European Commission

JRC SCIENCE FOR POLICY REPORT

Insights into the European market for bio-based chemicals

Analysis based on 10 key product categories

Jurjen Spekreijse

Tijs Lammens

Claudia Parisi

Tévécia Ronzon

Martijn Vis

2019

Joint Research Centre

EUR 29581 EN

Contact information
Name: Claudia Parisi
Address: Edificio EXPO, c/ Inca Garcilaso, 3, E-41092 Seville (Spain)
Email: JRC-D4-SECRETARIAT@ec.europa.eu

JRC Science Hub
https://ec.europa.eu/jrc

JRC112989
EUR 29581 EN

Print	ISBN 978-92-79-98419-8	ISSN 1018-5593	doi:10.2760/673071
PDF	ISBN 978-92-79-98420-4	ISSN 1831-9424	doi:10.2760/549564

Luxembourg: Publications Office of the European Union, 2019

How to cite this report: Spekreijse, J., Lammens, T., Parisi, C., Ronzon, T., Vis, M., *Insights into the European market of bio-based chemicals. Analysis based on ten key product categories*, EUR 29581 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-79-98420-4, doi:10.2760/549564, JRC112989.

Title Insights into the European market of bio-based chemicals

Abstract
Bio-based products can bring new functionalities to the market and make the EU economy more sustainable. According to this analysis, based on ten key chemical categories, the EU produces 4.7 Mt/a of bio-based chemicals which represents a bio-based share of about 3.0%, although the market is diverse and large differences can be found between product categories. Under a business-as-usual scenario, the overall bio-based share of the market is not expected to increase rapidly, with an estimated CAGR of 3.6%. Hurdles are still present in the development of the bio-based industry (e.g. production costs), but also big opportunities have been identified and new policy measures could help.

Contents

Acknowledgements 3
Executive summary 4
1 Introduction 12
1.1 Background of the study 12
1.2 Objectives 12
1.3 Scope and limitations of the study 13
1.4 This report 14
2 Methodology 15
2.1 Identification and selection of bio-based product categories 15
2.2 Characterisation of the longlist of bio-based products 16
2.3 Selection of 20 bio-based products for value chain description 18
2.4 Selection of 50 representative bio-based products for market description 19
2.5 Methodology for market data collection on 50 bio-based products 23
2.5.1 Market data uncertainty indicator 23
2.5.2 Statistical data 24
2.5.3 Other market data 27
2.6 Method for market data collection at product category level 27
2.7 Analysis of data quality and gaps 28
3 Results 29
3.1 Value chain description 29
3.2 Production and bio-based share 30
3.2.1 Production and bio-based share of 50 bio-based products 30
3.2.2 Production and bio-based share at product category level 36
3.3 Price and turnover 41
3.3.1 The prices of the 50 bio-based products 41
3.3.2 Turnover figures for the 50 bio-based products.......................................45
3.3.3 Price and turnover data for the 10 bio-based product categories 46
3.4 The EU's consumption and trade 47
3.4.1 Data on consumption and net trade for 50 bio-based products 47
3.4.2 Consumption and EU import dependence at product category level 53
3.5 Feedstock use, feedstock import dependence and land use 55
3.5.1 Feedstock use of the 50 bio-based products 55
3.5.2 Land requirement of the 50 bio-based products 58
3.5.3 Feedstock use, import dependence and land use at product category level 61
3.6 Future market size 64
3.7 Private investments 67

3.8 Importance of Member States and the EU 68
3.8.1 Importance of Member States 68
3.8.2 Importance of the EU 69
3.9 Maturity level 71
3.10 SWOT analysis on future development potential 72
4 Conclusions and recommendations 81
4.1 Conclusions.. 81
4.2 Recommendations 84
List of abbreviations and definitions 94
List of figures 96
List of tables 97
Annexes 99

Acknowledgements

This publication is part of the contribution of the Joint Research Centre (JRC) to the European Commission's Knowledge Centre for Bioeconomy. The research was funded by an administrative arrangement between the Directorate-General for Research and Innovation (DG RTD) and the JRC.

The authors would like to thank the other members of the bioeconomy team at JRC Seville (Robert M'barek, George Philippidis and Patricia Gurría) for reviewing the document and providing useful input; Maria Fernandez Gutierrez and Garbiñe Guiu of DG RTD for their help in defining the scope of the study and their useful feedback; and, finally, Marios Avraamides and Elena Garbarino for the final review of the document.

Authors

Jurjen Spekreijse

Tijs Lammens

Claudia Parisi

Tévécia Ronzon

Martijn Vis

Executive summary

Background

Europe's economy depends on oil and gas for the chemicals and energy sectors and for all kinds of everyday products. However, fossil resources are scarce and their use harms the environment and our climate. Bio-based products can be substituted for fossil-based materials and bring new functionalities to the market, making the economy more sustainable and reducing its dependence on fossil resources. Industry, supported by governments and large research programmes such as Horizon 2020, has developed an array of innovative bio-based products, which are expected to find their way onto the market in increasing numbers. However, monitoring the development of the bio-based economy is challenging, since no official European databases are dedicated to bio-based products for industrial use, such as bio-based chemical products.

Scope and goal

This study aims to provide a detailed description of a segment of the EU bio-based products sector, represented by 10 chemical product categories, and its application markets:

- platform chemicals
- solvents
- polymers for plastics
- paints, coatings, inks and dyes
- surfactants
- cosmetics and personal care products
- adhesives
- lubricants
- plasticisers (and stabilisers for rubber and plastics)
- man-made fibres

More specifically, the study provides a comprehensive list of bio-based products in this segment, specifying how they relate to statistical nomenclature where possible. It also aims to quantify market and market dynamic indicators as well as to provide land footprint information.

This market study focuses on bio-based products that are already commercially available. It covers not only innovative bio-based products but also bio-based products that have been being produced for some time (e.g. turpentine, rayon and cellulose acetate). The scope of this study is the EU market. Consequently, it includes certain bio-based products that are produced in third countries and imported onto the EU market.

This study constitutes a first concrete step towards describing a market that has a high potential but which has not yet been extensively studied and on which few data are available by applying a detailed methodology to achieve a very thorough data collection, which had not yet been done in this area. Therefore, despite the variable levels of uncertainty of the data provided (highlighted throughout the report), this report is the first of its kind and has a high value for the bio-based sector.

Methodology

From a longlist of 350 bio-based products, developed as part of the Bio-Based Industries Joint Undertaking project RoadToBio, 208 products that are available at commercial scale (technology readiness level ≥ 8) were selected. From this list, 50 bio-based products were identified as representative of the 10 product categories (3-9 per product category) and 20 value chain descriptions were created (2 products per category). A detailed market assessment was carried out on the 50 selected products, covering production in the EU, price, turnover, consumption, trade, feedstock use and agricultural land requirement. Based on the analysis of the 50 products, additional literature and expert interviews, market information on the product categories was collected, covering EU production and market share, the EU's import dependence, future market size, private investment, the importance of Member States and the EU to production, maturity level and a strengths, weaknesses, opportunities and threats (SWOT) analysis. This information has been summarised in a factsheet for each product category.

The two main statistical databases relevant for the collection of information on bio-based products are (i) the Prodcom survey, which collects and disseminates statistics on the production of industrial (mainly manufactured) goods, using data compatible with the NACE and CPA classifications, and (ii) international trade data available from Eurostat's Easy Comext database, classified in accordance with the Combined Nomenclature (CN 2016) and the CPA classification, among other systems. Each of the 50 bio-based products investigated was classified in accordance with Prodcom and CN 2016. The usability of the statistical data strongly correlates with the product coverage of the codes. Some CN and Prodcom codes represent a single bio-based product, some represent a limited group of products and, in some cases, one CN or Prodcom code represents many products. In addition, production data on bio-based products can be obtained only if the code concerns a product that is only bio-based (not a drop-in, that is, a bio-based version of an existing chemical); otherwise, only the total production of the bio-based and fossil-based products can be obtained.

The statistical information had to be complemented with information from the literature, publicly available commercial market studies, expert interviews and, as a last resort, own expert estimates. The reliability of the information collected was scored using an uncertainty indicator.

Main results

Production, bio-based share and consumption

The total (combined fossil- and bio-based) production and the bio-based share of total production were estimated and are presented in Table 1.

Table 1: Estimates of total EU production, the bio-based share of production and the consumption of bio-based products for each category

Product category	EU bio-based production (kt/a)	Total EU production (kt/a)	EU bio-based production share (%)	EU bio-based consumption (kt/a)
Platform chemicals	181	60,791	0.3	197
Solvents	75	5,000	1.5	107
Polymers for plastics	268	60,000	0.4	247
Paints, coatings, inks and dyes ([a])	1,002	10,340	12.5	1,293
Surfactants	1,500	3,000	50.0	1,800
Cosmetics and personal care products ([a])	558	1,263	44.0	558
Adhesives ([a])	237	2,680	9.0	320
Lubricants ([a])	237	6,764	3.5	220
Plasticisers ([a])	67	1,300	9.0	117
Man-made fibres	600	4,500	13.0	630
Total	4,725	155,639	3.0	5,489

([a]) No total EU production data were found; it has been assumed that total EU production (fossil- and bio-based) equals the total EU market (fossil- and bio-based consumption).

Platform chemicals and polymers for plastics dominate total EU production, while, for these categories, the bio-based share is only 0.3% and 0.4% and bio-based production 181 kt/a and 268 kt/a, respectively. It is interesting to observe that the categories paints, coatings, inks and dyes, and surfactants have high bio-based production volumes, although they are less commonly thought of as being bio-based than, for instance, bio-plastics. The bio-based share of surfactants, 50%, is remarkably high compared with those of other product categories. This can be explained by the high share of bio-based oleochemicals used in surfactants. It is difficult to estimate the exact bio-based share of cosmetics and personal care products, as more than 5,000 synthetic and bio-based products exist in this category. Total EU bio-based production for all 10 product categories included in Table 1 is 4.7 Mt/a, representing an overall bio-based share of about 3.0% of the 156 Mt/a total EU production.

Price and turnover
The average prices for the bio-based product categories were obtained from the average prices of the products included in those categories, weighted by production volume. The results are presented in Table 2.

Table 2: Prices and turnover figures for bio-based products aggregated to product category level

Product category	Price (EUR/kg)	Turnover (EUR million/a)
Platform chemicals	1.48	268
Solvents	1.01	76
Polymers for plastics	2.98	799
Paints, coatings, inks and dyes	1.62	1,623
Surfactants	1.65	2,475
Cosmetics and personal care products	2.07	1,155
Adhesives	1.65	391
Lubricants	2.33	552
Plasticisers	3.60	241
Man-made fibres	2.65	1,590
Total	1.94	9,167

With a few exceptions (vanillin and *N*-acetyl glucosamine), the prices of the products are below EUR 10/kg. The prices of bulk chemicals, such as platform chemicals and solvents, are generally around EUR 1-2/kg, whereas more specialised products such as cosmetics and personal care products and plasticisers are generally more expensive.

The bio-based platform chemicals show relatively low turnover figures for the EU-28 due to their low production volumes and relatively low prices. The opposite is observed in the bio-based product categories that are closer to the end user, such as cosmetics, lubricants and man-made fibres.

In some cases, turnover data could be obtained directly, through statistical analysis. In most cases, they were obtained indirectly, by multiplying total EU production of a bio-based product by its price. Since consumption equals production plus import minus export, consumption can be derived from production and net trade, and net trade from production and consumption (assuming no changes in stocks).

Feedstock use and land requirement
Figures for the bio-based products' feedstock use and land requirement were calculated based on estimates of feedstock use per tonne of product and agricultural yields. They are reported in Table 3 and Figure 1. Among the vegetable oil-based products, those that are derived from a specific, non-palm oil (e.g. nylon-11, produced

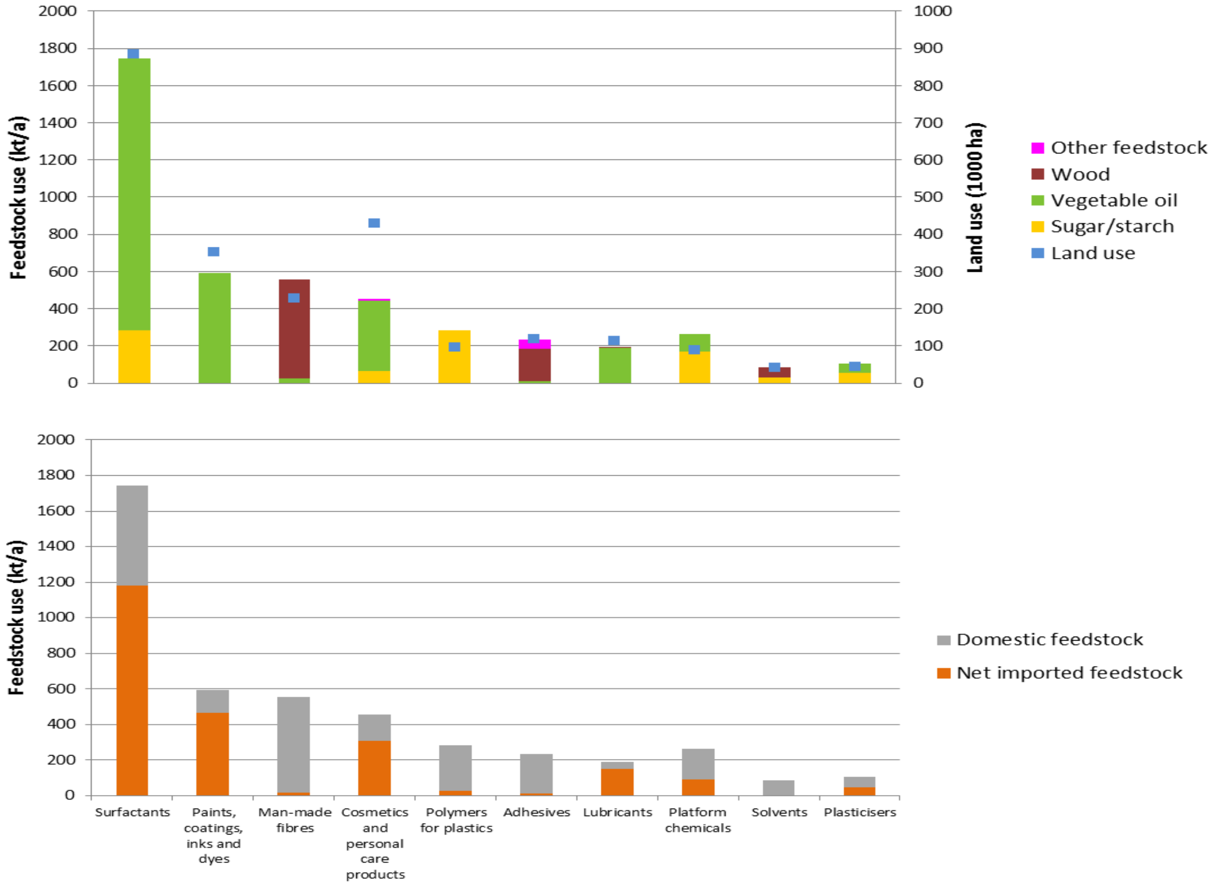
from castor oil, or epoxidised soybean oil (ESBO)) generally use more land per unit of product than other vegetable oil-based products. This can be explained by the significant share of palm oil in the overall vegetable oil mix, with oil palm being a high-yield crop compared with other oil crops. For all product categories, import dependence in relation to feedstock use was determined. It should be noted that the land use estimates here do not distinguish between different types of land. Moreover, other possible impacts on biodiversity, such as eutrophication, have not been taken into account either.

Table 3: Feedstock and land use for EU production of bio-based products at product category level

	Feedstock use for EU production of bio-based products			Land use for EU production of bio-based products	
Product category	**Total (including imports) (kt/a)**	**Imported feedstock ([a]) (kt/a)**	**Import depen-dency (%)**	**1,000 ha**	**ha/t product**
Platform chemicals	262	90	34	88	0.49
Solvents	87	3	3	42	0.56
Polymers for plastics	284	28	10	95	0.36
Paints, coatings, inks and dyes	593	468	79	351	0.35
Surfactants	1,744	1,179	68	885	0.59
Cosmetics and personal care products	456	306	67	430	0.77
Adhesives	232	14	6	117	0.49
Lubricants	192	149	78	114	0.48
Plasticisers	106	46	44	43	0.64
Man-made fibres	555	19	3	228	0.38
Total	4,511	2,302	51	2,393	0.51

([a]) These data refer only to imports of feedstock for EU production of bio-based products, not to imports minus exports, as there are of course no exports of feedstock for EU production of bio-based products.

Figure 1. Feedstock use and land use for EU production of the 10 categories of bio-based products (product categories are ordered by bio-based production, from the largest to the smallest)



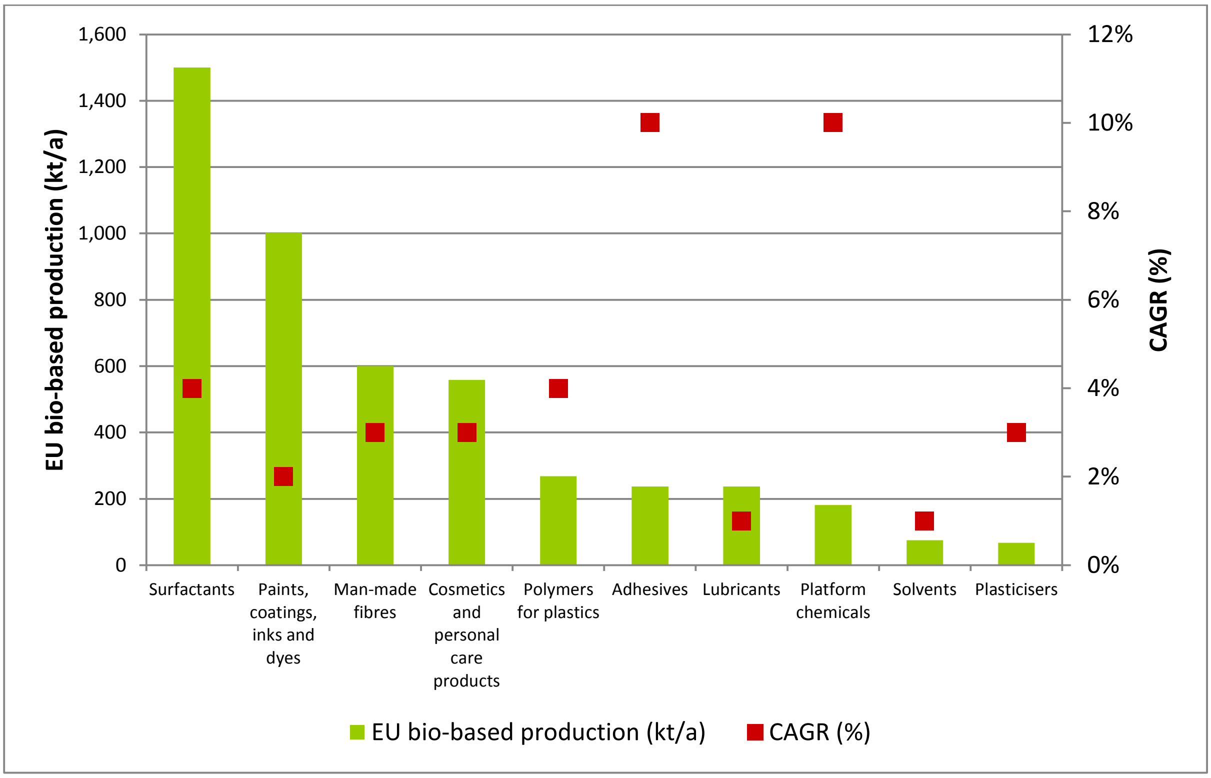
Future market size and private investments

Future market size (Table 4 and Figure 2) was assessed by estimating the compound annual growth rate (CAGR) of the bio-based market in question, i.e. the mean annual growth rate of production over a specified period longer than one year, based on literature and interviews. In absolute numbers, most growth is expected in the market for surfactants because this market is already large. Platform chemicals and adhesives are expected to grow the most in relative terms, at 10% per year. The market for bio-based solvents is not expected to grow much, because of the low priority given to producing bio-based alternatives. Bio-lubricants are also expected to see a low growth rate.

Table 4: Predicted EU bio-based production and private investment in 2025

Product category	CAGR (%)	Bio-based production in 2025 (kt/a)	Total private investment (EUR million/a)
Platform chemicals	10	353	128
Solvents	1	80	16
Polymers for plastics	4	353	144
Paints, coatings, inks & dyes	2	1,151	437
Surfactants	4	1,974	805
Cosmetics and personal care products	3	687	349
Adhesives	10	462	195
Lubricants	1	254	63
Plasticisers	3	83	52
Man-made fibres	3	738	494
Total	2	6,134	2,683

Figure 2. CAGR of the 10 bio-based chemical product categories compared with bio-based production



Private investments (Table 4) are particularly difficult to assess and have been calculated based on estimates of the share of capital expenditure (CAPEX) in the prices of the 50 bio-based products, aggregated to product category level. In the period 2018-2025 private investment amounting to EUR 2.7 billion per year is expected for the 10 product categories, consisting of EUR 1.9 billion in replacement investments and EUR 0.8 billion in expansion investments to increase total production capacity.

Maturity level

The maturity levels of the bio-based product categories within the EU have been derived from the number of EU countries producing the selected 50 bio-based products, the number of production sites and the period during which the product has been being produced. Table 5 provides an overview of the maturity levels of the bio-based product categories in the EU. There is wide variety in the maturity of the bio-based markets. Only a few markets already enjoy high maturity, and for very different reasons. The market for surfactants is mature owing to a long tradition of using surfactants derived from fats and oils. Cosmetics and personal care products include a large number of mature bio-based products, as this sector uses lots of (partly) bio-based ingredients, and there is consumer demand for natural cosmetics. Finally, there is a mature market for bio-based lubricants owing to regulations in a number of Member States about lubricants that are lost to the environment (e.g. for chainsaws). The products that are typically produced in large volumes — namely platform chemicals, solvents, and paints, coatings, inks and dyes — have a very young bio-based market and a low share of bio-based products.

Bio-based product import dependence

The EU is net import dependent in 8 out of 10 product categories (Table 5). In the case of bio-based lubricants and polymers for plastics, the EU is a net exporter. In the cases of most products with a negative import dependence (i.e. higher exports than imports), the difference was very small. Exceptions are lactic acid (−32 kt/a) and starch used for polymers (–80 kt/a) for which the EU is a net exporter. Most import dependences are in the range of 30-50 kt/a, with the greatest import dependences relating to vegetable oil-based products such as ricinoleic acid (152 kt/a), ethoxylated fatty alcohols (308 kt/a) and ESBO (100 kt/a).

Table 5: EU import dependence, importance of the EU and top three most important Member States at product category level

Product category	Maturity level	EU import dependence	Importance of the EU	Top three Member States		
Platform chemicals	Low	Low	Medium	Belgium	France	Sweden
Solvents	Low	Medium	Low	Sweden	Germany	Belgium
Polymers for plastics	Medium	Net exporter	High	Italy	France	Germany
Paints, coatings, inks and dyes	Low	Medium	Low	Germany	France	Italy
Surfactants	High	Low	Medium	Germany	Belgium	Netherlands
Cosmetics and personal care products	High	Low	High	Germany	France	Switzerland
Adhesives	Medium	Medium	High	Finland	Belgium	Sweden
Lubricants	High	Net exporter	High	Finland	Sweden	Germany
Plasticisers	Low	High	Low	Italy	Spain	France
Man-made fibres	Medium	Low	Medium	Austria	Portugal	Germany

Importance of the EU

The importance of the EU can be understood by considering the share of EU bio-based production in total EU production compared with the equivalent figure at global level, and supplementing these data with information related to the import dependence of the EU. The EU has a high overall importance for the production of adhesives, polymers for plastics, cosmetics and lubricants. Low importance was found in the product categories solvents; paints, coatings, inks and dyes; and plasticisers. For some markets that do not have high maturity and have a low bio-based share, such as platform chemicals, the EU has a medium level of importance. This is caused by the fact that, like the EU market, the global market has a low maturity level and a low bio-based share.

Importance of Member States

The importance of Member States within the EU has been estimated based on the number of active companies in each Member State and the Member States' contributions to total EU production of the 50 products. Where necessary, the information was supplemented with data about active firms from publicly available summaries of market reports. There was a large overlap in the most important Member States for the various categories, with Belgium, France, Germany, Italy and the Nordic countries often making the top three. All the Member States identified as most important for any product category are located in the EU-15.

SWOT analysis

A SWOT analysis was carried out based on the literature and expert interviews in order to assess the opportunities for further developing and commercialising bio-based products. In general, high research and development activity and beneficial properties such as biodegradability were seen as strengths. Many additional benefits of bio-based products emerged, such as lower toxicity, lower greenhouse gas emissions and greater safety. Challenging purification processes and the currently lower or inconsistent quality of some bio-based products were identified as weaknesses. The often higher cost of producing bio-based products compared with the fossil-based versions is a challenge mentioned for nearly every product category, usually in relation to high biomass prices or relatively new and not yet optimised technology. Another major weakness of bio-based products is their higher land use compared with fossil-based products, which has a negative environmental impact. In addition, the willingness of consumers to pay a premium for green products seems to depend on the market sector. The greatest perceived threats are consumers having a low level of awareness of bio-based products and increasing public criticism. Public awareness is higher for some product categories (e.g. bio-based plastics, bio-based lubricants) than for others (e.g. surfactants, adhesives, partly bio-based cosmetics and personal care products).

The experts interviewed considered that regulatory measures restricting the use of fossil-based products by demanding certain sustainability criteria could create markets for bio-based products. Such regulations exist (with differing levels of impact) for bio-based lubricants, surfactants, polymers for plastics and plasticisers. There are, for example, regulations to enforce the use of biodegradable products, exemplified by the regulations on lubricants that are lost to the environment. However, the experts view the lack of general measures constraining the use of fossil resources (e.g. a general carbon tax) as a threat for some product categories, preventing the further development of bio-based technologies.

Conclusions and recommendations

The EU bio-based product market is diverse and significant differences can be found between product categories. For example, solvents and platform chemicals both have a very small percentage of bio-based products, whereas surfactants and cosmetics already include a large percentage of bio-based products. Even within categories with similar percentages of bio-based products, the differences are significant: whereas bio-based platform chemicals are expected to grow rapidly in the coming years (CAGR 10%), bio-based solvents are expected to grow at a much slower rate (CAGR 1%). In general, the bio-based market is still relatively small, with the average share of bio-based products in the overall market being 3.0%. In a business-as-usual scenario, the bio-based share of the market is not expected to increase rapidly, with EU bio-based production having an estimated CAGR of 3.6%. Only platform chemicals and adhesives have an expected CAGR above 5%. However, the introduction of stimuli for the entire bio-based market may still be possible. The most common hurdle observed across all product categories is the higher cost of producing bio-based products. This issue is less pronounced in some product categories, such as cosmetics and personal care products, where there is more willingness among consumers to pay a premium. A reduced environmental impact is often accompanied by a higher monetary cost. For this reason, it is often argued that fossil-based products are priced too cheaply, since they do not internalise the costs of their environmental impact. A fossil carbon tax is seen by experts as a way of creating a level playing field for all products, promoting those that are more sustainable without prioritising specific products.

The bio-based materials covered in this report are to a large extent used in manufacturing everyday products for citizens. Thus, a better understanding of the market should help in developing strategies to increase consumer interest in more sustainable, bio-based products (which is also one of the key ideas behind the bioeconomy strategy).

1 Introduction

1.1 Background of the study

Europe's economy depends on oil and gas for the chemicals and energy sectors and for all kinds of everyday products. However, fossil resources are scarce and their use harms the environment and our climate. Bio-based products are defined as products that are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilised materials (EC, 2012); they can be substituted for fossil-based materials and bring new functionalities to the market. They can make the economy more sustainable and reduce its dependence on fossil resources. In addition, European citizens have expressed that they consider there is a need to rethink the way we live our lives in order to halt climate change and prevent global warming, according to various Eurobarometer surveys (Gaskell et al., 2006; Eurobarometer, 2009, 2010). European Commission policies and strategies on industry, the bioeconomy and the circular economy have all emphasised the need to support the development of innovative bio-based products (EC, 2012, 2014, 2015a).

Industry, supported by governments and large research programmes such as Horizon 2020, has developed an array of innovative bio-based products, which are expected to find their way onto the market in increasing numbers.

However, monitoring the development of the bio-based economy is challenging. No official European databases are dedicated to bio-based products for industrial use, such as bio-based chemical products. The many products, the very complex value chains, the novelty of many of the products and the difficulty of retrieving information from the private sector make data collection in this sector very difficult. The JRC has carried out several studies in the past three years with the objective of analysing and monitoring developments in the EU bioeconomy, and these studies generally considered bio-based products as an aggregated sector and described it using rough estimates (Ronzon et al., 2017a; EC, 2018).

The JRC survey of EU companies producing bio-based chemicals and composite products (Nattrass et al., 2016) certainly contributed to our understanding of the trends that characterise the EU bio-based industry; however, the results of the survey cannot be interpreted as absolute numbers because of the heterogeneity of the responses and the difficulty of obtaining input from a substantial number of the key economic actors. Moreover, detailed studies have been carried out at EU Member State level, such as that by Raschka and Carus (2012) in Germany and that by the French Environment and Energy Management Agency (ADEME) (2015). However, to date there has been no EU-wide overview of the market for bio-based products at the level of product categories.

This report is intended to help fill the data gaps identified in descriptions of the EU bio-based product market by focusing on 10 categories of bio-based chemical products and on specific indicators for market description and feedstock/land use related to the bio-based products analysed.

1.2 Objectives

This study aims to provide a detailed description of a segment of the EU bio-based products sector, represented by 10 chemical product categories, and its application markets. More specifically, the study seeks to provide a comprehensive list of bio-based products in the 10 categories representing this segment, specifying how they relate to statistical nomenclature where possible. It also aims to quantify market and market dynamic indicators as well as to provide land footprint information.

The study is an attempt to collect and share publicly available information, thus contributing to the monitoring of the development of the bioeconomy, indirectly supporting market actors and policy-makers to make appropriate decisions to realise a more heavily bio-based economy. The use of a transparent methodological approach, combining official statistics, publicly available market studies and expert interviews, provides an insight into the degree to which these different sources are able to provide relevant data. Data gaps are identified and described, providing input to the further development of efforts to monitor the bioeconomy.

1.3 Scope and limitations of the study

According to the definition provided in the European Commission's Lead Market Initiative (EC, 2007):

> Bio-based products refer to non-food products derived from biomass (plants, algae, crops, trees, marine organisms and biological waste from households, animals and food production). Bio-based products may range from high-value added fine chemicals such as pharmaceuticals, cosmetics, food additives, etc., to high volume materials such as general bio-polymers or chemical feedstocks. The concept excludes traditional bio-based products, such as pulp and paper, and wood products, and biomass as an energy source.

In line with this definition, the scope of this study includes non-energy and non-traditional bio-based chemicals, entirely or partially constituted by renewable raw materials from biomass and intended for a wide variety of application areas. In the study, 10 bio-based chemical product categories on which relevant market data have been collected have been identified:

- platform chemicals
- solvents
- polymers for plastics
- paints, coatings, inks and dyes
- surfactants
- cosmetics and personal care products
- adhesives
- lubricants
- plasticisers (and stabilisers for rubber and plastics)
- man-made fibres.

Pharmaceuticals and feed applications (e.g. additives) were excluded from the scope of the study, in order to maintain a clearly delimited focus, because of the complexity of the bio-based products field and the impossibility of covering all the products under the definition given.

Finished goods derived from the bio-based products (e.g. plastic bottles derived from the polymers studied) are not addressed in the market analysis part of this study but only considered in describing the application sectors of bio-based value chains.

In addition, it was decided to exclude bio-composites, as they are composed of many different bio-based materials, which makes it extremely difficult to link them to existing statistics. Agrochemicals were excluded, as industry interest in producing bio-based pesticides (e.g. bio-based glyphosate) is expected to be limited and industrial fertilisers mainly consist of inorganic elements. Natural products directly applied as fertilisers, such as manure and compost, are outside the scope of the study. It was deemed appropriate to exclude enzymes, since this product category has rather different characteristics from the other product categories. First, it involves a final product, enzymes, rather than a final product category (e.g. some enzymes could fall into the product category detergents). Second, official European statistics such as ProdCom (ProdCom codes 20.14.64.50 and 20.14.64.70) already report data on enzymes. Therefore, retrieving market indicators for the product category enzymes should be less problematic than for the other bio-based products and product categories.

Furthermore, this market study focuses on bio-based products that are already commercially available. Therefore, only products with an estimated technology readiness level (TRL) of 8 or 9 are included (see sections 2.2. and 2.4). The study covers not only innovative bio-based products but also bio-based products that have been being produced for some time (e.g. wood turpentine, rayon and cellulose acetate), striving for a complete overview of the market for bio-based products. The scope of this study is the EU market. Consequently, it includes certain bio-based chemicals that are produced in third countries and imported onto the EU market. This provides an insight into the import dependence of the EU in relation to bio-based products.

The specific categories chosen for investigation in the study are further described in section 2.1.

This study constitutes a first concrete step towards describing a market that has a high potential but which has not yet been extensively studied and on which few data are available by applying a detailed methodology to achieve a very thorough data collection, which had not yet been done in this area. Therefore, despite the variable levels of uncertainty of the data provided (highlighted in the chapter on methodology and in the description of the results), this report is the first of its kind and provides comprehensive information for all stakeholders in the bio-based sector.

1.4 This report

This report provides market information on production volumes, bio-based share, price, turnover, consumption and trade for 50 representative bio-based chemical products in 10 product categories. Their land footprint is estimated in terms of feedstock use and land use. In addition, for each of the 10 product categories, market dynamics and potential future growth are established by quantifying feedstock imports, future market size, private investments, the importance for their production of Member States and of the EU, maturity level and technological development potential, this analysis being carried out in the form of a SWOT analysis.

Special regard has been had for data transparency, and the report gives an account of the data sources used and assesses the reliability of the information collected (see section 2.5.1).

Chapter 2 presents the methodological approach employed in this study for the market analysis of the 50 representative bio-based products and the 10 product categories. Chapter 3 presents the results obtained, organised by indicator. Conclusions and recommendations on the European market for bio-based products, as well as addressing data gaps, can be found in Chapter 4. Annex 1 consists of the longlist of bio-based products on which the study is based. Annex 2 gives the Combined Nomenclature (CN 2016) and Prodcom codes corresponding to the 50 selected bio-based products. Annex 3 describes the value chains of 20 selected products and, finally, Annex 4 reports on the brief factsheets in which the market data are summarised for each bio-based product category investigated in this study.

The bio-based products covered in this report are to a large extent used for the manufacturing of everyday products for citizens. Thus, a better understanding of the market should help in developing strategies to increase consumer interest in more sustainable, bio-based products (which is also one of the key ideas behind the bioeconomy strategy).

2 Methodology

The methodology followed included the identification and selection of the 10 bio-based product categories in the scope of the study (section 2.1), the establishment of a longlist of bio-based products (section 2.2), the selection of 20 bio-based products from this longlist for value chain description (section 2.3) and the selection of 50 representative bio-based products from this longlist for detailed market research (section 2.4). Section 2.5 describes the methods used for the market data collection on the 50 representative bio-based products and section 2.6 presents the approach followed at the level of each bio-based product category. Finally, an analysis of data quality and data gaps is presented in section 2.7.

2.1 Identification and selection of bio-based product categories

The product application categories in the study are based on the NACE classification system, in order to maximise opportunities to link with available statistical data. NACE (Nomenclature statistique des activités économiques dans la Communauté européenne, or Statistical Classification of Economic Activities in the European Union) is the industry standard classification system used in the European Union (Eurostat, 2008). The first four digits of each NACE code, which represent the first four levels of the classification system, are the same in all European countries. They classify industrial products in accordance with their type. The CPA (Classification of Products by Activity), which adds 2 digits to the NACE classification, has been used when more detail was needed.

Organic chemicals (containing carbon atoms) of the NACE group 20 (‘Manufacture of chemicals and chemical products’, ranging from 20.11 to 20.60) formed the basis for the first level of categorisation: product application category. Categories without organic chemicals, such as ‘other inorganic basic chemicals’ (20.13), were excluded from the selection of product categories, since generally they are not produced from bio-based feedstocks. When the NACE codes were too broad, the selection was made based on the more detailed CPA codes, i.e. for the product application categories lubricants and plasticisers (in NACE group 20.59).

The list of 10 product application categories is presented in Table 6.

Table 6: List of 10 product application categories

Product application category
Platform chemicals
Solvents
Polymers for plastics
Paints, coatings, inks and dyes
Surfactants
Cosmetics and personal care products
Adhesives
Lubricants
Plasticisers (and stabilisers for rubber and plastics)
Man-made fibres

Platform chemicals are chemical building blocks and starting materials in the manufacture of a broad range of products. As an example of a platform chemical, ethylene can be used in the production of many different polymers and is also the starting material for compounds such as styrene and synthetic fatty acids. **Solvents** are compounds that are able to dissolve other substances without chemically changing them. **Polymers for plastics** comprise a whole family of polymers with various properties and applications. Plastics are usually classified by the chemical structure of the polymer's backbone and side chains. **Paints, coatings, inks and dyes** are mixtures of several components, of which the largest volume consists of solvents and polymers. **Surfactants** are usually amphiphilic organic compounds containing both hydrophobic groups (the tail) and hydrophilic groups (the head). **Cosmetic and personal care products** include bath and shower products, decorative cosmetics, deodorants, perfumes, hair, skin and mouth care products, shaving products, soap and sun protection products. **Adhesives** are substances applied to one surface or both surfaces of two separate items to bind them together and prevent their separation. **Lubricants** are substances, usually organic, used to reduce friction between surfaces in mutual contact, which ultimately reduces the heat generated when the surfaces move. **Plasticisers** or dispersants are additives that increase the plasticity or decrease the viscosity of rubber and plastics. **Man-made fibres** are polymers that are spun into fibres for various applications, and include a huge number of consumer and industrial products.

2.2 Characterisation of the longlist of bio-based products

The longlist developed as part of the Bio-Based Industries Joint Undertaking (BBI JU) project RoadToBio (Lammens et al., 2017) was used as initial basis for this study, because of the similar scope of the projects. The RoadToBio list was screened, resulting in about 350 bio-based products (see Annex 1) that fall within the above 10 product application categories.

To facilitate comparisons with earlier studies and statistics ([1]), the bio-based products on the list were characterised in accordance with their:

- application (Prodcom code ([2]));
- main chemical characterisation (e.g. ester, acid, etc.);
- TRL;
- bio-based carbon content of the product at the level of the molecule (not to be confused with the bio-based share of total production of the product);
- nature as a drop-in product or a dedicated bio-based product (see further explanation below).

Prodcom code

Each individual bio-based product on the longlist has been assigned a Prodcom code, so that it can be linked to existing statistics and value chains in the chemical industry.

Main chemical characterisation

The chemical characterisation of the bio-based products refers to their main functional groups, i.e.:

alcohol	ketone
aldehyde	hydrocarbon mixture
alkane	nitrile
alkene	organic acid
alkyne	peptide
amide	phosphate
amine	polyamide

([1]) In previous studies, bio-based products have often been classified in accordance with their chemical characteristics (organic acids, alcohols, etc.), sometimes with a left-over group that was further divided on the basis of product application (e.g. surfactants, solvents, etc.). By using a classification based on both NACE/Prodcom (product application) and chemical group, we have ensured that the results of this study are compatible with those of earlier studies such as the recent survey by JRC (Nattrass et al., 2016).

([2]) Prodcom codes (eight digits) are more detailed than NACE codes (four digits) and CPA codes (six digits).

amino acid
anhydride
aromatic
ester
ether
gas
halogenated compound
imide
polyester
polyether
polyol
polysaccharide
polyurethane
protein
rubber
vinyl polymer
other

Technology readiness level

The TRL scale measures the maturity of a technology, from the initial concept (level 1) to its commercial maturity through to the full deployment of the product in the marketplace (level 9). The EU Horizon 2020 programme uses the following descriptions of the TRLs (EC, 2016):

TRL 1	basic principles observed
TRL 2	technology concept formulated
TRL 3	experimental proof of concept
TRL 4	technology validated in lab
TRL 5	technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	system prototype demonstration in operational environment
TRL 8	system complete and qualified
TRL 9	actual system proven in operational environment (e.g. competitive manufacturing in the case of key enabling technologies).

Only bio-based products with a TRL of 8 or higher are expected to have substantial market volumes and were considered relevant for this study. They represent 208 bio-based products of the full list of 350. Note that TRL values are based on technology readiness at global level, i.e. a production technology can have reached a global TRL of 9 even if there is no production in the EU-28.

Bio-based carbon content

Many bio-based products are 100% bio-based in terms of carbon content, but by no means all of them. In particular, products that 'combine' different molecules, such as (co-)polymers, adhesives, paints, etc., are often only partly bio-based. Products that are based on drop-in molecules, such as polyethylene, can have a bio-based carbon content of anything between 0% and 100%. Therefore, for each product the usual bio-based carbon share of the molecule was indicated.

Drop-in product or dedicated bio-based product

For the market study, it was very important to make a distinction between two main types of bio-based products:

1. drop-in bio-based products, i.e. bio-based chemically identical versions of existing products that have established markets (e.g. ethylene, polyethylene (PE), polypropylene, polyethylene terephtalate (PET));
2. dedicated bio-based products, which can be produced only via a bio-based pathway and do not have an identical fossil-based counterpart (e.g. lactic acid, levulinic acid, succinic acid, polyhydroxyalkanoate (PHA), polylactic acid (PLA)).

In general, drop-in bio-based products are not distinguishable from fossil-based products in statistics, but the total combined market size of the fossil- and the bio-based products can be obtained. Few dedicated bio-based products are covered by statistics (rayon and cellulose acetate, for example, are). Therefore, for each bio-based product it was necessary to determine whether it was a drop-in or a dedicated bio-based product. It is important to bear in mind that both drop-in and dedicated bio-based products can be fully or partly bio-based, i.e. in the latter case they are obtained from a mixture of bio-based and fossil-based feedstock, as in the case of PET.

2.3 Selection of 20 bio-based products for value chain description

To illustrate the 10 product categories, a typical value chain has been described for two bio-based products per product category. The value chain starts with feedstock production (e.g. sugar production), takes in bio-based intermediates and/or products (e.g. bio-based polybutylene succinate) and ends with final product applications (e.g. food packaging). The bio-based products for the value chain descriptions were selected using the following criteria:

1. The product's TRL is ≥ 8 (i.e. at least one production plant is operational at commercial scale).
2. The product accounts for a significant proportion (in terms of market volume) of the product category.
3. The product is a typical/exemplary bio-based product within the product category.
4. The products cover a range of different types of products in terms of chemical characteristics (e.g. alcohols, acids) and types of feedstock used (e.g. sugar, vegetable oil).

Table 7 presents the selected products.

Table 7: The 20 products selected for value chain description

Product category	Value chain 1	Value chain 2
Platform chemicals	Ethylene glycol	Acetic anhydride
Solvents	Ethyl lactate	Wood turpentine
Polymers for plastics	PET	PHA
Paints, coatings, inks and dyes	Alkyd resins	Polyurethane
Surfactants	Esterquats	Carboxymethyl starch
Cosmetics and personal care products	Xantan	*N*-acetylglucosamine
Adhesives	Furfuryl alcohol	Epoxy resins
Lubricants	Methyl palmitate	Polyoxyethylene oleate
Plasticisers and stabilisers for rubber and plastics	Epoxidised soybean oil (ESBO)	Succinic acid
Man-made fibres	Polyamide-11 (nylon-11)	Polytrimethylene terephthalate (PTT)

The value chains are described in a schematic way and are presented in Annex 3. Intermediate products in the value chain and indicative amounts of feedstock are taken into account and values given for one tonne of product. Furthermore, for each value chain, the following aspects are briefly described:

- product description
- production process
- product properties
- applications
- market
- data sources used.

2.4 Selection of 50 representative bio-based products for market description

Along with data at the level of the product application category, market data were collected for a selection of bio-based products. Information at the product level is more specific, its reliability can be better assessed and the use of statistical information is often easier. The total number of bio-based products to be investigated was limited to 50, divided into 10 product application categories (see Table 8). To ensure a representative sample of products in each category, the number of products per category (five on average) was kept flexible, ranging from three to nine, depending on the range of products occurring in the category.

Selection criteria

The main purpose of the selection of 50 bio-based products was to be able to gather representative data at product level that could subsequently be extrapolated to product category level, especially when product category data were not available. As with the selection of the 20 products for value chain description — which are in fact included in the list of 50 — the 50 bio-based products were selected from the original longlist of 350 bio-based products (see Section 2.2.) using certain criteria:

1. The product's TRL is ≥ 8 (i.e. at least one production plant is operational at commercial scale).
2. The product accounts for a significant proportion (in terms of market volume) of the product category.
3. The products cover a range of different types of products in terms of chemical characteristics (e.g. alcohols, acids) and types of feedstock used (e.g. sugar, vegetable oil).

For product categories that contain many different bio-based products, i.e. no single product covers a significant part of the product category (as in the cases of platform chemicals and of cosmetics and personal care products), a greater number of representative products were chosen. Together, these products form a representative sample of the overall product category.

It should be noted that many products can be classified in multiple categories, as shown in Annex 2, and thus care was taken not to select the same product more than once. The selection of each product is explained below, by category.

Platform chemicals

Products that are used as platform chemicals but typically used in other product categories (e.g. lauryl alcohol) were excluded. These products were included in the other product categories instead. A noteworthy exclusion is methanol, since it is commonly used for fuel, rather than as a platform chemical. Platform chemicals form, by definition, a large group with many different products, since they feed into other product categories. Therefore, it is not feasible to achieve full market coverage, and instead a broad selection of nine products was made to achieve the best representation possible (criterion 2).

Since platform chemicals tend to be small molecules, many typical bio-based platform chemicals are derived from ethanol. This resulted in four of the nine selected products originating from ethanol (ethylene, ethylene glycol, acetic acid and acetic anhydride). However, to ensure full representation, five products that are not derived from ethanol were included as well. Also to comply with criterion 3, products with different chemical characteristics were selected, including an alkene, alcohols, polyols, organic acids, an anhydride and a halogenated compound.

Solvents

Organic solvents can be divided into three main groups: oxygenated, hydrocarbon, and halogenated solvents. No bio-based halogenated solvents with a TRL of at least 8 are available yet. In the hydrocarbon group, only two solvents were identified as having a TRL of 8 or above: isoalkanes and wood turpentine. Isoalkanes are commonly used as lubricants and were therefore included in the lubricant category. Hence wood turpentine was selected as representative of hydrocarbons. The coverage of the solvent category was completed by selecting four oxygenated compounds with significant market volume: isobutanol, ethyl acetate, ethyl lactate and acetone (criterion 2).

To ensure that the diversity of the group was reflected by the five entries, the main novel bio-based solvents (e.g. ethyl lactate), drop-in bio-based solvents (e.g. ethyl acetate) and increasingly popular traditional bio-based solvents (i.e. wood turpentine) were included. This resulted in coverage of various feedstocks, ranging from sugars to forestry products, and a range of characteristics, including esters, an alcohol, a ketone and a hydrocarbon (criterion 3).

Polymers for plastics

Packaging is the main application for bio-based plastics and, therefore, the packaging market was used as a guide to covering a significant proportion of the polymers for plastics category. Here, the products with the largest share are PET, PE, PHA, PLA and starch used for plastics. It should be noted that specifically 'starch used for plastics' was chosen, and not 'starch blends', in order to choose a product at the same point in the value chain as the other polymers. This should be taken into account when comparing the data presented here with other information sources. In addition to these, polyurethane (PUR) is a dominant product in the construction, transport and consumer goods sectors. However, PUR has many applications in coatings and was therefore included in that category instead (see Annex 2 for the allocation of each product to a category). To adhere to criterion 3, care was taken to include the main biodegradable polymers as well. These are starch used for plastics, PHA and PLA.

Paints, coatings, inks and dyes

Paints, coatings, inks and dyes are mixtures of several components, of which the largest volume consists of solvents and polymers. These solvents and polymers were often better included in the dedicated product categories. PUR and alkyd resins are exceptions: they represent this product category well and form a large proportion of the polymers used in paints, coatings, inks and dyes (criterion 2). To better represent this product category, an important additive (ricinoleic acid) was also included. This resulted in a range of products with different characteristics (criterion 3), with an organic acid, a PUR and a polyester.

Surfactants

Surfactants are a broad group that include surfactants, soaps and detergents. There are many different applications for each of these three subcategories, and they all have their own optimised formula. Nonetheless, to ensure that the majority of the product category was captured (criterion 2), some more general products were included, such as glycolipids, sophorolipids and esterquats. Since these products all have vegetable oil as a feedstock, products with different feedstocks (i.e. alkyl polyglucosides (APG) (sugars) and carboxy methyl starch (starch)) were added to adhere to criterion 3.

Cosmetics and personal care products

Cosmetics and personal care products form a very diverse product category. Many cosmetics are built up from a base compound to give texture and foaming properties. These are then supplemented by a wide variety of additives to give health benefits or aromatic properties to the final formula. Criterion 2 was addressed by selecting base compounds, such as xanthan, ethoxylated fatty alcohols, lauryl alcohol and stearyl alcohol, that are used in large volumes. To capture the diversity of the cosmetic product category (criterion 3), important bio-based additives were selected as well, such as *N*-acetyl glucosamine. Leaving aside the base compounds, which can be covered reasonably well, the remaining products are used in small quantities and for specific final products. Therefore, two typical products (limonene and vanillin) were chosen to represent this part of the product category.

Adhesives

An adhesive is commonly created from a polymer, sometimes in the form of its monomer, and a solvent. The solvent product category provides good coverage of the solvent part of adhesives. However, important bio-based adhesives include polymers and monomers, which are not represented in other product categories. These products, i.e. methacrylates, furfuryl alcohol, epoxy resins and tall oil rosin, form the bulk of the bio-based adhesive market (criterion 2). They derive from different types of feedstock (e.g. tall oil rosin from wood, furfuryl alcohol from sugar) and have diverse chemical characteristics, with, for example, furfuryl alcohol being an aromatic monomer and epoxy resins being polyethers (criterion 3).

Lubricants

Bio-based lubricants form a relatively small part of the bio-based market and can therefore be sufficiently represented by few typical products (criterion 2). Since most bio-based lubricants originate from vegetable oils, three vegetable oil derivatives (isoalkanes, fatty acid methyl esters (FAME) and fatty acid polyethylene glycol (PEG) esters) were included in the list. Tall oil fatty acids (from wood) were selected to complete the product category and ensure coverage of different feedstock uses (criterion 3).

