers (MTBE, TAME)	Bioethanol or biomethanol and isobutylene (fermentation)	Industrial	Blending components with gasoline

[94] http://www.biofuelstp.eu
[95] USDA Foreign Agricultural Service, 2016

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Fuel	Feedstock/ Process	Scale of production	Uses
Second generation			
Cellulosic ethanol	Agricultural residues (straw, corn stover etc), lignocellulosic raw materials (e.g. wood chips), energy crops (miscanthus, switchgrass etc.) (hydrolysis, fermentation)	Pilot plant/ Demonstration	Petrol substitute Petrol blend component Feedstock for petrol additive ETBE
Advanced biodiesel	Waste fats and oils (used cooking oil, waste animal fats etc.) Pulp industry residues (gasification, FT process, transesterification)	Research	Substitute diesel, transportation fuel, power generation fuel
BTL (Biomass to Liquid)	Woody residues, forest wastes, energy crops (gasification, FT process)	Demonstration	Diesel engines Aviation fuel
Bio-SNG (Bio-synthetic natural gas)	Lignocellulosic feedstock (gasification)	Pilot and demonstration	Car fuel
HEFA (Hydroprocessed Esters and Fatty acids) HVO (Hydrotreated Vegetable Oils)	Waste fats and oils (Hydrotreating)	Industrial	Aviation fuel Diesel engines
BioDME (dimethylether)	Forest products, agricultural by-products, organic waste, energy crops, black liquor	Demonstration	Substitute for diesel fuel, transportation fuel, power generation fuel, domestic gas
Biohydrogen	Biogas (steam reforming), organic substrates (fermentation)	Research Demonstration	Transport fuel
Biobutanol	Cereal crops, sugar cane, sugar beet, lignocellulosic materials	Research	Blended with gasoline in conventional petrol

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Fuel	Feedstock/ Process	Scale of production	Uses
	(fermentation)		engines
Biomethanol	Natural gas, coal, biogas (thermochemical)	Industrial	Blended with gasoline in conventional spark-ignition engines Shipping fuel
Bio-oil	Forestry residues, crop residues, waste paper, organic waste (fast pyrolysis, thermochemical conversion)	Research Demonstration	To be converted in biofuels after refining
Tall oil	Pulp and paper industry residues	Commercial scale up	To produce biodiesel

The most common biofuel is bioethanol, which is mainly derived from sugar or starch crops after yeast fermentation (first generation bioethanol). Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane number and improve vehicle emissions. Biodiesel is the second most common liquid biofuel and Europe is the biggest producer and consumer of biodiesel. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Use of biodiesel has grown exponentially over the last decade, and it is expected to continue growing. In 2014, the EU consumed 134 million tonnes of oil equivalent (TOE) of biodiesel for transportation uses: 84 million TOE in Sweden and 50 million TOE in Germany. EU bioethanol production reached its highest level in 2014 – 5.3 billion litres – as the sector benefitted from the low feedstock prices and the restrictive measures on bioethanol imports. [96]

Advanced biofuels are notably popular for research and future widespread commercial use in Europe. Renewable hydrocarbon biofuels are yet another potential and practical use for advanced biofuels. Renewable petroleum gasoline, diesel, and jet fuel are all possible outcomes from the biological and thermodynamic processes in converting biomass into fuel.

[96] USDA Foreign Agricultural Service, 2016

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7.3. BIOPLASTICS

With the term bioplastics, a whole family of plastic materials with differing properties and applications are referred to. These materials may either be bio-based, or bio-degradable or both.

Three main groups may be distinguished:

- **Bio-based or partly bio-based, non-biodegradable commodity plastics** (bio-based PE, Polypropylene (PP) or PET) and bio-based technical performance polymers, such as PTT or Thermoplastic Copolyester Elastomer (TCP). Bio-based PE, PP and PET originate from bioethanol. Bio-PE is already produced commercially and bio-PP and -PVC are following soon. Their main application is for packaging materials. Bio-based technical performance polymers are used in textile fibres, automotive applications etc.;
- **Both bio-based and biodegradable plastics**, such as PLA, Polyhydroxyalkanoates (PHA). These materials have been available on industrial scale only for a few years and have been primarily used for short-lived products such as packaging. In the future, a dynamic development of their applications area is expected with the introduction of new bio-based monomers such as succinic acid, butanediol, fatty acid derivatives etc.;
- **Biodegradable plastics that are produced by fossil fuels**, such as Polylactic acid Polybutylene adipate-co-terephthalate (PBAT). These are mainly used in combination with starch or other bioplastics to improve their application-specific performance by their biodegradability and mechanical properties.

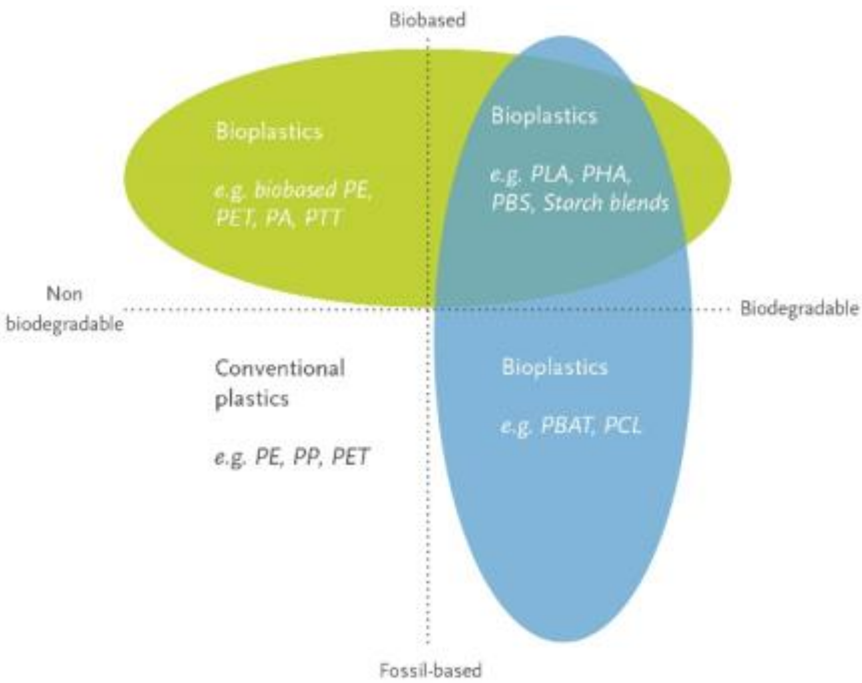

Figure 16: Types and properties of bioplastics[97]

[97] European Bioplastics and Nova Institute, 2016

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A vast array of products derives from bioplastics using conventional plastic processing technologies. For almost every conventional plastic material and application there is a bioplastics alternative available on the market that has the same properties and potentially offers additional advantages. The packaging sector is the main application of bioplastics, that includes flexible packaging and rigid packaging. Bioplastics are also being used in consumer goods (like toys, bicycle helmets etc.), in the automotive and transport sectors, in the building and construction sector, agriculture, electronics (phone touch screens, for example) etc. The main applications of bioplastics are presented in Table 11

Table 11: Bioplastics applications

Bioplastic	Applications
Packaging	Rigid packagings for cosmetics, food trays, lunch boxes, single use utensils
	Flexible packagings (films, trays) for fresh food
	Shopping bags, containers, paper coatings, trash bags
Agriculture	Mulch films, transplanting seedling pots, vegetation nets, feromone traps
Consumer electronics	Casings, circuit boards and data storage, screen consumer casings, loud speakers, keyboard elements, vacuum cleaners, mouses
Automotive	Sturdy dashboard components, solid interior or exterior features
Consumer goods and household appliances	Moisturizers, skin rejuvenating agents, pH control, antimicrobial, diapers, sanitary packages
Medicine	Surgical pins, sutures, staples, swabs, wound dressings, bone replacements and plates, blood vessel replacements

The bioplastics production value chain is presented in Figure 17.

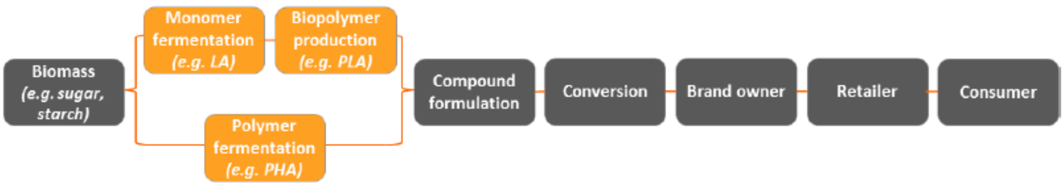

Figure 17: The value chain of bioplastics[98]

[98] BIOTIC, 2015

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In the same product category, lignocellulosic polymers are grouped and presented. Cellulose pulp is already in use in a number of high- value markets, including the production of clothing fibres, films and filters. Cellulose acetate production amounts to 700.000 tonnes per year and it is a well-established market. Similarly, high- value applications exist for hemicellulose polymers, but in contrast to cellulose polymers, these appear to be niche products, developed by single producers. Lignin, mostly in the form of lignosulphonates that is lignin that has been modified to become water soluble, is also used for a variety of low- value applications including as an animal feed, as dust control, binders and as dispersants, but the quality of this lignin is relatively poor. Both cellulose and lignin products are derived from wood materials through the pulping industry.

Table 12: Status of lignocellulosic polymer markets in 2012 [99]

Product	Applications	Maturity
Cellulose fibres	Textiles, clothes, packaging	Commercial
Cellulose ethers	Personal care, pharmaceuticals, detergents, cosmetics, paint, food etc.	Commercial
Nitrocellulose	Explosives, lacquer, food products	Commercial
Cellulose esters	Films, moulding, extrusion, fibres and lacquers	Commercial
Hemicellulose	Barrier films in packaging	Development
Hemicellulose	Adhesives	Commercial
Hemicellulose	Medicinal (wound barriers)	Commercial
Hemicellulose	Agronomy (seed coatings and soil stabilization)	Commercial
Hemicellulose Alkylpolypentosides	Cosmetics (ingredients)	Commercial
Lignin	Phenols and adhesives (eg. for applications in the wood based panels industry)	Development
Lignin	Dispersants (i.e. to increase fluidity and stabilisation) in concrete, textile dye etc.	Commercial
Lignin	Dust control (e.g. on unpaved roads)	Commercial
Lignin	Binding agent (eg in animal feed), resins, oil well drilling, mud additive	Commercial
Lignin	Vanillin (artificial vanilla flavor)	Commercial

[99] Kretschmer et al., 2013

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In terms of market penetration, bioplastics make up approximately 1-1.5% of the 300 million tons of plastic produced annually. However, there is a notable growth in the market (20%-100% per year) especially due to the fact that the demand is rising and more materials, applications and products appear and it is expected the share of bioplastics will grow to 2-2.5% of the overall plastic production in the next few years. The global production capacity of bioplastics is expected to reach 6.1 million tons in 2021 from the 4.2 million tons produced in 2016. [100] The bioplastics market section exists 25 years now (beginning with recycled thermoplastics or wood fibres). In Europe as in North America there are approximately 60-70 manufacturers while in China there are about 300.

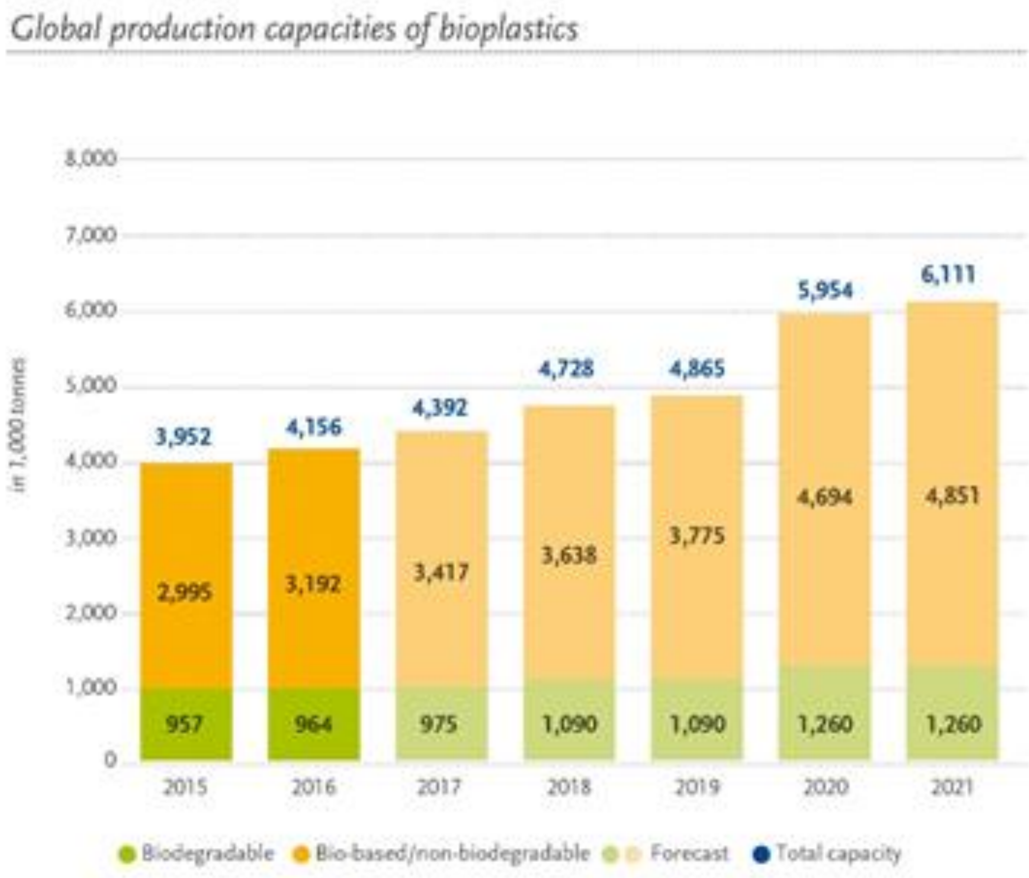

Figure 18: Global production capacities of bioplastics[101]

Nowadays, bio-based plastics have established a market that grows rapidly both in Europe and globally. This growth is driven mostly by bio-based, non-biodegradable plastics, such as polyurethanes (PUR) and drop-in solutions, such as bio-based PE and bio-based PET.

[100] http://www.european-bioplastics.org/market/
[101] European Bioplastics and Nova Institute, 2016

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7.4. FOOD AND FEED INGREDIENTS

Bio-based food and feed ingredients are the products used in food and feed industry which could be produced by any biotechnology process. These compounds could be from microbial, animal or plant sources, but also food wastes and by-products from food and feed industries are potentially sources to find different molecules and develop new ingredients as shown in Table 13. They are produced from biomass through fermentation or enzymatic hydrolysis.

Table 13: Common bio-based food and feed ingredients derived from food industry

Food industry sector	Relevant bio-based products derived
Fruit and vegetable	Glucose, citric and linoleic acids, tocopherols, polyphenols, ascorbic acid, dietary fibre, pectins, and pigments.
Grain processing	Vitamins, minerals, key unsaturated fats, β-glucans, dietary fibre, antioxidants and different sterols.
Brewery and winery	Flavouring agents, enzymes, single cell protein (SCP), substrate for microalgae cultivation, cellulose and non-cellulosic polysaccharides, sugars, proteins, acids and antioxidants.
Marine	High calibre protein, lipids with high levels of unsaturated fatty acids, hydrolysates from fish guts/cleanings, peptides, and products from crustaceans such as chitosan, chitosan oligomers, glucosamines, omega-3 oils, chitin and chitosan, fish protein hydrolysates, algal constituents, carotenoids and antioxidants.
Meat	Bioactive peptides using hydrolysis or fermentation with antimicrobial, antioxidative, antithrombotic, antihyper-tensive or anticancerogenic activities.
Dairy	Solvent proteins (β-lactoglobulin, α-lactalbumin, immunoglobulin, bovine serum albumin, lactoferrin, and lactoperoxidase), high content of essential amino acids with antimicrobial, anticarcinogenic or biological activities.

