Report on case study “New wood-based products”

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D8.2: Report on case study “New wood-based products”

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Monitoring the Bioeconomy

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Summary

Technology and innovation are key drivers of the development of the bioeconomy by fostering the development of innovative and climate-friendly bio-based products and technologies. This case study on new wood-based products deals with the emerging markets for forest products, looking into innovations with market potential that use woody biomass and their derivatives as feedstock. These products should be sustainable, regarding the sourcing of feedstock, product design (e.g., concerns about recyclability), production process, waste and residue treatment, among others. The bio-based products should represent an improvement to older technologies or to fossil-based products, in terms of reduced emissions of greenhouse gas (GHG) and other pollutants, reduced waste, among others.

Our case study identified products to be reviewed selected based on their estimated Technological Readiness Level (TRL), time-to-market estimation or potential to increase in market size (for novel products). We also took into consideration a broad market potential and the circularity aspects of the product and production process. Our analysis was based on (1) interviews with selected stakeholders as part of scoping the product landscape and select relevant products and define product categories, (2) a survey with stakeholders in the field, and (3) extensive document analysis. There is a wide range of products that can be manufactured from biomass resources. We reviewed nine products from five main product categories, namely construction materials, bioplastics, biochemicals, wood-based composites and textiles focusing on feedstock requirements, sustainability aspects and compatibility with existing value chains.

There are several innovative wood-based products (e.g., CLT and textile fibres) that are already today produced at an industrial scale in Europe and can be expected to increase their market share in the coming years. Some up-and-coming products, that are not yet produced at an industrial scale but are entering mature markets are biochemicals, bioplastics and to some extent bio-based composites. These products are entering mature markets, and in many cases can fully drop into established value chains. The range of wood-based products covered in this case study is reflected in the variety of fossil-based products and materials that can be substituted.

The ease of market introduction of new innovative products relies heavily on the products' ability to take advantage of existing value chains. In general, many of the products reviewed in our study are fully drop-in, which is a huge advantage when it comes to market introduction. Products that require adjustments to production lines or methods are less likely to get into the market without strong external drivers that push for bio-based alternatives. Only a few products are completely new and thus require new value chains. These products are generally not replacing fossil-based alternatives but rather create new, specialized market segments.

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1 Introduction

The updated EU Bioeconomy Strategy, adopted in October 2018, aims to develop a sustainable bioeconomy for Europe, strengthening the connection between economy, society and the environment. The updated Bioeconomy Strategy addresses the competing use of biological resources (i.e., animals, plants, micro-organisms, and derived biomass, including organic waste), encompassing multiple sectors and policies with a view to achieving policy coherence and synergies. Technology and innovation are key drivers of the development of the bioeconomy (Aguilar et al. 2009; Wesseler and von Braun 2017; Kardung et al. 2021). For example, technological development is considered of key importance for the development of innovative and climate friendly bio-based products and technologies (Lovrić et al. 2020).

Innovative bio-based products should also be sustainable, when considering the sourcing of feedstock, product design (e.g., concerns about recyclability), the production process, waste, and residue treatment, etc. Other items to be considered are the use of resources (e.g., energy, water and other) and emission of pollutants during processing or manufacturing a product, to ensure that the bio-based products will have low carbon and water footprints. The bio-based products should represent an improvement to older technologies or to fossil-based products, in terms of reduced emissions of greenhouse gas (GHG) and other pollutants, reduced waste, among others. Another environmental issue to be considered is the release of microplastics during regular use afterwards when discarded (World Economic Forum 2016).

These issues and constraints are pushing industries to develop technologies and processes that are more sustainable for the environment. For instance, fossil-based plastics and composites used in packaging are being substituted with bioplastics (Philp et al. 2013), cellulose-based foam (Hjelt et al. 2021), and other renewable materials. Cement, steel, and other GHG-intensive materials are also being partially substituted with wood structural elements in construction of buildings (Antikainen et al. 2017; Green and Taggart 2017; Churkina et al. 2020; D’Amico et al. 2021). Other industries, such as the fashion industry, are starting to look into producing and using textiles that are less resource-intensive, that cause less pollution and that can be recycled at the end of the product lifecycle (Kataja and Kääriäinen 2018). There is a wide range of products that can be manufactured from biomass resources. However, some of these products and technologies are either in early stages of development or are, at least at the moment, deemed technically or economically unfeasible.

This case study focuses on new wood-based products (Subtask 8.2.1) and deals with the most significant emerging markets for wood-based products, looking into innovations with market potential that use woody biomass and their derivatives as feedstock. Several previous studies have tried to identify new/emerging bio-based products, but were not specific to the forest sector (University of Bologna and Fraunhofer ISI 2018; COWI et al. 2019), or they focused on specific product categories such as chemicals (Lettner et al. 2018; Spekreijse et al. 2019). Hurmekoski et al.

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(2018) looked at new products manufactured by the forest sector, but focused on Finland, Sweden, the United States and Canada. The case study presented in this report aims to review 5-10 emerging wood-based products in the EU, covering a wide range of wood-based product categories. Specifically, we try to answer the following research questions:

- What are the main new wood-based products that could be economically produced in Europe from lignocellulosic biomass from forests in the near to medium future?
- What fossil-based chemicals or materials could the new wood-based products substitute?
- What are the requirements for biomass quality and quantity?
- To which extent are these products compatible with existing value chains?

Where does this case study fit on BioMonitor?

The aim of WP8 is to test, validate and fine-tune the operationalization of the three pillars of the BioMonitor project, and provide feedback for improvements and recommendations for their implementation. These objectives are being met through six case studies. The common outputs for the case studies include: 1) the lessons learnt and best practices for data collection, 2) the test and validation of new indicators, 3) the provision of new data for models applied in WP5, and 4) the validation of the BioMonitor Model Toolbox output at a cross-regional, cross-sector, and product level.

This case study on new wood-based products supported the identification in WP3 (Task 3.2) of bio-based sectors that require extending the Statistical Classification of Economic Activities in the European Community (NACE) and the National Accounting Systems (NAS). The background information on the wood-based products reviewed in this case study report has been used in WP3 to propose extending PRODCOM (CPA) codes and Combined Nomenclature (CN) codes for specific bio-based products. In addition, the outcomes from this case study will be used in WPs 4 and 5 to improve and extend the economic models with information on the production (technologies, efficiencies, etc.) of cross-laminated timber, ethylene from wood sugars and textile fibers.

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2 Material and Methods

A multitude of products could be classified as “new wood-based products”. To help narrow down the number of options of innovative products to be reviewed, we defined the following criteria:

- the feedstock used to manufacture the product should be derived from wood or from by-products obtained during the industrial processing of wood (e.g., black liquor from the pulping process);
- the products should cover a range of product typologies from five categories, namely: construction materials, textiles, chemicals, bioplastics and composites;
- the products should be able to substitute fossil-based or GHG-intensive materials; and
- the products should have a Technology Readiness Level (TRL; see Table 1) between 5 and 9 to indicate that products could come to the market in the next 5-10 years.

Table 1 – The nine Technology Readiness Levels (TRL), as used within the European Union (EU)

Level	Description
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in laboratory
TRL 5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated in a relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	System prototype demonstration in an operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Source: Horizon 2020 (2014)

Considering the previously defined criteria for new wood-based products, a first list of potential products was created based on knowledge acquired in previous research projects, from scientific and grey literature, and from news articles. This preliminary list was then improved upon with a structured web search using keyword blocks such as:

a) Keywords block one: "wood-based" OR "bio-based" OR "wood";
b) Keywords block two: previously defined product category (e.g., construction materials).

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An example of a string used during the web search is, as follows:

(wood-based OR bio-based OR wood) AND ("construction materials" OR textiles OR chemicals OR plastics OR bioplastics OR composites)

While compiling the list of potential products, we also checked which research institutes and companies that are involved in the development or manufacture of products. This list of potential stakeholders operating in the EU was improved upon based on expert knowledge, members of forest and wood industry associations and consortia. Once the preliminary list of potential products and stakeholders was built, we proceeded with the design of the data collection methodology, which would be composed of interviews with stakeholders, literature review and an online survey with stakeholders. The steps involved in the development of the case study are presented in Figure 1.

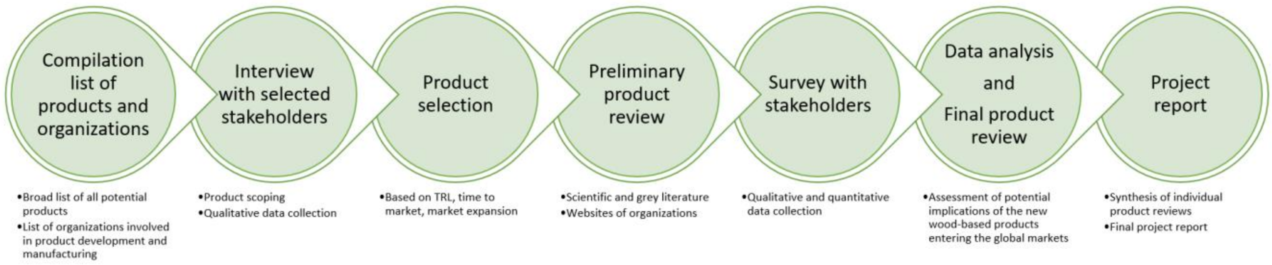

Figure 1. Steps for the development of the case study

2.1 Data collection

Information on the development and characteristics of products and technologies is not often widely available. To answer our research questions, we therefore collected qualitative information and quantitative data using a combination of data collection methodologies, namely: interviews, surveys, and scientific and grey literature review. This allowed us to triangulate the data from these three sources and make the findings more robust. The procedure adopted in each of these methods is described in the sections that follow.

2.2.1 Interviews

Our case study focused on assessing new and emerging products. Because a myriad of wood-based products is currently available on the market and under development, a direct contact with product developers through interviews was deemed the most efficient avenue for product scoping. As

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previously described, we compiled a preliminary list of products and organizations developing and manufacturing innovative wood-based products. To reduce bias towards one or few European regions, we made sure the listed organizations were operating in several countries within the EU.

Since the main objective of the interview was to scope for new products and considering that organizations are usually involved in the development of several products, we decided that, for each product category (i.e., construction materials, textiles, chemicals, bioplastics and composites), two organizations would be selected for an interview. From a pool of 39 stakeholders, we selected 12 organizations based on the variety of products in development, the geographical location (of their facilities) and whether our team members had previously established contact with the organization.

The interview questionnaire (see Appendix 1) was built with the main objective to scope for innovative products being developed in the organization. We also aimed to collect qualitative data about the production process and the value chain, as well as to get insights about the (future) markets. The interviews were semi-structured, using the questionnaire as the basis, but opening the discussion according to the stakeholder's interest. The online interviews lasted for about one hour and the notes were recorded in written format.

2.2.2 Literature review

The preliminary list of products to be reviewed was built based on the products' estimated TRL (from 5-9), and time to enter the market (for new products) or potential to increase in market size (for novel products). We also took into consideration a broad market potential and the circularity aspects of the product and production process. The potential products that did not meet the criteria previously defined (e.g., products at early stages of development) were not retained in the pool of potential products. We also focused on products that could be produced in the EU in the short to medium term, i.e., that could potentially enter the market in the next 5-10 years. Once the products were selected, we conducted a review of scientific and grey literature, as well as websites of the manufacturing companies and research institutes.

2.2.3 Surveys

The information collected during the interviews with stakeholders and the literature review on new wood-based products was complemented with data gathered through an online survey. The questionnaire was built to collect qualitative and quantitative data (see Appendix 2). Thirty-nine stakeholders from the industry and research institutes were contacted through email. We asked all stakeholders to complete an electronic survey, which would take between 15-20 minutes to complete. We used the online platform SurveyMonkey™ for its flexibility regarding the types of

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questions (from open-ended to multiple-choice), the quick turnaround, the ease of distribution, and ease of use for respondents, which increased the chances of participation.

The organizations were given two months to participate on the survey. After this period, we sent a reminder with the link to the survey to all organizations. Three weeks more were given and then the survey was closed. We also duplicated the survey, however, with a different link. The link to this separate survey was shared on social media channels from the BioMonitor project, as well as those of the European Forest Institute and nova-institute. By creating a separate survey, we would be to distinguish the answers by our stakeholders from the ones given by organisation representatives through social media to reduce the risk for flawed or incomplete data.

2.2 Justification of research approach

This case study included a wide variety of products, as the scope was not determined by the end-product but rather by the feedstock used for products. This diversity in products and in the market maturity of the diverse products presented a methodological complication, especially with regards to quantification. By identifying these issues early on, the case study methodology included both qualitative assessments and quantitative analysis. The initial scoping of the products was done through interviews with stakeholders representing a wide range of innovative wood-based products. Based on the interview, product categories were identified and a survey was constructed to collect data from a larger number of stakeholders. Based on the scoping exercise, several common factors were identified and could potentially be quantified and analysed despite the diversity in the stakeholder dataset.

Overall, this case study sought to identify five to ten new wood-based products in the EU, with potential markets, that could contribute to climate change mitigation through substitution in the near to medium future (5-10 years). Because we anticipated that each wood-based product would have a different value chain and a different market, the units of analysis in this case study were, thus, the individual new wood-based products that were reviewed. Therefore, this case study was composed of up to ten units of analysis.

2.3 Design of the case study

The ***case*** that was studied in subtask 8.2.1 was the segment of the forest sector that is actively working (i.e., developing and producing) innovative wood-based products. As previously mentioned, the ***units of analysis*** were the individual new wood-based products reviewed in this case study. The ***type of design*** adopted in this study was the multiple case design with embedded

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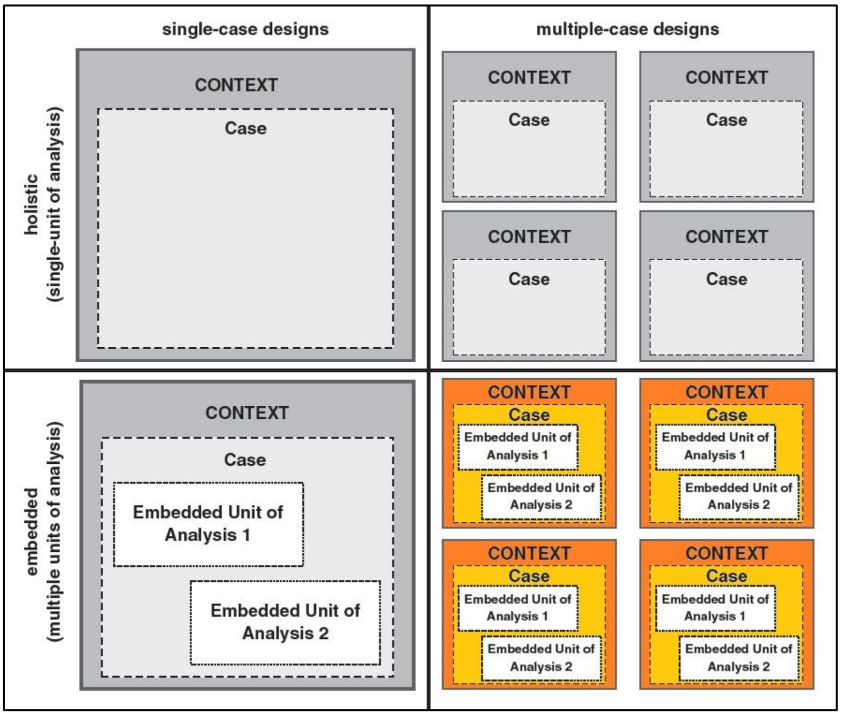
units of analysis (Figure 2), where several organisations – some working with several types of bio-based products – were involved as stakeholders to give a broad overview of the forest sector. Thus, the embedded units of analysis were the individual innovative wood-based products.



