Report about market structure and development, key actors and, quality requirements for cellulose, hemicellulose and lignin (D6.4)

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FRACTION

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Executive summary

The overall scope of this report (D6.4) is to document the market potential for FRACTION end products. The report also provides findings about market drivers and barriers, key actors (potential customers and competitors) and, quality requirements. The report is focused on the industrial market as producers of bio-based components, chemicals and materials are considered as the key customers for the bio-based compounds resulting from the research and piloting in the FRACTION project. The report-at-hand is elaborated as a qualitative analysis and builds on desk research, interviews and roundtables. So far, roundtables have been organized in Spain, Switzerland, and Finland and contribute with insights from national stakeholders about research and innovation, commercial opportunities, and new value chains. The roundtables and interviews especially contribute with findings to underpin the commercial perspectives and to understand the market dynamics.

The FRACTION project centers round the lignocellulosic biorefinery concept and wood as feedstock. The most important end products (chemicals) resulting from the project are shown below. The market assessment is designed to capture the opportunities and challenges that are identified for high value applications for cellulose, polyurethanes, 5-HMF, and phenolic resins.

Potential industrial applications of FRACTION end products

Biomass with lignocellulose	**Platform chemical / bio-based building block**	**FRACTION end-product**	**Potential industrial application**
Cellulose	Cellulose	High-value celluloses, nanocellulose, micro-fibrillated cellulose, cellulosic fibers	Smart packaging materials Textiles Emerging applications
Hemicellulose	Ketoses	5-HMF	PEF (for bio-based plastic)
	Furfural to succinic acid	Polyurethanes	Coatings and adhesives, Bioplastics, polymers
	Furfural	1,5 Pentanediol	Polyesters (for fibers, materials)
Lignin	Lignin	Vanillin	Flavor and fragrance
	Lignin	Polyurethanes	Coatings and adhesives
	Lignin	Phenolic resins	Insulation foams Adhesives

(Based on interviews with FRACTION partners, 2022)

The analysis in this report has shown that <u>there is an existing and expanding market for FRACTION end products</u>, with examples from selected industrial applications to underpin the findings. It could well be stated that market growth rates for the selected industrial applications by far exceed the growth rates for similar conventional applications. Keeping in mind that several of the industrial applications that could be enabled by FRACTION end products are regarded as emerging, e.g., cellulosic compounds for solar cells, the analysis has provided grounds to believe that future market opportunities for FRACTION end products could prove very promising.

Exchanging fossil-based components in an industrial formulation with bio-based components is not a 1:1 issue but depends on the industrial system, market requirements and, use strategy. It is important to consider if or how a formula would need to be adapted to manufacture a bio-based product that is a real alternative (complete substitute) to a fossil-based product, for example foams. It is evident that policies and the EU Green Public Procurement scheme are important for increasing demand for bio-based products. It is also clear that the market share for bio-based products is generally at a low level compared to fossil-based counterparts. This balance is most likely to remain stable, however, the share of bio-based products is expected to grow stronger by some industrial applications than others. Particularly applications where bio-based products can carry more attributes than fossil-based products, or in segments where the scale of the bio-based alternative is either related to a large volume or a high-value market.

Quality requirements for the FRACTION end-products depend on the performance requirements and market requirements; the latter are often implemented through sustainability certification schemes. It is a fundamental requirement for using bio-based components (chemicals and materials) in industrial applications that the final product (e.g., a coating) has the same performance and functionality as if it was produced with non-bio-based components. This is clear from interviews with producers of bio-based components, from literature and stakeholder consultations at roundtables. Successful use of bio-based components depends on how well they perform in an industrial system and, this performance is defined according to the functionality, miscibility, and processability of the bio-based component.

Customer demands for products with attributes such as *biodegradable, compostable, produced from renewable biological sources, produced without the use of petrochemicals, or products with a reduced CO_2 emission* are important for increasing demand for bio-based products. Bio-based products should not appear differently from their counterparts made from fossil-based resources. For example, non-transparent bio-based coatings might give a wrongful impression of the quality of the coating or the product itself – think of transparent or orange coatings on metal pieces. Another example is the burnt woody smell that follows from using lignin in e.g., bio-based foams. From interviews with producers of bio-based components it is revealed that the expected sensory appearance (visual, smell, feel) of the final product must not be compromised when using bio-based components.

Companies in the bio-based industry may benefit from having one or more schemes for documenting sustainability – whether this being an LCA approach, transparency in bio-based content, or otherwise. The key issue is that diverse certifications are available and target biomass, product, processing technique or, value chain. Given the diversity of sustainability schemes, it is obvious that transparent communication about the schemes' requirements as well as the application of this information by companies is of pivotal importance for maintaining market trust in bio-based products and their value chains. From a FRACTION perspective there is much to gain from the growing awareness and use of sustainability schemes for bio-based products and value chains: The bigger attention from market players (e.g., customers, regulators, investors and others) on bio-based products, the more the need for transparency in the market. FRACTION end products are natural candidates for certification under one or more sustainability scheme.

The future bioeconomy is assumed to target high-value applications in much smaller market segments where emerging technologies or materials play an important role (Schorneck, 2022, roundtables and interviews). This development pattern implies that bio-based products and materials that will be introduced in the market in the near future are targeted niche or emerging segments where high prices could be obtained. Looking up-stream in the value chain, this would induce more attractive market conditions for suppliers of bio-based components and chemicals such as those derived in FRACTION project because such chemicals or materials could be customized. Further to this line, in high priced markets additional attributes as for example "*made from bio-based ingredients*", "*made from renewable resources*", "*compostable*", "*light-weight*" or "*recyclable*" become more important and so contribute to underpin a high value supply chain.

The report has assessed and documented the market for the end products from the FRACTION project. The market is real with all its challenges, opportunities, structures and actors. Also, the industrial applications that are documented in the report are of relevance to the FRACTION end products. There is still quite a gap from the current TRL of ca. 4 for the FRACTION end products and until the FRACTION end products could be launched in a commercial context. Much more development work needs to be done including thorough testing in various industrial systems and findings solutions for scaling up to supply industrial customers. The market for bio-based chemicals and materials will display promising growth rates in the near future and it is a foremost important mission of the FRACTION project to engage in the European bioeconomy for the benefit of economic, environmental and social prosperity.

Contents

Definitions

Bio-based: using biological materials as starting point for chemical synthesis or as material for industrial processing – in contrast to using fossil sources.

Bio-based component (chemical or material) used in the manufacturing of bio-based products. FRACTION end-products are considered as bio-based components.

Building blocks are bio-based chemicals that are important intermediates for chemical synthesis into an array of value-added chemicals.

End-products: those chemical compounds that are the aim of the FRACTION valorization pathways, thus selected chemicals made from lignocellulosic feedstock. These end products are used in recipes for manufacturing bio-based products like insulation foams or bio-based plastics.

GHG: greenhouse gases, for example CO2.

Industrial system: the combination of ingredients, process, technology, specifications and knowledge to produce a defined product in a specific industrial context

Lignocellulosic biorefinery: a biorefinery concept based on the utilization of dry biomass like wood or crops for the production of bio-based fuels and chemicals via thermochemical conversion.

Platform chemicals: chemicals, such as succinic acid, that can serve as substrate for synthesizing specialty / high value chemicals.

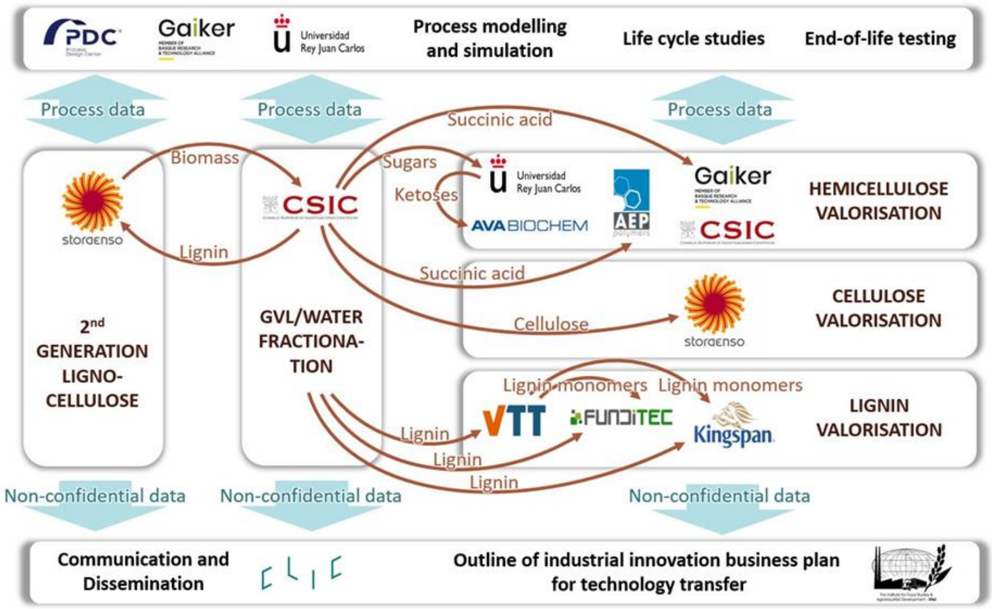
1 Introduction

1.1 Introducing the FRACTION project and context

The transition to bioeconomy is underpinned by policies at EU and national levels including documents such as the Bioeconomy strategy, the Circular economy strategy, and the Sustainable Development Goals of the United Nations. Together, these initiatives promote sustainable use of available natural resources through a bigger inclusion of renewable materials and circular value chains. However, contemporary practices by industry and society for use of resources are dominated by demands for products that are made from fossil-based sources as for example plastics, chemicals, clothes or energy. The fossil-based products are long-time rooted in the market enjoying a position of "being part of every-day life". Bio-based products today only account for very few per cent of the market, with variations between segments and applications. If bio-based products are to increase their share of the market it would require that bio-based products were price-competitive, available in sufficient quantities and, demand patterns by industry and consumers motivated a market-pull in various segments.