Bio-based food and feed ingredients consist a growing market with big demand and competition. Bio-based food and feed ingredients have numerous applications in various sectors of the food industry such as dairy products, beverages, oils and fats, animal feed, infant nutrition, snack foods and bakery goods etc. and fall in six major categories:

- **Probiotics:** This term is used to name edible microorganisms with several associated health benefits for humans and animals. The probiotics market in Europe was valued at 100 million EU in 2010. The Western European market for probiotic bacteria cultures is

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focused on four areas – dairy products, animal feed, supplements and infant nutrition – and it was valued at EUR 30-36 million, and the US market was worth EUR 127 million;

- **Prebiotics:** Fructo-oligosaccharides that when digested have a positive impact on the composition of bacteria in the digestive tract. Nearly all carbohydrate-based food products, such as bread and cereals, but also margarines, fruit juices and dairy drinks, can be enriched with prebiotics. The fructan market (which includes inulin and fructooligosaccharide) is the biggest segment. However, the fructan market reached EUR 180 million in 2010, attracting several new market participants;
- **Dietary fibres:** Dietary fibres are increasingly used to replace fat in food dietary products;
- **Peptides:** Bioactive peptides and proteins are a group of functional ingredients that is of growing interest due to their functional properties, e.g. anti-cholesterol, anti-flammatory and antioxidant properties. Their major applications are in sport drinks and animal feed;
- **Terpenes:** The terpenes sub-category of carotenoids includes beta-carotene, lycopene, astaxanthin and lutein – which are also widely used for animal feed, as food colouring, in cosmetics, in pharmaceuticals and in dietary supplements. The beta-carotene on the market is usually synthetic and its production is concentrated at DSM and BASF, which have a combined share of over 80%. However, the use of naturally- derived carotenoid is increasing, particularly in functional food and health food applications;
- **Phenols:** Polyphenols, being traditional food colorants, are increasingly marketed as antioxidants food ingredients. Last researches focused on the study of polyphenols suggest that these molecules can protect against cancer and cardiovascular diseases, as well as increase anti-inflammatory activity.
- **Nutraceuticals:** The term “nutraceutical” combines two words – “nutrient” (a nourishing food component) and “pharmaceutical” (a medical drug). The name was coined in 1989 by Stephen DeFelice, founder and chairman of the Foundation for Innovation in Medicine, an American organization located in Cranford, New Jersey. Nutraceuticals is a broad umbrella term that is used to describe any product derived from food sources with extra health benefits in addition to the basic nutritional value found in foods. They can be considered non-specific biological therapies used to promote general well-being, control symptoms and prevent malignant processes.

Bio-based animal feed co-products are also generated through biorefinery processing for the production of biofuels, mainly bioethanol and biodiesel (see also Table 6 and Table 7). Currently, co-products are an important feed resource in many countries, for ruminants, non-ruminants and aquaculture. Due to the expansion of the feedstock used for bio-fuels production (from first to second generation), several co-products have been introduced in the

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global market and can be used as livestock feed. This trend is on-going, increasing both in complexity and in the number of livestock species that are benefiting, as shown in Table 15.

Table 14: Feedstock used for bioethanol and biodiesel production, their feed co-products and major areas of utilization[102]

Feedstock	Co-product	Co-product utilization for animal feed
Maize Sorghum Wheat Triticale Rye, barley Co-products from biodiesel production	Distillers grain (DG) Wet distillers grain (WDG) Dried distillers grain (DDG) Dried distillers grain with added solubles (DDGS) DDGS with high protein additive Maize oil, maize-condensed distillers soluble, maize gluten feed	Distillers grains (DG), Distillers dried grains with solubles (DDGS), Wet distillers grain (WDG), DDGS-HP for beef cattle DG for dairy cattle DG for pigs DG for poultry DDGS as grazing supplements for ruminants DDGS for aquaculture
Sugar cane Sugar beet, sweet sorghum Cassava	Vinasse (multi-nutritional blocks/ pellets/meal) Sugar cane tops, bagasse and molasses Sugar beet tops, fermentable palatable waste Grain/ bagasse/ foam/ froth/ steam/ vinasse/ syrup from 'sugary stems' Cassava residue plus sludge from cane processing	Sugar cane co-products including use of effluents for cattle Sugar cane bagasse with supplements and cassava residue for cattle and other ruminants
Soybean Rapeseed Vegetable oils Maize oil	Crude glycerine Oil seed cake (mechanically extracted) and meal (solvent extracted) after methanol removal	Oil seed cake and meal used for pigs, beef cattle, fish, dairy, poultry Glycerol as drench and supplement for dairy cattle
Camelina sativa	Camelina meal (no irrigation needed, rich in aminoacids and antioxidants)	Poultry (broilers and layers)
Jatropha	*Jatropha platyphylla* and *Jatropha curcas* Kernel meal and protein isolate (heated, detoxified)	Fish, turkeys and pigs
Oil palm Babussa	Oil palm fronds, trunks, pressed fibre, empty fruit bunches, kernel cake, oil mill effluent	Ruminant feeding and complete diets based on oil palm for poultry, pigs and freshwater fish

[102] FAO, 2012

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Feedstock	Co-product	Co-product utilization for animal feed
		Oil palm and babussa feed for collared peccary
Seed oils	Co-products derived from bioethanol and biodiesel production	In livestock feed as feed additives

7.5. BIOSURFACTANTS

Biosurfactants are surfactants in which at least one of the two groups (hydrophilic or hydrophobic) is obtained from biological natural sources, i.e. produced from plants or animal fats, or on microbial cell surfaces or secreted as extracellular products by various microorganisms such as yeasts, bacteria and filamentous fungi. The first generation of biosurfactants are made entirely from renewable feedstock (mainly starch and vegetable oils - fatty acids) through chemical synthesis, while the second generation of biosurfactants are produced from renewable feedstock through microbial fermentation.

Biosurfactants can be of high or low molecular weight, and based on their chemical structure they are classified as: [103]

- glycolipids (rhamnolipids, trehaloselipids, sophorolipids);
- lipopeptides and lipoproteins;
- fatty acids;
- phospholipids;
- neutral lipids;
- polymeric biosurfactants;
- particulate biosurfactants.

Due to their chemical structures, biosurfactants are characterized by several properties, including emulsification, foaming, detergency, wetting, dispersing or solubilisation traits, thickening, microbial growth enhancement and metal sequestering, which make them applicable in many industries and for a wide range of applications, the largest of which are currently detergents, followed by personal care products and industrial and institutional cleaners.

Bio-based surfactants are produced mainly by using oleochemical raw materials including vegetable seed oils such as coconut and palm oils, plant carbohydrates such as sorbitol, sucrose and glucose or from animal fats such as tallow. In recent years, oleochemical feedstock sources of surfactants have been changing. In particular, animal fat has been replaced by vegetable oils and soybean oils, while fish oil use has reduced due to high prices caused by the growing demand for its antioxidant activity. Overall, the feedstock availability remains a major

[103] Gautam and Tyagi, 2006

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challenge for the market due to the increasing biomass utilization in biofuels and other downstream applications. In addition, the variability in prices due to the supply demand gap is a key restraint for the development of the market. One of the current strategy, also to reduce costs of raw materials, which are estimated to account for 10 - 30% of the total production costs, [104] is to use low-cost raw materials like agro-industrial wastes, which are cheap and available in huge quantities, such as cassava waste water, palm oil mill effluent, groundnut waste, soybean waste, olive mill waste, orange peel waste, potato peel waste and sugar waste. [105]

Due to their wide set of structures and properties, surfactants can be found as components of various products which are used in many industries and for several applications such as household detergents, personal care, industrial cleaners, food processing, oleo-field chemicals, agricultural chemicals, textiles, emulsion polymerization, paints and coatings, lubricant and fuel additives, metal working, mining chemicals, pulp and paper production, leather processing, etc. The largest end use market for surfactants is household cleaning detergents.

The major current and possible future applications and/or type of products for different end-user industries of biosurfactants could be summarized as:

- **Agriculture**: Mobilizing agents to enhance the solubility of bio-hazardous chemical compounds, hydrophilization agents of heavy soils to obtain good wettability and distribution of fertilizers in the soil, microbial "helpers" for the adsorption of soil particles occupied by pollutants, anti-caking agents of fertilizers, promoters of spreading and penetration of pesticides, bio-pesticides against several insects (e.g. the fruit fly *Drosophila melanogaster*); [106]
- **Cosmetics:** Due to their diverse properties, i.e. emulsification, foaming, water binding capacity, collagen neosynthesis stimulator, spreading and wetting ability, they are used as ingredients in various products such as cleansing cosmetics, nail care, body massage accessories, eye shades, tooth paste, soaps, shampoos, lipsticks etc.;[107]
- **Detergents industry:** Biosurfactants such as cyclic lipopetides are stable detergents in a wide range of pH and temperature values; they show good emulsion formation capability with vegetable oils and they are compatible with already used laundry detergents;[108]
- **Environmental field:** Several biosurfactants are able to bind and remove from the soil heavy metals (including Cd, Pb and Zn), thus contributing to the remediation of contaminated soils/sites;[109]

[104] Kamalijeet and Sokhon, 2014
[105] Banat et al., 2014
[106] Fakruddin, 2012
[107] Gharaei-Fathabad, 2011
[108] Fakruddin, 2012
[109] Gautam and Tyagi, 2006

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- **Food industry:** Biosurfactants are used to create and stabilize emulsions and aerated systems, control the agglomeration of fat globules, improve texture and shelf-life of bakery products, modify rheological properties of wheat dough and improve consistency and texture of meat products;[110]
- **Medicine:** Biosurfactants can be used as antimicrobials, antivirals, anti-cancer agents, anti-adhesive agents, immunological adjuvants and gene delivery carriers;[111], [112], [113]
- **Oil industry:** Biosurfactants are used to improve oil recovery due to their selectiveness, thermotolerance, halotolerance, anaerobicity and small quantities needed;
- **Petroleum biotechnology:** Biosurfactants can be used in fields as bio-corrosion and biofouling degradation of hydrocarbons within oil reservoirs, enzymes and biocatalysts for petroleum up-grading. They act as a biocatalyst for up-grading of petroleum and enhance oil recovery process by microbes which play an important role in clean-up of oil containers/ storage tanks and formation of products from petrochemicals.[114]

The world-wide use of surfactants has grown enormously over the past few decades, but it has also been estimated that in the EU, 50% of the surfactants produced have hydrophobic tails derived from palm or coconut oil. Driven by the sustainability agenda, a major change has occurred in the past few years and companies using surfactants in their products are now looking to replace some or all of the chemical surfactants with sustainable ones.

In 2012 the global demand for biosurfactants was 330,200 tonnes and is expected to increase to 461,991.67 tons by 2020, growing at a CAGR of 4.3% from 2014 to 2020.[115]In terms of revenue, the market was valued at USD 1,610.3 million in 2012 and is expected to reach USD 2,308.8 million by 2020, with a CAGR of 5.4% from 2014 to 2020.

According to the evaluations made within the EU-FP7 BIO-TIC project, in 2030 the European bio-based surfactants market could have a market value between 0.8 million EUR and 1.8 B EUR.[116]

[110] Krishnaswamy et al., 2008
[111] Rodriguez et al., 2016
[112] Kitamoto et al., 2002
[113] Liu et al., 2010
[114] Perfumo et al., 2010
[115] Grand View Research, 2015
[116] BIOTIC, 2014

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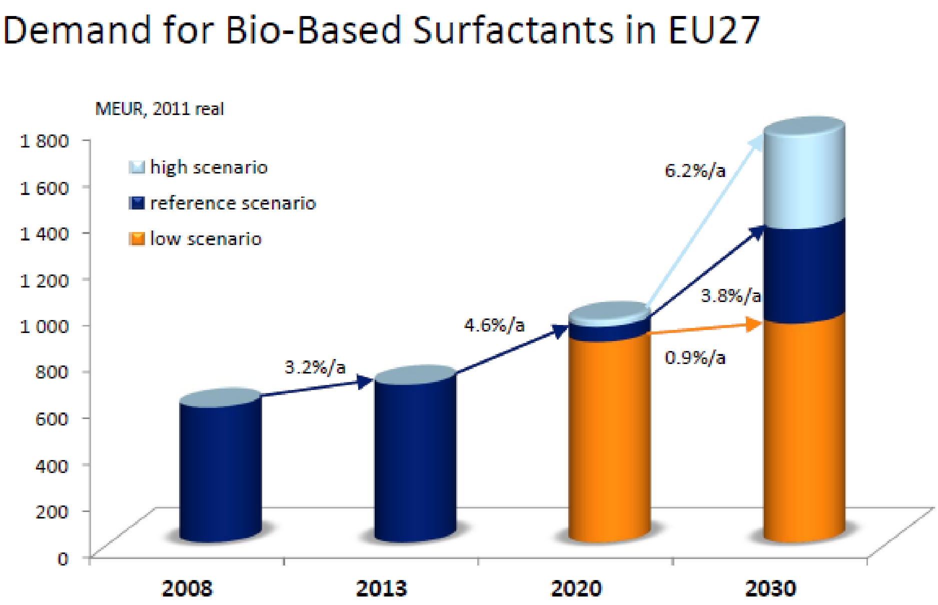

Figure 19: Biosurfactant Market Projections to 2030[117]

Geographically, the biosurfactants market can be segmented into North America (United States, Canada, Mexico and rest of North America), Europe (Germany, United Kingdom, France, Italy and rest of Europe), Asia-Pacific and the rest of the World.[118] Europe is the leading market, accounting for more than 50% of the global market and North America and Asia-Pacific follow. Asia-Pacific is considered to be one of the most promising markets since it is foreseen to witness significant growth over the next years. In particular, importance of Asia relies on the fact that is a large producer of vegetable oil, which is used as a feedstock for biosurfactants.

Rhamnolipids, sophorolipids and mannosylerythritol lipids (MEL) are the key product segments of the microbial biosurfactants market. In particular, the market is mainly driven by the growing demand for sophorolipids, which accounted for over 50% share of the whole market in 2014. The strong growth of sophorolipids can be attributed to their high production yields. Rhamnolipids are the second leading product segment for microbial biosurfactants and are widely used in bioremediation and improved oil recovery in addition to personal care applications (*e.g.* moisturizers and shampoo).

House- hold detergent was the largest application of biosurfactants accounting for 44.6% of market in 2013. The growing environment concern with synthetic surfactants in detergent is expected to lead to an increased usage of biosurfactants owing to their lower toxicity. In addition, biosurfactants have superior foaming properties as compared to synthetic surfactants making them ideally suited for use in detergents. Personal care was the second largest application of biosurfactants accounting for over 10% of global consumption in 2013. The growing market for personal care products in emerging economies coupled with

[117] BIOTIC, 2014
[118] Grand View Research, 2015

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increasing awareness of advantages of bio-based products is expected to boost the demand for biosurfactants over the years 2013-2020.