Source: Yin (2009)

Figure 2. Types of case study designs

The ***development stage***, as seen in D8.1, is mostly classified as "new bio-based products or industries". Exceptions are related to products that are already in the market, but which are expanding in market size (e.g., cross-laminated timber). These would then be at a "mature" development stage. The ***bio-based pathway*** in our case study was the "multiple commodities" type, where several wood-based products were assessed. We used a stratified ***sampling strategy***, with groups or strata defined by the product categories of our interest (i.e., construction materials, textiles, chemicals, bioplastics, and composites). The ***connection between research questions and units of analysis*** is presented in Table 2.

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Table 2 – Connection between research questions and units of analysis in subtask 8.2.1

Research question	Connection with the units of analysis
What are the main new wood-based products that could be economically produced in Europe from lignocellulosic biomass from forests in the near to medium future?	This research question helps identify the units of analysis and frame them within a context (i.e., lignocellulosic biomass from forests, near to medium future).
What fossil-based chemicals or materials could the new wood-based products substitute?	This research question helps (1) narrow down the units of analysis to products that have a potential for substitution, and (2) add specificity to the wood-based products.
What are the requirements for biomass quality and quantity?	This research question helps define the information gathered from stakeholders and, thus, estimate the future availability of feedstock for existing and new products, and the quality requirements of the raw material.
To which extent are these products compatible with existing value chains?	This research questions adds information on the technical maturity of the units of analysis.

2.4 Context

The context in which new wood-based products have been and are emerging is of course not static, however here we briefly describe some of the drivers behind the development of these products as well as some other contextual factors affecting the case study. Wood has always been a valuable feedstock for human societies but fell out of fashion as new cheap and versatile materials, such as plastic, took over the market. In modern day society, we have increased the awareness of environmental impact and use of limited resources, meaning that there is an increasing demand for renewable and sustainable alternatives to fossil-based feedstock. There are also some specific drivers promoting wood as feedstock over agricultural crops. Wood can often be grown on soils that are unsuitable for food and feed production, which means that as demands for food and feed increases, while available land suitable for agriculture is thought to be depleted due to climate change, wood has a significant advantage as feedstock for various products.

Naturally, the development of innovative wood-based products occurs mostly in countries with a traditionally strong forest industry and where the large forestry companies actively seek out and support start-ups or initiatives that work with innovative products. These countries also have national research organizations that are either focused on forest industry or have divisions devoted to research on forest-based products or improvements of existing products. Another factor that will affect the development of innovative products is the support systems and legislation, both national and in an EU-context. Legislation that drives development in the field can, for example, be restrictions or restrictive policies that are set in place to decrease use of fossil resources or, in some cases, completely ban fossil-based alternatives. Support systems can be programs that provide support for development of products, testing of products or to support scale up in manufacturing of products.

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A complete listing and description of potential contextual factors affecting the case study is difficult as it would comprise everything. Factors that we have excluded above but that could potentially have an influence are, for example, access to suitable testing sites, educated staff and customer demand. For the first two, the differences should not be noticeable between EU countries, but it can be a factor in expansion globally. Customer demand is definitely a factor as sustainability is an increasing customer preference, but demand is also highly dependent on competitive pricing – a factor that is, in turn, closely connected to legislation and policies.

2.5 Data analysis method

The information collected during the literature review on wood-based products and the data obtained from the research centres and industry representatives were combined to assess the potential implications of the new wood-based products entering the global markets. A coding system was used to categorize the qualitative data. As the stakeholders used different terms for the same object, we harmonized the content as much as possible, making sure information was not lost in this process.

We performed a stepwise backward elimination of the products mentioned by the stakeholders, removing the ones that did not use feedstock from the forest sector, that had low TRL or that were already on the market but did not have the potential to expand their market size. We then considered the availability of information about these products, eliminating the ones for which limited information was available. Finally, we analysed the selected dataset using a grounded theory approach, having our research questions as basis (Lazar et al. 2017).

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3 Results

3.1 Interview results

From the 12 stakeholders that were selected for the interview, 10 were able to participate. The specific products mentioned by the interviewed stakeholders are presented in Table 3.

Table 3 – Products mentioned during the interview with stakeholders

Category	Product	Main uses
Construction materials	Cross-laminated timber (CLT)	Building elements
	Laminated veneer lumber (LVL)	Building elements
	Wood foam/cellulose foam	Insulation (thermal and acoustic), packaging
Chemicals	Lignin-based adhesives	Adhesives
	Glycols	Bioplastics, biofuels, etc.
	Nanocrystalline cellulose (NCC)	Biomedical products, hydrogels, 3D-printing, etc.
	Lignin-based carbon black	Fillers for tyres
	Wood-based chemicals building blocks	Bioplastics, detergents, cosmetics, resins, etc.)
	Biodiesel	Biofuels
	Bio-naphtha	Biofuels
Bioplastics	Bioplastics from tall oil	Packaging
	Bioplastics from ethylene	Packaging
	Flexible packaging material	Barrier material in packaging
Wood-based composites	Sulapac material	Packaging, daily use products, etc.
	3D molded parts	Parts for automotive, transport and furniture industries
	Wood-plastic composites	Decking, outdoor furniture, etc.
	UPM formi	Injection molding
	Bio-based polymer	Material for 3D printing
Textile fibres	Lyocell fibre	Staple fibre for textiles
	Kuura/Ioncell fibre	Staple fibre for textiles
	Veocell	Fibre for nonwovens
	TreeToTextile (process)	Fibre for textiles

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The products mentioned during the interviews were well-distributed in the five pre-established categories (i.e., construction materials, chemicals, bioplastics, wood-based composites, and textile fibres). Having this preliminary list, we proceeded with the survey to gather more specific data about some of these products.

3.2 Survey results

From the list of 39 stakeholders, 10 participated on the survey and contributed with some qualitative and quantitative data. This is a participation rate of 26%, which is expected for this type of survey. We had an additional 22 participants who participated using the link shared in social media, but only 11 of them contributed with relevant data. The distribution of stakeholders within the EU was quite balanced, with a slightly higher response rate from participants from Germany, Ireland, and Finland (Figure 3).

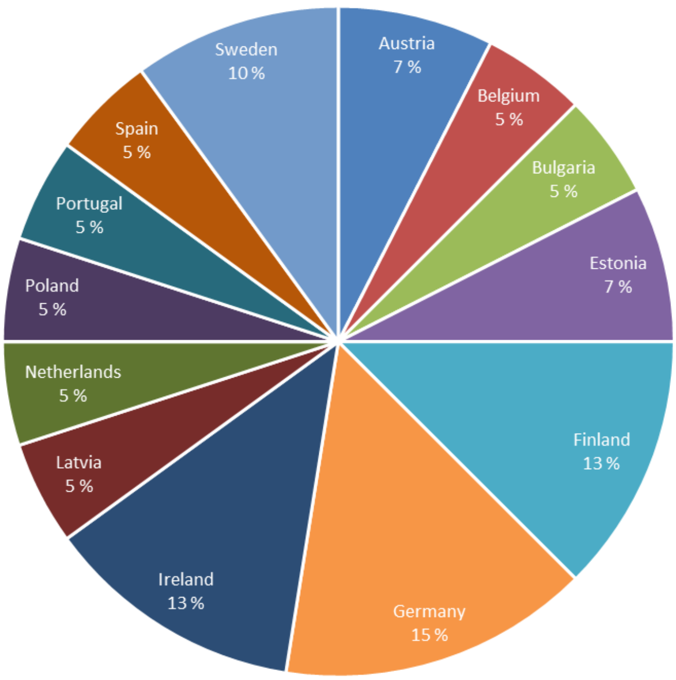

Figure 3. Country representation on survey

Two of the stakeholders were representatives from start-ups, seven in small or medium-sized enterprises, eight in multinationals, and five in research institutes. The products mentioned by these stakeholders during the survey were well-balanced across the five product categories, which indicates that our study was able to equally cover equally the different industries operating the in the wood products sector (Figure 4).

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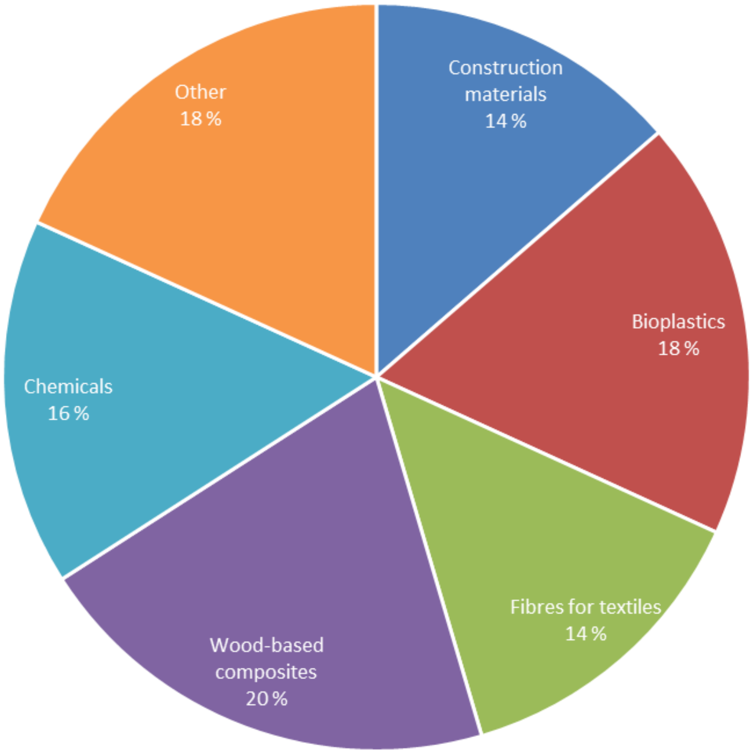

Figure 4. Proportion of products covered in the survey with stakeholders in each category

Some products classified as "Other" and mentioned by stakeholders in the survey were related to energy and food. Other products grouped in this category included, namely: fibre-based barrier material, pulp for paper, packaging materials, and biofuels. From all the pool of products mentioned by the stakeholders, sixty-four percent of the products were considered intermediate, and thirty-six were final products.

Among the types of feedstock mentioned by the stakeholders, regardless of the type of product, wood pulp and wood chips were the two most common ones, followed by sawdust and others (Figure 5). The latter included materials such as wood residues, waste, sludge, cellulose-based materials, and industrial sugars.

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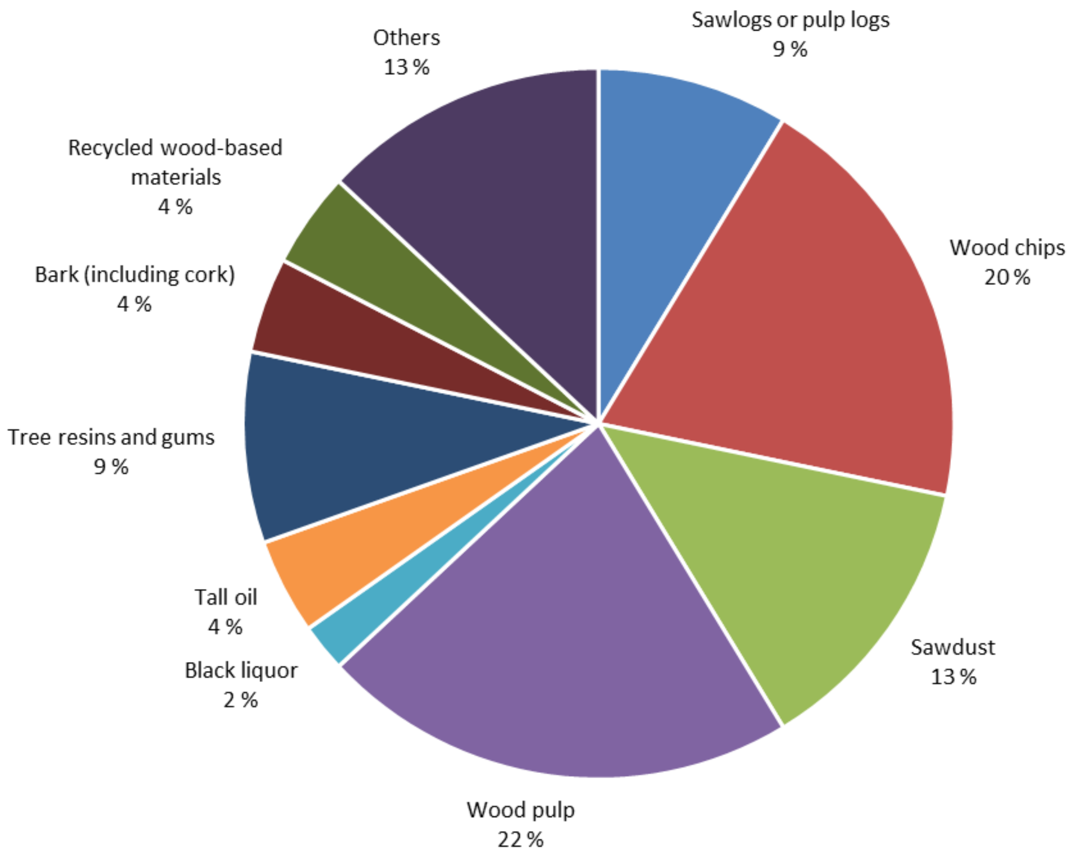

Figure 5. Type of feedstock

We were also interested in knowing the distance from the source of bio-based feedstock to the processing plant (Figure 6). This is connected to the type of product to be produced and with the regional development of the sector.

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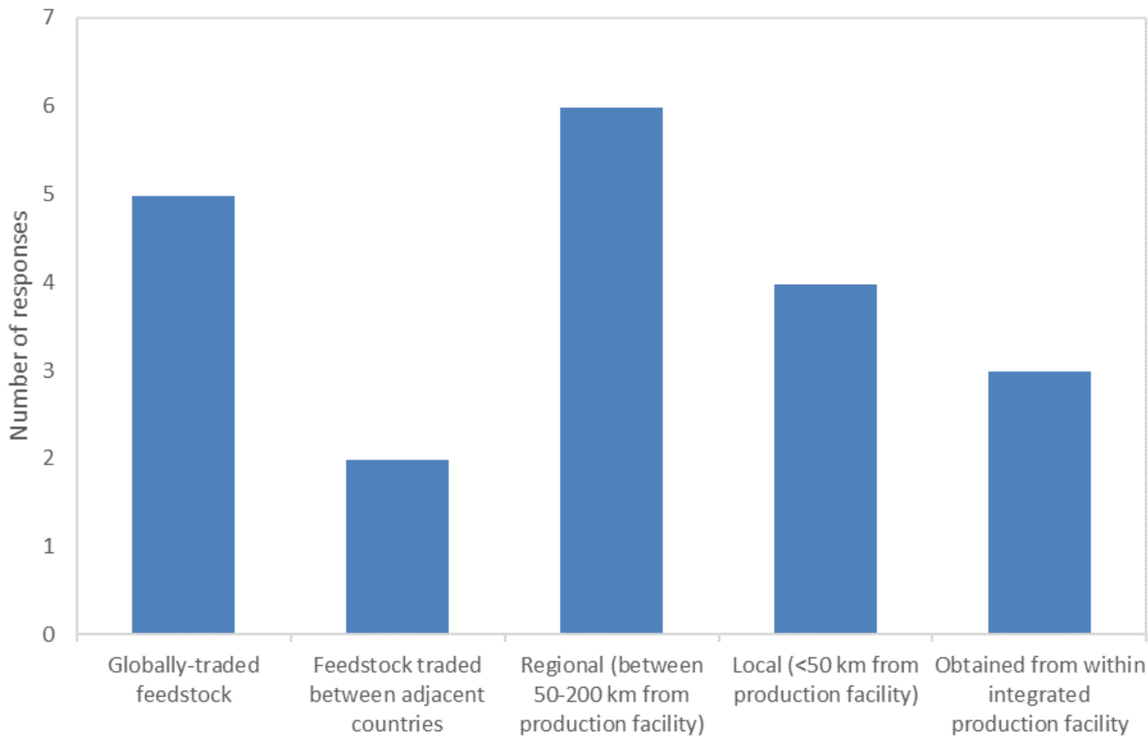

Figure 6. Distance from the source of bio-based feedstock to the processing plant

Most of the feedstock is obtained regionally (50-200 km from production facility), followed by globally traded feedstock. For some products, especially the ones developed or produced by companies that work with a large assortment of products, the feedstock was obtained from within an integrated production facility. Very few respondents source their feedstock from adjacent countries. Most stakeholders expect an increase in the biomass demand for their products; half of them expect an increase by more than 10% and half an increase by less than 10%. When asked if the wood-based product in question could substitute to some extent a fossil-based or GHG-intensive product in the value chain, most stakeholders replied that their products are considered drop-in (Figure 7).