FRACTION is a research and innovation project with a core objective of achieving a TRL of 5 for the fractionation process; a process that enables an integrated biorefining approach to valorizing cellulose, hemicellulose and lignin, Figure 1. Once developed and tested, this process that should make it cheaper and more efficient to produce bio-based building blocks and end-products and by this, contribute to increasing the competitiveness of the bio-based industry and enhance the availability of bio-based products. It is therefore essential for the exploitation work in the project to understand the dynamics in the markets for those bio-based building blocks and bio-based end-products that are produced in FRACTION and, to assess the opportunities and barriers by industrial applications for the end-products (chemicals).

Figure 1: FRACTION valorization pathways and partnership, 2022



FRACTION project is centered round the lignocellulosic-feedstock biorefinery concept and an innovative fractionation process resulting in pathways for valorizing cellulose, hemicellulose and lignin. Until recently it has not been common among European biorefineries to apply a dedicated strategy to valorize the lignin beyond using it for heat (Wenger et al, 2018). With the processes resulting from FRACTION project, it is foreseen that hemicellulose and lignin could play a more important role in producing platform chemicals like succinic acid and end products like polyurethane or phenolic resins. In this perspective, the results from FRACTION project could prove to be a game-changer for lignocellulosic-feedstock biorefineries.

There is still much work to be done before the commercial potential of the project can be realized – for the fractionation process and the industrial applications of the bio-based building blocks and end-products. With this point of departure, it is the intention of the report to support the exploitation work in the project but may also serve as inspiration for entrepreneurship, innovation and business development in the European bioeconomy.

1.2 Scoping the market assessment

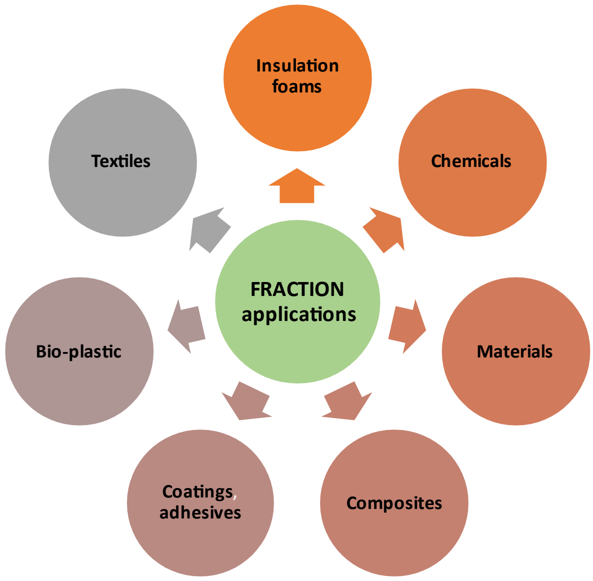
The report at hand compiles the market assessment for the end-products that are achieved in FRACTION project by covering the market structure and development, key actors, and quality requirements in the European market[1]. The report targets the industrial market, as FRACTION end products are destined for use in industrial formulations. So, the consumer market is not included in the scope of the work. The report is important for understanding the exploitation potential for results derived in the FRACTION project.

The market potential of the platform chemicals is not addressed in this report. This is because platform chemicals such as succinic acid and furfural (Table 1) are intermediary compounds in the chemical reactions of the project. The importance of studying reactions leading to succinic acid and furfural are related to achieving a higher yield of purer chemicals – not the application of the chemicals in an industrial formulation.

The FRACTION project is designed to validate the supply chains for the production of bio-based chemical building blocks and end-products from the cellulose, hemicellulose and lignin streams stemming from a novel technology for fractionation of biomass. The report-at-hand will assess the market potential by selected industrial applications that are relevant for end-products resulting from chemical reactions in the FRACTION project, Figure 2.

[1] As described for D6.4 in the Grant Agreement of the FRACTION project.

Figure 2: Main industrial applications for FRACTION end products



(Own elaboration, 2022)

Table 1 shows how the main building blocks and end-products from the FRACTION project could be relevant for industrial applications. It is seen that the chemical industry, plastics and packaging materials, and technical applications are important for valorization of the bio-based components derived in the project. This is further explored in Chapter 3.

Table 1: Potential industrial applications of FRACTION end products

Biomass with lignocellulose	**Platform chemical / bio-based building block**	**FRACTION end-product**	**Potential industrial application**
Cellulose	Cellulose	High-value celluloses, nanocellulose, micro-fibrillated cellulose, cellulosic fibers	Smart packaging materials Textiles Emerging applications
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(Based on interviews with FRACTION partners, 2022)

With industrial applications of FRACTION end products being at the center stage of the report, the next chapter 2 introduces the European markets for bio-based products and the main trends and drivers that shape these markets. In chapter 3, those industrial applications that are relevant for FRACTION end products are explored. The main actors (customers and competitors) are presented in chapter 4, and in chapter 5 quality requirements and sustainability certification schemes are discussed. The report is pulled together in chapter 6. Examples of how companies are adapted to the bioeconomy are given across the report. These examples are intended for illustration of how the work in FRACTION project, including the end products, is relevant for a bio-based industrial production.

1.3 Methodology

The market study is elaborated as an explorative and qualitative analysis with selected quantitative data. Given the exploitation context of the report, it has been a priority to arrive at an analysis that informs about market potential and development trends at a European level and for industrial applications (main segments). Due to the emphasis on research in the FRACTION project it is decided to focus on dynamics, trends and scales for studying the market. This should provide findings about opportunities and challenges for, in a long-term view, taking FRACTION end products into a commercial context. The issue of key actors is addressed in the view of potential customers to FRACTION end products, and competitors in the capability to produce similar end products. Prices for bio-based and fossil-based building blocks and chemicals are determined by demand and supply, location, currency, and the oil prices, hence there is more than one price for a chemical. As FRACTION is a research project with a TRL of 4-5, thus far from market-readiness, it is decided not to include research on prices for this report.

The analysis is based on a combination of desk research, interviews, and stakeholder consultations. Desk research has been carried to gather literature and statistics about the European markets for bio-based chemicals and materials; to identify key actors, and to capture information about market drivers and barriers, and quality requirements. Data source include academic papers, statistics, reports, newsletters and internet. To obtain an overview of potential markets and applications for FRACTION end products, desk research has explored literature about biorefineries, market assessments for bio-based products, value chains, and emerging applications. The gathered literature has been explored to achieve an aggregated understanding of the market and dynamics targeted at the industrial application, e.g., plastic packaging, rather than researching markets in a country-context.

To best understand the dynamics in the market and to identify quality requirements, telephone interviews have been organized with industrial partners in the FRACTION project:

- AVA Biochem AG, Switzerland
- AEP Polymers srl, Italy
- Kingspan Insulation B.V., Belgium
- Stora Enso AB, Sweden

Respondents in interviews represented executive level or innovation. Interviews were carried out during September 2022 based on semi-structured interview guides with questions about market size, structures, growth rates, major players, quality requirements and market development trends (Appendix 1). Due to confidentiality issue and data protection, findings from interviews are referred to as "interviews, 2022" in the text. After the interview a summary was forwarded to the interviewee for validation. The aim of the interviews was to gain insights from industry partners to underpin and validate findings from literature about the specific industrial applications. It is fair to state that findings from literature and interviews are aligned.

An important element in the FRACTION project is the roundtables. These events are organized in six countries during the project, and the aim is to gather local stakeholders from industry, research, knowledge transfer and other to enhance knowledge exchange between the FRACTION project and stakeholders. The roundtables are important for learning about bioeconomy in a local context and for retrieving information about trends, challenges and opportunities in various industrial segments. Until now, roundtables have been organized in Spain, Switzerland and Finland. Findings from these events are used for the market assessment.