Plasticisers and stabilisers for rubber and plastics

The market for plasticisers and stabilisers is relatively small and therefore the selection was restricted to three products. Two of the plasticisers with the largest production volumes are succinic acid and epoxidised soybean oil (ESBO), which were selected to cover a significant proportion of the product category (criterion 2). They are obtained from relatively simple, one-step conversions (fermentation of sugar and epoxidation of soybean oil). Thus, azelaic acid was added as a compound that is a more complex chemical derivative (from oxidation of purified fatty acids). This complies with criterion 3 by including three products with very different value chains.

Man-made fibres

This category is quite diverse, with traditional and novel bio-based fibres and with dedicated and drop-in chemicals. The diversity of the group was captured by selecting traditional bio-based fibres, such as rayon and cellulose acetate, together with a drop-in chemical (i.e. polytrimethylene terephthalate (PTT)) and two dedicated bio-based fibres (i.e. polyamide-11 and polyamide-4,10). These five selected products cover the market well (criterion 2) and have very different chemical characteristics (criterion 3), being a polyester, a polysaccharide, a polyether and two polyamides.

Resulting selection of 50 bio-based products

The 50 selected bio-based products are presented in Table 8.

Table 8: Selection of 50 bio-based products listed by product category

Platform chemicals	
Ethylene Ethylene glycol Propylene glycol (1,2-propanediol) 1,3-Propanediol Acetic acid	Acetic anhydride Sebacic acid Lactic acid Epichlorohydrin
Solvents	
Isobutanol Ethyl acetate Ethyl lactate	Acetone Wood turpentine
Polymers for plastics	
PE PET Starch used for plastics	PHA PLA
Paints, coatings, inks and dyes	
Ricinoleic acid PUR	Alkyd resins
Surfactants	
Glycolipids (other than sophorolipids) Esterquats Sophorolipids	APG Carboxymethyl starch
Cosmetics and personal care products	
Limonene Lauryl alcohol Stearyl alcohol Vanillin	Xanthan Ethoxylated fatty alcohols *N*-acetyl glucosamine
Adhesives	
Methacrylates Furfuryl alcohol	Epoxy resins Tall oil rosin
Lubricants	
Isoalkanes Tall oil fatty acids	FAME (e.g. methyl palmitate) Fatty acid PEG esters (e.g. polyoxyethylene oleate)
Plasticisers and stabilisers	
Azelaic acid Succinic acid	ESBO
Man-made fibres	
PTT Rayon Cellulose acetate	Polyamide-11 (nylon-11) Polyamide-4,10 (nylon-4,10)

2.5 Methodology for market data collection on 50 bio-based products

This section presents the method used for market data collection on the selected 50 bio-based products. Section 2.5.1 explains how the authors dealt with uncertainties. Section 2.5.2 presents the method used for collecting data from official statistics, and section 2.5.3 presents the method used for collecting data from other sources, such as specialist market data suppliers, literature and individual companies. The resulting market assessment methodology for each indicator (production, turnover, etc.) is presented in Chapter 3.

2.5.1 Market data uncertainty indicator

Market data were obtained from a variety of sources with different levels of reliability. Therefore, an uncertainty indicator (UI) was developed, ranging from 1 for very reliable data (i.e. values obtained directly from producers) to a maximum of 4 for the least reliable data (i.e. authors' own estimates).

UI base values for each data source are as follows:

- directly from companies: 1
- scientific peer-reviewed literature: 2
- Prodcom and CN 2016 data: 2
- market data specialists: 2
- other reports and websites: 3
- authors' estimates: 4

The quality of data depended not only on the data source but on several additional factors. The base UI scores as defined above were adjusted (up to a maximum score of 4) when any of the following circumstances applied:

- For every 5 years that have passed since the publication of the data: +1.
- For every calculation performed with the data: +1.
- When multiple different data sources independently included similar data: –1.
- When multiple different data sources included different data: +1.

When no recent data could be found, the UI was increased by 1 point for every 5 years that had passed since the data were published.

When data are combined in calculations, such as calculating the price from the total export volume and the total export revenue, uncertainties are introduced. To indicate the lower reliability of the outcome, the UI was increased by 1 point for every transformation. Simple conversions, such as that from dollars to euros, or from pounds to tonnes, didn't change the UI.

When two or more data sources presented a similar end result, the credibility of that result increased and the UI decreased by 1 point, provided that these data sources did not have a common origin. However, when different data sources reached very different estimates, the real value was assumed to lie in between the two estimates. In this case, the average was taken, and the UI was increased by 1 point.

A potential risk related to the application of this method is that incomplete datasets could still obtain the best reliability score (UI 1). For example, if two production facilities of 10 kt/a are reported by two recent sources and they both report their correct production, this will lead to a production value of 20 kt/a with the highest UI of 1. However, a third production facility that does not disclose information about its production could be missing. This would lead to a falsely reported lower production with a quality indicator for very reliable data. It is impossible to prove that there is no missing data, and this should be taken into account when considering the data presented in this report.

2.5.2 Statistical data

Currently, no official European databases are dedicated to bio-based products for industrial use. The extent to which statistical information can be used to monitor the bioeconomy is explored in, inter alia, Dammer et al. (2014) and Ronzon et al. (2017b). In this study, the authors built on these findings and used statistical data at product level (Prodcom, Eurostat's Easy Comext database) to obtain market information on the 50 selected bio-based products for the indicators production, price, turnover, consumption and trade, where possible.

Prodcom

Prodcom is a country-specific annual survey that collects and disseminates statistics on the production of industrial (mainly manufactured) goods, both in value and quantity terms, in the European Union, using the Prodcom classification of goods.

Production and trade data (in value and volume) were obtained on each of the 50 products. This information was obtained for the latest available years (2000-2016) and for all declarants available. The data collected were ProdVal (production in euros) and ProdQNT (production in 100 kg).

CN 2016

Trade statistics classified by CN 2016 were used to obtain statistical data on imports and exports. Even though all the relevant data could be obtained using Prodcom codes, the CN 2016 codes have the advantage of often having more specific product categories. For example, the Prodcom code for sebacic acid is '20143381', which refers to a group of organic acids, whereas the CN 2016 code is the more specific '29171310, Sebacic acid'. Intra- and extra-EU trade data (import and export) were collected as amounts (in 100 kg) and values (in euros).

Completeness and consistency of statistical data

The Prodcom and CN 2016 databases are not complete. For example, not every declarant (a country or a group of countries) has an entry for every year, which means either that the information is not available or that the information has been concealed, for example to protect the confidentiality of a single producer in a country.

In addition, inconsistencies were found. For example, quantities (e.g. production volumes) reported for the EU-28 are regularly lower than these for the EU-27 for the same period. The origin of these inconsistencies is unclear. In this study, the EU-28 data were used, since the EU-28 is its focus. Because of the incompleteness and inconsistency of the official statistics, Prodcom and CN 2016 were allocated the UI 2, rather than 1 for the most reliable data.

Data collection

Production and trade quantities were retrieved for the latest year available. Care was taken to distinguish an empty field from a field in which zero production was declared. For example, the production of ethylene (Prodcom 20141130) in Belgium is said to have been 1.5 million tonnes in 2011 and no data are available for 2012-2016. In this case, 1.5 million tonnes is taken as the ethylene production in Belgium. In the United Kingdom, 467 kt was said to have been produced in 2009; however a production of zero tonnes of ethylene was said to have been produced in 2012-2016. In this case, the latest reported production of zero tonnes is taken as the ethylene production in the UK. When no data were available for any of the years, 'n/a' was used, to distinguish that situation from a field with zero production.

Import price, export price and production were computed by dividing value data (expressed in euros) by quantity data (expressed in 100 kg) for the latest commonly available year. Next, the values for intra-EU trade and extra-EU trade were averaged.

Relevance of statistical data for this market study

The usability of the statistical data strongly correlates with the product coverage of the Prodcom and CN codes. Each CN and Prodcom code was assigned a relevance indicator, i.e. high, medium or low.

- The CN and Prodcom codes that represent only one bio-based product were given the relevance indicator 'high'. For example, propylene glycol is represented by Prodcom 20142320 'Propylene glycol (propane-1,2-diol)'.
- CN and Prodcom codes that represent product categories in which the bio-based product is explicitly mentioned were given the relevance indicator 'medium'. In this case, the bio-based product forms a significant part of the group of products within the CN or Prodcom code. For example, furfuryl alcohol is included in Prodcom 20145215 'Tetrahydrofuran, 2-Furaldehyde, Furfuryl alcohol, Tetrahydrofurfuryl alcohol and Piperonal'.
- Finally, the CN and Prodcom codes that represent product categories in which the bio-based product is not explicitly mentioned were given relevance the indicator 'low'. In this case, the bio-based product may form only a small and insignificant part of the group of products within the CN or Prodcom code. For example, lactic acid is a 'carboxylic acid with alcohol'. It is part of Prodcom 20143475 'Carboxylic acid with alcohol, phenol, aldehyde or ketone functions'.

In addition to establishing the relevance of the Prodcom and CN 2016 codes, it was important to distinguish between drop-in bio-based and dedicated bio-based products (as explained in section 2.2). For dedicated bio-based products, statistics can be used directly, while for drop-in bio-based products only data on the combined market of the drop-in product and its fossil equivalent are available.

The combination of the relevance indicator for the CN or Prodcom code and whether the product is a drop-in or dedicated bio-based product gives rise to different situations, which determine the possibility of obtaining useful statistical information from the Prodcom and CN statistics. Table 9 summarises these situations.

The Prodcom and CN 2016 codes for the 50 products are listed in Annex 2.

Table 9: Relevance of Prodcom and CN classifications for the investigated dedicated and drop-in bio-based products

Product	Prodcom relevance	CN 2016 relevance	Drop-in / dedicated
Platform chemicals			
Ethylene	High	High	Drop-in
Ethylene glycol	High	High	Drop-in
Propylene glycol (1,2-propanediol)	High	High	Drop-in
Propanediol (1,3-)	Low	Low	Drop-in
Acetic acid	High	High	Drop-in
Acetic anhydride	High	High	Drop-in
Sebacic acid (decanedioic acid)	Low	High	Dedicated
Lactic acid	Low	Medium	Dedicated
Epichlorohydrin	Low	High	Drop-in
Solvents			
Butanol (iso-)	High	Medium	Drop-in
Ethyl acetate	High	High	Drop-in
Ethyl lactate	Low	Medium	Dedicated
Acetone	High	High	Drop-in
Wood turpentine	Low	High	Dedicated

Product	Prodcom relevance	CN 2016 relevance	Drop-in / dedicated
Polymers for plastics			
PE	High	High	Drop-in
PET	High	High	Drop-in
PHA	Low	Low	Dedicated
PLA	Low	High	Dedicated
Starch used for plastics	Medium	High	Dedicated
Paints, coatings, inks and dyes			
Ricinoleic acid (12-hydroxyoctadec-9-enoic acid)	Low	Low	Dedicated
PUR	High	High	Drop-in
Alkyd resins	Medium	High	Drop-in
Surfactants			
Glycolipids (other than sophorolipids)	Low	Low	Dedicated
Esterquats	Low	Low	Dedicated
Sophorolipids	Low	Low	Dedicated
APG	Low	Low	Dedicated
Carboxy methyl starch	Low	Low	Dedicated
Cosmetics and personal care products			
Limonene	Low	Low	Dedicated
Lauryl alcohol	Low	Medium	Drop-in
Stearylic alcohol (1-octadecanol)	Low	Medium	Drop-in
Vanillin	Low	High	Drop-in
Xanthan	Low	Low	Dedicated
Ethoxylated fatty alcohols	Medium	Low	Drop-in
N-acetyl glucosamine	Low	Low	Dedicated
Adhesives			
Methacrylates	Low	Low	Drop-in
Furfuryl alcohol	Medium	Medium	Dedicated
Epoxy resins	Medium	High	Drop-in
Tall oil rosin	Medium	Medium	Dedicated
Lubricants			
Alkanes (iso-)	High	High	Drop-in
Tall oil fatty acids	Medium	Medium	Dedicated
FAME (e.g. methyl palmitate, stearate, laurate)	Low	Low	Dedicated
Fatty acid PEG esters (e.g. polyoxyethylene oleate, palmitate)	Low	Low	Dedicated
Plasticisers			
Azelaic acid (nonanedioic acid)	Low	Medium	Dedicated
Succinic acid	Low	High	Drop-in
ESBO	Low	Low	Dedicated
Man-made fibres			
PTT	Low	Low	Drop-in
Rayon	High	High	Dedicated
Polyamide-11 (nylon-11)	Medium	Low	Dedicated
Polyamide-4,10 (nylon-4,10)	Low	Low	Dedicated
Cellulose acetate	High	High	Dedicated

Based on these different situations, a data collection approach was developed for each indicator (i.e. production, price, turnover, trade and consumption) using a combination of statistical and other market data; these approaches are presented in the relevant sections of Chapter 3.

2.5.3 Other market data

In addition to the statistical data, market data on production, price, consumption and trade were obtained from specialist market data suppliers, literature and individual companies.

From specialised market studies, only the free and publicly available data were used for this report. In particular, the list of main companies producing specific (categories of) bio-based products helped further investigation in the literature search and the analysis of data from individual companies. The estimates from these market data specialists were evaluated to be reasonably reliable and were therefore given the UI 2.

In addition, a thorough literature search was performed through Google Scholar, ISI Web of Knowledge, etc., to identify market data on the bio-based products in each product category. Market data from peer-reviewed sources were given the UI 2.

When no data could be obtained from market data suppliers or scientific literature, other sources were used, such as reports from consultancy firms, project reports or specialised websites. In the absence of information on the reviewing process of these reports and data, they were given the UI 3.

When market data were still missing in the three former data sources, individual companies were consulted either through their corporate websites or through individual interviews. Although this was time consuming, the directly collected data were seen as most reliable, with the UI 1.

Finally, in the last resort, a best estimate was produced by the authors, with appropriate argumentation. These estimates were given the lowest quality indicator (UI 4).

2.6 Method for market data collection at product category level

Data at product category level were estimated based on aggregated information on the 50 bio-based products, supplemented by information from the literature, in particular freely available excerpts from commercial market reports, and validated in expert interviews. Simple aggregations from the 50 bio-based products analysed in detail would have resulted in an incomplete picture. First, they would have ignored the remaining 158 bio-based products from the longlist (excluded because of time constraints). For example, in the case of bio-based platform chemicals, there are many more bio-based products than those we investigated in detail, and the total production of those omitted may be greater than the sum of that for all the platform chemicals investigated here. Second, in many cases the investigated bio-based products are applied in more than one product category (see Annex 2), and the data on the application of bio-based final products are fragmentary.

To complement the data collected, one expert on each product category was contacted, resulting in eight interviews with experts from industry associations and two interviews with experts from companies. Both the data on the 50 selected products and preliminary market data at product category level were discussed. This sometimes yielded new data and/or led to better estimates. The interviews were also designed to enable us to understand the experts' views on the bio-based product categories and obtain an insight into the categories' SWOT analyses. For confidentiality reasons, the respondents are not directly quoted or named.

For each indicator at the product category level, the general approach adopted to collecting data is presented in the relevant section of Chapter 3.

2.7 Analysis of data quality and gaps

With regard to the 50 bio-based products, not all data gaps could be closed after going through the statistical data sources (see section 2.5.2) and other market data sources (see section 2.5.3).

The number of times a specific UI was assigned to the data used reflects their quality. Table 10 shows the distribution of UI values for each of the indicators covered (production, price, etc.).

Table 10: Distribution of UIs by market indicator for the 50 bio-based products.

UI	Bio-based production	Total production	Bio-based price	Fossil-based price	Turnover	Consumption	Trade
1	12	4	5	6	6	0	0
2	16	17	20	9	10	5	8
3	7	17	10	8	12	18	10
4	15	12	15	0	22	21	24

For each of the indicators covered (production, price, etc.), specific observations about the level of uncertainty of the data presented are made in the corresponding section, including an account of the occasions when no data value could be sourced and/or calculated at all.

It is important to highlight that the uncertainty of the market information provided at product category level is directly dependent on the available time and data sources. It should be noted that some of the numbers are based on estimates and therefore have a high level of uncertainty. This relates in particular to the data on feedstock use, land use, future market size and private investments. Despite the uncertainty related to certain estimates reported, this study is highly valuable, since it constitutes a first concrete step towards depicting a still little known market with a high potential.

The market data on the 50 bio-based products creates a picture of overall bio-based production in the EU. However, no useful results can be achieved by the direct summation of the production volumes within each product category, as explained in section 2.6. This was addressed by estimating the values at product category level separately and comparing the results with the results for the individual products.

3 Results

This chapter presents the results of the market assessment of the bio-based chemical industry at product and product category level, as well as the 20 value chain descriptions. For the 50 selected bio-based products (see section 2.4), the assessment covers production, price, turnover, consumption and trade, feedstock use and land requirement. Based on the information collected and presented on the 50 products, additional literature research and interviews, the chapter also presents market data at the level of the 10 product categories. The market data at product category level cover production and the bio-based share of production, price, turnover, consumption and trade, the import dependence of the EU, feedstock use and land requirement, future market size, private investment, the importance of Member States and the EU, maturity level and a SWOT analysis. The market data at product category level are summarised in factsheets presented in Annex 4.

3.1 Value chain description

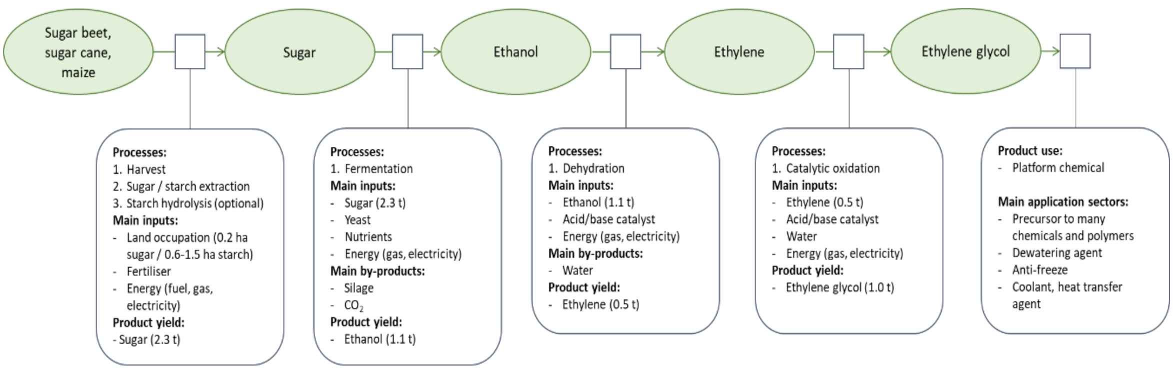
As explained in Chapter 2, Annex 3 presents the descriptions of the value chains of the 10 product categories analysed in this study, based on 20 representative products (two per category). The criteria for choosing the 20 products are thoroughly described in section 2.3. As an example, the value chain description for the platform chemical ethylene glycol is shown in Figure 3. The value chain descriptions report the paths from the biomass feedstock (e.g. sugar) via bio-based intermediates (e.g. bio-based polybutylene succinate) to final product and application (e.g. food packaging).

The value chains are described in a schematic way. Indicative amounts of feedstock and any intermediate products in the value chain are added and related to one tonne of product. Differences can be observed between products that consume larger amounts of biomass and products for which the use of biomass is more efficient. This is more clearly illustrated in section 3.5.1 on the feedstock use of the whole list of 50 chemical products and, consequently, of the 10 chemical product categories.

From the value chain description, it can be observed that the level of complexity varies from product to product, with examples of very complex chains, such as those of many sugar-derived polymers, and examples of value chains with only a few links, such as those of ESBO and succinic acid.

The difference between entirely bio-based products (e.g. ethylene glycol, wood turpentine and PHA) and partly bio-based products (e.g. PET, PTT and alkyd resins), as explained in section 2.2, can also be clarified through graphic representation. In fact, in the example of PET, it can be observed that the initial biomass feedstock is sugar, from which ethylene glycol is derived, but then terephtalic acid is added to the process, which is still only fossil-based at commercial level, and this results in a final PET composition that is approximately 30% bio-based.

Figure 3. Value chain description for the platform chemical ethylene glycol



3.2 Production and bio-based share

3.2.1 Production and bio-based share of 50 bio-based products

As explained in the methodology chapter, only for 2 dedicated bio-based products out of 50 (rayon and cellulose acetate) were production data directly obtained from statistics, since those products are associated with specific Prodcom codes. In all other cases, production data had to be obtained from the literature or authors' own estimates. Note that (statistical and literature) data on production were used to determine use of feedstock and agricultural land as well.

In Table 11, the yearly bio-based production volumes of each of the 50 products selected are presented, together with total EU production (fossil- and bio-based) and bio-based share. For each data point, the reliability of the data has been estimated using the UI explained in section 2.5.1.

Total EU production of each product is classified under a single product category only, although in many cases the product is likely to be used in other product categories (see Annex 2), and sometimes in applications outside the scope of this study as well. In order not to introduce any additional uncertainty into the data, the authors did not estimate the share of each substance attributable to the different product categories. An exception was made for FAME, as reported below in the 'Lubricants' subsection.

There are many differences in the production structures of bio-based products in the EU. Whereas some products are produced only in one location, such as furfuryl alcohol, others are produced in multiple locations throughout the EU, such as PLA. The availability of data also differs by product: for some products all production sites and quantities are publicly disclosed, whereas for a select group of products no production data could be obtained from statistics, literature or other reports, and thus the authors estimated missing values to the best of their knowledge based on the available data. For each of the 50 products, the approach to obtaining bio-based production data is described below.

Table 11: Production of bio-based products and their share of total production in the EU-28

Product	EU bio-based production (kt/a) ([a])	UI	Total EU production (kt/a)	UI	EU bio-based share (%)
Platform chemicals					
Ethylene	0	1	19,050	3	0
Ethylene glycol	0	1	1,180	1	0
Propylene glycol (1,2-propanediol)	20	1	633	2	3
Propanediol (1,3-)	8	2	8	3	100
Acetic acid	24.5	1	968	3	3
Acetic anhydride	10	4	185	3	5
Sebacic acid (decanedioic acid)	0	3	0	3	n.a. ([b])
Lactic acid	64.5	2	64.5	2	100
Epichlorohydrin	36	2	265	2	14
Solvents					
Butanol (iso-)	0	1	157	3	0
Ethyl acetate	36	1	167	3	22
Ethyl lactate	0	3	0	3	n.a.
Acetone	0	2	1,421	2	0
Wood turpentine	70	2	70	2	100

Product	EU bio-based production (kt/a) ([a])	UI	Total EU production (kt/a)	UI	EU bio-based share (%)
Polymers for plastics					
PE	0	1	7,052	3	0
PET	0	2	3,316	2	0
PHA	2	2	2	2	100
PLA	7	1	7	1	100
Starch used for plastics	130	2	130	2	100
Paints, coatings, inks and dyes					
Ricinoleic acid (12-hydroxyoctadec-9-enoic acid)	0	4	0	4	n.a.
PUR	39	2	3,500	2	1
Alkyd resins	432	3	432	3	100
Surfactants					
Glycolipids (other than sophorolipids)	10	4	10	4	100
Esterquats	130	4	130	4	100
Sophorolipids	50	4	50	4	100
APG	50	3	50	3	100
Carboxy methyl starch	25	4	25	4	100
Cosmetics and personal care products					
Limonene	4	4	4	4	100
Lauryl alcohol	100	4	167	4	60
Stearylic alcohol (1-octadecanol)	100	4	167	4	60
Vanillin	1.5	1	9	3	17
Xanthan	44	4	44	4	100
Ethoxylated fatty alcohols	240	4	400	2	60
N-acetyl glucosamine	0	4	0	4	n.a.
Adhesives					
Methacrylates	10	4	646	3	2
Furfuryl alcohol	40	1	40	1	100
Epoxy resins	4	2	900	2	0.4
Tall oil rosin	141	3	141	3	100
Lubricants					
Alkanes (iso-)	0	2	0	2	n.a.
Tall oil fatty acids	2	2	2	2	100
FAME (e.g. methyl palmitate, stearate, laurate)	116	4	116	4	100
Fatty acid PEG esters (e.g. polyoxyethylene oleate, palmitate)	50	4	50	4	100
Plasticisers					
Azelaic acid (nonanedioic acid)	13	2	13	2	100
Succinic acid	23	1	23	3	100
ESBO	0	2	0	2	n.a.
Man-made fibres					
PTT	0	2	0	2	n.a.
Rayon	600	3	600	3	100
Polyamide-11 (nylon-11)	23	1	23	1	100
Polyamide-4,10 (nylon-4,10)	1	3	1	3	100
Cellulose acetate	165	3	165	3	100

([a]) Bio-based production indicates the total production of products that are wholly or partly bio-based. For example, the bio-based PET molecule is currently only 30% bio-based, meaning that the remaining 70% is still produced from fossil resources.

([b]) n.a., not available.

Platform chemicals

Platform chemicals based on ethylene are mostly produced in Brazil, which is a large producer of bio-based ethanol, or Asia. No significant amounts of bio-based ethylene or ethylene glycol are produced in Europe (Jogdand, 2015). The only ethylene glycol production in the EU-28 is 26 t/a in Italy by M&G (Lunt, 2014).

Bio-based propylene derivatives are more widely produced in Europe, where 20 kt/a propylene glycol is produced by Oleon in Belgium (Biddy et al., 2016) and 8 kt/a 1,3-propanediol is produced in France by Metabolic Explorers (ADEME, 2015). Although 1,3-propanediol is a drop-in chemical, no fossil-based production of 1,3-propanediol takes place in Europe. Fossil-based 1,3-propanediol is produced in the US by Shell (Patel et al., 2006).

Bio-based products from the acetic acid platform are produced in Örnsköldsvik in Sweden, where SEKAB produces 24 kt/a of acetic acid (SEKAB, 2018). All the bio-based products and intermediates in Örnsköldsvik are produced on site, meaning that none of the starting materials are imported (Gregg et al., 2017). SEKAB produces bio-based acetic anhydride as well, but no production figures are made public. The authors estimate production of acetic anhydride at 10 kt/a, i.e. less than the other assessed bio-based chemicals produced at SEKAB (acetic acid, 24 kt/a, and ethyl acetate, 36 kt/a (SEKAB, 2018)).

No sebacic acid production was identified in the EU. The main producers are China, Brazil and India (Tuszynski et al., 2008).

Lactic acid production takes place in many countries in the EU-28; however, only a few have significant production volumes. Lactic acid is produced mostly in Spain, by Purac (55 kt/a), followed by Belgium, Germany and the Netherlands (Biddy, 2016). Combined EU production has been estimated at 64.5 kt/a (Biddy et al., 2016), assuming that the predicted production of Cellulac in Ireland of 100 kt/a has not yet been achieved.

Finally, bio-based epichlorohydrin production in the EU-28 takes place in France, where it is produced by Solvay (10 kt/a) (ADEME, 2015; Jogdand, 2015), and in Czechia, where it is produced by Spolchemie (26 kt/a) (Conroy, 2014).

Solvents

Of the five solvents selected for this study, isobutanol and acetone are not produced from biomass in Europe. Bio-based isobutanol is produced by Gevo Inc. and Butamax Advance Biofuels LCC in the US (Butamax Advance Biofuels LCC, 2018; Gevo Inc., 2018). Global Bioenergies is the only company active on the market for bio-based acetone in the EU. It is currently at the pilot stage (kilogram-scale production in Germany) and expected to reach tonne scale in 2018 (GlobeNewswire, 2016).

Ethyl acetate is produced by SEKAB at the Örnsköldsvik site in Sweden at a scale of 36 kt/a (SEKAB, 2018). Cellulac has been planning to produce ethyl lactate in Ireland, but no confirmation that production has started could be found (De Guzman, 2013).

Wood turpentine production consists mainly of sulphate turpentine (55 kt/a), which is a by-product of the pulping process. The remaining 45 kt/a is made up of 15 kt/a obtained as gum turpentine and 30 kt/a of gum rosin (Ukkonen, 2016).

Polymers for plastics

Bio-based PE is currently produced only in Brazil (E4tech, 2015). Another polymer that derives from bio-based ethylene, PET with a 30% bio-based content, is not produced in Europe either. Depending on the information source, EU bio-based PET production may be estimated at 0 kt/a in 2013 (Davies, 2013) or at 200 kt/a in 2017 (Aeschelmann et al., 2017), but expert interviews confirmed that no production of bio-based PET is currently taking place in the EU. Global production of bio-based PET is estimated at 496 kt/a (GlobeNewswire, 2016).

Other bio-based polymers for plastics have multiple production sites in the EU. PHA production is reported by, inter alia, Biomer in Germany (1 kt/a) (E4tech, 2015) and Bio-on in Italy (10 kt/a) (Lunt, 2014). Because experts disagreed with regard to the Italian production, PHA production has been estimated by the authors at 2 kt/a.

PLA is also manufactured at multiple sites by many producers for a total estimated production of 7 kt/a (E4tech, 2015; Jogdand, 2015; Aeschelmann et al., 2017). One older source (Davies, 2013) mentions the company TMO Renewables as producing 3 kt/a in the UK. In the same year, however, TMO Renewables entered administrative receivership (Lane, 2014). The largest remaining producers in the EU are now in the Netherlands (Synbra, 5 kt/a) and Belgium (Futerro, 1.5 kt/a). Outside the EU, PLA is also produced in Switzerland (Sulzer, 1 kt/a) (Davies, 2013; E4tech, 2015).

The EU starch industry is of a significant size, with the amount of starch used for plastic production estimated at 250 kt/a by several sources (Wolf et al., 2005; Jogdand, 2015; Aeschelmann et al., 2017). However, this figure covers all plastic derived from starch, which includes starch blends (i.e. starch blended with other components, usually fossil-based polymers or additives). As explained in section 2.4, this study considers only the starch fraction used to produce these blends. Therefore, the amount of starch used for polymers reported in this study is lower than the amounts reported in these other sources, since the additives and compounds used for blending are not taken into account here. According to the expert interviews, the amount of starch used for these starch polymers is 130 kt/a. Some of the major producers in the EU include Rodenburg in the Netherlands (40 kt/a) and Novamont in Italy (20 kt/a) (Wolf et al., 2005).

Paints, coatings, inks and dyes

No data relating directly to ricinoleic acid production in the EU were identified. Ricinoleic acid is a castor oil derivative and 80% of castor oil and its derivatives are produced in India, with Brazil and China being other important production sites (Grand View Research, 2016a). Therefore, the authors assumed that the volume of ricinoleic acid production in the EU was insignificant (0 kt/a).

Bio-based PUR production in the EU is estimated at 39 kt/a from a total of three unnamed companies (Jogdand, 2015). One of these companies was identified as Metzeler-Schaum in Germany by Wolf et al. (2005). However, global bio-based PUR production has lower estimates, ranging from 1.6 kt/a (Grand View Research, 2015a) to 13 kt/a (Shen et al., 2009) to 28 kt/a (Harmsen and Hackmann, 2013). Even though these estimates were made in 2009-2013, there is nonetheless significant uncertainty about bio-based PUR production.

Estimates of alkyd resin production range from 400 kt/a (van Haveren et al., 2007) to 464 kt/a (Cision, 2013), with roughly 270 kt/a produced in Germany, Italy and the Netherlands (Cision, 2013). Therefore, an intermediate value of 432 kt/a was chosen. Germany is the largest producer in the EU, and alone accounts for 190 kt/a of production (Business Wire, 2011).

Surfactants

The biosurfactants market is difficult to quantify using the open literature. Few data on production are available and many estimates need to be made. Only the production volume of APG — 50 kt/a by Cognis in Germany — is publicly available (Belgacem, 2011). The production volume of esterquats in the EU is estimated to be similar to the European consumption of esterquats, at 130 kt/a (HERA, 2008).

For the other surfactants, there are no reliable data available and best estimates were made by the authors. Since APG is one of the largest biosurfactants in terms of production volume (Grand View Research, 2015b), the production volume of each lipid cannot be higher than the production volume of APG. A much larger production volume of sophorolipids than of other glycolipids, such as rhamnolipids, is expected (Grand View Research, 2015b). Together, they are estimated at 60 kt/a with 50 kt/a of sophorolipids and 10 kt/a of other glycolipids. The amount of carboxy methyl starch is estimated at 20% of all starch produced for plastics, i.e. 25 kt/a of carboxy methyl starch.

These five surfactants add up to an EU production of 265 kt/a, which represents a significant proportion of the global bio-based surfactant market of 350-460 kt/a (Grand View Research, 2015b). Such a large calculated EU share of global production could be due to the allocation of these surfactants' production only to the surfactant category, although they are also used in other application categories.

Cosmetics and personal care products

Limonene is produced in several EU countries (Germany, Italy, Spain and the UK) but no European production data could be found. Total global production of limonene is estimated at 70 kt/a (Ciriminna et al., 2014). Since limonene is obtained as a by-product of fruit juice processing, limonene production was estimated to be related to orange juice production. Global production of orange juice was estimated at 1,700 kt for 2017 (USDA, 2018), with 6% taking place in Europe (101 kt in 2016/2017 (USDA, 2016). Assuming that 6% of limonene production takes place in the EU results in an estimate of 4 kt/a.

Data on the bio-based production of fatty alcohols are not available and only an estimate of the total (fossil- and bio-based) production at 550 kt/a in western Europe could be found (Arpe, 2012). It is estimated that 60% of the production of fatty alcohols is bio-based (Arpe, 2012), i.e. the EU produces 330 kt/a of bio-based fatty alcohols. On the assumption that lauryl alcohol and stearylic alcohol both take up roughly one third of fatty alcohol production, their production has been estimated at 100 kt/a each.

Bio-based vanillin in Europe is mostly produced by Borregaard in Norway (1.5 kt/a) (Borregaard, 2018) and a small amount is produced by Solvay in France (50 t/a) (Solvay, 2018). No data about total vanillin production in the EU were found. With a bio-based share of one sixth (Dignum et al., 2001), total EU vanillin production has been estimated at 9 kt/a. This is considered a reasonable estimate compared with the total global production of vanillin (19 kt/a) (Grand View Research, 2017a).

Xanthan is mostly produced in Austria (by Jungbunzlauer Austria AG), France (by Cargill and Dupont), China and the US (García-Ochoa et al., 2000; Williamson et al., 2013). Since no production data for these sites are publicly available, an estimate was made based on global production of 132 kt/a in 2012 (Williamson et al., 2013). Assuming that the three areas (China, the EU and the US) have an equal share of production, estimated xanthan production in the EU is 44 kt/a. Taking into account that Austria is considered the main producer of xanthan, with France being a minor producer, and that the total exported from France was 11 kt in 2012 (Williamson et al., 2013), the estimate of 44 kt/a is deemed reasonable.

The bio-based share of fatty alcohol production is estimated at 60% (Arpe, 2012). The same has been considered likely to apply to ethoxylated fatty alcohols, resulting in an estimated European production of 240 kt/a. Note that, in the production of ethoxylated fatty alcohols, only the fatty alcohols used are bio-based and the ethylene oxide used is of fossil origin.

The production of *N*-acetyl glucosamine takes place mostly close to the chitin market. The authors assume that most *N*-acetyl glucosamine is produced in Asia and that no significant European producers exist.

Adhesives

The only known production site for fully bio-based methacrylates is a pilot plant in France, making 10 t/a of fully bio-based methacrylic acid. This pilot plant was to shut down in 2016 (De Guzman, 2014). Partly bio-based methacrylates — of which only the side group is bio-based, being derived from vegetable oil — are still being produced in the EU. They are made by Evonik and Arkema; however, no data on the EU's output are publicly available (Drujon, 2016). The authors estimated production in the EU to be lower than that of bio-based polyamides, resulting in an estimate of 10 kt/a.

Bio-based furfuryl alcohol is made in Belgium by TransFuran Chemicals from furfural produced in the Dominican Republic. Its reported annual output of furfuryl alcohol is 40 kt (IFC, 2018).

European bio-based epoxy resin production can be found in Finland, where Amroy produces 4 kt/a (Keinänen and Kaila, 2018).

Tall oil rosin consists of the heavy fractions of tall oil distillation. In the EU, 141 kt/a of tall oil rosin is produced. Production takes place mainly in Scandinavia, with a yearly output of between 99 kt (Baumassy, 2014) and 137 kt (Peters and Stojcheva, 2017). The remaining production can be found in Austria and France (Baumassy, 2014).

Lubricants

FAME is predominantly used as fuel, but also finds applications in other sectors, such as lubricants. The *EU Biofuels Annual* for 2017 estimates a FAME production of 21,150 million litres (Flach et al., 2017), with an average density of 0.87 kg/l (Bamgboye et al., 2008). This results in a total production of 18.4 Mt/a. In Germany, about 6.4 Mt of oil and fat is produced, of which 40.5 kt/a (0.63%) is used in bio-lubricants (Busch, 2016); extrapolating this share to the EU results in a European production volume of 116 kt of bio-lubricants from FAME.

Isoalkanes are produced by Neste in the Netherlands (800 kt/a) and Finland (380 kt/a) (De Guzman, 2012). According to the expert interviews, their distillation into lubricants is not yet done commercially (i.e. there is no EU lubricant production from bio-based alkanes).

Tall oil fatty acids, which are obtained from tall oil distillation, have a production volume for use as lubricants of 2 kt/a in the EU (based on an expert interview). With Sweden and Finland being the top producers of tall oil in the EU, it can be assumed that tall oil fatty acids production also takes place mostly in the Nordic countries (Peters and Stojcheva, 2017).

The only lubricants for which an estimate needed to be made were fatty acid PEG esters. These compounds are produced in the EU by Sasol, but no quantities are made public (Sasol, 2018). The amount of fatty acid PEG esters produced in the EU is assumed to be less than but in a similar range to fatty alcohol production (100 kt/a), and the authors therefore assumed a production of 50 kt/a.

Plasticisers

The production of bio-based plasticisers is well documented and for all three selected plasticisers in this study relevant information was found. ESBO is the only plasticiser not produced in Europe in large quantities. Arkema (from France) is the only European company producing it, in Blooming Prairie, Minnesota (Arkema, 2018). Azelaic acid is produced in one site in the EU, Matrìca in Italy, at a volume of 12.8 kt/a (FIRST2RUN, 2015).

Succinic acid is a well-known example of a bio-based product, and production data for it can be found in several sources (E4tech, 2015; Jogdand, 2015; Biddy, 2016; BIO, 2016). The total production of 23 kt/a is done mainly in Spain by Succinity (10 kt/a) and in Italy by Reverdia (10 kt/a). The remainder is produced in France by BioAmber (2 kt/a) and in Germany by Myriant (1 kt/a). The total global succinic acid market (fossil- and bio-based) was estimated at 47.5 kt/a for 2014 (Grand View Research, 2016b). Therefore, it is assumed that no significant amount of fossil-based succinic acid is produced in the EU.

Man-made fibres

Of the five man-made fibres selected for this study, only PTT is not produced in Europe. The European companies involved in bio-based PTT, Dupont and Metabolix Explorer, both have their production sites outside of the EU (in the US and Malaysia, respectively) (Lunt, 2014).

Both for rayon and cellulose acetate, Prodcom production data are available. EU rayon production is reported at 482 kt/a in Prodcom and at 370 kt/a for western Europe by Bywater (2011). The interviewed experts estimated a 600 kt/a production, assuming that the published data were incomplete.

EU production of cellulose acetate is reported at 160 kt/a in Prodcom and at 169 kt/a by ICIS (2000). The average was rounded to 165 kt/a. The UI for this value is 3, due the estimate of 500 kt/a reached by Qin (2014). Most of the cellulose acetate production in the EU is done in the UK, by Acordis (72 kt/a), followed by Germany (40 kt/a) and France (32 kt/a), both by Rhodia. The remaining 25 kt/a is produced in Italy by Acetati (ICIS, 2000).

Polyamide-11 (nylon-11) is produced in France by Arkema. Its plant in Marseille has a capacity of 22.75 kt (Dubois, 2014). Polyamide-4,10 (nylon-4,10) is produced in the EU by DSM under the tradename Ecopaxx (DSM, 2018). However, no production quantities are made public. Total European bio-based polyamide production was estimated to be 24 kt/a by an interviewed expert. Since nylon-11 has a production volume of 23 kt/a, the remaining 1 kt/a is considered to be nylon-4,10 production.

Uncertainties

Relatively good data could be obtained for the production of bio-based and fossil-based products in the EU. Even though the statistical data did not provide many bio-based production data, this could be compensated for by production data from literature and reports. The Prodcom data were often not useful for obtaining bio-based production numbers because of the many drop-in chemicals. Data on drop-in chemicals could, however, be used to determine the total production of many products. Prodcom data proved unsatisfactory for groups that consisted of many chemicals under one Prodcom code.

After an extensive search of open literature, obtaining production data for the product categories cosmetics and personal care products, and surfactants proved to be most difficult, and it was for these categories that the largest amounts of poor-quality data were produced. In these groups, 10 of the 12 production data points were given the UI 4.

Platform chemicals, polymers for plastics, man-made fibres, solvents and plasticisers had the greatest data availability, and only the production of acetic anhydride needed to be estimated.

3.2.2 Production and bio-based share at product category level

The bio-based share is defined as bio-based production divided by total (combined fossil- and bio-based) production within one product category. In some cases, bio-based production and total production were known, and the bio-based share could be calculated directly. In other cases, data on total production and the bio-based share of the product category were available and were used to obtain bio-based production. In a few cases, only an indication of the EU bio-based market (consumption) could be found in the literature.

Estimates of EU bio-based production, total EU production and the bio-based share of production for each product category are presented in Table 12. For each product category, a slightly different approach was taken, depending on data availability, as explained in the text following the table.

Uncertainties

Since a variety of methods were used to obtain figures for bio-based share and bio-based production at category level, there are no general uncertainties to the method. The resulting values were checked with the values at product level to confirm that they were compatible and that any differences could be explained.

Table 12: Estimates of total and bio-based EU production and the bio-based share of production for each product category

Product category	EU bio-based production (kt/a)	Total EU production (kt/a)	EU bio-based share (%)
Platform chemicals	181	60,791	0.3
Solvents	75	5,000	1.5
Polymers for plastics	268	60,000	0.4
Paints, coatings, inks and dyes ([a])	1,002	10,340	12.5
Surfactants	1,500	3,000	50.0
Cosmetics and personal care products ([a])	558	1,263	44.0
Adhesives ([a])	237	2,680	9.0
Lubricants ([a])	237	6,764	3.5
Plasticisers ([a])	67	1,300	9.0
Man-made fibres	600	4,500	13.0
Total	4,725	155,639	3.0

([a]) No total EU production data were found; it has been assumed that EU production equals the EU market (consumption).

Platform chemicals

About 90% of the global bio-based production capacity for platform chemicals is accounted for by seven chemicals: lactic acid, epichlorohydrin, ethylene glycol, ethylene, sebacic acid, 1,3-propanediol and propylene glycol (Aeschelmann et al., 2017). All these products are included in our selection of bio-based platform chemicals, and we assume that they form 90% of the EU bio-based production of platform chemicals. The bio-based share was determined by dividing the bio-based production volume by the total platform chemical production of 60.791 kt/a (PCE, 2018).

Solvents

According to Roa and Velazquez (EC, 2013), 1.5% of EU solvent production is currently bio-based. With a production of 5,000 kt of solvents per year in the EU (ESIG, 2018), the production of bio-based solvents is estimated at 75 kt/a. This is slightly lower than the sum of the figures for bio-based ethyl acetate and wood turpentine production presented in section 3.2.1 (36 kt/a and 70 kt/a). This deviation can be explained, as not all wood turpentine is used as a solvent.

Polymers for plastics

The expert interviewed estimated that the EU's bio-based plastics production capacity is 297 kt/a, including 264 kt of starch blends, 24 kt of polyamides, 6.7 kt of PLA and 2.3 kt of PHA. Without any data on capacity utilisation, a 90% capacity utilisation was assumed, resulting in an estimated yearly production of polymers for plastics of 268 kt. Total plastics production in the EU in 2017 has been estimated at 60,000 kt (Plastics Europe, 2018), leading to an estimated bio-based share of 0.4%.

Paints, coatings, inks and dyes

Using the market value of paints and coatings in the EU, which was USD 38.24 billion in 2017 (Cision, 2017a) and the global market value of USD 160.5 billion (Rohan, 2018), and assuming that production equals the market in the EU, it is expected that 23.8%, in value terms, of paints and coatings are produced in the EU. Calculating 23.8% of the global production of 43,400 kt/a (Grand View Research, 2017b) resulted in an estimated EU production of paints, coatings, inks and dyes of 10,340 kt/a. The authors estimated that the bio-based share (in quantity terms) is 12.5%, an estimate that was considered accurate by the experts interviewed.

Surfactants

In the EU, 3,000 kt of surfactants are produced each year (CESIO, 2015), and it is indicated that 'surfactants containing at least one constituent derived from renewable natural raw materials have about 50 per cent share of the total surfactant market in Europe'. BASF considers that 'today we have in Europe a split between bio-based and petrol-based surfactants of 40 vs. 60%' (Tropsch, 2015), possibly owing to the significant use of bio-based oleochemicals in surfactants. Rust and Wildes (2008) indicate that US surfactant production is based on 60% oleochemical (bio-based) feedstock. Given the above information, it is estimated that 50% of surfactants are (partly) bio-based, i.e. an EU production of 1,500 kt/a of bio-based surfactants. This number is significantly higher than the sum of the production figures for the bio-based products investigated in detail, indicating that there are probably other surfactants of significance in the product category (e.g. methyl ester ketone, sorbitan esters) in addition to those investigated in detail here.

Cosmetics and personal care products

The EU market for cosmetics and personal care products is valued at EUR 73 billion (NCV, 2018). Statistics or other information on the volume in tonnes or cubic metres are not available at product category level. An average price per kilogram for cosmetics and personal care products was determined to link market value with volumes. The Dutch Cosmetics Association (NCV, 2017) provides Dutch market data (consumption) for the various subcategories within cosmetics and personal care products. Consumer price information on typical products within each subsector was collected, and a weighted average price for the product category of cosmetics was found of EUR 64.1/kg, as shown in Table 13.

Table 13: Estimation of the average final consumer price of cosmetics and personal care products at product category level

Product subcategory	Sales in Netherlands in 2016 (EUR million)	Price (€)	Quantity	Unit	Density (kg/l)	Price (EUR/kg)	Total quantity (kt)
Bath and shower products	159.7	10	0.4	l	0.9	27.8	5.7
Decorative cosmetics	388.7	3.59	0.002	kg	1	1,795.0	0.2
Deodorants	155.8	4	0.15	l	0.9	29.6	5.3
Perfumes	459.8	16	0.02	l	0.9	888.9	0.5
Hair care products	353.7	7	0.25	l	0.9	31.1	11.4
Skin care products	425.6	5	0.03	l	0.9	185.2	2.3
Mouth care products	178.6	3	0.075	l	0.9	44.4	4.0
Shaving products	21.7	4	0.2	l	0.9	22.2	1.0
Soap (liquid soap and bar soap)	43.7	3	0.2	l	0.9	16.7	2.6
Sun protection products	74.6	6	0.2	l	0.9	33.3	2.2
Subtotal	**2,261.9**						**35.3**
Other	98.2						6.3
Total	2,360						41.6

The next step was to determine the bio-based share. According to Medicinenet (2018), the cosmetics industry uses more than 5,000 different ingredients; the European database of cosmetic ingredients and substances (CosIng, 2018) has more than 25,000 entries, consisting of a mixture of synthetic and natural (bio-based) ingredients. This makes it difficult to determine the bio-based content of these products. ADEME (2015) indicates that 97% of the cosmetics produced in France are at least partly bio-based, with an average bio-based content of 40%; the other 3% are 100% bio-based. Therefore, ADEME (2015) indicates that 100% of cosmetic products are at least partly bio-based. We estimate that the EU market for 100% natural cosmetics is 7% ([3]), and — like ADEME (2015) — assume that the other cosmetics and personal care products are 40% bio-based, resulting in a total bio-based share of 44%.

Given the large average number of ingredients in each final cosmetic product, the observation of ADEME that all cosmetics are (partly) bio-based is assumed to be correct. However, since this study focuses on bio-based products that are used in cosmetics and personal care products, and not on the final products themselves, we will work with the estimate that 44% of the substances used in cosmetics and personal care products are bio-based, resulting in total EU production of 558 kt of bio-based intermediates for cosmetics and personal care products.

Adhesives

The adhesives market generates a turnover of EUR 13,400 million in the EU (FEICA, 2014). Based on an assumed price of EUR 5/kg, the total adhesives market consists of approximately 2,680 kt/a of products. The bio-adhesives market was estimated at 320 kt in 2014 (Global Market Insights, 2015). Taking into account the EU's import

([3]) The turnover of German natural cosmetics is EUR 1 billion (Cosmetic Business, 2015), whereas the total cosmetics turnover in Germany is EUR 13.6 billion (Statista, 2018). This results in an estimated share of the market of 7% for 100% bio-based cosmetics.

dependence of 35% (see section 3.4.2), EU production of bio-based adhesives is estimated at 237 kt/a. Assuming that total EU adhesives production equals total EU consumption, the bio-based share is estimated at 9%.

Lubricants

The European demand for lubricants is approximately 19% of the global demand of 35.6 Mt/a, which equals 6.8 Mt/a (Mang and Gosalia, 2017). In section 3.4.1, EU consumption of bio-lubricants is estimated at 220 kt/a (FIRST2RUN, 2015). This figure was confirmed by Global Industry Analysts (2012), according to which the European market for bio-lubricants was expected to reach 240 kt/a in 2017. One interviewed expert estimated the bio-based share at 3.5%, which would result in an estimate of European bio-lubricant production of 237 kt/a.

In section 3.1, the production of bio-lubricants is estimated at 319 kt/a, consisting of 116 kt of FAME, 14 kt of isoalkanes, 50 kt of fatty acid PEG esters and 139 kt of tall oil pitch. These numbers were adjusted based on the feedback from an expert interview. It was made clear that tall oil pitch is not used as a lubricant; rather, tall oil fatty acids are used. Their total EU production is estimated at 2 kt/a. Moreover, the isoalkanes produced by Neste are not yet distilled at a commercial scale into fractions that can be used as lubricants, and therefore there are currently no bio-based isoalkanes produced in Europe. This makes European bio-based lubricant production of 237 kt/a appear a reasonable estimate.

Plasticisers

The total European plasticisers market has been estimated at 1.3 Mt for 2015 (Plastics Insight, 2016). A European bio-based share of 9% was derived from the worldwide bio-based plasticisers market size of 887.3 kt/a (Grand View Research, 2017c) divided by the total worldwide market size of 9.75 Mt/a (Ceresana, 2017). Combining the European plasticisers market with the bio-based share and assuming that the market equals the production results in an estimated bio-plasticiser production of 117 kt/a in Europe. Applying the import dependence figure of 74% (seeTable 19) results in European production of 67 kt/a of bio-plasticisers. The high import dependence is caused by significant imports of ESBO (100 kt/a).