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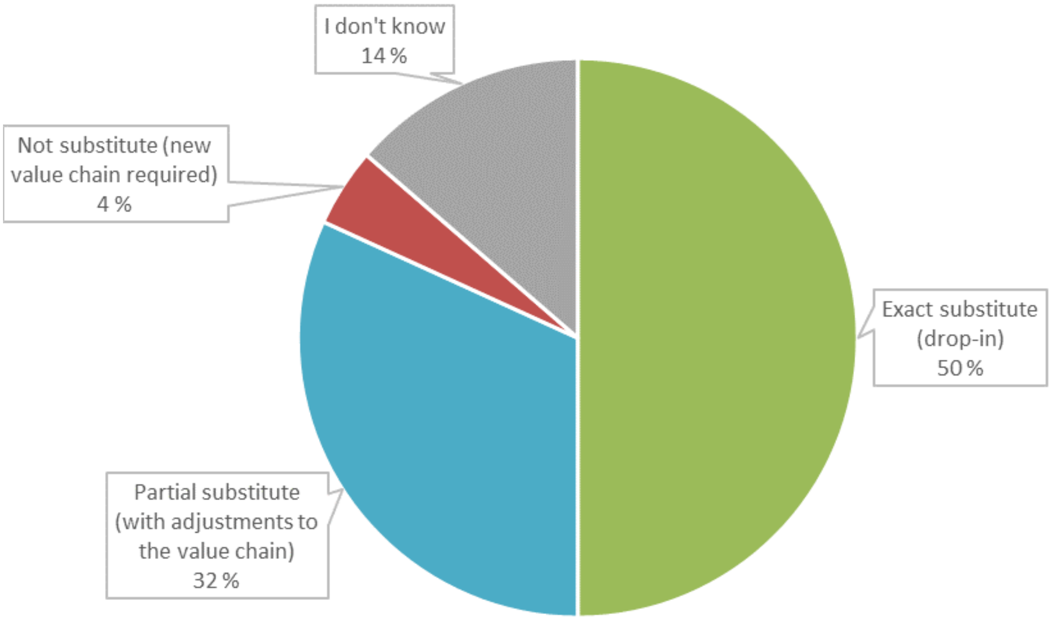

Figure 7. Substitution of fossil-based or GHG-intensive products by wood-based products

About a third (32%) of the new wood-based products is considered a partial substitute to fossil-based or GHG-intensive products, and some adjustments will be needed in the value chains. Most stakeholders mentioned technical difficulties as the greatest obstacle for introducing their products to the market or increasing their market share. The second greatest obstacle involved the shift in production scale from pilot to full scale, and the third largest obstacle was the customer preference for traditional (i.e., fossil-based or GHG-intensive) products. Other difficulties that were mentioned were the low feedstock availability and the high price of the raw material, the supply chain and market development, and the low availability of venture capital and governmental support. From the stakeholders who participated on the survey, 38% said that these difficulties could be largely alleviated by EU policies, 33% said that they could be slightly alleviated, and 29% did not know or did not answer the question.

3.3 Product reviews

Among the products mentioned by the stakeholders during the interviews and survey, some were in early stages of development and others had still limited information available on the technology development and production process. The final list of products selected for review is presented in Table 4.

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Table 4 – Innovative products selected for review

Category	Product or technology	TRL	Estimated time-to-market (years)	Main uses
Construction materials	CLT	>9	-	Building elements
	Wood foam	5-6	5-10	Insulation (thermal and acoustic), packaging
Chemicals	Lignin-based adhesives	8	5-10	Adhesives
	Glycols	6-7	5-10	Bioplastics, biofuels
Bioplastics	Bioplastics from ethylene	>9	-	Packaging
	Bioplastics from tall oil	8-9	<5	Packaging
Wood-based composites	Wood-based composites	>9	-	Packaging, single-use items, bathroom furniture
Textile fibre	Lyocell technology	>9	-	Staple fibre for textiles
	Ionic liquid technology	9	<5	Staple fibre for textiles

Among the selected products, CLT, wood-based composites and textile fibres using the lyocell technology are considered novel products, as they have been on the market for many years. However, these products have the potential to increase in market share. The other products are considered innovations and have just reached the market, are in pilot phase or will likely be in the market in the next decade. The product reviews, with information on feedstock sources, TRL and time to market, and on the fossil-based counterparts, are presented in the sections that follow.

3.3.1 Construction materials

The construction materials covered by this study used mostly feedstock from regional sources and in few instances from local sources or adjacent countries, with two stakeholders importing less than 10% of the biomass required to manufacture the product. The type of feedstock varies according to the final product, and includes sawlogs, wood chips, sawdust, and wood pulp. Only one of the stakeholders mentioned the volume of biomass used each year to manufacture their product, which varied from 800 thousand to 1 million cubic metres. Most stakeholders agree that the volume demand of wood biomass to produce the construction materials will increase considerably (by more than 10%) in the next 10 years.

Below we describe in more details the three selected wood-based products that have applications in building construction, namely: CLT, lignin-based adhesives and wood foam. Because these selected construction materials are very diverse in feedstock requirements, manufacturing processes, and applications, they will be reviewed separately.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 773297.

3.3.3.1 Cross laminated timber (CLT)

The CLT is a product that is already on the market. It is a solid wood panel with variable final dimensions that are made according to the purpose of use. It is usually composed of three to seven layers of sawnwood or structural composite lumber, placed side-by-side, arranged crosswise to each other at a 90° angle and glued together on their wide faces and sometimes on the narrow faces (Figure 8) (Brandner et al. 2016). Structural composite lumber includes laminated veneer lumber, laminated strand lumber, oriented strand lumber, and parallel strand lumber (Karacabeyli and Gagnon 2019). CLT thickness usually varies between 1.5-5 cm, and width between 6-24 cm. Custom dimensions are possible for CLT panels, with restrictions defined by transportation (Think Wood 2020).

Photo credit: Stora Enso

Figure 8. CLT panels

The CLT panels are strong, yet light compared to the materials traditionally used in construction (e.g., concrete or steel). Because of its high load-bearing capacity, CLT can be used in several structural applications, as well as ceilings, floors, and walls (Anttonen 2015) (Figure 9). Some of the advantages of building with CLT is the fast construction and assembling time, low overall weight, adequate resistance, and flexibility for earthquake prone areas (Anttonen 2015), the possibility to produce prefabricated elements (Hurmekoski et al. 2018), and good thermal and fire performance. The fact that CLT allows for a lighter construction helps reduce the cost and complexity of foundations and footings (UNECE/FAO 2015). In 2015, the first European standard on CLT was published (EN 16351:2015), specifying the product requirements.

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Photo credit: Stora Enso

Figure 9. Building structure using CLT elements

The general production process of CLT involves the visual and mechanical grading of the sawnwood, planing and cutting the sorted lumber pieces, applying adhesive, laying up the lumber side-by-side and stacking the layers at a 90° angle, pressing, and cutting to size. The type of adhesive typically used is formaldehyde-free polyurethane, but other adhesives (e.g., phenol-resorcinol formaldehyde and emulsion polymer isocyanate) can be used according to the wood species and other technical requirements. Some companies avoid using adhesives, opting for nails or wooden dowels to join the wood boards (Muszynski et al. 2020).

The size of the CLT panels can vary according to specifications of each project, with thickness usually varying between 1.6-5.1 cm, and width 6-24 cm. The maximum dimensions are 3 m in width and 12 m in length, frequently restricted by transportation regulations (Karacabeyli and Gagnon 2019).

Feedstock requirements

CLT is usually produced using coniferous species (Swedish Wood 2019), such as spruce, pine, larch, and fir. The tree species influences on the production process (e.g., lamination, bonding), appearance and properties of the final product (e.g., shrinkage and swelling, mechanical resistance). Because CLT is used as a structural element, it is important to know the quality of the individual wood components, but also have knowledge on their combined behaviour and the effect of parameters of the manufacturing process on the performance of the final product (Karacabeyli and Gagnon 2019). The lumber used in CLT must be machine stress-rated or strength-graded according to relevant standards (for the consumer), and the outer layers must additionally go through visual grading. Currently, there is no information available regarding the quantity of wood needed to produce one unit of CLT.

Sustainability aspects involving CLT

The CLT elements can substitute concrete, masonry and steel in the construction of commercial, industrial and residential buildings. Being a wood-based product, CLT can contribute to lowering the GHG emissions of the overall construction. Buildings constructed with wood-based materials emit

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20-50% net less GHG over a 100-year period than comparable constructions built with steel or concrete building systems (Upton et al. 2008). According to one study, the construction of mid-rise urban buildings using engineered wood products could decrease GHG emissions of 5 to 1196 Mt CO_2 per year until 2050 (excluding carbon storage effects), depending on floor space per capita, the amount of wood used in construction and how fast countries adopt new building practices (Churkina et al. 2020). The biogenic carbon content for CLT at the mill gate is 762 kg CO_2 eq./m^3 (or 207.8 kg C/m^3) (Stora Enso 2020). Using CLT as floor slabs in buildings could contribute to reducing GHG emissions by on average 50 Mt CO_2 eq. (excluding carbon storage effects) (D'Amico et al. 2021).

Simulations with buildings where CLT substituted for traditional construction materials (e.g., steel, concrete, and bricks) have demonstrated to consume 12% to 23% less energy, according to a study done in China (Dong et al. 2019). However, the buildings that used CLT consumed more energy during the summer because of the cooling system, which indicated that, at least for China, the best use of this type of construction system would be in colder regions.

Compatibility with existing value chains

The CLT elements have been on the market for many decades and the value chain for traditional construction materials has evolved to include this and other engineered wood products. A simplified value chain for CLT is presented in Figure 10.

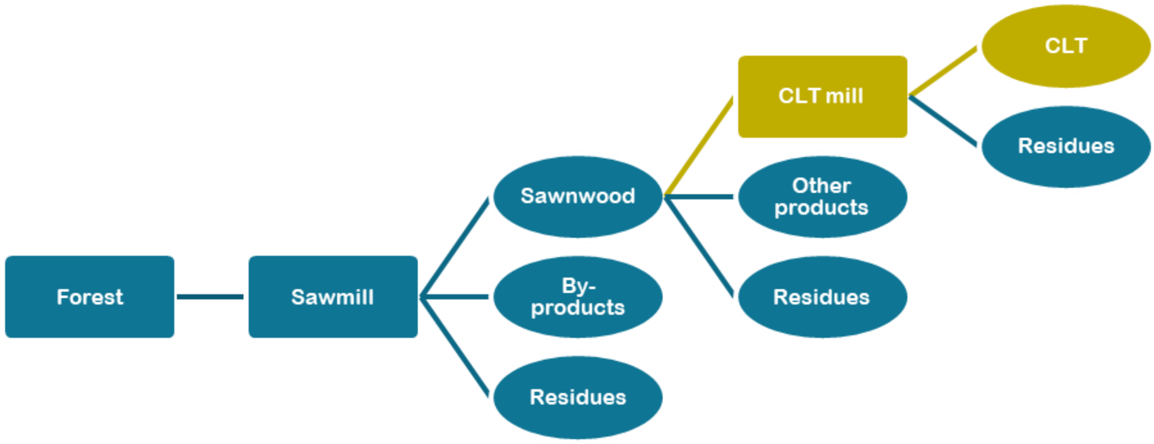

Figure 10. Simplified value chain for CLT

Current global demand and production

There are currently about 60 registered production lines of CLT across the world (Jauk 2019), but this number is increasing. The global production of CLT was around 625,000 m^3 in 2014 (UNECE/FAO 2015) and was expected to reach 2.0-2.5 $Mm^3$by the end of 2020 (Muszynski et al. 2020). Most of the global production (70%) comes currently from Germany, Austria, and Switzerland, 14% from the rest of the EU (notably Italy and France), and 16% from the rest of the world (Muszynski et al. 2020).

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According to estimates, Europe currently produces around 1.8 million cubic metres per year of CLT (UNECE/FAO 2018). The CLT industry in the EU, especially in Germany, Austria, and Switzerland, is very much focused on exports to other European countries and overseas markets (UNECE/FAO 2015). The market has been increasing especially due to the boost in construction of multistorey wood buildings across the globe.

3.3.3.2 Wood foam

Wood foam is a lightweight, cellulose-based rigid foam with sponge-like pores, that has low bulk density and high insulating properties (Figure 11). It can be produced in several densities, depending on the use. The wood foam tiles can be used as acoustic or thermal insulation material in walls or as middle layer in sandwich boards for furniture and doors. The wood foam tiles can be sawn, glued, drilled, and produce little dust. It can be combined with metal sheets to form a composite panel, which improves the fire resistance properties.

Photo credit: Fraunhofer WKI | Manuela Lingnau   Photo credit: VTT | Juha Hakulinen

Figure 11. Wood foam tiles as insulation material (left) and possible application in packaging (right)

Because wood foam is not yet being produced commercially, the process for producing the foam mat is still at a laboratory scale, with TRL 5-6. During the production process, wood chips are reduced to fibres through thermo-mechanical pulping, traditionally used in the pulp and paper industry. Water is added to create a fibre suspension and the foam is created with the addition of protein that acts as foaming agent. Hydrogen peroxide is added to activate the binding forces of the wood fibres and air is pumped to increase the pore size. The foam suspension is dried by convection at 130 °C for 30 minutes, and kept overnight at 70 °C. In a commercial production process, the wood foam mats would then be cooled and cut to size.

Depending on the use, it can be produced in the form of tiles or panels, with densities that can vary from 40 to 280 kg/m^3(Fraunhofer Institute 2020). The strength of the final product is influenced by

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the foam density, being the lower the density, the less strong the tile or panel. Much like in paper, the fibre length also influences on the mechanical properties of the wood foam. Tiles produced with longer fibres (e.g., pine) have higher tensile strengths when compared to tiles produced with shorter fibres (e.g., beech) (Ritter n.d.).

As mentioned, the wood foam panels could be used for thermal and acoustic insulation, due to the adequate insulating properties. Low density wood foam panels have thermal conductivity similar to wood fibre insulation boards (around 0.04 W/m·K) and slightly higher than polystyrene (0.03 W/m·K) (Fraunhofer Institute 2020). Therefore, wood foam could be a feasible substitute for these materials. Regarding the acoustic insulation properties, a 30-mm thick medium density (70 kg/m^3) beech wood foam tile has sound absorption equivalent to an 80-mm polystyrene tile (Ritter n.d.).