Also, industrial cleaner applications are reported to gain at over 4% throughout the period 2015-2023, mainly due to increasing acceptance of natural surfactants and favourable regulations for biosurfactants market which should play a significant role for alkyl polyglucosides (APG) usage in industrial cleaner applications, *e.g.* paint stripping and oil surface cleaning. Concerning the food industry, a 4.5% increase in the biosurfactants market size is expected to be achieved, mainly in relation to the sorbitan esters which find applications in confectionery, dairy and bakery products for which they are used as stabilizers, foams, gels and emulsifiers.[119]

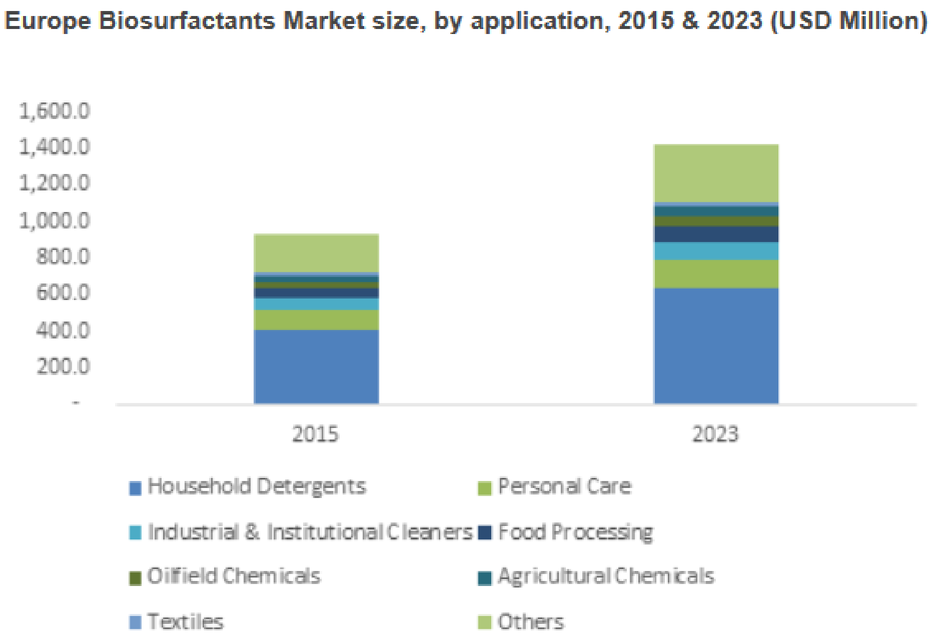

Figure 20: European biosurfactants market size in relation to the products application[120]

Global biosurfactants market share is concentrated with top five market players which accounted for over 65% of the overall volume in 2015.

7.6. BIOLUBRICANTS

Biolubricants are primarily triglyceride esters, which are mainly derived from the transesterification of plant oils such as high oleic canola oil, castor oil, palm oil, sunflower seed oil, rapeseed oil, soybean oil from vegetables, and tall oil from tree sources. The major vegetable oil used in Europe for industrial products is rapeseed. The term refers to all plant-

[119] Global Market Insight, 2016
[120] Global Market Insight, 2016

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derived lubricants, regardless if they are biodegradable or not and if they are blended with biodegradable mineral oils or not.

As vegetable oils have an excellent lubricity and adhesivity, but poor oxidation and low temperature stabilities, in order to use plant-based oils as lubricants, special additives and chemical modifications are necessary to get products for end- use applications [121]. Formulations are very complex and they are usually a blend of several types of oils.

Just like their synthetic counterparts, biolubricants are used in a variety of applications and industries. Their use is preferred in machinery that loses oil directly into the environment during use and in machinery used in sensitive to pollution leakages areas such as in aquatic, agricultural and forest environments or in food processing and packaging applications, where contact between food and lubricant is often technically inevitable. Additionally, compared to petroleum-based lubricants, biolubricants offer a safer and less toxic work environment due to higher flashpoints, constant viscosity and less oil mist and vapor emissions.[122]

Table 15: Biolubricants applications

	Products
Applications	Automotive oils, hydraulic oils, process oils, demolding oils, lubricating greases, chainsaw (cutting) oils, compressor oils, turbine oils, industrial gear oils, metal working oils, 2-stroke engine oils, marine oils and drilling fluids.
End-user industries	Power industry, automotive industry, aviation, military, construction, water management, marine, food industry, agriculture, forestry, household.

The two major user groups in the global biolubricants market are automotive and industrial.

Automotive industry occupied over 56% of the volume share in 2015, revenue in this segment is expected to see a 5% CAGR from 2013 through 2018. Within this segment, automotive engine oils dominate the industry, since these oils exceed the performance of conventional engine oils. Furthermore, bio-based engine oils display higher inherent biodegradation rate, low toxicity to aquatic organisms, and very low levels of bioaccumulation that are boosting their application in the sector.

In the automotive industry in 2015, **commercial transportation** occupied over 43% of the volume, owing to growing awareness regarding fuel efficiency and maintenance in heavy and light-duty trucks. Improvement of vehicle quality is directly proportional to a reduction in environmental impact of these vehicles, which has garnered high popularity for these lubricants in the segment.

[121] Gupta et al., 2012
[122] State of Washington, 2011

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The **consumer automotive segment** of biolubricants is also growing, since consumers are increasingly investing in advanced technologies and performance enhancing products to comply with fuel efficiency regulations.

In the **industrial segment** hydraulic oils and process oils occupied a significant portion of the volume. Revenue in this segment is expected to see a 6.7% CAGR from 2013 through 2018. These oils are widely utilized in technical and chemical industries to improve production processes. Growing demand for specialty chemicals in emerging economies of Asia Pacific is expected to drive consumption of these oils. [123]

More than 90% of the lubricant market is dominated by mineral and related oils, which are heavily contaminating the environment, but have wide availability and low price. Biolubricants are a very small part of the overall lubricant market, predominantly used in the US and Europe, as their high costs – over double the price of standard lubricants – limits their appeal elsewhere.

However, the biolubricants market is expected to take an increased share in the lubricant market over time, as although petroleum based products are cheaper, well known and highly stable, they do not offer the advantages of being biodegradable and non-toxic. High performance, environmentally-friendly lubricants are therefore highly sought after, and represent a distinct opportunity[124]. There has already been an increase in the market value of biolubricants up to 2015 and the market value is expected to grow at 5.4% CAGR from 2016 to 2024, owing to increasing application in the transportation and manufacturing industries.

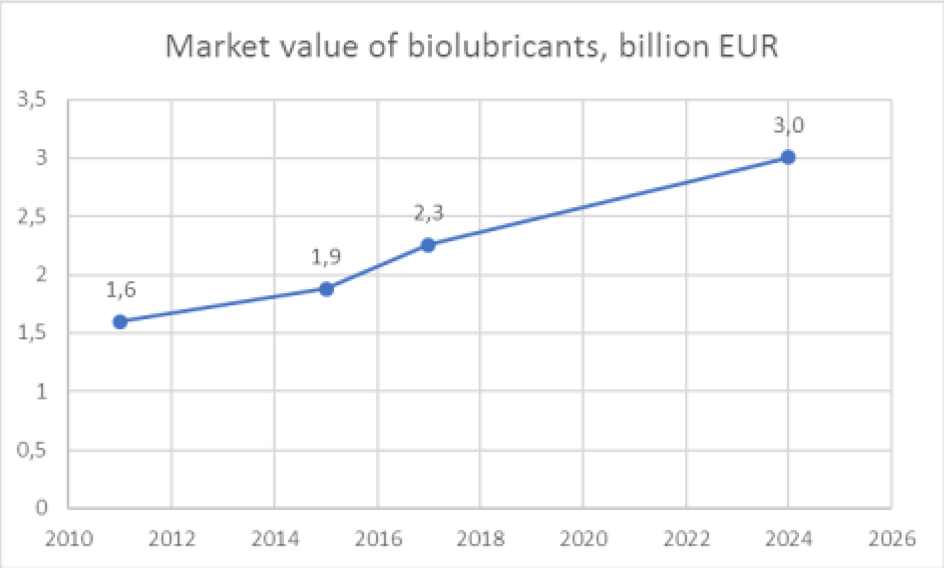

Figure 21: Market value of biolubricants, billion EUR (adapted from [125], [126], [127])

[123] Grand View Research, 2016
[124] Transparency Market Research, 2012
[125] Grand View Research, 2016
[126] Transparency Market Research, 2012

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Currently North America and Europe are the most important markets for biolubricants, with lack of awareness and high pricing posing major hurdles to widespread appeal and usage in other parts of the world. In the future, increasing environmental concerns and emphasis on shift from non-biodegradable lubricants to the environmentally safe and 'green' Biolubricants will drive high-powered growth. Nowadays, North America and Europe together account for 85-90% of global market. [128]

Of those, **North America is the largest market** and will continue to maintain a leading position in the market until 2018. It is estimated that North America will constitute a significant 38.1% of the global market share of biolubricants in 2018. In the North American region, Biolubricants will register a CAGR of 5.6% by revenue and a CAGR of 7.4% by volume from 2013 through 2018.

Europe holds the second position and Germany plays a major role in boosting the market for biolubricants together with the Nordic quartet (Sweden, Denmark, Norway and Finland). The European Biolubricants market volume in 2006 amounted to 0.12 Mt or about 2% of the total lubricant market to be compared to 0.10Mt in 2000 and 0.11Mt in 2002. [129] While volume growth is small, revenue growth is larger because of higher price. Annual lubricant production in the EU was estimated at 5.2 Mt in 2008 and the share of biolubricant production in the EU totalled 0.15 Mt in 2008 and is estimated to grow to at CAGR of 3.6% until the year 2020 (0.23Mt).

[127] BIOCHEM, 2010
[128] Aslanian, N., 2015
[129] Frost and Sullivan, 2007

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8. Existing relevant legislation/ policies

8.1. The European Strategy to Support Bioeconomy

The bioeconomy has been identified as a key element contributing to the European Commission's political strategy. In his 2014 Agenda for Jobs, Growth, Fairness and Democratic Change, President Juncker identified 10 key priorities for the Commission, with the bioeconomy being central in the following three of them: [130]

- **A New Boost for Jobs, Growth and Investment:** The innovative bioeconomy is an important source of new jobs – especially at local and regional level, and in rural and coastal areas – and there are big opportunities for the growth of new markets, for example in bio-fuels, food and bio-based products;
- **A Resilient Energy Union with a Forward-Looking Climate Change Policy:** Europe needs to diversify its sources of energy and can support breakthroughs in low-carbon technologies with coordinated research. Replacing fossil raw materials with biological resources is an indispensable component of a forward-looking climate change policy;
- **A Deeper and Fairer Internal Market with a Strengthened Industrial Base:** Innovative bio-based and food industries will contribute in raising the share of industry in GDP from 16% to 20%.and to creating a circular, resource-efficient economy. The food and drink industry is already the largest manufacturing sector in the EU.

Several EU policies – both implemented and under development – are already shaping the bioeconomy's investment capabilities and decisions. The most relevant are: [131],[132]

- **The 2012 Europe's Bioeconomy Strategy**, that aims at ensuring fossil materials are replaced with sustainable and renewable alternatives. The second pillar of the strategy focuses on the development of markets and competitiveness in bioeconomy sectors (such as the bio-based product sector) by sustainably increasing primary production, conversion of waste streams into value-added products (biorefineries), and mutual learning mechanisms for improved production and resource efficiency;
- **The 2030 Climate and Energy Framework** with new targets for emission reductions, renewable energy and energy efficiency and the related Emission Trading System (ETS);
- **The Circular Economy Package** adopted by the European Commission in December 2015, includes revised legislative proposals to stimulate Europe's transition towards a circular economy which should boost global competitiveness, foster sustainable economic growth and generate new jobs;

[130] https://ec.europa.eu/commission/publications/president-junckers-political-guidelines_en
[131] http://ec.europa.eu/growth/sectors/biotechnology/bio-based-products_el
[132] CEPI, 2017

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- **The EU's Industrial Policy**. The bio-based products sector, as key enabling technology, is one of the priority areas with high potential for future growth and societal challenges addressing;
- **The European Innovation Partnerships (EIP)** to accelerate the market take-up of innovations that address key challenges for Europe. Specifically, the EIP for Agricultural Productivity and Sustainability and the EIP on Raw Materials contribute to ensuring a steady supply of food, feed and biomaterials and to boost recycling and re-use of materials.
- **The European Fund for Strategic Investments (EFSI)**, which, beyond its focus on infrastructure, may offer new funding opportunities for transformative investment
- **The EU framework programme for research Horizon 2020**, including the Bio-based Industries Public Private Partnership (BBI-JU), a public-private partnership between the EU and the Bio-based Industries Consortium
- **The Commission Expert Group for Bio-based products**, which was set up in 2013 for an initial period of four years representing EU countries and state agencies, public procurers, non-governmental organizations, academia and businesses to advise the Commission on the development of the bio-based products sector
- **The European Industrial Bioenergy Initiative**. One of the industrial initiatives that aim to prioritize and facilitate 'first-of-a-kind' demonstration of innovative bioenergy value chains in Europe, strengthening EU technology leadership and boosting advanced biofuel contribution to 2020 EU targets.
- **The European Biofuels Technology Platform (EBTP).** The EBTP brings together advanced biofuels stakeholders across Europe to guide and prioritise R&D, help meet EU transport targets and to inform the general public with accurate information on various aspects of advanced biofuels. Has a wide range of stakeholders in research, industry, government, non-governmental organizations and related professions.

The Commission works on ensuring a coherent approach to the bioeconomy through different programmes and instruments including the Common Agricultural Policy, the Common Fisheries Policy, Horizon 2020, European environmental initiatives, the Blue Growth initiative for the marine sector and the European Innovation Partnership on Sustainable Agriculture.

In Horizon 2020, the EU Framework Programme for Research and Innovation Societal Challenge "Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research and the Bioeconomy" foresees a budget of more than €3,851 million. Horizon 2020, contributes €975 million to the public-private partnership "Bio-based Industries Joint Undertaking", which directly leverages a €2,730 billion contribution from the Bio-based Industries Consortium (BIC).