Man-made fibres

European production of man-made fibres was 4.5 Mt in 2016 (CIRFS, 2017). From the interviews, it was estimated that 600 kt of these fibres are bio-based, resulting in a bio-based share of 13%.

Conclusions on production data

The data on the EU production volumes of 50 bio-based products give a valuable indication of bio-based production within the 10 product application categories included in the scope of this study.

Platform chemicals and polymers for plastics dominate total EU production, while, for these, the bio-based share is only 0.3% and 0.4% and bio-based production 181 kt/a and 268 kt/a, respectively. It is interesting to observe that cosmetics and personal care products; paints, coatings, inks and dyes; and surfactants have high bio-based production volumes, although these product categories are less commonly thought of as being bio-based than, for instance, bio-plastics. The bio-based share of surfactants, 50%, is remarkably high compared with those of other product categories. This can be explained by the high share of bio-based oleochemicals used in surfactants. It is difficult to estimate the exact bio-based share of cosmetics and personal care products, as more than 5,000 synthetic and bio-based products exist in this category.

Furthermore, bio-based products that have a longer production history have higher production volumes in the EU than more novel bio-based products. For example, large amounts of alkyd resins and rayon are produced in the EU, whereas little to no bio-based epoxy resins and ethylene are produced in the EU.

With total EU bio-based production for all 10 product categories amounting to 4.7 Mt/a, bio-based chemicals have a share of about 3.0% of the 156 Mt/a total EU production. Total EU production of the 50 bio-based products that were investigated in detail in section 3.2.1 is 3.0 Mt/a, amounting to about 63% of total bio-based production for the 10 product categories. This seems to be a realistic share, given that the 50 most important bio-based products were selected from a total of 208 bio-based products.

It must be emphasised that the total presented for each product category is indicative, based on literature and assumptions. Moreover, there is potential for double counting. For example, platform chemicals such as ethylene are often used as starting materials for polymers such as polyethylene. Moreover, surfactants and solvents are important ingredients in cosmetics and personal care products, and in paints, coatings, inks and dyes. This may lead, for instance, to double counting when calculating feedstock use and land use for these products.

3.3 Price and turnover

3.3.1 The prices of the 50 bio-based products

In a context of scarce data, different types of sources have been consulted for the compilation of price data. Therefore an order of priority has been set up from priority 1 to 7 that reflects the reliability of the source:

- Priority 1: Production price from expert interview
- Priority 2: Production price 2015 or more recent quoted in the literature
- Priority 3: Production price from Eurostat - Prodcom
- Priority 4: Export price from Eurostat - Comext
- Priority 5: Production price 2014 or older quoted in the literature
- Priority 6: Market price on the consumer market (Alibaba)
- Priority 7: Fossil price

The resulting price compilation is presented in Table 14. Each product price is quoted from the most reliable source available. For instance, when information from expert interview (priority level 1) is available, it is not been mixed with information from other less reliable sources (e.g. literature or Eurostat statistics). When the most reliable source of information quotes a price range, or in case there are several sources with the same level of priority (e.g. two sources from the literature), the minimum and maximum prices are presented in Table 14. The average is used for further calculations (e.g. price at product category level, turnover and investments). Finally, when no price information could be found for a given bio-based product, the price of its corresponding fossil product is taken as an informative reference (UI = 4).

Price data in US dollars were converted to euros using the yearly average exchange rate for the corresponding year (Oanda, 2018).

With a few exceptions (vanillin and *N*-acetyl glucosamine), the prices of the products are below EUR 10/kg. The prices of bulk chemicals, such as platform chemicals and solvents, are generally around EUR 1-2/kg, whereas more specialised products such as cosmetics and personal care products and plasticisers are generally more expensive. There are exceptions to this general rule of thumb, such as sebacic acid among the platform chemicals (EUR 3.51/kg), ethyl lactate among solvents (EUR 3.15/kg) and ESBO among the plasticisers (EUR 0.75-EUR 1.33/kg).

Uncertainties

For each data point, the reliability of the data has been estimated using a UI, as explained in section 2.5.1.

In the case of bio-based products, 12 products could not be matched with price data. For these products, the prices were assumed to be the same as for their fossil-based equivalents, and the data were given the UI 4. They relate to the prices of bio-based platform chemicals (two products), solvents (one product), polymers for plastics (one product), paints, coatings, inks and dyes (two products), cosmetics and personal care products (three products), adhesives (two products) and lubricants (one product). In the case of 3 other bio-based products, the only source of information found is the alibaba webpage. They have also been attributed the UI 4.

Even for bio-based products that had reliable price data, it was not possible to make a realistic estimate of a potential green premium. The price data were obtained from different sources and covered different years. This resulted in a spread of prices considered too large to reveal an accurate premium for bio-based products.

Table 14: Price data on the 50 bio-based products investigated

Product	**Prices (EUR/kg), bio-based**			**UI**	**Prices (EUR/kg), fossil-based**			**UI**
	Result	**Min.**	**Max.**		**Result**	**Min.**	**Max.**	
Platform chemicals								
Ethylene	$1.49^{(l)}$	1.17	1.8	1	$0.6^{(l)}$			2
Ethylene glycol	$1.26^{(l)}$	1.17	1.35	2	$1.01^{(p)}$			3
Propylene glycol (1,2-propanediol)	$1.68^{(l)}$	1.01	2.34	2	$1.04^{(l)}$	0.81	1.26	1
Propanediol (1,3-)	$1.58^{(l)}$			2	$1.49^{(l)}$	1.35	2.75	1
Acetic acid	$0.56^{(l)}$			2	$0.68^{(l)}$			2
Acetic anhydride	$1.09^{(fp)}$			4	$1.09^{(p)}$			3
Sebacic acid (decanedioic acid)	$3.51^{(c)}$			3	na			
Lactic acid	$1.46^{(l)}$	1.17	2.07	1	na			
Epichlorohydrin	$2.12^{(fp)}$			4	$2.12^{(c)}$			3
Solvents								
Butanol (iso-)	$1.55^{(l)}$			2	1.5(p)			3
Ethyl acetate	$1.04^{(fp)}$			4	$1.04^{(l)}$	1.02	1.05	2
Ethyl lactate	$3.15^{(l)}$			2	na			
Acetone	$1.26^{(p)}$			2	1.15			3
Wood turpentine	$1^{(l)}$	0.66	1.35	2	na			
Polymers for plastics								
PE	$1.5^{(l)}$			3	$1.33^{(l)}$	1.2	1.45	1
PET	$1.04^{(fp)}$			4	$1.04^{(l)}$	0.95	1.13	1
PHA	$5.43^{(l)}$	5	5.85	1	na			
PLA	$1.85^{(l)}$	1.65	2	1	na			
Starch used for plastics	$3^{(l)}$			2	na			
Paints, coatings, inks and dyes								
Ricinoleic acid (12-hydroxyoctadec-9-enoic acid)	$1.64^{(l)}$	1.64	1.65	2				
PUR	$3.5^{(fp)}$	3	4	4	$3.5^{(i)}$	3	4	2
Alkyd resins	$1.45^{(fp)}$			4	$1.45^{(p)}$			3
Surfactants								
Glycolipids (other than sophorolipids)	$4.5^{(l)}$			2	na			

Product	**Prices (EUR/kg), bio-based**			**UI**	**Prices (EUR/kg), fossil-based**			**UI**
	Result	**Min.**	**Max.**		**Result**	**Min.**	**Max.**	
Esterquats	0.98[a]	0.91	1.04	4	na			
Sophorolipids	3.15[l]	1.8	4.5	2	na			
APG	1.8[l]	0.9	2.7	2	na			
Carboxy methyl starch	0.66(a)	0.58	0.74	4	na			
Cosmetics and personal care products								
Limonene	8.55[l]	8.1	9	2	na			
Lauryl alcohol	1.79[fp]			4	1.79[l]	1.26	2.7	1
Stearylic alcohol (1-octadecanol)	2.25[fp]			4	2.25[l]	1.8	2.7	2
Vanillin	12.5[l]			2	13.5[l]			2
Xanthan	4.09[l]	1.76	8.82	3	na			
Ethoxylated fatty alcohols	1.56[fp]			4	1.56[l]	1.51	1.6	2
N-acetyl glucosamine	80[l]	20	140	3	na			
Adhesives								
Methacrylates	1.98[fp]			4	1.98[l]			2
Furfuryl alcohol	1.82[p]			3	na			
Epoxy resins	3.74[fp]			4	3.74[p]			3
Tall oil rosin	1.52[p]			3	na			
Lubricants								
Alkanes (iso-)	1.75[fp]			4	1.75[p]			3
Tall oil fatty acids	0.585[C]	0.53	0.64	3	na			
FAME (e.g. methyl palmitate, stearate, laurate)	2.35[i]	1.7	3	2	na			
Fatty acid PEG esters (e.g. polyoxyethylene oleate, palmitate)	2.35[i]	1.7	3	2	na			
Plasticisers								
Azelaic acid (nonanedioic acid)	5.33[c]			3	na			
Succinic acid	2.64[l]	2.57	2.7	1	4.50[l]	2.16	8.1	1
ESBO	1.06[a]	0.75	1.33	4	na			
Man-made fibres								
PTT	2.3[l]			2	4[l]			2
Rayon	2[i]			2	na			
Polyamide-11 (nylon-11)	2.61[p]			3	na			
Polyamide-4,10 (nylon-4,10)	5.42[l]	3.23	7.61	3	na			
Cellulose acetate	5[l]			2	na			

[a] market prices from Alibaba; [c] Export price from Eurostat – Prodcom, [fp] fossil price for the corresponding fossil-based product, [i] Production price from expert interview, [l] Production price from literature, [p] Production price from Eurostat – Prodcom.

Sources of Table 14

Aeschelmann, F., Carus, M., 2017, Bio-based Building Blocks and Polymers, Global Capacities and Trends 2016-2021, nova-institut

Alibaba, 2018:
https://tr101487128.fm.alibaba.com/product/50028581362-0/Esterquat.html
https://hbyxcmc.en.alibaba.com/product/60350581616-801725254/Large_manufacturer_Carboxymethyl_Starch_CMS_Ceramic_industry_detergent_grade_rock_oil_grade.html
https://www.alibaba.com/product-detail/Best-Price-PMMA-Polymethacrylates-in-China_60486324340.html?spm=a2700.7724857.main07.19.47550cafKQUc19
https://www.alibaba.com/product-detail/Polyethylene-glycol-fatty-acid-ester-series_60320524811.html?spm=a2700.7724857.main07.17.28a3dce8Ie7Ev5
https://www.alibaba.com/product-detail/Dop-Plasticizer-Replacement-Syntheses-Material-PVC_60605584575.html?spm=a2700.7724857.main07.121.4da97786deTfQJ

Biddy, M.J., Scarlata, C., Kinchin, C., 2016, Chemicals from Biomass: A Market Assessment of Bioproducts with Near-Term Potential, National Renewable Energy Laboratory (NREL)

Bridgewater, A.V., 2012, Report on Non-Biofuel Value-Added Products, Deliverable 5.1, Dibanet

Burns., 2017, http://www.neilaburns.com/surfactants-monthly-review-october-november-2017/

Carignatto, C.R.R., Oliveira, K.S.M., Gomes de Lima, V.M., Neto, P. de O., 2011, New Culture Medium to Xanthan Production by Xanthomonas campestris pv. Campestris, Indian J Microbiol, 51(3), 283-288

E4Tech Ltd, Re-CORD, Wageningen University and Research Centre, 2015, From the Sugar Platform to biofuels and biochemicals, Final report for the European Commission Directorate-General Energy, V2.1

Einbu, A., 2007. Characterisation of chitin and a study of its acid-catalysed hydrolysis, https://brage.bibsys.no/xmlui/bitstream/handle/11250/245569/122471_FULLTEXT01.pdf?sequence=1

Gallage, N.J., Møller, B.L., 2015, Vanillin – Bioconversion and Bioengineering of the Most Popular Plant Flavor and Its De Novo Biosynthesis in the Vanilla Orchid, Molecular Plant, 8, 40-57

ICIS 2016a, https://www.icis.com/resources/news/2016/09/08/10032669/price-and-market-trends-europe-fatty-alcohol-talks-delayed-amid-feedstock-spikes/

ICIS 2017a, https://www.icis.com/resources/news/2016/08/18/10027026/market-outlook-new-mma-capacity-in-middle-east-could-change-global-trade-flows-from-2017/

ICIS, 2016, https://www.icis.com/resources/news/2017/10/06/10150143/europe-etac-prices-stable-sipchem-switches-production-from-etac-to-butac/

ICIS, 2006,
https://www.icis.com/chemicals/channel-info-chemicals-a-z/

Jogdand, S.N., 2015, Current status of bio-based chemicals, Biotech Support Services (BSS), India

Jongedijk, E., Cankar, K., Buchhaupt, M., Schrader, J., Bouwmeester, H., Beekwilder, J., 2016, Biotechnological production of limonene in microorganisms, Appl. Microbiol. Biotechnol., 100, 2927-2938

Nova-institut, 2017, http://news.bio-based.eu/media/2017/07/17-07-04-PR-Commercialisation-of-bio-based-building-blocks.pdf

Oleoline, 2017, http://www.hbint.com/datas/media/59636f875e3e88b6e0a35181/two-weekly-oleochimicals.pdf

OpenPR, 2018,
https://www.openpr.com/wiki/lauryl-alcohol-price-trend-and-market

Orbichem 2013ª, Davies, P. 2013, Chemical business focus, issue number 001, 20th September 2013, Tecnon OrbiChem

Orbichem 2013b, Acetic Anhydride, http://www.orbichem.com/userfiles/CNF%20Samples/aca_13_11.pdf

Santos, D.K.F., Rufino, R.D., Luna, J.M., Santos, V.A., Sarubbo, L.A., 2016, Biosurfactants: Multifunctional Biomolecules of the 21st Century, In. J. Mol. Sci. 17, 401

Ukkonen, K.A., 2016, Pine Chemicals – Global view, Nopek Oy, Pine Chemicals Association, Inc., http://c.ymcdn.com/sites/www.pinechemicals.org/resource/resmgr/2016_ic_-_santiago/2016_IC_Santiago-_Presentations/Monday_Speaker_2-_Keijo_Ukko.pdf

Van den Oever, M., Molenveld, K., Van der Zee, M., Bos, H., 2017, Bio-based and biodegradable plastics – Facts and Figures, report nr. 1722

Wakatsuki, 2015, http://www.orbichem.com/userfiles/APIC%202015/APIC2015_Keiji_Wakatsuki.pdf

Williamson, I.A., Pearson, D.R., Aranoff, S.L., Pinkert, D.A., Johanson, D.S., Broadbent, M.M., 2013, Xanthan Gum from Austria and China, Publication 4411, U.S. International Trade Comission

Wolf, O., Crank, M., Patel, M., Marscheider-Weidemann, F., Schleich, J., Hüsing, B., Angerer, G., 2005, Techno-economic Feasibility of Large-scale Production of Bio-based Polymers in Europe, DG JRC, Technical Report EUR 22103 EN

Xiang, L., 2015, Polyamide Intermediates – World Market Overview, http://www.orbichem.com/userfiles/APIC%202015/APIC2015_Liu_Xiang.pdf

3.3.2 Turnover figures for the 50 bio-based products

Turnover figures are available in the Prodcom database; however, only two products have a relevant Prodcom code without being a drop-in chemical. No reports or studies were found specifically mentioning European turnovers. Therefore, all other turnovers were calculated from the production and price data. Since all production and price data could at least be estimated, no data gaps exist for turnover.

The results of this analysis and the applicable UIs are presented in Table 15. UIs are directly related to the uncertainty associated with the production and price data used in calculating turnover.

With low production volumes in the EU and relatively low prices, the bio-based platform chemicals show relatively low turnover figures for the EU-28. The highest turnovers can be found in the bio-based product categories that are closer to the end user, such as cosmetics, lubricants and man-made fibres. This is not surprising, given that these bio-based products have higher prices and higher production volumes in the EU.

Table 15: Turnover figures for bio-based products produced in the EU-28 (EUR million)

Product	Turnover	UI
Platform chemicals		
Ethylene	0	1
Ethylene glycol	0	1
Propylene glycol (1,2-propanediol)	34	2
Propanediol (1,3-)	13	3
Acetic acid	14	2
Acetic anhydride	11 (fp)	4
Sebacic acid (decanedioic acid)	0	3
Lactic acid	95	2
Epichlorohydrin	76 (fp)	4
Solvents		
Butanol (iso-)	0	1
Ethyl acetate	37 (fp)	4
Ethyl lactate	0	3
Acetone	0	2
Wood turpentine	70	3
Polymers for plastics		
PE	0	1
PET	0	2
PHA	12	2
PLA	13	1
Starch used for plastics	390	3
Paints, coatings, inks and dyes		
Ricinoleic acid (12-hydroxyoctadec-9-enoic acid)	0	4
PUR	136 (fp)	4
Alkyd resins	626 (fp)	4
Surfactants		
Glycolipids (other than sophorolipids)	45	4
Esterquats	127	4

Product	Turnover	UI
Sophorolipids	157	4
APG	90	3
Carboxy methyl starch	16	4
Cosmetics and personal care products		
Limonene	34	4
Lauryl alcohol	179[(fp)]	4
Stearylic alcohol (1-octadecanol)	225[(fp)]	4
Vanillin	19	2
Xanthan	180	4
Ethoxylated fatty alcohols	374[(fp)]	4
N-acetyl glucosamine	0	4
Adhesives		
Methacrylates	20[(fp)]	4
Furfuryl alcohol	73	3
Epoxy resins	15[(fp)]	4
Tall oil rosin	214	4
Lubricants		
Alkanes (iso-)	0	2
Tall oil fatty acids	1	3
FAME (e.g. methyl palmitate, stearate, laurate)	273	4
Fatty acid PEG esters (e.g. polyoxyethylene oleate, palmitate)	117	4
Plasticisers		
Azelaic acid (nonanedioic acid)	68	3
Succinic acid	61	1
ESBO	0	2
Man-made fibres		
PTT	0	2
Rayon	1200	3
Polyamide-11 (nylon-11)	59	3
Polyamide-4,10 (nylon-4,10)	5	4
Cellulose acetate	825	3

[(fp)] Turnover calculated using the fossil price (see Table 14)

3.3.3 Price and turnover data for the 10 bio-based product categories

The product category prices presented in Table 16 correspond to weighted average prices computed from the individual product prices (of the 50 products) for each category. Turnover has been determined by multiplying price by production volume at product category level. The results are presented in Table 16. As the price data are given as a range, the resulting turnover data are also presented as a range. Price and turnover data have to be understood as factory prices (and turnover figures) for inputs for the fabrication of final products. Consumer prices and turnover figures for final products are generally much higher, especially in end-use sectors such as cosmetics and personal care products, lubricants, and paints, coatings, inks and dyes.

Table 16: Prices and turnover figures for bio-based products aggregated to product category level

Product category	Production (kt/a)	Price (EUR/kg)	Turnover (EUR million/a)
Platform chemicals	181	1.48	268
Solvents	75	1.01	76
Polymers for plastics	268	2.98	799
Paints, coatings, inks and dyes	1,002	1.62	1,623
Surfactants	1,500	1.65	2,475
Cosmetics and personal care products	558	2.07	1,155
Adhesives	237	1.65	391
Lubricants	237	2.33	552
Plasticisers	67	3.60	241
Man-made fibres	600	2.65	1,590
Total	4,725	1.94	9,167

3.4 The EU's consumption and trade

3.4.1 Data on consumption and net trade for 50 bio-based products

The consumption of and trade in the 50 bio-based products investigated are discussed together because they are dependent on each other and missing data can be estimated from equation (1) assuming no stock variation.

Production − Consumption + Import − Export + Stock variation = 0 **Equation (1)**

Trade data collection focused mainly on the determination of EU net trade (i.e. extra-EU imports minus extra-EU exports). Comext extra-EU trade data were retrieved directly for dedicated bio-based products with specific CN codes and multiplied by a bio-based share for drop-in bio-based products with specific CN codes. Bio-based shares correspond to bio-based production (in volume) over total production, thus assuming that the proportion of bio-based product in trade follows the proportion of bio-based product in production in the EU. Where no EU production of a drop-in bio-based product takes place, the bio-based share of worldwide production was taken from the literature. Where a product was associated with a CN code that covers multiple products, it could be assumed that the production of and trade in the bio-based product were proportional to the production of and trade in the total group of products within the code.

The literature provides hardly any trade data, but it reports consumption data fairly well. Therefore, net trade could be estimated from production and consumption data using equation (1) and assuming no stock variation. Market reports often provided information on the markets in specific areas, such as the US, China or Europe. By using the data on Europe, an indication of consumption within the EU-28 could be obtained, assuming that consumption in Europe is more or less equal to consumption in the EU-28.

Table 17 presents the resulting data on consumption and net trade for the 50 bio-based products and their respective UIs. Further details on each product category are presented in the text following the table.

Uncertainties

Consumption and trade were the most challenging data to obtain, and this is reflected in the higher UIs for these data points. Often, either consumption or trade data could be found, but it was rare to have a source for both. The missing data points were calculated using production figures. When neither consumption nor trade data were available, data gaps arose. With no data to base estimates on, the consumption of several products could not be determined, and data gaps exist in these product categories. This was the case for a total of eight products, in the product categories surfactants (three products), cosmetics and personal care products (two products), lubricants (two products), and man-made fibres (one product).

Table 17: EU-28 consumption and net trade (import minus export) for 50 bio-based products

Bio-based product	EU-28 consumption (kt/a)	UI	Import-export from CN 2016 (kt/a)	EU-28 net trade (kt/a)	UI
Platform chemicals					
Ethylene	0.06	4		0.06	4
Ethylene glycol	10	4		10	4
Propylene glycol	18	3		−2	3
Propanediol (1,3-)	9	4		0,8	4
Acetic acid	39	3		14	3
Acetic anhydride	15	4		5	3
Sebacic acid	21	3	22.2-1.2	21	2
Lactic acid	33	3		−32	4
Epichlorohydrin	35	3		−1	3
Solvents					
Butanol (iso-)	22	3		22	4
Ethyl acetate	72	3		36	3
Ethyl lactate	21	4		21	4
Acetone	0.04	4		0.04	4
Wood turpentine	71	3	0.9-0.04	0.9	2
Polymers for plastics					
PE	3	4		2,6	4
PET	214	4		−214	4
PHA	7	4		5	4
PLA	28	3	21.4-0.7	21	2
Starch used for plastics	50	3		−80	2
Paints, coatings, inks and dyes					
Ricinoleic acid	152	4		152	4
PUR	35	4		−4	4
Alkyd resins	472	3	83-43.2	40	4
Surfactants					
Glycolipids (other than sophorolipids)	n.d. ([a])	n.d.		n.d.	n.d.
Esterquats	130	2		0	4
Sophorolipids	n.d.	n.d.		n.d.	n.d.
APG	45	3		−5	4
Carboxy methyl starch	n.d.	n.d.		n.d.	n.d.
Cosmetics and personal care products					
Limonene	n.d.	n.d.		n.d.	n.d.
Lauryl alcohol	104	4		4	4
Stearylic alcohol	104	4		4	4
Vanillin	2	3		0.5	3
Xanthan	60	4		16	4

Bio-based product	EU-28 consumption (kt/a)	UI	Import-export from CN 2016 (kt/a)	EU-28 net trade (kt/a)	UI
Ethoxylated fatty alcohols	548	4		308	4
N-acetyl glucosamine	n.d.	n.d.		n.d.	n.d.
Adhesives					
Methacrylates	13	4		3	4
Furfuryl alcohol	60	3	20.1-0.2	20	3
Epoxy resins	4	3		−0.1	3
Tall oil rosin	226	4	89-4.3	85	3
Lubricants					
Alkanes (iso-)	0	2		0	2
Tall oil fatty acids	2	4		0	4
FAME	n.d.	n.d.		n.d.	n.d.
Fatty acid PEG esters	n.d.	n.d.		n.d.	n.d.
Plasticisers					
Azelaic acid	16	3	3.6-0.8	3	3
Succinic acid	22	2	0.2-0.9	−0.7	2
ESBO	100	4		100	4
Man-made fibres					
PTT	n.d.	n.d.		n.d.	n.d.
Rayon	599	3	0.4-1.7	−1	2
Polyamide-11 (nylon-11)	28	4		5	4
Polyamide-4,10 (nylon-4,10)	28	4		27	4
Cellulose acetate	190	3	41.2-16.4	25	2

([b]) n.d., not determined.

Platform chemicals

Many platform chemicals have a dedicated CN 2016 product category. Comext data were retrieved directly for sebacic acid (a dedicated bio-based product). They were multiplied by the corresponding bio-based shares for propylene glycol, acetic acid, acetic anhydride and epichlorohydrin (drop-ins).

With no existing European production of bio-based ethylene glycol, its bio-based share was calculated at global level (1.6%) from a global bio-based production of 275 kt/a (Jogdand, 2015) and a total global production of 17,183 kt/a ([4]) (Global CSS Institute, 2018). Taking 1.6% of the net trade in ethylene glycol (617.7 kt/a, CN 2016 data) resulted in a net trade figure of 10 kt/a. Consumption was then determined also to be 10 kt/a.

As no bio-based ethylene is produced in Europe, its consumption was first determined and used to estimate import dependence. The bio-based share of ethylene was determined at global level (0.03%, with a global production of bio-based ethylene of 375 kt/a from a total global production of ethylene of 140,000 kt/a (Broeren, 2013)). It is therefore estimated that 60 t/a of bio-based ethylene are consumed in the EU out of the total (fossil- and bio-based) of 21.5 kt/a reported by Arpe (Arpe, 2012). All 60 t/a are imported.

Of the 1,3-propanediol consumed in the world, 90% is used for the production of PTT in non-EU countries. If we assume equal market shares for North America, Asia-Pacific

([4]) Calculated on the base of the amount of ethylene oxide used for ethylene glycol production.

and Europe of the remaining 10%, only 3% of global production is consumed in the EU. This is close to the 5% European market share estimated in 2012 by TMR (TMR, 2014).

Finally, EU lactic acid consumption is estimated at 33 kt/a (NNFCC, 2008). The remaining import dependences were determined by subtracting figures for production from those for consumption.

Solvents

Import dependence for wood turpentine could be obtained from Comext data. Import dependence for bio-based ethyl acetate was obtained from the Comext figure multiplied by the European bio-based share. For ethyl lactate, the CN 2016 group 'Lactic acid, its salts and esters' was used to obtain a figure for net trade from Comext. Assuming that lactic acid and ethyl lactate are the largest contributors to this group, the value for lactic acid was subtracted to obtain an estimate for ethyl lactate. These values were then used to calculate EU-28 consumption.

For isobutanol, consumption was estimated at 110 kt/a, of which 45% is expected to be bio-based (Grand View Research, 2016c). Finally, consumption of acetone has been estimated by Tecnon OrbiChem at 1.4 kt/a (Xiaojue, 2013). A global bio-based production of 174 kt/a (E4tech, 2015) and a total global production of 5,500 kt/a (Xiaojue, 2013; E4tech, 2015) gave a global bio-based share of 3.2%, which was used to estimate EU-28 bio-based consumption. Using the production data for these two products, the EU-28's import dependence was also determined.

Polymers for plastics

For two products in this group (cellulose acetate and rayon), trade data could be obtained from the Prodcom and Comext databases. The resulting import dependences were used to calculate the EU-28's consumption of these products. For PLA, this resulted in a consumption of 28 kt/a, close to the estimate by nova-Institute of 33 kt/a, which could be expected to be slightly higher, since it includes PLA copolyesters (Kaeb et al., 2016). For starch, this calculation results in negative consumption. This could be caused by the many different ways in which starch can be categorised, as explained in sections 2.4 and 3.2.1. Different categories cause inconsistencies when different stages in the value chain are considered, i.e. including more or less components of the starch blend. In this study, only the starch that is used in the starch blend is taken into account, while the other components used to make the starch blend are outside the scope of the analysis. Rather than taking a negative value for consumption, the estimate of 50 kt/a for starch copolyester compounds from the nova-Institute report was used (Kaeb et al., 2016). This led to an estimated net trade of –80 kt/a, showing that the EU is a net exporter of starch used for plastics.

For PE, Prodcom and Comext trade data were used in combination with the bio-based share of production. The bio-based share of the world production of ethylene, which is 0.27% according to Broeren (2013), was used as an estimate. Consumption was estimated by adding up net trade and production.

The European consumption of bio-based PET is estimated at 27.1% of the global market (Cision, 2017b). The global market for bio-based PET was estimated at 790.4 kt/a in 2015 (Grand View Research, 2017d). This results in consumption of 214 kt/a of bio-based PET in Europe. With no EU production, the entire 214 kt/a is considered as imported.

The EU-28 market for PHA was estimated based on the global PHA market, which is estimated at 17 kt/a (E4tech, 2015). As it is indicated that China and Europe are the major markets for this product, the EU-28's consumption was set at 7 kt/a, as a best estimate by the authors. This would mean that there is a small net trade of 5 kt/a.

Paints, coatings, inks and dyes

The consumption of ricinoleic acid is not known and has been estimated from the castor oil derivative market. This market has been estimated at 718.5 kt/a (Cision, 2016). With Europe being responsible for 21% of castor oil consumption (Gunstone et al., 2007), this led to an estimate of 152 kt/a of ricinoleic acid imported and consumed (there is no production in the EU). It should be noted that ricinoleic acid that is produced and consumed by the same company does not enter the market and is not included in EU-28 production figures. However, this ricinoleic acid is included in the figures for consumption and and thus affects estimated EU import dependence for ricinoleic acid.

For PUR, import dependence was multiplied by the bio-based share of European production to give a consumption of bio-based PUR of 35 kt/a. This is slightly lower than the figure for EU-28 production.

The consumption of alkyd resins was estimated to be 472 kt/a in 2010 (European Coatings, 2011). This gives a figure for import dependence of 40 kt/a. Comext data show net trade of −33 kt/a. It can be concluded that, compared with the large production and consumption of nearly 500 kt/a, the net trade in alkyd resins is relatively small either way.

Surfactants

There are no statistical data on surfactants that can be used to determine trade quantities. This is because the CN 2016 codes for surfactants are intended to capture the application level rather than ingredient level. For example, there is a code for soaps and surfactants for toilet use (3401 11 00), but no specific CN 2016 code for APG. The only consumption data that could be obtained from other sources were from the Human and Environmental Risk Assessment (HERA) project, which estimates EU consumption at 130 kt/a (HERA, 2008).

APG consumption accounts for 25% of global demand for biosurfactants (Grand View Research, 2015b). Assuming that the percentage is similar for the European market, 45 kt/a of APG are consumed in the EU-28 and EU import dependence is −5 kt/a.

Since little information could be obtained at product level, the surfactant market was investigated at category level as well. European consumption of bio-based surfactants was estimated at 179 kt for 2013, over 50% of global biosurfactant consumption (De Almeida et al., 2016). This is almost the same as our estimated consumption of just esterquats and APG together (175 kt/a). A likely explanation is that esterquats are not classified as biosurfactants in the study by De Almeida et al., and therefore not accounted for in this figure.

Cosmetics and personal care products

In the cosmetics and personal care products category, vanillin is the only product with a specific CN 2016 code. The data obtained from Prodcom and Comext statistics, combined with the share of bio-based production in Europe, resulted in figures for consumption of 2 kt/a and for import dependence of 0.5 kt/a for bio-based vanillin.

Trade data for lauryl alcohol and stearyl alcohol were estimated by dividing the import dependence of their CN 2016 group, 'Dodecan-1-ol (lauryl alcohol), hexadecan-1-ol (cetyl alcohol) and octadecan-1-ol (stearyl alcohol)', by 3, assuming the same dependence for each of the three fatty alcohols. This gave a small import dependence of 4 kt/a and thus a figure for consumption of 104 kt/a, which is close to the EU-28's production.

The size of the xanthan market has been estimated by the US International Trade Commission; however, its report is not fully public and some figures have not been disclosed (Williamson et al., 2013). The report mentions that the US, the EU and Saudi Arabia are the three largest markets. The US market is estimated at 74 kt/a and the Saudi Arabian market at 18.5 kt/a. This leaves an EU market of between 45 kt/a and 74 kt/a. The EU-28 xanthan market was therefore assumed to be close to 60 kt/a. This gave an estimated import dependence of 16 kt/a.

For ethoxylated fatty alcohols, EU-28 consumption was estimated based on the global market value of EUR 4,662 million. The European market accounts for 34.7% of the global market, that is, EUR 1,618 million (Grand View Research, 2017e). Using the average of the price range determined in this study (EUR 1,77) and multiplying by the bio-based share of 60%, the EU-28 market for ethoxylated fatty alcohols could be estimated at 548 kt/a, resulting in an import dependence of 308 kt/a.

For limonene and *N*-acetyl glucosamine, no market data could be found. In an attempt to close these data gaps, market data at product category level were investigated. The European bio-based cosmetics market was worth EUR 2,250 million in 2015 (Grand View Research, 2016d). With a total European cosmetics market of EUR 77 billion (Cosmetics Europe, 2018), the bio-based share of the cosmetics market is 3%. Europe exports EUR 17,200 million of cosmetics and personal care products, which means that an estimated EUR 500 million of bio-based cosmetics are exported from Europe each year. No import dependences or data on volumes imported could be obtained from public market studies.

Adhesives

Comext data were used for furfuryl alcohol and tall oil rosin. Even though the CN 2016 code is not entirely specific and consists of products other than just furfuryl alcohol, it is likely that furfuryl alcohol makes up the majority of the CN 2016 code. Moreover, the import dependences for these products are relatively small compared with their EU-28 production volumes. Therefore, the figure from CN 2016 could be used without creating significant errors. For epoxy resins, Comext data were multiplied by the bio-based share of European production. These data were combined with production data to obtain the EU-28's consumption of these products.

Global methacrylate demand was estimated at 2.75 million tonnes in 2006, of which 30% is consumed in Europe (NNFCC, 2008). Combined with the bio-based share of European production, this led to an estimated consumption of 13 kt/a of bio-based methacrylates. Combined with the production figure, this resulted in an import dependence of 3 kt/a.

Together, the selected bio-based adhesives have a consumption of 302 kt/a, which is close to the bio-based adhesives consumption of 328 kt/a estimated by Vincentz (2013). However, the selection of the bio-based adhesives was based on representativeness and diversity, rather with the aim of reflecting consumption volume, and it is possible that some heavily consumed products have not been investigated.

Lubricants

For tall oil fatty acids, the main producers and consumers globally are the EU and the US (TMR, 2015). It was therefore assumed that there is little net international trade in tall oil fatty acids, which resulted in an import dependence of zero and a figure for consumption of 2 kt/a.

The isoalkanes produced by Neste are not yet at commercial scale as lubricants. With Neste being the only identified producer of bio-based isoalkanes, there is no consumption or trade in this bio-based product for lubricant use yet. No relevant data were available for FAME and fatty acid PEG esters. For this reason, bio-based lubricants were investigated also at category level. The European consumption of bio-based lubricants is 220 kt/a (FIRST2RUN, 2015). This means that, in Europe, the consumption of FAME and fatty acid PEG esters, together with the bio-based lubricants not investigated in this study, is roughly 80 kt/a.

Plasticisers

For azelaic acid and succinic acid, import dependence was directly calculated from Comext import and export data. This resulted in a very small import dependence for both products (3 kt/a and −0.7 kt/a, respectively), giving figures for European consumption that are very close to the European production figures (16 kt/a and 22 kt/a, respectively).

The European consumption of ESBO was determined based on the global consumption, which is estimated at 328 kt/a (Grand View Research, 2017c). With China and the US being the most important markets for bio-based plasticisers (Grand View Research, 2017c), the authors assumed a consumption of no more than 100 kt/a. Since no production takes place in the EU, the full 100 kt/a is considered to be imported.

Man-made fibres

Both rayon and cellulose acetate have specific CN 2016 product codes and the Comext data were used directly to determine import dependence and consumption in the EU-28. Rayon has a very small import dependence, and the EU exports slightly more rayon than that it imports (−1 kt). Import dependence for cellulose acetate is slightly higher, at 25 kt, but still small compared with its large production volume and therefore large consumption (190 kt/a and 125 kt/a, respectively).

Global bio-based polyamide consumption is 11.9% of total polyamide consumption, which leads to a total of 244 kt/a of bio-based polyamide consumption (European Bioplastics, 2017). The estimated European share of the total market volume is 34.8%, which gives a bio-based polyamide consumption of 85 kt/a in the EU-28. Without specific figures for the two polyamides, the consumption of each is estimated to be about one third of the total bio-based polyamide consumption, giving a consumption of 28 kt/a for both nylon-11 and nylon-4,10. These figures are slightly lower than the estimated production of the products, indicating an import dependence of 5-27 kt/a.

With no production in Europe and the application of PTT in carpets, significant consumption is expected and therefore significant import dependence. However, no reliable consumption or trade data could be obtained. Moreover, there are no data publicly available on consumption or import dependence for man-made fibres as a group.

Conclusions on consumption and trade data at product level

The EU-28 is often a net importer of bio-based products. When net exports were found, they were often very small in quantity (e.g. −2 kt/a for propylene glycol). Exceptions are lactic acid (−32 kt/a) and starch used for polymers (−80 kt/a). Most import dependences are in the order of 30-50 kt/a, with the biggest imports being of vegetable oil-based products, such as ricinoleic acid (152 kt/a), ethoxylated fatty alcohols (308 kt/a) and ESBO (100 kt/a).

3.4.2 Consumption and EU import dependence at product category level

To obtain an indication of the degree of import dependence as a percentage of consumption, the net trade in each product (i.e. import minus export) has been divided by consumption. Import dependence at product category level was estimated by taking the weighted average of the import dependences of the individual products within each product category. The weighting was done on the basis of consumption. Subsequently, the resulting import dependence was classified as low (0-25%), medium (26-50%) or high (> 50%). Where there was no import dependence, i.e. a net export, the indicator 'net exporter' was used (Table 18). When net trade had been determined, it was possible to calculate consumption at category level also. Where very few data at product level were available, as in the case of lubricants, production and consumption data at product category level were used to determine the net trade figure.

Table 18: The EU import dependence classification system applied

Degree of import dependence (% of consumption)	**Import dependence class**
< 0%	Net exporter
0-25%	Small
26-50%	Medium
> 50%	Large

Conclusions on consumption and import dependence at category levelTable 19 shows the production, consumption and import dependence of the EU for the bio-based product categories. The EU is a net importer for 8 out of 10 bio-based product categories. For bio-based lubricants and polymers for plastics, the EU is a net exporter. Where the import dependence is classified as 'low', it is possible that the EU is actually a net exporter, because of the level of uncertainty in the data on production and/or consumption at product category level. In the case of plasticisers, a large import dependence was found, mainly because 100% of the ESBO consumed in the EU is imported, and production of plasticisers within the EU is rather low. Although the data were extrapolated from those for the 50 products to product category level, creating uncertainty in the results, it can be concluded that the EU is currently a net importer of bio-based products.

Uncertainties

When assessing the reliability of the figures presented, it is important to take into account that the import dependence for the products within a product category can vary significantly. For example, within the category polymers for plastics, there are large exports of starch used for plastics, resulting in a large negative net trade. In the same group, polyethylene is not produced in a bio-based form in the EU, and the full consumption is imported, leading to an import dependence of 100%. These differences are not visible in the import dependence figures at category level, although of course they can be observed in the import dependence figures at product level. Furthermore, in some product categories, the import dependence at category level has been determined based on only a few products. The presentation of the results also depends to some extent on the thresholds chosen. For example, with differently defined small, medium and large groups — small, 0-33%; medium, 34-66%; and large, > 66% —import dependence for bio-based paints, coatings, inks and dyes would change from large to medium. The other import dependences would not be affected.

Table 19: Production, consumption and import dependence for bio-based products at product category level in kt/a

Product category	Production (kt/a)	Consumption (kt/a)	Net trade (kt/a) (import minus export)	Degree of import dependence ([a])	
Platform chemicals	181	197	16	9% ([b])	Low
Solvents	75	107	32	43% ([b])	Medium
Polymers for plastics	268	247	−21	−8% ([b])	Net exporter
Paints, coatings, inks and dyes	1,002	1,293	291	29% ([b])	Medium
Surfactants	1,500	1,800	300	20% ([b])	Low
Cosmetics and personal care products	558	558	0	0% ([c])	Low
Adhesives	237	320	83	35% ([b])	Medium
Lubricants	237	220	−17	−8% ([d])	Net exporter
Plasticisers	67	117	50	74% ([b])	High
Man-made fibres	600	630	30	5% ([b])	Low
Total	4,725	5,489	764	14%	Low

([a]) Net exporter, < 0%; low, 0-25%; medium, 26-50%; high, > 50%.

([b]) Extrapolated from the 50 bio-based products investigated in detail.

([c]) Production is based on market data (consumption); no data could be found from which to obtain net trade and import dependence figures, which were set at zero, as neither high imports nor high exports were expected.

([d]) Derived from production and consumption figures at product category level.

3.5 Feedstock use, feedstock import dependence and land use

3.5.1 Feedstock use of the 50 bio-based products

To obtain good estimates of feedstock use, the value chains of the 50 products selected were mapped in a similar way to the 20 value chains discussed in section 3.1 and included in Annex 3, although in less detail. This was done in a series of steps, starting from each final product and moving back one conversion step at a time, with the conversion efficiency (based on mass) calculated each time. In this manner, the overall conversion efficiency (from feedstock to product) was calculated for each value chain. This conversion efficiency value was subsequently used in combination with the production data to obtain the amount of feedstock needed for the production of each of the 50 selected bio-based products in the EU.

Allocation factors were applied in calculating the feedstock use of the bio-based products. An example would be the production process of propylene glycol, typically obtained from glycerol, which is derived from vegetable oil. Glycerol usually represents 10% of the weight of the triglycerides in vegetable oil. Thus the actual amount of vegetable oil that is needed to produce 1 t of propylene glycol is 14 t, from which 1.4 t of glycerol is derived, which is subsequently converted into 1 t of propylene glycol. Since glycerol and fatty acids (or fatty acid esters) are co-products from the processing of vegetable oil, the allocation of all the feedstock use (i.e. 14 t of vegetable oil) to only propylene glycol would paint a very unrealistic picture of the actual situation. Another example would be wood-based products such as vanillin, for which the feedstock use would be 333 t of wood per 1 t of vanillin if all the wood use were allocated to that product alone. Therefore, an allocation, on a mass basis, was done in all cases, with the exception of orange peel and sugar cane bagasse (for limonene and furfuryl alcohol, respectively), which were considered to be industrial residues (of orange juice and sugar production, respectively) rather than co-products. For those two feedstocks, the allocation was done on an economic basis, using data published in life cycle assessments (e.g. in the Ecoinvent database at https://www.ecoinvent.org/database/database.html).

Table 20 shows a summary of the results, i.e. the average feedstock required to produce one tonne of each product, and the total feedstock required for the total amount of each bio-based product produced in the EU each year. The latter was calculated by multiplying feedstock use per tonne of a certain product by the EU production volume of that product as shown in Table 11Table 11. All the data are expressed on a dry matter basis.

In some cases, the feedstock use is less than the amount of product, possibly because only the bio-based feedstock was calculated, while some products also have non-bio-based components (e.g. fossil carbon, chlorine, etc.). For the products on the list that are partly bio-based, the bio-based share (by mass) that was assumed in the calculations has been indicated in brackets after the name of the product in Table 20.

Uncertainties

The most important data gap here is that a feedstock can have multiple sources. For example, a product originating from vegetable oil can be produced from palm, rapeseed, soy, etc. Since certain feedstocks are imported, it is not always clear which feedstock is used for what product. This data gap was solved by using the world average of all oil crops combined when no specific oil crop was identified. This assumption had a significant impact on estimated land use, since the yields of oil palm (3.5 t/ha) and other oil crops (0.5-1 t/ha) are very different.

Table 20: Feedstock use of the 50 selected bio-based products

Bio-based product	**Feedstock type**	**Feedstock used per tonne of bio-based product produced** (t/t prod., with allocation correction)	**Feedstock used for EU production of bio-based product (kt/a)**
Platform chemicals			
Ethylene	Starch/sugar	4.3	0
Ethylene glycol	Starch/sugar	2.3	0
Propylene glycol	Vegetable oil	1.4	28
Propanediol (1,3-)	Starch/sugar	2.5	20
Acetic acid	Starch/sugar	2.0	48
Acetic anhydride	Starch/sugar	2.0	20
Sebacic acid	Castor oil	1.2	0
Lactic acid	Starch/sugar	1.3	84
Epichlorohydrin	Vegetable oil	1.0	36
Solvents			
Butanol (iso-)	Starch/sugar	2.6	0
Ethyl acetate	Starch/sugar	1.2	43
Ethyl lactate	Starch/sugar	1.1	0
Acetone	Starch/sugar	2.3	0
Wood turpentine	Wood	1.1	80
Polymers for plastics			

Bio-based product	Feedstock type	**Feedstock used per tonne of bio-based product produced** (t/t prod., with allocation correction)	**Feedstock used for EU production of bio-based product (kt/a)**
PE	Starch/sugar	4.3	0
PET (27%)	Starch/sugar	0.7	0
PHA	Starch/sugar	2.9	7
PLA	Starch/sugar	1.6	11
Starch used for plastics	Starch	1.0	130
Paints, coatings, inks and dyes			
Ricinoleic acid	Castor oil	1.2	0
PUR (45%)	Vegetable oil	0.5	20
Alkyd resins (60%)	Vegetable oil	0.6	259
Surfactants			
Glycolipids (other than sophorolipids)	Vegetable oil	5.0	50
Esterquats (73%)	Vegetable oil	0.8	106
Sophorolipids	Vegetable oil	1.5	77
APG	Starch/sugar and vegetable oil	0.6 and 0.5	55
Carboxy methyl starch (80%)	Starch	0.8	20
Cosmetics and personal care products			
Limonene	Orange peel	2.2	9
Lauryl alcohol	Vegetable oil	1.1	108
Stearylic alcohol	Vegetable oil	1.1	106
Vanillin	Wood	1.0	2
Xanthan	Starch/sugar	1.3	57
Ethoxylated fatty alcohols (50%)	Vegetable oil	0.5	119
N-acetyl glucosamine	Crab or shrimp shells	0	0
Adhesives			
Methacrylates (73%)	Vegetable oil	0.8	8
Furfuryl alcohol	Sugar cane bagasse	1.0	40
Epoxy resins (50%)	Vegetable oil	0.5	2
Tall oil rosin	Wood	1.0	141
Lubricants			
Alkanes (iso-)	Vegetable oil	0.4	0
Tall oil fatty acids	Wood	1.0	2
FAME (90%)	Vegetable oil	0.9	104
Fatty acid PEG esters (60%)	Vegetable oil	0.6	30
Plasticisers			
Azelaic acid	Castor oil	2.1	27
Succinic acid	Starch/sugar	1.3	29
ESBO	Soybean oil	1.3	0
Man-made fibres			
PTT (33%)	Starch/sugar	1.0	0
Rayon	Wood	1.0	576
Polyamide-11 (nylon-11)	Castor oil	1.3	31
Polyamide-4,10 (nylon-4,10) (67%)	Castor oil	0.9	1
Cellulose acetate (47%)	Wood	0.7	123

3.5.2 Land requirement of the 50 bio-based products

Land use can be inferred from the feedstock use estimates for the EU production of the 50 bio-based products. However, different feedstock options are possible for the production of a given bio-based product, depending on various factors (price, logistics, accessibility, etc.). For instance, fermentation products such as lactic acid are typically made from maize starch in the US, from cane sugar in Brazil, from beet sugar in the Netherlands and from tapioca starch in Thailand. In some cases, intermediate products or even feedstocks such as vegetable oils are shipped from one country (or continent) to another. Therefore, it was decided to calculate land use on the basis of world averages, using (1) average crop yields in tonnes per hectare, (2) average feedstock extraction from crops as a percentage and (3) worldwide production data on typical crops.

In Table 21, the resulting feedstock yields per hectare and the proportion that the crop makes up of worldwide average sugar, starch, pulpwood, vegetable oil or orange production are shown (proportion of crop in feedstock type (%)), including the averages calculated for the main types of feedstock. Since many products can be made from either sugar or starch, the proportion that each crop makes up of worldwide sugar and starch production is given in the final column (proportion of crop in total sugar and starch (%)). On the basis of the average yields that were determined, the average land use per ton of bio-based product was determined for each of the 50 products (Figure 4).

Obviously, some bio-based products are more land intensive than others. Taking a closer look at those products reveals that most of the products that require more land are made from castor oil only, for example sebacic acid, ricinoleic acid, azelaic acid, polyamide-11 (nylon-11) and polyamide-4,10 (nylon-4,10). This stems from the difference between the yield of castor oil and the yield of other oil crops. Palm yields on average 3.5 t/ha of palm oil (on plantations in countries such as Malaysia, the yield may even be greater than 5 t/ha), while other oil crops such as soybean, rapeseed, and castor beans yield on average less than 1 t/ha. Therefore, products that are made from various vegetable oils (including palm oil) need on average three times less land than products that are made from a dedicated vegetable oil crop, such as sebacic acid, nylon-11 and ESBO.