When coming in contact with water, the wood foam remains dimensionally stable, swelling less than 1% when placed in cold water for 24 hours. However, because it is made of cellulose, it is a hydrophilic material. As expected, the capacity to absorb water does not depend on the wood foam density (and size of pores), but on the type of feedstock used. During tests, pine foam absorbed less water than foam produced with beech. The fact that wood foam is hydrophilic could be a detrimental characteristic if this product is used in an environment prone to the development of fungi. Therefore, some additional treatment to the final product may be necessary.

The wood foam can also be used with other materials to combine and improve certain properties. A wood-metal composite material called HoMe foam (from German “Holz-Metall”) combines the two materials to improve the flexural strength of the wood foam (Ritter 2019a). The reinforcement of the wood foam with a metal skeleton produces a lightweight material, suitable in sandwich-constructions, and that can be implemented in stiffening and acoustically insulating components (Ritter 2019a).

Another possibility is to combine wood foam and textile-reinforced concrete to produce a low-weight element (Ritter 2019b). While concrete is considered a GHG-intensive material, reducing the volume of this material in buildings by adding wood foam could help reduce the overall CO_2 emissions of the overall construction project. This wood foam-concrete product has technical characteristics that are similar to the commercial sandwich construction elements (Ritter 2019b). The advantage of this new product is that it uses wood foam instead of polyurethane or extruded polystyrene – both fossil-based materials – used in the traditional products.

Feedstock requirements

The only component used in the production of wood foam is wood fibre, either from coniferous (e.g., pine) or deciduous (e.g., beech) species. It can be produced from woody residues from forest operations, small logs, non-commercial trees, and even cellulose-rich agricultural waste. No binders or resins are used in the production of wood foam; thus, it does not contain toxic or harmful substances.

Sustainability aspects involving wood foam

Wood foam tiles can substitute expanded polystyrene boards in building construction, for acoustic or thermal insulation in walls, as middle layer in doors and furniture. Other insulation materials that can be potentially displaced are polyurethane and polyisocyanurate foam boards. For insulation purposes, polyurethane and polyisocyanurate are typically more expensive than polystyrene, but are also more efficient (Pavel and Blagoeva 2018). Among all types of thermal insulation materials, including glass wool, stone wool and the aforementioned foam boards, expanded polystyrene is the most popular, with a market share of 27% (based on 2015 values) (Pavel and Blagoeva 2018). For this technology to reach industrial-scale production, it is still necessary to improve the drying process of the foam mat. At the moment, drying is a very energy-consuming process, which can make this product less attractive for commercial production.

Compatibility with existing value chains

While nearly any type of woody feedstock can be used to manufacture wood foam, it is likely that its production will be connected to the pulp and paper industry, either connected to an existing pulp mill or operating in a similar fashion. Wood foam will be likely produced in a simplified value chain as presented in Figure 12.

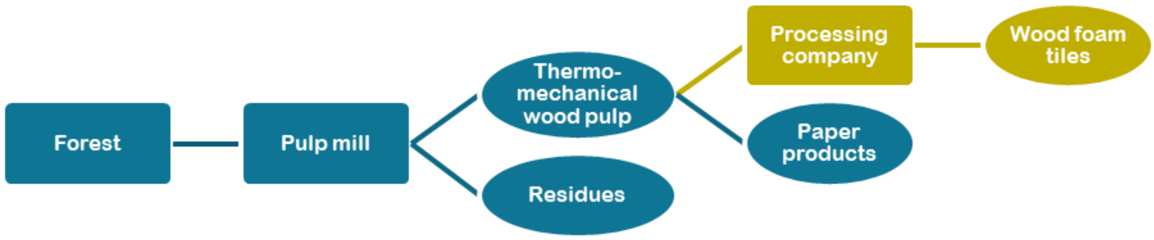

Figure 12. Simplified value chain for wood foam tiles

Current global demand and production

Wood foam is not yet being produced commercially, but it could become a replacement for certain types of polystyrene (e.g., expanded polystyrene and polystyrene foams). The global production capacity of polystyrene in 2018 was estimated to be around 15.5 million tonnes and is expected to increase slightly to about 15.6 million tonnes, by 2023 (Statista 2019). However, the production volume is around 71% of the production capacity (HDIN Research 2019), which means that the production volume in 2018 was around 11.0 million tonnes. Regarding specifically the expanded

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polystyrene, its global market was estimated at 8.0 million tonnes in 2018 and projected to reach 10.9 million tonnes by 2023 (Markets and Markets 2018). Most of the growth is attributed to the construction industry, the largest consumer of this type of material.

3.3.2 Chemicals

The feedstock for producing chemicals varies according to the type of product. Stakeholders mentioned as sources of raw material, sawlogs and pulp logs, wood chips, sawdust, wood pulp, tree resins and gums, and recycled wood-based materials. For chemicals in general, feedstock was usually sourced regionally, usually locally or globally. No respondent answered that chemicals were produced using raw materials from an integrated production facility. According to one of the stakeholders, the share of imported biomass in total biomass used for the chemical product was less than 10% per year, while the other stakeholders could not estimate the share or did not answer the question.

The only stakeholder who could inform the share of produced volume that was expected to be exported indicated that more than 90% was destined to the domestic market. According to the stakeholders, the three greatest obstacles for increasing the product's market share were the technical difficulties, the process of going from pilot to full scale, and the customer preference for fossil-based products. Stakeholders also mentioned the bureaucracy, and the need for permits and certification, indicating that EU policies could help alleviate these difficulties by targeting this area.

When asked if eco-design was considered during product development, the stakeholders responded that it was somewhat important to not important at all. They were especially interested in the use of low impact raw materials and optimised production processes to minimise negative environmental impacts, and the substitution of fossil-based materials. Some of the chemicals produced by the organisations involved in this study were biodegradable in water and soil, compostable at home or in commercial or industrial composting facilities. Some chemical products were not compostable.

Below we describe in more details the two selected bio-based chemical products, namely: lignin-based adhesives and glycols. Because these two chemical products are very distinct and have different feedstock requirements, manufacturing processes, and applications, they are presented separately.

3.3.2.1 Lignin-based adhesives

Lignin is one residue from the wood industry that could potentially be used for many high value-added products, such as carbon fibres (Souto et al. 2018), pharmaceutical materials (Gil-Chávez et

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al. 2019), 3D printing composites (Yu and Kim 2020), adhesives (Li et al. 2018; Alinejad et al. 2019), building blocks and platform chemicals (Neis-Beeckmann 2017; Wong et al. 2020). One of these chemical building blocks is catechol, which can be used in paints, fragrances, and medications. Catechol monomers may also be a substitute of resorcinol in formaldehyde resins (Neis-Beeckmann 2017). Because lignin is the most abundant natural phenolic polymer, it could also be used as substitute for phenol in phenolic adhesives (Kalami et al. 2017; Luo and Shuai 2020). The TRL varies according to the production process and the type of end-product. One of the lignin-based phenolic adhesives that can be found in literature had an estimated TRL of 8 (University of Bologna and Fraunhofer ISI 2018).

Feedstock requirements

Lignin is a by-product of the pulp and paper industry, most of which is currently burnt to produce energy for the industry (Hu et al. 2011). Estimates of lignin availability vary between 50-100 million tonnes per year (Neis-Beeckmann 2017; Bajwa et al. 2019). One of our stakeholders produces 50 thousand tonnes of lignin each year in one single mill. However, from the global lignin production, less than 5% are used for value-added purposes, such as phenolic resins, foams, and surfactants (Hu et al. 2011; Bajwa et al. 2019). Due to the large availability of this raw material with high potential for value-added products (Hu et al. 2011) and the lower price of lignin compared to fossil-based phenol (University of Bologna and Fraunhofer ISI 2018), the industry decided to invest in the development of lignin-based adhesives to substitute fossil-based phenolic compounds. There are several processes for recovering lignin from black liquor with quality that would be suitable for phenolic resins and polyurethane foams (University of Bologna and Fraunhofer ISI 2018). Among the several sources of lignin, the best fossil-based phenol substitute is the one from pine obtained through the kraft pulping process (Tejado et al. 2007).

Sustainability aspects involving lignin-based adhesives

Adhesives are an important factor that influences the environmental performance of engineered wood products, especially when it comes to the sourcing of raw materials, emissions of volatile organic compounds during the use stage, and disposal at the end of the life cycle (Messmer 2015). Other advantages of substituting fossil-based phenolic resins by their lignin-based counterparts is the lower use of energy during production (Siddiqui 2013). For this, bio-based adhesives have been considered a possible solution for substituting some synthetic adhesives. While using lignin-based adhesives in engineered wood products is not yet cost effective, substituting part of the synthetic phenol by industrial lignin in the adhesive composition is technically feasible, producing good results (Nakos et al. 2016; Hemmilä et al. 2017).

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Compatibility with existing value chains

Investments on the development of lignin-based products are being made especially by the pulp and paper industry. Some adjustments are needed to the value chain to include biorefineries that can fractionate the black liquor into value-added chemicals and produce lignin-based adhesives. A simplified value chain for lignin-based adhesives is presented in Figure 13.

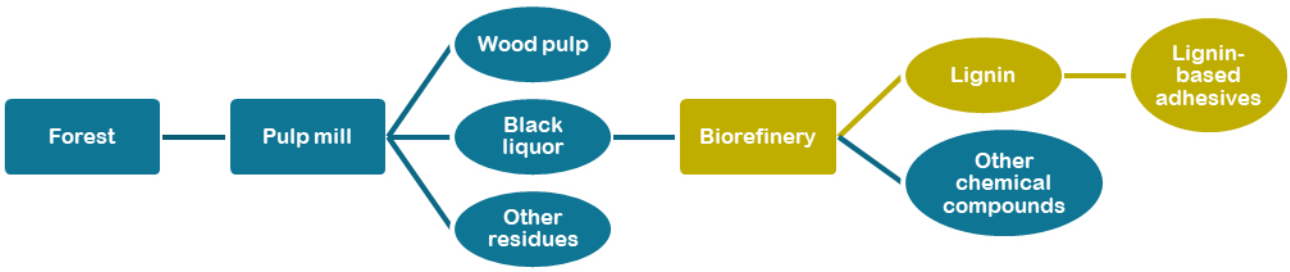

Figure 13. Simplified value chain for lignin-based adhesives

Current global demand and production

The global lignin market demand in 2014 was estimated at about 3.5 billion euros and is expected to reach 5 billion euros by 2022, at a compound annual growth rate (CAGR) of 4.9 % (University of Bologna and Fraunhofer ISI 2018). The production of lignin is expected to increase to 225 million tonnes per year, by 2030 (Bajwa et al. 2019). Phenol production volumes have reached 8 million tonnes per year, and it is expected to grow at a CAGR of 3.9% until 2028 (University of Bologna and Fraunhofer ISI 2018).

3.3.2.2 Glycols

One type of glycol, which is used in the production of polyesters for textiles and packaging, is mono-ethylene glycol (MEG). Currently, 99% of MEG is produced from fossil sources. Regardless of the feedstock source, MEG is an important chemical building block for polyethylene terephthalate (PET) or polyethylene furanoate (PEF) polymers, which are commonly used for bottles and packaging, textile fibres, automotive, and solvents for paints, among others. For more information about MEG, see also the section on bioplastics from ethylene.

Another type of glycol is mono-propylene glycol (MPG). MPG is a clear, colourless and viscous liquid. It is soluble in water and has hygroscopic properties. Industrial MPG is commonly used as an anti-freeze agent. It has many applications including de-icing of airplanes and also as a heat transfer fluid (e.g., engine coolant). It can also be used as a chemical intermediate in the production of unsaturated polyester resins and is a solvent used in the manufacturing of detergents. Apart from industrial use, MPG of higher purity has a wide range of other uses including being an additive in

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cosmetics and personal hygiene and skin care products. Feed-grade MPG can also be used in cattle feed, particularly to avoid ketosis.

To the best of the authors knowledge, the most advanced facility aiming to produce glycols from woody biomass is an industrial-scale plant currently under construction in Germany. That would put the TRL level for wood-based glycols at 6-7. An example of a biorefinery producing glycols can be seen in Figure 14.

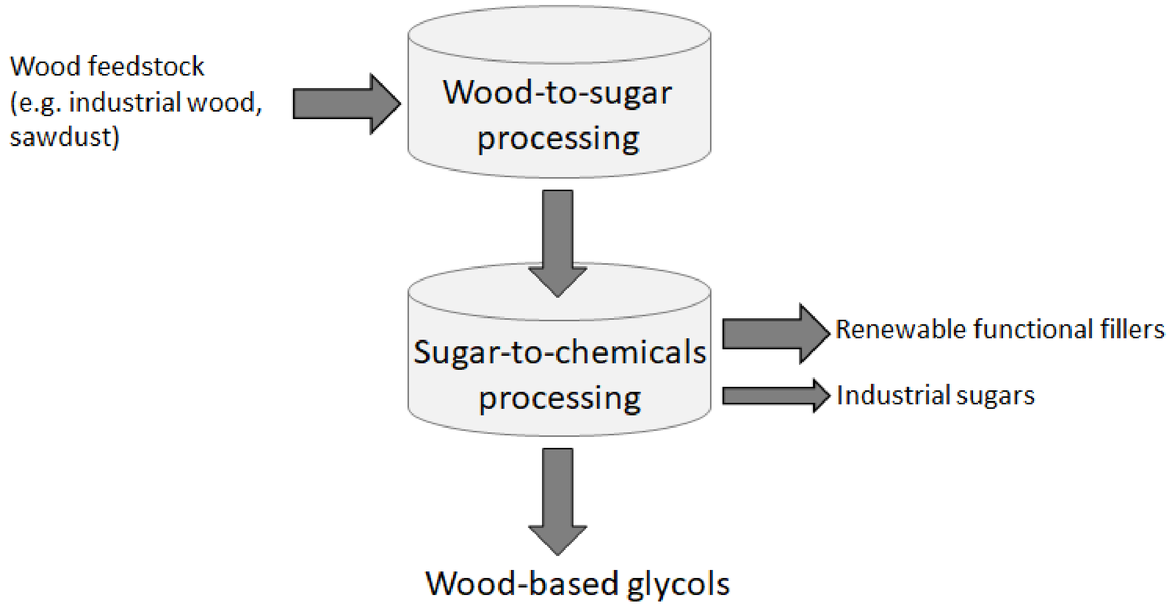

Figure 14. Example of a biorefinery producing glycols (adapted from UPM)

Feedstock requirements

Wood-based glycols are made from sugars extracted from woody biomass. The biomass can have various origins and forms, such as branches and other forest residues, wood chips or sawdust from different tree species. The wood of broadleaved trees is a good source of technical sugars. If demands for feedstock increase, there is a future possibility to do clone selection aiming for trees with appropriate saccharification properties. Feedstock would normally be locally sourced, and availability is not predicted to be a problem as there is a variety of possible sources.

The absolute majority of MPG is derived from petroleum, but there are producers of biobased MPG. Bio-based MPG is primarily produced from plant-based glycerine. The environmental impact of bio-based glycerine varies depending on feedstock and production. There is also an effort by a SME-instrument supported company in EU to produce MPG from agricultural waste.

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Sustainability aspects involving glycols

The environmental impact of glycols and glycol production can be attributed to a multitude of factors. The feedstock used for production should be renewable and transport of raw material limited. At the other end of the product lifecycle the waste management has a significant impact on the product sustainability. Efforts to recycle MPG at airports are well under way but as the recycling of biochemicals falls outside of the scope for this case study we will not cover that further.