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8.2. EU LEGISLATION

Table 16: Bioeconomy and bio-based products relevant legislation

ACT	DESCRIPTION	RELEVANT PRODUCTS/ VALUE CHAINS
Regulation 1907/2006 on REACH	All chemicals produced in and imported into the EU need to be registered in REACH, an integrated system for the registration, evaluation, authorization and restriction of chemicals. Regarding bio-based products, naturally occurring substances and polymers are exempted from REACH if they follow certain criteria, but the obligation to REACH may still apply for some biosurfactants and bio-chemicals.	Biosurfactants, bio-chemicals
Reg. EC 648/2004 on detergents	Regulation EC No: 648/2004 requires clear and precise description of the biodegradability of the surfactant and test methods to give assurance of its aerobic biodegradability. Moreover, it contains requirements relating to ingredient labelling of detergents and the need for manufacturers to have full ingredient datasheets available for use by medical personnel. This regulation establishes rules designed to achieve the free movement of detergents and surfactants for detergents in the internal market while, at the same time, ensuring a high degree of protection of the environment and human health.	Biosurfactants
EU Ecolabel[133]	The EU Ecolabel covers a wide range of product groups, from major areas of manufacturing to tourist accommodation services. Key experts, in consultation with main stakeholders, develop the criteria for each product group in order to decrease the main environmental impacts over the entire life cycle of the product. Bio-based products can be granted an EU Ecolabel if the specific criteria of the product group are fulfilled. In particular, lubricants receiving the EU Ecolabel need to prove a minimum content of bio-based carbon between >45% and >70% (depending on the type of lubricant). Regarding biosurfactants, they are concerned for the following product categories: 1) All purpose cleaners 2) Dishwashing detergents 3) Hand dishwashing detergents 4) Industrial & institutional automatic dishwasher detergents 5) Industrial & institutional laundry detergents 6) Laundry detergents	Biolubricants Biosurfactants

[133] http://ec.europa.eu/environment/ecolabel/products-groups-and-criteria.html

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ACT	DESCRIPTION	RELEVANT PRODUCTS/ VALUE CHAINS
	7) Rinse-off cosmetic products 8) Soap & shampoos 9) Laundry detergent 10) Automatic dishwashing Machine detergent 11) Sanitary cleaners 12) Hard surface cleaners 13) Textiles.	
Nordic ecolabel[134]	The Nordic Swan Ecolabel is the official Ecolabel of the Nordic countries, a voluntary and positive practical tool for consumers to help them actively choose environmentally sound products with 63 product groups. The Nordic Swan Ecolabel is an ISO 14024 type 1 Ecolabelling system and is a third-party control organ. In the product group “sanitary products”, bio-based materials in the form of fluffy pulp and bio-based polymers are included. Also, there is a product category for disposables for food, where bio-based products also apply.	Bio-chemicals Bioplastics
Blue Angel label[135]	The Blue Angel label is an environmental label organized by the federal government of Germany for environmentally friendly products. Criteria are developed for each individual product group that must be fulfilled by those products and services awarded with the Blue Angel. In order to reflect technological advances, the Federal Environmental Agency reviews these criteria every three to four years.	Bioplastics Biolubricants
Directive 2009/28/EC The Renewable Energy Directive	The Renewable Energy Directive establishes an overall policy for the production and promotion of energy from renewable sources in the EU, establishing a mandatory 20% share of renewable energy sources in the EU final energy mix by 2020. The Directive lists biomass as a renewable energy source and aims inter alia to achieve greater mobilization of existing timber reserves. It mandates Member States to draft national renewable energy action plans and sets conversion efficiency thresholds above which Member States may promote bioenergy technologies. The Renewable Energy Directive does not specify any sustainability criteria for biomass, although it sets for biofuels and bioliquids. On November 30th, 2016, the Commission published a proposal for a revised	Bioenergy Biofuels

[134] http://www.nordic-ecolabel.org/criteria/product-groups/
[135] https://www.blauer-engel.de/en

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ACT	DESCRIPTION	RELEVANT PRODUCTS/ VALUE CHAINS
	Renewable Energy Directive to make the EU a global leader in renewable energy and ensure that the target of at least 27% renewables in the final energy consumption in the EU is met by 2030.	
Directive 2009/30/EC The Fuel Quality Directive	Directive 2009/30/EC amends petrol and diesel specifications and introduces a requirement on fuel suppliers to reduce the greenhouse gas intensity of energy supplied for road transport (Low Carbon Fuel Standard). Regarding Biofuels, the Directive establishes sustainability criteria that must be met if they are to count towards the greenhouse gas intensity reduction obligation.	Biofuels
Directive 2015/1513/EC The Indirect Land Use Directive	With this Directive, rules came into force to control the risk of indirect land use change from food and feed to crops for biofuels and enhance the transition to second generation biofuels. Towards this direction, a cap of 7% on the contribution of biofuels produced from 'food' crops, and a greater emphasis on the production of advanced biofuels from waste feedstock is defined.	Biofuels
Directive 2003/87/EC The European Emissions Trading Scheme	Directive 2003/87/EC established European Emissions Trading Scheme to promote reductions of GHG emissions in a cost-effective and economically efficient manner. At present, operators do not have to surrender EUAs against emissions from any type of bioenergy, i.e. biomass is considered as carbon neutral, based on the assumption that the carbon released when solid biomass is burned will be re-absorbed during tree growth. Although rules will change from 1 January 2013 for biofuels and bioliquids (see section 2.2.2, below), the current regime will be maintained for biomass.	Bioenergy Biofuels
Directive 2012/27/EC The Energy Efficiency Directive	The Energy Efficiency Directive requires Member States to develop national heating and cooling plans and set non-binding energy efficiency targets towards the 2020. Furthermore, through the implementation of Directive 2009/125/EC on eco-design and Directive 2010/30/EU on energy labelling, the Commission is currently working to address the energy-efficiency (and other environmental aspects) of different types of small-scale biomass boilers, stoves and fire places.	Bioenergy
Directive	The 2010 Energy Performance of Buildings Directive is the main legislation when it comes to reducing	Bioenergy

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ACT	DESCRIPTION	RELEVANT PRODUCTS/ VALUE CHAINS
2010/31/EC The Energy Performance of Buildings Directive	the energy consumption in buildings. On the 30 November 2016 the Commission proposed an update to the Energy Performance of Buildings Directive to help promote the use of smart technology in buildings and to streamline the existing rules.	
Directives 2005/89/EC, 2003/96/EC, 2009/72/EC The Electricity Production Legal Framework	Directive 2005/89/EC establishes measures aimed at safeguarding security of electricity supply so as to ensure proper functioning of the EU internal market for electricity, an adequate level of interconnections between Member States, an adequate level of generation capacity and balance between supply and demand. Directive 2003/96/EC restructured the Community taxation framework of energy products and electricity. Article 16 authorizes partial or total tax exemption for biofuels when used in their pure state or in mixtures. The goal is to encourage countries to exempt biofuels from taxes to make them more competitive. Finally, Directive 2009/72/EC aimed at introducing common rules for the generation, transmission, distribution and supply of electricity. It also lays down universal service obligations and consumer rights and clarifies competition requirements.	Bioenergy
Directives 2010/27/EC, 2009/29/EC, 2008/50/EC, 2008/101/EC The Greenhouse Gas Emissions Legal Framework	Directive 2010/27/EC lays down rules on integrated prevention and control of pollution arising from industrial activities. It sets out provisions to prevent or reduce emissions into air, water and land and to prevent the generation of waste. Directive 2009/29/EC amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. The amendments provide for the reduction of greenhouse gas emissions to be increased to contribute to the levels of reductions that are considered scientifically necessary to avoid dangerous climate change. Furthermore, these provisions aim at reaching the Union's goal of at least 20% greenhouse gas reductions by 2020. Directive 2008/50/EC on ambient air quality and cleaner air for Europe merges the existing legislation in this field, lays down new air quality objectives for fine particles and establishes the possibility for time extensions for complying with limit values. Directive 2008/101/EC amending Directive 2003/87/EC to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. The amendments provide for the inclusion of aviation within	Bioenergy Biofuels

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ACT	DESCRIPTION	RELEVANT PRODUCTS/ VALUE CHAINS
	the EU Emissions Trade System, nevertheless, the lack of a global consensus has limited the application of this normative to EU and non EU airlines flying within the Union territory. Finally, another relevant legislation act is the Council Decision of 25 April 2002 concerning the approval of the Kyoto Protocol.	
Directives 2008/98/EC, 2004/35/EC, 2000/76/EC The Waste Legal Framework	Directive 2008/98/EC establishes a legal framework for the treatment of waste within the Union. It aims at protecting the environment and human health through the prevention of the harmful effects of waste generation and waste management. Furthermore, it introduces the concept of waste hierarchy. Directive 2004/35/EC on environmental liability about the prevention and remedying of environmental damage establishes a framework based on the polluter pays principle to prevent and remedy environmental damage, as damage to protected species and natural habitats, damage to water and damage to soil. Directive 2000/76/EC on the incineration of waste aims to prevent or reduce as afar as possible negative effects on the environment caused by the incineration and co-incineration of waste through stringent operational conditions emission limit values for waste incineration and co-incineration plants.	All biomass feedstock originating from waste streams Biorefineries Bioenergy
Directive 2008/1/EC The Integrated Pollution Prevention and Control Directive	Directive 2008/1/EC concerns integrated pollution prevention and control. It applies to combustion plants exceeding 50 Megawatt and operators would be required to apply for permits under this Directive.	Bioenergy Biorefineries
EU Forest Strategy	In September 2013, the Commission adopted a new EU Forest Strategy with the view to address in a holistic way the overall increasing demands put on forests by many end-uses, including bioenergy. The 2020 objective of this strategy is to ensure and demonstrate by 2020 that all EU forests are managed according to the principle of sustainable forest management (SFM) and that the EU's contribution to promoting sustainable forest management and reducing deforestation at global level is strengthened.	Forestry biomass Lignocellulosic biomass Bioenergy

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ACT	DESCRIPTION	RELEVANT PRODUCTS/ VALUE CHAINS
	These objectives were further confirmed by Member States and the European Parliament in the Seventh EU Environmental Action Programme. With respect to the issue of forestry biomass sustainability, it should be recognized that the development of SFM criteria measurable is not yet sufficiently advanced for use throughout all life-cycle phases at EU-level.	
Regulation 95/2010/EC The EU Timber Regulation	The EU Timber Regulation came into force on 3 March 2013 This Regulation prohibits placing illegally harvested timber on the EU market. To achieve this, the Regulation sets out procedures which those trading timber within the EU must put in place to minimize the risk of illegal timber being sold.	Forestry biomass Lignocellulosic biomass Bioenergy
Regulations 258/97 and 2015/2283 on novel foods and novel food ingredients	This Regulation concerns the placing on the market within the Community of novel foods or novel food ingredients. Foods and food ingredients falling within the scope of this Regulation must not present a danger for the consumer, mislead the consumer, differ from foods or food ingredients which they are intended to replace.	Bio-based food and feed ingredients

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8.3. Standards

8.3.1. European standards

In the area of bio-based products, the European Committee for Standardization (CEN) develops both standards covering horizontal aspects of bio-based products, as well as standards for specific bio-based product groups such as biolubricants, bio-polymers, biosurfactants and bio-solvents.

Table 17: European standards about bio-based products

Horizontal	Product-specific
CEN/TR 16208:2011 Bio-based products- Overview of standards	CEN/TR 15932: 2010 Plastics - Recommendation for terminology and characterization of biopolymers and bioplastics
EN 16640:2017 Bio-based products - Bio-based carbon content - Determination of the bio-based carbon content using the radiocarbon method	CEN/TS 16137:2011 Plastics - Determination of bio-based carbon content
CEN/TR 16721:2014 Bio-based products - Overview of methods to determine the bio-based content	CEN/TR 16227:2011 Liquid petroleum products – Biolubricants – Recommendation for terminology and characterization of Biolubricants and bio-based lubricants
EN 16575:2014 Bio-based products – Vocabulary	CEN/TS 16295:2012 Plastics - Declaration of the bio-based carbon content
	CEN/TS 16766:2015 Bio-based solvents - Requirements and test methods
CEN/TR 16957:2016 Bio-based products - Guidelines for Life Cycle Inventory (LCI) for the End-of-life phase	EN 16807:2016 Liquid petroleum products - Biolubricants - Criteria and requirements of Biolubricants and bio-based lubricants
EN 16751:2016 Bio-based products - Sustainability criteria	EN 16900:2017 Fast pyrolysis bio-oils for industrial boilers - Requirements and test methods
EN 16760:2015 Bio-based products - Life Cycle Assessment	CEN/TS 17035:2017 Surface Active Agents - Bio-based surfactants - Requirements and test methods

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Horizontal	Product-specific
EN 16785-1:2015 Bio-based products - Bio-based content - Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis	Solid biofuels standards series[136]
EN 16848:2016 Bio-based products - Requirements for Business to Business communication of characteristics using a Data Sheet	

8.3.2. Biomass certification schemes

There are not mandatory certification requirements at EU level. However, some countries have taken initiatives to develop mandatory biomass certification system and regulations that cover the whole supply chain. These are Belgium and UK and to a lesser extent the Netherlands, Italy and Spain. These national and regional solid biomass sustainability certification schemes are:

- Flemish Green Power Certificates (FL-GSC)- Belgium;
- Walloon Green certificate granting system (Wall-CV)- Belgium;
- Brussels Green Certificate granting system (Bru-CV)- Belgium;
- UK's Renewables Obligation (Amend.) Order 2010 (RO)- UK;
- Scottish Biomass Heat Scheme (SBHS)- UK.

Several voluntary biomass certification systems concerning sustainability criteria also exist. These can be divided in Sustainable Forest Management Systems (SFMS) that provide guidelines and rigorous assessment for forest management and other certification systems created by electricity suppliers, pellets producers etc. The most important SFMS are:

- SFMS by Forest Stewardship Council (FSC);
- Programme for the Endorsement of Forest Certification (PEFC);
- Sustainable Forest Initiative (SFI)- USA;
- Sustainable Forest Management programme of Canadian Standards Association (CSA);
- Finnish Forestry Certification System (FFCS;)

136 https://standards.cen.eu/dyn/www/f?p=204:32:0::::FSP_ORG_ID,FSP_LANG_ID:19930,25&cs=19F087DBDE0BACDFD4078ABA84D4941DC

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Other voluntary biomass certification schemes are:

- Green Gold Label- by Dutch energy company Essent and Control Union Certifications (www.greengoldlabel.org) (Netherlands);
- The Electrabel Label- by Laborelec (Belgium);
- Drax Power Sustainability Policy (UK);
- Nordic Ecolabelled biofuel pellets (www.nordic-ecolabel.org);
- NTA 8080 certification system;
- Industrial Wood Pellets Buyers Initiatives;
- Sustainable Biomass Partnership (SBP)- www.sustainablebiomasspartnership.org;
- International System for Carbon Certification (ISCC and ISCC+)-http://www.iscc-system.org/en/;
- Roundtable on Sustainable Biomaterials (RSB)- http://rsb.org/;
- REDcert- https://www.redcert.org/index.php?lang=en;
- Better Biomass- http://www.betterbiomass.com/;
- Roundtable on Sustainable Palm Oil- http://www.rspo.org/about;
- Bonsucro- http://www.bonsucro.com

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9. Barriers and future trends

9.1. Barriers/ considerations towards the development of the bio-based market

9.1.1. Introduction

There are various hurdles hampering the implementation of the EU's Bioeconomy strategy. In the bio-based industry domain the main constraints towards its uptake, are mostly derived from: [137]

- the high production cost of bio-based products in comparison to the conventional products;
- the high feedstock prices and problems due to logistics and transportation;
- the technological and commercial immaturity of many related processes and products
- the lack of funding for investments in R&D and production;
- intellectual property issues;
- lack of products certification.

The most important barriers towards the development of the bio-based products market are their high pricing in terms of purchase and the technological barriers that still face many of the related processes. Bio-based products are three times more expensive than their fossil-fuel derived equivalents, both because of the high feedstock prices and the high capital and operating costs of related production processes, many of which are still at an R&D or demonstration level. The low prices of fossil fuels in the last years worsen the situation as they make the use of biomass feedstock economically unattractive.

Regarding the feedstock-related barriers for the development of the bio-based products sector, there is a need for continuous supply of biomass during the year. The biorefineries that are being used in the production of bio-based products should operate yearly while the availability of each type of biomass depends on the season. The fact that different types of biomass out of season should be available all the year in adequate quantities, both in local and regional level, leads to logistic and organizational difficulties. Hurdles arise, also, from the inefficient available biomass transport and distribution infrastructure and networks. The distance between the biomass location and the processing facilities affects the transportation costs and the quality of biomass and therefore influence the efficiency and competitiveness of the entire value-chain. This constraint could turn into an advantage because it promotes the local development in some rural areas (i.e. the south of Italy). It could represent a new form of economy: from delocalisation of industry where the labour cost is lower, to localisation (or

[137] S2BIOM D8.1, 2015

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reconversion) of plants where the feedstock is available. Moreover, the costs of biomass feedstock in Europe are high compared to other regions of the world, mainly because of: [138]

- the continuous use of agricultural residues rather than alternative solutions;
- the limited availability of nutrients and water in some areas;
- the seasonality of the different biomass types.

Additionally, there is no commonly accepted and agreed practice either for the evaluation of emissions derived from the direct and indirect land use for bio-based production purposes, or for the quantification of the impacts of biomass production on regional biodiversity. Therefore, there is a need to implement additional assessment and certification approaches such as the Environmental Risk Assessment (ERA) or the Eco-Management and audit Schemes (EMAS) (sustainable agricultural practices). The same applies to labelling and certification of bio-based products, as there is no standardized recognized label or quality standard for them, uniformly accepted on EU or global level. In fact, there is a high risk of bio-based products falsification, which makes necessary the existence of certified labelling, that guarantees quality control performed as well as clear information about the origin and identifiable value chain of bio-based products.