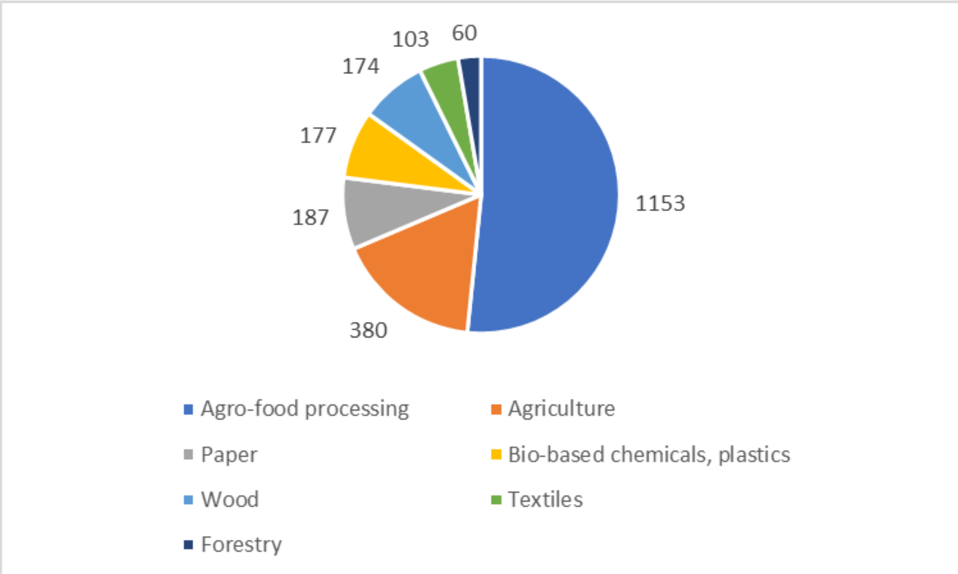
2 Shaping the market for bio-based products

2.1 Overview of European markets for bio-based products

The bioeconomy covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms, and derived biomass including organic waste), their functions and principles. The bio-based sector produces and uses renewable biological resources and/or applies biological processes and principles to deliver bio-based products, services or processes. There are conventional bio-based products made traditionally from biomass such as wood, cork, natural rubber, paper textiles or wooden construction materials. Then, there are the more recently developed products such as bio-based chemical, bio-based plastics, materials or substances (EU Commission, 2018, p41). Biofuels are also to be recognized as bio-based products. However, biofuels are not included in the scope of this report.

Food and agriculture account for nearly half of the turnover in the EU bioeconomy, followed by the sectors paper production, bio-based chemicals, and forestry, Figure 3. The manufacturing of bio-based chemicals, rubber and plastics presented the highest value-added, followed by the paper industry and bio-based textiles. In 2015, the highest value-added annual growth occurred in the manufacturing of bio-based chemicals (26%) and bio-based plastics (+13%) (EU Commission, 2018 p29). Germany, France, Italy and Spain generated nearly half of the total EU bioeconomy value added in 2015.

Figure 3: Turnover per sector in the EU bioeconomy, 2015 (billion EUR)



(EU Commission, 2018 p29)

Countries around the Baltic Sea (Finland, Sweden, Estonia and Latvia) have bio-economies that are oriented towards processing of wood, including paper manufacturing. Particularly for Finland and Sweden, paper manufacturing accounts for 20-25% of the countries' bio-economy. In Italy and Portugal, 14% and 16% respectively, of their bio-economies come from manufacturing of bio-based textiles. The bioeconomy of Switzerland is based on wood with timber, paper and energy being the main fields. However, the Swiss bioeconomy is developing towards high-value chemicals and materials that can be derived from wood (Schorneck D., 2022; Badra D. 2022). Finally, 36% of Ireland's and 35% of Denmark's bio-economies stem from manufacturing of bio-based chemicals, pharmaceuticals, plastics and rubber. This shows that **there is not one single bioeconomy in Europe but several bio-economies adapted to the local context** (EU Commission, 2018 p30).

Feedstock availability is a key issue for developing the bioeconomy. Research and stakeholder consultations have documented that the development of a bioeconomy (i.e., supply and demand for bio-based products) is based on the availability of local feedstocks. This is the case for Denmark, where processing of grass and manure into feed protein and biogas have taken the center stage. In Spain the bioeconomy is developing from feedstocks stemming from pruning (olives, orchards), woodland, and grasslands. Other sources of feedstock are derived from marine sources or from waste; such feedstocks are gaining increasing attention for various purposes in the bioeconomy. The essence is that the availability of feedstock determines the baseline of the local bioeconomy. As FRACTION project centers round the lignocellulosic biorefining processes, the feedstocks used are eucalyptus, white birch and *pinus sylvestris* (Alonso D.M., 2022).

The market for bio-based products appears as two main segments:

1. A high-value market for advanced substances, chemicals or materials that enable new applications or new markets to emerge. The emerging high-value market segments call for advanced levels of technologies for e.g., for manufacturing of the bio-based product or for managing the inclusion of the bio-based substance (drop-in or adapted recipe). For some applications, the technologies are still under development. However, once operational, the high-value segment offers huge potential for replacing fossil-based chemicals and materials as well as using bio-based products in combination with new technologies.

2. The other segment targets those applications and sectors, where bio-based products or chemicals are used in big volume and for less expensive applications. Examples of applications in this segment could be packaging materials, composites, less advanced bio-plastics, or biofuels.

By 2019, the EU production of bio-based products stood at 4.7 million tons, Table 2 (Spekreijse et al, 2019). Platform chemicals and polymers for plastics dominate total EU production, while, for these categories, the bio-based share is only 0.3% and 0.4%, respectively. It is observed that the categories paints and surfactants have high EU production volumes, although they are less commonly thought of as being bio-based than, for example, bio-plastics. It is estimated that EU production of bio-based products would increase to 6.1 million tons by 2025; this equals growth of more than 30% since 2019, Table 2. Platform chemicals and adhesives are expected to grow the most in relative terms (10% per year). The market for bio-based solvents is not expected to grow much because of the low priority given to producing bio-based alternatives (Spekreijse et al, 2019 p8).

Table 2: EU production of bio-based products and share of bio-based products, 2019 and 2025

Product category	**EU bio-based production, (1000 T/year)**	**Total EU production (bio-based and fossil), 1000 T per year,**	**EU bio-based production share (%),**	**EU bio-based consumption (1000 T/year),**	**Estimated EU bio-based production (1000 T per year) 2025**
Platform chemicals	181	60791	0.3	197	353
Solvents	75	5000	1.5	107	80
Polymers for plastic	268	60000	0.4	247	353
Paints, coatings, inks, dyes	1002	10340	12.5	1293	1151
Surfactants	1500	3000	50	1800	1974
Cosmetics and personal care	558	1263	44	558	687
Adhesives	237	2680	9	320	462
Lubricants	237	6764	3.5	220	254
Plasticizers	67	1399	9	117	83
Man-made fibers	600	4500	13	630	738
TOTAL	4725	155639	3	5489	6134

(Spekreijse et al, 2019 p6)

There is a significant variation in the maturity of market segments for bio-based products. The market for surfactants is regarded as quite mature, owing to a long tradition for using surfactants derived from fats and oils. Cosmetics and personal care products include a large number of mature bio-based products as the segment uses many bio-based ingredients; consumer demand for natural products is important. The products that are produced in large volumes (platform chemicals, solvents, paints and coatings) have very young bio-based markets and a low share of bio-based products (Spekreijse et al, 2019 p9).

The market for bio-based chemicals and plastics is global. Europe is the market leader holding one third of the global market for bio-based chemicals and 36 % of the global bio-plastics market. Europe holds similar shares (ca. 30 %) of the global production capacity for bio-based chemicals and plastics (Spekreijse et al, 2021 p5). The EU is a net-importer of bio-based products. Referring to the product categories in Table 2, the EU is a net-exporter of bio-based lubricants and polymers for plastics. In contrast, the EU is a net-importer for product categories such as platform chemicals, solvents, paints and coatings, adhesives and man-made fibers. In a global perspective, the EU has a high importance for the production of adhesives, polymers for plastics, cosmetics and lubricants (Spekreijse et al, 2019 p10).

2.2 Key trends impacting on industrial demand for bio-based products

Recycling to reduce waste – example of plastic packaging

The packaging industry is impacted by major global trends such as challenges with plastic litter, requirements for a reduced climate impact, and targets for recyclability of packaging materials. The EU has set ambitious targets to recycle 50 % of all plastic waste by 2025 and quadruple sorting and recycling capacity by 2030 (compared to 2015). By 2022, it is assumed that 2 out of 3 PET bottles are collected for recycling in Europe with a collection rate of up to 90 % in some countries. The upcoming revision of the Packaging and Packaging Waste Directive legislation will likely set mandatory recycled content targets in order to boost the availability of recycled PET (Poole, 2022). Such changes in EU legislation indicate that all actors along the supply chain, particularly in the food and drinks sector, should be more aware about alternatives to new PET bottles. However, the organization Plastics Recyclers Europe has argued that recyclers are experiencing shortages of sorted plastic waste, which could slow down the transition toward a circular plastic economy. It is evident that there is a growing pressure on producers of plastic packaging materials and the food industry that action must be taken to move towards a circular economy. Here, alternatives to fossil-based PET materials such as bio-based PET (known as PEF) is anticipated to be a good solution for replacing fossil-based PET. One of the end products in FRACTION is 5-HMF that is used in the synthesis of PEF.

Reduced environmental impact from production and consumption – example of textiles and fibers

The textile industry contributes with 10 % of global emissions of greenhouse gases and China alone contributes with 35 % of global emissions from the textile industry. According to the European Environmental Agency, production and consumption of shoes, clothes and household textiles e.g., bedlinen and cloth for furniture, produced an emission of 121 million tons of CO2 in 2020 (Holt, 2022). During the last 20 years, global production of textiles has doubled while prices have declined by 30 %. Furthermore, the share of synthetic materials like polyester has increased by more than 60 % to reduce the price on the finished goods (Holt, 2022). The European consumption of textiles for clothes, shoes and household textiles amounted to 6.6 million tons of cloth made from natural fibers (e.g., cotton and wool) and synthetic fibers (e.g., polyesters). Further, it is calculated that 60-70 % of the textiles are made from polymers. It is evident that textile production and consumption holds a huge potential for reducing greenhouse gas emissions and environmental impact from (micro-)plastic (Holt, 2022).