The substitution potential for replacing petroleum-based raw material for wood feedstock in glycol production is potentially huge. At the current capacity we will not see a decrease in demand for fossil-based glycol sources as the market increases at a rate that surpasses the expected production of wood-based glycol. In the market segment of bio-based glycols there are other feedstocks sources used to produce glycols from sugars. MPG can also be produced from plant-based glycerine or from glycerol that can be obtained as a side-product from production of biodiesel.

Compatibility with existing value chains

Glycols made from woody biomass are identical to the chemicals manufactured from non-renewable resources, and thus are considered drop-in in the value chain for downstream applications. A simplified value chain for glycols, more specifically for MEG, is presented in Figure 15.

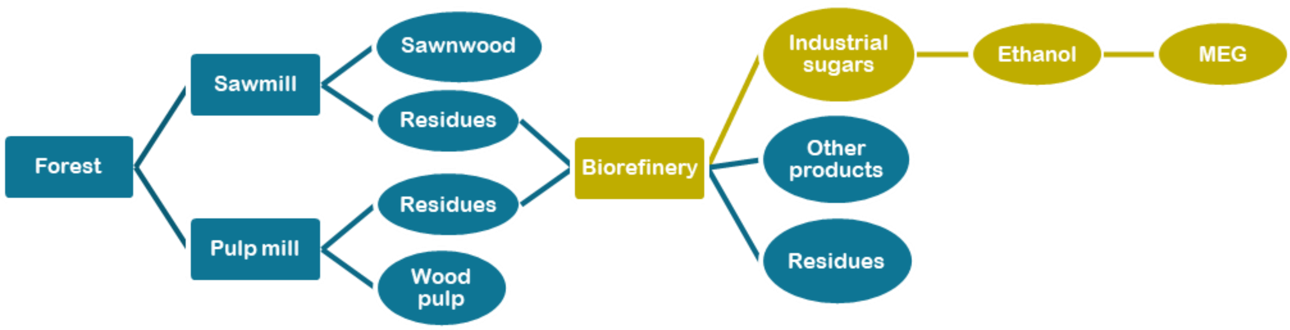

Figure 15. Simplified value chain for MEG

Current global demand and production

The production of wood-based glycols is still at an early stage of development and there is no full-scale production plant in use as of today. The current demand for bio-based glycols is highest in North America and Europe while the increase in demand for glycols is higher in the Asia-Pacific region. Ethylene glycol is expected to have a global production capacity amounting to more than 65 million metric tonnes in 2024 (Statista 2021). That is a fairly significant increase from the world's production capacity of ethylene glycol in 2019, which was nearly 42 million metric tonnes (Statista 2021).

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MEG production is projected to grow from 28 million tonnes to 35 million tonnes in 2035, with a CAGR of 3.5%. The global market for MPG is predicted to grow with a CAGR of around 3.9%, primarily driven by industrial growth in the Asia-Pacific region, but also the Middle East and in Africa. The market driving the increase is transportation and automotive industry.

3.3.3 Bioplastics

There are several types of plastics that can be produced from bio-based sources, from first, second and third generation feedstocks. First-generation feedstocks are carbohydrate-rich crops that can be consumed by animals (feed) and humans (food) (e.g., corn, potato, sugarcane, and sugar beet). Second-generation feedstocks are crops and plants that are not suitable for food or feed (e.g., trees), or that are waste from first-generation feedstock (e.g., bagasse and waste vegetable oil). Lastly, third-generation feedstock come from algae.

Most bioplastics (46%) are produced from biogenic by-products, such as tall oil generated during the kraft pulping process, and first-generation feedstock, such as starch and plant oils (Carus et al. 2020). The forest-industry has been focusing on the development and manufacture of bioplastics from second-generation feedstock, using industrial side streams especially from the pulp and paper industry. One of the advantages of using industrial side streams from the forest industry as feedstock for bioplastics instead of annual crops is that woody biomass usually comes from nonarable lands. Thus, the GHG emissions related to land use change are minimal (De Bruycker et al. 2014). Cellulose is also use to produce biopolymers, mostly for cellulose acetate, at much smaller share (9%) compared to biogenic by-products and first-generation feedstock (Carus et al. 2020).

In general, bioplastics from forest-based sources are suitable for both injection moulding (to produce hard plastic containers) and blown film and cast film extrusion lines (to produce flexible packaging) (Figure 16). When produced as granulates for injection moulding, they have high transparency and clarity, and it is possible to dye the material. When produced as films, they are clear, transparent, and easy to use in thermoforming.

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Photo credit: Woodly

Figure 16. Bioplastic granulates (left) and packaging (right)

One of the second-generation feedstocks that can be used to produce bioplastics and polyurethanes is lignin (Wang et al. 2019). Currently, about 50 million tonnes of kraft lignin are produced worldwide each year (Lettner et al. 2018), but it is estimated that only 1-2% is recovered and used as raw material for products (Lora and Glasser 2002). Some companies are taking advantage of the availability of this feedstock to produce bioplastics for several uses. In agriculture, for example, the use of single-use plastics in mulch films and containers for seedlings is the standard practice. However, this type of plastic cannot be recycled, and end in landfills after one crop season. To solve this issue, biodegradable plastics made from lignin sourced from the wood industry are being produced. The advantage of the lignin-based plastic over other bioplastics (e.g., from corn or potato starch) is that it takes longer to biodegrade (Hammerich 2018), being suitable for the use in agriculture.

Other bioplastics are being further developed to use paper sludge (a waste from the paper industry) as feedstock, or other side streams and by-products from the wood industry (e.g., as tall oil and ethylene). Thus, the forest industry can offer many options of feedstock for bioplastics, especially when focusing on the better use of undervalued by-products, residues, and waste. In the next sections we present information about bioplastics produced from two sources of raw material from the forest industry, namely: ethylene (produced from industrial sugars such as glucose) and tall oil (obtained from the kraft pulping process).

3.3.3.1 Bioplastics from ethylene

Ethylene is one of the most important platform chemicals in use (Mozaffarian 2015), which can be used to produce a myriad of products (Spekreijse et al. 2019). It is mostly produced from petroleum but can also be obtained from bio-based sources, typically from maize, beets and sugarcane, but

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also from woody biomass. Some companies are converting the sugars found in wood into MEG (Figure 17) to produce bioplastic films as a substitute to the fossil-based plastic coating in liquid carton containers.

Feedstock requirements

Ethylene is commonly produced from (fossil-based) naphtha, gas oil and condensates, but the bio-based counterpart can be produced through dehydration of bioethanol (Mozaffarian 2015). Bioethanol, in turn, can be produced from any type of woody biomass, as its main component is cellulose, which is primarily composed of the sugar glucose. Other types of fermentable sugars (e.g., xylose and mannose) can also be found in wood and could be used as sources for ethanol. In addition, ethanol can also be produced using certain types of bark as feedstock (Reina et al. 2016). Therefore, the feedstock to produce bioplastics using the ethylene pathway could be small logs and forest residues, wood chips, sawdust, among others. Based on the responses from our stakeholders, the feedstock comes mostly from regional sources, and at times from local or globally traded sources.

Estimating the quantity of woody biomass to produce one unit of ethylene-based bioplastic is not a simple task, as there are many factors that influence on the product yield. Some examples of factors affecting the volume of ethylene-based bioplastics are, namely: the tree species and part of the tree used as raw material, the process used to extract the sugars, and the process used to produce ethanol and ethylene, among others. To illustrate the variations due to some of these factors, the ethanol yield obtained from woody biomass may vary from 2% on unbleached pine pulp (Przybysz Buzała et al. 2017) to 53% on unbleached kraft pulp of eucalyptus (Branco et al. 2020). Remembering that the conversion of wood to ethanol is only one part of the complex manufacturing process of ethylene-based bioplastics.

Sustainability aspects involving bioplastics

Bioplastics are a substitute for several types of fossil-based plastics, such as polyethylene and polyurethane. These bioplastics are technically equivalent to their fossil-based counterparts (European Bioplastics 2020). Bioplastics have the potential to solve some of the current problems associated with traditional plastics. One of the advantages of bioplastics production within the forest sector is using raw material from a renewable source as feedstock, especially from industrial side streams and waste. Another advantage is the reduced emission of GHG associated with the production and use of the raw materials (Mozaffarian 2015).

One common misconception is that all bioplastics are necessarily more sustainable than fossil-based plastics and this is due, at least in part, to the number of terms frequently used for these materials (e.g., “bio-based”, “biodegradable”, “compostable”, “recyclable”) and their understanding from the consumer. While using biomass as feedstock may help solve the issues related to the use of non-

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renewable resources and help reduce GHG emissions, it may not necessarily contribute to reducing plastic pollution, as bioplastics are not necessarily biodegradable, compostable or recyclable (Maier 2018; Tenhunen and Pöhler 2020). For this reason, it is important to take sustainability aspects into consideration during product conception and manufacture and have adequate disposal of the material at the end of its life to avoid pollution, especially caused by microplastics (Neves et al. 2020). Regardless of the feedstock used to produce (bio)plastics, it is crucial to have an effective collection system in place, where the materials are properly sorted and delivered to the appropriate recycling or composting facilities to stop, or at least drastically reduce, pollution.

It is also important to mention that currently many bioplastics are only partially bio-based. Bio-PET, for instance, is produced from ethylene glycol from biomass. However, it also requires terephthalic acid in the production process, which is only available commercially from fossil sources, resulting in a bio-PET that is approximately 30% bio-based (Spekreijse et al. 2019).

Compatibility with existing value chains

The bioplastics value chain connected to the forest sector starts with the feedstock supply from other industries and several intermediate steps until the production of the bioplastic pellets. Figure 17 presents, in a simplified way, one of the possible routes for producing bioplastics from wood-based sources.

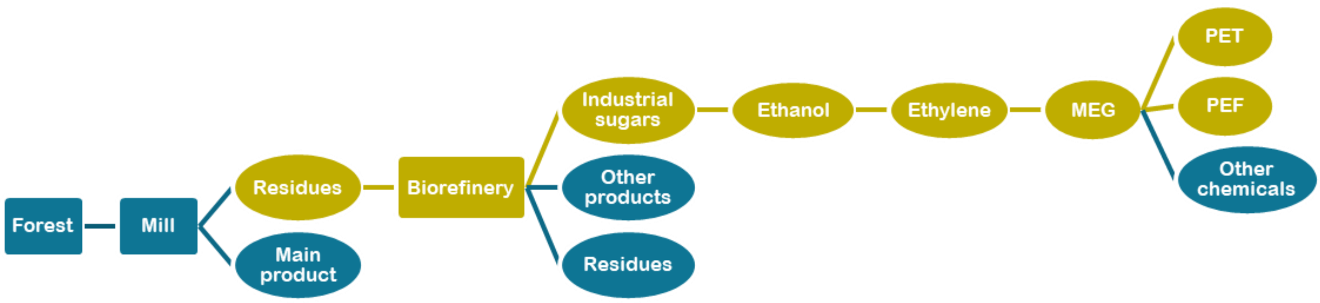

Figure 17. Simplified value chain for bioplastics PET and PEF from monoethylene glycol (MEG)

One possible way to produced bioplastics from ethylene would be to use woody biomass, preferably residues from a sawmill or pulp mill, and convert the wood sugars into ethanol. From the perspective of the forest sector, there is a need for a new value chain to produce these chemicals and bioplastics.

Current global demand and production

The EU annual production of fossil-based ethylene is around 19 million tonnes (Spekreijse et al. 2019). The global production of bio-ethylene in 2013 was around 420 thousand tonnes, representing only 0.3% of the ethylene global production (Mozaffarian 2015). A that point, woody biomass did

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not have a share in the bio-ethylene production, as the technology was not yet mature enough. Bio-ethylene (and its derivatives) are consumed, but not yet produced in large scale the EU (Spekreijse et al. 2019).

Bioplastics produced with feedstock from the forest industry are still at the early stages in terms of volume produced and development of technology and the production process. Companies investing in the development of wood-based bioplastics are mostly located in Europe (e.g., Finland, the United Kingdom, Belgium, the Netherlands) and in North America. When we consider all types of bioplastics – the majority being produced from first-generation feedstock – they represent only 1 percent of the total volume of plastics produced annually (around 335 million tonnes) (Gyekye 2019). The production capacity of second- and third-generation feedstock bioplastics is expected to grow to 4.3 million tonnes by 2022 (Gyekye 2019).

One of the issues with increasing bioplastics production is finding enough raw material, as even access to adequate secondary feedstock may be difficult (Gyekye 2019). These constraints concern finding the adequate feedstock (i.e., consistent and with the desired properties) at an adequate distance from the biorefinery, and possible competition for raw material with other bio-based products.

3.3.3.2 Bioplastics from tall oil

One of the side streams currently used in the production of bioplastics is tall oil. This by-product from the pulping process has always been used as a source of energy for the industry. However, value can be added to the crude tall oil by fractionating it into several chemical compounds. One of these derivatives is the naphtha, which can be used in the production of biodiesel and bioplastics (De Bruycker et al. 2014; Mäntyranta 2020). In addition, crude tall oil can be used to produce, among other chemicals, ethylene and the bioplastics produced from this chemical compound (De Bruycker et al. 2014), as seen in the previous section.

One type of bioplastics that can be produced in this value chain is polyethylene, which is technically equivalent to the same material produced from fossil sources (European Bioplastics 2020). Therefore, bio-based polyethylene can be used for food packaging without changes in legislation.

Feedstock requirements

According to the stakeholders who participated on the survey, to produce bioplastics their companies use mostly feedstock from regional sources, and sometimes from local or globally traded sources. One large manufacturing company sources woody residues from sustainably managed forests near the processing plant.

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Sustainability aspects involving bioplastics

These bioplastics can substitute fossil-based plastics such as polyethylene and polyurethane, being considered drop-in (European Bioplastics 2020). One of the advantages of bioplastics from the forest sector is using renewable raw materials, industrial side streams and waste. In addition, GHG emissions during product manufacture and use of the raw materials are lower than fossil-based plastics (Mozaffarian 2015). Some bioplastics from tall oil, such as the barrier films for liquid packaging, can be recycled with paperboard, helping improve the circularity of these products.

Biodegradability is a characteristic that may be important in some sectors (e.g., agriculture) and for producing (bio)plastics that are not recyclable (e.g., plastic films). However, in general, producing biodegradable plastics should not be the norm, as this may increase incorrect waste disposal, and the focus should be on reusable and recyclable materials (Maier 2018). This is especially important considering that over 400 million tonnes of plastics are produced globally each year, and that over 75% of this amount becomes waste each year (Geyer et al. 2017).

Compatibility with existing value chains

The development of bioplastics from tall oil is connected to the pulp and paper industry. Some adjustments are needed to the value chain to include biorefineries that can fractionate the black liquor from the pulping process and produce bio-naphtha from crude tall oil. A simplified value chain for bioplastics from tall oil is presented in Figure 18.