Table 21: Feedstock yields from commodity crops used for the production of bio-based products

Crop	Feedstock type	Feedstock yield (t/ha)	Proportion of crop in feedstock type (%)	Proportion of crop in total sugar and starch (%)
Sugar cane	Sugar	9.1	85	17
Sugar beet	Sugar	9.8	15	3
Maize	Starch	3.5	58	46
Potato	Starch	3.6	6	5
Wheat	Starch	1.6	30	24
Tapioca	Starch	2.9	6	5
Pine tree	Pulpwood	1.6	n.a. ([a])	
Beech tree	Pulpwood	3.4	n.a.	
Castor bean	Vegetable oil	0.6	0.4	
Oil palm	Vegetable oil	3.5	38	
Soybean	Vegetable oil	0.6	34	
Rapeseed	Vegetable oil	0.7	12	
Sunflower	Vegetable oil	0.6	8	
Coconut	Vegetable oil	0.8	5	
Palm kernel	Vegetable oil	0.4	4	
Orange tree	Oranges	23.7	n.a.	
Average	Sugar/starch	4.2		
Average	Sugar	9.2		
Average	Starch	2.9		
Average	Vegetable oil	1.7		

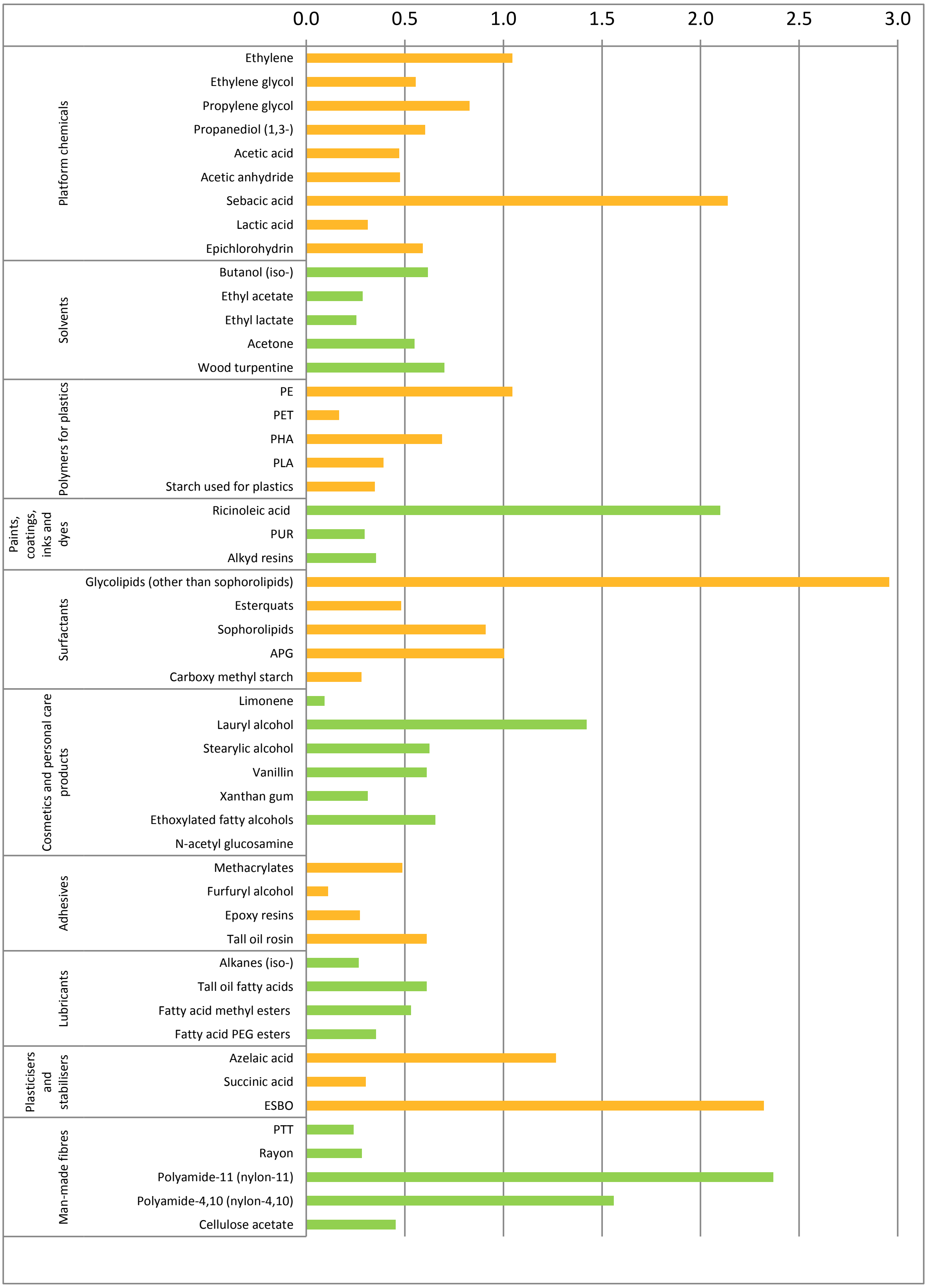
Note: Feedstock yield (in t/ha) is the part of the crop yield in the field (in t/ha) that is actually used as raw material.

Proportion of crop is the percentage that each crop makes up of the total volume of feedstock (weight in production). For example, 85% of sugar originates from sugar cane and 15% from sugar beet.

Proportion of crop in total sugar and starch is the percentage that each crop makes up of the total volume of sugar and starch (weight in production). For example, 17% of sugar and starch originates from sugar cane.

([a]) n.a., not available.

Figure 4. Land use (hectares per tonne of bio-based product)



3.5.3 Feedstock use, import dependence and land use at product category level

Based on the feedstock use of the 50 products as presented in section 3.5.1 and the production data at product category level, the weighted average feedstock use was estimated for four main feedstock categories — sugar/starch, vegetable oil, wood and other — as within these categories feedstocks are to a large extent interchangeable.

Dependence for EU production of bio-based products on feedstocks from outside the EU was estimated using FAOSTAT data (base year 2013) on the EU production, extra-EU imports and extra-EU exports of these feedstocks. Consumption was estimated as the sum of production and imports minus exports. Import dependence for each feedstock was determined by dividing net trade (import minus export) by EU consumption. Where import dependence was negative, i.e. the EU is a net exporter, extra-EU import dependence was set at zero. In these cases, it was assumed that 100% of the feedstock used for the production of bio-based products originates from within the EU-28. Subsequently, the percentages of feedstock types within each feedstock category (e.g. sugar/starch) — as established for the land requirement calculations in section 3.5.2 — were used to determine weighted import dependences at feedstock category level (see Table 22). This factor was multiplied by the feedstock use for each product category resulting in a value for feedstock import dependence at product category level.

Based on the 50 bio-based products investigated, for each product category the weighted average land use per tonne of product was calculated. The land use for each feedstock category depends on the proportion of individual feedstock types within each feedstock category, calculated based on worldwide production figures for these feedstocks (this is similar to the approach to calculating land use for the 50 bio-based products). The figure for average land use was multiplied by the figure for total annual production for each product category to calculate the annual land use for each product category.

Table 22: Feedstock categories and their import dependences

Feedstock category	Type	% of type in category	% extra-EU import dependence	Weighed extra-EU import dependence (%)
Sugar and starch	Sugar crops	20	2	10
	Maize	46	10	
	Potatoes	5	0	
	Wheat	24	0	
	Tapioca	5	100	
Vegetable oil	Castor bean	0.4	100	79
	Oil palm	38	100	
	Soybean	34	91	
	Rapeseed	12	0	
	Sunflower	8	18	
	Coconut	5	100	
	Palm kernel	4	100	
Wood	Pulp wood	100	0	0
Other	Oranges	100	8	8

Table 23 and Table 24 show the estimated feedstock and land use needed for the EU production of the bio-based product categories. Vegetable oil is the dominant feedstock for the traditional bio-based sectors such as surfactants; paints, coatings inks and dyes; and cosmetics and personal care products, while the new bio-based products from platform chemicals and polymers for plastics mainly use sugar and starch. The significant use of wood for man-made fibres is explained by the dominance of rayon in this product category. The overall feedstock import dependence of bio-based products is 51%, which is rather high, mainly caused by the significant use of vegetable oil in the production of many bio-based products, which are imported to a large extent. Land use figures largely follow those for feedstock use, in that those product categories that use large amounts of feedstock also tend to use large amounts of land. The data in Tables 23 and 24 are also reported in graphic form in Figure 5.

Conclusions on feedstock use at category level

Data on feedstock consumption follow production data quite closely (including with regard to imports of feedstock), with surfactants being the category that consumes the largest amounts of biomass, followed by paints, coatings, inks and dyes, while solvents and plasticisers currently require the smallest amounts.

If we look at biomass consumption (including consumption of imported feedstock) per tonne of bio-based product, the most intense consumer is the category plasticisers (with 2.27 tonnes of feedstock per tonne of product per year), while man-made fibres require less biomass (0.96 tonnes per tonne of product per year). However, these data are subject to a high degree of uncertainty and should be interpreted with care.

Regarding import dependence for feedstock, it is higher for paints, coatings, inks and dyes, and in lubricants (which are very much dependent on oil-based feedstock), and lower for solvents and man-made fibres (which are dependent rather on sugar/starch-based feedstock).

The estimates for land use generally follow the data on feedstock use, with land use for cosmetics and personal care products being the greatest (0.77 ha/t; see Table 24). This can be explained by the high impact of lauryl alcohol on the calculation, its being a product with a high production volume in the EU and the production of which relies on coconut oil crops, which are not land-efficient compared with oil palm.

It should be noted that land use is only one of the impacts of a value chain. In addition to land use, we must also pay attention to other impacts such as greenhouse gas emissions, fine particle formation and eutrophication. Moreover, the land use figures estimated here are absolute numbers and no information has been collected on, for instance, land use change (e.g. conversion of peatland or rainforests to arable land).

Uncertainties

With regard to the methodology, it is important to note that a number of assumptions were made, resulting in uncertainties. It was assumed that feedstock types within each feedstock category were fully interchangeable, and that the shares of feedstock types in global production were similar to the shares actually used in the EU bio-based product sector. Moreover, uncertainties in calculating production and feedstock use in the value chains of the 50 products were carried over to the estimates of feedstock use at product category level. The extrapolation from the 50 selected products as representatives of the 10 product categories as a whole certainly adds to the overall uncertainty. Finally, it should be noted that, as explained with regard to the production volumes, some double counting may occur in the totals, as a proportion of the platform chemicals are fed into polymers for plastics, solvents are used in paints, coatings, inks and dyes, etc.

Table 23: Total feedstock use and feedstock imports for the EU production of bio-based products at product category level

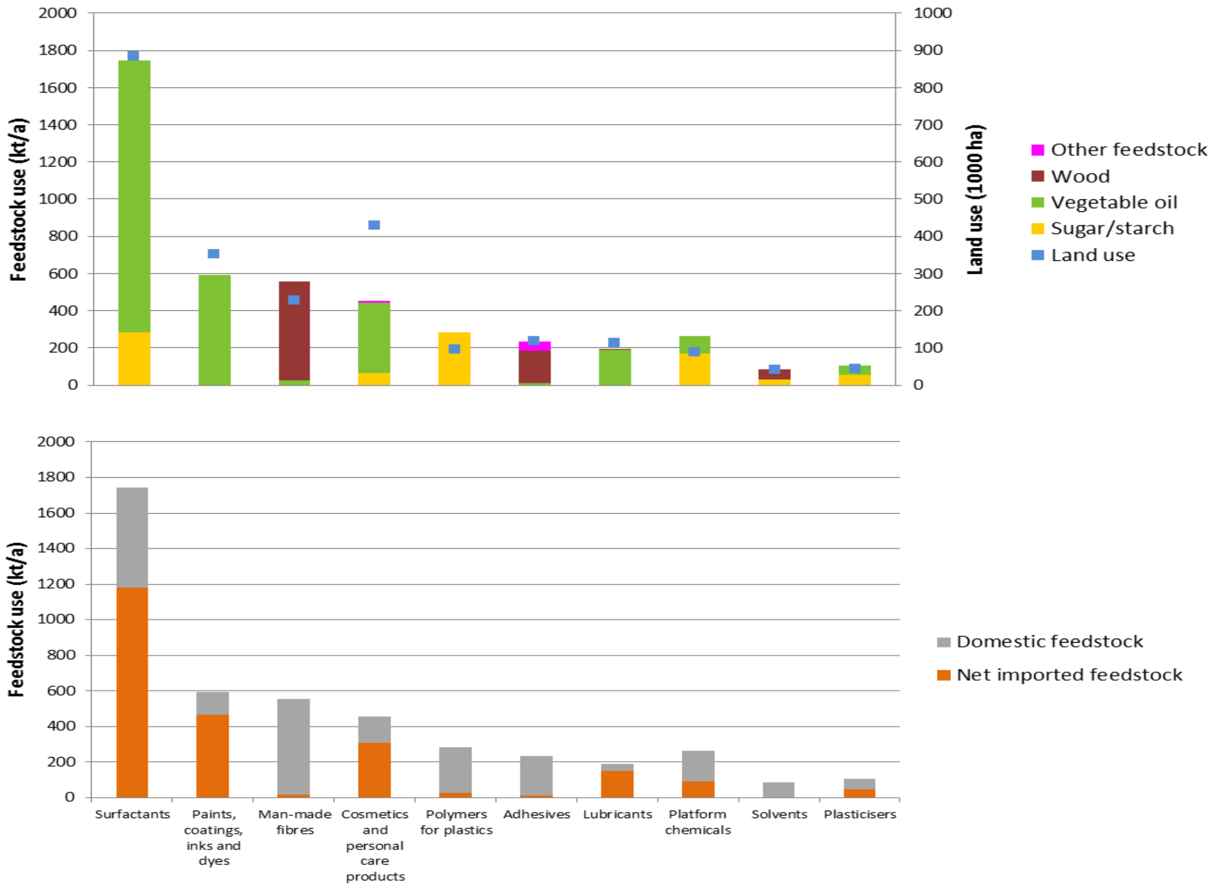
	Total feedstock use (including imports) (kt/a)					Imported feedstock ([a]) (kt/a)	
Product category	Sugar/ starch	Veg. oil	Wood	Other	Total	**Imports (kt/a)**	**Import depen-dency (%)**
Platform chemicals	169	93	0	0	262	90	34
Solvents	30	0	57	0	87	3	3
Polymers for plastics	284	0	0	0	284	28	10
Paints, coatings, inks and dyes	0	593	0	0	593	468	79
Surfactants	284	1,460	0	0	1,744	1,179	68
Cosmetics and personal care products	65	378	2	10	456	306	67
Adhesives	0	12	171	49	232	14	6
Lubricants	0	189	3	0	192	149	78
Plasticisers	54	52	0	0	106	46	44
Man-made fibres	0	24	532	0	555	19	3
Total	886	2,802	764	59	4,511	2,302	51

([a]) These data refer only to imports of feedstock for EU production of bio-based products, not to imports minus exports, as there are of course no exports of feedstock for EU production of bio-based products.

Table 24: Land use of bio-based products at product category level

Product category	**(1,000 ha)**	**ha/t product**
Platform chemicals	88	0.49
Solvents	42	0.56
Polymers for plastics	95	0.36
Paints, coatings, inks and dyes	351	0.35
Surfactants	885	0.59
Cosmetics and personal care products	430	0.77
Adhesives	117	0.49
Lubricants	114	0.48
Plasticisers	43	0.64
Man-made fibres	228	0.38
Total	2,393	0.51

Figure 5. Feedstock use and land use for EU production of the 10 categories of bio-based products (product categories are ordered by bio-based production, from the largest to the smallest)



3.6 Future market size

The size of the market for each product category in 2025 was assessed by estimating the compound annual growth rate (CAGR), i.e. the geometric mean annual growth rate of production over a specified period of time longer than 1 year. The CAGR in terms of revenue is often included in publicly available summaries of market reports on chemicals. In our approach, the CAGR was estimated by the authors, taking into account an analysis of the maturity of the market, drivers and constraints, and the potential for technological development. Subsequently, the CAGRs were discussed during the expert interviews and adjusted if necessary. The estimated CAGRs are briefly explained in Table 25.

Uncertainties

The future investment in bio-based production capacity is by definition uncertain. It depends on a complex combination of factors such future oil prices, consumer behaviour and technological development. Therefore, the predictions regarding the future markets are intended as indicative extrapolations based on current trends.

Table 25: Estimation of the compound annual growth rate

Product category	CAGR (%)	Explanation
Platform chemicals	10	Petrochemicals have a low CAGR, but bio-based platform chemicals are expected to grow faster and new plants are being constructed that bring new products onto the market, e.g. new plants that produce products such as butanediol
Solvents	1	The development of bio-based solvents is not yet very advanced and the industry feels no impetus to convert to bio-based solvents, focusing on other issues instead, e.g. volatile organic compounds
Polymers for plastics	4	The number is based on ~20% over 5 years, estimated during expert interviews
Paints, coatings, inks and dyes	2	Bio-based paints, coatings, inks and dyes are expected to grow but only by a few percent, according to the expert interviewed
Surfactants	4	Bio-based surfactants are already a mature market and growth is expected to be low to medium. The number is based on Tsagaraki (2017)
Cosmetics and personal care products	3	Bio-based products in cosmetics and personal care products have the advantage that a high cost is less of an issue. Consumers prefer natural products, which will continue to drive the bio-based cosmetics market. This was confirmed during the expert interviews. The share of bio-based products in conventional cosmetics is not expected to change much
Adhesives	10	There is still a lot of growth potential for bio-based adhesives and the market is expected to show significant growth, which was confirmed in the expert interviews
Lubricants	1	According to the experts interviewed, there will be no significant growth in investment in the already mature bio-based lubricants market
Plasticisers	3	There is no expert interview data on bio-based plasticisers and a conservative estimate was made by the authors
Man-made fibres	3	The growth rate in terms of investment is expected to be low to medium, based on an expert interview. A small but significant amount of capacity is expected to be added to bio-based man-made fibres
Total	3.8	Calculated weighted average

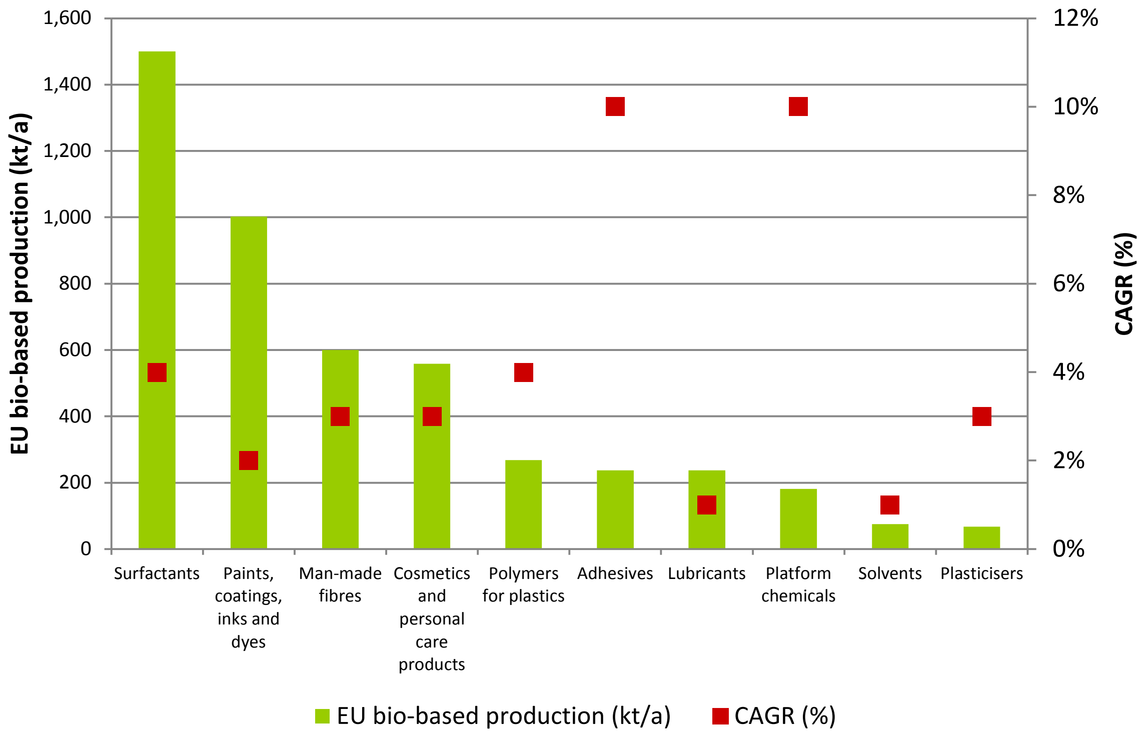
Predicted bio-based production growth and total production in 2025 are shown in Table 26. Figure 6 presents current bio-based production (as estimated in section 3.1.2) and the estimated CAGR for each category. In absolute numbers, most growth is expected in the market for surfactants because this market is already large. Platform chemicals and adhesives are expected to grow the most in relative terms, at 10% per year. The market for bio-based solvents is not expected to grow much, because of the low priority given to producing bio-based alternatives in this product category. Bio-lubricants are also expected to see a low growth rate, unless stimulating legislation is put in place.

Based on the analysis of the growth in investment and production in the period to 2025 at product category level, it is expected that the market for bio-based products will grow at a yearly average of 3.8% from 4.7 Mt/a to 6.1 Mt/a in 2025. The market will increase by 3.0 Mt of bio-based products, with cosmetics, surfactants and adhesives being the product categories with the largest expected increase in production.

Table 26: Predicted EU bio-based production in 2025

Product category	Production CAGR (%)	Current bio-based production (kt/a)	Production growth 2018-2025 (kt)	Bio-based production in 2025 (kt/a)
Platform chemicals	10	181	172	353
Solvents	1	75	5	80
Polymers for plastics	4	268	85	353
Paints, coatings, inks and dyes	2	1,002	149	1,151
Surfactants	4	1,500	474	1,974
Cosmetics and personal care products	3	558	128	687
Adhesives	10	237	225	462
Lubricants	1	237	17	254
Plasticisers	3	67	15	83
Man-made fibres	3	600	138	738
Total	2	4,725	1,408	6,134

Figure 6. CAGR of the 10 bio-based chemical product categories compared with bio-based production



3.7 Private investments

Private investments can be split into replacement investments, which serve to maintain the current production capacity, and expansion investments. It is particularly difficult to obtain reliable data on capital investment at either product or product category level. Data on private investments are sensitive, and production processes vary considerably in scale and complexity, resulting in large differences in capital costs. As a proxy, a calculation method has been established and applied for all product categories, based on an estimate of the share of capital expenditure (CAPEX) in the price of the product, which is assumed to be higher for more complex and longer value chains.

The amount of expansion investment in the period 2018-2025 has been estimated based on expected production growth as shown in Table 26 (section 3.6) combined with estimates of CAPEX per kilotonne of production at product category level.

In order to estimate the CAPEX per kilotonne of product, calculations were made using price data available at the level of the 50 bio-based products investigated in detail. Products with one, two or more conversion steps are assumed to have a low, medium or high CAPEX intensity of 15%, 25% or 40% of the price of the product, respectively. Multiplying the price of each product (in EUR/kg) by the CAPEX intensity results in the amount of CAPEX expenditure per kilogram of product. Assuming that all expansion and replacement investments will depreciate within 10 years, we can calculate how much has been invested to make the current yearly production of the product possible. Investments in all the products in each product category were added up and divided by total production in that product category, resulting in an estimate of CAPEX per kilotonne of product at product category level.

The method provides a transparent estimate of private investment costs over a limited time. However, it is dependent on several assumptions. First, the share of CAPEX in the price of the product is a rough estimate, based on the number of conversion steps and an analysis of the capital costs per conversion step. The price data for the products have varying UIs. In addition, the 50 bio-based products investigated in detail cover approximately 63% of the total market for bio-based products, which creates uncertainty about the investment needed to produce the remaining 37% of bio-based products in each product category. Nevertheless, the method followed is a fact-based approach, and it would require very significant efforts to collect data on the actual investment costs for each bio-based product, because of the complexity of the processes and the sensitivity of the data.

The capital costs per kilotonne of production capacity calculated for each product category and the expected replacement investments, expansion investments and total private investments are presented in Table 27.

In the period 2018-2025 private investment in additional bio-based production capacity amounting to more than EUR 5.5 billion is expected for the 10 product categories, reaching almost EUR 786 million per year. In addition, replacement investments in existing bio-based production capacity are also estimated to reach EUR 13.3 billion between 2018 and 2025, which is EUR 1.9 billion per year, based on an assumption regarding the depreciation of equipment over 10 years (10% of existing production capacity replaced each year). Total private investment in bio-based production equipment is expected to amount to EUR 19 billion, or EUR 2.7 billion per year, for the 10 product categories. These figures do not cover only 'innovative' bio-based products. Several sectors (surfactants, cosmetics and personal care products, man-made fibres) traditionally use a lot of biomass in their production processes, and are also accounted for.

Table 27: Estimates of private investment in bio-based production capacity for the 10 product categories in the period 2018-2025

Product category	CAPEX	Replacement investments		Expansion investments		Total private investment	
	Million EUR/kt	Million EUR/a	Million EUR 2018-2025	Million EUR/a	Million EUR 2018-2025	Million EUR/a	Million EUR 2018-2025
Platform chemicals	3	54	380	74	515	128	896
Solvents	1.9	14	100	1	10	16	110
Polymers for plastics	3.7	99	694	45	313	144	1,007
Paints, coatings, inks and dyes	3.6	361	2,525	77	536	437	3,061
Surfactants	3.7	555	3,885	250	1,753	805	5,638
Cosmetics and personal care products	4.7	262	1,837	86	603	349	2,440
Adhesives	3.5	83	581	112	787	195	1,368
Lubricants	2.4	57	398	6	41	63	439
Plasticisers	5.8	39	273	13	90	52	363
Man-made fibres	6.2	372	2,604	122	855	494	3,459
Total		1,897	13,277	786	5,505	2,683	18,782

3.8 Importance of Member States and the EU

3.8.1 Importance of Member States

Two methods were used to collect data on the importance of each Member State for the production of bio-based products. The first method used production data on the 50 bio-based products investigated in detail. For the second method, information provided in summaries of market reports was used.

During the collection of production data on the 50 bio-based products, information was also gathered on production facilities and their locations. To obtain a top three most important Member States in terms of active companies, each country's share of the production of each bio-based product was determined. For example, epichlorohydrin is produced in France and Czechia. In France, 10 kt/a is produced and in Czechia 26 kt/a is produced. Thus, 28% of the bio-based epichlorohydrin produced in the EU is produced in France and the remaining 72% is produced in Czechia. This method was applied to all known bio-based production sites and the totals added. For example, this gave France 128 percentage points for platform chemicals (28% of the epichlorohydrin and 100% of the 1,3-propanediol produced in the EU is produced in France). Comparing the total percentage points led to a top three Member States for each product category, where sufficient production data was available.

For three product categories, less than three production sites were identified in the collection of production data and an alternative method was applied. In these cases, the publicly available summaries of market reports, which often include a list of producing companies, were investigated. Each company that was mentioned in at least two market studies was taken into account. The Member State where the company was based received points for each mention. For example, BASF was mentioned in three of the five market reports on bio-based solvents, which resulted in 3 points for Germany.

Uncertainties

The first method is very dependent on the 50 bio-based products selected to represent the 10 product categories. The pool of information is small, as only three to nine products in each category were investigated, and therefore each product chosen has a significant impact on the overall result. Uncertainties arise from the use of market reports in the second approach to obtaining the top three Member States because a lot of companies listed in these reports are multinationals operating internationally. Their production sites may well be located in a different Member State from the headquarters, or even outside the EU. Therefore, the importance of the Member State may be different in this case than if the first method could have been applied. Because of its expected lower uncertainty, the first method took precedence over the market study method.

The results of the rankings are presented in Table 29.

There is a large overlap in the most important Member States for the various categories, with Belgium, France, Germany, Italy and the Nordic countries often making the top three. All the Member States identified as most important for any product category are located in western Europe.

3.8.2 Importance of the EU

The importance of the EU can be understood by considering the share of EU bio-based production in total EU production compared with the equivalent figure at global level, and supplementing these data with information related to the import dependence of the EU. The criteria for determining the importance of the EU are presented in Table 28 below.

Table 28: Criteria for determining the importance of the EU

EU share of global bio-based production > EU share of total global production	EU share of global bio-based production < EU share of total global production	Import dependence:	Importance of the EU
Yes	No	—	High
No	Yes	Low	Medium
No	Yes	Medium/high	Low

- When the EU share of global production of the bio-based products in the category is higher than the EU share of total production of products in the category, the importance of the EU is considered high.
- When the EU share of global bio-based production is lower than its share of total production, and import dependence is low, the importance of the EU is considered medium. Although the bio-based share of production is smaller in the EU than in other parts of the world, the low import dependence indicates that the EU is not very dependent on the rest of the world.
- When the EU share of global bio-based production is lower than its share of total production, and import dependence is medium or high, the importance of the EU is considered low. Here, the production in the EU of the bio-based products is

relatively small compared with that of the fossil-based products in the category. Moreover, the medium or high import dependence shows that many bio-based products in the category need to be imported from other parts of the world. The EU plays a relatively minor role in the production of these bio-based product categories.

The application of this method meant that worldwide bio-based and total (fossil- and bio-based) production data had to be collected at product category level in addition to the information already collected on EU production and import dependence. Worldwide production volumes were obtained from market reports. Where these figures were not available, they were estimated based on other available data, such as the total market value. At global level, consumption and production were assumed to be the same, i.e. no change in stock was assumed. For total global cosmetics production, and global bio-based adhesives production no data were found. These figures were derived from their respective market values. The values for global bio-based production of paints, coatings, inks and dyes; surfactants; and cosmetics and personal care products were based on the EU bio-based shares of production.

The top three most important Member States and the importance of the EU at product category level are presented in Table 29.

According to this analysis, the EU has a high overall importance for the production of adhesives, polymers for plastics, cosmetics and personal care products, and lubricants. Low importance was found in the product categories solvents; paints, coatings, inks and dyes; and plasticisers. For some markets that do not have high maturity and have a low bio-based share, such as platform chemicals, the EU has a medium level of importance. This is caused by the fact that, like the EU market, the global market for these products also has a low maturity level and a low bio-based share.

Uncertainties

The importance of the EU as determined above depends on data from market reports, which are not always clear about definitions. For example, 'biosurfactants' are often used as a synonym for 'bio-based surfactants', but a clear definition of these terms is often missing. Moreover, any uncertainties discussed with regard to the method used to calculate import dependence (see Section 3.4.2) also apply here.

Table 29: Top three most important Member States and the importance of the EU at product category level

Product category	Top three most important Member States			Proportion of global production taking place in the EU (%)		Importance of the EU
				Total	Bio-based	
Platform chemicals	Belgium	France	Sweden	15	7	Medium
Solvents	Sweden	Germany	Belgium	23	3	Low
Polymers for plastics	Italy	France	Germany	19	27	High
Paints, coatings, inks and dyes	Germany	France	Italy	24	18	Low
Surfactants	Germany	Belgium	Netherlands	17	17	Medium ([a])
Cosmetics and personal care products	Germany	France	Switzerland	37	37	High ([a])
Adhesives	Finland	Belgium	Sweden	35	54	High
Lubricants	Finland	Sweden	Germany	19	38	High
Plasticisers	Italy	Spain	France	13	8	Low
Man-made fibres	Austria	Portugal	Germany	5	2	Medium

([a]) EU share and EU bio-based share are based on the same assumptions, leading to the same figures. The assessment of importance is therefore based on the EU bio-based share and import dependence.

3.9 Maturity level

For each product category the maturity level of the products was determined using the following four criteria: geographical spread (number of producing EU countries), number of production sites, number of active companies and maturity of the technology (more or less than 10 years of production). The maturity of each of the 50 bio-based products investigated was estimated and the result translated into a low, medium or high rating. A product was considered mature when more than two of the following applied to that product in the EU: more than one production site, produced in more than one country, produced by more than one company and produced for more than 10 years. Mature products received a score of 1, while other products received a score of 0. These scores were averaged for each product category, and each was given a maturity rating of low (< 0.4), medium (0.4-0.6) or high (> 0.6). If necessary, the scores were adjusted based on the feedback from the expert interviews. The resulting maturity ratings are presented in Table 30.

Bio-based markets vary widely in maturity. Only a few markets already have a high level of maturity, and for very different reasons. Surfactants have a mature market owing to a long tradition of using products originating from fats and oils. Cosmetics and personal care products include a large number of mature bio-based products because this sector has lots of (partly) bio-based products, and there is a drive from consumers to use natural ingredients. Finally, lubricants have a mature bio-based market because of regulations requiring their use in a number of Member States. In those countries, lubricants that are lost to the environment, such as lubricants for chainsaws, must be bio-based to limit their environmental impact. Products that are typically produced on a larger scale, such as platform chemicals, solvents, and paints, coatings, inks and dyes, have very young markets.

Uncertainties

Uncertainties in the method arise from the bias towards mature bio-based products in the selection of the 50 products. The 50 products were chosen based on their relevance and representativeness, which led to the selection of more mature products. This was compensated for by the selection of bio-based products that are not produced in the EU, resulting in a low maturity rating. With the small selection of products in some categories (e.g. only three products in paints, coatings, inks and dyes), the influence of a single product was significant. This was overcome by conducting (a number of) interviews. Moreover, the lack of accuracy was compensated for by using the ratings large, medium and small, rather than quantifying the maturity levels using figures.

Table 30: Maturity ratings for the bio-based product categories

Product category	Maturity
Platform chemicals	Low
Solvents	Low
Polymers for plastics	Medium
Paints, coatings, inks and dyes	Low
Surfactants	High
Cosmetics and personal care products	High
Adhesives	Medium
Lubricants	High
Plasticisers	Low
Man-made fibres	Medium

3.10 SWOT analysis on future development potential

An assessment of the potential for technological development considers the opportunities for further developing and commercialising bio-based products starting from the current situation. To assess the innovation potential of the bio-based chemical industry, a strengths, weaknesses, opportunities and threats (SWOT) analysis was performed for the product categories, based on the following four aspects of technological development potential (Mohannak et al., 2014; De Prato et al., 2015):

1. Innovation and technological readiness (I&T)
   - This covers technological maturity, skills needed, uniqueness of the product, etc.
2. Economic and market potential (E&M)
   - This covers market size, customer base, capital needed, market pull and push, etc.
3. Social and environmental impacts (S&E)
   - This covers environmental impact, health hazards and benefits, employment, etc.
4. Legal and regulatory factors (L&R)
   - This covers the EU legal framework, restrictions on the use of substances, availability of grants, loans, guarantees and other funding opportunities, etc.

For each product category, a literature review and expert interviews were performed to gather relevant strengths, weaknesses, opportunities and threats. These were each assigned to one of the four aspects of technological development potential.

Special attention was paid to issues regarding the use of alternative biomass resources. Production processes that are not flexible with regard to their feedstock can experience supply issues and significant price fluctuations. Production processes that are able to switch to feedstocks of lower price and quality can produce at lower costs, provided that additional pre-treatment costs are limited. Production processes that are able to switch from first generation biomass (e.g. sugar, starch, oil) to second generation biomass (e.g. straw, wood residues, organic waste) will generate advantages in sustainability and green marketing. The potential for development, however, depends strongly on the production process applied. For each product category, based on the main type of process, the possibility of developing processes that use alternative feedstocks were assessed.

The results are presented as a SWOT overview in Table 31 and summarised in the following text. The most important messages for each product category emerging from the SWOT results were analysed in more detail with the help of the experts interviewed and are reported in the text following the table.

In general, I&T are considered high for bio-based products and are often seen as a strength. Examples are high research and development (R&D) activity and beneficial properties such as biodegradability ([5]). Typical weaknesses within I&T are challenging purification processes and lower or inconsistent quality of some of the bio-based products.

The main issue in relation to E&M is the often higher cost of producing bio-based products compared with their fossil-based counterparts. This weakness is mentioned for nearly every product category and by many different data sources. The willingness of consumers to pay a premium for green products is debated and is said to depend on the market sector.

S&E are critical for driving bio-based production. Many benefits are mentioned, such as lower toxicity, lower greenhouse gas emissions and the greater safety of bio-based products. A major weakness of bio-based products is their increased land use, which has a negative environmental impact. The greatest perceived threats in this category are consumers having a low level of awareness of bio-based products and increasing public criticism towards bio-based products (e.g. bio-plastics). Public awareness is higher for some product categories (e.g. bio-plastics, bio-lubricants) than for others (e.g. surfactants, adhesives, partly bio-based cosmetics and personal care products).

Finally, L&R are very diverse and dependent on the product category. L&R that restrict (limit or ban) the use of fossil-based products can create markets for bio-based products, such as for bio-based lubricants, as explained below, or can stimulate development of bio-based products with funding. The absence of general L&R discouraging the use of fossil resources (e.g. a general carbon tax) is seen as a threat for some product categories, preventing the further development of bio-based products and production technologies.

Uncertainties

It should be noted that, due to the time available, the sample size for interviews was limited to 10 experts; thus the opinion or data point from each source that was consulted was taken into account and no ranking could be made. A more precise picture of the issues should be generated by either conducting multiple interviews for each product category or using other methods, such as the Delphi technique applied by Mohannak et al. (2014).

([5]) It should be noted that biodegradability is a complex issue, since different definitions apply (biodegradability strongly depends on environmental conditions and may require human intervention). Harmonised rules for defining and labelling compostable and biodegradable plastics are being created by the European Commission (http://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-swd.pdf).

Table 31: SWOT analysis of bio-based products at product category level

	Strengths	Weaknesses	Opportunities	Threats
Platform chemicals	• Diverse feedstock use, which creates flexibility in the supply chain (I&T; 2) • Promotional benefits (S&E; 2)	• High (production) cost (E&M; 2)	• Need to reduce fossil dependence in other downstream sectors, which creates a market for bio-based building blocks (S&E; 2)	• Lack of skilled workforce (I&T; 2) • Large amount of investment needed for new production plants (E&M; 2) • Biomass availability in case of full rollout (E&M; 2) • Low oil price (E&M; 1) • Low public awareness of bio-based products (S&E; 2) • Continual changes in environmental legislation and protocols (L&R; 2) • Potential legislation based on technical measures and not directly aimed at reducing greenhouse gas emissions (a CO_2 tax) (L&R 1) • Lack of grants for bio-based products (L&R; 2)
Solvents	• Functional benefits, such as biodegradability (I&T; 3) • Widespread R&D activity (I&T; 3) • Promotional benefits (S&E; 1)	• High (production) cost (E&M; 1, 3)	• Need to reduce fossil dependence in certain sectors, which creates a demand for bio-based solvents (S&E; 3). • Growing demand or market (E&M; 3) • Toxicity of fossil products (S&E; 3) • Increasing awareness of harmful effects of fossil-based solvents in personal care (S&E; 3)	• Perceived lack of available biomass, owing to the large consumption volumes of solvents, to replace all fossil products in case of full rollout (S&E; 1) • Lack of incentive to change (E&M, 1)
Polymers for plastics	• Functional benefits of newly developed materials (I&T; 1, 2, 4, 5) • Widespread R&D activity (I&T; 4) • Creation of jobs (S&E; 4)	• Need for technological improvements (I&T; 1, 2) • High (production) cost (E&M; 1, 2)	• Decreasing cost after scaling up (E&M; 1) • Consumer demand (E&M; 1) • Pull from large brand owners (E&M; 1) • Need to reduce fossil dependence (S&E; 4) • Growing awareness of the impact of fossil products on the environment (S&E; 1, 4)	• Lack of infrastructure (I&T; 2) • Lack of investment (E&M; 2) • Low oil price (E&M; 1) • Higher cost of bio-based plastics compared with their fossil-based counterparts (E&M; 1) • Increasing public criticism of bio-based plastics (S&E; 1) • Bio-plastics production and plastic recycling sectors are not in

			• Regulations stimulating the market for bio-based products in some Member States (L&R; 1, 4, 15)	harmony (S&E; 1) • Lack of carbon taxation (L&R; 1) • Lack of standardisation and absence of a legislative framework (L&R; 2)
Paints, coatings, inks and dyes	• Functional benefits (I&T; 1) • Widespread R&D activity (I&T; 6) • Advanced small-scale technology (I&T; 1)	• Lower quality compared with fossil-based equivalents (I&T; 6) • Difficulty of obtaining unsaturated compounds from biomass (I&T; 1) • Lack of purchase guarantee in order to move from pilot to commercial scale (E&M; 1) • High (production) cost (E&M; 1, 7) • Increased land use (S&E; 1) • Lack of subsidies for the move from pilot to commercial scale (L&R; 1)	• Need for development of a bio-based version of the polyol part of alkyd resins (I&T; 1) • Possibility of asking for a green premium (E&M; 1) • Volatile petrochemical prices (E&M; 1, 7) • Need to reduce fossil dependence (S&E; 7) • Need for greener solvents (S&E; 1) • Growing awareness of the impact of fossil products on the environment (S&E; 1) • Political instability of oil-producing countries (S&E; 7)	• Unwillingness to pay a green premium (E&M; 1) • Perceived competition with food and/or energy supply (S&E; 1, 7) • Investments in large-scale plants are hindered by lack of a secure sales market (E&M; 1).
Surfactants	• Functional benefits (e.g. biodegradability) (I&T; 8, 9) • Low toxicity (S&E; 8)	• Difficult purification processes (I&T; 2) • Difficult to scale up (I&T; 2) • High (production) cost due to the cost of substrates and the more challenging purification processes (E&M; 1, 2, 8)	• Rising demand for greener surfactants (E&M; 8) • Volatile petrochemical prices (E&M; 8) • Increasing awareness of harmful effects of fossil-based products (S&E; 8) • Regulations restricting the use of fossil products, e.g. Regulation (EC) No 648/2004 (L&R; 8, 16)	• Price too high compared with fossil alternative (E&M; 1) • High biomass prices (E&M; 2) • Biomass availability (E&M; 2) • Low public awareness of bio-based products (S&E; 2) • Difficult registration process for new products (L&R; 2) • Lack of grants (L&R; 2)
Cosmetics and personal care products	• Functional benefits (e.g. foaming properties or solubility) (I&T; 9, 10) • Widespread R&D activity (I&T; 10) • Promotional benefits of marketing cosmetics as 'natural' (S&E; 1, 9)	• High (production) cost (E&M; 10) • Long tradition prevents claiming green premium without rebranding (S&E; 9)	• Growing demand or market (E&M; 10) • Increasing consumer disposable income (E&M; 10) • Need to reduce fossil dependence (S&E; 10) • Rising demand for 'chemical-free' products (S&E; 10)	• 'Bio-based' is a poor marketing term (S&E; 1) • Cosmetics are often partly bio-based but only 100% bio-based cosmetics can be sold as 'natural', which is a good marketing term (S&E; 1)

			• Growing awareness of the impact of fossil products on the environment (S&E; 10) • Approval from health and safety regulatory bodies (L&R; 11)	
Adhesives	• Increasing number of bio-based applications (I&T; 11) • Widespread R&D activity (I&T; 11)	• Difficulties in maintaining a consistent quality of product (I&T; 1) • Lack of tools to assess environmental impacts (S&E, 11) • Increased land use (S&E; 1) • Not a very 'circular' type of product: limited possibilities for recycling, such that the only end-of-life option is often incineration (S&E; 1)	• Costs of storing hazardous substances (E&M; 11) • Need to reduce fossil dependence (S&E, 11) • Growing awareness of the impact of fossil-based products on the environment (S&E; 1) • Potential regulations stimulating the market for bio-based products (L&R; 11)	• Unwillingness to pay a green premium (E&M; 1) • Perceived competition with food and/or energy supply (S&E; 1, 11) • Low interest on the part of customers in bio-based adhesives as part of other products (S&E; 1)
Lubricants	• Functional benefits (e.g. high lubricity and adhesivity) (I&T; 2, 12) • Widespread R&D activity (I&T; 12) • Mainly based on well-developed oils and fats platform (I&T; 1) • Less environmental impact upon leakage (S&E; 2) • Low aquatic toxicity (S&E; 12) • Low bioaccumulation (S&E; 12) • Reduction of greenhouse gas emissions (S&E; 13)	• Difficult to obtain desired properties, such as odour free, stable to oxidation, and a large range of viscosities (I&T; 2) • Lower quality (I&T; 1) • Highly dependent on a single feedstock (I&T; 2, 12) • Poor low temperature properties (I&T; 2) • High (production) cost of bio-based product (E&M; 1, 2, 12) • Continuous injection of funds necessary (E&M; 2, 13)	• Growing automotive industry increases demand for lubricants (E&M; 1) • Volatile petrochemical prices (E&M; 2) • Stimulation of the market for bio-lubricants along with that for biofuels possible (E&M; 1) • Regulations stimulating the market for bio-based products in total-loss applications, such as Commission Decision 2011/381/EU (L&R; 12, 17) • Industrial applications with a strict regulatory framework (L&R; 12) • Increasingly high emission standards (L&R; 14)	• Price of bio-lubricants higher than that of other lubricants (E&M; 1) • Lubricants are a commodity market, so a price premium is unlikely to be achieved (E&M; 1) • Low public awareness (S&E; 2) • Lack of promotional benefit due to the products' applications (E&M; 1) • Differing regional regulations (L&R; 2) • Increasing efficiency in the use of lubricants and the possible rise of electric cars could reduce future market demand for lubricants (E&M; 1)
Plasticisers	• Functional benefits, in particular biodegradability for their application in biodegradable plastics (I&T; 5)	• High (production) cost of bio-based products due to feedstock, compared with the costs of phthalate-based plasticisers (E&M; 5)	• Growing demand or market (E&M; 5) • Toxicity of petrochemical products (S&E; 5) • Restriction on the use of certain phthalates as part of	• Fluctuating biomass prices (E&M; 5) • Continual changes in environmental guidelines (L&R; 5) • Changes in blending policies (L&R;

	• Reduction of weight in vehicles (I&T; 5) • Fewer side effects (S&E; 5) • Greater safety (S&E; 5) • Reduction of greenhouse gas emissions (S&E; 5)		REACH (L&R; 5)	5)
Man-made fibres	• Functional benefits (I&T; 1) • Preference for natural fibres for applications with skin contact (S&E; 1) • Promotional benefits when marketed as a biodegradable product (E&M, 1).	• Not every mill can use every type of wood (I&T; 1) • Technical limitations on introducing non-wood fibres into composites (I&T; 1)	• Use for mechanical reinforcement of bio-plastics (I&T; 1) • Appetite for investment (E&M; 1) • Growing demand and market (E&M; 1) • High EU environmental standards (L&R; 1)	• Lack of investment for pilots and demos (E&M; 1) • Lower environmental standards outside the EU (L&R; 1) • Lack of inclusion of all industry in funding schemes (the distinction between traditional and novel bio-based man-made fibres divides the industry) (L&R; 1)

References in the table: 1. Expert interviews, 2. Tsagaraki, 2017, 3. Grand View Research, 2015c, 4. European Bioplastics, 2017, 5. Grand View Research, 2017b, 6. TMR, 2016, 7. European Coatings, 2017, 8. MRF, 2018, 9. Dammer et al., 2017, 10. Grand View Research, 2018, 11. Vincentz, 2013, 12. Grand View Research, 2016e, 13. Cision, 2012, 14. Grand View Research, 2015d, 15. EC, 2015b, 16. EC, 2004, 17. EC, 2011.

Platform chemicals

The market for platform chemicals is large, and a conversion from fossil-based to bio-based platform chemicals would make a real impact in terms of dependence on fossil feedstocks. An additional strength of bio-based platform chemicals is their diverse range of possible feedstock uses, which creates flexibility in the supply chain. To make a real impact in terms of reducing CO_2, large investments will need to be made in the platform chemical sector. It will take time for the industry to make these investments. Biomass availability is also seen as a threat. To replace large amounts of fossil feedstock with biomass, a large amount of land will be required to grow these feedstocks. Finally, according to the expert interviewed, legislation could be a constraint, if it were to promote a specific technique rather than focusing on the problems that it was designed to solve, for example if it did not directly target greenhouse gas emission reduction (a CO_2 tax).

Solvents

The market for solvents is also large. However, the amount of solvents produced in the EU is small compared with the EU production of platform chemicals. This fact, combined with more pressing matters such as REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) classification, volatile organic compound (VOC) emissions, safe transport issues, and health and safety issues, gives the industry little incentive to focus on a transition of its feedstock base. The CO_2 emissions caused by the production of solvents are seen as minor compared with the abovementioned problems that need to be dealt with by the industry. Moreover, from the expert interview it became clear that the amount of biomass needed to replace the feedstock of the entire solvent industry is perceived as very large and the associated land use requirement is seen as a constraint.

Polymers for plastics

Bio-based plastics can help in addressing sustainability issues relating to biodegradability, fossil oil dependence and CO_2 emission reduction. Recycling is a well-known solution to extend the lifespan of plastics and decrease their environmental impact. Unfortunately, the expert interviewed had the impression that, rather than supporting the rise of bio-based plastics, the recycling industry lobbies against it. This is a constraint when new legislation is developed. Brand owners (e.g. Lego, IKEA) and end users (including citizens) are increasingly aware of the negative impact of fossil-based plastics, which may lead them to favour biodegradable bio-based polymers for use in plastics. Some Member States, such as France and Italy, already favour the use of biodegradable plastics, by applying Directive (EU) 2015/720 on plastic bags for consumers (EC, 2015b). Bio-based polymers are more expensive than their fossil-based counterparts, and few users are willing to pay a green premium. The introduction of a carbon tax would help to establish a level playing field and create fairer competition.

Paints, coatings, inks and dyes

The main driver for using bio-based feedstock for the production of paints, coatings, inks and dyes is to reduce VOC emissions, which are dangerous to human health and can cause harm to the environment. There is strong motivation within the sector to increase sustainability. Higher production costs and uncertainty about market uptake (described as 'lack of purchase guarantee' by the expert interviewed) are seen as the main threats to investments in scaling up commercial production of bio-based paints, coatings, inks and dyes.

Surfactants

Bio-based surfactants often offer functional advantages over their fossil counterparts, such as biodegradability or lower toxicity. This results in a rising demand for bio-based surfactants to diminish the harmful effects of fossil-based products. The market is further stimulated by legislation that favours the use of biodegradable surfactants, such as Regulation (EC) No 648/2004 (EC, 2004). Owing to the higher feedstock costs and the difficult separation steps required, bio-based surfactants have high production costs, which are seen as one of the weaknesses for this category.

Cosmetics and personal care products

Cosmetics and personal care products are purely a business-to-consumer market and therefore are affected much more than other categories by the promotional features of bio-based products. They are often labelled as 'natural' products, which is seen as a more appealing marketing term than 'bio-based'. However, the term 'natural' can be used only for products that are 100% bio-based, while most bio-based cosmetics are only partly bio-based. Other drivers and constraints, such as higher costs and legislation, play only minor roles in relation to cosmetics and personal care products.

Adhesives

The market for bio-based adhesives is growing, due to the growing awareness of the negative impacts that fossil-based products have on the environment. Moreover, with help from the strong R&D in the sector, the number of applications of bio-based adhesives is increasing. A challenge for the development of bio-based adhesives is the observed difficulty of manufacturing products with consistent properties to guarantee consistent quality.

Lubricants

An important existing market for bio-based lubricants is represented by total-loss applications in, for example, chainsaws. Bio-lubricants are commonly used in chainsaws in Austria, Germany and the Nordic countries. The European Ecolabel for Lubricants (EC, 2011) is not used only in Green Public Procurement: a number of Member States (Austria, Belgium, France, Germany) require the use of Ecolabel-certified bio-lubricants in environmentally sensitive areas; Italy taxes mineral oil-based lubricants; and Portugal requires the use of bio-based oil for two-stroke engines (Krop, 2014). Moreover, the large automotive industry provides an important market and could become a significant driver for the use of bio-based lubricants. On the other hand, the increasing efficiency in the use of lubricants and the possible rise of electric cars could reduce future market demand for lubricants. As a product necessary for car maintenance, bio-based lubricants are not likely to gain significantly from promotional benefits, despite being a final product known to the public. Given that lubricants are a commodity product, the motivation to pay a premium for bio-lubricants is expected to be low. Therefore, stimulating legislation would have a crucial role in increasing the market for bio-based lubricants.