Regarding the characteristics of bio-based products, many of them display lower performance compared to their fossil-fuel derived equivalents. This fact hinders considerably their market acceptance, given also their higher price compared to conventional products.

Investment barriers and financial hurdles to the wider adoption of bio-based products are deriving also from the limited availability of public R&D funding, the limited public support for scale-up activities, which makes also difficult the demonstration activities for up-scaling of products and processes, as well as the limited financial support for new production facilities. There are gaps at policy and subsidy level. At EU level, bio-economy policy should take a more “business-case” approach than a “go-green” approach, with specific subsidy regimes and financial support tools and measures.

Regarding the relevant legislation framework, there is not much dedicated legal act except from sorts of policy papers to promote bioeconomy. There is the absence of level-playing field in promoting certain bio-based products, while there are landing mandates for bio-fuels and not for other bio-based products e.g. for biochemical. Specifically, for RED Directive’s targets, the system of how to manage to reach them for each member state is not ready yet (responsibilities, incentives, fines, sustainability criteria etc.). It is up to the Member states to set specific targets and monitoring systems with national legislative acts. Till today, the majority of Member states are just in the process of amending their legislation. This creates unstable conditions and market for potential investors in the EU. It also implies the existence of inconsistencies between strategies and implementation schedules between different EU

[138]BIOTIC, 2015

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regions. On the other hand, there are some contradictions in European legislation, regarding different interests and the need to increase the diffusion of the bioeconomy and environmental protection but protect the market, especially in economical crisis conditions. Subsequently, there are cases where legislation implies conflict among ambitious goals in terms of sustainability and market needs on the other hand

Moreover, the larger public is still relatively unaware of the potential benefits of bio-based products and applications, being therefore unwilling to pay for the price difference. This suggests a barrier to public acceptance and use of bio-based products that inevitably affects the development of the related industry. There is

Finally, the sustainable implementation of a bio-based strategy is hindered also by the lack of well trained workforce derived from academia/industry/primary production sector, the lack of cooperation among the different stakeholders in the various stages of a value chain, the inability to connect and shape up the activities carried out by the industry and the academic research institutions, the absence of harmonized “intellectual Property” (IP) regulations and the high patent costs.[139]

In Table 18, the main hurdles that obstruct the development of a sustainable bioeconomy and thus the bio-based industry and market, as they have been identified by the research carried out and the stakeholders interviews are presented:

Table 18: Barriers towards a sustainable bio-based products production and market exploitation

Barriers to sustainable production and market exploitation of bio-based products	
Feedstock- related barriers	• High costs of biomass feedstock produced in EU. • Inadequate availability of biomass feedstock at the required quality, quantity and price throughout the year • Seasonality in biomass feedstock production • Inefficient transport and distribution systems of several biomass feedstock types • Inefficient recovery systems for (bio)waste that could possibly be used as feedstock for bio-based products
Industry- related barriers	• Low technology readiness level and commercialization status for many bio-based products • Lack of cooperation between the stakeholders in the relevant value chains • Hurdles in establishing partnerships between academia and industry • Limited financial support for new production facilities • Lack of a trained workforce
Market- related barriers	• Low price of crude oil and natural gas that make the use of

[139] BIOTIC, 2015

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Barriers to sustainable production and market exploitation of bio-based products	
	biomass feedstock and bio-based production processes economically unattractive • High cost of bio-based products compared to their fossil-fuel derived equivalents • Lower performance of many bio-based products compared to their fossil-fuel derived equivalents • No dedicated and detailed EU legislation framework, conflicts between sustainability goals and market needs, lack of uniform standardization and certified labelling for bio-based products • Gaps in the policy and subsidy framework • Intellectual property related barriers • Low public awareness of the benefits of using bio-based products • Lack of reliable and sufficient information about bio-based products

Finally, general concerns are rising regarding the bioeconomy and its environmental impact. While bio-based products produce lower environmental loads in comparison to their fossil equivalents, for impact categories such as the climate change and the non-renewable energy consumption, on the contrary other indirect impacts such as eutrophication, acidification and land use, are considered to be blur not clearly identified.[140]

In the following paragraphs, identified barriers and hurdles specific to the bio-based product categories presented in this report, are discussed, based on literature review and stakeholders interviews conducted under Task 2.1.

9.1.2. Bio-based chemical building blocks

Europe has an established chemical industry with an important market for chemical building blocks and many potential end-users. However, many hurdles hamper the development of bio-based chemical building blocks and the relative weight of these hurdles may vary according to which specific block is under consideration.

The top hurdles identified from work under BIOTIC project[141] are raw material availability, quality and price, cost-competitiveness of final products, and uncompetitive production processes. Taxes, regulation and regulation volatility are also perceived as hurdles. Issues over incentives, funding and investments for scale up were less important in comparison.

[140] S2BIOM D8.2, 2015
[141] BIOTIC, 2015

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Table 19:Barriers in Chemical building blocks field[142]

Bio-based chemical building blocks barriers	
Current market and technologies are not able to support large- scale production of bio-based chemicals.	Stakeholders are not keen on changing their production processes.
Production costs are high (extraction, productivity, concentration, DSP).	Lack of incentives and subsidies.
Difficulties in balancing raw material availability, quality and price.	Lack of investments and capital
Low public awareness	Lack of skilled workforce
Lack of definition of waste (2G feedstock)	Lack of incentives and subsidies

9.1.3. Bionergy & Biofuels

Despite the significant benefits that derived from the production and consumption of bioenergy, there are some barriers that hinder their uptake around Europe.

First of all, in Eastern and Southern Europe, most of the countries are not familiar with bioenergy practices, which has negative impact in the total attribution of EU in bioenergy field. It is also observed, that in countries such as Germany and France where the bioenergy sector has a strong presentation, the social acceptance has diminished and there is the perception "not in my back yard".

Moreover, an important barrier is the relatively low level of awareness of the general public about bioenergy and its benefits and implications and the fairly common societal belief that waste management should only be conducted by public sector, rising suspicions and mistrust upon any other initiatives.

Particular concern is caused also, by the fact that Environmental non-governmental organizations in Europe and in US are supporting worrying messages about capping bioenergy and challenge the climate impact of bioenergy. Although Renewable Energy Directive is adequately addressing sustainability issues and covers issues of monocultures very well, there is a propaganda to fight bioenergy, based on the abovementioned concerns. Policies should focus on a good dissemination campaign and clear interpretation of the facts/numbers about bioenergy benefits, implications and sustainability.

In terms of global economy, an inhibitor factor to the expansion of bioenergy field, is the development of shale gas in the US and the economic turndown which led to a collapse of the barrel price, divided by four in less than two years, impacting that way the competitiveness of bioenergy.

In biofuels sector, as EBTP-SABS project indicates[143], the main hurdles in biofuels deployment arise at policy and financing level. It seems that the biofuels growth market is strictly

[142] BIOTIC, 2015

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dependent to the relevant policy evolution. The following barriers in biofuels field are presented in Table 20.

Table 20: Hurdles in biofuels field (adapted fromd[144])

Hurdles in biofuels field
- High production costs - Availability problems and high costs of the necessary feedstocks - Absence of a stable financial, policy and regulatory support - Food versus fuel utilization of biomass - Insufficient infrastructure for collection of agricultural residues - Lack of public acceptance

9.1.4. Bioplastics

The bioplastics market and technology is growing rapidly and there are several drivers for the use of bio-based polymers. However, there some concerns that may hinder their growth and market penetration. More specifically, these hurdles are related to:[145]

- the high production cost compared to fossil-based products;
- the lack of standardization and the absence of a framework for their marker uptake;
- the lack of financial investments;
- the need for technological improvements;
- the lack of necessary infrastructure.

9.1.5. Biolubricants

Towards the uptake of biolubricants, the barriers on industry, societal, company and product level are presented in Table 21:

Table 21: Hurdles in the uptake of the biolubricants sector (adapted from [146,147,148,149])

Barriers towards sustainable biolubricants production and market exploitation	
Industry Level	Biolubricants production remains highly dependent on the supply of vegetable & animal oils that are by-products of other industrial

[143] http://www.biofuelstp.eu/downloads/papers/report-on-barriers-to-biofuels-deployment-in-europe-draft.pdf
[144] BIOTIC, 2015
[145] BIOTIC, 2015
[146] Grand View Research, 2016
[147] Transparency Market Research, 2012
[148] Gupta et al., 2012
[149] Bart et al., 2012

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Barriers towards sustainable biolubricants production and market exploitation	
	processes.
	Complex processing technologies increase the initial cost of production.
	High production costs - biolubricant companies need to constantly look for ways and means to bring down the costs of their products if they are to compete with mineral oil lubricants and other synthetic lubricants.
	Biolubricants face stringent regulations worldwide. Adherence to these varying types and degrees of regulations in different geographical regions requires meticulous planning on the part of manufacturers and distributors alike.
Society Level	Lack of public awareness related to the benefits of bio-based lubricants.
Company Level	Measurement and communication of environmental benefits and product properties.
	Development of better raw material supply.
	Scaling up from pilot scale to industrial scale production.
	Availability, reliability and cost of new technologies.
	Need for securing profitability and competitiveness ability to participate in transfer of knowhow and technology through networking of product and equipment manufacturers, service providers and researchers.
Product Level	Need to achive a lower temperature-dependance on the physical properties, i.e. to make either a higher or lower temperature use accessible (now poor low-temperature properties).
	Need to improve inertness, i.e. to prolong performance time (now inadequate oxidative stability).
	Need to improve the range of available viscosities.
	Need to improve ecological properties.
	Need to remove possible bad odour.

9.1.6. Food and feed ingredients

Although the research related to the development of new bio-based ingredients for food applications has increased steadily, the European legislation framework is not evolving at the same pace as the substitution of new raw materials for wastes or residues to develop new food, ingredients and feed has important implications in food security and public health, that have to be considered and assessed. There are important legal restrictions both for possible feedstock to enter in the bio-based food and feed ingredients value chain, for the approval of a new food and feed ingredients to enter the market and for novel food or health claims for

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some additives. These restrictions may delay the market penetration of the further developments in bio-based food additives.

In the case of animal by-products used as possible feedstock for bio-based food and feed ingredients, existing EU legislation is extremely restrictive, notwithstanding the fact that this could be a potential market. For feedstock from plant origin, the situation is easier for by-products of food fit for human production but more complicated for lignocellulosic feedstock not intended for human consumption. For the rest, organic waste (manure and slurry, fermentable fraction of MSW etc.) there is no potential at the moment.

Another possible barrier related to bio-based food and feed ingredients is the low public acceptance, as consumers often have the false idea that biotechnology products are not natural, as they are made in a lab.

Finally, the relevant market is characterized by great heterogeneity. The different legislative requirements in different countries or economic spaces causes practical obstacles in imports/ exports of bio-based food and feed ingredients.

9.1.7. Biosurfactants

The major constraint to the growth of biosurfactants market sector is the high production costs, compared to those of the synthetic and plant derived surfactants. Key factors affecting production costs are:

- cost of substrates;
- mixture of products and therefore cost of purification;
- problems in upscaling;
- higher cost of downstream processing also due to the use of antifoam agents.

In this context the availability of feedstock remains a major concern for the market as biomass is extensively used for the production of biofuels and other downstream bio-based applications. The demand supply gap also results in high raw material prices, which results in higher prices for the final products. As for downstream processing, which usually requires multiple steps, costs strictly depend on the employed strain, the biosurfactant mixtures produced and the application of the product, since for some industrial applications a high purity grade is not necessary and thus purification costs are reduced. Strategies adopted to increase yields and productivities and therefore to make the process more cost-effective are based on:

- development of more efficient bioprocesses, including optimization of fermentative conditions and downstream recovery processes;
- use of cheap and waste substrates;
- development of overproducing strains.

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As highlighted in the BIOTIC project[150], additional critical aspects that can prevent or slow down the development of biosurfactants are associated with:

- the absence or poor financial incentives at national/European level to support R&D and demonstration projects/activities before upscaling;
- complex procedures to register new biosurfactants;
- lack of public awareness about bio-based surfactants and their applications.

Table 22: Main barriers for biosurfactants market uptake.

Main barriers for biosurfactants market uptake
- High production costs as compared to plant derived and synthetic surfactants. - Difficulties in recovering pure biosurfactants (for pharmaceutical, cosmetic and food applications). - Strong foam formation which limits production yields. - Time consuming, expensive and sometimes difficult EU legislative requirements (particularly for registration of new products).

9.2. Drivers/ future trends

The shape of the future bioeconomy will depend on breakthroughs in basic and applied research in the biological sciences; commercial opportunities, and innovations in regulations and business models. However, the shape of the bioeconomy in 2030 will also hinge on external factors that will influence the location, size and types of markets for bio-based products. These external factors include population and incomes, demographics and education, energy consumption, the availability and cost of key resources such as energy, food and water and both supporting and competing technologies. [151]

A recent JRC analysis[152] revised the projections described by OECD for 2030. According to this analysis, the bioeconomy is set to face considerable challenges in the years ahead that could dwindle the optimistic vision of the bioeconomy as motor boosting jobs and growth. To make sure that the bioeconomy reaches its potential in terms of productivity growth, secure and responsible biomass usage, climate action etc., there is a clear need for significant and targeted investments in related initiatives. In addition to that, a global international cooperation is needed to address the environmental challenges. The cooperation of different fields – agriculture, forestry, fisheries and aquaculture, food- must be achieved. Innovation would with more likelihood happen in the areas between those domains, since the domains themselves are already established and „old“. The potential market will emerge from cross value chains. Last but not least, for the potential of the bioeconomy to be realized, a

[150] BIOTIC, 2014
[151] OECD, 2009
[152] JRC, 2016

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substantial change of mentality, not only in the consumers, but also in the policy makers and the industry should be achieved.

Regarding bio-based products and their public acceptance in general, the overall industry trend is to focus on delivering products with similar or even better performance and technical characteristics than the conventional, fossil-fuel derived ones, so as to counterbalance their higher cost.

In terms of biomass feedstock, there is a huge potential in waste deriving from the agrifood value chain that could be valorised for bio-based production and in organic waste in general, as presented in Paragraphs 6.1.4 and 6.1.5. The development of these supply and value chains seems to be more efficient economically when organized at a local level. There is a positive interest from local agrifood industries in the EU to incorporate innovative processes and valorize their processing residues.

In the field of bio-based chemicals, the main market drivers are moving towards less petroleum dependency and feedstock diversification (multiple feedstock inputs) and aim to increase consumer environmental responsibility, enhance the idea of sustainability to manufacturers and offer innovative products. Succinic acid derivatives and products deriving from lignin and tannin platforms are considered as the most close-to-the market bio-based chemicals.

Regarding the bioplastics sector, multiple trends are identified. One of them is to increase the bio-based content in more bio-plastics materials. Another trend is to enhance compostable plastic materials applications in the packaging sector. Finally, one very promising trend is the development of completely new materials, that haven't been in the market yet, with new properties and functionalities compared to the conventional plastics. In this way, bioplastics won't just consist an alternative to conventional plastics but a new offer of improved and better qualities.