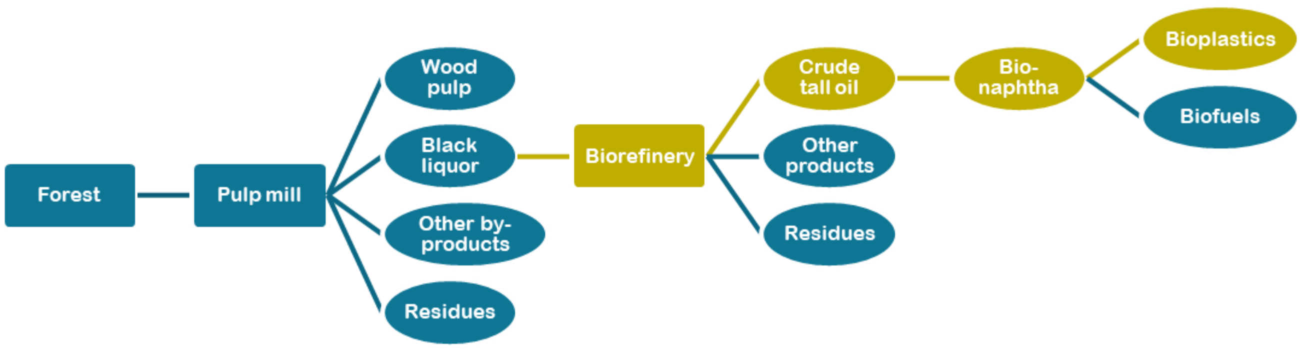

Figure 18. Simplified value chain for bioplastics from tall oil

Current global demand and production

The estimated global production of crude tall oil is around 2 million tonnes, from which about 650 thousand tonnes are produced in Europe (Fraunhofer Institute 2016), and production is expected to increase to 2.3 million tonnes by 2030 (Aryan and Kraft 2021). However, only a small fraction of the current production is used to manufacture bioplastics. The production capacity of bioplastics,

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from second- and third-generation feedstock combined, is estimated to grow to 4.3 million tonnes by 2022 (Gyekye 2019).

One food manufacturer has been using beverage cartons with bioplastic barrier since 2019, putting on the market more than 40 million of the 100 percent wood-based packaging that year. According to the company, by substituting bioplastics in the beverage cartons the fossil-based plastic consumption will be reduced by 180 thousand kilograms per year (Packaging Europe 2019). The production capacity of bioplastics in general is limited by the feedstock availability (Gyekye 2019), quality, and at an adequate distance from the biorefinery. Competition for raw material with other bio-based products (e.g., biodiesel) is also an issue that must be taken into consideration when developing bioplastics.

3.3.4 Wood-based composites

Wood-based composites, or wood-thermoplastic composites, are products made with wood from various sizes (flour, fibres, particles, chips, or solid wood) and a binding agent or thermoset polymer. These products were created to reduce the plastic content in products, while conferring a more natural appearance (Carus and Partanen 2019). Wood-based composites have been used for many decades as construction material (in decking, siding, roofing, etc.). These durable products combine the workability of wood, but have higher resistance to water, higher overall durability and require less maintenance. Nowadays, wood-based composites are being used to produce a large variety of products (Figure 19), from small disposable products, such as beverage straws, to furniture and large heavy-duty objects.

Some companies, concerned about the sustainability of the resources and aiming to steer away from the use of plastics, started investing in producing wood-based composites with a high percentage of bio-based raw materials, that can be mechanically recycled, or that are compostable or biodegradable. Some of the new wood-based composites are made with bio-based binders (such as polypropylene or polylactide) (Mäntyranta 2020) or with binders that are fully biodegradable.

Because of the large variety of uses of wood-based composite products, the raw materials and the production process vary according to the requirements for the final product. Some products may use logs or solid wood as raw material, while the source for others may be industrial side streams. Other aspects that are also important in the production of wood-base composites are the choice of binding agent or polymer, and the use of additives to improve bonding, product performance (e.g., ultraviolet light stabilizers, flame retardants), and processability.

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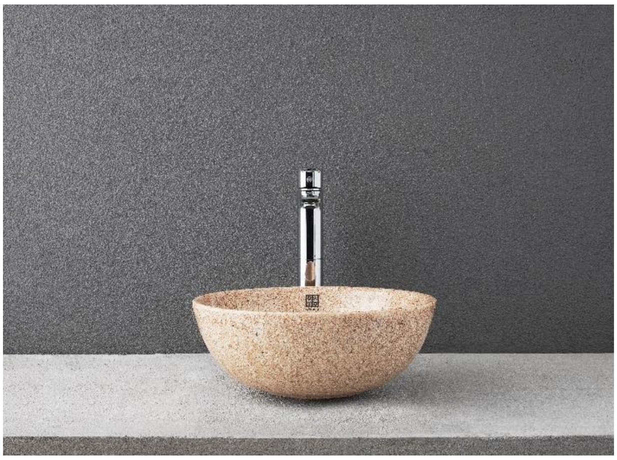

Photo credit: Sulapac Photo credit: Woodio

Figure 19. Products made of wood-based composites

Feedstock requirements

Several sizes of wood elements can be used to produce composites, such as solid wood pieces, wood chips, sawdust, and wood fibres. Wood flour may be used to confer an appearance similar to ceramic or moulded plastics. Wood fibres are frequently used when the workability and mechanical properties are important elements in the final product. If products are designed to have a more natural appearance, larger chips and fibre bundles may be used. The stakeholders mentioned they also use by-products from the forest sector as raw materials. According to one stakeholder, 400-700 kilograms of woody feedstock are required to produce 1 cubic metre of wood-based composite.

Most companies developing or producing wood-based composites mentioned sourcing their feedstock from regional or local sources. One of the stakeholders mentioned that less than 10% of the biomass used for the composite is imported each year. The stakeholders expect the volume demands of wood biomass used to produce the composites to increase (either slightly or considerably) in the coming 10 years.

Sustainability aspects involving wood-based composites

These wood-based composites can substitute plastics used in the manufacture of durable products (such as containers, hangers, countertops, etc.) or single-use products (such as beverage straws). As with bioplastics, the development of these wood-based composites is being stimulated by the ban on plastic and polystyrene packaging, and other single-use products (UNEP 2018).

For certain applications, wood-based composites can also be an alternative to durable, yet non-renewable and GHG-intensive, materials such as natural stones (e.g., granite, marble) and porcelain.

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The bio-based materials in the new wood-based composites are used as reinforcement and fillers to reduce the proportion of fossil carbon in the products, while increasing the proportion of renewable carbon. The share of bio-based carbon can be increased by substituting fossil-based plastics and resins by bio-based binders. One type of wood-based composite, intended for durable, waterproof products, has a lower carbon footprint than their ceramic counterparts. According to a life-cycle assessment, the carbon footprint of the whole product life cycle is 55 kilograms lower per unit than ceramic (Nurmio 2018). The share of bio-based materials in the composites produced by our stakeholders was above 76%.

The importance of eco-design in early product development varied from "not so important" to "very important". Among the eco-design aspects were considered during the main product development, our stakeholders mentioned the use of low impact raw materials and optimised production processes to minimise negative environmental impacts; the design for ease of maintenance, reparability, upgradability and adaptability; and the design considering recyclability, biodegradability and waste minimization at the end of life. Some of these wood-based composites were designed to minimize the consumption of energy and natural resources, as well as the production of waste and GHG-emissions. At the end of the life cycle, depending on the type of wood-based composite, they can be mechanically or chemically recycled. Others are fully biodegradable in water and in soil, not releasing any microplastics in the environment, and compostable following the standard EN 13432, which requires the material to fully biodegrade in less than 12 weeks. One of our stakeholders mentioned that one type of composite was not compostable, but still had the option of being at least partly recycled.

Compatibility with existing value chains

All stakeholders who participated in the interview and survey confirmed that their products are already on the market. Therefore, the value chain for this material has already been developed/adapted from traditional value chains. The stakeholders indicated that their wood-based composites are drop-in. However, when it comes to the percentage of fossil-based or GHG-intensive materials that the wood-based composites can substitute, the answers from our stakeholders varied from 10-19% to 90% or more, which evidences the large variation in substitution according to the type of product and its end-use. A simplified value chain for wood-based composites is presented in Figure 20.

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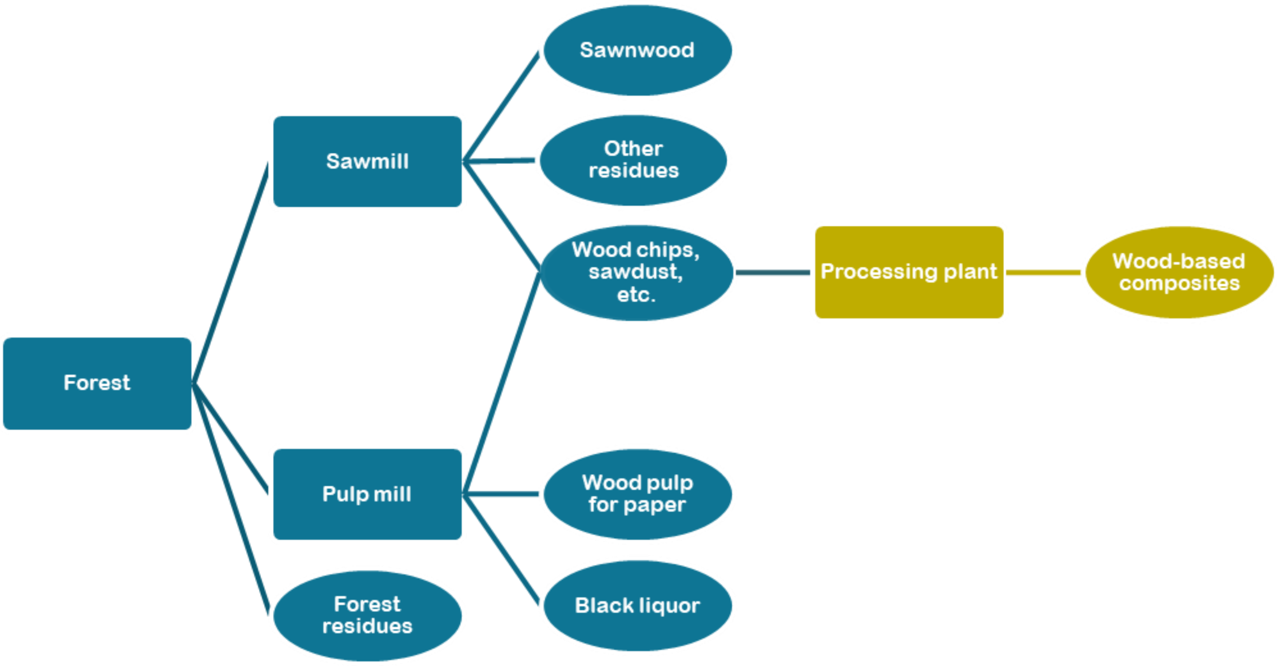

Figure 20. Simplified value chain for wood-based composites

Current global demand and production

In Europe, there are about 35 bio-based composite producers, from nine countries. In 2018, the production was nearly 470 thousand tonnes of bio-based composites (nova-Institute 2019). The largest producer of these granulates in Europe is Portugal, where the production of cork-based composites was over 50 thousand tonnes, in 2018. Other important producers of bio-based composites in Europe, in terms of volume, are Belgium, Germany, France, Finland, and Sweden (Carus and Partanen 2019). Among the bio-based materials that are used as reinforcement in composites, cork has the largest share (around 60%), followed by wood and cellulose fibres (over 25%) and other natural fibres (around 15%) (Carus and Partanen 2019).

The stakeholders that participated in our study mentioned that at least 50% of the production volume is expected to be exported. When asked about the greatest obstacles for increasing the product's market share, the stakeholders mentioned the customer preference for traditional (i.e., fossil-based or GHG-intensive) products, the technical difficulties, the lack of holistic metrics for sustainability (e.g., microplastics accumulation is not included in environmental impact assessments), fragmented waste infrastructure, among others. The stakeholders believed that difficulties could be slightly alleviated by EU policies that reinforce the incentives towards waste reduction, as some of the product generate very low waste during manufacturing. According to them, the difficulties could be largely alleviated if, in the policy making guidelines, there was a level playing field for the mechanical, chemical and organic recycling paths of plastics and composites. In addition, in the extended producer responsibility schemes and in the essential requirements of

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packaging, the role of organic recycling should be clarified and acknowledged as one important recycling route. Finally, there should be stronger collaboration between the whole biowaste value chain, and some requirements for the biowaste management plants to accept packaging waste that is tested according to the standard EN 13432.

3.3.5 Textile fibres

Many wood-based textile fibres (e.g., viscose and lyocell) are categorized as man-made cellulosic fibres. Viscose has already been produced for over 100 years, but some viscose production processes generate toxic chemical waste (Sayyed et al. 2019), cause water and air pollution and are energy-consuming, among other issues (Changing Markets Foundation 2017). The production process of man-made cellulosic fibres is usually based on dissolving wood pulp and wet spinning. Lyocell is considered a bio-based environmentally friendly production method, and wood fibre being promoted as preferred natural fibre compared to fossil-based and even cotton (Shen et al. 2010).

Newer technologies for textile fibre production (e.g., Ioncell, Kuura and Spinnova) are straying away from the use of harsh chemicals, opting for a combination of mechanical treatment and non-harmful chemicals, such as one type of ionic liquid. These new fibres (Figure 21) are usually not even considered man-made cellulosic fibres because there is no dissolving of wood in any stage of the process.

Photo credit: Spinnova

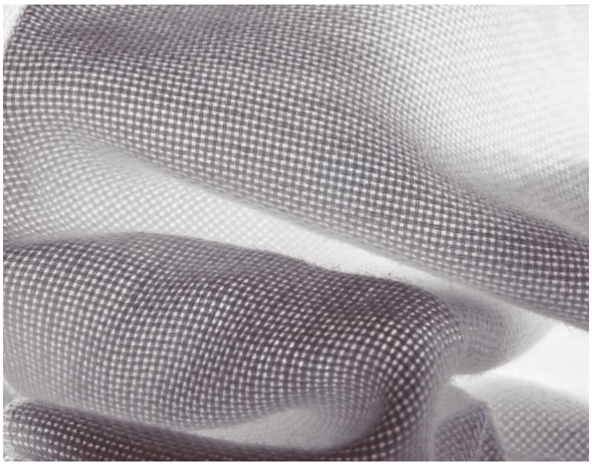

Photo credit: Spinnova

Figure 21. Wood-based staple fibres for textiles (left) and textile fabric (right)

Some of these newer technologies have yet to become operationally feasible at a commercial scale, but they represent more sustainable alternatives to the current textiles production. Some wood-based textile fibres mentioned by our stakeholders have a TRL of 5-6, while others (e.g., lyocell) are

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already in the market. Because these wood-based fibres for textiles have some similarities, the feedstock requirements, the sustainability aspects involving these fibres, their compatibility with existing value chains and the global demand and production will be reviewed together. More details about how these fibres differ are given later in this report.

Feedstock requirements

According to our stakeholders, wood-based textile fibres were produced with feedstock from varied sources, from integrated production facilities to globally traded sources. One of the stakeholders mentioned that 60-69% of the biomass is currently imported. The types of feedstock used by the processing plants are sawlogs or pulp logs, wood chips and wood pulp.

To produce one tonne of cellulose fibres, it is required about 2.5 tonnes of wood as input. One of the stakeholders mentioned that their company uses about 1.8 million tonnes per year of biomass to produce their textile fibre. When asked about the changes in demand of biomass for their product, our stakeholders stated they expect the volume demands to increase around 10% in the next 10 years.

Sustainability aspects involving the wood-based fibres for textiles

These new technologies for textile fibres come to solve some of the problems associated with the production of fossil-based fibres (such as polyester and other synthetic fibres), water and energy-intensive fibres (such as cotton), as well as improve the circularity in the textiles value chain (Antikainen et al. 2017; Ellen MacArthur Foundation 2017). Wood-based fibres have lower environmental impact than cotton, polyester, and polypropylene fibres, which is attributed to the use of renewable energy during the production process, lower use of chemicals, lower GHG emissions, and lower water consumption (Shen et al. 2010).