Plasticisers

The restriction on certain toxic phthalate-based petrochemical plasticisers in toys and childcare articles as part of REACH (ECHA, 2018), and the possibility that this restriction could be further expanded to other phthalates and applications in the future, offers an opportunity to develop bio-based alternatives. In addition, biodegradability is crucial when plasticisers are developed for biodegradable plastics. A major challenge is the higher cost of bio-based alternatives to fossil-based plasticisers.

Man-made fibres

The bio-based features of man-made fibres are seen as a promotional benefit when marketed as relating to the natural origin of fashion products. Consumers prefer natural products in contact with their skin. Biodegradability is also a promotional benefit. Overall, environmental standards in Europe are high and drive the production of bio-based man-made fibres. However, lower standards outside the EU are seen as a constraint on the industry. Moreover, fibres manufactured by certain industries do not always qualify for current funding schemes, for example fibres originating from the pulp and textile industries.

Conclusions

The promotional benefits of bio-based products are heavily dependent on the product's application. For cosmetics and personal care products, there is a clear benefit when a product is 100% bio-based and can be labelled as 'natural'. However, for surfactants, there is no added benefit, since it they are available only as part of the final consumer product. The markets for bio-based versions of such products need to be stimulated by laws and regulations, rather than by consumer preferences.

Many bio-based products are more expensive to produce. It is often seen as difficult to compete financially with the fossil industry, which has been optimised for many decades. Moreover, the experts interviewed doubt that there is sufficient willingness to pay a green premium for bio-based products. However, a recent survey conducted by nova-Institute as part of the European project BIOFOREVER concluded that there is a willingness to pay a green premium in relation to many applications (Carus et al., 2018). An international tax on the use of fossil carbon is often seen as the ultimate solution. However, the experts interviewed are pessimistic about the feasibility of reaching international agreements on such a law.

4 Conclusions and recommendations

4.1 Conclusions

The conclusions of this study focus on the current status and possible future development of each bio-based product category, based on the results obtained and the data gaps identified during the execution of the study.

Current status and future development of each bio-based product category

The main findings for each product category are presented in the following paragraphs. Factsheets offering a more detailed one-page summary for each product category can be found in Annex 4.

Platform chemicals

The total platform chemicals market is huge, with a global production of 403 Mt/a; however, the bio-based platform chemicals market is still young, which is clear from the small bio-based share, 0.3%. The significant investments needed for conversion to a bio-based industry are a major hurdle to be overcome, and the chemical industry will need time to make these investments. Since new plants are being constructed, it is expected that the bio-based platform chemicals market will grow rapidly.

Solvents

Only 3% of worldwide bio-based solvents production takes place in the EU, and 43% of the bio-based solvents consumed in the EU are imported. These figures are not expected to change soon, with the industry focusing on more pressing problems, such as VOC emissions, rather than greenhouse gas emission reduction.

Polymers for plastics

The environmental concerns relating to plastic use are very visible to consumers, which has resulted in a pull from major brands in the EU to move towards bio-based polymers for plastics. Combined with the strong starch production in the EU, this results in net exports of bio-based polymers for plastics. The market is expected to continue to grow by 4% per year in the coming 5 years.

Paints, coatings, inks and dyes

With a couple of traditional bio-based products, such as alkyd resins, the paints, coatings, inks and dyes product category currently has a bio-based share of about 12.5%. The bio-based market for paints, coatings, inks and dyes is expected to grow, but not by more than a few percent. Weaknesses lie in the perceived risk of investing in this category and uncertainty about sales of the bio-based products.

Surfactants

The large-scale use of bio-based oleochemicals in surfactants leads to a high bio-based share, 50%. Bio-based surfactants often have functional benefits such as lower toxicity and/or biodegradability over petrol-based surfactants. Bio-based surfactants form a stable, mature market, which is expected to grow at the same rate as the total surfactants market.

Cosmetics and personal care products

Cosmetics and personal care products have the advantage of being directly influenced by the end consumer. The desire for natural products, together with a history of bio-based products derived from fats and oils, results in a mature bio-based cosmetics market. Another advantage is that increased production costs play less of a role, with consumers willing to pay a green premium. The market is expected to continue to grow and seems to be particularly driven by consumer demand.

Adhesives

The EU produces a large volume of adhesives, accounting for 35% of global production. The EU's contribution to the bio-based adhesives market is even more pronounced, with 54% of the 441 kt/a global bio-based adhesive production coming from the EU. The industry expects that this market will continue to grow even further, with an increasing number of applications.

Lubricants

Owing to regulations on total-loss lubricants, bio-based lubricants already have a mature market, which is found mostly in the Nordic countries. In these countries, total-loss lubricants are used, for example, for chainsaws. Further market growth in, for instance, the (potentially much larger) market for bio-based engine lubricants will depend on the introduction of stimulating legislation. Otherwise, the bio-based lubricant market is not expected to grow much.

Plasticisers

Thanks to a decrease in the use of certain toxic phthalate-based plasticisers in toys and childcare articles, there has been an increasing demand for bio-based alternatives. However, the higher costs of these plasticisers limit the market potential. Production takes place mostly outside the EU, with only 8% of bio-based plasticisers being produced within the EU's borders. This results in the EU having a high import dependence in relation to these products.

Man-made fibres

Both total and bio-based man-made fibre production take place mainly outside the EU, i.e. only 2% of the global 36 Mt/a production happens in the EU. The market is very mixed, with some very mature products, such as rayon and cellulose acetate, and some newer products, such as nylon-4,11 and PTT. Not all of these products are covered by policies and regulations that are designed to promote bio-based man-made fibres.

Current status and future development of the bio-based market in the EU

The EU bio-based market is diverse and large differences can be found between product categories. For example, the bio-based shares within the product categories solvents and platform chemicals are very small, whereas surfactants and cosmetics and personal care products already enjoy large bio-based shares. Even within the categories with similar bio-based shares, the differences are large; for example, where bio-based platform chemicals are expected to grow rapidly in the coming years, bio-based solvents are expected to grow at a much slower pace.

In general, the bio-based market is still small, with an overall bio-based share of 3%. Without a powerful support scheme, the bio-based share of the market is not expected to increase much, with the EU's bio-based production having an estimated total CAGR of 3.6%. Only platform chemicals and adhesives have expected CAGRs above 5%.

Remaining data gaps

After having collected all the available data from statistics, there were a significant number of data gaps. Substantial effort was put into filling them using the available literature. Where this proved unsuccessful, related data were used to come to best estimates. However, not all the data gaps could be closed.

- Relatively good data could be obtained for the production of bio-based and fossil-based products in the EU. Even though the statistical data do not include many bio-based production data, this could be compensated for by production data from literature and reports. After an extensive search of open literature, obtaining production data for the product categories cosmetics and personal care products and surfactants proved to be most difficult.

- A considerable amount of price data could be collected from the literature analysis, supplemented by statistical analysis. However, even for the products that have reliable price data, no information on a potential green premium could be obtained. The data were obtained from different sources and covered different years and concepts. This resulted in a spread of prices considered too large to reveal an accurate premium for bio-based products.
- Turnover figures are available in the Prodcom database; however, only two products have a relevant Prodcom code without being a drop-in chemical. Therefore, all other turnovers were calculated from the production and price data.
- Consumption and trade figures were the most challenging data to obtain and this is reflected in the higher UIs for these data points. Often, either consumption or trade data could be found, but only occasionally was there a source for both. The remaining data points were calculated using production figures.
- The amount of feedstock used was determined by investigating the value chains of all 50 bio-based products selected for investigation. The most important data gap here is that a feedstock can have multiple sources. For example, a product originating from vegetable oil can be produced from palm, rapeseed, soy, etc. Since certain feedstocks are traded internationally, it is not always clear which feedstock is used for each product. This data gap was addressed by using the world average of all oil crops combined when no specific oil crop was identified.

In terms of product categories, the largest data gaps can be found in the product categories surfactants and cosmetics and personal care products. Polymers for plastics, solvents and plasticisers present the most complete data. The data gaps for surfactants and cosmetics and personal care products could be caused by the fact that most of these products are not new in the bio-based market and therefore less attention is paid to the construction of new plants or increased production numbers, whereas the novel drop-in products do receive attention when they replace fossil-based chemicals. Moreover, market assessments of bio-based products often focus on platform chemicals and polymers, ignoring advances in products and categories that are closer to the end consumer. Finally, these groups are represented in the statistical data at application level, rather than chemical level. For example, there is a code for soaps and surfactants for toilet use (3401 11 00), but no specific CN 2016 code for APG.

The market data on the 50 bio-based products create a picture of overall bio-based production in the EU. However, no useful results can be achieved by the direct summation of the production volumes within each product category. For example, in the case of bio-based platform chemicals, there are many more bio-based products than those we investigated in detail, and the total production of those omitted may be greater than the sum of that for all the platform chemicals investigated here. Moreover, in many cases the investigated bio-based products are applied in more than one product category. This data gap was solved by estimating the values at product category level separately and comparing the results with the results for the individual products.

4.2 Recommendations

Recommendations on the creation of a competitive environment for the European bio-based sector are made based on the results of this study, as are recommendations on improving statistical data collection on bio-based products.

Recommendations on the creation of a competitive environment for the EU bio-based sector

Two common denominators can be observed across all product categories: the overall bio-based market in the EU is small and growth, in a business-as-usual scenario, is expected to not exceed 5%, with the exception of only a few product categories. Therefore, in order to realise the EU bio-based economy's potential, further measures need to be taken.

The market analysis and interviews confirmed that every product category has its own successes and faces its own challenges. Therefore, a deeper insight analysis needs to be performed on the hurdles that each product category faces and tailored solutions need to be designed for each of them. The SWOT analysis presented in this study on the basis of few expert interviews shows a number of common themes and a couple of specific themes. It would be useful to further extend this analysis with broader stakeholder engagement, for example in the context of one of the following:

- projects supported by BBI JU, the public-private partnership of the European Commission and the Bio-Based Industries Consortium (e.g. RoadToBio: Roadmap for the Chemical Industry in Europe towards a Bioeconomy);
- projects supported by the European Commission (e.g. the new Horizon 2020 project BioMonitor);
- studies commissioned by the Directorate-General for Research and Innovation (e.g. BIO-SPRI: Support to Research and Innovation Policy for Bio-based Products).

What can be concluded on the basis of this study is that some product categories have already benefited from regulatory measures at EU or Member State level, for example in the case of lubricants. The strong incentives to use biodegradable total-loss lubricants provide a competitive advantage for bio-based lubricants. Such measures can have a positive impact on the uptake of dedicated bio-based products with functional benefits such as biodegradability and will have a greater impact on product categories that include a lot of dedicated bio-based products.

With regard to bio-based drop-in chemicals, the main benefits are a reduction in the use of fossil resources and thus a potential reduction in environmental impacts related to the extraction and use of oil and gas (i.e. pollution, climate change, etc.) ([6]), rather than any functional benefits offered by the bio-based products. The chemical industry prefers legislative incentives aimed at the envisaged replacement, for example by internalising external costs associated with the use of fossil products. In some cases, 'smart' production routes already exist, whereby bio-based drop-in chemicals can be made following a more cost-effective pathway than their fossil equivalents (e.g. in the case of epichlorohydrin). These products have been called 'smart drop-ins' (Carus et al., 2017). They offer a business opportunity for an industry that is looking for new viable business cases. Their development could be supported by, for example, government investment incentives (grants, loans, guarantees, etc.).

The issue of production costs is less pronounced in some product categories, such as cosmetics and personal care products, where there is more willingness to pay a green premium. A reduced environmental impact is often accompanied by a higher monetary

([6]) It should be noted that, apart from total land use, this study did not look at the environmental impacts and benefits of bio-based products. The environmental benefits of bio-based chemicals differ from product to product and several life cycle assessment studies have been performed on various products (see, for example, the project BIO-SPRI: https://www.ecologic.eu/14774).

cost. For this reason, it is often argued that fossil products are not priced to take into account their environmental impact. A carbon tax is seen by the chemical industry as a way of creating a level playing field for all products, promoting products that are more sustainable without prioritising specific products.

Recommendations on data collection

This study provides a detailed insight into the market for 10 selected product categories. A substantial effort has been made to make the data collection process transparent, and to indicate uncertainties in estimates. Uncertainties could be reduced in the following ways:

- Data at product category level remain somewhat rudimentary, and a bottom-up approach from product to product category is the best way to establish a detailed overview of bio-based production within each product category.
- In this study, a list of 208 commercially available bio-based products was established, of which 50 were investigated in detail. It is recommended that the remaining 158 products be investigated, to establish a more detailed picture of the products within each category.
- Since many bio-based products are applied in different product categories, it is recommended that efforts be made to quantify the share of production in each product category. It is acknowledged that this would require substantial efforts and involve challenges relating to data availability.
- Some bio-based products (e.g. platform chemicals) are used in the production of other bio-based products (e.g. polymers), which could result in double counting and thus overestimates, in particular of feedstock use. To determine the feedstock use of the bio-based sector with more accuracy, the feedstock and material flows between products should be mapped. Such a material flow analysis would depend on value chain descriptions, and there would be uncertainties related to these, as there are often multiple production processes that can be used to produce the same product. However, in the context of this study, 50 value chain descriptions were created, of which 20 are provided in Annex 3, showing that it is possible to carry out such an analysis.
- Additional research is recommended to investigate the surfactants and cosmetics and personal care product categories in more detail, as these product categories are large and have high bio-based shares, while not many data are publicly available. These are established sectors, and little specific attention is paid to the fact that biomass feedstock is used in them.

To improve the availability of data on bio-based markets in the long term, the European statistical system could be improved. Two sources of European statistical data were used to retrieve market data on the 50 bio-based products selected for investigation in this study. These two sources, Prodcom and Comext, are both limited in their usefulness for obtaining data on the bio-based market. Prodcom codes are specific to chemicals or groups of chemicals, and chemicals that have large production volumes seem to be given priority in receiving their own Prodcom code. This results in only a few dedicated bio-based chemicals that do not have a fossil counterpart receiving their own Prodcom code. Other bio-based chemicals are either combined with their fossil counterpart in one Prodcom code or share their code with a large group of chemicals, or both. The CN 2016 codes are more specific, and more chemicals have their own code. However, the number of bio-based products that have their own code is still very limited. To increase the usefulness of the European statistics in understanding the bio-based market, more bio-based products need to be given their own CN 2016 and Prodcom codes. This could either happen when their production becomes large enough or be done by regrouping the chemicals in such a manner that bio-based products share their codes only with other bio-based products.

References

Please note that the internet sources referred to were consulted between November 2017 and April 2018.

ADEME, 2015. 'Marchés actuels des produits biosourcés et évolutions à horizons 2020 et 2030'. Agence de l'Environnement et de la Maîtrise de l'Énergie. http://www.ademe.fr/sites/default/files/assets/documents/2015-ademe-etude-marches-produits-biosources-evolutions-horizons-2020-2030-slides.pdf.

Aeschelmann, F., Carus, M., Baltus, W., Carrez, D., de Guzman, D., Käb, H., Philp, J., Ravenstijn, J., 2017. *Bio-based Building Blocks and Polymers: Global Capacities and Trends 2016-2021*. nova-Institut, Hürth, Germany.

Arkema, 2018. 'Vikoflex® epoxidized vegetable oils'. https://www.arkema-americas.com/en/products/product-portal/range-viewer/Vikoflex-epoxidized-vegetable-oils/.

Arpe, H.J., 2012. *Industrial Organic Chemistry*, 5th, completely revised edition. Wiley-VCH.

Bamgboye, A.I., Hansen, A.C., 2008. 'Prediction of cetane number of biodiesel fuel from the fatty acid methyl ester (FAME) composition'. *Int. Agrophysics* 22, pp. 21-29.

Baumassy, M., 2014. 'The talloil industry: 100 years of innovation'. PCA International Conference, Forchem Oy, Aforchem. https://www.researchgate.net/publication/296709891_The_talloil_industry_100_years_of_innovation.

Belgacem, M.N., 2011. Monomers, Polymers and Composites from Renewable Resources. Elsevier.

Biddy, M.J., Scarlata, C., Kinchin, C., 2016. *Chemicals from Biomass: A Market Assessment of Bioproducts with Near-Term Potential*. National Renewable Energy Laboratory.

BIO, 2016. *Advancing the Biobased Economy: Renewable Chemical Biorefinery Commercialization, Progress, and Market Opportunities, 2016 and Beyond*. Biotechnology Innovation Organization. https://www.bio.org/advancing-biobased-economy-renewable-chemical-biorefinery-commercialization-progress-and-market.

Borregaard, 2018. 'The flavor that carries — vanillin for 50 years. http://www.borregaard.com/News/The-flavor-that-carries-Vanillin-for-50-years.

Broeren, M., 2013. *Production of Bio-ethylene, Energy Technology System Analysis Programme (ETSAP)*. International Renewable Energy Agency (IRENA).

Busch, R., 2016. 'Marktanalyse: Verwendung von Pflanzenölen in der Industrie'. In *Gulzower Fachgespräche* Band 54, Bioschmierstofftagung 2016, 6-7 December 2016, Neuss, pp. 35-46. https://www.fnr.de/fileadmin/allgemein/pdf/veranstaltungen/bioschmierstofftagung_2016/GFG_Band_54_Bioschmierstoff-Tagung_web.pdf.

Business Wire, 2011. 'EU alkyd resins market is reducing in size according to BAC'. https://www.businesswire.com/news/home/20111125005195/en/EU-Alkyd-Resins-Market-Reducing-Size-BAC.

Butamax Advance Biofuels LCC, 2018. 'About Butamax Advanced Biofuels'. http://www.butamax.com/biofuel-company.aspx.

Bywater, N., 2011. 'The global viscose fibre industry in the 21st century: the first 10 years'. In: Lenzing, *Lenzinger Berichte*, pp. 22-29. https://www.lenzing.com/index.php?type=88245&tx_filedownloads_file%5bfileName%5d=fileadmin/content/PDF/03_Forschung_u_Entwicklung/Ausgabe_89_2011.pdf.

Carus, M., Dammer, L., Puente, Á., Raschka, A., Arendt, O., 2017. 'Bio-based drop-in, smart drop-in and dedicated chemicals'. nova-Institute, Hürth, Germany. https://www.roadtobio.eu/uploads/news/2017_October/RoadToBio_Drop-in_paper.pdf.

Carus, M., Partanen, A., Dammer, L., 2018. 'Detailed evaluation of GreenPremium prices for bio-based products along the value chain'. Bioforever paper 2018-03. nova-Institute, Hürth, Germany. https://bioforever.org/sites/default/files/publications/2018-03/Detailed-eval-GreenPremium-prices-for-bb-prod-along-value-chain.pdf.

Ceresana, 2017. *Market Study: Plasticisers*, 4th edition. Ceresana.

CESIO, 2015. 'CESIO statistics 2015'. http://www.cesio.eu/media/industry-data/CESIO-Statistics-2015.pdf.

CIRFS, 2017. 'About man-made fibres'. European Man-Made Fibres Association. https://www.cirfs.org/man-made-fibers/man-made-fibers.

Ciriminna, R., Lomeli-Rodriguez, M., Cara, P.D., Lopez-Sanchez, J.A., Pagliaro, M., 2014. 'Limonene: a versatile chemical of the bioeconomy'. *Chem*. *Commun*. 50, pp. 15288-15296.

Cision, 2012. 'Cision PRWeb'. https://www.cision.com/us/pr-web/.

Cision, 2013. 'EU alkyd resins market examined by BAC in in-demand research report'. http://www.prweb.com/releases/2013/8/prweb10992525.htm.

Cision, 2016. 'Global castor oil and derivatives market 2016-2024: market expected to reach $2.30 billion — research and markets'. https://www.prnewswire.com/news-releases/global-castor-oil-and-derivatives-market-2016-2024-market-expected-to-reach-230-billion---research-and-markets-300342570.html

Cision, 2017a. 'Europe paints and coatings market forecast 2017-2024'. https://www.prnewswire.com/news-releases/europe-paints-and-coatings-market-forecast-2017-2024-300492113.html.

Cision, 2017b. 'Global bio-based polyethylene terephthalate (pet) market analysis 2014-2025 — research and markets'. https://www.prnewswire.com/news-releases/global-bio-based-polyethylene-terephthalate-pet-market-analysis-2014---2025---research-and-markets-300448150.html.

Conroy, W., 2014. 'Czech Spolchemie to build glycerine plant for green ECH, resins'. ICIS News. https://www.icis.com/resources/news/2014/03/07/9760690/czech-spolchemie-to-build-glycerine-plant-for-green-ech-resins/.

CosIng, 2018. EU database of cosmetic ingredients and substances. http://ec.europa.eu/growth/tools-databases/cosing/index.cfm?fuseaction=search.simple.

Cosmetic Business, 2015. 'Europe's leading natural cosmetics market'. http://www.cosmetic-business.com/de/News/europes-leading-natural-cosmetics-market/287467.

Cosmetics Europe, 2018. 'Cosmetics and personal care industry overview'. https://www.cosmeticseurope.eu/cosmetics-industry/.

Dammer, L., Piotrowski, S., Carus, M., 2014. *Study on: Methodology Framework for the Bioeconomy Observatory. Project: Bioeconomy Information System and Observatory Project (BISO) — Set-up of the Bioeconomy Observatory*.

Dammer, L., Carus, M., Iffland, K., Piotrowski, S., Sarmento, L., Chinthapalli, R., Raschka, A., 2017. Current situation and trends of the bio-based industries in Europe. Pilot Study for BBI-JU. nova-Institut, Hürth, Germany.

Davies, P., 2013. 'Chemical business focus: a monthly roundup and analysis of the key factors shaping world chemical markets'. Tecnon OrbiChem.

De Almeida, D.G., Da Silva, R., Luna, J.M., Rufino, R.D., Santos, V.A., Banat, I.M., Sarubbo, L.A., 2016. 'Biosurfactants: promising molecules for petroleum biotechnology advances'. *Front. Microbiol.* 7, p. 1718.

De Guzman, D., 2012. 'Neste Oil expands in bio-naptha'. Green Chemicals Blog. https://greenchemicalsblog.com/2012/11/08/neste-oil-expands-in-bio-naptha/.

De Guzman, D., 2013. 'Cellulac to build a lactic acid plant'. Green Chemicals Blog. https://greenchemicalsblog.com/2013/12/30/cellulac-to-build-lactic-acid-plant/.

De Guzman, D., 2014. 'Global Bioenergies commercialization in momentum'. Green Chemicals Blog. https://greenchemicalsblog.com/2014/08/11/global-bioenergies-commercialization-in-momentum/.

De Prato, G., Nepelski, D., Piroli, G., 2015. *Innovation Radar: Identifying Innovations and Innovators with High Potential in ICT FP7, CIP & H2020 projects*. JRC Scientific and Policy Reports. Publications Office of the European Union, Luxembourg.

Dignum, M.J.W., Kerler, J., Verpoorte, R., 2001. 'Vanilla production: technological, chemical, and biosynthetic aspects'. *Food Rev. Int*. 17, pp. 199-219.

Drujon, X., 2016. 'Towards sustainable UV-curable coatings: challenges and opportunities for the wood coating industry'. PRA Woodcoatings Congress, Amsterdam. https://www.researchgate.net/publication/309487596_Towards_Sustainable_UV-Curable_Coatings.

DSM, 2018. 'EcoPaXX®-PA410: the green performer'. https://www.dsm.com/products/ecopaxx/en_US/home.html.

Dubois, J.L., 2014. *Arkema, une présence historique sur le marché des produits biosourcés*. Arkema. https://kipdf.com/arkema-une-presence-historique-sur-le-marche-des-produits-biosources_5ae3df277f8b9aba728b45d5.html.

E4tech, 2015. *From the Sugar Platform to Biofuels and Biochemicals: Final Report for the European Commission, Directorate-General Energy*. E4tech (UK) Ltd, Consorzio per la Ricerca e la Dimostrazione sulle Energie Rinnovabili (RE-CORD), Stichting Dienst Landbouwkundig Onderzoek, Wageningen University and Research Centre (WUR). https://ec.europa.eu/energy/sites/ener/files/documents/EC%20Sugar%20Platform%20final%20report.pdf.

EC, 2004. Regulation (EC) No 648/2004 of the European Parliament and of the Council of 31 March 2004 on detergents. OJ L 104, 08/04/2004 p. 1-35. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32004R0648&from=en.

EC, 2007. *Accelerating the Development of the Market for Bio-based Products in Europe: Report of the Taskforce on Bio-based Products — Composed in Preparation of the Communication 'A Lead Market Initiative for Europe' (COM(2007) 860 final)*. European Commission.

EC, 2011. Commission Decision 2011/381/EU of 24 June 2011 on establishing the ecological criteria for the award of the EU Ecolabel to lubricants (notified under document C(2011) 4447). OJ L 169, 29.6.2011, p. 28-39. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011D0381.

EC, 2012. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Innovating for Sustainable Growth: A Bioeconomy for Europe (SWD(2012) 11 final). http://ec.europa.eu/research/bioeconomy/pdf/official-strategy_en.pdf.

EC, 2013. 'Monthly note: industrial policy indicators and analysis'. June 2013. European Commission, drafted by Roa and Velazquez, http://ec.europa.eu/DocsRoom/documents/10121/attachments/1/translations/en/renditions/pdf

EC, 2014. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: For a European Industrial Renaissance (COM/2014/014 final). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014DC0014.

EC, 2015a. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Closing the Loop — An EU Action Plan for the Circular Economy (COM/2015/0614 final). http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614.

EC, 2015b. Directive (EU) 2015/720 of the European Parliament and of the Council of 29 April 2015 amending Directive 94/62/EC as regards reducing the consumption of lightweight plastic carrier bags. OJ L 115, 6.5.2015, p. 11-15. https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32015L0720&from=EN.

EC, 2016. Annex G of the General Annexes: Horizon 2020 Work Programme 2016–2017. European Commission Decision C(2017)2468 of 24 April 2017. https://ec.europa.eu/research/participants/portal/desktop/en/support/faqs/faq-2890.html.

EC, 2018. 'Knowledge Centre for Bioeconomy'. European Commission. https://ec.europa.eu/knowledge4policy/bioeconomy.

ECHA, 2018. Annex XVII To REACH Entry 51 and 52 — conditions to restriction, restrictions on the manufacture, placing on the market and use of certain dangerous substances, mixtures and articles. European Chemicals Agency. https://echa.europa.eu/substances-restricted-under-reach.

ESIG, 2018. 'European Solvents Industry Group'. www.esig.org.

Eurobarometer, 2009. *Europeans' Attitudes towards the Issue of Sustainable Consumption and Production: Analytical report*. Flash Eurobarometer No 256. The Gallup Organisation. https://ec.europa.eu/commfrontoffice/publicopinion/flash/fl_256_en.pdf.

Eurobarometer, 2010. *Biotechnology: Report*. Special Eurobarometer 341/Wave 73.1. TNS Opinion & Social. https://ec.europa.eu/commfrontoffice/publicopinion/archives/ebs/ebs_341_en.pdf.

European Bioplastics, 2017. 'Bioplastics market data 2017: global production capacities of bioplastics 2017-2022'. http://docs.european-bioplastics.org/publications/market_data/2017/Report_Bioplastics_Market_Data_2017.pdf.

European Coatings, 2011. 'Study indicates slowdown in EU alkyd resins market'. http://www.european-coatings.com/Markets-companies/Raw-materials-market/Study-indicates-slowdown-in-EU-alkyd-resins-market.

European Coatings, 2017. 'Bio-based coatings: Sustainability 2.0'. http://www.european-coatings.com/Raw-materials-technologies/Technologies/Bio-based-coatings-Sustainability-2.0.

Eurostat, 2008. *NACE Rev. 2: Statistical classification of economic activities in the European Community*. Eurostat Methodologies and Working papers. Luxembourg, p. 367.

FEICA, 2014. 'The European adhesive and sealant industry: facts & figures 2014'. http://www.feica.eu/cust/documentview.aspx?DocID=1615.

FIRST2RUN, 2015. *D6.1 — Market Analysis of Biobased Materials and Products*. FIRST2RUN Horizon 2020/BBI JU project. http://www.first2run.eu/.

Flach, B., Lieberz, S., Rossetti, A., 2017. *EU Biofuels Annual 2017*. GAIN Report Number NL7015. Global Agricultural Information Network.

García-Ochoa, F., Santos, V.E., Casas, J.A., Gómez, E., 2000. 'Xanthan gum: production, recovery, and properties'. *Biotechnol. Adv.* 18, pp. 549-579.

Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Corchero, C., Fischler, C., Hampel, J., Jackson, J., Kronberger, N., Mejlgaard, N., Revuelta, G., Schreiner, C., Torgersen, H., Wagner, W., 2006. *Europeans and Biotechnology in 2005: Patterns and Trends*. Special Eurobarometer 244b/Wave 64.3. Eurobarometer.

Gevo Inc, 2018. 'About Gevo'. https://gevo.com/about-us/.

Global CSS Institute, 2018. 'Ethylene oxide production'. https://hub.globalccsinstitute.com/publications/ccs-roadmap-industry-high-purity-co2-sources-sectoral-assessment-%E2%80%93-final-draft-report-2.

Global Industry Analysts, 2012. 'European biolubricants market to reach 240 thousand tonnes by 2017, according to new report by Global Industry Analysts, Inc.'. http://www.prweb.com/releases/biolubricants/biodegradable_lubricants/prweb9278405.htm.

Global Market Insights, 2015. 'Bioadhesive (green adhesive) market size, industry analysis report, application development, price trend, competitive market share & forecast, 2016-2023'. https://www.gminsights.com/industry-analysis/bioadhesive-market.

GlobeNewswire, 2016. 'Bio based polyethylene terephthalate (PET) market size over $13 billion by 2023: Global Market Insights, Inc.'. https://globenewswire.com/news-release/2016/05/31/844530/0/en/Bio-Based-Polyethylene-Terephthalate-PET-Market-size-over-13-Billion-by-2023-Global-Market-Insights-Inc.html.

Grand View Research, 2015a. 'Bio-based polyurethane (PU) Market analysis by product (rigid foams, flexible foams, CASE), by end-use (furniture & interiors, construction, automotive, footwear) and segment forecasts to 2020'. https://www.grandviewresearch.com/industry-analysis/bio-based-polyurethane-industry.

Grand View Research, 2015b. 'Biosurfactants Market analysis by product (rhamnolipids, sophorolipids, MES, APG, sorbitan esters, sucrose esters) and segment forecast to 2020'. https://www.grandviewresearch.com/industry-analysis/biosurfactants-industry.

Grand View Research, 2015c. 'Bio solvents market analysis by product (lactate ester, soy methyl ester alcohol, glycols) by applications (paints & coatings, adhesives & sealants, printing inks) and segment forecasts to 2020'. https://www.grandviewresearch.com/industry-analysis/bio-solvents-market.

Grand View Research, 2015d. 'Marine lubricants market size, share & trends analysis report by product (engine oil, hydraulic oil, gear oil, turbine oil, greases), by region (North America, Europe, APAC), competitive landscape, and segment forecasts, 2018-2025'. https://www.grandviewresearch.com/industry-analysis/marine-lubricant-market.

Grand View Research, 2016a. 'Castor oil and derivatives market analysis by product (sebacic acid, ricinoleic acid, undecylenic acid, castor wax, dehydrated castor oil), by application (lubricants, surface coatings, biodiesel, cosmetics & pharmaceuticals, plastics & resins) and segment forecasts to 2024'. https://www.grandviewresearch.com/industry-analysis/castor-oil-derivatives-industry.

Grand View Research, 2016b. 'Succinic acid market analysis by application (1,4 BDO, resins, coatings, dyes & inks, pharmaceuticals, polyurethanes, food, plasticizers, cosmetics, solvents & lubricants, de-icing solutions) and segment forecasts to 2022'. https://www.grandviewresearch.com/industry-analysis/succinic-acid-market.

Grand View Research, 2016c. 'Isobutanol market analysis by product (synthetic, bio-based), application (oil & gas, solvents & coatings, chemical intermediates) and segment forecasts to 2022'. https://www.grandviewresearch.com/industry-analysis/isobutanol-market.

Grand View Research, 2016d. 'Organic personal care market size, share & trends analysis report by application (skin care, hair care, cosmetics, oral care), by region (North America, Europe, APAC, CSA, MEA), and segment forecasts, 2018-2025'. https://www.grandviewresearch.com/industry-analysis/organic-personal-care-market.

Grand View Research, 2016e. 'Biolubricants market analysis by raw material (vegetable & animal oil), by application (automotive (automotive engine oils, gear oils, hydraulic oils, transmission fluids, greases, chainsaw oils), industrial (process oils, demolding oils, industrial gear oils, industrial greases, metal working fluids)), by end-use (industrial, commercial transportation, consumer automotive) segment forecasts to 2024'. https://www.grandviewresearch.com/industry-analysis/biolubricants-industry.

Grand View Research, 2017a. 'Vanillin market size worth $724.5 million by 2025'. https://www.grandviewresearch.com/press-release/global-vanillin-market.

Grand View Research, 2017b. 'Paints and coatings market by product (high solids, powder, waterborne, solvent-borne), by material (acrylic, alkyd, polyurethane, epoxy & polyesters), by application, and segment forecasts, 2018-2025'. https://www.grandviewresearch.com/industry-analysis/paints-coatings-market.

Grand View Research, 2017c. 'Bio plasticizers market analysis by product type (citrates, castor oil, esbo, succinic acid), by application (packaging, consumer goods, automotive, construction, textiles), and segment forecasts, 2018-2025'. https://www.grandviewresearch.com/industry-analysis/bio-plasticizers-market.

Grand View Research, 2017d. 'Bio-based polyethylene terephthalate (PET) market analysis by application (bottles, technical, consumer goods), by region (North America, Europe, Asia Pacific, Central & South America), and segment forecasts, 2018-2025'. https://www.grandviewresearch.com/industry-analysis/bio-based-polyethylene-terephthalate-pet-industry.

Grand View Research, 2017e. 'Alcohol ethoxylates market analysis by product (fatty alcohol, lauryl alcohol, linear alcohol), by application (emulsifier, dispersing agent, wetting agent), by end-use, and segment forecasts, 2018-2025'. https://www.grandviewresearch.com/industry-analysis/alcohol-ethoxylate-market.

Grand View Research, 2018. 'Organic personal care market size worth $25.11 billion by 2025'. https://www.grandviewresearch.com/press-release/global-organic-personal-care-market.

Gregg, J.S., Bolwig, S., Hansen T., Solér, O., Amer-Allam, S.B., Viladecans, J.P., Klitkou, A., Fevolden, A., 2017. 'Value chain structures that define European cellulosic ethanol production'. *Sustainability* 9, p. 118.

Gunstone, F., Harwood, J., Dijkstra, A., 2007. *The Lipid Handbook*. CRC Press.

Harmsen, P., Hackmann, M., 2013. *Green building blocks for biobased plastics*. Wageningen UR Food & Biobased Research. http://edepot.wur.nl/261762.

HERA, 2008. *Human and Environmental Risk Assessment on Ingredients of Household Cleaning Products: Esterquats Environmental Risk Assessment Report*, Edition 1.0. Human and Environmental Risk Assessment.

ICIS, 2000. 'Cellulose acetate flake'. https://www.icis.com/resources/news/2000/03/20/108382/cellulose-acetate-flake/.

ICIS, 2006. 'Indicative chemical prices A-Z'. https://www.icis.com/chemicals/channel-info-chemicals-a-z/.

IFC, 2018. 'TransFuran Chemicals (TFC)'. International Furan Chemicals. http://www.furan.com/tfc.html.

Jogdand, S.N., 2015. *Current status of bio-based chemicals*. Biotech Support Services (BSS), India.

Kaeb, H., Aeschelmann, F., Dammer, L., Carus, M., 2016. *Market Study on the Consumption of Biodegradable and Compostable Plastic Products in Europe 2015 and 2020*. nova-Institut, Hürth, Germany.

Keinänen, P., Kaila, K, 2018. *Advanced Epoxy Resins For Composites*. Amroy Europe OY.

Krop, H., 2014. 'Greening your portfolio: use the EU Ecolabel for Lubricants (why, how, what and future)'. IVAM Research and Consultancy on Sustainability. http://www.innovhub-ssi.it/c/document_library/get_file?uuid=0305bf4a-e917-4b0e-ab5a-bd61ad16580e&groupId=11654.

Lane, J., 2014. 'The year of consolidation: TMO enters receivership'. Biofuels Digest. http://www.biofuelsdigest.com/bdigest/2014/01/08/the-year-of-consolidation-tmo-enters-receivership/.

Lunt, J., 2014. *Marketplace Opportunities for Integration of Biobased and Conventional Plastics*. Agricultural Utilization Research Institute. https://www.auri.org/assets/2014/09/AIC185.biobased1.pdf.

Mang, T., Gosalia, A., 2017. 'Lubricants and their market'. In: Dresel, W., Mang, T. (eds.), *Lubricants and Lubrication*. Wiley-VCH. https://onlinelibrary.wiley.com/doi/10.1002/9783527645565.ch1.

Medicinenet, 2018. 'What's in YOUR Cosmetics?' https://www.medicinenet.com/script/main/art.asp?articlekey=26084.

Mohannak, K., Samtani, L., 2014. 'A Criteria-based approach for evaluating innovation commercialisation'. Presented at the DRUID Society Conference, CBS, Copenhagen, 16-18 June 2014. https://conference.druid.dk/acc_papers/i1xk9l9pli4jnefryvacrvpjdy22.pdf.

MRF, 2018. 'Bio-based surfactants market research report — forecast to 2023'. Market Research Future. https://www.marketresearchfuture.com/reports/bio-based-surfactants-market-3907.

Nattrass, L., Biggs, C., Bauen, A., Parisi, C., Rodríguez-Cerezo, E., Gómez-Barbero, M., 2016. *The EU Bio-based Industry: Results from a Survey*. JRC Technical Report. Publications Office of the European Union, Luxembourg.

NCV, 2017. *Jaarverslag 2016*. Nederlandse Cosmetica Vereniging. https://www.ncv-cosmetica.nl/download_file/1434/416/.

NCV, 2018. 'Europese markt'. Nederlandse Cosmetica Vereniging. https://www.ncv-cosmetica.nl/cosmetica/marktgegevens/europese-markt/.

NNFCC, 2008. *Biochemical Opportunities in the United Kingdom*. National Non-Food Crops Centre, York, UK.

Oanda, 2018. 'Average exchange rates'. https://www.oanda.com/currency/average.

Patel, M., Crank, M., Domburg, V., Hermann, M., Roes, L., Hüsing, B., Overbeek, L., Terragni, F., Recchia, E., 2006. *Medium and Long-term Opportunities and Risks of the Biotechnological Production of Bulk Chemicals from Renewable Resources: The Potential of White Biotechnology*. The BREW Project final report. Utrecht University, Utrecht.

PCE, 2018. 'Petrochemicals Europe'. http://www.petrochemistry.eu/about-petrochemistry/facts-and-figures/capacity-and-production-data.html.

Peters, D., Stojcheva, V., 2017. *Crude Tall Oil Low ILUC Risk Assessment*. Ecofys, Utrecht.

Plastics Europe, 2018. 'Plastics: the facts 2017'. Association of Plastic Manufacturers. http://www.plasticseurope.org/application/files/2415/1689/2630/2017plastics_the_facts.pdf.

Plastics Insight, 2016. 'Europe plasticisers market'. https://www.plasticsinsight.com/europe-plasticisers-market/.

Qin, Y., 2014. 'Global fibres overview'. Presented at the Synthetic Fibres Raw Materials Committee Meeting at APIC, Pattaya, 16 May 2014. Tecnon OrbiChem. https://www.orbichem.com/userfiles/APIC%202014/APIC2014_Yang_Qin.pdf.

Raschka, A., Carus, M., 2012. *Industrial Material Use of Biomass: Basic Data for Germany, Europe and the World*. nova-Institut, Hürth, Germany. http://bio-based.eu/?did=1650&vp_edd_act=show_download.

Rohan, 2018. 'Paints & coatings market worth 209.36 billion USD by 2022'. https://www.marketsandmarkets.com/PressReleases/paint-coating.asp.

Ronzon, T., Lusser, M., Klinkenberg, M. (ed.), Landa, L., Sanchez Lopez, J. (ed.), M'Barek, R., Hadjamu, G. (ed.), Belward, A. (ed.), Camia, A. (ed.), Giuntoli, J., Cristobal, J., Parisi, C., Ferrari, E., Marelli, L., Torres de Matos, C., Gomez Barbero, M., Rodriguez Cerezo, E., 2017a. *Bioeconomy Report 2016*. JRC Science for Policy Report. European Commission, Brussels.

Ronzon, T., Piotrowski, S., M'Barek, R., Carus, M., 2017b. 'A systematic approach to understanding and quantifying the EU's bioeconomy'. *Bio-based Appl. Econ.* 1, pp. 1-17.

Rust and Wildes, 2008. Surfactants — a market opportunity study update. Cited in: Dammer, L., Carus, M., Piotrowski, S., Puente, Á., Breitmayer, E., de Beus, N., Liptow, C., 2017. Current situation and trends of the bio-based industries in Europe with a focus on bio-based materials — Pilot Study for BBI JU nova-Institute, June 2017. nova-Institut, Hürth, Germany.

Sasol, 2018. *Surfactants: Product Range*. http://www.sasoltechdata.com/MarketingBrochures/Surfactants.pdf.

SEKAB, 2018. 'Green chemicals are crucial to a climate-safe society'. http://www.sekab.com/sustainability/work-in-progress/green-chemicals-are-crucial-to-a-climatesafe-society/.

Shen, L., Haufe, J., Patel, M.K., 2009. *Product Overview and Market Projection of Emerging Bio-based Plastics*. PRO-BIP 2009. Final report. European Polysaccharide Network of Excellence and European Bioplastics.

Solvay, 2018. 'Solvay boosts European natural vanillin capacity, introduces new products and upgrades research and innovation platform'. https://www.solvay.com/en/media/press_releases/171128-solvay-boosts-European-natural-vanillin-capacity.html.

TMR, 2014. '1,3-Propanediol market for polytrimethylene terephthalate (PTT), polyurethane, personal care & detergents, electrical & electronics and other application: global industry analysis, size, share, growth, trends and forecast, 2013-2019'. Transparency Market Research. https://www.transparencymarketresearch.com/propanediol-market.html.

TMR, 2015. 'Tall oil fatty acid market (product type — oleic acid, linoleic acid, linoleic acid, maleic acid, and stearic acid; applications — dimer acids, alkyd resins, fatty acid esters, dimer acid, and fatty acid soaps; end use — soaps and detergents, coatings, lubricants, plastics, fuel additives, metal working fluids, adhesives, asphalt additives, and biofules) — global industry analysis, size, share, growth, trends and forecast 2014-2022'. Transparency Market Research. https://www.transparencymarketresearch.com/tall-oil-fatty-acid-market.html.

Statista, 2018. 'Consumption value of cosmetics and personal care in Europe in 2016, by country (in million euros)'. https://www.statista.com/statistics/382100/european-cosmetics-market-volume-by-country/.

TMR, 2016. 'Synthetic & bio-based coatings for automotives — global industry size, market share, trends, analysis and forecast, 2012-2018'. Transparency Market Research. https://www.transparencymarketresearch.com/synthetic-bio-based-coatings-automotives.html#tab-1.

Tropsch, J., 2015. 'Bio-based SURFACTANTS (Official Mandate M/491)'. BASF. Presentation by Juergen Tropsch as convener of European Committee for Standardization Technical Committee 276, WG3, 18 June 2015.

Tsagaraki, E., Karachaliou, E., Delioglanis, I., Kouzi, E., 2017. *D2.1 Bio-based Products and Application Potential*. Bioways. http://www.bioways.eu/download.php?f=150&l=en&key=441a4e6a27f83a8e828b802c37adc6e1.

Tuszynski, W., Bessette, P.A., 2008. 'An evaluation of sebacic acid and azelaic acid as thickeners in lithium complex greases'. *NLGI Spokesman* 72. http://www.ivanhoeindustries.com/pdfs/NLGI%20Paper%202008.pdf.

Ukkonen, K.A., 2016. *Pine Chemicals: Global View*. Pine Chemicals Association, Inc.

USDA, 2016. *EU-28 Citrus Annual 2016*. GAIN Report Number SP1634. United States Department of Agriculture. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Citrus%20Annual_Madrid_EU-28_12-7-2016.pdf.

USDA, 2018. *Citrus: World Markets and Trade*. United States Department of Agriculture. https://apps.fas.usda.gov/psdonline/circulars/citrus.pdf United States Department of Agriculture.

Van den Oever, M., Molenveld, K., Van der Zee, M., Bos, H., 2017. *Bio-based and Biodegradable Plastics: Facts and Figures*, Report No 1722. Wageningen University.

van Haveren, J., Oostveen, E.A., Micciché, F., Noordover, B.A.J., Koning, C.E., van Benthem, R.A.T.M., Frissen, A.E., Weijnen, J.G.J., 2007. 'Resins and additives for powder coatings and alkyd paints, based on renewable resources'. *J. Coat. Technol. Res.* 4, pp. 177-186.

Vincentz, 2013. '"Biobased": an inseparable part of the adhesives market'. Presented at the European Coatings Conference, Düsseldorf, 21-22 February 2013. http://www.european-coatings.com/content/download/182320/3724318/file/00_Market%20overview_Miriam%20von%20Bardeleben,%20Vincentz.pdf.

Williamson, I.A., Pearson, D.R., Aranoff, S.L., Pinkert, D.A., Johanson, D.S., Broadbent, M.M., 2013. *Xanthan Gum from Austria and China*, Publication 4411. US International Trade Commission, Washington D.C.

Wolf, O., Crank, M., Patel, M., Marscheider-Weidemann, F., Schleich, J., Hüsing, B., Angerer, G., 2005. *Techno-economic Feasibility of Large-scale Production of Bio-based Polymers in Europe*. JRC Technical Report. European Commission, Brussels.

Xiaojue, C., 2013. 'Phenol and acetone'. Presented at the Chemicals Committee Meeting at APIC, Taipei, 10 May 2013. Tecnon OrbiChem. http://cpmaindia.com/pdf/apice2013_chen_xiaojue.pdf.

List of abbreviations and definitions

Abbreviation	Description
APG	Alkyl polyglucosides
BBI-JU	Bio-based Industries Joint Undertaking
BDO	1,4-butanediol
CAGR	Compound Annual Growth Rate
CAPEX	Capital expenditures
CN2016	Combined Nomenclature 2016 (European classification of goods used for foreign trade statistics)
CO_2	Carbon Dioxide (greenhouse gas)
CPA	European Classification of Products by Activity
DG RTD	Directorate-General for Research and Innovation (European Commission)
E&M	Economic and market potential
ESBO	Epoxylated soybean oil
EU	European Union (28 countries of the EU)
EU-15	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom
FAME	Fatty acid methyl ester
ha	Hectare
I&T	Innovation and technological readiness
JRC	Joint Research Centre of the European Commission
kton	kiloton (1000,000 kg)
L&R	Legal and regulatory impacts
LCA	Life Cycle Analysis
Mton	Megaton (1000,000,000 kg)
n.a.	Not applicable
NACE	Nomenclature Statistique des Activités dans la Communauté Européenne (statistical classification of economic activities in the European Communities)
n.d.	No data
PA	Poly(amide)
PBS	Poly(butylene succinate)
PE	Poly(ethylene)
PEG	Poly(ethylene) glycol ester
PET	Poly(ethylene terephthalate)
PHA	Poly(hydroxyalkanoate)
PLA	Poly(lactic acid)
PP	Poly(propylene)
PRODCOM	Production Communautaire (classification of goods used for statistics on industrial production in the EU)
PTT	Poly(trimethylterphthalate)
PUR	Poly(urethane)
R&D	Research and Development
REACH	Registration, Evaluation, Authorization and restriction of Chemicals. (European legislation on registration, evaluation and market access of chemicals)
S&E	Social and environmental impacts
SD	Standard Deviation
SWOT	Analysis of Strengths, Weaknesses, Opportunities and Threats
t	ton (1000 kg)
ton	1000 kg
TOFA	Tall oil fatty acids

TOR	Tall oil rosin
TRL	Technology Readiness Level
UI	Uncertainty Indicator (indicating reliability of data as developed within the context of this report)
USD	United States Dollar
VOC	Volatile Organic Compounds
a	Annum or year

List of figures

Figure 1. Feedstock use and land use for EU production of the 10 categories of bio-based products (product categories are ordered by bio-based production, from the largest to the smallest) 8

Figure 2. CAGR of the 10 bio-based chemical product categories compared with bio-based production 9

Figure 3. Value chain description for the platform chemical ethylene glycol 29

Figure 4. Land use (hectares per tonne of bio-based product) 60

Figure 5. Feedstock use and land use for EU production of the 10 categories of bio-based products (product categories are ordered by bio-based production, from the largest to the smallest) 64

Figure 6. CAGR of the 10 bio-based chemical product categories compared with bio-based production 66

List of tables

Table 1: Estimates of total EU production, the bio-based share of production and the consumption of bio-based products for each category 5

Table 2: Prices and turnover figures for bio-based products aggregated to product category level 6

Table 3: Feedstock and land use for EU production of bio-based products at product category level 7

Table 4: Predicted EU bio-based production and private investment in 2025 8

Table 5: EU import dependence, importance of the EU and top three most important Member States at product category level 10

Table 6: List of 10 product application categories 15

Table 7: The 20 products selected for value chain description 18

Table 8: Selection of 50 bio-based products listed by product category 22

Table 9: Relevance of Prodcom and CN classifications for the investigated dedicated and drop-in bio-based products 25

Table 10: Distribution of UIs by market indicator for the 50 bio-based products. 28

Table 11: Production of bio-based products and their share of total production in the EU-28 30

Table 12: Estimates of total and bio-based EU production and the bio-based share of production for each product category 37

Table 13: Estimation of the average final consumer price of cosmetics and personal care products at product category level 39

Table 14: Price data on the 50 bio-based products investigated.............................42

Table 15: Turnover figures for bio-based products produced in the EU-28 (EUR million) 45

Table 16: Prices and turnover figures for bio-based products aggregated to product category level 47

Table 17: EU-28 consumption and net trade (import minus export) for 50 bio-based products 48

Table 18: The EU import dependence classification system applied 54

Table 19: Production, consumption and import dependence for bio-based products at product category level in kt/a 55

Table 20: Feedstock use of the 50 selected bio-based products 56

Table 21: Feedstock yields from commodity crops used for the production of bio-based products 59

Table 22: Feedstock categories and their import dependences 61

Table 23: Total feedstock use and feedstock imports for the EU production of bio-based products at product category level 63

Table 24: Land use of bio-based products at product category level........................63

Table 25: Estimation of the compound annual growth rate.....................................65

Table 26: Predicted EU bio-based production in 2025 66

Table 27: Estimates of private investment in bio-based production capacity for the 10 product categories in the period 2018-2025 68

Table 28: Criteria for determining the importance of the EU 69

Table 29: Top three most important Member States and the importance of the EU at product category level 71

Table 30: Maturity ratings for the bio-based product categories...............................72

Table 31: SWOT analysis of bio-based products at product category level 74

Table 32: Longlist of bio-based products 99

Table 33: Correspondence of the 50 analysed products with CN2016 and Prodcom codes and the ten categories of the study. 103

Table 34: Overview of described value chains per product category 106

Annexes

Annex 1: Longlist of bio-based products

The longlist of 350 bio-based products is presented in Table 32.