There seems to be an emerging change in demand patterns by the textile industry towards sustainable fibers. With the FRACTION end products in mind, particularly high-grade cellulose, there is an interesting market development taking place in the textile industry where polyester and other polymers from non-fossil sources may experience a growing market.

It is the EU Commission's intention to spur a circular approach to the huge consumption of textiles in the EU. Following this, it is envisioned that in few years, all textile products in the European market are sustainable; can be repaired and/or recycled; are produced from recycled or sustainably produced fibers; are produced without hazardous chemicals and made with respect for the humans and the environment. Would such market requirements be implemented it could spur the demand for sustainably produced fibers significantly, a development that could motivate the manufacturing of fibers based on the principles in the FRACTION project. Given the fact that most textiles are produced in Asia (interview, 2022), the future

EU regulations about sustainable textiles are anticipated to have a strong impact on the global production of textiles. However, it may take a few years while EU institutions discuss the details in the new legislation before any concrete legislation is put forward (Holt, 2022)

Energy efficiency

The prices on energy have more than doubled during 2021-2022 inducing all actors in the public and private sectors to pay attention to energy saving in order to reduce costs. Energy savings may be achieved through an array of strategies:

- Cut down on the use of energy (e.g., heat or electricity);
- Change to other energy sources (e.g., solar panels or wind farms);
- Implement changes in the way energy is consumed, for example changes in the organization of production; install more energy efficient machines including computers; change routines in households; or
- Exploit opportunities for saving energy by using insulation materials.

End-products of the FRACTION project, such as bio-based phenolic resin or polyurethane, can be used for making foams for insulation and other purposes. Insulation foams are used for protecting, e.g., pipes, floors or walls from giving off heat or cold, or for insulation panels used for housing, industrial and office buildings (interview, 2022). Given the strong rise in energy costs that are witnessed during 2022 across Europe, it is evident that measures to reduce energy costs are high on the agenda.

EU Green Public Procurement

It has been estimated that public sector procurement amounts to 14 % of EU GDP (Buying-Green-Handbook-3rd-Edition.pdf (europa.eu). This huge procurement volume places the public sector in a unique position to influence and promote the implementation of circular economy and bioeconomy. EU's Circular Action Plan and the Bioeconomy Strategy are two central documents laying down the visions and action points for a more green, fair and sustainable EU.

Recently, the EU Green Public Procurement Directive was revised, and the underlying Green Public Procurement criteria (GPP criteria) were (re-)defined for a number of product categories, including building materials, mobility, chemicals and food. The GPP public procurement approach is a voluntary system aimed at fostering a transition to circular economy aspects and reduce the environmental impact from production and consumption. Procurers in the public sector (national, regional and municipal levels) use the GPP criteria when putting out a call for tender for procurement of goods and services, in, for example, calls for tenders for textiles for the social care sector, for green mobility solutions, or for energy saving measures in public buildings. The GPP criteria define for groups of products and services a range of sustainability requirements that can be used in the call for tender. Bidders have to explain how they will meet these sustainability requirements. Once the bids from potential suppliers are received, the procurement official will assess the bids to find the one with the best match of quality, prices and sustainability. Below, examples of GPP criteria that are relevant for the industrial applications targeted in the FRACTION project are given.

In January 2018, the new GPP criteria for paints, varnishes and road markings were published. The criteria aim at minimizing the impact from production and product wastage; reduce the use of hazardous properties of the overall formula; promote durable paints; and incentivize the minimization of waste (Green Public Procurement - Environment - European Commission (europa.eu).

In October 2019, the new GPP criteria for food, catering services and vending machines were published. The main aim of these criteria is to reduce the environmental impact from food production and serving in the public sector. The GPP criteria specifically target an improved management of waste (including recycling); avoidance of single-use plastic items; and reduce energy consumption in kitchens (Green Public Procurement - Environment - European Commission (europa.eu)

Given the economic, social and environmental importance of the construction sector, many public authorities are committed to moving towards more sustainable materials. The most significant environmental impact from construction is relate to the energy consumption in the buildings. Other important factors to consider are the materials used in the construction, waste generation during construction, and more recently, recyclability of construction materials (Buying-Green-Handbook-3rd-Edition.pdf (europa.eu) p 68). GPP criteria targeted at the construction sector generally aim at addressing the overall environmental impact of the building and the environmental characteristics of the individual components, e.g., insulation panels.

Example

The Netherland's Ministry for Environment and Infrastructure were on to procurement of sustainable coffee cups for the administration (Westkämper, 2017). The call for tender specified that innovation and bio-based materials would be a criterion for assessing the bids together with price and quality. Further, suppliers were asked to provide information about:

- What kind of biomaterials were used and where the biomaterials came from;
- If the biomaterials were sustainably sourced;
- The share of the bio-based material in the cups and how it was measured;

For the winning supplier, it would be requested that the coffee cups were compostable and, the supplier should provide information about future sustainability measures. The coffee cup, that was chosen by the Dutch procurement official, was made from corn starch and sugar beet fibers, the cup was biologically degradable and compostable according to standard EN 13432. The example shows how an ordinary product (coffee cup) becomes an important tool in a sustainability context, and how public procurers may choose sustainability criteria. The example demonstrates the complexity of producing and marketing bio-based products.

2.3 Use strategy

Bio-based chemicals need to demonstrate similar functionalities to fossil-based alternatives if the bio-based chemicals are to fully or partly replace fossil-based alternatives. There are two main strategies for using bio-based chemicals in industrial applications:

Drop-in strategy:
In this strategy, bio-based compounds or materials are added to an existing formula to replace a certain share of the fossil-based compounds. Given that there are vast differences across applications, drop-in strategies in most cases lead to only few per cent inclusion of the bio-based chemical. Making a drop-in

strategy work requires adaptations in recipes and processes to produce a certain product (e.g., a coating or composite material). The purpose of adding bio-based chemicals to an existing formulation is to produce a product with a bio-based component, reduced climate impact and, with similar performance (chapter 5) as the fossil-based product that is currently available in the market. A draw-back of the drop-in strategy is scale: if the bio-based compound or material is not available in sufficient quantities to satisfy demand by an industrial application, then it will not be considered. It is therefore necessary for a supplier of bio-based components or materials to ensure a coherent supply chain for supplying to the industrial market (interviews and Schorneck D., 2022).

Replacement[2] strategy:
Here, bio-based components are used to replace fossil-based alternatives to create new bio-based chemicals or materials. An example is the use of bio-based chemicals to produce bio-based plastic. The replacement strategy may imply changing the recipe as well as adapting the production process. This may lead to altered performance of the final product, for example softer or less heat-resistant bio-based plastics. Replacing a fossil-based component with a bio-based one could induce the creation of a new bio-based material or a new product. The replacement strategy is connected with a market-pull for e.g., certain materials or products (Mayer, 2022). The reformulation strategy may be useful if a change in recipe could provide a final product with additional attributes, for example "compostable" or "reduced weight"

This chapter has provided an overview of the European bioeconomy along with trends that impact on the development of the industrial market for bio-based products. Exchanging fossil-based components in an industrial formulation with bio-based components is not a 1:1 issue but depends on the industrial system, market requirements, and use strategy. It is important to consider if or how a formula would need to be adapted to manufacture a bio-based product that is a real alternative to a fossil-based product, for example foams. It is evident that policies and the EU Green Public Procurement scheme play a major role in driving the demand for bio-based products forward. It is also clear that the market share for bio-based products is generally at a low level compared to fossil-based counterparts. This balance is most likely to remain stable, however, the share of bio-based products is expected to grow stronger by some industrial applications than others. Particularly applications where bio-based products can carry more attributes than fossil-based products, or in segments where the scale of the bio-based alternative is either related to a large volume or a high-value market. This will be further explored in chapter 3.

[2] Replacement strategy may also be known as dedicated-use strategy

3 Market potential by selected industrial applications

End products from FRACTION project are used in formulations to produce bio-based products such as insulation foams, coatings or polymers; refer to Figure 2. The following sections will provide insights to market dynamics by selected industrial sectors of high relevance for FRACTION end products.

3.1 High value applications for cellulose

Cellulosic fibers can be used to synthetize polyesters like viscose, rayon, and artificial fibers such as Modal and Lyocell, Table 3. Viscose and rayon are used as cheap substitutes for natural fibers like cotton. Lyocell fibers are used in apparels, home textiles, surgical products, vehicle carpeting and cigarette filters. In 2016 the global market for Lyocell fibers was valued at 850 million USD. Other applications for cellulosic fibers are for non-woven materials like tissues, diapers and medical products, or for carpets. By 2015, clothing accounted for 60 % of the global cellulose fibers market. The global demand for cellulosic fibers is anticipated to grow by ca. 9 % per year to reach a market worth of 36 billion USD by 2024 (Wenger et al, 2018 p25). Table 3 also shows the narrow gaps between the prices of polyester fibers, viscose fibers and, cotton that has spurred demand for cellulosic fibers in the textile industry.