The basic future trend in the field of bioenergy, is towards the production of energy along with the production of other streams/ products of high value (bioplastics, bio-chemicals, pharmaceutical products from plants etc.), to keep the cost of bioenergy production low. This can be achieved through biorefineries. The currently existing biorefineries operate on a relatively small number of production process steps and derived products with the most commonly found products being a liquid biofuel and heat. In general, the bioenergy sector matures and becomes more efficient at biomass mobilization and conversion, able to deliver small to large- scale solutions. In future trends of the sector, the increase of short rotation coppice, the increase of imports of pellets to the EU, the future importance of saw mills as a provider of by-products both for the bioenergy and material sector are considered. Especially regarding energy cropping, it is expected to grow in countries with temperate climate, where there is sufficient amount of rainfalls and subsequent vegetation growth. Moreover, there is an interesting perspective in bioenergy communities in the future, as there is a trend of several decentralized small bioenergy production units using the available local biomass feedstock and cover their local energy needs. Finally, CHP and electricity production through gasification and

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pyrolysis as well as the production of second- generation bioethanol also exhibit considerable market potential for the next years.

In bio-based food and feed ingredients, it seems that there is a big potential for animal feed production, using agro-based waste as feedstock, or by-products from biorefineries. However, possible food and feed safety issues that arise in such recycling of biomass to be used as animal feed should be seriously considered and studied. Additionally, new trends in food at consumer's level and consumers expectations in food colour, taste, texture, healthy diets, nutritional contents, etc, will push producers to develop new ingredients to fulfil these new needs. Bio-based food and feed ingredients can enable tailored or individualized diets, suited to the customers' needs or taste, by enhancing natural resource efficiency at the same time. The whole sector is called neutraceutic food and also gathers significant potential for bio-based production.

The biolubricants industry is growing based on environmental concerns as some countries have already banned the use of non-biodegradable lubricants in sensitive areas, at least in applications where oils are lost into the soil and surface water. Other motivations are concerns about oil prices and high technical substitution potential. Several studies show that biolubricants also have a longer lifespan than mineral lubricants. Biolubricants are more expensive than conventional products, which is the major barrier to market uptake. However, the higher cost may be partly offset by the reduced need for replacement due to the longer lifespan of their bio-based counterparts. [153] Key growth drivers are expected to be biolubricants for applications such as transformer oils, new product development in line with OEM specifications and expansion of existing ISO product lines leading to increased varieties.

According to OECD[154], the full potential of the bioeconomy will require intelligent and flexible government policy and leadership to support research, markets, and create incentives for private firms to invest in biotechnology. "If suitable policies are implemented, the bioeconomy could meet many of the pressing challenges: The goal is a more innovative and low-emissions economy, reconciling demands for sustainable agriculture and fisheries, food security, and the sustainable use of renewable biological resources for industrial purposes, while ensuring biodiversity and environmental protection". The wide diffusion of the bioeconomy will be influenced by public research support, regulations, intellectual property rights, and social attitudes. An important role to the long-term process of changing mentality towards the realization of the bioeconomy could also play several intermediate players, such as clusters, and associations etc. The creation of policy to support the development of the bioeconomy is clearly a complex challenge. The policy framework needs to be coherent, holistic and supportive, evaluating risks and benefits in collaboration with all relevant policy sectors, academia, industry and civil society. Both the public sector and the private sector must be involved in designing this policy agenda, with as open and inclusive a dialogue as possible.

[153]Transparency Market Research, 2012
[154] OECD, 2009

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10. CASE STUDIES

Table 23: Bio-based products and value chains case studies

DESCRIPTION	RELEVANT VALUE CHAIN	RELEVANT PRODUCTS
Integrated pulp, paper and chemicals biorefinery Using wood feedstock, Borregaard, (http://www.borregaard.com, Norway) produces lignin products, specialty cellulose, vanillin (1st larger producer worldwide), bioethanol and microfibrillar cellulose, animal feed and fertilizers for a variety of applications in sectors such as agriculture, fisheries, construction, pharmaceuticals and cosmetics, foodstuffs, batteries and biofuels. Borregaard is one of the world's most advanced and sustainable biorefineries, originating from a paper pulp company 125 years ago, with nine production plants globally.	Biorefineries (lignocellulosic)	Lignin-based products Advanced specialty cellulose Vanillin derivatives Fine chemicals for pharmaceutical market Bioethanol
Biorefinery for food ingredients Roquette (http://www.roquette.com, France) is a biorefinery leader in specialty food and feed ingredients and pharmaceutical excipients using plant-based raw materials such as corn, wheat, potatoes and peas. Roquette operates in over 100 and currently employs more than 8,000 people worldwide.	Biorefineries (sugar/starch)	Food and feed additives Proteins and derivatives Fibres Polyols Cereal sugars Native and modified starches Cyclodextrins Organic acids and organic acid salts
An advanced pulp mill Domsjö Fabriker (http://www.domsjo.adityabirla.com, Sweden) is an example of a pulp mill that has taken steps towards a more complex biorefinery. Main products are specialty cellulose (used e.g. in textile), ethanol, lignin (2nd largest producer worldwide), carbonic acid and biogas.	Biorefinery (integrated pulp, energy)	Cellulose (main applications: viscose for fashion and textiles, medical tablets, food applications) Lignin Bioethanol

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DESCRIPTION	RELEVANT VALUE CHAIN	RELEVANT PRODUCTS
		Biogas Bioresin Soil conditioners Green liquor (cleansing chemical) Solid biofuels (knot residue, bark, sawdust)
Bio-Energy-Village in Germany Jühnde (http://www.bioenergiedorf.de/index.php?id=5&L=1, Germany) is Germany's first village, which uses renewable biomass - energetic plants in form of silage and wood chips- in order to produce heat and electricity and create a CO_2 neutral balance. By utilizing the three components of the bio-energy plant: (a) anaerobic digestion plant with a block-type thermal power station, (b) wood chip burning boiler (to meet high demand in winter), (c) village heating grid, they succeed to generate annually around 5.000.000 kWh of electricity, to fed the village heating grid with 4.500.000 kWh annually, and supply the households with 3.500.000 kWh annually.	Forestry biomass potential Waste valorisation	Bioenergy
Open market for digestate from anaerobic digestion in Uppsala, Sweden Uppsala Vatten (Uppsala Water) is in charge of several municipal services, such as water, sanitation and waste management. The company has eight recycling centres that receive all types of waste, from general household to Waste Electric and Electronics Equipment, bulky waste, hazardous waste and more. When it comes to treatment, the company owns a sanitary landfill for waste disposal and a modern biogas plant for the treatment of biowaste. The biowaste that is treated is collected directly from households through a separate collection. Although located in Uppsala, Uppsala Vatten also receives waste from neighbouring municipalities, as well as slaughterhouses and other producers of biowaste. Uppsala Vatten also has a biomethane station installed downtown that has biomethane available to be used for	Waste valorization	Bioenergy Biofuels

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DESCRIPTION	RELEVANT VALUE CHAIN	RELEVANT PRODUCTS
transport fuel.		
Bio-based products from flax and hemp-VeLiCa http://www.velica.org **(Italy)** VeLiCa is a pilot project financed by Regione Lombardia (Italy) with the aim to make again gainful the growing of flax and hemp in Regione Lombardia (Northern Italy) where it used to be widespread at the beginning of the 20th century. This target will be pursued by the exploitation of all the parts of the plant to make different products with different added value. The oil produced from flax and hemp seeds will be used for the production of bio-diesel, biolubricants with high flash point and polyols to be used for the production of biopolymers. Valuable oils isolated by selective enzymes will be obtained for the nutraceutical market. The fibers of the plants will be used to produce bio-PET or other bioplastics. Finally, the residues of all the abovementioned processes will be used as animal feed, cosmetic ingredients and maybe antioxidants.	Improved agro-based production	Biolubricants Bio-diesel Bio-chemicals Bioplastics
Succinic acid, bio-1,4 butanediol on corn substrate Bioamber **http://www.bio-amber.com** **(Canada)** is a joint venture established between DNP Green Technology and ARD (Agro-Industrie Recherches et Développements) manufacturing bio-based succinic acid and bio-based 1,4-butanediol at an industrial scale plant using technology that is cost competitive with the petrochemical processes. The production technology is based on *E. coli* bacterium on corn substrate. The process consumes CO_2 gas, which gives an additional advantage over petrochemical processes. Bioamber also has made an acquisition of a plastic producer to move down the value chain. The company plans to build market demand by negotiating the sale of technology platform licences for large- scale succinic acid plants. A second product platform that uses biotechnology to produce the building blocks for nylon is being developed, by leveraging its yeast and has exclusively in-licensed a patent protected metabolic pathway that enables the conversion of sugar into adipic acid, hexamethylene diamine (HMD) and caprolactam.		Bio-succinic acid Bio-1, 4 butanediol

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DESCRIPTION	RELEVANT VALUE CHAIN	RELEVANT PRODUCTS
These are the monomers used to produce both nylon 6,6 and nylon 6.		
Bioplastics from lignocellulosic materials The TECNARO GmbH www.tecnaro.de (Germany) is an innovative company that develops and produces its own bioplastics and biocomposites based on lignocellulosic raw materials. TECNARO is among the leading technology companies with its thermoplastic biomaterials ARBOFORM®, ARBOBLEND® and ARBOFILL®. Lignocellulosic feedstock is used for the products manufacturing. The products has a number of technological advantages over synthetic plastics compounds as a strong engineering material and applications in many sectors.	Forestry biomass potential Plant biomass potential	Thermoplastic bioplastics applications for: Agriculture, construction and landscape, technical parts, furniture, musical instruments, toys, sports and leasure, household items, clothing industry and packaging
Biosurfactants The French company Wheatoleo (http://www.wheatoleo.com, France) is owned 100% by ARD, a leading company in biorefinery research and development activities. At ARD (located in Bazancourt-Pomacle, in the Champagne Ardennes region of France), research and development in the production of biosurfactants from co-products of the farming industry first began in 1997. Cutting-edge technologies in the fields of plant cracking, industrial biotechnology and green chemistry have been employed with the aim of utilizing plant biomass to produce high- value products. These research projects involved several European partners and were co-financed by the EU (FAIR-CT 97-3130). ARD is now considered as a leader in the field of pentose chemistry which ultimately led to the formation of Wheatoleo, a new biosurfactant company. Since its creation in 2009, Wheatoleo have produced and commercialised a range of new bio (based) surfactants. The first marketed products are known as alkyl poly pentosides (APPs) (also known under their trade name: APPYCLEAN). These compounds are made from pentoses (bio-based chemicals extracted from plant cell walls) and fatty alcohols. These 'green' surfactants have applications in cosmetics and	Plant biomass potential	Biosurfactants

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DESCRIPTION	RELEVANT VALUE CHAIN	RELEVANT PRODUCTS
detergents, cleaning, oil fields and agrochemicals sectors.		
Biofuel from palm oil and waste fats and oils Neste Oil (https://www.neste.com/na/en/about-neste/who-we-are/research/nexbtl-technology-0) has developed a process of hydrogenation to produce Hydrogenated Vegetable Oils (HVO) with the product name NExBTL. NExBTL can be used as drop-in fuel for road transportation and as aviation fuel. Kinds of feedstock used are palm oil and waste fats and oils, consisting mainly of palm fatty acid distillate, animal fats, used cooking oils and in smaller volumes tall oil, pitch, technical corn oil and spent bleaching oil. In 2015, 68% of the feedstock consisted of waste fats and oils and the company's goals is to use only waste oils and fats as from 2017.	Waste valorization	Advanced biofuels
Second generation bioethanol The world's largest advanced biofuels refinery with a production capacity of 40.000 tons of cellulosic ethanol annually, reducing emissions by up to 80-90%, was officially opened on 9th October 2013 at Crescentino (Italy). The plant engineering, procurement and construction was conducted by BIOCHEMTEX (http://www,biochemtex.com), powered by PROESA technology, of which Beta Renewables is the exclusive licensor (http://www.betarenewables.com/en). Kinds of feedstock used are local wheat straw, rice straw and Arundo donax to ethanol. Lignin extracted during production is used for power generation and covers the facility's energy needs and provides electricity to the local grid as well.	Plant biomass potential	Cellulosic bioethanol (2nd generation ethanol) Bioenergy (power)
A gasification plant for biofuels and bioenergy GoBiGas (Gothenburg Biomass Gasification Project- http://gobigas.goteborgenergi.se/English_version/About_us) is a major Swedish project set out to build a plant to produce biogas via the gasification of waste from forestry (branches, stumps, woodchips etc.). Through gasification, syngas is firstly produced which is further processed to biogas. Produced biomethane is distributed	Forestry biomass potential	Biomethane Bioenergy (heat, power)

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via existing gas grid and the heat surplus is recycled in the form of district heating or as electricity.		
Second generation bioethanol from various waste streams In the facilities of St1 in Finland **(**http://www.st1.eu/st1-in-brief), bioethanol is produced from a variety of food industry waste streams: Biowaste from households, leftover dough from bakeries, expired bread and other organic waste from shops, waste from beer and other beverage production, waste and process residues from confectionery production, starch- and sugar-containing waste from the food industry	Waste valorization	Bioethanol
Biomass Logistics and Trade Centers[155] The EU funded 'Biomass Trade Centres' project has produced guidelines on setting up regional Biomass Logistic and Trade Centres. Biomass Logistic and Trade Centre (BLTC) is a regional supply centre providing wood fuels, run by farmers and/or forest entrepreneurs. The central aim of the centres is to secure a high-quality, local source of wood fuel all year round to the heating systems of both private households and businesses and to construct a collective rural marketing channel for biomass fuels and energy services. The product range includes fuel wood, forest wood chips, other biomass fuels, and energy services. Services provided include fuel delivery, involvement in wood energy contracting projects, and expert advice on all issues relating to the proper use of wood fuels. There are a number of BLTCs based in different regions around Austria, Italy, Slovenia, and Germany, with Croatia, Greece, Ireland, Romania and Spain being further countries of focus.	Forestry biomass potential	Bioenergy
Hemicellulose-based barrier material-www.xylophane.com[156] A spin-out from Chalmers University (Sweden) has developed the Skalax product with	Plant biomass potential	Lignocellulosic biopolymers

[155] Kretschmer et al., 2013
[156] Kretschmer et al., 2013

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Xylophane technology. Skalax is biodegradable barrier material derived from xylan, a hemicellulose material found in a wide range of agricultural by-products such as the husks and hulls of cereals, and an additive approved for food contact applications. It forms an effective barrier to oxygen, grease, aroma, mineral oils and harmful leachable products and can be applied using conventional coating technologies. Skalax can substitute for aluminium and metallised foils and oil-based plastic barriers in a wide range of applications including, but not limited to, the packaging of dry soups and sauces, oxygen-sensitive dairy products, greasy snacks and pet foods, as well as aromatic products such as spices and coffee. The scale-up, use and production of Skalax was funded through RenewPACK project (EU LIFE+) from 2012-2016. During the fall of 2016, Seelution AB acquired the Xylophane technology.		
Coating starches and bio-based lubricants- Renewable adhesives binders for the paper industry Coatings usually applied in the paper and board industry are suspensions composed of pigments and latex as synthetic binder used to fix the pigments to the paper. Cargill (http:// www.cargill.com) develops non-toxic, 100% biodegradable coating starches (adhesives and binders) from feedstock such as corn and soy-based products for various applications such as paper bags, corrugated board, wallpaper, lamination, pharmaceutical preparations, furniture and plywood. Using various vegetable monounsaturated oils such as lauric acid oils (coconut or palm kernel) the company also produces biolubricants used in various applications such as chainsaw lubricants, high temperature processing fluids, rolling oils and process oils, machine lubricants etc. These products conform to EU Ecolabel requirements	Agro-based production	Biolubricants Bio-adhesives
Bio-based products for food ingredients, flavours and nutrition A number of butyl esters that are currently being formulated as food ingredients in	Agro-based production	Food and feed ingredients