Table 32: Longlist of bio-based products

Platform chemicals	***Platform chemicals continued***
Acetaldehyde	Mannose
Acetic acid	Methacrylic esters
Acetic anhydride	Methane
Acetoin	Methanol
Acetone	Octadecanedioic acid (1,18-)
Alkanes (iso-)	Octanol (2-)
Aminoundecanoic acid (11-)	Oleic acid
Ammonia	Oxalic acid
Arabinose	Palmitic acid (aka hexadecanoic acid)
Arabitol	Pelargonic acid (aka nonanoic acid)
Azelaic acid (aka nonanedioic acid)	Pentanediamine (1,5-)
Bio-'naphtha'	Propane
Bio-syngas	Propanediol (1,3-)
Butanediol (1,2-)	Propylene glycol (aka 1,2-propanediol)
Butanediol (2,3-)	Ricinoleic acid (aka 12-Hydroxyoctadec-9-enoic acid)
Butanol (iso-)	Sebacic acid (aka decanedioic acid)
Butanol (n-)	Sorbose
C10+ olefins	Starch
Capric acid (aka decanoic acid)	Stearic acid (aka octadecanoic acid)
Caproic acid (aka hexanoic acid)	Stearylic alcohol (1-octadecanol)
Caprylic acid (aka octanoic acid)	Succinic acid
Cellulose	Tall Oil, Crude (CTO)
Cetostearyl alcohol	Tall Oil, Distillated (DTO)
Cetylic alcohol (palmityl alcohol)	Turpentine
Citric acid	Undecanoic acid (aka undecylic acid)
Docosahexaenoic acid	
Epichlorohydrin	
Ethanol	**Solvents**
Ethyl acetate	Acetic acid
Ethyl lactate	Acetone
Ethylene	Alkanes (iso-)
Ethylene chloride (aka vinyl chloride)	Butanediol (1,2-)
Ethylene glycol	Butanol (iso-)
Ethylene oxide	Butanol (n-)
Farnesene	C10+ olefins
Fatty alcohols	Ethanol
Fatty amines	Ethyl acetate
Fructose	Ethyl lactate
Furfural	Ethylene glycol
Furfuryl alcohol	Furfural
Glucose	Furfuryl alcohol
Glutamic acid / Monosodium glutamate	Glycerol
Glycerol	Glycerol carbonate
Glycerol carbonate	Heptanol
Heptanoic acid (aka enanthic acid)	Lactate esters
Heptanol	Limonene
Isosorbide	Methanol
Itaconic acid	Octanol (2-)
Kojic acid	Poly(ethylene glycol) - PEG
Lactic acid	Propanediol (1,3-)
Lactide	Propylene glycol (aka 1,2-propanediol)
Lauric acid (aka dodecanoic acid)	Turpentine
Lauryl alcohol	
Levulinic acid	

Surfactants	***Paints, coatings, inks and dyes continued***
Alkyl polyglucosides (APG)	Carboxymethyl cellulose
Alkyl polypentosides (C5-surfactants)	Cellulose acetate
Alkyl-glycosides (from monosaccharide)	Cellulose ethers
Capric acid (aka decanoic acid)	Chitin/Chitosan
Caproic acid (aka hexanoic acid)	Ethoxylated fatty alcohols
Caprylic acid (aka octanoic acid)	Ethyl acetate
Carboxy methyl starch	Ethyl lactate
Carboxymethyl cellulose	Ethylene glycol
Cellulose ethers	Farnesene
Cetostearyl alcohol	Fatty alcohols
Cetylic alcohol (palmityl alcohol)	Indigo
Docosahexaenoic acid	Lactate esters
Enzymes	Lecithin
Esterquats	Lignin
Ethoxylated fatty alcohols	Lignin polymers functionalized
Ethylene diamine disuccinate	Methacrylic esters
Ethylene oxide	Octadecanedioic acid (1,18-)
Farnesene	Octanol (2-)
Fatty acid PEG esters (e.g. polyoxyethylene oleate)	Oxalic acid
Fatty alcohols	Poly(ethylene glycol) - PEG
Fatty amines	Poly(urethane) - PUR
Glycolipids	Ricinoleic acid (aka 12-Hydroxyoctadec-9-enoic acid)
Heptanoic acid (aka enanthic acid)	Rosin
Lauric acid (aka dodecanoic acid)	Scleroglucan
Lauryl alcohol	Tall Oil Fatty Acids (TOFA)
Lecithin	Tall Oil Rosin (TOR)
Lignin	Turpentine
Lipopeptides	Zeaxanthin
Octadecanedioic acid (1,18-)	
Oleic acid	
Oxalic acid	**Polymers for plastics**
Palmitic acid (aka hexadecanoic acid)	Alkyd resins
Pelargonic acid (aka nonanoic acid)	Carboxy methyl starch
Poly(ethylene glycol) - PEG	Carboxymethyl cellulose
Ricinoleic acid (aka 12-Hydroxyoctadec-9-enoic acid)	Cellulose
Rosin	Cellulose acetate
Sophorolipids	Cellulose esters
Sorbitan esters	Cellulose ethers
Starch (alkylated)	Chitin/Chitosan
Stearic acid (aka octadecanoic acid)	Epoxy resins
Stearylic alcohol (1-octadecanol)	Ethylene Propylene Diene Monomer (EPDM) rubber
Tall Oil Fatty Acids (TOFA)	Guayule
Undecanoic acid (aka undecylic acid)	Lignin
	Lignin polymers functionalized
	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) - PHBV
Paints, coatings, inks and dyes	Poly(amide-10,10) - nylon-10,10
Acetone	Poly(amide-10,12) - nylon-10,12
Alginate	Poly(amide-11) - nylon-11
Alkyd resins	Poly(amide-4,10) - nylon-4,10
Azelaic acid (aka nonanedioic acid)	Poly(amide-4,6) - nylon-5,6
Beta-carotene	Poly(amide-5,10) - nylon-5,10
Butanol (iso-)	Poly(amide-6,10) - nylon-6,10
Butanol (n-)	Poly(butylene adipate-co-terephthalate) - PBAT
Carboxy methyl starch	Poly(butylene succinate) - PBS

Polymers for plastics continued	***Cosmetics and personal care products cont.***
Poly(butylene succinate-co-adipate) - PBSA	Lauric acid (aka dodecanoic acid)
Poly(ethylene glycol) - PEG	Lauryl alcohol
Poly(ethylene terephthalate) - PET	Lecithin
Poly(ethylene) - PE	Leucine
Poly(hydroxyalkanoates) - PHA	L-Hydroxyphenylalanine (aka tyrosine)
Poly(hydroxybutyrate) - PHB	Limonene
Poly(lactic acid) - PLA	Lipopeptides
Poly(methacrylate)s	Lysine
Poly(trimethylene terephthalate) - PTT	Mannose
Poly(urethane) - PUR	Methionine
Pullulan	N-acetyl glucosamine
Rayon	Octadecanedioic acid (1,18-)
Starch	Octanol (2-)
Starch (alkylated)	Oleic acid
	Pantothenic acid (aka Vit B5)
	Phenylalanine
Cosmetics and personal care products	Phospholipids
Acetoin	Poly(ethylene glycol) - PEG
Acetone	Proline
Alanine	Propanediol (1,3-)
Arabinogalactan	Ricinoleic acid (aka 12-Hydroxyoctadec-9-enoic acid)
Arginine	Scleroglucan
Ascorbic acid (aka vitamin C)	Sebacic acid (aka decanedioic acid)
Aspartic acid	Serine
Astaxanthine	Squalene
Biotin (aka vitamin B7)	Starch
Butanediol (1,2-)	Stearylic alcohol (1-octadecanol)
Butanol (n-)	Terpenes
Carboxymethyl cellulose	Threonine
Cellulose ethers	Trypthophan
Cetostearyl alcohol	Valine
Cetylic alcohol (palmityl alcohol)	Vanillin
Chondroitin	Vitamin A
Coenzyme Q10 (ubiquinone)	Vitamin B12
Dextran	Vitamin B2
Dihydroxyacetone	Vitamin B3
Ethoxylated fatty alcohols	Xanthan
Ethyl lactate	Xylitol
Ethylene diamine disuccinate	
Eugenol	
Fatty acid PEG esters (e.g. polyoxyethylene oleate)	**Plasticisers (and stabilisers for rubber and plastics)**
Fatty alcohols	Azelaic acid (aka nonanedioic acid)
Fatty amines	Carboxymethyl cellulose
Gelatin	Epoxydised soybean oil (ESBO)
Glutamic acid / Monosodium glutamate	Ethoxylated fatty alcohols
Glutamine	Farnesene
Glycerol	Isosorbide
Heptanol	Lignin polymers functionalized
Histidine	Polyols (Agrol)
Hyaluronic acid	Sebacic acid (aka decanedioic acid)
Isoleucine	Succinic acid
Kojic acid	
Lactamide	
Lactoferrin (proteins)	

ADHESIVES	***Lubricants cont.***
Acetone	Stearic acid (aka octadecanoic acid)
Butanol (n-)	Tall Oil Pitch (TOP)
Carboxy methyl starch	Undecanoic acid (aka undecylic acid)
Carboxymethyl cellulose	Xanthan
Epoxy resins	
Ethyl acetate	
Ethyl lactate	**FIBRES**
Farnesene	Carboxy methyl starch
Furfuryl alcohol	Carboxymethyl cellulose
Gelatin	Cellulose
Lactate esters	Cellulose acetate
Lignin polymers functionalized	Cellulose esters
Methacrylic esters	Cellulose ethers
Octanol (2-)	Epoxy resins
Poly(ethylene glycol) - PEG	Poly(amide-10,10) - nylon-10,10
Poly(methacrylate)s	Poly(amide-10,12) - nylon-10,12
Poly(urethane) - PUR	Poly(amide-11) - nylon-11
Rosin	Poly(amide-4,10) - nylon-4,10
Scleroglucan	Poly(amide-4,6) - nylon-5,6
Starch	Poly(amide-5,10) - nylon-5,10
Tall Oil Fatty Acids (TOFA)	Poly(amide-6,10) - nylon-6,10
Tall Oil Rosin (TOR)	Poly(butylene adipate-co-terephthalate) - PBAT
	Poly(butylene succinate) - PBS
	Poly(ethylene terephthalate) - PET
Lubricants	Poly(ethylene) - PE
Alkanes (iso-)	Poly(hydroxyalkanoates) - PHA
Azelaic acid (aka nonanedioic acid)	Poly(hydroxybutyrate) - PHB
Base oil (oil used for lubricant, Ref134)	Poly(lactic acid) - PLA
Butanol (n-)	Poly(methacrylate)s
C10+ olefins	Poly(trimethylene terephthalate) - PTT
Capric acid (aka decanoic acid)	Poly(urethane) - PUR
Caproic acid (aka hexanoic acid)	Rayon
Caprylic acid (aka octanoic acid)	Starch (alkylated)
Carboxymethyl cellulose	
Cellulose ethers	
Cetylic alcohol (palmityl alcohol)	
Chitin/Chitosan	
Docosahexaenoic acid	
Ethylene oxide	
Farnesene	
Fatty acid methyl esters (e.g. methyl palmitate)	
Fatty acid PEG esters (e.g. polyoxyethylene oleate)	
Fatty alcohols	
Heptanoic acid (aka enanthic acid)	
Lauric acid (aka dodecanoic acid)	
Lauryl alcohol	
Lecithin	
Octadecanedioic acid (1,18-)	
Octanol (2-)	
Oleic acid	
Palmitic acid (aka hexadecanoic acid)	
Pelargonic acid (aka nonanoic acid)	
Poly(ethylene glycol) - PEG	
Sebacic acid (aka decanedioic acid)	

Annex 2: Correspondence of the 50 selected bio-based products with CN2016, Prodcom and the ten categories

Table 33 provides the CN2016 and Prodcom correspondence table for the 50 selected bio-based products and the indication of the categories to which each product belongs. The method for collection of statistical data is described in more detail in section 2.5.2.

Table 33: Correspondence of the 50 analysed products with CN2016 and Prodcom codes and the ten categories of the study.

Product	**CN2016**	**CN 2016 Relevance**	**Prodcom**	**Prodcom relevance**	**Drop-in/dedicated**	Platf Chem	Solv	Polym	Paint	Surf	Cosm	Adhes	Lubr	Plast	Man-m	Other
Ethylene	2901 21 00	high	20141130	high	drop-in	x										
Ethylene glycol	2905 31 00	high	20142310	high	drop-in	x	x		x							x*
Propylene glycol (aka 1,2-propanediol)	2905 32 00	high	20142320	high	drop-in	x	x									
Propanediol (1,3-)	2905 39 28	low	20142337	low	drop-in	x	x				x					
Acetic acid	2915 21 00	high	20143271	high	drop-in	x	x									
Acetic anhydride	2915 24 00	high	20143277	high	drop-in	x										
Sebacic acid (aka decanedioic acid)	2917 13 10	high	20143381	low	dedicated	x					x		x	x		
Lactic acid	2918 11 00	medium	20143475	low	dedicated	x										
Epichlorohydrin	2910 30 00	high	20146379	low	drop-in	x										
Butanol (iso-)	2905 14 90	medium	20142240	high	drop-in	x	x		x							
Ethyl acetate	2915 31 00	high	20143215	high	drop-in	x	x		x			x				
Ethyl lactate	2918 11 00	medium	20143475	low	dedicated	x	x		x		x	x				
Acetone	2914 11 00	high	20146211	high	drop-in	x	x		x		x	x				
Wood turpentine	3805 10 30	high	20147140	low	dedicated	x	x		x							
Poly(ethylene) - PE	3901 10 10	high	20161035	high	drop-in			x							x	
Poly(ethylene terephthalate) - PET	3907 60 20	high	20164062	high	drop-in			x							x	
Starch used for plastics	3505 10	high	10621170	medium	dedicated			x								
Poly(hydroxyalkanoate) - PHA	3907 99 90	low	20164090	low	dedicated			x							x	
Poly(lactic acid) - PLA	3907 70 00	high	20164090	low	dedicated			x							x	

Ricinoleic acid (aka 12-Hydroxyoctadec-9-enoic acid)	2918 19 98	low	20143475	low	dedicated	x			x	x	x					
Poly(urethane) - PUR	3909 50 90	high	20165670	high	drop-in			x	x			x			x	
Alkyd resins	3907 50 00	high	20164050	medium	dedicated			x	x							
Glycolipids (other than sophorolipids)	3913 90 00	low	20165960	low	dedicated					x						
Esterquats	3402 12 00	low	20412030	low	dedicated					x						
Sophorolipids	3402 19 00	low	20412090	low	dedicated					x						
Alkyl polyglucosides (APG)	3402 13 00	low	20412050	low	dedicated					x						
Carboxy methyl starch	3913 90 00	low	20165960	low	dedicated			x	x	x		x			x	
Limonene	2902 19 00	low	20141215	low	dedicated		x				x					
Lauryl alcohol	2905 17 00	medium	20142265	low	drop-in	x				x	x		x			
Stearylic alcohol (1-octadecanol)	2905 17 00	medium	20142265	low	drop-in	x				x	x					
Vanillin	2912 41 00	high	20146135	low	drop-in						x					x**
Xanthan	3913 90 00	low	20165960	low	dedicated						x		x			
Ethoxylated fatty alcohols	3402 13 00	low	20412050	medium	drop-in				x	x	x			X		
N-acetyl glucosamine	2924 19 00	low	21102060	low	dedicated						x					
Methacrylates	3906 90 90	low	20165390	low	drop-in			x				x			x	
Furfuryl alcohol	2932 13 00	medium	20145215	medium	dedicated	x	x					x				
Epoxy resins	3907 30 00	high	20164030	medium	drop-in			x				x			x	
Tall Oil Rosin (TOR)	3806 10 00	medium	20147150	medium	dedicated				x			x				
Alkanes (iso-)	2901 10 00	high	20141120	high	drop-in	x	x						x			
Tall Oil Fatty Acids (TOFA)	3806 10 00	medium	20147150	medium	dedicated								x			
Fatty acid methyl esters (e.g. methyl palmitate, stearate, laurate)	1518 00 91	low	20592000	low	dedicated								x			x***
Fatty acid PEG esters (e.g. poly(oxyethylene oleate), palmitate)	1518 00 91	low	20592000	low	dedicated					x	x		x			
Azelaic acid (aka nonanedioic acid)	2917 13 90	medium	20143381	low	dedicated	x			x				x	x		

Succinic acid	2917 19 20	high	20143381	low	drop-in	x								x		
Epoxydised soybean oil (ESBO)	1518 00 91	low	20592000	low	dedicated									x		
Poly(trimethylene terephthalate) - PTT	3907 91 90	low	20164080	low	drop-in			x							x	
Rayon	5502 00 10	high	20602120	high	dedicated										x	
Poly(amide-11) - nylon-11	3908 10 00	low	20165450	medium	dedicated			x							x	
Poly(amide-4,10) - nylon-4,10	3908 90 00	low	20165490	low	dedicated			x							x	
Cellulose acetate	5502 00 40	high	20602140	high	dedicated			x	x						x	

Platf = Chem Platform chemicals; Solv = Solvents; Polym = Polymers for plastics; Paint = Paints, coatings, inks and dyes; Surf = Surfactants; Cosm = Cosmetics and personal care product; Adhes = Adhesives; Lubr = Lubricants; Plast = Plasticisers; Man-m = Man-made fibres.
x* = heat transfer liquid / antifreeze; x** = food; x*** = biodiesel.

Annex 3: Value chain descriptions

As illustration of the ten selected bio-based product categories, the value chains and application sectors have been described by giving two specific examples of bio-based products per product category and describing a typical value chain for each example, from feedstock (e.g. sugar), via bio-based intermediate and/or product (e.g. bio-based polybutylene succinate) to final product (e.g. food packaging). The following value chains are presented in this Annex.

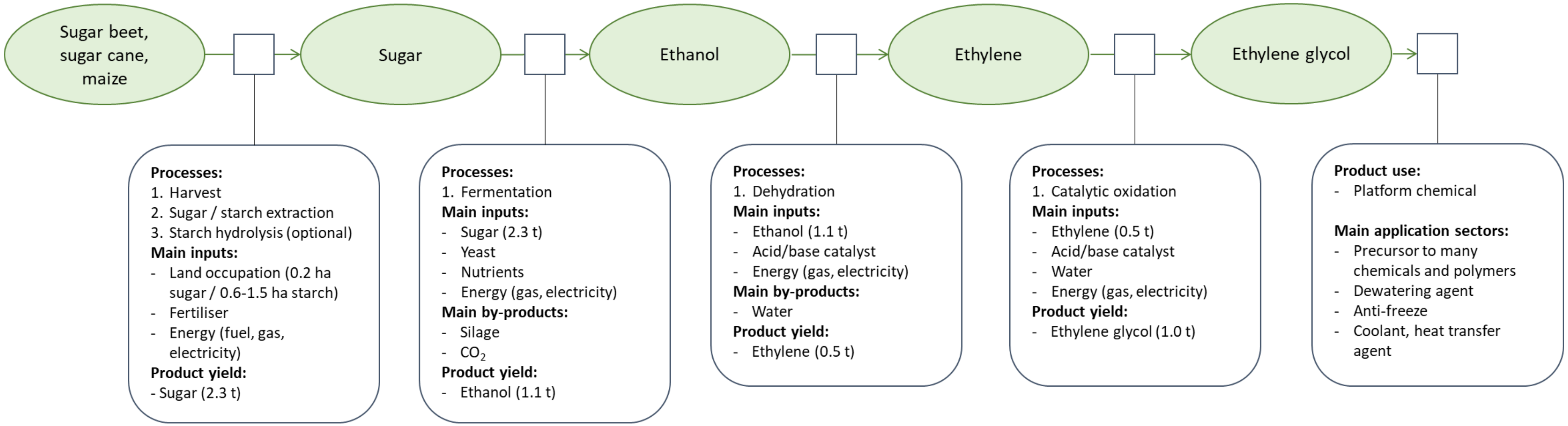
Table 34: Overview of described value chains per product category

Product category	Value chain 1	Value chain 2
Platform chemicals	Ethylene glycol	Acetic anhydride
Solvents	Ethyl lactate	Wood turpentine
Polymers for plastics	Poly(ethylene terephthalate) (PET)	Poly(hydroxyalkanoate) (PHA)
Paints, coatings, inks and dyes	Alkyd resins	Polyurethane
Surfactants	Esterquats	Carboxymethyl starch
Cosmetics and personal care products	Xantan gum	N-acetylglucosamine
Adhesives	Furfuryl alcohol	Expoxy resins
Lubricants	Methyl palmitate	Poly(oxyethylene oleate)
Plasticisers (and stabilisers for rubber and plastics)	Epoxylated soybean oil (ESBO)	Succinic acid
Man-made fibres	Polyamide-11	Poly(trimethylterphthalate) (PTT)

The value chains are described in a schematic way. Indicative numbers of feedstock and intermediate products in the value chain are added and related to one tonne of product. Furthermore, for each value chain, the following topics are briefly described:

- Product description
- Production process
- Product properties
- Applications
- Market
- Used data sources.

Organic platform chemicals – ethylene glycol



Product description

Ethylene glycol is a platform chemical with a broad range of applications. The colourless, odourless liquid is of hygroscopic nature. Ethylene glycol was synthesised first in 1859 by Wurtz. The commercial production started, then via ethylene chlorohydrin, in 1925.

Production process

Several bio-based routes for ethylene glycol exist with the most important production proceeding via ethylene produced from ethanol. In this route, sugars are fermented to produce ethanol. The ethanol is then chemically converted to ethylene glycol in a pathway that proceeds via ethylene and ethylene oxide. More direct routes to produce bio-based ethylene glycol from sugars are currently being developed, but have not yet reached TRL 8. They could use for example a hydrogenolysis of xylitol, sorbitol or glycerol.

Product properties

Ethylene glycol, ethane-1,2-diol or monoethylene glycol (MEG) is a sweet, colourless liquid. The other varieties of ethylene glycols, diethylene and triethylene, are less common with 90% of the market being MEG.

Applications

Ethylene glycol is a typical platform chemical that can be used as a precursor for many compounds in many fields, such as dyes, polymers, fibres, automotive, pesticides, cleaners, preserving agents, and wood treatment. Next to this, it can directly be used as dewatering agent, coolant, heat transfer agent, or anti-freeze.

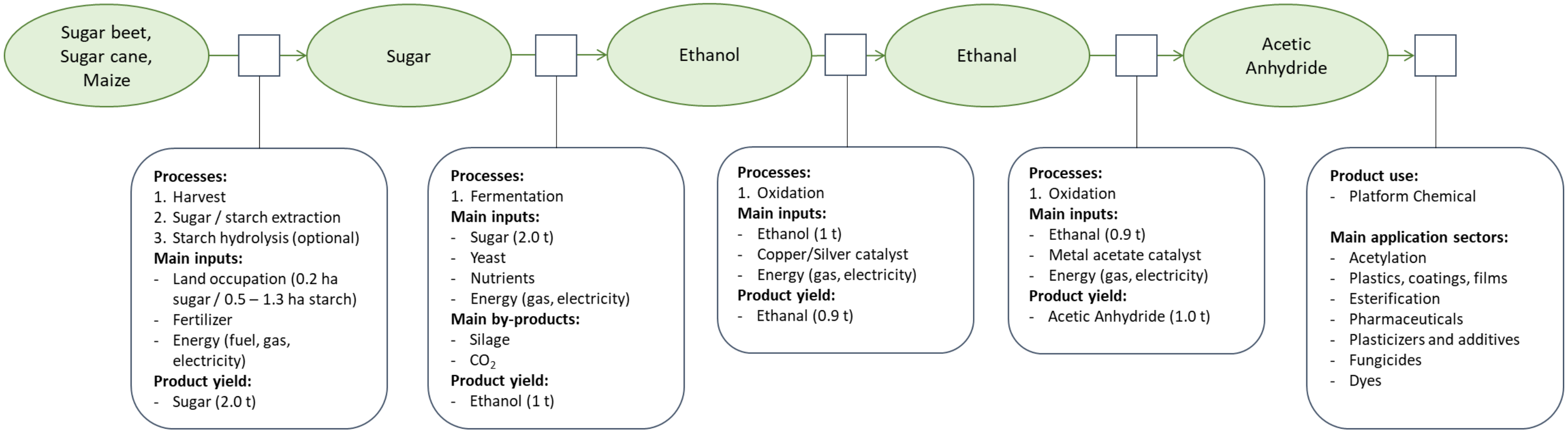
Market

The world market for ethylene glycol is dominated by SABIC with 28% of the market share. Other major players are DOW, Sinopec and Shell. The world market for bio-based ethylene glycol is large, with prospects of 3 million ton bio-based MEG produced in 2020.

Data sources

- Gilbert, R. (2001) Ethylene glycol, Online course http://natasha.eng.usf.edu/gilbert/courses/modelandanalysis/portfolios_2001/1_project_1/alupoaei_ethylene_glycol.pdf
- https://www.grandviewresearch.com/industry-analysis/ethylene-glycols-industry
- https://www.avantium.com/renewable-chemistries/mekong/
- Harmsen, P., Hackmann, M. (2013), 'Green building blocks for bio-based plastics'
- IfBB (2016) "Biopolymer facts and statistics 2016", https://www.bio-pro.de/index.php/download_file/16018/9152/

Organic platform chemicals: acetic anhydride



Product description

Acetic Anhydride is the anhydride of acetic acid. In contact with water acetic anhydride will break down to acetic acid. In laboratories it is often used as such, however in industry its applications are focused on the properties of the anhydride itself.

Production process

Acetic anhydride production starts at the production of ethanol from sugar. Ethanol is then oxidised to ethanal (acetaldehyde) with yields typically between 97 and 99 %. The oxidation uses a catalyst to prevent overoxidation of the product, this catalyst is commonly an alloy or oxide of copper and/or silver. Ethanal and unconverted alcohol are separated by washing the waste gas with alcohol and by distillation. Ethanal is then converted to acetic anhydride by atmospheric oxidation using a metal acetate as catalyst.

Product properties

Acetic anhydride is a colourless liquid with a pungent smell that has many uses as a platform chemical. Its acetyl group gives the molecule a key reactive site that is exploited in the synthesis routes of many products, ranging from acetylating cellulose and coatings to the production of aspirin.

Applications

Main uses of acetic anhydride as platform chemical are:

- Acetylation of cellulose
- Production of plastics, coatings and films
- Esterification of alcohols
- Synthesis of pharmaceuticals
- Synthesis of plasticisers and additives
- Solvent for fungicides and dyes

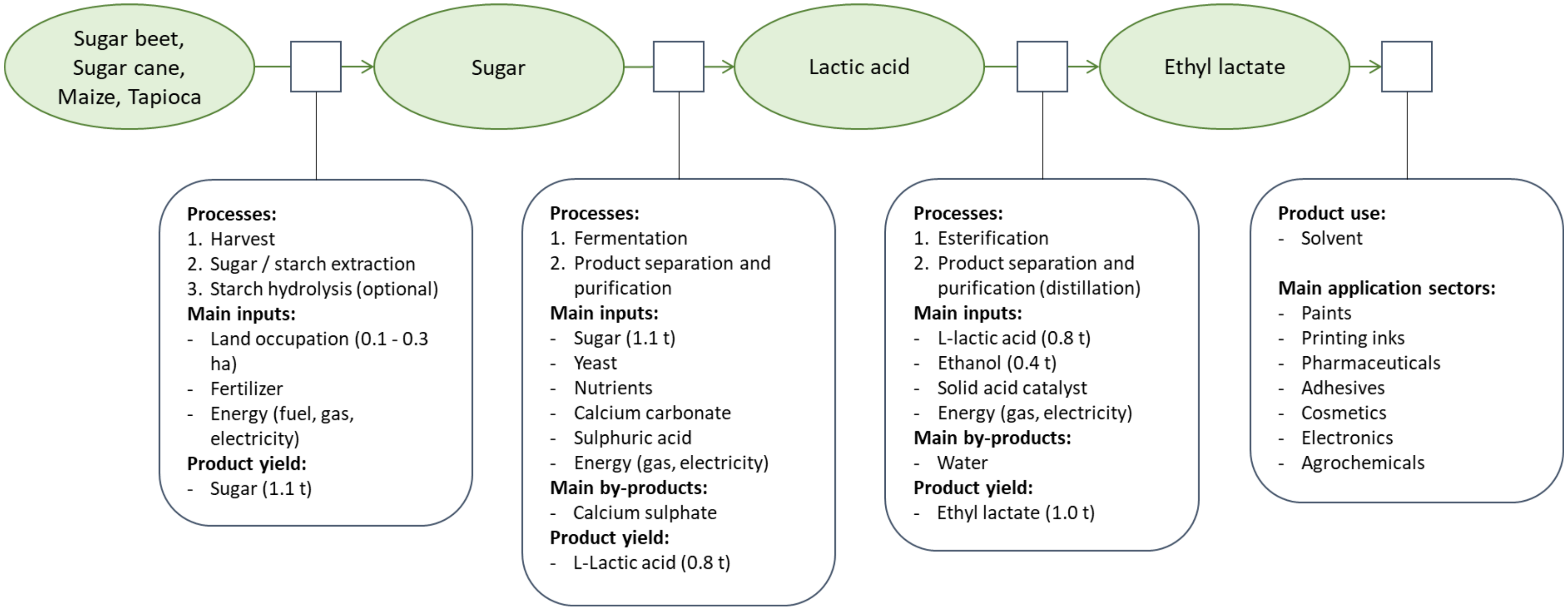
Market

Bio-based acetic anhydride is mainly produced by the Swedish company SEKAB from ethanal. Another potential pathway is to produce acetic anhydride from acetic acid. The main players for the production of bio-based acetic acid are Celanese, Jubilant Lifescience, Sekab, and Songyuan Ji'an Biochemical.

Data sources

- Celanese, (2013), 'Acetic Anhydride'
- Cheminfo Services, (2014), 'Bio based chemical import replacement initiative, chemical markets and biochemical options for alberta.'
- E4Tech, (2015), 'From the Sugar Platform to biofuels and biochemicals'
- http://www.sekab.com
- IfBB (2016) "Biopolymer facts and statistics 2016", https://www.bio-pro.de/index.php/download_file/16018/9152/
- Ullman's Encyclopedia of Industrial Chemistry, (2012), 'Acetaldehyde', Wiley-VCH Verlag GmbH & Co

Solvents – ethyl lactate



Product description

Ethyl lactate is an ester of lactic acid and ethanol, which are both produced from biomass. Therefore ethyl lactate is a 100 % bio-based product. It is known as a non-toxic, biodegradable solvent that can replace common petroleum-derived solvents such an N-methylpyrrolidone and toluene.

Production process

The first step in the production process of ethyl lactate is the harvest of the biomass (e.g. sugarcane, maize, tapioca, etc.), followed by the extraction of sugar (or extraction of starch and its conversion to glucose). The sugar is subsequently converted to L-lactic acid via microbial anaerobic fermentation. Which microorganism is used depends on which type of sugar is used as feedstock. During the fermentation process calcium carbonate is continuously added to keep the pH constant, around 6. The resulting product is calcium lactate. In the purification section calcium lactate is first converted into lactic acid before further purification. This conversion is typically done with sulphuric acid, resulting in the formation of calcium sulphate (gypsum) as a by-product. The purified lactic acid is converted to ethyl lactate via a catalytic esterification process with ethanol, typically using a solid acid catalyst. The main by-product of this reaction is water, the ethyl lactate is purified by distillation.

Product properties

Ethyl lactate has many attractive characteristics that translate into environmental benefits and performance advantages. It is 100%-biodegradable and breaks down into carbon dioxide and water. It is easy and inexpensive to recycle. It is non-corrosive, non-carcinogenic and non-ozone depleting. There are no oral or inhalation toxicity problems. It has no environmentally hazardous ingredients and is fully bio-based. And because it evaporates slowly, it is considered a very low volatility VOC.

Applications

Main applications of ethyl lactate are as a solvent in: paints and inks, pharmaceuticals, adhesives, cosmetics, electronics and agrochemicals.

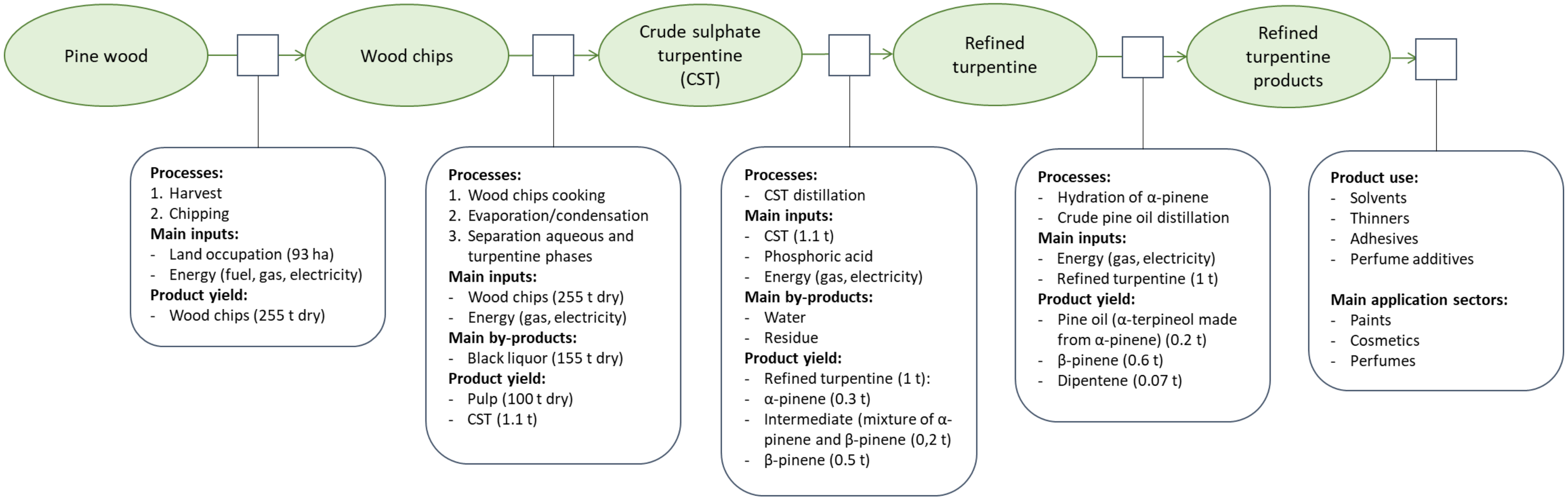
Market

Estimated prices for ethyl lactate in the USA are 3-4 $/kg and they are expected to be able to compete with 2 $/kg solvents. Currently in the USA there are 3 production facilities, by ADM, Galactic and Cargill Dow. Galactic has a 15 kta facility.

Data sources

- M.J. Biddy, C. Scarlata, C. Kinchin, "Chemicals from biomass: a market assessment of bioproducts with near-term potential", *NREL report* 2016
- J.B. Dunn, F. Adom, N. Sather, J. Han, S. Snyder, "Life-cycle Analysis of Bioproducts and Their Conventional Counterparts in GREET™", *Argonne report* 2015
- C.S.M. Pereira, V.M.T.M. Silva, A.E. Rodrigues, "Ethyl lactate as a solvent: Properties, applications and production processes – a review", *Green chemistry* 2011, 13, 2658

Solvents - wood turpentine



Product description

Wood turpentine is an oil obtained from pine trees, and is different from the mineral turpentine that can be bought in the supermarket. It can be obtained as by-product from Kraft pulping (sulphate turpentine) or obtained from live trees, mainly pines (gum turpentine). As gum turpentine production is very labour intensive, in Europe sulphate turpentine production is dominant.

Production process

Crude sulphate turpentine (CST) is obtained as a by-product at sulphate cooking of cellulose. Volatile matters in wood of softwood species that are distilled off with water vapour. The CST can be distilled into "heads" (volatile compounds with no commercial value), and α - and β-pinene. Of these, β-pinene can be sold as is and α-pinene can be further processed to make pine oil by reacting it with phosphoric acid.

Product properties

Wood turpentine is a colourless, oily, odorous, flammable, water-immiscible liquid.

Applications

Crude sulphate turpentine is applied as a solvent; pine oil is used as a solvent, disinfectant and deodorant / perfume additive, and β-pinene is used to produce camphor and insecticides. Furthermore, wood turpentine and its derivatives are used as a raw material in the synthesis of resins, adhesives, flotators, oil additives, biologically active substances, and polymerisation activators.

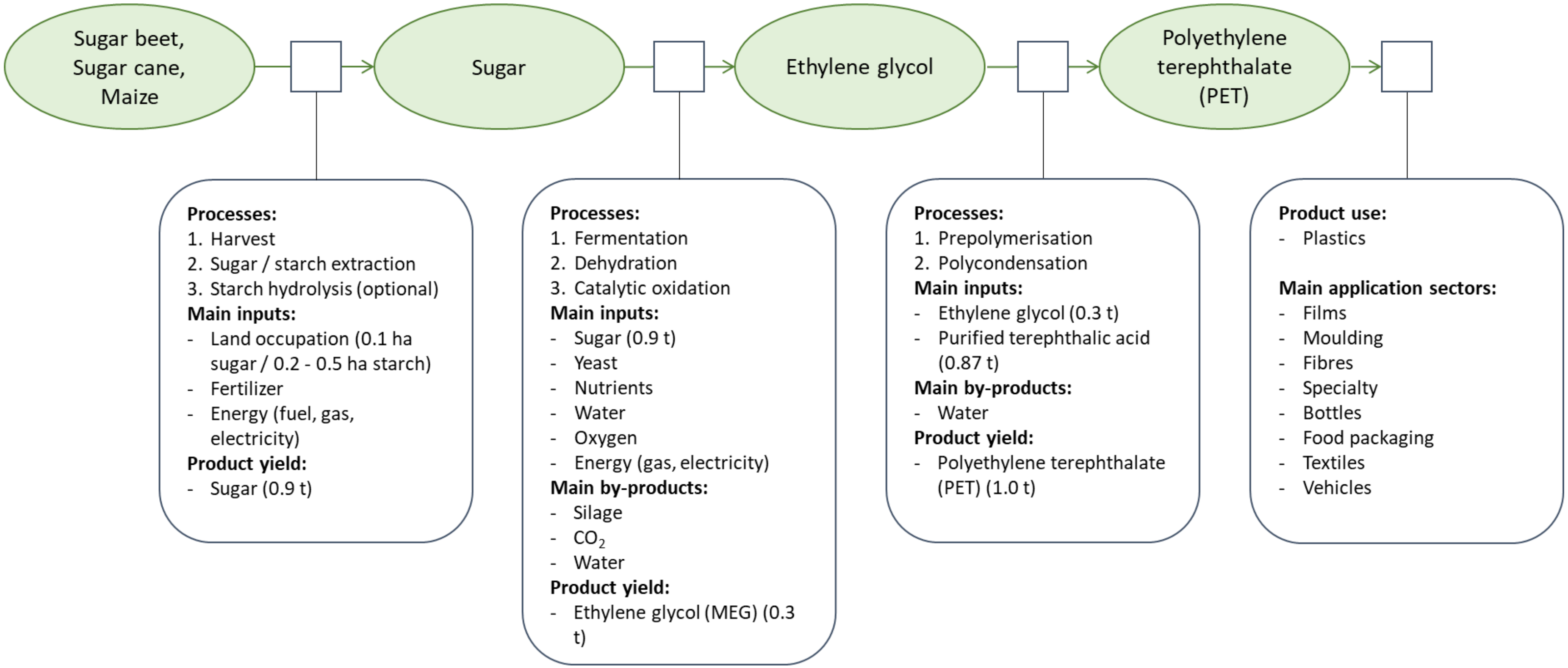
Market

The global production of wood turpentine is approximately 330.000 tonnes from all sources; almost 100.000 tonnes (30%) is estimated to be gum turpentine, and the bulk of the remainder is sulphate turpentine.

Data sources

- FAO (1995) Non-wood forest products 1, Flavours and fragances of plant origin, chapter 8: turpentine from pine resin. http://www.fao.org/docrep/v5350e/V5350e10.htm
- https://www.megaglori.com/what-is-turpentine/
- NZ Institute of Chemistry (2008) The forestry industry, Turpentine production and processing, https://nzic.org.nz/ChemProcesses/forestry/4F.pdf
- Pine Chemical Group (2017) Product data sheet – crude sulphate turpentine. http://www.pinechemicalgroup.fi/wp-content/uploads/2015/07/Product-Data-Sheet-CST.pdf
- Storaenso (2017) Tall oil and turpentine, http://biomaterials.storaenso.com/ProductsServices-Site/Pages/Tall-oil-and-Turpentine.aspx

Polymers for plastics - polyethylene terephthalate (PET)



Product description

Bio-based polyethylene terephthalate (PET) is a drop-in chemical that directly replaces fossil based PET. PET is made of an ethylene glycol and terephthalic acid moiety. Currently, only the ethylene glycol part is bio-based, resulting in a 30% bio-based material. Bio-based terephthalic acid can be made, but has not yet been commercialised.

Production process

Bio-based PET is made of bio-based ethylene glycol which is polymerised with terephthalic acid. The production of bio-based terephthalic acid has not yet reached TRL 8, which is why fossil-based terephthalic acid is currently used, resulting in 30% bio-based PET. The polymerisation step of ethylene glycol and terephthalic acid commonly proceeds in two steps. In the first step, low molecular weight PET is obtained from ethylene glycol and terephthalic acid. In a second reactor a large vapour-liquid surface area results in high molecular weight PET. This second step has a short reaction time to prevent the formation of side products.

Product properties

PET is plastic that is widely used for packaging material. It is a direct replacement of fossil based PET as a drop-in chemical and is therefore not compostable. Because it is molecular identical, it can be recycled together with fossil based PET.

Applications

PET is a commonly used polymer for a range of applications including films, moulding application, fibres and specialty outlets. These result in use in bottles, food packaging, textiles and vehicles.

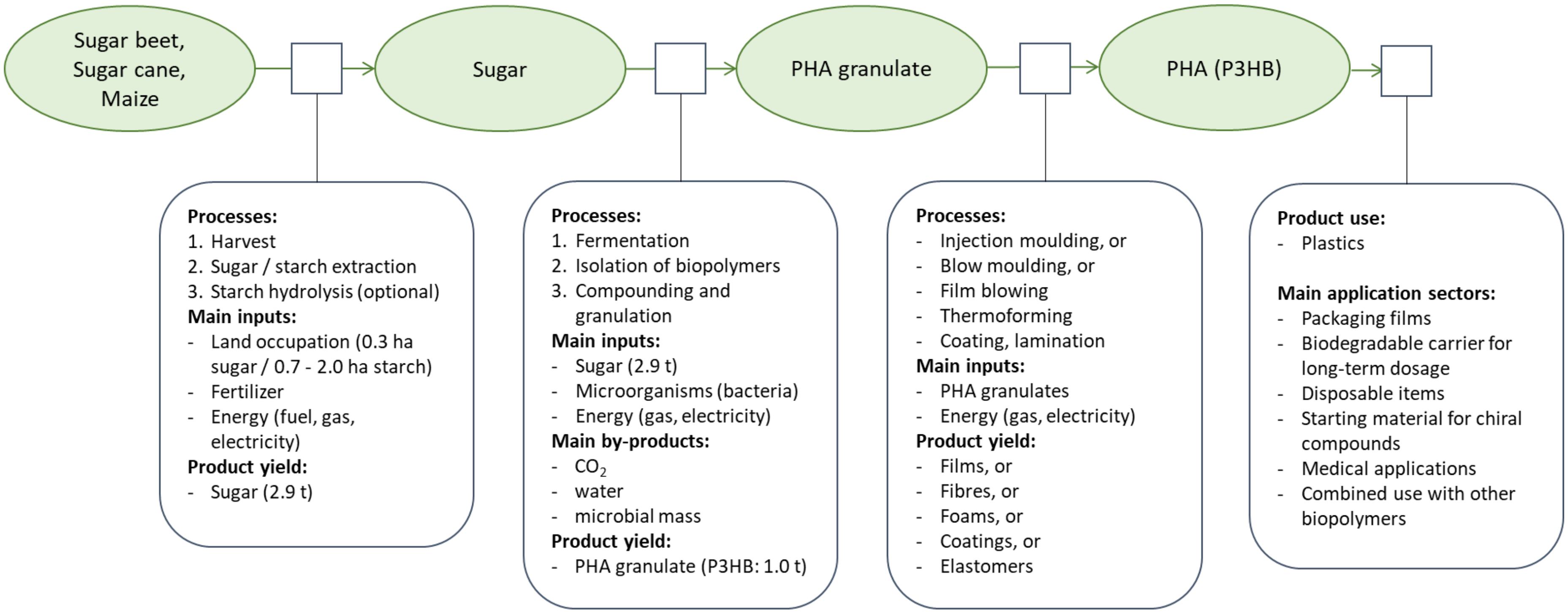
Market

Well-known examples of bio-based PET include the 'PlantBottle' from Coca Cola and Heinz, of which the technology is now also used by Ford for car seats. Bio-PET is produced mostly in Asia. Examples of companies that currently produce bio-PET are Teijin and Inorama Venture, which produce 100 kton per year and 300 kton per year respectively.

Data sources

- IfBB (2016), "Biopolymer facts and statistics 2016", https://www.bio-pro.de/index.php/download_file/16018/9152/
- http://www.coca-colacompany.com/stories/great-things-come-in-innovative-packaging-an-introduction-to-plantbottle-packaging
- Jogdand, S., (2015), 'Current status of bio-based chemicals'
- Kim, I.S., Woo, B.G., Choi, K.Y., Kiang, C., (2003), 'Two-Phase Model for Continuous Final-Stage Melt Polycondensation of Poly(ethylene terephthalate). III. Modeling of Multiple Reactors with Multiple Reaction Zones, J. Appl Pol. Sci., 90, 1088-1095

Polymers for plastics - Polyhydroxyalkanoate (PHA)



Product description

Polyhydroxyalkanoate (PHA) is a polymer produced by micro-organisms from fermentable biomass such as sugar, starch, vegetable oils and in the future possibly by biodegradable waste. The simplest PHA, called P3HB or just PHB appears in nature and can be regarded as the most important commercially available PHA. Also a few industrial companies started to develop other short chain length (scl) PHAs like P4HB, P3HB4HB and PHBV, and medium chain length (mcl) PHAs like PHBH and PHBO for large scale production and industrial applications.

Production process

The sugars are fermented with the support of micro-organisms. As opposed to most fermentations, the biopolymer accumulates within the cells of the micro-organisms. A production of 2.5 $gh^{-1}L^{-1}$ can be achieved with 80% biopolymer accumulation on dry weight basis. Subsequently the biopolymers need to be isolated from within the micro-organisms. This down-stream processing of the biopolymer is one of the bottlenecks of the process. The purified biopolymer is further processed by compounding and granulation steps.

Product properties

PHAs are compostable and biodegradable in anaerobic digestion plants, in soil and even in seawater. Its vapour barrier is comparable with those of polyolefins, which gives an advantage compared to other bio-based plastics. PHAs are not transparent, which can be a disadvantage in some packaging applications.

Applications

Main applications:

- Packaging films (for food packages), bags, containers, paper coatings.
- Biodegradable carrier for long-term dosage of drugs, medicines, insecticides, herbicides, insecticides or fertilizers.
- Disposable items such as razors, utensils, diapers, feminine hygiene products, cosmetics containers, shampoo bottles, cups etc.
- Starting material for chiral compounds.
- Medical applications – Surgical pins, sutures, staples, swabs, wound dressings, bone replacements & plates and blood vessel replacements, Stimulation of bone growth by piezoelectric properties.

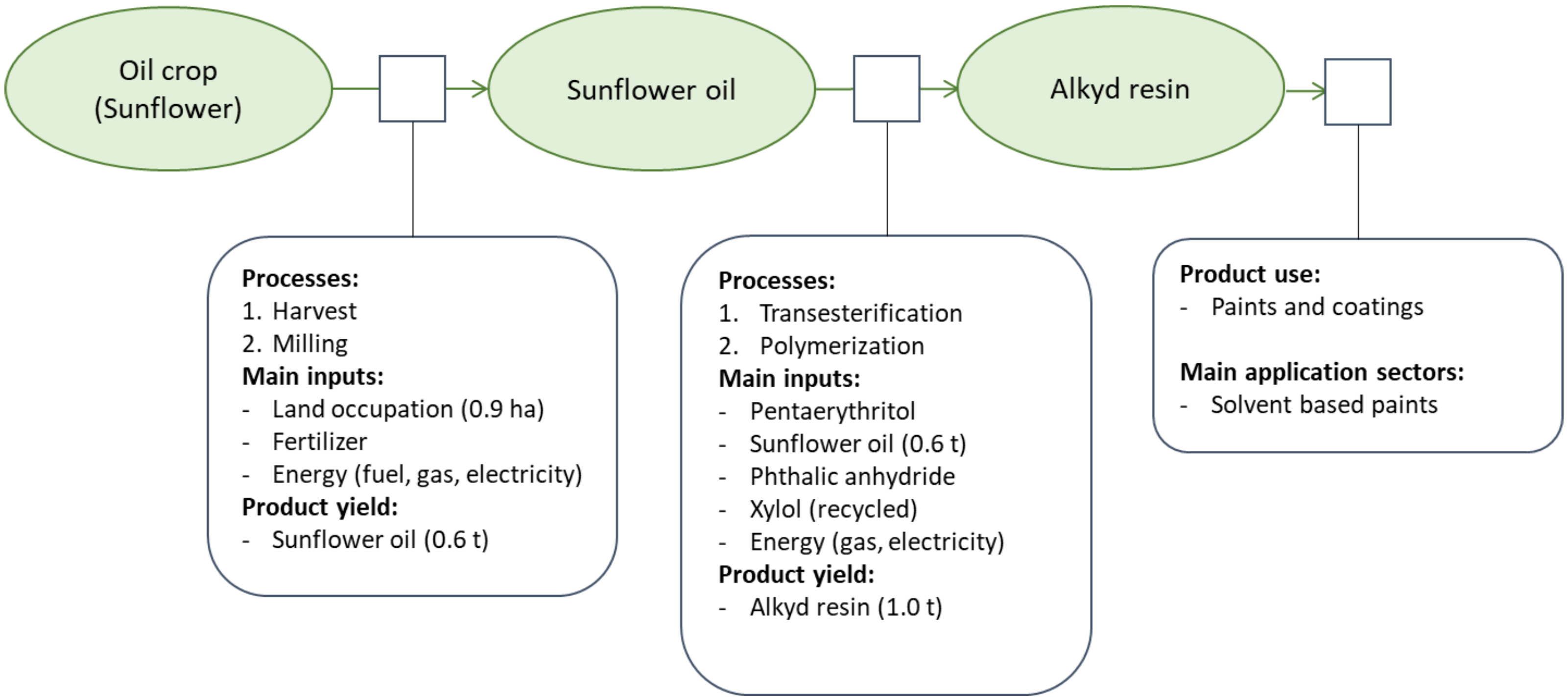
Market

The PHA market price in 2014 was € 3.8 - 5 per kg of biopolymer, in 2013 the total global market volume of sold product was only 1000 tonnes; but given the projections given by several companies, production volumes could now be higher. Currently the most important producers are Meredian, Kaneka and Newlight Technologies.

