Roadmap for the Chemical Industry in Europe towards a Bioeconomy

Action Plan

2019

Contents

Acronyms

Acronym	Full form
1G feedstock	First generation feedstock
2G feedstock	Second generation feedstock
3G feedstock	Third generation feedstock
5-HMF	5-hydroxymethylfurfural
BBI JU	Bio-based Industries Joint Undertaking
BIC	Bio-based Industries Consortium
BTG	Biomass Technology Group B.V.
Cefic	European Chemical Industry Council
CEN	The European Committee for Standardization
CIRFS	Comité International de la Rayonne et des Fibres Synthétiques OR European Man-Made Fibres Association
DECHEMA	Gesellschaft für chemische Technik und Biotechnologie e.V. (Society for Chemical Engineering and Biotechnology)
E4tech	E4tech (UK) Ltd.
EC	European Commission
ECPA	The European Crop Protection Association
ESIG	European Solvents Industry Group
EUBP	European Bioplastics
GHG	Greenhouse gas
GMO	Genetically modified organism
kt/yr	kilo tonnes per year
L	Large
LAS	Linear alkylbenzene sulfonate
M	Medium

Acronym	Full form
MES	Methyl ester sulfonate
MIBK	Methyl isobutyl ketone
Mt/yr	Million tonnes per year
NACE	*Nomenclature statistique des activités économiques dans la Communauté européenne.* Statistical classification of economic activities in the European Community
NATRUE association	True Friends of Natural and Organic Cosmetics
nova-Institute	Nova-Institut für politische und ökologische Innovation GmbH
PEF	Polyethylene furanoate
PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoate
PLA	Polylactic acid
PRODCOM	**Prod**uction **Com**munautaire
PTT	Polytrimethylene terephthalate
PVC	Polyvinyl chloride
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (EU regulation)
RoadToBio	Roadmap for the Chemical Industry in Europe towards a Bioeconomy (Project Acronym)
S	Small
SME	Small and Medium-sized Enterprises
TRL	Technology Readiness Level
VOCs	Volatile organic compound(s)

Glossary

1G feedstock	First generation feedstock: The source of carbon is sugar, lipid or starch directly extracted from a plant. The crop is actually or potentially considered to be in competition with food.
2G feedstock	Second generation feedstock: The carbon is derived from cellulose, hemicellulose, lignin or pectin. For example, this may include agricultural and forestry wastes or residues, or purpose-grown non-food feedstocks (e.g. Short Rotation Coppice, Energy Grasses).
3G feedstock	Third generation feedstock: The carbon is derived from aquatic autotrophic organism (e.g. algae). Light, carbon dioxide and nutrients are used to produce the feedstock "extending" the carbon resource available for biochemicals production. This means, however, that a heterotrophic organism (using sugar or cellulose to produce biochemicals) would not be considered as 3G.
Bio-based drop-in chemicals	Bio-based versions of existing petrochemicals which have established markets. They are chemically identical to existing fossil-based chemicals.
Bio-based smart drop-in chemicals	A sub-group of drop-in chemicals. They are also chemically identical to existing chemicals based on fossil hydrocarbons, but their bio-based pathways provide advantages compared to the conventional pathways. Drop-in chemicals are 'smart drop-ins' if at least two of the following criteria apply: • The Biomass Utilization Efficiency from feedstock to product is significantly higher compared to other drop-ins. • Their production requires significantly less energy compared to other production alternatives. • Time-to-product is shorter due to shorter and less complex production pathways compared to the fossil-based counterpart or other drop-ins. • Fewer toxic chemicals are used or occur as by-products during their production process compared to the fossil-based counterpart or other drop-ins.
Dedicated bio-based chemicals	Chemicals which are produced via a dedicated pathway and do not have an identical fossil-based counterpart. As such, they can be used to produce products that cannot be obtained through traditional chemical reactions and products that may offer unique and superior properties that are unattainable with fossil-based alternatives.
NACE (Nomenclature of Economic Activities)	NACE is the European statistical classification of economic activities. NACE groups are organised according to their business activities. Statistics produced based on NACE are comparable at European level and, in general, at world level in line with the United Nations' International Standard Industrial Classification (ISIC).
PRODCOM	PRODCOM uses the product codes specified on the PRODCOM list, which contains about 3900 different types of manufactured products. Products are identified by an 8-digit code: • The first four digits are the classification of the producing enterprise given by the Statistical Classification of Economic Activities in the European Community (NACE) and the first six correspond to the CPA • The remaining digits specify the product in more detail

Introduction

The RoadToBio project is funded by the EU under the Horizon 2020 research and innovation programme. Its aim is to provide a roadmap for the European chemical industry to exploit potential opportunities offered by the bioeconomy and increase the share of bio-based products. The **RoadToBio bio-based chemicals roadmap for the European chemical industry** ("RoadtoBio roadmap") aspires to increase the share of bio-based or renewable feedstock[1] to 25% of the total volume of organic chemicals raw materials/feedstock used by the chemical industry in 2030. To meet societal needs the biomass used for bio-based chemicals must meet stringent sustainability criteria including on direct and indirect land use change.

The 25% target was set by the Bio-based Industries Consortium (BIC) in the 2017 Strategic Innovation and Research Agenda (SIRA), which provides innovation and research guidelines for the European biorefinery sector.