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many food recipes are partially bio-based as they employ carboxylic acids that are or can be derived from natural oils. Greenbiologics (http://www.greenbiologics.com) is the leading global player in renewable n-butanol, produced through fermentation of sugars from renewable feedstock and uses n-butanol to provide renewable butyl-esters to be used as higher value flavor and fragrance additives for the food industry. Examples: **a) butyl acetate:** an ester of butanol and acetic acid, which could be available as 100% renewable by utilizing renewable n-butanol and existing technology of vinegar production for acetic acid. It is a naturally occurring substance commonly used in banana, butter, pineapple, raspberry and strawberry flavoured or scented products, **b) butyl cinnamate:** this compound is the ester of butanol and cinnamic acid, which can be isolated from ground cinnamon. It can be used in formulations of chocolate, cocoa or fruity flavours used in bakery, beverages, candies, ice creams etc. c) **butyl laurate:** Lauric acid is abundant in coconut and palm kernel oils. Butyl laurate can be produced by the esterification of these oils with n-butanol. It is known for adding exotic flavours such as cape gooseberry, malt whiskey, papaya and spineless monkey orange to food and beverages.		
Bio-based PET bottle Since its introduction in 2009 by Coca-Cola, PlantBottle packaging (up to 30% plant based) has been distributed in a variety of packaging sizes across water, sparkling, juice and tea beverage brands—from Coca-Cola to DASANI to Gold Peak. Today, PlantBottle packaging accounts for 30 percent of the Company's packaging volume in North America and 7 percent globally, some 6 billion bottles annually, making The Coca-Cola Company a large bioplastics end user. There is a goal to convert all new PET plastic bottles by 2020. In 2015, the company introduced the first 100% bio-based PET bottle (PlantBottle) made entirely from plant materials. PlantBottle packaging uses patented technology that converts natural sugars found in plants into the ingredients for making PET plastic bottles. The packaging looks, functions and recycles like	Agro-based production	Bioplastics

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traditional PET but has a lighter footprint on the planet and its scarce resources. Today, the company uses sugarcane and waste from the sugarcane manufacturing process to create the PlantBottle packaging.		
Bioplastics for the automotive sector Many car makers like BMW, Renault, Toyota, Fiat, and Mercedes Benz already incorporate recycled and bio-based plastic materials in the pursuit to make their cars more sustainable. Bio-based plastics help to make cars lighter to save fuel and they provide additional means to reduce carbon emissions and the impact on the environment. Examples: a) PME Ecotechnilin is a company that specializes in the production of non-woven felt materials by mixing polypropylene fibres with natural fibres. The automotive industry moulds them into car parts like wheel housings, trunk floors, arm rests, door panels, dashboards etc. Brands that use these compounds include PSA, Opel, Jaguar, Kia, Toyota, Mercedes, BMW, Volkswagen, b) Mitsubishi Chemical Corporation recently offered its resin Durabio for use in the automotive industry. This compound is equal to polycarbonate and is partly produced from bio-based isosorbide. The next step would be the use by the automotive industry of its Polysorb-D (an isosorbide di-ester) as a substitute for its phthalate based plasticisers. c) Car manufacturer Ford recently announced to team up with spirits brand Jose Cuervo to develop bioplastics form agave biowaste leftover from the tequila-making process. The growth cycle of the agave plant takes a minimum of seven years. Once harvested, the heart of the plant is roasted and pressed to extract the juices for distillation. The remaining fibres are usually turned into compost. Ford and Jose Cuervo are now using the fibres to create bioplastics for use in vehicle interior and exterior components such as wiring harnesses, HVAC units, and storage bins.	Waste valorization	Bioplastics
OSIRYS project- Forest-based composites for interior partitions	Forestry biomass potential	Bioplastics

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OSIRYS FP7 project (http://osirysproject.eu/about/) developed a bio-based fire-resistant panel from with bio-based polymers. This panel has a bio-based content of around 75% and can be used in interior partition walls, curtain wall systems, multi-layer facades etc. Compared to traditional building materials that emit contaminants such as VOCs, formaldehyde, particulates and fibres, this new panel contributes to a healthier indoor environment and air quality. The materials developed by OSIRYS project have been used in two case studies: The Mart Reinik School Stadium Building in Tartu, Estonia and a housing block in Donostia- San Sebastian, Spain.		Construction materials
From vegetable oils to biochemicals, building blocks for bioplastics, bases for lubricants, bioherbicides, bioadditives for rubbers and plasticizers for polymers In 2011, a part of a pre-existing petrochemical site in Sardinia was converted into a biorefinery by Matrica (http://www.matrica.it- Italy), a company set up by NOVAMONT (the world's leading company in bioplastics) and Versalis. The plant is located in an area with a wealth of marginal lands suitable for the sustainable production of biomass from low-input multiannual crops that are well suited to the biorefinery's feedstock needs. Thereby, a virtuous model of cooperation with the local community which systemises and leverages all the elements of the value chain in synergy with farmers, the research system and local industries and institutions has been established. The environmental restoration, the re-employment of local skilled personnel, the valorisation of the local agricultural supply chain, the reusing of locally grown biomass led to the valorization of the territory. Matrìca's plants use a world's first proprietary technology developed by NOVAMONT research, which differs radically from existing technologies: it does not use ozone in the oxidative cleavage reaction of vegetable oil and enables high production capacities through a safe and low-impact process. Three plants are currently in operation: the first is the plant for the conversion of vegetable oils into monomers, providing intermediates for bioplastics (azelaic acid) and bioherbicides (pelargonic acid), as well as a range of new	Agro-based production Biorefineries	Biochemicals Bio-based building blocks Bioplastics Bases for lubricants Bio-additives for rubbers and plasticizers for polymers

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proprietary products. The second plant, downstream of the first one, produces extender oils developed for the tyre market, and plasticizers for specialty elastomers (like NBR and CR) and PVC, while the third plant can convert monomers and intermediates into high value- added products, such as bases for biolubricants and products for pharmaceutical, homecare and cosmetic formulations.		
Wood-based renewable biodiesel from paper mill byproducts The UPM Lappeenranta biorefinery (http://www.upm.com/Businesses/upm-biofuels/Pages/default.aspx) is the first biorefinery worldwide that produces UPM BioVerno diesel from crude tall oil, a residue of UPM's own pulp production. The commercial production of UPM BioVerno renewable diesel started in January 2015 in Lappeenranta, Finland. The annual capacity is 120 million litres of biofuels. The biorefinery is based on UPM's own innovations and it employs 75 people directly and 150 people indirectly.	Biorefinery (integrated pulp, energy) Forestry biomass potential	Biofuels
Interior design elements out of pine needles Pine needles, considered as a useless by-product of forestry, are utilized by OkkaStyle (http://okka.eu/en- Estonia) to produce acoustic wall or ceiling panels and interior panels	Forestry biomass potential	Construction materials
A fast pyrolysis plant in existing CHP unit producing bio-oil In Eastern Finland in the city of Joensuu (http://www.biopad.eu/wp-content/uploads/Case-study-of-Fortum-in-Joensuu.pdf), Fortum is a CHP plant responsible for maintaining the district heating network of 180 kilometers that transport energy over 40,000 inhabitants. This CHP unit is mainly using wood and peat as a raw material and the production capacity is 50MW for electrical power, 110 MW district heating power and 30 MW in a separate heating plant unit. The big plant is also able to use other raw material such as reed canary grass or other energy crops. In November 2013, a fast-pyrolysis unit was integrated to the existing CHP-unit and is	Forestry biomass potential Agro-based production	Bioenergy Bio-oil

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estimated to produce 50,000 tons per year bio-oil (pyrolysis oil). After the installation, the need of wood increase from 300,000 cubic meters to 600,000 cubic meters annually. The new fast pyrolysis technology based bio-oil plant is the first of its kind in the world on an industrial scale.		
Microbic biomass and proteins from agroindustrial waste In line with biorefinery concept, agroindustrial waste such as cheese whey wastewater from the diary industry is converted to high- value products such as microbic biomass (yeast) that is used in food industry and proteins by BioInnoTech (http://www.bioinnotech.it/language/en/1147-2/- Italy). Proteins can be used as dietary supplements for athletes and as nutraceutical elements. They can be also used as additives for food, for instance food for animals.	Waste valorization	Food and feed additives
Italian Flagships Italy shows important projects of reconversion of industrial sites affected by the crisis, into biorefineries for the production of bioproducts and biochemicals from renewable sources, with positive impacts on employment, the environment, product profitability and integration with oil-based products to enable greater specialisation and competitiveness. Investments of over a billion euro have already been made for the reindustrialisation of decommissioned or no longer competitive sites of national importance and for the construction and launch of four flagship plants, the first of their kind in the world. Some of these projects, coordinated by Italian leading players in bio-based industries sector have been recognized as flagship initiatives in Europe by the BBI Joint Undertaking. • Succinic Acid (Cannano Spinola – AL) • 1.4 BDO from RRM (Adria – RO)	Bio-refineries	Bio-based chemicals Advanced biofuels

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• Aviation Fuel (Modugno – BA) • basis for Bioplubricants and Bioadditives for Rubber (Porto Torres – SS) • Azelaic Acid and Pelargonic Acid (Porto Torres – SS)		

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Table 24: Selected bio-based chemicals and bioplastics case studies (adapted from [157]

Bio-based chemical	Actors	Key market and value proposition	Cost relative to fossil alternative	GHG saved vs. fossil alternative
Acrylic acid	BASF-Cargill-Novozymes (EU) OPXBio-Dow (USA). Focus for both partnerships is on 3-HPA route	Drop-in replacement for a widely used chemical intermediate	20 - 48% better than the fossil-based when commercial	>70%
Adipic acid (ADA)	Biochemtex and DSM (EU) Some US projects have reached pilot scale (Rennovia, Verdezyne).	Drop-in replacement meeting demand for nylon 6,6 and polyurethanes	Expected to be cost competitive (lower capex and utilities)	70-95%, depending on N2O intensity of fossil process
1,4 – Butanediol (BDO)	Genomatica (USA) main actor. BASF, Novamont, DSM, Biochemtex making BDO and PBT based on Genomatica technology. JM-Davy BDO is via Myriant's succinic acid	Drop-in replacement for fossil BDO. BDO is used to make GBL, THF and PBT	15-30% lower than fossil and competitive at an oil price of 45 $/barrel	70-117% depending on the process and electricity co-product substitution
Farnesene	Only one market player, US-based Amyris. There are no major European players.	Moisturiser emollients, durable easy-cast tyres, and jet fuel properties consistent with C15 iso-paraffin	Already attractive in emollients; close to market in tyres; high compared to jet	Up to 80% compared with fossil jet
2,5 furan-dicarboxylic acid	Development led by Avantium in the EU. Corbion Purac, AVA	Substitute for TPA to make new class of polyethylene furanoate	High since at small-scale, yet to be commercialised	45-68%

[157] E4tech, RE-CORD and WUR (2015)

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Bio-based chemical	Actors	Key market and value proposition	Cost relative to fossil alternative	GHG saved vs. fossil alternative
(FDCA)	Biochem and Novozymes also active in this space in Europe	(PEF) polymers. Application in drinks bottles as superior gas barrier vs PET		
Isobutene	Small number of players, only Global Bioenergies and Lanxess in EU. *Gevo and Butamax are the main developers of isobutanol*	Rubber for automotive, and as a precursor for fuel & lubricant additives and biofuels. Might be used as food antioxidant	Could be profitable under high oil price market conditions	20-80%
Poly-hydroxy-alkanoates (PHAs)	Modest EU activity compared with China and the Americas. Biomer and Bio-on are the key EU players. Metabolix the largest US player	Fully biodegradable, niche use in sutures. Tuneable properties means could be used in most aspects of plastics industry	High costs. May fall via integration with sugar mills	20% with starch feedstock, 80% with sugarcane and 90% with LC feedstock
Poly-ethylene (PE)	Braskem in Brazil is the only commercial scale producer	Drop-in replacement for fossil PE, the most commonly produced plastic globally – main application in packaging	Sold at 30-60% above to fossil PE. Higher volumes may see price differential fall	>50% using sugarcane. Higher savings with LC feedstock
Polylactic acid (PLA)	A few large industry participants; NatureWorks (USA) and Corbion Purac (NL) dominate PLA and LA production respectively. ~9 other EU producers of PLA and LA.	Bio routes preferred to fossil. PLA suitable for packaging, insulation, automotive and fibres. Durable, degradable, easily composted, low toxicity	Costs unconfirmed, but improved at scale. Slightly higher market price than fossil PS, PP and PET.	30-70% vs fossil PP, PS and PET. Could rise to 80% with improved conversion
Succinic acid	2 main actors in Europe (Reverdia, Succinity) and a further	Drop-in replacement for fossil, and near-drop-in for adipic acid in resins, plasticisers, and	Equal to fossil costs since 2013. Fossil succinic acid	75-100+%, depending on feedstock production and

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Bio-based chemical	Actors	Key market and value proposition	Cost relative to fossil alternative	GHG saved vs. fossil alternative
	2 globally (BioAmber, Myriant)	polyester polyols	now only niche	grid intensity

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Appendix A: List of Interviewees

Organization	Country	Description	Webpage
Partner responsible: AINIA			
INIA- Instituto Nacional de Investigaciones Agrarias	Spain	INIA is the National Institute for Agricultural and Food Research and Technology, assigned to the State Secretariat of Research, Development and Innovation of the Ministry of Economy and Competitiveness. As a Public Research Organization it has a dual function, being responsible for the management and coordination of agrifood research at the national level and for the execution of research projects, in close collaboration with the relevant socioeconomic sectors.	http://www.inia.es/
OCU- Consumers and Users Organization	Spain	The Organization of Consumers and Users (OCU) is the most important consumer organization of Spain with more than 300,000 members	http://www.ocu.org
IATA- Instituto de Agroquímica y Tecnología de Alimentos	Spain	The Institute of Agrochemistry and Food Technology (IATA) is a centre of the CSIC with more than 50 years of experience and tradition in the Valencian Community and facilities measuring more than 14,000 m². The mission of IATA is to contribute to scientific advancement and technological development in science and food technology, promoting quality basic and applied multidisciplinary research that is of service and gives technological support to the agro-food sector	https://www.iata.csic.es/
AINIA	Spain	AINIA is a technology centre with more than 25 years of experience in research, development and innovation. With more than 700 associated companies and 1,300 clients, we work to motivate the competitiveness of companies through innovation.	www.ainia.es
CSIC – CEBAS- Centro Superior de Investigaciones Científicas - Centro de Edafología y Biología	Spain	The Spanish National Research Council (CSIC) is the largest public institution dedicated to research in Spain and the third largest in Europe. Belonging to the Spanish Ministry of Economy and Competitiveness through the Secretary of State for Research, Development and Innovation, its main objective is to develop and promote research that will help bring about scientific and technological progress,	http://www.csic.es/home http://www.cebas.csic.es/

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Organization	Country	Description	Webpage
aplicada del Segura		and it is prepared to collaborate with Spanish and foreign entities in order to achieve this aim. The aim of CEBAS-CSIC is to generate through investigation necessary knowledge which make possible the development of strategies to achieve the sustainability of the scant resources which exist / existing in semiarid areas, through their correct management and making possible the development of a quality agriculture and obtaining healthy and safe vegetable food.	
IVIA- Instituto Valenciano de Investigaciones Agrarias	Spain	The Valencian Institute for Agronomic Research (IVIA) is an autonomous entity of the Valencian Regional Government. It promotes scientific research and technological development in the Valencian agri-food sector. Through its research and transfer activity, it is an effective partner for progress and the prestige of the agri-food sector. The IVIA mission is to contribute to productive and sustainable agricultural activity promoting the competitiveness of the agricultural, livestock and agro-food sectors by generating knowledge that respond to the technical, economic, and social demands through applied research and excellent and optimal transfer of results	http://www.ivia.gva.es/
Partner responsible: CIVITTA			
Fortum Eesti Ltd	Estonia	Fortum is a leading clean-energy company that provides its customers with electricity, heating and cooling as well as smart solutions to improve resource efficiency. Fortum employs ca 8,000 professionals in the Nordic and Baltic countries, Russia, Poland and India, and 62% of their produced electricity generation is CO_2 free. In Estonia Fortum is dealing with: - combined heat and electricity production and distribution in Pärnu and Tartu counties - offering energy solutions for local heating and large production companies in Pärnu and Tartu counties	www.fortum.com
Addinol Lube Oil OÜ	Estonia	Vender of lubricants. Subsidiary of ADDINOL Lube Oil GmbH	http://www.addinol.ee/
Estonian Research	Estonia	The Estonian Research Council is a governmental foundation that was	http://www.etag.ee/en/