Data sources

- Chen, G. (2010) Industrial Production of PHA, Plastics from Bacteria: Natural Functions and Applications, Microbiology Monographs, Vol 14.
- http://bioplasticsinfo.com/polyhydroxy-alkonates/applications-of-pha-as-bioplastic/
- Kootstra, M., H. Elissen, S. Huurman (2017) PHA's (Polyhydroxyalkanoates): General information on structure and raw materials for their production, a running document for "kleinschalige bioraffinage WP9: PHA". ACRRES Application Centre for Renewable Resources, WUR.
- Ravensteijn, J. (2014) PHA …… Is it here to stay?, keynote presentation at KCPK meeting *Papier en PHA, a match made in heaven?*, kenniscentrum papier en karton, 8 May 2014.
- IfBB (2016) "Biopolymer facts and statistics 2016", https://www.bio-pro.de/index.php/download_file/16018/9152/

Paints, coatings, inks and dyes - Alkyd resins



Product description

Alkyd resins are created by introducing vegetable oil into the polyester production process. The alkyd resins are used in paints together with driers that promote the crosslinking of unsaturated fatty acid moieties in the resin with atmospheric oxygen. Common fatty acid sources are oil from coconut, linseed, safflower, soybean, sunflower, and tall oil.

Production process

Typically Pentaerythritol and vegetable oil are heated (up to 270 °C) to enable a transesterification reaction to mainly form monoesters of PE. After cooling to 150 °C, phthalic anhydride is added, and the alkyd resin is formed after an additional heating step (240 °C). The reaction can be monitored by viscosity and acidity measurements. The reaction is pushed to completion by removing the water with evaporation of the xylol used as solvent. The ratio starting materials chosen will influence the final product and the bio-based content, which ranges from 15 to 75%. A typical percentage of 60% vegetable oil was chosen for the value chain calculations.

Product properties

Alkyd resins are used in self-drying formulas where the vegetable oil moiety hardens by cross-linking. This process has been used for many years, but recently started to move to the use of less volatile components due to health issues. Alkyd resins are used in paints and primers that are available for professionals and on the do-it-yourself market.

Applications

Main applications are solvent based paints.

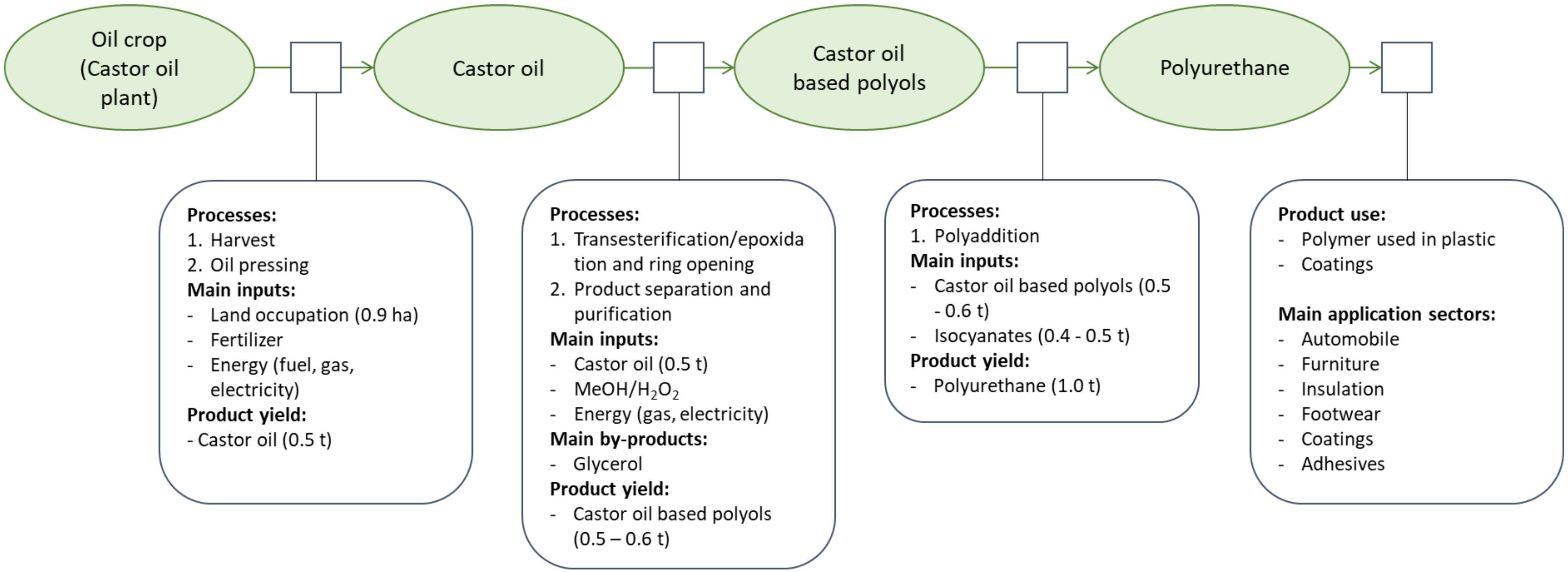
Market

The most important alkyd resin producer in Europe is Germany with a production of 190 kton in 2010. Other significant western European countries for the production of alkyd resins are Italy and France.

Data sources

- http://Allnex.com, 'coating resins renewable raw material'
- https://knowledge.ulprospector.com/3944/pc-basics-alkyd-resin-technology/
- https://www.coatingsworld.com/issues/2012-03/view_market-research/study-says-eu-alkyd-resins-market-slowing-down-880937/7908
- https://www.pcimag.com/articles/98699-bio-based-resin-technology-helping-define-high-performance
- NZ Institute of Chemistry (2002) Industrial resins, http://nzic.org.nz/ChemProcesses/polymers/10A.pdf
- Schmidt, J.H., (2015), 'Life cycle assessment of five vegetable oils', Journal of Cleaner Production, 87, 130-138.

Paints, coatings, inks and dyes - polyurethane



Product description

There are several types of polyurethanes with different product properties. Rigid polyurethane is used in panels and doors, whereas flexible polyurethane is used in seating and insulation. For coatings, polyurethane dispersions (PUD) are often applied, where the polyol used in the synthesis also contains a carboxylic acid group to allow the PU to disperse in water.

Production process

Polyurethane consists of a polyol and an isocyanate. There are many types of polyurethane with different level of flexibility for each application. The commonly found bio-based polyurethanes have a polyol based on vegetable oils. There are several processes to convert vegetable oils to polyols, which include epoxidation and ringopening, transesterification, ozonolysis, thiol-ene coupling, and hydroformulation. A vegetable oil that is naturally rich in polyols, such as castor oil, could also be used directly.

Product properties

Commercial polyurethane can be obtained from reacting bio-based polyols with fossil diisocyanates. The polyols mainly originate from vegetable oils, which gives the PU a bio-based content of 30% to 70%, depending on the type of the polyol. Bio-based polyols could also be obtained from sugars, succinic acid, and adipic acid, which all give different product properties. The isocyanates needed for PU synthesis are currently only available from fossil resources.

Applications

Main applications of bio-based polyurethane can be divided in three classes

- Rigid foam (automotive panels and doors, furniture)
- Flexible foam (automotive seating, insulation, footwear)
- Coatings, adhesives, sealants and elastomers (CASE) (small market of tailored products)

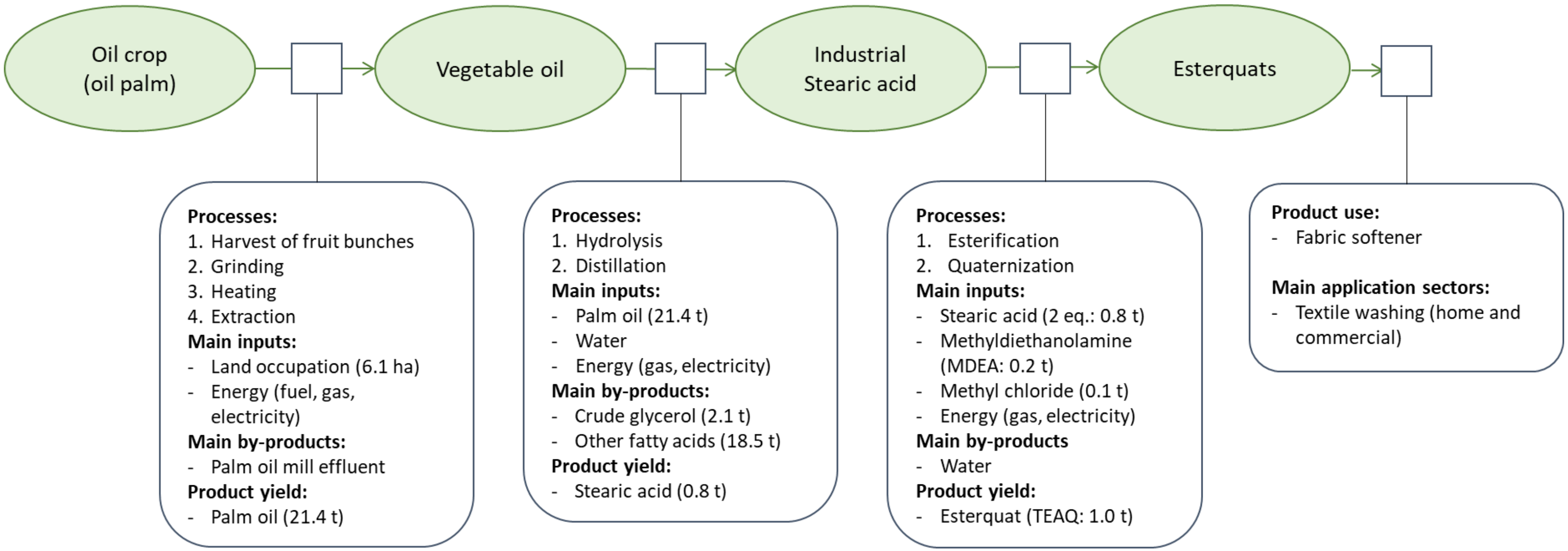
Market

Global bio-based PU market estimations range from 1.6 kton in 2013 and 13 kton in 2009 to 28 kton in 2011, however, production of bio-based PUR in the EU alone has been estimated at 39 kton in 2013. Either case is small compared to 14.000 kton of fossil PU. The market of bio-based PU is expected to continue to grow, mainly due to the increasing demand of flexible foams for construction in developing markets. Companies that market bio-based polyurethane based on vegetable oil include BASF, Bayer, Cargill, Dow, and Urethane Soy Systems. PU based on sugars and their fermentation products is marketed by Bayer, Cargill and Merquinsa.

Data sources

- Cavani, F, Albonetti, S., Balile, F. and Gandini, A. (eds.) (2016) Chemicals and fuels from bio-based building blocks, Volume 2, Wiley-VCH Verlag GmbH & Co.
- Grand View Research (2015), report summary 'Bio-Based Polyurethane (PU) Market Analysis By Product (Rigid Foams, Flexible Foams, CASE), By End-Use (Furniture & Interiors, Construction, Automotive, Footwear) And Segment Forecasts To 2020', http://www.grandviewresearch.com/industry-analysis/bio-based-polyurethane-industry
- Harmsen, P., Hackmann, M., (2013), 'Green building blocks for bio-based plastics', report WuR.
- Institute for Bioplastics and Biocomposites, (2016), 'Biopolymers, facts and statistics'
- Jogdand, S.N., 2015. Current status of bio-based chemicals, Biotech Support Services (BSS), India
- Shen, L., Haufe, J., Patel, M., (2009), 'Product overview and market projection of emerging bio-based plastics'

Surfactants - esterquats



Product description

Esterquats are a widely used class of biodegradable cationic surfactants, which give detergents their fabric softening qualities. They were introduced in the early 1980s when concerns were raised about the environmental profile of DHTDMAC (Di-Hardened Tallow DiMethyl Ammonium Chloride), a fabric conditioner. Most, if not all, fabric conditioners marketed in Europe are now comprised of the three Esterquat types: TEAQ (triethanol amine quat), DEEDMAC (diethyloxyester dimethylammonium chloride), and HEQ (Hamburg Esterquat). The development of TEAQ made it possible to increase the amount of active material from 4-8% to 20-24%.

Production process

In the 1970s BASF and Hoechest patented the production of methyldiethanolamine (MDEA), which can esterify with fatty acids to produce TEAQ. MDEA is combined with two equivalents of fatty acids and consecutively quaternised with methyl chloride, dimethyl sulphate or benzyl chloride. Product yields are not publicly available and full conversions are assumed. For fabric softeners, industrial stearic acid (a mixture of stearic acid, palmitic acid and a small amount of oleic acid) is a popular choice of fatty acid and methyl chloride for the quaternisation. Stearic acid is commonly obtained from palm oil, but can also be obtained from coconut oil.

Product properties

Esterquats are quaternary ammonium compounds, having one or two long fatty ester chains, which lead to rapid breakdown of compounds in water. They combine a good environmental profile, especially in terms of ready and ultimate biodegradability, with the structural features required for an effective fabric conditioner.

Applications

Esterquats are mainly used as biodegradable fabric softeners.

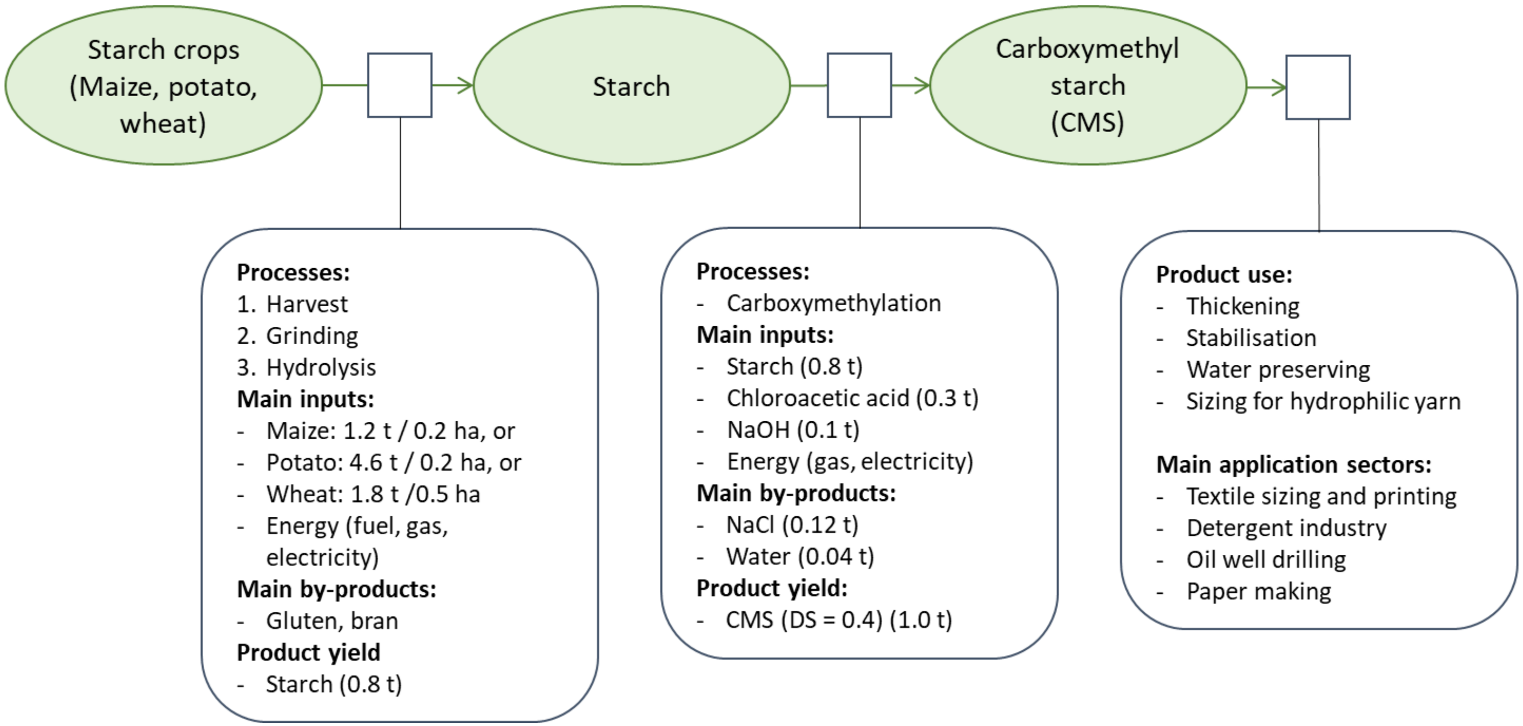
Market

The total volume of Esterquat surfactants used in Europe is estimated to be 130,000 tonnes/year on an active matter basis. About 99% of this volume is covered by the use as fabrics conditioner.

Data sources

- Abbas, S.K. (2015) Production of 60,000 MTPA of oleochemical methyl ester from RBD palm kernel oil, experiment findings. https://www.researchgate.net/publication/303074405_PRODUCTION_OF_60000_MTPA_OF_OLEOCHEMICAL_METHYL_ESTER_FROM_RBD_PALM_KERNEL_OIL
- Eastman, http://www.eastman.com/Pages/ProductHome.aspx?product=71103653, accessed in Nov 2017.
- FAO (2002) Small-scale palm oil processing in Africa, FAO agricultural services bulletin 148 http://www.fao.org/DOCrEP/005/Y4355E/y4355e04.htm
- HERA (2008) Esterquats Environmental Risk Assessment Report, Edition 1.0, Human and Environmental Risk Assessment on ingredients of Household Cleaning Products (HERA), March 2008, http://www.heraproject.com/files/17-e-01-03-2008%20%20hera%20eq%20environment%20final%20draft.pdf
- http://www.grandviewresearch.com/industry-analysis/stearic-acid-market, accessed in November 2017
- Mishra, S., Tyagi, V., (2007), 'Ester Quats: The Novel Class of Cationic Fabric Softeners', Journal of Oleo Science, 6, 56, 269-276.
- Schmidt, J.H., (2015), 'Life cycle assessment of five vegetable oils', Journal of Cleaner Production 87, 130-138
- The essential chemical industry online (2017) Surfactants. http://www.essentialchemicalindustry.org/materials-and-applications/surfactants.html.

Surfactants - carboxymethyl starch



Product description

Carboxymethyl starch (CMS) is an important modified starch type, with unique properties due to the presence of a negatively charged functional group (CH_2COO^-).

Production process

Starch is commonly produced from starch crops such as potatoes, maize and wheat. Etherification of starch with chloroacetic acid, chloroacetic acid salts or esters results in CMS. Various types of carboxymethyl starch with different properties can be obtained by varying the degree of substitution (DS).

Product properties

CMS is a bio-based and biodegradable product which is soluble in water. Its properties and applications depend mainly on the degree of substitution (DS) (low, medium, high), but also on the distribution of the carboxymethyl groups within the repeating units, its molecular weight, degree of crystallinity etc. The solubility of carboxymethylated starch in non-aqueous solvents increases with increasing substitution.

Applications

CMS has a wide range of applications in industries, mostly used for purposes of thickening, stabilisation, and water preserving. It is also used in textile industry as thickening agent in textile printing paste and as sizing agent especially for hydrophilic yarn. In soaps a small addition of CMS increases the suspending power and overall washing efficiency of a soap, but the same amount of CMS greatly improves the suspension action and overall efficiency with a sodium salt of surface active agents in the detergents.

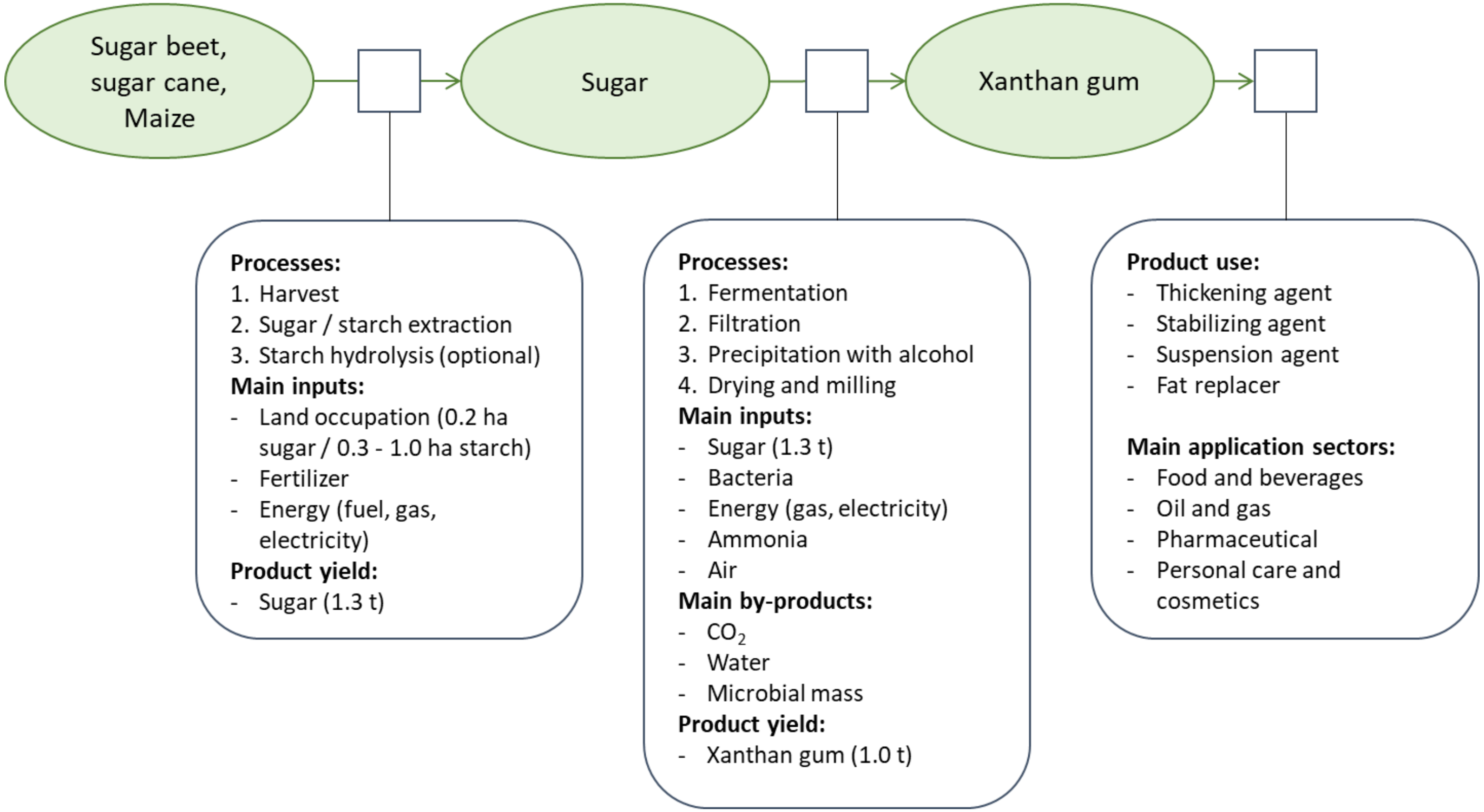
Market

There is no direct information available on the CMS market. Using the estimate of the market of starch used for polymers, the CMS production in the EU is estimated at 25 kton/y.

Data sources

- http://www.optimumbiotech.com/catalog/11
- Kamm, P., P. Gruber, M. Kamm (2006) Biorefineries – industrial processes and products, status quo and future directions. Wiley-VCH Verlag GmbH & Co KGaA Weinheim.
- Nattapulwat, N. Purkkao and O. Suwithayapan (2009) Preparation and Application of Carboxymethyl Yam (Dioscorea esculenta) Starch, AAPS PharmSciTech. 2009 Mar; 10(1): 193–198., https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2663684/
- Patel industries (2017) http://carboxymethyl-starch.com/, part of company website.
- Spychaj, T., K. Wilpiszewska and M. Zdanowicz (2013) Medium and high substituted carboxymethyl starch: synthesis, characterisation and application, Polymer Institute, West Pomeranian University of Technology, Czczecin, Poland, in Starch 2013, 65, 22-23.
- Starch Europe (2017) https://www.starch.eu/european-starch-industry/#prettyPhoto[gallery]/4/

Cosmetic products - xanthan



Product description

Xanthan is a polysaccharide produced from simple sugars using a fermentation process. It was discovered in the 1950s and derives its name from the strain of bacteria used for the production (*Xanthomonas campestris*). It is used extensively in the food industry as a thickening agent and as stabiliser to prevent ingredients from separation.

Production process

Simple sugars are fermented with a strain of the Xanthomonas bacteria. After a sufficient amount is produced, the fermentation broth is filtrated in one or more steps, and the xanthan gum is precipitated using an alcohol (e.g. methanol). After drying and milling a white to cream-coloured powder remains.

Product properties

Xanthan ($C_{35}H_{49}O_{29}$) is composed of pentasaccharide repeating units, comprising glucose, mannose, and glucuronic acid in the molar ratio 2:2:1. Xanthan is used as a thickening agent since it can increase the viscosity of a liquid already at very low concentrations. It is readily soluble in water. Another relevant property of xanthan is that it is "shear-thinning". This means that under shear stress the viscosity decreases. This is advantageous in e.g. food applications where liquids need to be high-viscosity during storage but free-flowing during use. Also in the oil and gas industry xanthan is used as an additive in drilling mud because of this property.

Applications

Xanthan is used mostly in the sectors food and beverages (in salads, bakery products, dairy products, pet foods, syrups and toppings, sauces and gravies) and oil and gas. To a lesser extent it is used in the sectors personal care & cosmetics and pharmaceutical. In products it functions as a thickening agent, stabilising agent, suspension agent, and fat replacer.

Market

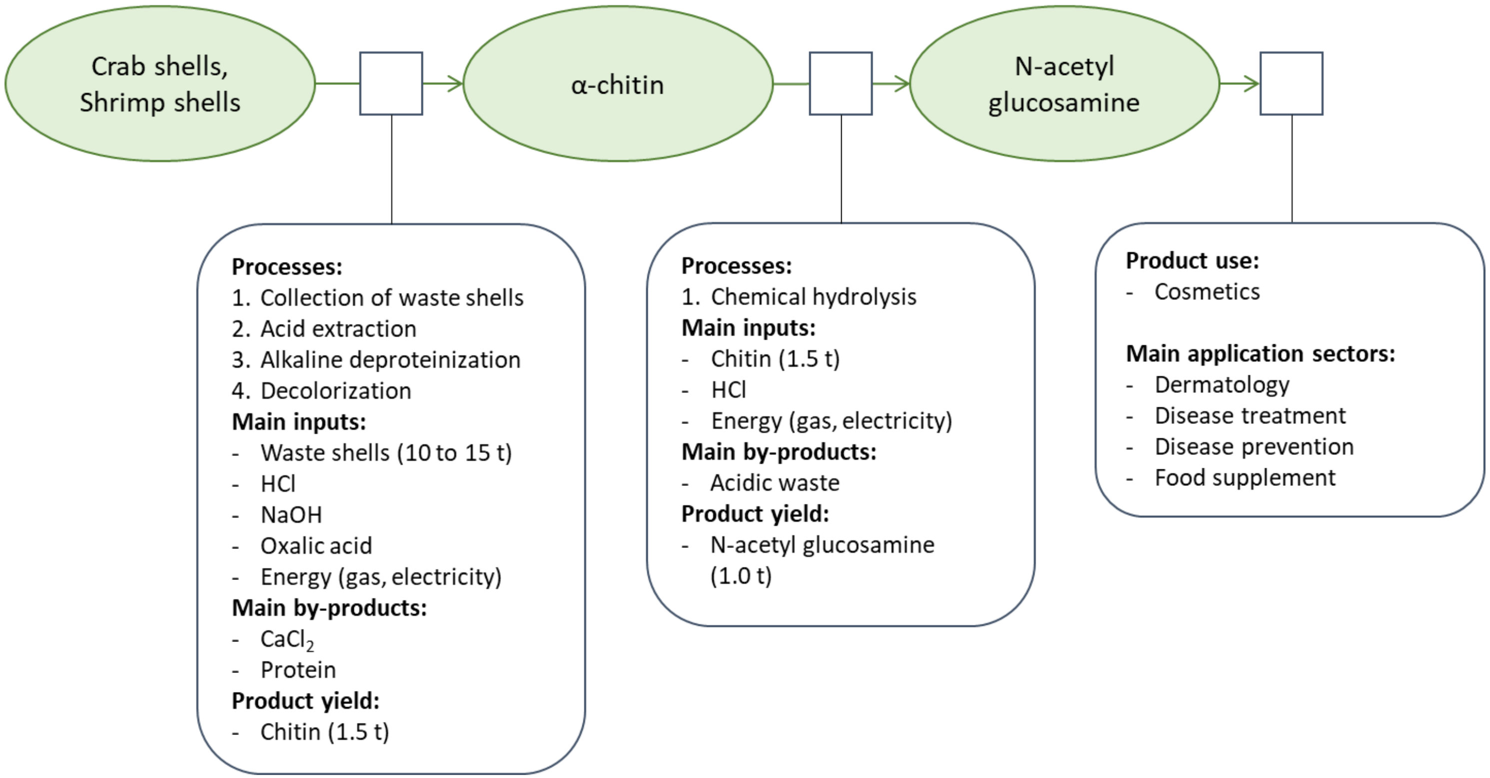
In 2012 the total world market volume was 132,000 tonne/year (estimated at 600 million USD). In 2016, the world market volume has risen to 722 million USD, and in 2023 the total market volume is expected to increase to 1,076 million USD with a CAGR (compound annual growth rate) of 5.9%.

Current producers are Danisco, Cargill, Jungbunzlauer, Pfizer Inc., Archer Daniels Midland (ADM), Solvay Group, CP Kelco and Fufeng Group Company Ltd.

Data sources

- Palaniraj, A., Jayaraman, V. (2011) "Production, recovery and applications of xanthan gum by Xanthomonas campestris", Journal of Food Engineering 106, 1–12 (2011)
- Ghasem D. Najafpour (2007) "Biochemical Engineering and Biotechnology", Elsevier (2007)
- http://www.grandviewresearch.com/industry-analysis/xanthan-gum-market
- https://www.alliedmarketresearch.com/xanthan-gum-market
- IfBB (2016) "Biopolymer facts and statistics 2016", https://www.bio-pro.de/index.php/download_file/16018/9152/

Cosmetic products - N-acetylglucosamine



Product description

N-Acetyl glucosamine is a compound with broad applications obtained from the hydrolysis of chitin. It is a monosaccharide with an acetylated amine, the monomer of the chitin polymer. The compound is a white, slightly sweet powder.

Production process

Waste streams from the large shrimp and crab production are collected for chitin production. The chitin is tightly bound to proteins and calcium carbonate that form the hard shells. The $CaCO_3$ is removed by dilute HCl treatment at room temperature to form $CaCl_2$ and CO_2. Protein is removed by alkaline deproteinisation at increased temperatures (up to 160 °C) while taking care to prevent deacetylation. An optional decolorisation step with oxalic acid can be included. The hydrolysis of chitin needs 15-36% HCl and 40 to 80 °C, which is mild enough to leave the N-acetyl glucosamine intact. 6.42 g/L product can be produced in an hour.

Product properties

Due to being a monosaccharide, N-acetylglucosamine is a non-toxic slightly sweet powder that next to cosmetic purposes has been used in food and pharmaceutical applications.

Applications

Cosmetics:

- Moisturising effect
- Reduce appearance of facial hyperpigmentation
- Improvement of skin (wrinkles and colour)

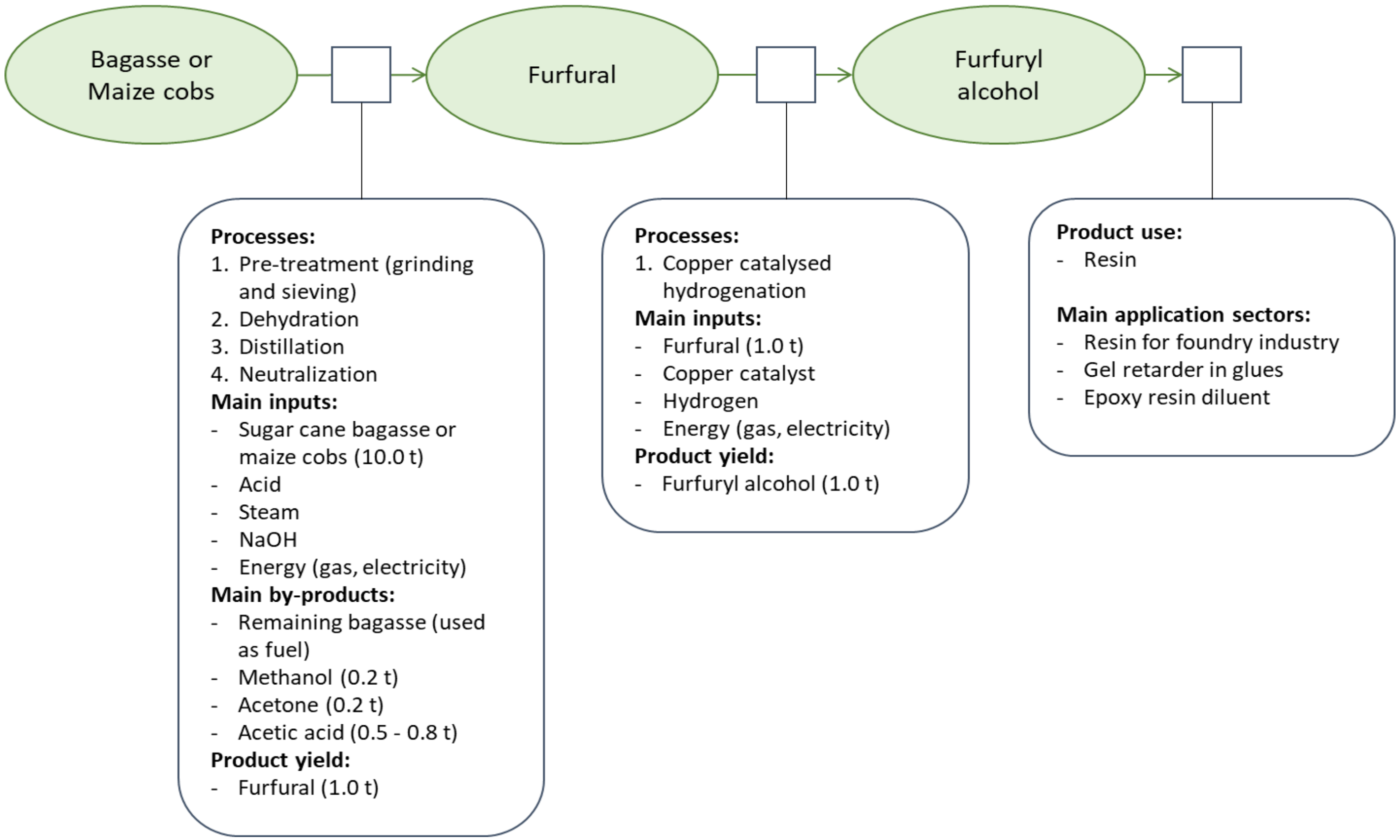
Market

N-acetyl glucosamine, together with de deacetylated glucosamine, have a global market of $2 billion in 2017. The expected global production in 2017 is 50.000 tons, which mainly takes place in China. The major markets of the compound is located in Europe, Asia and North America.

Data sources

- Chen, J. K., Shen, C. R. and Liu, C. L. (2010) 'N-acetylglucosamine: Production and applications', Marine Drugs, 8(9), pp. 2493–2516. doi: 10.3390/md8092493.
- Chen, J., Zhu, Y. and Liu, S. (2017) 'Functional Carbohydrates: Development, Characterisation, and Biomanufacture', CRC Press.
- Majekodunmi, S. O. (2016) 'Chitin, Chitosan, Deproteinisation, Demineralisation, Deacetylation, Pharmaceutical applications, Biological activities; Chitin, Chitosan, Deproteinisation, Demineralisation, Deacetylation, Pharmaceutical applications, Biological activities', American Journal of Polymer Science, 6(3), pp. 86–91. doi: 10.5923/j.ajps.20160603.04.
- Uno, K. et al. (2012) 'Effect of Chitin Extraction Processes on REsidual Antimicrobials in Shrimp Shells', Turkish Journal of Fisheries and Aquatic Sciences, 12, pp. 89–94. doi: 10.4194/1303-2712-v12_1_11.
- Younes, I. and Rinaudo, M. (2015) 'Chitin and chitosan preparation from marine sources. Structure, properties and applications', Marine Drugs, 13(3), pp. 1133–1174. doi: 10.3390/md13031133.

Adhesives - furfuryl alcohol



Product description

Furfuryl alcohol is a furanic that is produced from biomass waste streams. It was made commercially available in 1934 by the Quaker Oats company. In 1958 the use of furan resins as binders in the foundry industry started.

Production process

The production of furfuryl alcohol *via* furfural requires pentosane-rich biomass. Sugar cane bagasse, which is produced as a by-product by the sugar industry, meets this requirement and contains 25% to 27% pentosane. Corn cobs are also commonly used as feedstock. Both yield roughly 10% furfural. Bagasse is mixed with an acid at 153 °C to produce furfural. The furfural is stripped from the bagasse with steam and isolated by distillation. The remaining bagasse can be used as fuel. This process was developed by Quaker, who is no longer producing furfural themselves. The furfural is then converted with over 96% yield to furfuryl alcohol by a copper catalysed hydrogenation.

Product properties

Furfuryl alcohol is a colourless liquid with a low viscosity. Its versatile reactivity makes it a potential future platform chemical, but currently it is mostly known for its application as an adhesive in the foundry industry.

Applications

Main applications of furfuryl alcohol:

- Gel retarder in glues
- Epoxy resin diluent
- Resin for the foundry industry.

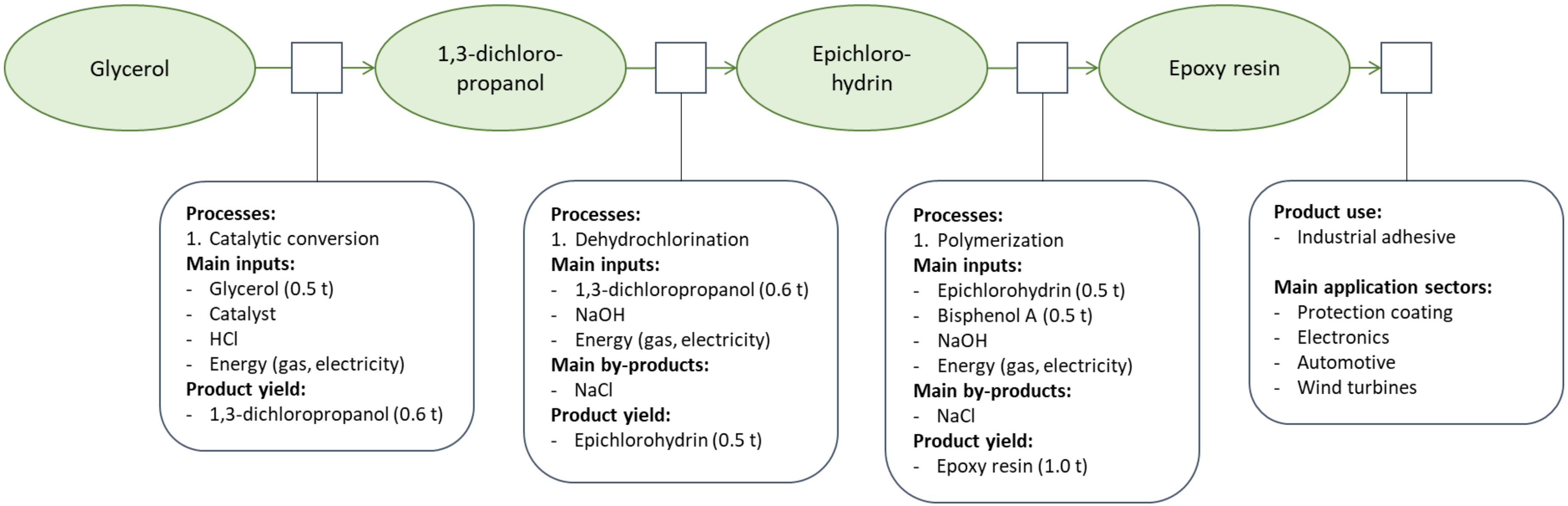
Market

Furfuryl alcohol is mainly produced by TransFuran Chemicals and Zibo Shuangyu Chemical. Estimated global market in 2006 was 8.6 kton/year with a price of 0.84 to 0.97 $/kg. In 2017, TFC alone already produces around 40 ktons a year using furfural from the Dominican Republic made of sugar cane bagasse.

Data sources

- Biddy, M., Scarlata, C., Kinchin, C., (2016), 'Chemicals from Biomass: A Market Assessment of Bioproducts with Near-Term Potential', National Renewable energy Laboratory.
- E4Tech, (2015), 'From the Sugar Platform to biofuels and biochemicals'
- Gebre, H., Fisha, K., Kindeya, T., Gebremichal, T., (2015), 'Synthesis of furfural from bagasse'
- http://www.furan.com/furfuryl_alcohol.html
- Win, D.T., (2005), 'Furfural – Gold from Garbage'
- Zwart, R., (2006), 'Biorefinery - The worldwide status at the beginning of 2006'

Adhesives - epoxy resins



Product description

Epoxy resins are a popular industrial adhesive. Bio-based epoxy resins can be produced from epoxidised fatty acids or from epichlorohydrin. Only the epichlorohydrin route is currently commercialised.

Production process

Bio-based epoxy resins can be produced from epoxidised fatty acids (not yet commercialised) or from epichlorohydrin. Glycerol is converted to 1,3-dichloropropanol with the use of HCl and a catalyst, which yields epichlorohydrin after treatment with sodium hydroxide. The epichlorohydrin then reacts with bisphenol A, which is currently fossil based, to form epoxy resins. Process inputs are based on molar ratios, since product yields are not publicly available.

Product properties

Epoxy resins from bio-based epichlorohydrin have the exact same properties as the fossil variant, with epichlorohydrin as a direct drop-in chemical. This leads to an adhesive with 30% bio-based carbon. To reach a fully bio-based product, an alternative to the fossil based bisphenol A needs to be found.

Applications

Main applications:

- Protection coatings
- Electronics
- Automotive and aerospace industry
- Wind turbine industry

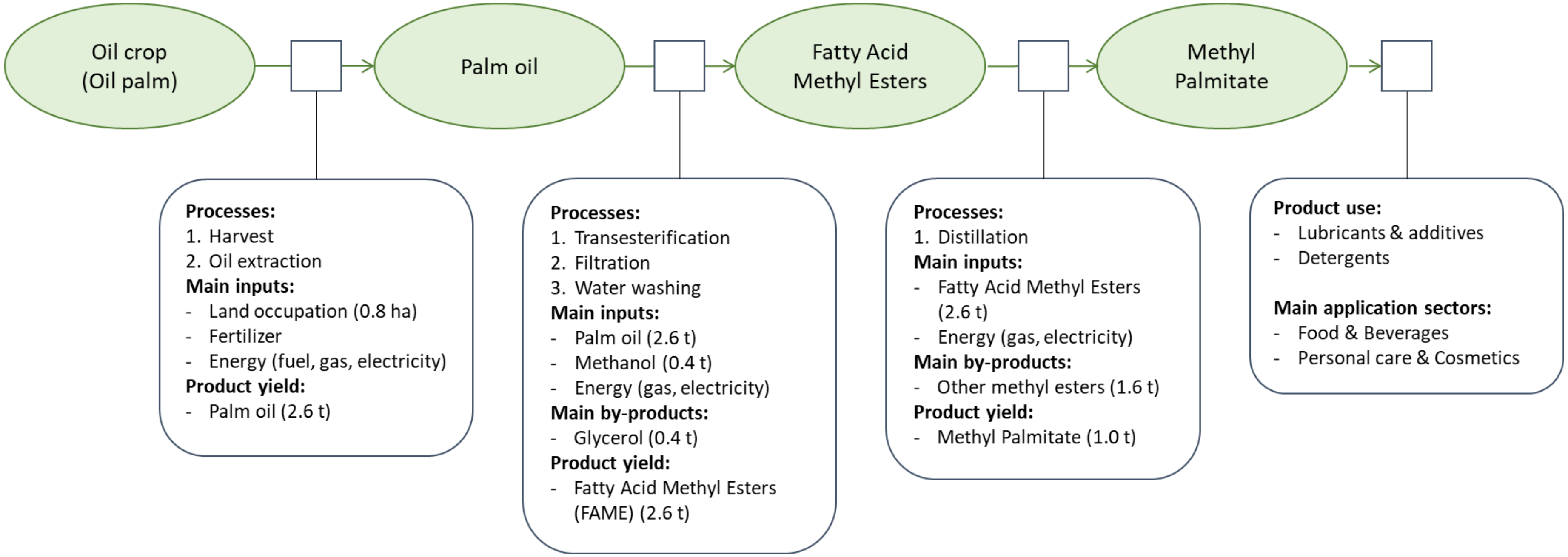
Market

Europe is the leading producer of bio-based epichlorohydrin, which is mainly used for epoxy resins, with the leading actors being Solvay, Spolchemie, and Yang Nong Jiang Su.

Data sources

- Bridgewater (2010) 'Identification and market analysis of most promising added-value products to be co-produced with the fuels'
- E4Tech (2015) 'From the Sugar Platform to biofuels and biochemicals'
- Jogdand, S. (2015) 'Current status of bio-based chemicals'
- NOVA (2015) 'Bio-based Building Blocks and Polymers in the World'.
- http://www.grandviewresearch.com/industry-analysis/epichlorohydrin-ech-market

Lubricants - methyl palmitate



Product description

Methyl palmitate (methyl hexadecanoate) belongs to the class of organic compounds known as fatty acid methyl esters (FAME). The molecules in biodiesel are primarily FAMEs, usually obtained from vegetable oils by transesterification with methanol and a catalyst. Besides methyl palmitate, other FAMEs are methyl oleate and methyl laureate. Methyl palmitate is currently mainly produced from palm oil, although other oils (from soybean, rapeseed, tallow, etc.) can also be used.

Production process

Palm oil consists of triglycerides. By esterification of these triglycerides using methanol the products are a mixture of various methyl esters (FAME) and glycerol. After glycerol separation by a centrifuge or a settling tank, the mixture is washed to remove residual catalysts and methanol. Through distillation the methyl esters can be separated with one of the products being methyl palmitate. The amount of methyl palmitate is dependent on the amount of palmic acid in the original oil. One of the advantages of using palm oil is that the amount of palmic acid, and hence the amount of methyl palmitate that can be produced is higher than in other oils (50% versus 2-20% in other oils).

Product properties

Methyl palmitate is a colourless liquid with a boiling point of 211.5°C that is soluble in alcohol and ether. The chemical formula is $C_{17}H_{34}O_2$. In the spectrum of FAME molecules, methyl palmitate is one of the heavier molecules. Lighter molecules are methyl octanoate/decanoate (C8-C10), medium-sized molecules are methyl laureate/myristate (C12-C14), and heavier molecules are the methyl palmitate/oleate (C16-C18).

Applications

Methyl palmitate is used as lubricant, detergent, emulsifier, in the food and beverages industry and in personal care and cosmetics.

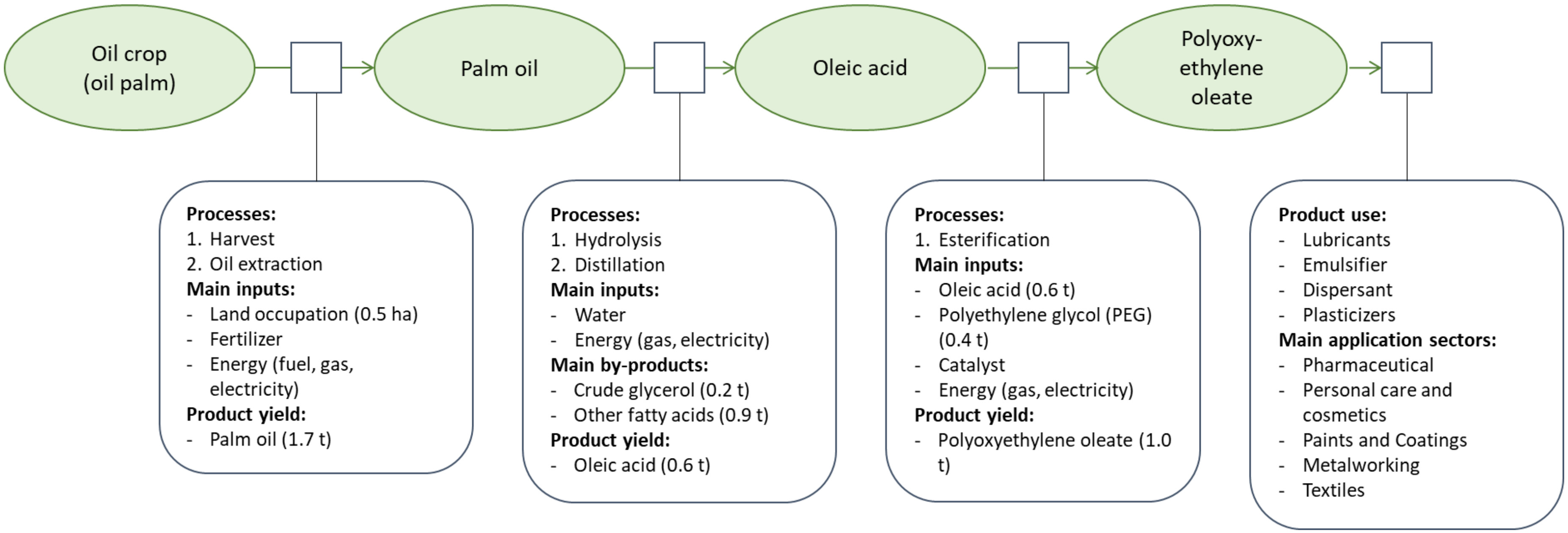
Market

The global palm methyl ester derivatives market size was estimated at 204 kilo tons in 2016, and is expected to grow at a CAGR (compound annual growth rate) of around 5.3% from 2017 to 2025 to exceed a total volume of over 320 kilo tons by 2025. Global market value is estimated to be USD 1 billion by 2025. The share of methyl palmitate in the methyl ester derivatives market (by weight) is estimated at 15-20%.