Table 3: Global production and price of selected natural and synthetic fibers, 2017

Fiber	**Volume (tons)**	**Price (USD/tons)**
Polyester fibers	50,100,000	1,400
Cotton	*23,270,000*	*1,700*
Viscose fibers	5,300,000	1,500
Lyocell and other artificial fibers	500,000	2,260
Viscose yarn	365,000	2,200
Wool	*2,000,000*	*10,000*

(Wenger et al, 2018 p31)

A common source of the cellulose for producing fibers for textiles is wood, thus emphasizing the relevance of cellulosic fibers in the context of the FRACTION project. By 2016, the global market for fibers was estimated at 100 million tons and the share of man-made cellulose fibers was ca. 7 % (7 million tons). The global market value of man-made cellulosic fibers was estimated at ca. 20 billion USD by 2015. Compared to natural cellulose fibers, the market share of man-made fibers was assumed to be ca. 62 %. The global market growth for man-made cellulosic fibers was estimated at ca. 9 % per year, mainly driven by an expanding textile industry in Asia (Wenger et al, 2018 p24).

Cellulose can be turned into micro- or nano-fibrillated cellulosic materials that could be used in applications such as films, nanocomposites, coatings, pharmaceuticals, separation membranes and, biomedical applications (Wenger et al, 2018 p3). It is estimated that one third of the total demand for nano-cellulose stems from manufacturers of composites, followed by paper and pulp (15 %) and, paints, films and coatings (15 %). By 2016, the global production of nanocellulose was calculated to 1000-1500 tons by small-scale and demonstration plants. The global market value for nanocellulose was 250 million USD by 2019 and, the annual growth rates yearly (2014-2019) stood at 19 %. Market analysts seem to agree that the global market for nanocellulose holds rapid growth rates with the scaling-up of the production being the most important barrier for exploiting the market opportunities (Wenger et al, 2018 p27).

In recent years, more attention has been drawn to producing more efficient yet cheaper solar cells. This application is very interesting for nanocellulose because of the growing need for renewable energy sources and due to technological development. For example, Chinese researchers have developed transparent nanocellulose paper-based (NCP) solar cells (a photoelectric conversion device) that could be used for wearable electronics and, potentially lead to a paradigm shift in consumer electronics. The NCP solar cells are interesting because they are produced from biodegradable materials, have a low processing cost, and can replace conventional silicon-based solar cells. Should NCP solar cells gain a foothold in the market, this technology could trigger the next generation of green flexible electronic devices (Gao et al, 2019) and significantly increase the demand for high-quality nanocellulose.

Other emerging applications for nanocellulose with major impact if successful are within the field of water treatment, dye removal, air purification and, microbe and virus decontamination. These applications indicate the importance of mechanisms for adsorption and separation for nanocellulose (Trache et al, 2020).

3.2 Bio-based chemicals, coatings and adhesives

The European bio-based chemicals market is diverse, and large differences are identified between product categories. For example, bio-based solvents and platform chemicals both account for a very small percentage of the market, while on the other hand, cosmetics and surfactants already enjoy a large bio-based share of the market. The growth rates are foreseen to vary greatly between the product categories, with platform chemicals expected to grow rapidly in the coming years. For bio-based solvents the anticipated growth rates are much lower (EU Commission, 2018 p43)

In the large picture, bio-based systems remain a niche in the global paint and coatings industry. However, the bio-based coating systems have proven to be robust and continue to show opportunities for growth. It is estimated that bio-based coatings account for 1 % of the global market for paints and coatings, and 5% of the global market value (Cagro, 2022). Bio-based resins are used for manufacturing bio-based coatings. The global market for bio-based coatings is forecasted to grow from 11.5 billion USD in 2022 to 18.2 billion USD by 2027; an increase in the market value of 9.5% per year in the forecast period (Markets and More, 2022). Another source estimates an annual growth rate of 5 % in value and 1% in volume in the global market for bio-based coatings (Cagro, 2022). Phenolic resins and polyurethanes are substances that could be used in the formulation of coatings, and these substances are important end products in FRACTION.

The main applications for bio-based coatings are for construction and woodworking, packaging, transportation, marine applications and other uses. Market growth is led by decorative coatings (paint) and industrial wood coatings (Cagro, 2022). There are still a range of technical challenges connected with bio-based coatings and paints such as yellowing or through-curing. Due to technical shortcomings, bio-based systems are not yet an alternative in certain applications like automotive or industrial systems, for example as top coating on metal substrates or wall coatings (Cagro, 2022 and interviews). Industry sources point out that bio-based ingredients are not drop-in solutions in e.g., paints and coatings. So, much research effort should go towards providing adequate properties to bio-based resins.

Demand for bio-based coatings is driven by an increasing awareness of climate impact from fossil-based resources and consumer health issues. The latter is connected with the use of bio-based coatings in decorative paints. Overall, there seems to be a growing awareness of the benefits for health and environment from using (water-borne) bio-based coatings at the expenses of solvent-borne coatings (Markets and More, 2022). Growing pressure from various government authorities to reduce the use of mineral oil-based coatings is likely to boost the growth of the global bio-based coatings market in the upcoming years (Cagro, 2022).

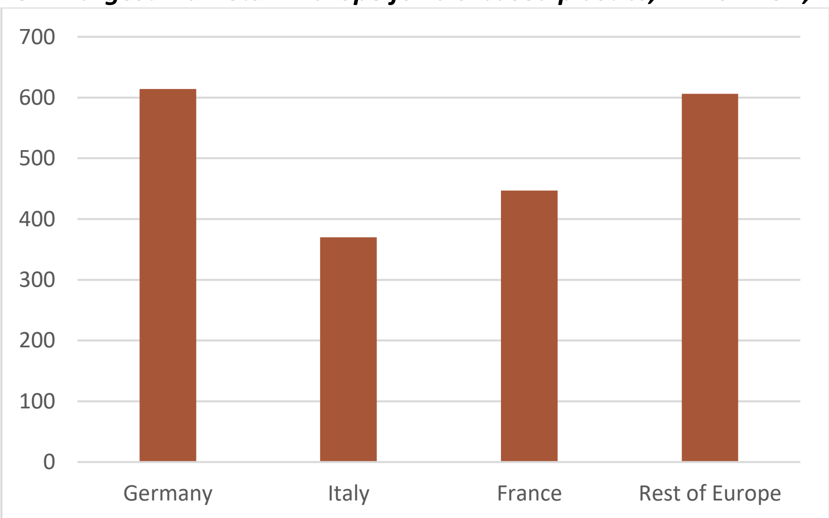
A main obstacle for bio-based coatings in the market is their higher price compared to the price of coatings made from fossil-based sources and, the price volatility occurring in the market for bio-based raw materials, for example vegetable oils (Cagro, 2022). Another challenge with regards to market development is availability of bio-based ingredients (e.g., resins) in sufficient quantities. As long as demand for bio-based resins is low (in volume), there seems to be no limits to supplies of raw materials for producing the bio-based resins. However, if supplies of raw materials (e.g., sugars, starches, lignocellulosic biomasses etc.) become tight, this would have an impact on market demand for bio-based coatings.

3.3 Bio-based polymers

Bioplastic materials are a broad field on their own, and the fact that diverse bio-based materials are transformed to monomers and later polymerized (often in combination with other bio-based or fossil-based compounds) into a variety of different polymers generates an enormous degree of complexity in market assessment (Wenger et al, 2018).

The European market for bio-based plastics is estimated at 2 billion EUR, with Germany accounting for nearly one third, Figure 4. The UK market is valued at 10 million EUR. The production capacity in Europe is assessed at 709,000 tons annually, indicating that Europe has a significant import of bio-based plastics. Germany is perceived to hold the largest production capacity for bio-based plastics in Europe with 254,000 tons per year followed by France (195,000 tons) and Italy (153,000 tons) (Spekreijse et al, 2021, p21).

Figure 4: Largest markets in Europe for bio-based plastics, million EUR, 2020



(Spekreijse et al, 2021 p 21)

A wide array of bio-based plastics is available in the European market including PET, PP, PLA, PBS, PHA, TPE, PU and PEF. PET represents the largest market share holding 26.6 % of the global production of bio-based plastics. Currently, there is no significant production of bio-based PET in Europe but there is a very significant market for bio-based PET within Europe – estimated at 240,000 tons per year. This amounts to 25 % of the global market for bio-based PET. Production of 100 % bio-based PET is still in its pilot phase and accounts for only 2.5 % of global PET production. Nearly 90 % of bio-based PET goes into the production of bottles for, e.g., soft drinks. It is estimated that 3 % of plastic bottles are bio-based (Spekreijse et al, 2021, p18). Another market report finds that demand for bio-based polymers is increasing, yet production volumes are too small to satisfy this demand. The market study reported that biopolymers made up ca 1-2 % of plastics manufactured in 2017 (Wenger et al, 2018 building on data from European Bioplastics).

Example

Tetrapak, a major producer of food packaging, works to reduce climate impact and switch to renewable materials (PackagingInsights.com, July 11, 2022). Tetrapak has a long-term roadmap to develop aseptic packaging that is fully renewable, recyclable and carbon-neutral and, will invest 100 million EUR annually the next 5-10 years in innovation for an enhanced environmental profile. Research has documented that ca. 40 % of global consumers would be more motivated to sort for recycling if packages were made entirely from paperboard and had no plastic or aluminum. Tetrapak is testing a fiber-based barrier to replace the aluminum layer in its cartons for improved climate impact and recyclability. This technology is currently (summer 2022) on shelf for commercial consumer testing for food carton packs distributed under ambient conditions. The aluminum layer is used for food safety reasons. In 2020, the polymer-based barrier has been tested in Japan leading to results about value chain implications, food safety and recycling rates. The example shows how a change of materials (from aluminum to fiber-based barrier) has implications across the packaging material composition, the opening/closure function, the sealing technology, and supplier collaboration and recycling assessment. The example also shows the global approach of the packaging industry.