As indicated by one of the stakeholders, there is a growing concern from consumers regarding the release of microplastics from use of synthetic textiles, as well as the environmental impacts from cotton production (Ellen MacArthur Foundation 2017). Pressure from the public sector is necessary to establish regulations, standards, and economic incentives to encourage the development of more sustainable products and to encourage the adoption of more sustainable practices by the textile industry, especially regarding circularity aspects (Hugill et al. 2020). There has been concern regarding the release of microplastics from synthetic textiles in the environment because of wear and tear during the normal product life cycle. It is estimated that about 67 million tonnes of synthetic fibres are produced each year (Textile Exchange 2020). Nearly 35% of the global releases of primary microplastics to the world water sources are attributed to the regular use and laundry of synthetic textiles (Boucher and Friot 2017). Therefore, substituting synthetic and non-biodegradable textile fibres with more sustainable options would contribute to reducing the pollution caused by microplastics. The European Commission is investigating possible actions to

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limit the release of microplastics in the environment from plastic production and the use of common products (e.g., tyres and textiles). The new Drinking Water Directive, for instance, will foster the development of a methodology to measure microplastics in water and, consequently, provide the necessary information for the Commission to regulate the manufacture of products that release microplastics (Council of the EU 2020).

During the early development stages of the product, ecodesign (i.e., considerations during the design phase on how the product could be reused or recycled) was only considered somewhat important. Stakeholders mentioned as important aspects during product conception the use of low impact raw materials, the use of optimised production processes to minimise negative environmental impacts, and the design considering recyclability, biodegradability and waste minimization at the end of life.

Depending on the type of wood-based textile fibre, it can be fully or partly recyclable. When it is only partly recyclable, the issues are mostly related to the end-use (which influences the type of fibre blends) and the collection systems in place. In theory, these fibres would be fully recyclable; however, the actual recycled content is likely closer to the textile value chain (i.e., less than 1% recycled for garments, and about 12% for cascade recycling). When blended with polyester or other fossil-based materials, filtering is required after dissolving the old textiles. There is also a concern from the manufacturers in producing recycled fibres that are also durable. According to one of the manufacturing companies, the recycling process itself can improve the quality of the final material.

According to our stakeholders, the share of bio-based materials in the wood-based textile fibres is 100%. Regarding the biodegradation of the material, these new staple wood-based fibres (i.e., without blending with other materials) are biodegradable in water and soil, compostable in commercial or industrial composting facilities, and in some cases at home. Details on the conditions and time for biodegradability are not yet available.

Compatibility with existing value chains

The wood-based textile fibres are partially compatible with existing value chains. The costs to produce wood-based fibres for textiles using new technologies must be comparable to other types of fibres for the activity to be economically feasible. The economic feasibility should be achieved in the form of an integrated mill, with a textile fibre production plant operating next to a pulp mill (Figure 22).

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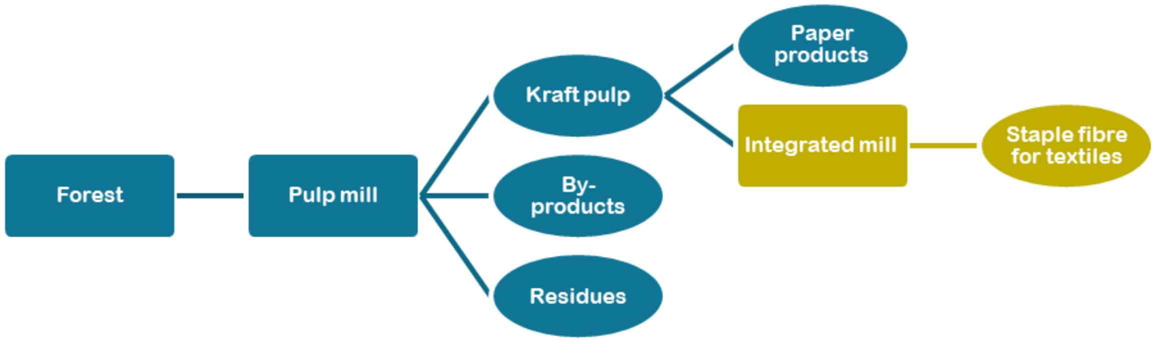

Figure 22. Simplified value chain for wood-based textile fibres

As many of the new wood-based fibres for textiles are not produced with dissolving pulp, as is the case for viscose and lyocell, in this simplified value chain the wood pulp from the kraft pulping process does not go through a pre-hydrolysis treatment. Regarding the side streams from this process, our stakeholders indicated that some by-products generated from the textile fibre process are common wood-based biorefinery products (e.g., acetic acid, furfural, xylans, lye, lignosulphonates, xylitol, sodium carbonate, sodium sulphate, and gypsum).

Current global demand and production

The current global textile fibre market is of 111 million tonnes per year. According to one of our stakeholders, whose product is already on the market, their estimated production volume is of 1.2 million tonnes of fibre per year. All stakeholders working with textile fibres mentioned that most of their production (over 90%) is or will be exported.

It is estimated that in 2030 the global production will reach 146 million tonnes (Textile Exchange 2020) (Figure 23). The demand for wood-based textile fibres is expected to continue increasing as a result from growth in global population and GDP, shortage of land for cotton production, environmental concerns associated with the production of textile fibres other than wood-based, changes in fashion, and the development of new technologies (Kallio 2021). In 2019, 52% of the global fibre production volume was polyester, 23% cotton, 6.4% man-made cellulosic fibres, and 18.6% others (Textile Exchange 2020).

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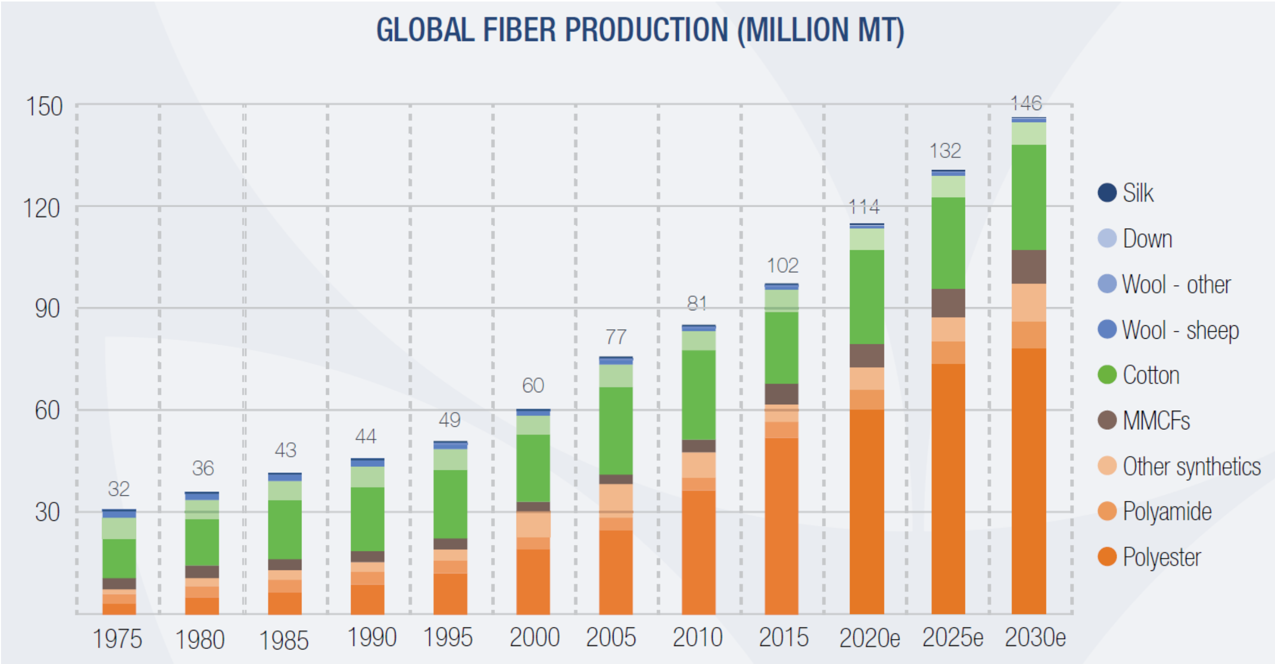

Source: Textile Exchange (2020)

Figure 23. Global fibre production trend

According to our stakeholders, the three greatest obstacles for introducing the wood-based textile fibres to the market are the cost compared to fossil-based or GHG-intensive products, the production scale and the customer preference for traditional products. However, if the product was already on the market, the three greatest obstacles for increasing their market share were technical difficulties, the production scale and the cost compared to fossil-based or GHG-intensive products. Stakeholders believed that, for products already established in the market, these difficulties could be largely alleviated by EU policies through increasing bio-based materials subsidies, banning of single-use plastics, and putting sustainable development goals in place. The difficulties would only be slightly alleviated for completely new products, but EU policies should focus on supporting commercial scale investments.

Below we describe in more details two types of wood-based fibres for textiles produced using newer processes, namely: lyocell technology and ionic liquid technology. Fibres produced using the lyocell technology are already on the market, and the ones produced using the ionic liquid technology are still in piloting phase, with commercial production set to start in 2025. These two types of fibres, while not the only ones being developed and produced, represent an evolution in production processes towards more sustainable materials.

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3.3.5.1 Lyocell technology

Lyocell fibre has a highly crystalline structure that allows good wet and dry strength. It has higher dry tenacity value than viscose fibre and is in strength almost equivalent to polyester fibre. It is the only regenerated cellulose fibre with a wet tensile strength higher than cotton. Compared to viscose, lyocell has a significantly reduced elongation. It can be blended, dyed and spun into fine count yarns. Lyocell is suitable for nonwovens due to its high strength, biodegradability, easy processing, absorbency, and potential to fibrillate (Borbély 2008).

The production of lyocell uses non-toxic N-methylmorpholine-N-oxide hydrate as solvent, 99% of which can be recovered and recycled. The dissolving grade wood pulp is mixed into a paste with the solvent, going through a high temperature dissolving unit and forming a clear viscous solution, which is filtered, pumped into spinnerets, and spun into the diluted solvent, where the cellulose fibres precipitate. The fibres are washed, dried, lubricants (such as silicone or soap) applied, carded (to separate the strands), and baled (Borbély, 2008).

Lyocell is a type of wood-based fibre that is already on the market. In 2019, it was the third most used man-made cellulose fibre type after viscose and acetate. Its market share is around 4.3% of all man-made cellulosic fibres, with a production volume of roughly 0.3 Mt. The compound annual growth rate from 2017 to 2022 is estimated at around 15%. This means that lyocell is expected to grow faster than other man-made cellulosic fibres (Textile Exchange 2020).

3.3.5.2 Ionic liquid technology

Among the new wood-based fibres that are not yet commercially available is the one using the ionic liquid technology. The type of fibre produced is soft and strong even when wet, can be dyed like other bio-based fibres such as cotton and viscose, and has properties that are similar or better than viscose and lyocell (Michud et al. 2016). They can also be used in technical applications, such as in composites, due to their high tenacity (Sixta et al. 2015).

The raw material is either kraft pulp or cellulosic waste streams (such as pre-treated textile waste with high cellulose content). Currently, the most common tree species used for this new type of fibre are birch and eucalyptus. The production of these fibres uses the non-toxic ionic liquid to dissolve the cellulose. Then, staple fibres are produced using a dry-jet wet spinning technology. The water and ionic liquid are re-circulated in the process in a closed loop. In addition to using a cleaner production process when compared to traditional technologies such as viscose, these new wood-based fibres have also the advantage of allowing for the use of unbleached pulp for paper as feedstock.

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3.3.6 Summary

The development of innovative forest-based products follows increasing awareness among governments, companies and consumers regarding the widespread use of fossil-based and GHG-intensive materials in products (Hurmekoski et al. 2018). Far from being exhaustive, the list of products reviewed in this study aimed to highlight some of the up-and-coming products and technologies that will likely become known to the public in the near future or that will continue to increase in market share. Table 5 summarizes the findings from this study.

Table 5 – Summary of the selected new and novel wood-based products

Category	Product	Feedstock requirements	Sustainability aspects	Compatibility with value chains
Construction materials	CLT	Usually coniferous sawnwood; possible to use deciduous, or structural composite lumber	End-of-life options: mechanical recycling, used as source of energy, biodegradation	Well-established value chain
	Wood foam	Wood fibre, either from coniferous or deciduous species	End-of-life options: used as source of energy, composting	Possibly connected to a pulp mill
Chemicals	Lignin-based adhesives	Any type of lignin is suitable; best results from black liquor from the kraft pulping process using pine	No emissions of volatile organic compounds, less energy during production	Possibly connected to a pulp mill
	Glycols	Best results from the wood of broadleaves	End-of-life options: possibility to be recycled	Possibly connected to a sawmill or pulp mill
Bioplastics	Bioplastics from ethylene	Any type of wood, and possibly bark of some tree species; ideally should use residues and industrial side streams	End-of-life options: recycling, composting (depending on type of material)	Possibly connected to a sawmill or pulp mill
	Bioplastics from tall oil	Industrial side streams from the pulping process	End-of-life options: recycling, composting (depending on type of material)	Possibly connected to a pulp mill
Wood-based composites	Wood-based composites	Wood flour, fibres, particles, chips or solid wood (depending on the final product)	End-of-life options: recycling, composting	Well-established value chain; connected to a sawmill or pulp mill
Textile fibres	Lyocell technology	Wood pulp	Production in closed loop. End-of-life options: recycling, composting	Well-established value chain
	Ionic liquid technology	Wood pulp from kraft process or other high-content cellulose feedstock	Production in closed loop, without harsh chemicals. End-of-life options: recycling, composting	Possibly connected to a pulp mill

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4 Discussion

4.1 Main findings

In this case study, we reviewed emerging wood-based products in the EU, covering a wide range of wood-based product categories. We identified a rich set of intermediate products with a range of potential end uses as well as end products in a variety of categories. The EU has a strong history and industry in the forest sector and the players in the field range from small start-ups to multinationals on the forest market. The variety of products is extremely wide, varying from molecules to bioplastics and composites to large items such as bathroom furniture and wood construction materials. The growth of these companies and their increasing share of the market in their specific segment could form a significant force in EU bioeconomy and should be treated as such. The research questions we aimed to shed light on were:

1. What are the main new wood-based products that could be economically produced in Europe from lignocellulosic biomass from forests in the near to medium future?
2. What fossil-based chemicals or materials could the new wood-based products substitute?
3. What are the requirements for biomass quality and quantity?
4. To which extent are these products compatible with existing value chains?

With regards to the first question, we found that the wood-based products most likely to be mature enough in their development to either already be in the market or to be close to market introduction belong to the following categories: construction materials, chemicals, plastics, composites and textiles (see Table 4). These products were not only selected based on product maturity and TRL, but also because the potential substitution effects in these categories are huge. We excluded products that are already on the market but occupy a very small or specialised niche. For all categories, the products reviewed can completely substitute their fossil-based counterpart- but production capacity is in most cases still quite low. As demands for e.g. chemicals and plastics are rising, we cannot expect to see a decrease in demand for fossil-based products in the short term, but the substitution potential is correspondingly enormous. This also means that the need for woody biomass is expected to increase, a conclusion that is shared by most respondents in the survey. Most products surveyed here do not have specific demands on biomass quality, many can be produced from what would normally be assumed as waste from the forest-based industry. In some cases, specific feedstock properties could be beneficial but are not necessary. All selected products can be considered drop-in in relevant value chains. Our selection criteria have most likely favoured drop-in products as we are aiming for market or close to market products. Products that would require new or modified value chains have a higher threshold to market introduction at a relevant scale.