Data sources

- Abbas, S.K. (2015) Production of 60,000 MTPA of oleochemical methyl ester from RBD palm kernel oil, experiment findings. https://www.researchgate.net/publication/303074405_PRODUCTION_OF_60000_MTPA_OF_OLEOCHEMICAL_METHYL_ESTER_FROM_RBD_PALM_KERNEL_OIL
- Pubchem (2017) Open chemistry database, https://pubchem.ncbi.nlm.nih.gov/compound/methyl_palmitate#section=Top
- http://www.grandviewresearch.com/industry-analysis/palm-methyl-ester-derivative-market
- https://www.alfa.com/en/catalog/L05509/
- http://www.grandviewresearch.com/press-release/global-palm-methyl-ester-derivative-market

Lubricants – Poly(oxyethylene oleate)



Product description

Poly(oxyethylene oleate) is also called poly(ethylene glycol) monooleate or PEG monooleate. It is a combination of a poly(ethylene glycol) (PEG) and oleic acid; a fatty acid present in many vegetable oils. Dependent on the length of the PEG molecule the product properties vary. It is common to list the average molecular weight of the PEG after the name to distinguish it from other PEG's. Examples are PEG 600 monooleate and PEG 200 monooleate.

Production process

PEG monooleate is produced by combining PEG with oleic acid. Oleic acid can be obtained from many vegetables oils. PEG is produced via monoethylene glycol (MEG), which is obtained from ethylene. Currently, fossil ethylene is used for this process, however there are also bio-based options to produce MEG. Bio-based routes to produce MEG utilize ethylene from ethanol or sugars via hydrogenolysis to produce sorbitol and xylitol, which can subsequently be converted to produce MEG.

Product properties

The structural formula of PEG monooleate can be described by $(C_2H_4O)_n$-$C_{18}H_{34}O_2$, whereby the latter part represents the monooleate, and the former is the PEG. PEG monooleate is a biodegradable and non-toxic liquid. PEG monooleate has excellent water/oil emulsifying properties.

Applications

PEG monooleate is used as lubricants in textile processing, cutting oils and metalworking fluids, solvent cleaners and emulsifiable degreasers, emulsifier for self-emulsifying herbicides, insecticide and fungicide, emulsifier for cosmetic creams and toiletry emulsions, and emulsifier for polymer latex production

Other applications have utilised its wetting/dispersing properties, e.g. as: pigment dispersants for both organic and inorganic pigments in aqueous and non-aqueous systems. plasticisers/viscosity modifiers in mastics, adhesives, emulsion paints and PVC plastisols

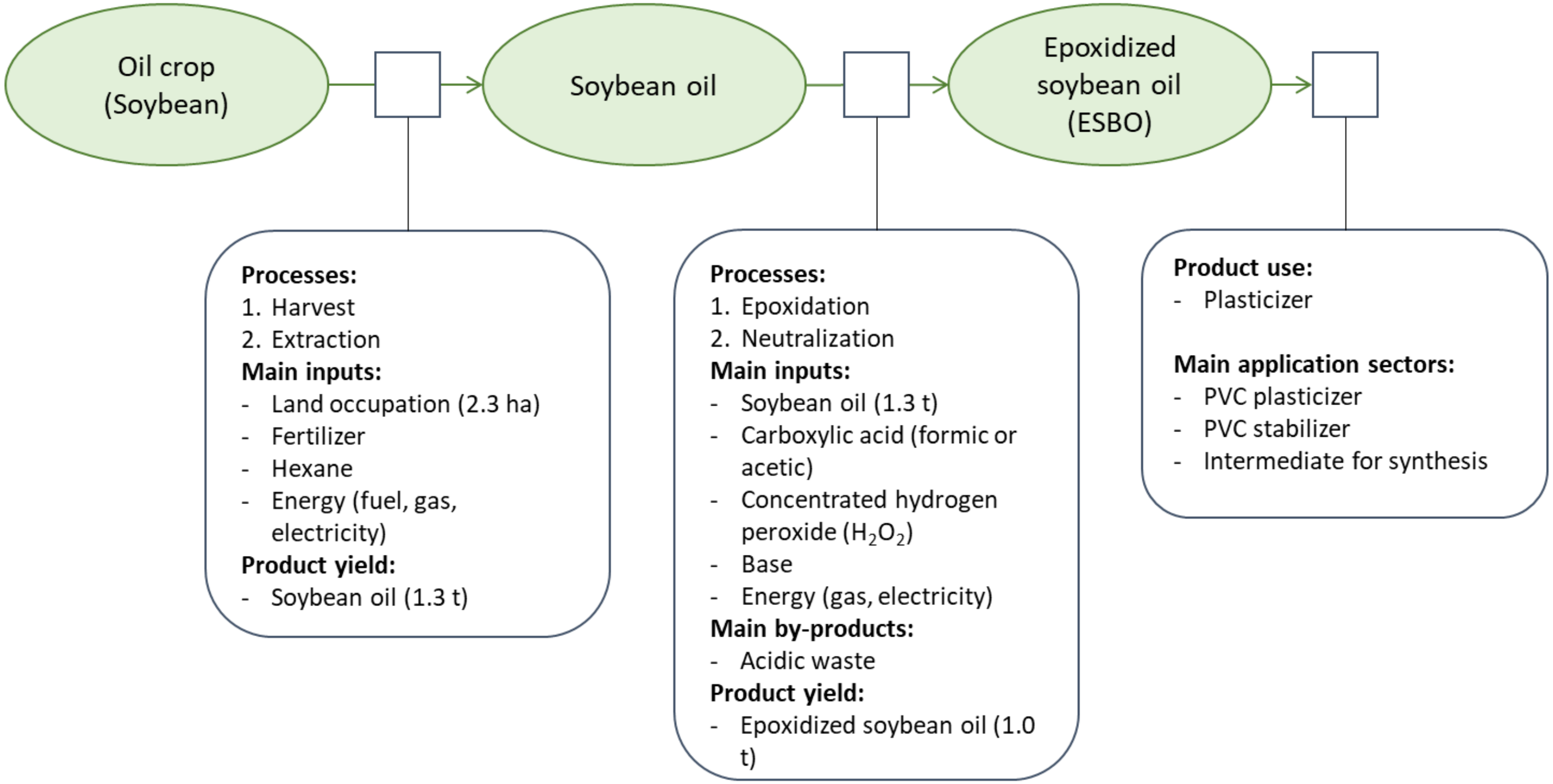
Market

The global polyethylene glycol (PEG) market is expected to reach USD 1.68 billion by 2020, starting from USD 1.15 billion in 2013. CAGR (compound annual growth rate) is 5.7%. The approximate volume in 2020 will be 550,000 ton/year. It is not known what part of the total PEG market is PEG monooleate.

Data sources

- Harmsen, P., Hackmann, M. (2013) Green building blocks for biobased plastics, WUR, http://www.groenegrondstoffen.nl/downloads/Boekjes/16GreenBuildingblocks.pdf
- http://www.chemnet.com/cas/en/9004-96-0/Polyethylene-glycol-monooleate.html
- http://www.oleon.com/product/derivatives/polyethylene-glycol-esters
- http://www.echem-group.com/product/peg-esters
- http://www.grandviewresearch.com/press-release/global-polyethylene-glycol-peg-market
- http://www.grandviewresearch.com/industry-analysis/polyethylene-glycol-peg-market
- IfBB (2016) "Biopolymer facts and statistics 2016", https://www.bio-pro.de/index.php/download_file/16018/9152/

Plasticisers and stabilisers for rubber and plastics - Epoxidised soybean oil (ESBO)



Product description

Epoxydised soybean oil (ESBO) is mainly applied as plasticiser for PVC. Traditional PVC plasticisers contain phthalates, which have negative health effects. ESBO is non-toxic, phthalate-free alternative to these traditional plasticisers.

Production process

The epoxidation of soybean oil is mainly performed using the Prilezhaev process. Concentrated H_2O_2 and a carboxylic acid, such as acetic or formic acid, are added to the soybean oil. This mixtures forms *in situ* peroxocarboxylic acids which are the active epoxidation species.

The reaction is exothermic and needs to be performed stepwise to prevent degradation of the product or H_2O_2. The excess of acid is neutralised with a base. Due to the aggressive reaction, selectivity is just above 80%.

Product properties

ESBO is a colourless to yellow viscous liquid that consists of a mixture of chemicals obtained from the epoxidation of soybean oil. It acts as a plasticizer for PVC and scavenges HCl released by PVC when it is heated. ESBO is light and water resistant, stable in water and oil, and is not toxic.

Applications

Main applications:

- Stabilizer and plasticizer in PVC
- Intermediate for the production of glycols, alkanolamines, polyols and polymers

It has potential applications in:

- High-temperature application lubricant
- Paint and coating component.

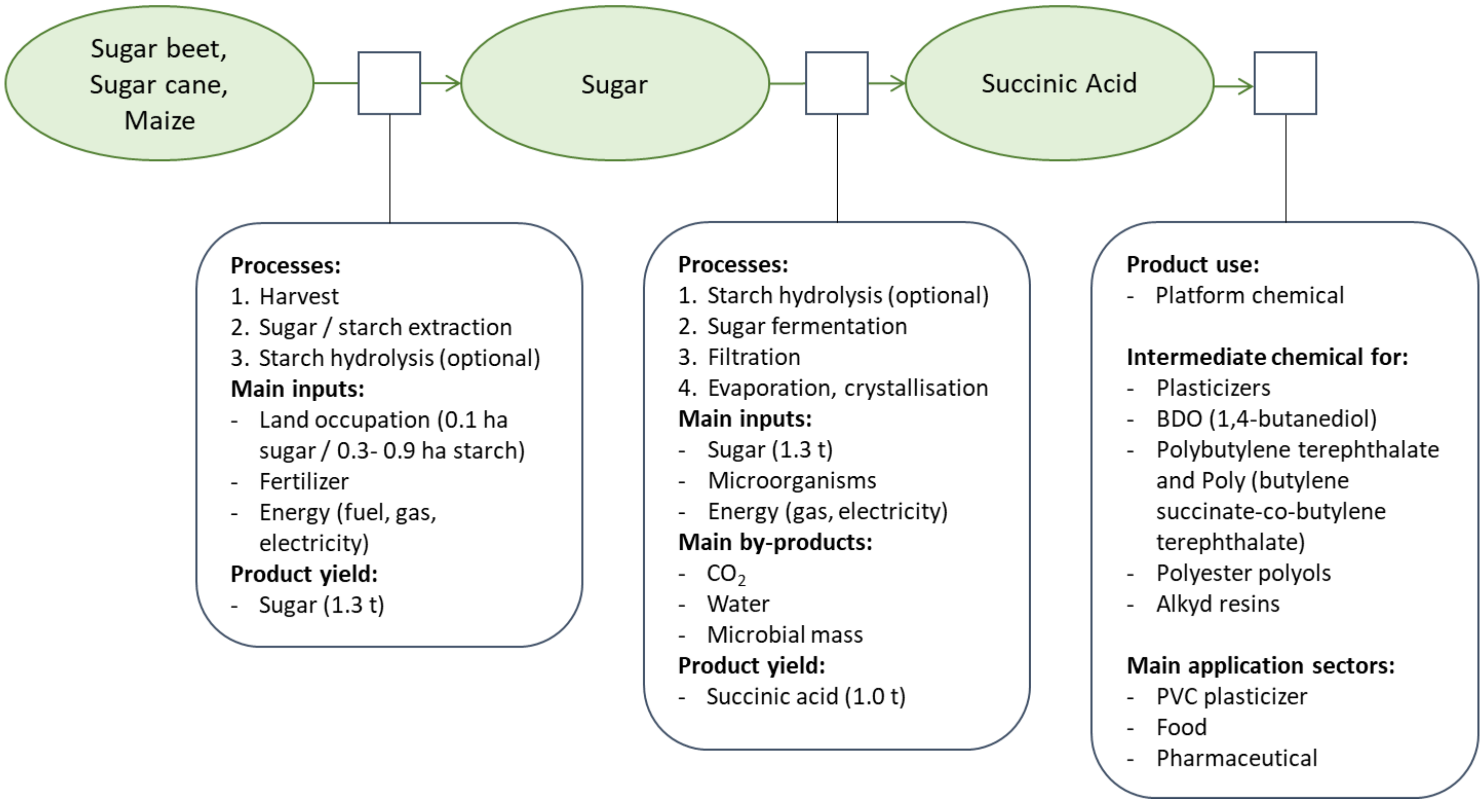
Market

The production of ESBO takes place mostly in South America, with a global production of 200 kton/year in 2010. ESBO is the largest bio-based plasticizer currently produced, holding 37% of the global market in 2016.

Data sources

- Atwood, D. A. (2016) Sustainable Inorganic Chemistry, 'Catalytic Epoxidation of Organics from Vegetable Sources', John Wiley & Sons
- Grand View Research (2017) 'Bio Plasticizers Market Analysis By Product Type (Citrates, Castor Oil, ESBO, Succinic Acid), By Application (Packaging, Consumer Goods, Automotive, Construction, Textiles), And Segment Forecasts, 2014 – 2025', http://www.grandviewresearch.com/industry-analysis/bio-plasticizers-market
- Schmidt, J. H. (2015) 'Life Cycle assessment of five vegetable oils', Journal of Cleaner Production, 87, 130-138
- Shandong Baolilai Plastic Additives Co. LTD (2016) ESBO technical data sheet, http://www.americaplastexpo.americaplastnews.com/uploads/3/5/4/1/3541003/tds-esbo.pdf

Plasticisers and stabilisers for rubber and plastics - Succinic acid



Product description

Succinic acid is a bio-based plasticiser that can be produced from sugars through fermentation. Other names for succinic acid are butanedioic acid and amber acid. In the past, succinic acid was produced from a fossil-based chemical (maleic anhydride), and world market size used to be relatively small at 16,000 – 18,000 tonne/year (1990). Due to technological advances in development of micro-organisms that can reach sufficient productivity, the potential of succinic acid as a bio-based platform chemical is being recognised.

Production process

Sugars are fermented with micro-organisms. After succinic acid is produced in a sufficiently high concentration, recovery and purification takes place. Each manufacturer has developed and patented their own recovery and purification process. Generally, steps are filtration, followed by evaporation and crystallisation.

Product properties

Succinic acid is a colourless, non-hazardous, water soluble crystal with a sour taste. The structural formula is $C_4H_6O_4$ and it is a dicarboxylic acid.

Applications

Succinic acid applications still include the traditional markets (food, pharmaceutical). However, it is one of the major bio-based plasticisers on the US market (by revenue), replacing the controversial fossil-based phthalate plasticisers. As a chemical intermediate, succinic acid can be used to produce: BDO (1,4-butanediol), Polybutylene terephthalate and Poly (butylene succinate-co-butylene terephthalate), Polyester polyols, Food, Pharmaceutical, Alkyd resins, and others. End products that can be produced using succinic acid as an intermediate are (i.a.) polyurethanes, paints and coatings, adhesives, sealants, artificial leathers, food and flavour additives, cosmetics and personal care products, biodegradable plastics, nylons, industrial lubricants, phthalate-free plasticisers, dyes & pigments and pharmaceutical compounds.

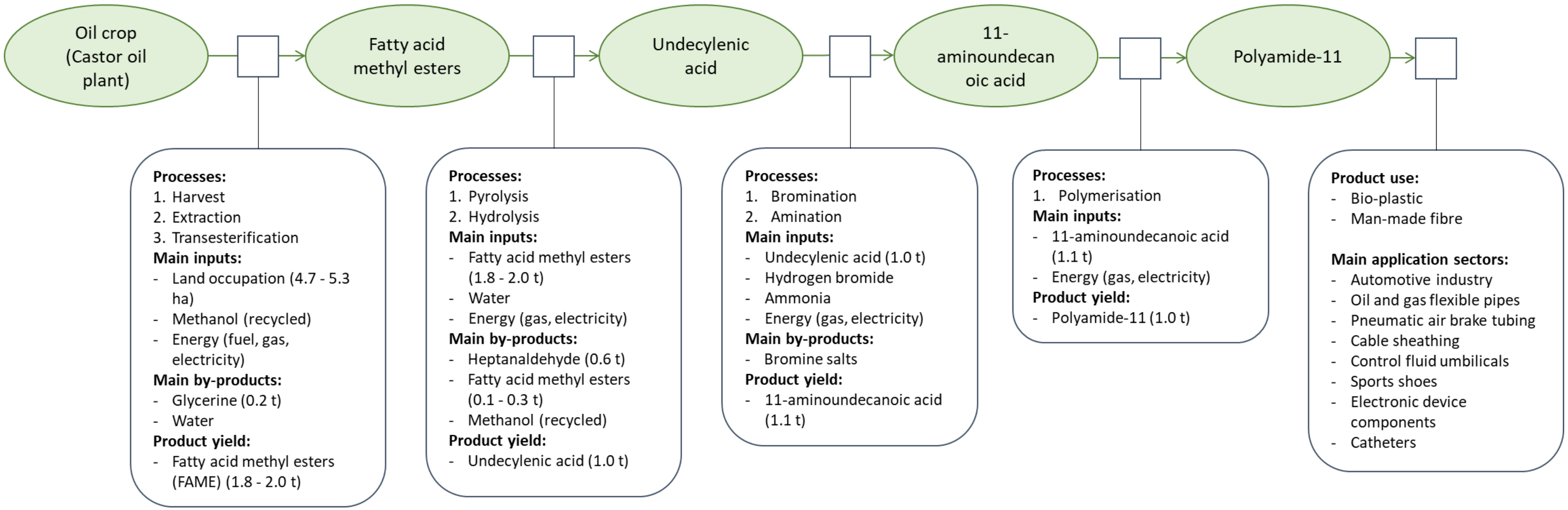
Market

Currently there are mainly four companies producing bio-based succinic acid worldwide: BioAmber, Reverdia (joint venture between DSM and Roquette Frères), Myriant, and Succinity GmbH (joint venture of BASF and Corbion Purac). Combined production capacity is estimated at 64,000 tonne/year in 2015. Total attainable market volume in 2020 has been estimated to be – by one source in 2013 – 600,000 tonne/year, with a CAGR (compound annual growth rate) of around 27.4%. Over half this market volume is for the production of BDO (1,4-butanediol). Estimated production costs for bio-based succinic acid are 41% of the fossil-based succinic acid production costs (1.17 USD/kg versus 2.86 USD/kg) which shows the potential of this bio-based material.

Data sources

- http://chemicalindustrydata.blogspot.nl/2016/02/projected-bio-succinic-acid-markets.html
- http://www.biofuelsdigest.com/bdigest/2015/04/30/the-does-12-top-bio-based-molecules-what-became-of-them/
- https://ceo.ca/@newswire/global-succinic-acid-market-analysis-trends-2013-2017
- https://pubchem.ncbi.nlm.nih.gov/compound/succinic_acid#section=Top
- https://www.grandviewresearch.com/industry-analysis/bio-plasticizers-market
- IfBB (2016) "Biopolymer facts and statistics 2016", https://www.bio-pro.de/index.php/download_file/16018/9152/
- Nghiem, N. P. Kleff, S., Schwegmann, S. (2017) "Succinic Acid: Technology Development and Commercialisation", Fermentation 3, 26 (2017), http://www.mdpi.com/2311-5637/3/2/26/pdf

Man-made fibres - polyamide-11



Product description

Polyamide-11 (or Nylon-11) is a polyamide and bioplastic produced from castor oil beans already for decades by a limited number of producers.

Production process

Castor oil is a vegetable oil obtained by pressing the seeds of the castor oil plant, a perennial flowering plant. Castor oil is produced outside Europe with China and India as the main castor oil-producing countries. Polyamide-11 is produced in various steps starting with a transesterification of methanol, producing glycerol as side product. The resulting mixture of fatty acid methyl esters is pyrolysed, where only the methyl ricinolate is cleaved, due to an OH group in close proximity of a double bond. The side streams of heptanaldehyde (starting material for fine chemicals) and remaining esters (solvent) are sold as valuable products. After hydrolysis, undecylenic acid is formed, which has also been commercialised. The double bond is first brominated anti-Markovnikov followed by an amination with ammonia. After this step the resulting monomer 11-aminoundecanoic acid is polymerised to obtain polyamide-11.

Product properties

Polyamide-11 has excellent resistance to chemicals (particularly hydrocarbons), ease of conversion in all thermoplastic processes, a wide range of working temperatures and high dimensional stability and low density. It is 100 % bio-based and non-biodegradable.

Applications

Polyamide-11 is commonly used in the oil and gas industry and the automotive industry. It is particularly suitable for offshore flexible pipes and for high pressure gas distribution systems located on the coast. It is also used in the automotive industry in various parts, among others air brake tubing, connectors fitting, injection moulded components, electrical and electronical components, emission control systems, etc.

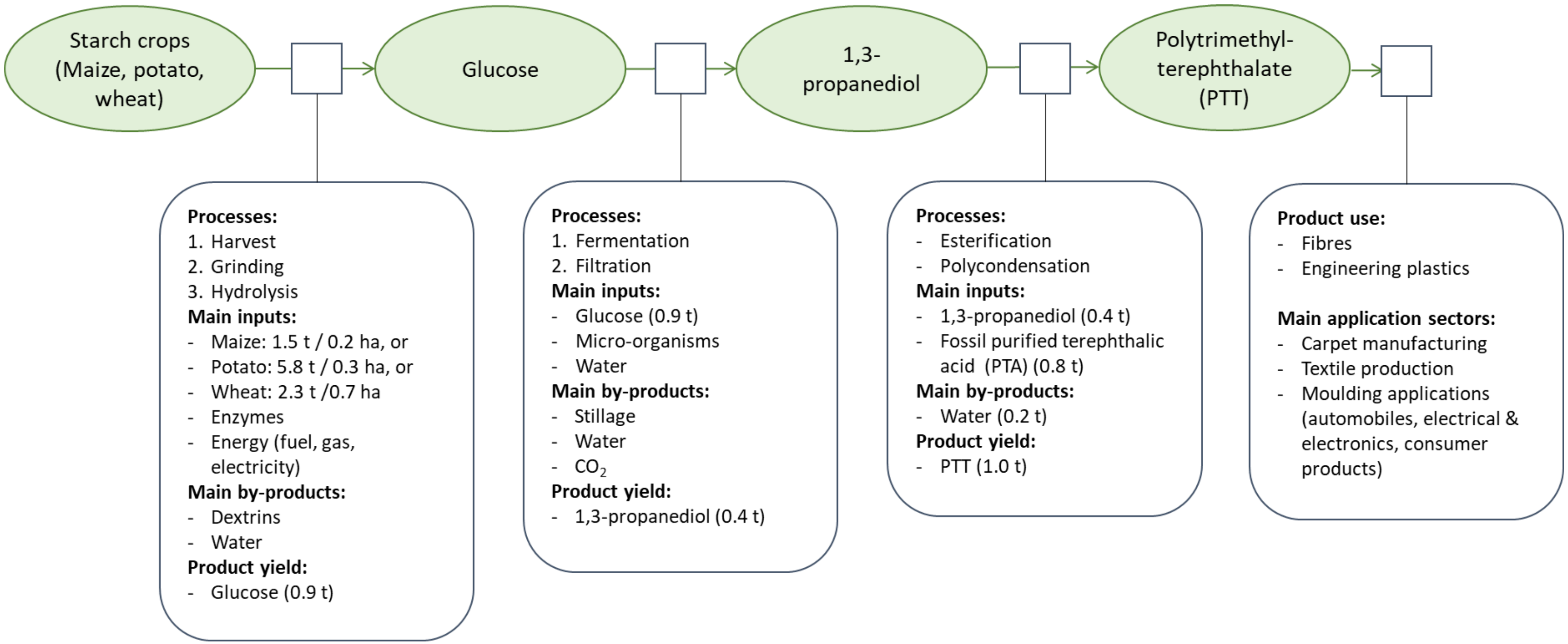
Market

Arkema is the sole or main producer of polyamide-11 under the name Rilsan® PA11. The total yearly production is estimated at 23 kton/year.

Data sources

- Cavani, F, Albonetti, S., Balile, F. and Gandini, A. (eds.) (2016) Chemicals and fuels from bio-based building blocks, Volume 2, page 536-537, Wiley-VCH Verlag GmbH & Co.
- IfBB (2016) "Biopolymer facts and statistics 2016", https://www.bio-pro.de/index.php/download_file/16018/9152/
- http://www.fosterpolymers.com/polymers/rilsan.php
- https://www.arkema.com/en/products/product-finder/product-viewer/Rilsan-Polyamide-11-Resin/
- Thomas, A., Matthäus, B., Fiebig, H., (2015), 'Fats and Fatty Oils', Ullmann's encyclopedia of industrial chemistry, Wiley-VCH Verlag GmbH & Co.

Man-made fibres – poly(trimethylterephthalate) (PTT)



Product description

Poly(trimethylterephthalate) (PTT) is a semi crystalline polymer that has many of the same advantages as its polyester cousins, PBT and PET, mainly used in textile and carpets. PTT is a fossil based polymer that can made partly bio-based by the use of bio-based 1,3-propanediol.

Production process

The 1,3-propanediol needed for production of partly bio-based PTT can be produced from sugar/glucose from sugar and starch crops, or, alternatively, from glycerine available as by-product of biodiesel production. Esterification with PTA and polycondensation results in PTT.

Product properties

It has physical properties similar to that of PET i.e. strength, toughness, stiffness & heat resistance and processing properties comparable to PBT i.e. rapid crystallisation and low melt & mould temperatures. It is also similar to polyamide (nylon 6 & nylon 6,6) and polypropylene for applications in fibre manufacturing. It is also possesses properties similar to that of polycarbonate required for moulding applications. Bio-based PTT has a bio-based content of 37% and is non-biodegradable.

Applications

PTT applications are primarily focused on fibres such as textiles and carpet. Over the past few years, it has witnessed an increase in applications for manufacturing monofilaments, engineering plastics and films.

Market

The global PTT market share is moderately consolidated with fierce competition on the basis of price, application development and services. Key companies include Toray, RTP Company, DuPont, Sinopec and CNPC (China National Petroleum Corporation). Dupont is the main producer of partly bio-based PTT, which is sold as Sorena®, based on its own bio-based 1,3-propanediol marketed under the trade name Susterra®.

Data sources

- http://www.dupont.co.uk/products-and-services/plastics-polymers-resins/thermoplastics/products/sorona-ep-thermoplastic-polymer.html
- http://www.duponttateandlyle.com/our_process
- https://www.gminsights.com/industry-analysis/polytrimethylene-terephthalate-ptt-market
- IfBB (2016) "Biopolymer facts and statistics 2016", https://www.bio-pro.de/index.php/download_file/16018/9152/

Annex 4: Factsheets for the bio-based product categories

For each product category, a factsheet has been produced, summarising the main results of the market study. Further details on the information provided in the factsheets, including underlying methods, sources and uncertainties, can be found in the main report. Below, each indicator used in the factsheets is briefly introduced.

Definition: the definitions of the product categories are provided in fuller detail in section 2.1.

Market indicators EU-28:

- EU production is described in section 3.2.
- The market indicators for the EU-28 can be found in Chapter 3: bio-based production and bio-based share in section 3.2; bio-based consumption in section 3.4; import dependence is defined as EU imports minus EU exports divided by EU consumption and is reported in section 3.4.2. The methods are described in section 2.6 and data were taken from statistics, open literature and reports, and expert interviews, complemented by authors' estimates where necessary.

Key products EU-28:

- The criteria for selecting the most representative products in each bio-based product category investigated are reported in section 2.4. The data on their production in the EU are described in detail in section 3.2.1.

Market description EU-28:

- The maturity levels of the bio-based products were determined using four criteria on the selection of 50 representative bio-based products: more than one production site in the EU; produced in more than one EU country; produced by more than one company; and produced for more than 10 years. 'High' maturity means that three to four criteria are fulfilled, 'medium' means that two criteria are fulfilled and 'low' means that one criterion or no criteria are fulfilled. The method and the results are described in full in section 3.8.
- The importance of the EU can be understood by considering the share of EU bio-based production in total EU production compared with the equivalent figure at global level. 'High' means that the EU bio-based production share is higher than in the rest of the world; 'medium' means that the EU bio-based share is lower than the world average, but with low import dependence; 'low' means that the EU bio-based share is lower than the world average and there is medium/high import dependence. The method and the results can be found in section 3.7.
- The average feedstock mix at product category level has been extrapolated from the feedstock use of the 50 bio-based products, weighted by production volume within each product category. More information on methods and results can be found in section 3.5.3.

Application sectors: the application sectors are mainly based on the value chain descriptions that are discussed in section 3.1 and included in Annex 3.

Drivers and constraints:

- The drivers and constraints are derived from the SWOT analysis presented in section 3.10, including the input from the expert interviews.

Conclusion and outlook:

- The conclusions and outlook describe the current status and future development of each bio-based product category. They are based on the market data and the SWOT analysis. They also form part of the conclusions of the report (section 4.1).

Disclaimer: the uncertainty in the market information provided at product category level is directly dependent on the available data sources. It should be noted that some of the figures are based on estimates and therefore have a high level of uncertainty. This *applies in particular to the data on feedstock use, land use, future market size and private investments.*

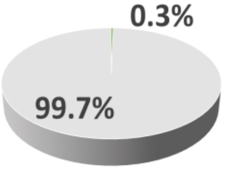
BIO-BASED PLATFORM CHEMICALS

DEFINITION

Platform chemicals are chemical building blocks and starting materials in the formulation of a broad range of products. Platform chemicals form, by definition, a large group and are very diverse in nature.

MARKET INDICATORS EU-28

Bio-based production:	Bio-based consumption:	Bio-based share in production:
181 kt/a	**197 kt/a**	



Import dependence: **9%**
Expected annual growth: **10%**

KEY PRODUCTS EU-28

- Bio-based platform chemicals made with bioethanol: **acetic acid** (24.5 kt/a) and **acetic anhydride** (10 kt/a).
- Other bio-based platform chemicals: **propylene glycol** (20 kt/a), **1,3-propanediol** (8 kt/a), **lactic acid** (64.5 kt/a) and **epichlorohydrin** (36 kt/a).
- Examples of bio-based platform chemicals consumed but not produced in the EU: **ethylene**, **ethylene glycol** and **sebacic acid**.

MARKET DESCRIPTION EU-28

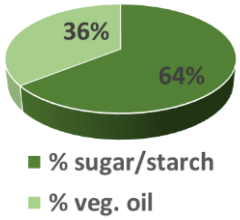
Production maturity

Low	Med	High

Importance of the EU

Low	**Med**	High

Feedstock use



APPLICATION SECTORS

Building blocks for chemical production

DRIVERS

- The need to reduce fossil dependence in other downstream sectors creates a market for bio-based building blocks.
- Diverse feedstock use creates flexibility in the supply chain.

CONSTRAINTS

- Large amount of investment needed for new production plants.
- Biomass availability in case of full rollout.
- Lack of legislation directly targeting greenhouse gas reduction (a CO_2 tax).

CONCLUSIONS AND OUTLOOK

The bio-based platform chemical market is still young, with a bio-based share of 0.3%. The large investments needed for conversion to a bio-based industry are a major hurdle to be overcome and the chemical industry will need time to find the funds. However, new plants are planned or under construction, which will cause rapid growth in the supply of bio-based platform chemicals.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

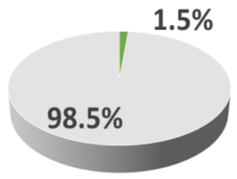
BIO-BASED SOLVENTS

DEFINITION

Solvents are compounds that are able to dissolve other substances without chemically changing them. Organic solvents can be divided into three groups: oxygenated, hydrocarbon and halogenated solvents.

MARKET INDICATORS EU-28

Bio-based production:	Bio-based consumption:	Bio-based share in production:
75 kt/a	**107 kt/a**	



Import dependence: **43%**
Expected annual growth: **1%**

KEY PRODUCTS EU-28

- Example of a bio-based solvent with oxygenated compounds: **ethyl acetate** (36 kt/a)
- Example of a hydrocarbon bio-solvent: **turpentine** (70 kt/a)
- Halogenated solvents have not yet reached TRL 8.
- Examples of bio-based solvents consumed but not produced in the EU: **iso-butanol**, **ethyl lactate**, **acetone**.

MARKET DESCRIPTION EU-28

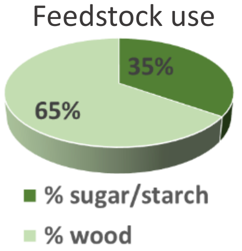
Production maturity

Low | Med | High

Importance of the EU

Low | Med | High

Feedstock use



APPLICATION SECTORS

Inks, paints, adhesives, cosmetics, thinners

DRIVERS

- The need to reduce fossil dependency.
- Increasing awareness of harmful effects of fossil-based solvents in personal care.
- Functional benefits, such as biodegradability.

CONSTRAINTS

- Perceived lack of biomass availability in case of a full rollout, due to the large volumes.
- High (production) costs.
- Lack of incentive to change.

CONCLUSIONS AND OUTLOOK

Only 3% of global bio-based solvents production takes place in the EU and 43% of the bio-based solvents consumed in the EU are imported. These figures are not expected to improve soon, with the industry dealing with more pressing problems such as VOC emissions and health and safety issues rather than greenhouse gas emission reduction. This keeps bio-based solvents limited to applications such as paints, coatings, inks, pharmaceuticals and cosmetics.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

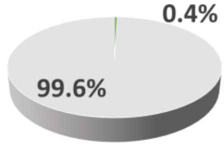
BIO-BASED POLYMERS FOR PLASTICS

DEFINITION

Plastics comprise a whole family of polymers with different properties and applications. Plastics are usually classified by the chemical structure of the polymer's backbone and side chains.

MARKET INDICATORS EU-28

Bio-based production:	Bio-based consumption:	Bio-based share in production:
268 kt/a	**247 kt/a**	



Import dependence: **–8%**
Expected annual growth: **4%**

KEY PRODUCTS EU-28

- The distinction is often made between biodegradable plastics and (non-biodegradable) drop-in plastics.
- Examples of biodegradable plastics: **starch used for plastics** (130 kt/a), **PHA** (2.3 kt/a) and **PLA** (7 kt/a)
- Examples of drop-in bio-plastics: **bio-PE** (0 kt/a) and **bio-PET** (0 kt/a).

MARKET DESCRIPTION EU-28

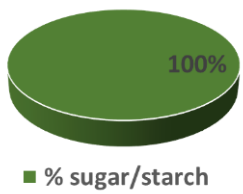
Production maturity

Low	**Med**	High

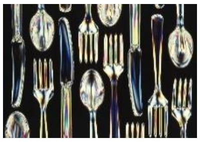
Importance of the EU

Low	Med	**High**

Feedstock use



APPLICATION SECTORS



Packaging, disposable items

DRIVERS

- Consumer demand.
- Growing awareness about environmental impact of fossil-based products.
- Pull from large brand owners.
- Widespread R&D activity.

CONSTRAINTS

- Bio-plastics production and the plastic recycling sectors are not in harmony.
- Higher cost of bio-based plastics compared with their fossil-based counterparts.
- Lack of investment and infrastructure.

CONCLUSIONS AND OUTLOOK

The environmental concerns relating to plastic use are very visible to consumers, which has resulted in a pull from major brands in the EU to move towards bio-based polymers for plastics to address sustainability issues such as biodegradability, fossil oil dependence and CO_2 emission reduction. Combined with the strong starch production in the EU, this results in net exports of bio-based polymers for plastics. The market is expected to continue to grow by 4% per year in the coming 5 years.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

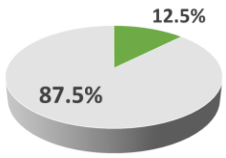
BIO-BASED PAINTS, COATINGS, INKS AND DYES

DEFINITION

Paints, coatings, inks and dyes are mixtures of several components, of which the largest volume consists of solvents and polymers.

MARKET INDICATORS EU-28

Bio-based production:	Bio-based consumption:	Bio-based share in production:
1,002 kt/a	**1,293 kt/a**	



Import dependence: **29%**
Expected annual growth: **2%**

KEY PRODUCTS EU-28

- The four main constituents of paints are solvents, binders, pigments and additives.
- **PUR** (39 kt/a) is a polymer that can be partly bio-based. **Alkyd resins** (432 kt/a) are bio-based polymers typically applied in paints, coatings and inks. **Ricinoleic acid** (0 kt/a) is an important bio-based additive.

MARKET DESCRIPTION EU-28

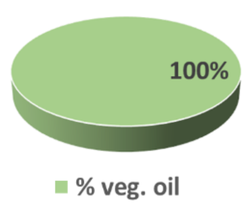
Production maturity

Low	Med	High

Importance of the EU

Low	Med	High

Feedstock use



APPLICATION SECTORS

Paints, coatings, inks and dyes

DRIVERS

- Reducing the environmental footprint to meet consumer demand.
- Functional benefits.
- Advanced small-scale technology.

CONSTRAINTS

- Investments in large-scale plants hindered by the lack of a secure sales market.
- Unwillingness to pay a green premium.
- Often lower quality than fossil-based versions.

CONCLUSIONS AND OUTLOOK

With some traditional bio-based products, such as alkyd resins, the paints, coatings, inks and dyes product category currently has a bio-based share of about 12.5%. The bio-based market is expected to grow, but not by more than a few percent. Weaknesses lie in the perceived risk of investing in this category and uncertainty about sales of the bio-based products.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

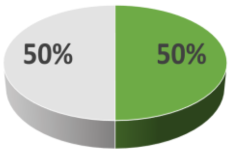
BIO-BASED SURFACTANTS

DEFINITION

Surfactants are usually amphiphilic organic compounds containing both hydrophobic groups (the tail) and hydrophilic groups (the head). Bio-based surfactants are surfactants in which at least one of the two groups is obtained from plants.

MARKET INDICATORS EU-28

Bio-based production:	Bio-based consumption:	Bio-based share in production:
1,500 kt/a	**1,800 kt/a**	



Import dependence: **20%**
Expected annual growth: **4%**

KEY PRODUCTS EU-28

- Many bio-based surfactants are based on vegetable oil, such as **glycolipids** (10 kt/a), **sophorolipids** (50 kt/a) and **esterquats** (130 kt/a).
- The category also contains products from sugar (**APG**, 50 kt/a) and starch (**carboxy methyl starch**, 25 kt/a).

MARKET DESCRIPTION EU-28

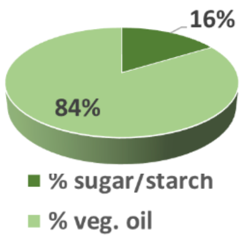
Production maturity

Low	Med	**High**

Importance of the EU

Low	**Med**	High

Feedstock use



APPLICATION SECTORS

Fabric softener, detergents, paper making

DRIVERS

- Functional benefits (low toxicity, biodegradability).
- Regulations restricting the use of fossil products (Regulation EC No 648/2004).

CONSTRAINTS

- High production cost due to the cost of substrates and the more challenging purification processes.
- Low public awareness about bio-based products.

CONCLUSIONS AND OUTLOOK

The large-scale use of bio-based oleochemicals in surfactants leads to a high bio-based share, 50%. Bio-based surfactants often have functional benefits such as lower toxicity and/or biodegradability over petrol-based surfactants. The market is further driven by legislation that favours the use of biodegradable surfactants. Bio-based surfactants form a stable, mature market, which is expected to grow at the same rate as the total surfactants market.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

BIO-BASED COSMETICS AND PERSONAL CARE PRODUCTS

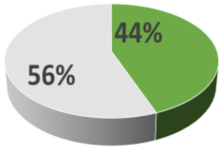
DEFINITION

Cosmetics and personal care products include bath and shower products, decorative cosmetics, deodorants, perfume, hair, skin and mouth care products, shaving products, soaps and sun protection products.

MARKET INDICATORS EU-28

Bio-based production:	Bio-based consumption:
558 kt/a	**558 kt/a**

Bio-based share in production:



Import dependence: unknown
Expected annual growth: **3%**

KEY PRODUCTS EU-28

- The cosmetics industry produces a broad range of products with more than 5,000 ingredients.
- A selection of bio-based compounds used in cosmetics are **xanthan** (44 kt/a), **lauryl alcohol** (100 kt/a) and **stearyl alcohol** (100 kt/a).
- ***N*-acetyl glucosamine** (0 kt/a), **limonene** (4 kt/a) and **vanillin** (1.5 kt/a) are examples of small volume products typically – but not only – used in cosmetics.

MARKET DESCRIPTION EU-28

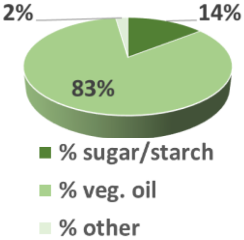
Production maturity

Low	Med	**High**

Importance of the EU

Low	Med	**High**

Feedstock use



APPLICATION SECTORS

Cosmetic and personal care products

DRIVERS

- Promotional benefit of marketing cosmetics as 'natural'.
- Growing demand or market, partly thanks to increasing consumer disposable income.

CONSTRAINTS

- 'Bio-based' is a poor marketing term.
- Cosmetics are often partly bio-based, but only 100% bio-based cosmetics are sold as 'natural', which is a good marketing term.

CONCLUSIONS AND OUTLOOK

Cosmetics have the advantage of being directly influenced by consumer demand. The desire for natural products, together with a history of bio-based products derived from fats and oils, results in a mature bio-based cosmetics market. Another advantage is that increased production costs play less of a role, with consumers willing to pay a green premium in this sector. The market is expected to continue to grow and seems to be particularly driven by consumer demand.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

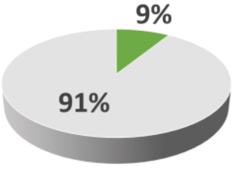
BIO-BASED ADHESIVES

DEFINITION

Adhesives are substances applied to one surface or both surfaces of two separate items to bind them together and prevent their separation.

MARKET INDICATORS EU-28

Bio-based production:	Bio-based consumption:	Bio-based share in production:
237 kt/a	**320 kt/a**	



Import dependence: **35%**
Expected annual growth: **10%**

KEY PRODUCTS EU-28

- Adhesives commonly consist of a polymer, sometimes in the form of a monomer, and a solvent.
- Examples of bio-based polymers in solvents: **methacrylates** (10 kt/a), **furfuryl alcohol** (40 kt/a), **epoxy resins** (4 kt/a) and **tall oil rosin** (141 kt/a).

MARKET DESCRIPTION EU-28

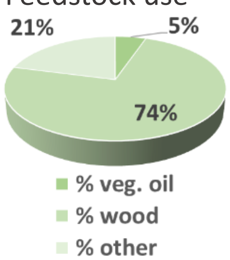
Production maturity

Low | **Med** | High

Importance of the EU

Low | Med | **High**

Feedstock use



APPLICATION SECTORS

Glues, paints, coatings, foundry industry, etc.

DRIVERS

- Growing awareness of the impact of fossil-based adhesives.
- Widespread R&D activity.
- Increasing number of bio-based applications.
- Regulations stimulating demand.

CONSTRAINTS

- Difficulties in maintaining consistent quality.
- Low interest of customers in bio-based adhesives as part of other products.
- Not a very ‘circular’ type of product (limited recycling possibilities).

CONCLUSIONS AND OUTLOOK

The EU produces a large volume of adhesives, accounting for 35% of global production. The EU’s contribution to the bio-based adhesives market is even more pronounced, with 54% of the 441 kt/a global adhesive production coming from the EU. The industry expects that this market will continue to grow even further, with an increasing number of applications.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

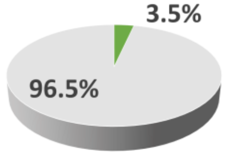
BIO-BASED LUBRICANTS

DEFINITION

Lubricants are substances, usually organic, introduced to reduce friction between surfaces in mutual contact, which ultimately reduces the heat generated when the surfaces move.

MARKET INDICATORS EU-28

Bio-based production:	Bio-based consumption:	Bio-based share in production:
237 kt/a	**220 kt/a**	



Import dependence: **–8%**
Expected annual growth: **1%**

KEY PRODUCTS EU-28

- Many lubricants are already produced with bio-based components, especially fatty acids, fatty alcohols and glycerol.
- Examples of bio-based lubricants are **iso-alkanes** (0 kt/a), **tall oil fatty acids** (2 kt/a), **fatty acid methyl esters** (116 kt/a) and **fatty acid PEG esters** (50 kt/a).

MARKET DESCRIPTION EU-28

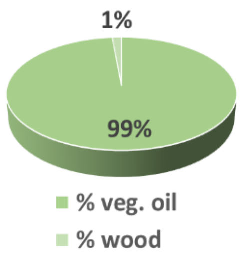
Production maturity

Low	Med	**High**

Importance of the EU

Low	Med	**High**

Feedstock use



APPLICATION SECTORS

Lubricants for chainsaws, engines, textiles, etc.

DRIVERS

- Growing automotive industry increases demand.
- Mainly based on the well-developed oils and fats platform
- Regulations stimulating use.

CONSTRAINTS

- Low awareness due to its applications.
- Difficult of obtaining desired properties (odour free, stable to oxidation, range of viscosities).
- More efficient use of lubricants and electric cars could decrease future demand.

CONCLUSIONS AND OUTLOOK

Owing to regulations on total-loss lubricants (e.g. Commission Decision 2011/381/EU), bio-based lubricants already have a mature market, which is found mostly in the Nordic countries. In these countries, total-loss lubricants are used, for example, for chainsaws. Further market growth will depend on the introduction of stimulating legislation in other sectors, for example for engine lubricants. Otherwise, the bio-based lubricant market is not expected to grow much.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

BIO-BASED PLASTICISERS

DEFINITION

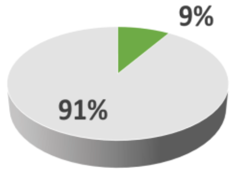
Plasticisers or dispersants are additives that increase the plasticity or decrease the viscosity of a material.

MARKET INDICATORS EU-28

Bio-based production: **67 kt/a**

Bio-based consumption: **117 kt/a**

Bio-based share in production:



Import dependence: **74%**
Expected annual growth: **3%**

KEY PRODUCTS EU-28

- **Succinic acid** (23 kt/a) is one of the most commonly used bio-based additives.
- **ESBO** is another commonly used bio-based plasticiser, but it is not produced in the EU.
- Another example of a bio-based plasticiser is **azelaic acid** (12.8 kt/a).

MARKET DESCRIPTION EU-28

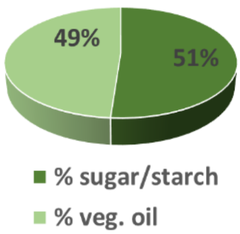
Production maturity

Low | Med | High

Importance of the EU

Low | Med | High

Feedstock use



APPLICATION SECTORS

Plastics production

DRIVERS

- Restrictions on the use of certain phthalates as part of REACH.
- Biodegradable plasticisers are important for application in biodegradable plastics.
- Greater safety.

CONSTRAINTS

- High production cost, due to feedstock, compared with the costs of phthalate-based plasticisers.
- Continuous changes in environmental guidelines.

CONCLUSIONS AND OUTLOOK

Thanks to a decrease in the use of certain toxic phthalate-based plasticisers in toys and childcare articles, there has been an increasing demand for bio-based alternatives. However, the higher costs of these plasticisers limit the market potential. Production takes place mostly outside the EU, with only 8% of bio-based plasticisers being produced within the EU's borders. This results in the EU having a high import dependence in relation to these products.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

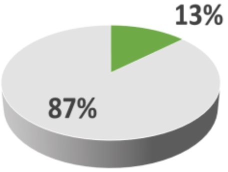
BIO-BASED MAN-MADE FIBRES

DEFINITION

Man-made fibres are polymers that are spun into fibres for various applications, which include a huge number of consumer and industrial products.

MARKET INDICATORS EU-28

Bio-based production:	Bio-based consumption:	Bio-based share in production:
600 kt/a	**630 kt/a**	



Import dependence: **5%**
Expected annual growth: **3%**

KEY PRODUCTS EU-28

- Examples of traditional bio-based fibres are **rayon** (600 kt/a) and **cellulose acetate** (165 kt/a).
- **Polyamide-11** (23 kt/a) and **polyamide-4,10** (1 kt/a) are dedicated bio-based fibres.
- **Polytrimethylene terephthalate** (**PTT**, 0 kt/a) is a drop-in bio-based fibre.

MARKET DESCRIPTION EU-28

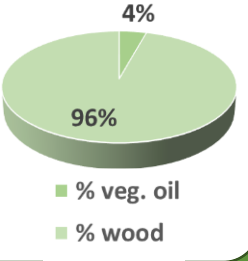
Production maturity

Low	**Med**	High

Importance of the EU

Low	**Med**	High

Feedstock use



APPLICATION SECTORS

Textiles, carpets, moulding, cables, pipes, etc.

DRIVERS

- Promotional benefit of a natural product.
- Promotional benefit when marketed as a biodegradable product.
- Growing demand and market.
- High EU environmental standards.

CONSTRAINTS

- Lower standards outside the EU.
- The distinction between traditional and novel bio-based man-made fibres, for example in relation to funding schemes, divides the industry.

CONCLUSIONS AND OUTLOOK

Both total and bio-based man-made fibre production takes place mainly outside the EU, i.e. only 2% of the global output of 36 Mt/a is produced in the EU. The market is very mixed, with some very mature products, such as rayon and cellulose acetate, and some newer products, such as polyamide-4,10 and PTT. Not all of these products are covered by funding schemes that are designed to promote a bio-based economy.

European Commission
Joint Research Centre

This factsheet is part of the report *Insights into the European market for bio-based chemicals*, produced by BTG Biomass Technology Group B.V. and the JRC D4 Unit in the framework of the European Commission's Knowledge Centre for Bioeconomy and with financial support from DG RTD. The contents of these factsheets are the sole responsibility of BTG and do not imply a policy position of the European Commission.

btg biomass technology group

-

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: http://europea.eu/contact

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

- at the following standard number: +32 22999696, or

- by electronic mail via: http://europa.eu/contact

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: http://europa.eu

EU publications

You can download or order free and priced EU publications from EU Bookshop at: http://bookshop.europa.eu. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see http://europa.eu/contact).

KJ-NA-29581-EN-N

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

doi:10.2760/549564

ISBN 978-92-79-98420-4