Polyurethanes (PUs) are polymers representing ca. 6% of the global polymer market with applications that include coatings, adhesives, foams, elastomers and, fibers. These products are used in diverse market segments that include packaging, building and construction, electronics, furniture and more. The global market for polyurethanes is estimated at 55 billion USD with a projected annual growth rate of 6 % (Fortune Business Insights, 2022). The market for PUs is segmented into rigid foam, flexible foam, molded foam, elastomers, adhesives and sealants, coatings, and others. Flexible foam is the largest segment with the most important usages being bedding applications and furniture. The use of flexible foam as specialty packaging for transportation of goods plays a significant role for driving demand upwards. Rigid PU foams are mainly used for insulation purposes of household devices, furniture, automotive applications, and for construction purposes (interview, 2022).

3.4 Other industrial applications

Under the term bio-based composites you find all composites that are made entirely or largely from biomass. Natural and wood fibers are combined with fossil-based or bio-based polymers to develop bio-based composites suitable for use in mechanical processes as well as in lightweight structures. FRACTION project aims at synthesizing a range of chemicals that could be used in bio-based composites, e.g., polyurethanes, phenolic resins, or polymers. The main motivation for using bio-based composites is the sustainability image based on a very low carbon-footprint. There are three main applications for bio-based composites: in the construction sector as material for terrace decking, fences and facades; in the automotive sector for saving weight in car interiors; and in furniture making due to an appealing touch and attractive design (Partanen, 2019 and Interview, 2022). According to calculations by the nova Institute, the market share of bio-based composites in Europe will rise from an annual volume of over 400,000 tons in 2017 to more than 800,000 tons in 2027, indicating an annual growth rate of 5-7 %. The construction sector is the biggest market for bio-based composites followed by molded parts targeted at the automotive industry.

Some of the FRACTION end products are relevant for the food industry, e.g., vanillin and intermediary compounds like lactic acid and succinic acid. Also, cellulose fibers are used as thickener or binding agent as well as modified cellulose derivatives that are used as emulsifying agents or stabilizers in food products. The mentioned compounds are classified by the EU as generally permitted food additives under Annex 1 of Directive 95/2/EC (Wenger et al, 2018). Vanillin is synthesized from lignin with a company like Borregaard being a major producer of wood-based vanillin (Sustainable and bio-based Vanillin - Borregaard)

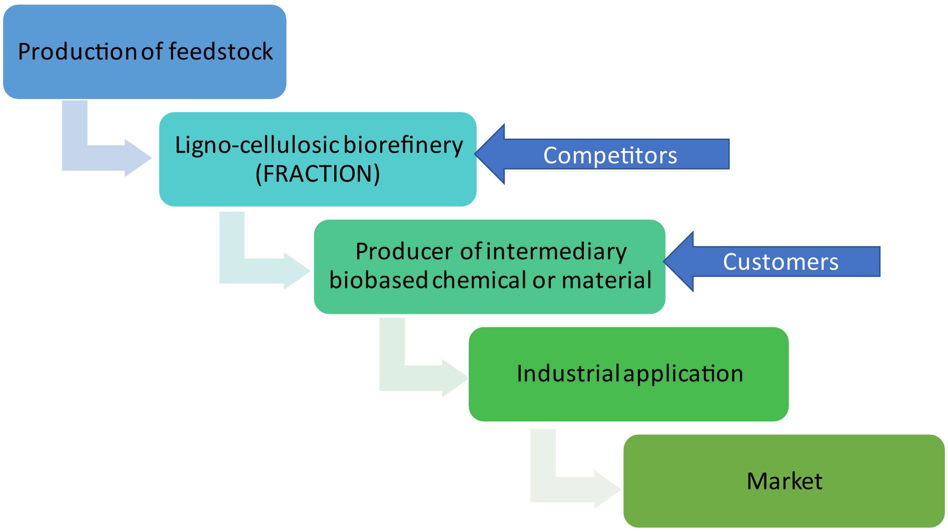
4 Key actors

4.1 Customers

Key actors are those companies that either could qualify as potential customers for FRACTION end products, or as competitors by already having similar chemicals in the market. This chapter will explore both customers and competitors to gain an overview of the competitive situation in the market of a lignocellulosic biorefinery. It should be emphasized that the chapter is explorative and not intended as an exhaustive analysis of the competitive situation as this is beyond the scope of the report.

The end products from FRACTION project are intended to be used by companies that produce bio-based compounds or materials that will be used in an industrial formulation to make a bio-based product. Figure 5 illustrates where in the value chain you find FRACTION's end products, as well as the customers and competitors.

Figure 5: Positioning customers and competitors within the FRACTION value chain.



(Own elaboration, 2022)

It is seen from Figure 5 that FRACTION end products are targeted at companies that would need certain bio-based building blocks to produce specific bio-based chemicals or materials. For example, lignin would be of interest to producers of phenolic resins and, this chemical would be sold on to, e.g., producers of bio-based foams, coatings or composites. Furan can be used in a process to manufacture 5-HMF, which is a chemical that is used to make biopolymers for, e.g., bio-based plastic, textiles or films (packaging material) (Bio-based chemistry | AVA Biochem (ava-biochem.com)). Table 4 provides examples of potential customers for FRACTION end products.

Table 4: Potential customers for FRACTION end products

FRACTION end product	Company /country	Customer's relevance
Furan	AVA Biochem (Switzerland)	Use furan for making 5-HMF (that is used by producers of PEF)
Furan	Avantium Renewable Polymers (the Netherlands)	Use furan-dicarboxylic acid as building block to make PEF
Lignin-based resin	Neste Borealis (Finland)	Used for making bio-based phenols
Wood pulp processing (lignin?)	Ineos (United Kingdom)	Use wood-based resins to make bio-based PVC, organized in joint venture with UPM Biofuels
Lignin, lignin-based resins	Tecnaro (Germany)	Produces bio-based granulates for bio-plastic
Bio-based resins	NPSP (the Netherlands)	Develops bio-based composite materials

(Based on internet searches, discussions at FRACTION Roundtables and literature)

The examples provided in Table 4 shows that potential customers of FRACTION end product could be found in several European countries. However, the bioeconomy is not limited to the borders of Europe, and Asian countries seem to be playing an increasingly bigger role in the world market. For example, China is a major producer of synthetic textiles, chemicals, plastics, as well as innovative consumer electronics and solar cells. All such applications could be produced with bio-based materials and chemicals and so, the market for FRACTION end products reaches in theory far beyond Europe.

4.2 Competitors

When looking for key actors it is also relevant to search for companies that produce similar end products as those derived in FRACTION. There are many such companies in the chemical industry, where some of the largest are for example Dupont, BASF, DOW, Covestro or Akzo Nobel (interviews, 2022). Typically, large companies like the ones mentioned before center their production on fossil-based raw materials, with manufacturing of bio-based chemicals and materials only accounting for marginal shares of the total production.

In contrast, other companies are dedicated to processing of renewable materials like lignocellulosic biomass from wood or agricultural crop residues. Table 5 provides examples of companies that could be regarded as competitors (competitive suppliers) to FRACTION end products because of their choice of raw material or target market/application.

Table 5: Potential competitors to FRACTION end products

Company (country)	Issue of competition	Similarities with FRACTION
Borregaard (Norway)	Commercial scale production of wood-based vanillin since many years (lignin pathway)	Lignin-based vanillin from wood (Norwegian Spruce)
Borregaard (Norway)	Leading commercial position in high value celluloses for food, pharma, cosmetics and coatings	High-value cellulose from wood (Norwegian Spruce)
Borregaard (Norway)	Production of binding agents, emulsion stabilizers	Lignin bio-based polymers from wood (Norwegian Spruce)
Lenzing (Austria)	High value application of cellulose fibers targeted at the textile industry. Production of furfural	Cellulose fibers from lignocellulosic biomass (wood)
Fibenol (Estonia)	Valorization of lignin from wood in bio-composites and insulation foams	Lignin valorization pathways targeted at bio-composites and insulation foams
Weidmann Fiber Technology (Switzerland)	Micro-fibrillated cellulose from wood pulp and perennial agricultural plants	High value cellulose applications
Neste OY (Finland)	Has established a commercial platform for lignocellulose	Lignocellulose valorization pathways
Royal Cosun (The Netherlands)	Production of micro-cellulose fibers for use in coatings, paints, personal care (sugar beet pulp)	Processing of lignocellulosic biomass (wood, bagasse)

(Based on internet searches, discussions at FRACTION Roundtables and literature)

There are many more companies in Europe and other locations that produce similar products as the FRACTION end products (refer to Table 1). It is beyond the scope of the report to map the competitive situation but, it may be concluded that there are already customers and competitors in the market.