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Organization	Country	Description	Webpage
Council		established to concentrate the funding of R&D and guarantee the better functioning of financing systems. One of the topics is bio-economy.	
Nordic Council of Ministers' Office in Estonia	Estonia	The Nordic Council of Ministers' Office in Estonia brings together Nordic and Estonian (or Baltic) politicians, civil servants, experts, representatives from the private sector and opinion leaders in areas of common interest: • Green growth, sustainable development and environment. • Challenges of the welfare model (fight against trafficking in human beings, gender equality, etc.). • Culture and creative industries. • Education, science and innovation. Regional cooperation (population development, (labour) migration, etc.). Under Green Growth, sustainable development and environment the Council is dealing also with promoting bio-economy. In 2011 they launched the Rohevik green growth forum, which focusses to the future – one that will be built on a sustainable and environmentally friendly way of life. The Council is also responsible for introducing the Nordic eco-label to Estonia.	http://www.norden.ee/en/
Ministry of Rural Affairs	Estonia	The Ministry of Rural Affairs has been the initiator of Bioeconomy Strategy in Estonia.	https://www.agri.ee/en
Partner responsible: FVA			
Agenzia per la coesione territorial (Agency for territorial cohesion)	Italy	Sector "Support and accompaniment of the implementation of Community programs and national projects" - They are one of the institutions in charge of the Italian Bioeconomy.	http://www.agenziacoesione.gov.it/it/
APRE - Italian NCP	Italy	APRE, the Agency for the Promotion of European Research, is a non-profit research organization. For over twenty-five years, APRE, in close collaboration with the Ministry of Education, University and Research (MIUR), has provided its members as well as businesses, government agencies, and private individuals,	http://www.apre.it

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Organization	Country	Description	Webpage
		information, support and assistance for participation in national and European programmes and collaborative initiatives (today, with particular reference to Horizon 2020) in the field of Research, Technological Development and Innovation (RTDI) and in the transfer of research results.	
MISE - Ministero dello Sviluppo Economico - The Ministry of Economic Development - Directorate General for Industrial Policy and Competitiveness - Division III - Policies for sustainable development and competitiveness	Italy	The Ministry of Economic Development is responsible for a wide variety of policies, including economic development and cohesion, energy and mineral resources, telecommunications, internationalisation and business incentives.	http://www.sviluppoeconomico.gov.it/index.php/en/
University of Bari Aldo Moro	Italy	The University of Bari is an historical University in South Italy and it is attended by about 60.000 students. They have some innovative research in Bioscience, Biotechnology and Biopharmaceutics, especially linked to the territory and the Puglia region.	http://www.uniba.it/english-version
Novamont	Italy	Novamont is one of the world's leading company in the sector of bioplastics and in the development of bioproducts obtained through the integration of chemistry, environment and agriculture.	http://www.novamont.com
Biochemtex S.p.A.- Gruppo Mossi Ghisolfi	Italy	Biochemtex is a global leader in the development and engineering of technologies and bio-chemical processes based on the exclusive use of non-food biomass, as an alternative to oil. The company is entitled to build cellulosic ethanol plants powered by PROESA technology, of which Beta Renewables is the exclusive licensor, like the Cresentino industrial scale cellulosic ethanol plant in	http://www.biochemtex.com

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Organization	Country	Description	Webpage
		Italy. Biochemtex also provides complete project solutions for large-scale production of biofuels and biochemicals.	
Eni S.p.A.	Italy	Energy Company. Oil&Gas exploration and production, refining and marketing of oil base products, electricity production and sales in Italy. Recently launched a Business Unit for renewable Energy. Active in R&D in all business sectors, and fully engaged in safety and environmental issues	http://www.eni.com
Bioinnotech	Italy	Startup based in Apulia. In line with bio-refinery concept, BioInnoTech aims to reusethe agroindustrial waste, converting them into high- value products, as microbic biomass and proteins. Currently the young innovative start-up gives value to the cheese whey, wastewater of the diary industry, through innovative biotechnological processes.	http://www.bioinnotech.it
Italian Technology Cluster of Green Chemistry SPRING	Italy	The National Technology Cluster of “Green Chemistry” SPRING – Sustainable Processes and Resources for Innovation and National Growth, has the objective of triggering the development of biobased industries in Italy, through an holistic approach to innovation, aimed at revitalising Italian chemistry in the name of environmental, social and economic sustainability. The members of SPRING are all large industry players, SMEs and all the main Italian public research organizations working in the field of transformation and collection of biomass. They operate in different ways in the field of bioeconomy and represent the entire Italian value-chain of “green chemistry”, from agriculture to research in the field of chemistry from renewable sources and industrial biotechnologies, to the processing of materials and bioproducts, to industrial transformation and finally to the disposal phase.	http://www.clusterspring.it
Partner responsible: IPL			
Institute of Materials Resource Management,	Germany	Professor Tuma and Andrea Thorenz are currently working with the REHAP project, which is aiming to strengthen the European bio-economy by creating novel materials from agricultural and forestry waste, and assessing how they can	http://www.mrm.uni-augsburg.de/

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Organization	Country	Description	Webpage
University of Augsburg		be used commercially in the green building sector. Still in the early stages of the project, the main task being they are undertaking at present involves a literature and data base review about the 'arisings' and focal substances like lignin, tannin or cellulose of the first aggregate, which will be used for the project. Arisings are the amount of base material available to be used at the start of the value chain in the development of bio-products.	
Julia Hailes		Biomass researcher and former advisor to M&S on the Packaging Advisory Group. Also worked with Cargill Dow on bio-based plastics and in particular, PLA. Cargill Dow run Natureworks, which organises stakeholder meetings examining the pros and cons of bio-plastic from a consumer viewpoint. Hailes believes there is a lot of miscommunication about bio-plastics and this is exploited by some organisations as a cynical ploy to play on consumer ignorance. Using bio-degradable plastic bags as an example, she states that "consumers think 'Green' and put them in the recycling. However, in putting bio-degradable plastics in the recycling, you basically contaminate the recycling and make the whole batch non-recyclable".	
FORESA	Spain	FORESA is a leading European chemical industry capable of providing intelligent solutions to the needs of clients in various industries with high quality products. Always taking care to protect the environment and looking for energy savings, provide products of high added value, helping our customers with solutions developed to suit their needs. FORESA since 1964 has acquired enough experience to now have a clear customer focus with vision towards an international dimension.	http://www.foresa.com
SENBIS Polymer Innovations	Netherlands	As of January 1st, 2017 Applied Polymer Innovations (API) will continue its activities under the name Senbis Polymer Innovations B.V. with a new owner. API has successfully build up the spin-off company Innofil3dD, which is a leading producer of monofilaments for 3D- printing. This new market segment has great potential and requires focus and further investments. For API there are	http://www.api-institute.com

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Organization	Country	Description	Webpage
		ambitions to have a bigger market reach and to expand services. In addition, API recognizes new spin-off potentials which require new efforts and investments. The split of the two companies and their ownership was therefore a logical choice. Senbis Polymer Innovations will continue to offer polymer research and related services with the same team. These services can be categorized in consultancy, laboratory analyses, pilot plant services and the production of specialty products (yarns and filaments). Senbis is investigating new spin-off activities together with partners, e.g. the development of a fully compostable polymer (PLA) twine used in the horticulture industry. In recent years, the team gained a lot of knowledge on the application of different biopolymers and is constantly discovering new opportunities."	
Biopolynov	France	Biopolynov is a research and development center, created by Natureplast (www.natureplast.eu), dedicated to the modification and the improvement of bioplastics' properties. Its R & D services are aimed at all actors intervening during product life: from its conception (raw materials and aditive producers, etc.), to its manufacturing (plastic converters) and its use (buyers and SMEs from various activity sectors: packaging, transportation, construction, products of mass consumption, etc.). "	http://www.biopolynov.com/en/
Partner responsible: LOBA			
CONENOR LTD	Finland	Independent of Conex offering, Conenor is today acting as international composite extrusion process and product developer, industry consultant and expert in client projects for natural fibre plastic and other waste based composites (NFC & WPC) and start-ups of new businesses. see reference http://www.upmprofi.com	http://www.conenor.com
Fraunhofer IAP (Institute for Applied	Germany	The Fraunhofer IAP specializes in researching and developing polymer applications. It supports companies and partners in the customized development and optimization of innovative and sustainable materials, processing aids and	http://www.iap.fraunhofer.de/en/fraunhofer-iap.html

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Organization	Country	Description	Webpage
Polymer research)		processes. In addition to characterizing polymers, the institute also produces and processes polymers in an environmental-friendly and cost effective way on a laboratory and pilot plant scale.	
CKade.com	The Netherlands	CKade empowers industries and governments in the bioeconomy through professional consultancy services based on a unique combination of expertise in biotechnology, biomass value chains, business management and government policy.	http://www.CKade.com
ENEA	Italy	ENEA is the second major Italian research organization, with around 2700 staff employees distributed in its 9 research centers all over the national territory. The Agency's activities are mainly focused on Energy Efficiency, Renewable Energy Sources, Nuclear Energy, Climate and the Environment, Safety and Health, New Technologies, Electric System Research.	http://www.enea.it
European Bioplastics	Germany	Founded in 1993, EUBP has been a key player in shaping the policy environment for our industry in Europe for over 20 years. Our foremost goal and commitment is to build and strengthen a supporting policy framework for bioplastics in the EU to thrive in through a strong network and engagement in dialogue with all relevant stakeholders	http://www.european-bioplastics.org
Partner responsible: PEDAL			
RISI	USA	RISI - the leading information provider for the global forest products industry.	http://www.risiinfo.com/employee/seth-walker/
Energochemica Trading	Slovakia	Energochemica SE was established in 2011 in Prague. Their main task is to build a chemical and energy holding which can become one of the leaders in the area of chlorine chemistry in the V4 countries. They are currently building biorefinery in Eastern Slovakia.	http://www.energochemica.eu
Slovak Environment Agency	Slovakia	SEA is a cross-cutting professional organisation of the Ministry of Environment of the Slovak Republic with a national scope. The main scope of its activity is aimed at providing specialised sectoral environmental protection, environmental	http://www.sazp.sk/public/index/index.php?lang=en

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Organization	Country	Description	Webpage
		science development, securing reporting obligations, international cooperation development, project management and implementation at the national and international level.	
ISINNOVA (BIOSURF Project)	Italy	BIOSURF is an EU-funded project under the Horizon 2020 programme for research, technological development and demonstration.	
Partner responsible: Q-PLAN			
Institute for Solid Fuels Technology and Applications	Greece	The Institute for Solid Fuels Technology and Applications (ISFTA) is the main Greek organisation for the promotion of research and technological development aiming at the improved and integrated exploitation of solid fuels and their by-products. Since 2002, it is one of the five institutes of the National Centre for Research and Technology Hellas (CERTH) and operates under the supervision of the General Secretariat for Research and Technology (GSRT) of the Ministry of Education, Lifelong Learning & Religious Affairs.	http://www.lignite.gr
FNR Agency for Renewable Resources	Germany	FNR is the central coordinating agency in the area of renewable resources in Germany. It coordinates activities on renewable resources throughout Germany according to the guidelines of the R&D Funding programme for Renewable Resources. It funds and supervises about 400 projects per year that focus on the energetic or material use of renewable resources.	http://www.fnr.de
Centre for Renewable Energy Resources and Savings	Greece	The Centre for Renewable Energy Sources and Saving (CRES) is the Greek national entity for the promotion of renewable energy sources, rational use of energy and energy conservation. In the modern demanding energy sector CRES is dynamically active, in the frame of the national and Community policy and legislation, for the protection of the environment and sustainable development. Working in the state of the art of technology development, CRES implements innovative projects and significant activities for the promotion and market penetration of new energy technologies.	http://www.cres.gr
CHIMAR	Greece	CHIMAR is an innovative R&D SME that develops and licenses competitive, state-	http://www.chimarhellas.com

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Organization	Country	Description	Webpage
		of-the-art industrial technology (know how) to the adhesives and wood-based panel industry. In the field of bio-based products, CHIMAR develops technology for bio-based resins derived from renewable biomass products or by-products. .	
Imperial College/ Faculty of Natural Sciences, Centre for Environmental Policy	UK	The Centre focuses on ground-breaking, internationally-recognised research and teaching that addresses key environmental and global policy challenges through the interdisciplinary study of science, technology and innovation.	http://www.imperial.ac.uk/environmental-policy/
Partner responsible: UNIBO			
Interdepartmental Centre for Industrial Agrofood Research - CIRI Agrofood	Italy	The Centre carries out and coordinates research activities mainly aimed at enhancing industrial interconnections, promoting research results and technology transfer to meet the needs of food- and food related industries.	http://www.agroalimentare.unibo.it/
Ulster University, School of Biomedical Sciences, Biomedical Sciences Research Institute	UK	The BMSRI is one of 6 Research Institutes (RI) within the Faculty of Life and Health Sciences. The BMSRI specialises in the study of the biological mechanisms (especially those which relate to gene-nutrient interactions) associated with degenerative diseases. The BMSRI is also exploiting the remarkable opportunities made possible by recent molecular advances: revolutionary changes in biomedicine and biotechnology that will soon transform whole industries and economies, but which offer particular advantages in our field. At Ulster University, the research group directed by Prof. I. Banat has a great experience on microbial biosurfactants' production and their biotechnological and industrial application for environmental, pharmaceutical and health related areas.	https://www.ulster.ac.uk/ http://biomed.science.ulster.ac.uk/research-institute/

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APPENDIX B: INTERVIEW SEMI-STRUCTURED QUESTIONNAIRE

A. GENERAL INFO

Category of bio-based products:	
A.1 Description of organization	
Name	
Country	
Webpage	
Description (2-3 lines)	
A.2 Interviewee	
Name	
Position	
Contact info (tel, e-mail)	
Other participants	

B. DISCUSSION

B.1 Discussion about the application areas/ market segments of the relevant bio-based product category

- √ Which are the application areas/ market segments? How these products are being used and from whom?

B.2 Discussion about the relevant market situation

- √ How would you estimate the current situation of the market potential and penetration of bio-based products in general and of the relevant category?
- √ Which you assume are the barriers and the considerations of this bio-based product category?
- √ What you presume to be the opportunities and the future trends of the relevant bio-based products category?

B.3 Discussion about legislation and policy framework

- √ What would you consider to be the gaps and the barriers in the existing legislation?
- √ Have you faced any inconsistencies among EU and national legislation?
- √ Would you suggest any recommendations for improvement?

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B.4 Discussion about the user's perspective

- √ From your experience, how users respond to this market area? Are they familiar with this category of products? If no, what you think could help raise their awareness about?

B5. Impact

- √ In your opinion, which are the social, economic and environmental impacts derived by the use of bio-based products in general?

B.6 Case studies

- √ Is there any representative example of case study you would like to share?

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