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As a part of bioeconomy, the market share for products from woody biomass varies depending on the product category. For construction elements, wood is the dominant raw material that competes with materials such as concrete. For bioplastics, the complex chemical composition of wood makes it a less attractive source than short rotation crops. However, with future demands for food production, the use of agricultural land to grow biomass for industrial use is less likely to be considered sustainable. Thus, the use of woody biomass for a diverse range of products could be an alternative that does not compete with food and feed production. Furthermore, forestry is generally a low environmental impact production system, as in Europe no or limited amounts of fertilizers and pesticides are used, it can prevent soil erosion in contrast to agriculture, and the processing of the material has several potentially valuable side streams. However, forests are more complex systems to manage. Also, breaking down the wood to usable components is a more energy-consuming process than to using agricultural crops. It is reasonable to conclude that the market demand for biomass will increase and that wood will have an environmental edge over annual crops.

Woody biomass can be used for a very broad variety of products that would not be usually connected to wood or paper (i.e., the number one wood product). Firstly, the pulping process generates side streams that can be used to lessen the waste from pulp mills. Residues are often used for internal energy consumption within the sector but are now increasingly processed for other products. Lignin can be extracted from black liquor and is the raw material for many wood-based products such as adhesives, material for batteries and resins. However, most of the products that constitute this case study’s units of analysis use wood or its derivatives and thus need wood in some form as raw material. It should be noted that many of the products can still use woody biomass that could be considered waste (i.e., sawdust, branches or wood types that are normally not used industrially). Several stakeholders named sawdust as raw material for their products. Potentially, an increasing demand for sawdust could make access to the material a limiting factor, especially since sawdust also is a source for bioenergy (frequently in the form of wood pellets).

Based on the product segments that wood-based products can enter and substitute fossil-based feedstock, intermediate products and end products, the potential market for wood-based products is huge. Market segments such as chemicals are not only responsible for high GHG emissions, but also at a very large scale. Even with wood-based products coming into the market, stakeholders predict that a very small proportion of traditionally manufactured chemicals will be substituted in the coming 10-20 years. This means that, with customer demand for renewable alternatives combined with EU policies favouring wood-based products, the drive for increasing production – and consequently the increase in biomass needs – will be high. The same reasoning is valid for the plastics segment, where we can already see a shift in the market as a result of policies targeting plastic use.

In a bioeconomy context, one must take into consideration the full lifecycle of products. This means that not only the source of raw material is important but also the ratio of bio-based material in the product, the energy consumption for manufacturing, the residues generated from manufacturing and use, and the product’s end-of-life. Almost all wood-based products covered in our survey were recyclable to some extent. Many were also biodegradable which indicates an environmental

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advantage, even if the results from full LCA are not known. It is also clear that the environmental impact is an important factor when working with these products. Most of the respondents from our survey have taken one or more eco-design factors into consideration during product development, and for many products at least a “cradle-to-gate" LCA was conducted.

In general, companies do experience difficulties in introducing their product in the market or increasing the market share. They believe these obstacles can be alleviated by EU policies. The level and type of support required differ. But stakeholders believe less bureaucracy, support for pilot-scale to full-scale production and subsidies for bio-based alternatives (as well as bans on fossil-based alternatives) can help alleviate these difficulties.

4.2 Potential caveats

As mentioned before, the case study aimed to identify products based on the raw material they were derived from. There are at best a few common points between the products making it difficult to group them as a whole unit to be analysed, thus the choice to treat each chosen product as a unit of analysis.

The market is still quite immature for most of the products, with only a few stakeholders actively developing or producing them. Grouping by product category is thus not a feasible approach as the sample size will be far too small for most quantification analyses. As a result of this, the outcome of the study is more qualitative than quantitative, and it should be judged as such. There is a lot of valuable information and the study provides insights in the current and upcoming situation regarding innovative wood-based products, despite it not being primarily a quantification study.

4.3 Feedback to other WPs

This case study on new wood-based products contributed to WP3 (Task 3.2) by suggesting potential wood-based products that have market grow potential. If these are not explicitly visible in statistics, they are candidates for integration. It also provided information that indicated which bio-based sectors that required extending NACE and NAS codes, and which wood-based products would benefit from extended PRODCOM and CN codes to specify the bio-based products. This case study also indicated that it is important to monitor the development of markets for bio-based products, information also important for WP3. In addition, the description of production processes, even if simplified, will be helpful to better integrate woody biomass flows in material flows model.

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The outcomes from this case study will be useful for WPs 4 and 5 to improve and extend the economic models with information on the production (technologies, efficiencies, etc.) of engineered wood products (more specifically CLT), ethylene from wood sugars and textile fibers.

4.4 Recommendations and best practices

One of the recommendations from this case study is to build up a network of contacts and stakeholders within the field of interest, alternatively making use of networks to establish a personal relationship with stakeholders, as this may help keep stakeholders engaged during the development of the study. If a personal connection is not available, one should try to establish a familiarity with the stakeholders one needs to connect with. One way is to approach them in their native language even if the following communication and the material used in data gathering are in English. If physical meetings are not possible and online tools are used, one should make sure that there are several options to connect, as some organisations do not allow specific platforms. In the case of online interviews, it is also important not to heavily rely on technical equipment or on the ability to record interviews. Telephone and pen and paper are still very reliable tools. Finally, it is also recommended to conduct interviews with two interviewers, as one person can drive the discussion while the other can focus on documentation.

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5 Conclusions

This case study covered new and novel wood-based products that are about to enter or that have entered the market but have the potential to expand their market size. There are several innovative wood-based products that are already today produced at an industrial scale in Europe and can be expected to increase their market share in the coming years. CLT and textile fibres are examples of such advanced products. Some up-and-coming products that are not yet produced at an industrial scale, but are entering mature markets and thus have a high potential to substitute fossil-based raw materials, are biochemicals, bioplastics and, to some extent, wood-based composites. These products are entering mature markets, and in many cases can fully drop into established value chains. The range of wood-based products covered in this case study is reflected in the variety of fossil-based products and materials that can be substituted.

The use of biomass is equally diverse, but most of the wood-based products reviewed in this study can use virgin biomass as well as wood residues and/or by-products from industrial side streams. This also means that, even though the volume demands are expected to increase, supply is not seen as a limiting factor.

The ease of market introduction of new innovative products relies heavily on the products’ ability to take advantage of existing value chains. In general, many of the products reviewed in our study are fully drop-in, which is a huge advantage when it comes to market introduction. Products that require adjustments to production lines or methods are less likely to get into the market without strong external drivers that push for bio-based alternatives. Only a few products are completely new and thus require new value chains. These products are generally not replacing fossil-based alternatives but rather create new, specialized market segments.

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Annex 1: questionnaire for interview

Introduction
1. What are some of the new wood-based products that are soon to come to the market? / What are the new technologies that are being developed that may open new possibilities to produce new products? 2. Among these ones you mentioned, which is the one you think there is more potential to have commercial success?
Advantages/disadvantages
3. What are the advantages of the new wood-based product? Or what will it provide a solution for? 4. What type of feedstock (e.g., virgin wood, biomass side-streams) is used to produce this/these product/s? 5. Where do you think the feedstock would come from? Is it locally produced, or internationally traded? 6. Other than the main component, does the production process involve other bio-based raw materials (such as chemicals, binding agents, etc.)? 7. Would you have an idea about the percentage of wood in this product? 8. Which bio-based products (based on feedstock other than wood) are being developed by your organisation?
Substitution
9. Is this product a substitute for a fossil-based product? If so, which product? 10. Considering the product that you mentioned, which fossil-based resources could be replaced with wood-based feedstock? 11. Regarding the use of resources and energy for the new products, do you know if the requirements are comparable to fossil-based products? 12. Regarding to manufacturing cost, is the process cost effective in comparison to traditional products?
Value chain
13. Who is the end user for your products? Do these already “exist” (meaning using products that will be substituted) 14. Can the wood-based products enter existing value chains? 15. If so- which adjustments are necessary (or no adjustment)

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Biomass quality and quantity
16. Do you think that access to biomass can be a limiting factor for your product(s)? 17. Do you know if the product has specific demands regarding biomass quality? 18. If so, do you believe that purpose made wood could address that challenge? (Purpose made wood- trees bred or modified for a specific chemical wood composition)
Prospects or visions
19. Having the products from your organization in mind, to which extent do you foresee that wood-based products will substitute fossil-based products? 20. In your opinion, how is the market for wood as feedstock going to evolve in the next 5-10 years? (Higher demand for specific wood types, faster rotation?)
Final questions
21. Because we will be doing a review of a selected number of wood-based products, would you be able to share or indicate information sources about the products discussed in the interview? 22. Would you be willing to participate in a 20-minute online survey on the same topic?

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Annex 2: questionnaire for online survey

1. What is the type of organization you are active in?
( ) start up
( ) small or medium-sized enterprise
( ) multinational
( ) research institute
( ) Other (please specify)

2. In which country(ies) is the main product being developed or produced?

3. Having the main product manufactured by your company in mind, to which of the following categories does it belong?
( ) Construction materials
( ) Bioplastics
( ) Fibres for textiles
( ) Wood-based composites
( ) Chemicals
( ) Other (please specify)

4. Is the main product considered an intermediate or a final product?
( ) Intermediate product
( ) Final product

5. What by-products are generated during the production of the main product?

6. What type of feedstock is used to manufacture the main product?
( ) Sawlogs or pulp logs
( ) Wood chips
( ) Sawdust
( ) Wood pulp
( ) Black liquor
( ) Tall oil
( ) Tree resins and gums
( ) Bark (including cork)
( ) Recycled wood-based materials
( ) Other (please specify)

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7. How much feedstock is needed to produce one unit of the main product? Please specify the amount and the unit (e.g. m^3 of roundwood equivalent / m^3 of main product; m^3 of roundwood equivalent / kg of main product). The answer can be given as a range.

8. Which of the following options would better describe the distance from the source of bio-based feedstock to your organization?
( ) Obtained from within integrated production facility
( ) Local (<50 km from production facility)
( ) Regional (between 50-200 km from production facility)
( ) Feedstock traded between adjacent countries
( ) Globally-traded feedstock
( ) My organization is only involved in the development of products
( ) Other (please specify)

9. How do you expect the volume demands of wood biomass to change in the coming 10 years to produce the main product?
( ) Decrease considerably (by more than 10%)
( ) Decrease slightly (by less than 10%)
( ) No change expected
( ) Increase slightly (by less than 10%)
( ) Increase considerably (by more than 10%)
( ) I don’t know

10. Is the main product already on the market?
( ) Yes
( ) No

11. If the main product is not yet on the market, what is the estimated time for it to reach the market?
( ) less than 5 years
( ) 5-10 years
( ) 11-20 years
( ) more than 20 years
( ) I don’t know

12. What is the estimated Technology Readiness Level of the main product?
( ) TRL 1-2
( ) TRL 3-4
( ) TRL 5-6
( ) TRL 7-8
( ) TRL 9
( ) I don’t know

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13. If the main product is already on the market, what was the volume of biomass used in the manufacture of the main product in your organization per year? The answer can be given as a range, in tonnes or cubic metres (please specify unit).

14. If the main product is already on the market, what is the share of imported biomass in total biomass used for the main product per year?
( ) <10%
( ) 10-19%
( ) 20-29%
( ) 30-39%
( ) 40-49%
( ) 50-59%
( ) 60-69%
( ) 70-79%
( ) 80-89%
( ) >90%
( ) I don't know
( ) The product is not on the market yet

15. What is the estimated production volume (in tonnes or in cubic metres) per year of the main product? The answer can be given as a range.

16. What is the share of bio-based materials in the main product?
( ) less than 5%
( ) 5-25%
( ) 26-50%
( ) 51-75%
( ) 76-99%
( ) 100%
( ) I don't know

Please indicate if this share is calculated as:
( ) carbon content
( ) bio-based material

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17. Which share of produced volume is expected to be exported?
( ) <10%
( ) 10-19%
( ) 20-29%
( ) 30-39%
( ) 40-49%
( ) 50-59%
( ) 60-69%
( ) 70-79%
( ) 80-89%
( ) >90%
( ) I don’t know

18. Which fossil-based or greenhouse gas-intensive material(s) could the main product from your company substitute?

19. What is the percentage of fossil-based or greenhouse gas-intensive materials could the main product from your company substitute?
( ) <10%
( ) 10-19%
( ) 20-29%
( ) 30-39%
( ) 40-49%
( ) 50-59%
( ) 60-69%
( ) 70-79%
( ) 80-89%
( ) >90%
( ) I don’t know

20. Could the main product from your company fully substitute a fossil-based or greenhouse gas-intensive product in the value chain?
( ) Yes, it could fully substitute a fossil-based product (drop-in)
( ) It could partially substitute, with adjustments to value chain
( ) No, it could not substitute a fossil-based product; a new value chain needs to be created
( ) I don’t know

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21. During the early development stages of the main product, how important was ecodesign (e.g. that a producer is already considering how the product could be reused or recycled in its design)?
( ) Extremely important
( ) Very important
( ) Somewhat important
( ) Not so important
( ) Not at all important

22. Which ecodesign aspects were considered during the main product development?
( ) Use of low impact raw materials
( ) Use of optimised production processes to minimise negative environmental impacts
( ) Design of durable and reparable products
( ) Design for ease of maintenance, reparability, upgradability and adaptability
( ) Use of optimized distribution systems, reusable packaging, and reduced package waste
( ) Design considering recyclability, biodegradability and waste minimization at the end of life
( ) Ecodesign was not considered during the main product development
( ) Other (please specify)

23. Is the main product recyclable?
( ) No, not recyclable at all
( ) Yes, fully recyclable
( ) Yes, partly recyclable. Please state the percentage of recyclable material

24. A biodegradable material is one "in which all the organic carbon can be converted into biomass, water, carbon dioxide, and/or methane via the action of naturally occurring microorganisms such as bacteria and fungi", within a reasonably short period of time (one year) after customary disposal (American Society for Testing and Materials).

Is the main product biodegradable?
( ) Yes, it is biodegradable in water
( ) Yes, it is biodegradable in soil
( ) No, it is not biodegradable

25. A compostable material is one that "undergoes degradation by biological processes during composting to yield carbon dioxide (CO2), water, inorganic compounds, and biomass at a rate consistent with other known compostable materials and that leaves no visible, distinguishable, or toxic residue" (American Society for Testing and Materials).

Is the main product compostable?
( ) Yes, it can be composted in commercial or industrial composting facilities
( ) Yes, it can be composted at home
( ) No, it is not compostable

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26. Are there Life-Cycle Assessments (LCA) available for this product?
( ) Yes, cradle-to-gate
( ) Yes, cradle-to-grave
( ) Yes, cradle-to-cradle
( ) No
If possible, please provide a link to the LCA study.

27. What do you perceive as the greatest obstacle for introducing the main product to the market or increasing its market share? Please rank the answers from 1 (most important obstacle) to 5 (least important obstacle).
( ) Cost compared to traditional fossil-based products
( ) Production scale (going from pilot to full-scale production, meeting demands)
( ) Customer stuck on traditional product
( ) Technical difficulties
( ) Other (please specify)

28. To what extent do you believe that these difficulties can be alleviated by EU policies?
( ) Largely alleviated
( ) Slightly alleviated

29. In what way could EU policies increase the probability of the main product to reach the market or to increase its market share?

30. Which share of the company’s total turnover is invested in R&D connected to new bio-based products?
( ) <10%
( ) 10-19%
( ) 20-29%
( ) 30-39%
( ) 40-49%
( ) 50-59%
( ) 60-69%
( ) 70-79%
( ) 80-89%
( ) >90%
( ) I don’t know

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31. What is the number of patents’ applications in your company for the production of the main product per year?
( ) none
( ) 1-5
( ) 6-10
( ) more than 10

(Question to restart survey)

32. Would you like to restart the survey for another product?
( ) Yes
( ) No

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