5 Quality requirements

5.1 Performance requirements for bio-based products

Quality requirements for the FRACTION end-products depend on the **performance requirements and market requirements; the latter implemented through sustainability certification schemes**. It is a fundamental requirement for using bio-based components (chemicals and materials) in industrial applications that the final product (e.g., a coating) has the same performance and functionality as if it was produced with non-bio-based components. This is clear from interviews with producers of bio-based components, from literature and stakeholder consultations at roundtables. Successful use of bio-based components depends on how well they perform in an industrial system. The performance of the bio-based component in an industrial system is defined according to the **functionality, miscibility, and processability of the bio-based component.**

Functionality refers to the ability of the bio-based chemical to provide similar functions to the final product as would be achieved when using non-bio-based components. For example, if bio-based resins are used to produce insulation foams, the insulation capacity should be the same as when the material was produced with fossil-based resins. Another example is from coatings: Performance of the bio-based product relates to mechanical strength, adhesion, surface hardiness, chemical resistance etc. (Interviews, 2022). This means if bio-based components are added to a formula or replace fossil-based chemicals, then performance of the produced product would not be changed (significantly). Functionality is regarded as a technical quality requirement that relates to the final product. In this line, functionality could also refer to the benefits that are provided to the final product when bio-based chemicals are used in the formulation, for example “biodegradability”, “compostable” or similar attributes.

Miscibility refers to how well the bio-based chemical can be mixed with other compounds in the recipe, thus the property of two substances to mix in all proportions to form homogeneous mixtures. Miscibility is a technical quality requirement that is closely linked with product specifications and the industrial system. An example of a quality requirement related to miscibility is *reactivity* which is understood as how well a pulp dissolves in liquid (interview, 2022).

Processability refers to how the bio-based chemical reacts in an industrial system, i.e., a suitable reactivity in combination with other components in the formula. This refers to, e.g., the behavior and interaction of the bio-based chemical with other components during processing; the property of the bio-based chemical to not undergo unintended chemical transformations during and after processing. Processability may also refer to the benefits or challenges from using bio-based chemicals in an industrial system, for example difficulties of cleaning production lines or preventing obstacles during processing.

Example

Processability is a technical quality requirement and defined according to a certain industrial production system or processing method. The German company Tecnaro GmbH, a supplier of bio-based granulates (used for bio-plastic), provides this information about the processability of its bio-based granulates: Suitable for injection, molding, extrusion, pressing, thermoforming, blow molding and 3-D printing (TECNARO – The Biopolymer Company | ARBOBLEND® ARBOFILL® ARBOFORM®). Similar information has been identified by other suppliers of bio-based ingredients and, could therefore guide the quality requirements for FRACTION end products with regards to processability.

Interviews with producers of bio-based components have revealed a range of examples of how technical specifications to the bio-based components in reality appear as quality requirements related to processability. Examples are listed below:

- Low degree of variability (of e.g., a fraction or pulp);
- Constant quality of the bio-based component;
- Viscosity;
- Hydroxy-value of the bio-based component;
- Purity (share of impurities, e.g., metals or non-intended bio-based fractions);
- Colour and smell of the bio-based component.

From discussions with industrial companies, it is clear that quality requirements targeted at the performance of the bio-based component may lead to quality requirements for the feedstock. Examples of such performance requirements are:

- For hemicellulose and furfural: less impurities;
- For lignin: molar mass, functionality and purity.

From the section above, it is evident that quality requirements for bio-based products, materials or compounds may be articulated according to a range of technical performance parameters. The main determinants for the performance quality requirements are the specifications of the customer to the supplier, and the industrial system. The importance of the latter relates to specific industrial setting, e.g., machines, processing techniques, formulation and knowledge. Most of FRACTION end products are not novel chemical compounds, but, the **innovation** lies in the pathways through which these compounds are produced, the overall fractionation system, and the purity or consistent quality of the compounds. As industrial customers would pose demand criteria addressing purity, processability and/or consistency, it is important for FRACTION end products to live up to (and document) such criteria for the compounds to be attractive to potential industrial customers.

5.2 Sustainability certification schemes

The market for bio-based products is driven by customer demands for products with attributes such as *biodegradable, compostable, produced from renewable biological sources, produced without the use of petrochemicals, or products with a reduced CO2-emission*. Market trends shape quality requirements, and producers of industrial products consider such market requirements in relation to the production process and final product. Quality requirements stemming from the market impact on the industrial producer and the supply chain. Bio-based products should not appear differently from their counterparts made from fossil-based resources. For example, non-transparent bio-based coatings might give a wrongful impression of the quality of the coating or the product itself – think of transparent or orange coatings on metal pieces. Another example is the burnt woody smell that follows from using lignin in, e.g., bio-based foams. From interviews with producers of bio-based components it is revealed that the expected sensory appearance (visual, smell, feel) of the final product must not be compromised when using bio-based components. Interviews with producers of bio-based components and literature reveal that "*sustainability"* is a quality requirement that is becoming increasingly important. For bio-based products (i.e., industrial applications) "*sustainability*" could refer to:

- Made from or with bio-based materials;
- Made from or with renewable resources;
- The product is part of circular economy;
- The product or production process is carbon-positive.

However, using *"sustainability"* as quality criterion is not without complications. Interviews reveal that industrial customers are showing an increasing demand for LCA-data in order to verify a sustainable production. As industrial products (e.g., coatings, plastics, chemicals etc.) are often made with more than one bio-based component, the producer would have to obtain LCA-data from suppliers of all bio-based components. This requires a huge effort from all parties involved (interviews, 2022). In the following section, an array of sustainability schemes is presented with the aim of showing how such schemes facilitate a transition to a circular, bio-based economy.

Several certification schemes are available to actors with requirements to document the amounts of bio-based materials or raw material origin. One such scheme is the **Bio-based Content** that characterizes the amount of biomass in solid, liquid or gaseous products, based on radiocarbon analysis and elemental analysis. The result is a validated content of biomass (biobasedcontent.eu). The Bio-based Content scheme is managed by the Dutch organization NEN. Table 6 shows examples of companies that have obtained the Bio-based Content certification. It is seen that the certification has a global appeal as companies in more continents have applied for the certification. It is further evident that this certification standard aims at documenting the specific content of bio-based material; in contrast to certifications that require a minimum content. This way, the Bio-based Content certification is an objective standard that enables a transparent and credible market communication to consumers and businesses.

Table 6: Examples of companies having the Biobased Content certification

Company (country)	Year of certification	Certified product	Bio-based content
Dermuth Deisel Lackfarben (Germany)	2018	Paints	5 %
BASF Polyurethanes (Germany)	2022	Polyurethane (brand name *Elastollan*)	48 %
Jiangxi Fuxing Leather Good (China)	2022	Bio-leather	80 %
Bastin Pack (Netherlands)	2020	Bio-based films for packaging	89 %
Bio4Pack (Germany)	2017	Compostable packaging material	89 %
Österreichisches Vialit (Austria)	2018	Binder for roadwork	100 %
BioCaps (Germany)	2022	Capsule	100 %

(Certificate holders | biobasedcontent.eu)

The certification scheme **OK Biobased** is applicable for certifying how many per cent bio-based material (in the form of renewable material) there is in a certain product or material. The certification spans across 1 star to 4 stars depending on the percentage renewable material. Of particular relevance to FRACTION, it is mentioned that the certification may also be obtained for intermediary products as for example FRACTION end products (OK biobased (tuv-at.be)).

Example

The Italian company Fabbri Group produces transparent films for packaging and packaging machines. The company has developed a transparent cling film made from 30 % renewable resources of plant origin. The film is certified with the OK Biobased label (BIOBASED STAR FILM – Gruppo Fabbri | Official WebSite)

The **RSB (Roundtable for Sustainable Biomaterials)** Standard for Advanced Products is a robust, credible and practical solution to help companies in a transition to use sustainable materials. The Standard is recognized as the strongest and most trusted of its kind by World Wildlife Fund (WWF), International Union for Conservation of Nature IUCN) and Natural Resources Defense Council (NRDC). As the Standard includes the full supply chain, it often has a direct impact on the supplies of novel feedstocks whether of bio-based or recycled origin. The Standard enables companies to demonstrate clearly that their products are produced more sustainably, with fewer fossil resources and reduced GHG emissions. The Standard offers certification of three categories (RSB, 2022a):

3. **Bio-based**: Products with this certification are made of feedstocks are from agriculture, forestry, marine, by-products or residues;
4. **Recycled content**: Products with this certification have recycled content, and feedstocks can be end-of-life products, by-products or residues, or recycled biogenic materials;
5. **Attributed system**: Products bearing this certification include those from production systems that use bio-based feedstock, non-bio-based end-of-life products, in combination with virgin fossil feedstock. The certification offers greater flexibility for manufacturers to bring innovative products to the market.

Example

Responsible sourcing is a strategic objective for Tetra Pak, and the company has become the first carton packaging provider in the food and beverage industry to launch a cap using certified recycled polymers. The cap is produced at the Tetra Pak factory in France; a site that has been boosted with a 100 million EUR investment to accelerate the transition to produce with sustainable resources. The new cap uses the RSB certification "Attributed system", and the corresponding recycled materials are tracked throughout Tetra Pak's supply chain. The cap is for liquid milk and made for the French dairy Elle & Vire (Packaging Insights, 2022).

Example

Ineos (UK) is certified with the RSB (Roundtable on Sustainable Biomaterials) certification. Ineos will use the certification for bio-attributed polyolefins to produce bio-based PVC films. The polyolefins are produced by UPM Biofuels from wood pulp. The collaboration of Ineos and UPM Biofuels is important for making plastic films from renewable materials and for committing to reduce environmental and climate impact from conventional plastic production (INEOS to use UPM BioVerno to produce bio-attributed polyolefins (packaging-gateway.com).

The **Roundtable on Sustainable Biomaterials (RSB)** is an international certification scheme aimed at ensuring a sustainable production and use of biomaterials. The scheme builds on 12 action points, e.g., land use, water use, soil, greenhouse gas emissions, local food security, land rights and use of technologies. Feedstocks, products, complete supply chains and, novel feedstocks and processing techniques can apply for the certification (RSB Standard Certification System Validation). **The scheme is interesting for FRACTION as it is open to new processing techniques and a value chain approach**. The RSB is a global membership-based organization including businesses, NGOs, academics, government, and UN organizations that work together to drive a just and sustainable transition towards a circular and bio-based economy.

From the section above, it is clear that companies in the bio-based industry may benefit from having one or more schemes for documenting sustainability – whether this being an LCA approach, transparency in bio-based content, or otherwise. The key issue is that various certifications are available and target biomass, product, processing technique, or value chain. Given the diversity of sustainability schemes, it is obvious that transparent communication about the schemes' requirements as well as the application of this information by companies it is of pivotal importance for maintaining market trust in bio-based products and their value chains. From a FRACTION perspective, there is much to gain from the growing awareness and use of sustainability schemes for bio-based products and value chains: The bigger attention from market players (e.g., customers, regulators, investors and others) on bio-based products, the more the need for transparency in the market. FRACTION end products are natural candidates for certification under one or more sustainability scheme.

Sustainability can be addressed with different and complementary approaches, like renewable raw materials and circular economy (recycled materials, unutilized / underutilized side streams of industries or biorefineries). Appropriate metrics are key to measure sustainability. Examples includes bio-based content (determined according to ASTM D6866 standard), Life Cycle Assessment (ISO 14040 and 14044 standards) and parameters like Carbon and Water Footprint. In particular, LCA methodologies take into consideration not only starting raw materials, but also the transformation processes which lead to chemical products (like polyols) and to end use materials (like polyurethane foam). Manufacturers willing to evaluate the environmental impact of their products ask their upstream supply chain for more and more reliable data on the ingredients, like bio-based content and LCA impact parameters. The closer the manufacturer is to the consumer market, the more frequent is the request of data. Companies using bio-based drop-in chemicals to replace fossil-based ones are requested to certificate their supply streams, to avoid improper exchange of bio and fossil-based raw materials. This demand for demonstrated and quantified environmental benefits links with the Corporate Social Responsibility of manufacturers, and can become a powerful tool for marketing and communication strategies (interview, 2022).

6 Discussion and conclusion

6.1 Discussion – market challenges and opportunities

Global challenges like climate impact, land and ecosystem degradation, coupled with a growing population, force society to find new ways of producing and consuming while respecting the ecological boundaries of planet Earth. Innovations in the way biological resources can be processed open up to a wide portfolio of new or adapted products that are made from renewable biological resources: bio-based products. The chemical syntheses in the FRACTION project are targeted at demonstrating how bio-based chemicals from cellulose, hemicellulose and lignin streams could become valuable components in the manufacturing of bio-based products.

Quality requirements for bio-based chemicals are the same as requested from fossil-based products. Bio-based drop-in products, having the same chemical structure and properties of their fossil benchmarks, are easily accepted into the market, provided that they are delivered with the same purity level. If performance is below standards, then the bio-based alternative is not considered. If the target product performs similar or better in presence of bio-based ingredients, then it is regarded as a new product in the market (interviews, 2022).

The analysis in the report-at-hand has shown that there already is a market for FRACTION end products, and that this market is expanding – with examples from selected industrial applications to underpin the findings. It could well be stated that the market growth rates for the selected industrial applications by far exceed the growth rates for similar conventional applications, Table 7.

Table 7: Market growth rates for potential industrial applications for FRACTION end products

Industrial application for bio-based product	Growth rate
Cellulosic fibers (for textiles)	9% annually 2019-2024
Nanocellulose (various applications)	19 % annually 2014-2019
Bio-based coatings and paints	5-9 % per year 207-2022
Polyurethanes	6 % annually in the coming years
Bio-based composite materials	5-7% annually 2017-2027

(Own elaboration based on literature, interviews and internet searches)

Despite appealing market growth rates, the market share for bio-based chemicals or materials in the selected applications remains limited – namely approx. few per cent. The old, or existing bioeconomy is centered around big volumes and low-priced bio-based products, particularly fuel. However, it has proven difficult to develop a profitable business for many companies in those segments where bio-based products compete on par with fossil-based products as for example in plastics or chemicals. A very important barrier for the transition to bio-based, e.g., chemicals or plastics, is that the markets (especially consumers) are not aware of how many of daily used products are in reality made from fossil resources. The awareness of existing alternatives among bio-based components and materials seems higher among industrial companies, yet the complexity of the market is huge. Consider here the big challenges of classifying chemicals or materials according to various standards. Here, it may prove highly useful to push for a stronger market uptake of certification schemes that promote transparency and accurate information about bio-based products, processes and value chains.

The future bioeconomy takes to targeting high-value applications in much smaller market segments, where emerging technologies or materials play a strong role (Schorneck, 2022, roundtables and interviews). This development pattern implies that bio-based products and materials that will be introduced in the market in the near future are targeting niche or emerging segments where high prices could be obtained. Looking up-stream in the value chain, this would induce more attractive market conditions for suppliers of bio-based components and chemicals such as the FRACTION end products because such chemicals or materials could be customized. Further in this line, in high priced markets, additional attributes such as "*made from bio-based ingredients*", "*made from renewable resources*", "*compostable*", "*light-weight*" or "*recyclable*" become more important yet contribute to underpin a high value supply chain.

Companies in the bio-based industry face a growing pressure from industrial customers to document sustainability of operations by signing up for one or more of the sustainability schemes – whether this being an LCA approach, transparency in bio-based content, or otherwise. The key issue is that various certifications are available and target biomass, product, processing technique or, value chain. Given the diversity of sustainability schemes, it is obvious that transparent communication about the schemes' requirements as well as the application of this information by companies it is of pivotal importance for maintaining market trust in bio-based products and their value chains.

Policies and the EU Green Public Procurement scheme play major roles for driving the demand for bio-based products forward. As illustrated in chapter 2, Green Public Procurement criteria are now in place for several of the industrial applications that are central to FRACTION end products. Hence, there are market measures that can be deployed to drive up demand for bio-based products.

Some market barriers are related to the (often wrongful) perception of bio-based products as less performing, which typically comes from past trials. Objective market barriers are often colour and odour, which are not in line with the standards offered by fossil-based benchmark. A typical example is the darker colour of amine hardeners in epoxy coatings, in applications where aesthetics is key. Development of new bio-based products must address these concerns in order to reduce market barriers. Similar examples are given in interviews and discussed at roundtables.

It is beyond the scope of this report to map costs for the selected bio-based applications, yet it is a fact that costs for bio-based products are still up to 25 % higher than for fossil-based products. This clearly shows that costs are very important for developing the market for bio-based products including those produced in FRACTION project. Price fluctuations on energy and materials have a strong impact on demand as prices for bio-based products have not increased at the same pace as prices for fossil-based products. It could be claimed that the current market turmoil is creating good opportunities for bio-based products (interview, 2022).

Due to the war in Ukraine and other uncertainties in the world, the prices on fossil-based chemicals have increased and this has narrowed the gap to the prices on bio-based chemicals. This market development stimulates demand for bio-based solutions. Example: lignin-based phenols can be 25 % more expensive than fossil-based phenols today, yet demand for bio-based phenols is still strong. This development is happening since the last 12 months (interview, 2022). A main obstacle for bio-based coatings in the market is their higher price compared to the price of coatings made from fossil-based sources and their vulnerability to resist price fluctuations on commodity raw materials, e.g., vegetable oils or glucose (Cagro, 2022).

6.2 Conclusion

The report has assessed and documented that there is a market for the end products from the FRACTION project. The market is real with all its challenges, opportunities, structures and actors. Industrial applications that can make use of FRACTION end products are already in the market. The market for bio-based chemicals and materials will display promising growth rates in the near future in emerging segments targeted at advanced uses of bio-based components.

There is still quite a gap from the current TRL of ca. 4 for the FRACTION end products and until the FRACTION end products could be launched in a commercial context. Much more development work needs to be done including thorough testing in various industrial systems.

To this end, it is the objective of the FRACTION project to provide solutions that contribute to an expanding European bioeconomy for the benefit of economic, environmental and social prosperity.

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Appendix 1 Questionnaire for interviews

6. What are the main industrial applications for your bio-based chemicals?

7. What companies would you say are the most important actors for the selected industrial applications?

8. How important are bio-based solutions for the above-mentioned companies?

9. How important are bio-based solutions for the above-mentioned applications?

10. Are FRACTION end products considered for replacement, drop-in or reformulation?

11. What is currently happening in the market for the selected industrial applications?

12. What are the most important market drivers and, how does it impact on the industrial market?

13. What are the most important market barriers?

14. How do these barriers impact on demand for the industrial applications?

15. What are the quality requirements to the FRACTION end product for the selected industrial application? Examples?

16. In what way do quality requirements for industrial applications impact quality requirements for cellulose, hemicellulose or lignin?

17. What factors shape quality requirements for bio-based solutions in the selected industrial applications?