The RoadToBio roadmap aims to provide an evidence-based foundation for the EU chemical industry upon which future industry and policy actions can be based. It consists of three different publications: An action plan, the strategy document and an engagement guide. To ensure it has credibility, it has been developed in consultation with stakeholders from industry, government and other organisations. The roadmap will be successful if governments and the chemical industry in Europe build on its evidence, analysis, key messages and strategic conclusions to increase the share of bio-based chemicals, delivering significant reductions in carbon emissions, increased energy efficiency, and creating a strong competitive position for the EU chemical industry in the decades to come.

1 This could be 1G, 2G as well as 3G feedstocks (see glossary for definitions)

Identifying bio-based chemicals opportunities and developing a roadmap

RoadToBio has focused on the following nine product groups:

adhesives, agrochemicals, cosmetics, lubricants, man-made fibres, paints and coatings, plastics/polymers, solvents, and surfactants.

These nine product groups cover a range of different NACE classes and PRODCOM groups, and with that a significant part of the chemical industry.

The current bio-based share of these nine product groups was estimated using Eurostat data, literature and market analysis[2] (see Figure 1).

The RoadToBio roadmap development involved the following research and analysis:

- Assessment of opportunities for introducing bio-based chemicals in existing value chains of the chemical industry (D1.1)[3]
- Development of nine case studies on potentially attractive opportunities for bio-based chemicals in Europe (D1.2)
- Identification of regulatory and societal barriers for increasing bio-based feedstock supply as well as bio-based chemicals demand (D2.1-D2.4)
- Analysis of interfaces and differences between the bio-based and circular economy (D2.5)
- Overview of bio-based chemicals/products in use. Analysis of desired sustainability characteristics[4] of fossil-derived products and bio-based substitutes (D4.2)
- Identification of opportunities and barriers for uptake of bio-based chemicals/products in the nine product groups considered. Recommended actions for different stakeholders to 2030 (D4.2)
- Identification of general barriers for bio-based chemistry and the bioeconomy in Europe. Recommended actions for different stakeholders (D4.2)
- Action plan (D4.3): this document
- Engagement guide (D4.4): The engagement guide is a series of three factsheets (Readers' guide, Communication guide, Key messages) that complement the roadmap by providing guidance on selected topics to help with implementation of the roadmap.

The roadmap development also involved stakeholder engagement activities:

- Monthly newsletters
- Webinars communicating interim results
- Interviews with key stakeholders
- Stakeholder review of key project deliverables
- Stakeholder workshops at key milestones of the project

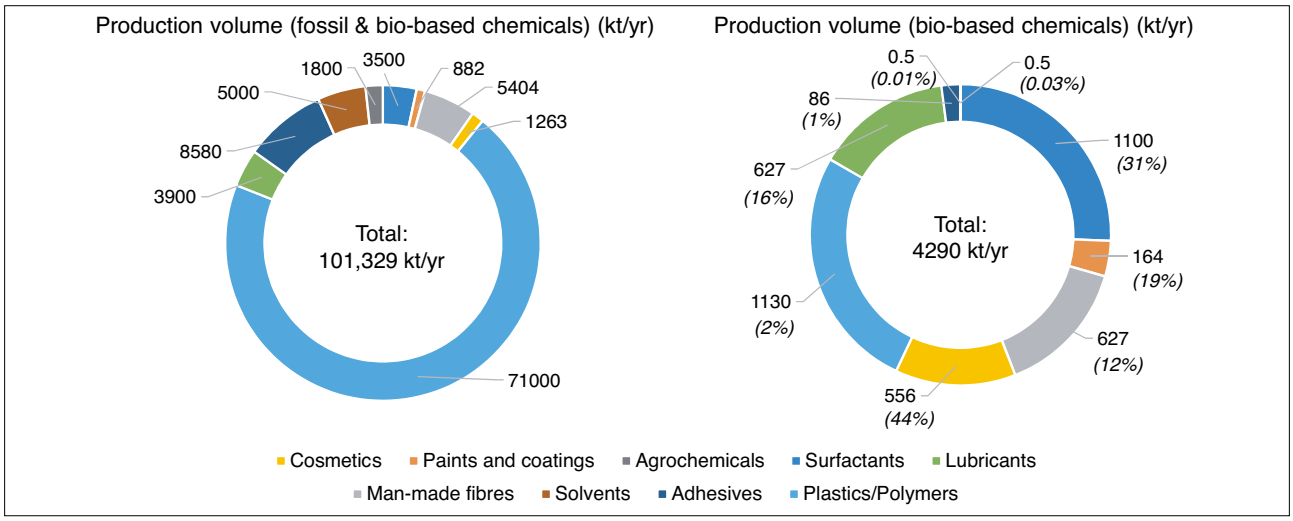


Figure 1: Comparison of volumes of bio-based chemicals and total volumes of chemicals in nine product groups (in kt/yr) in the EU. Reference year: 2015

2 Please note that these numbers are estimations based on various sources and market analysis.

3 D1.1, D1.2, etc. refer to RoadToBio interim deliverables. Annex A contains links to all project deliverables.

4 See Annex B for explanation

RoadToBio Action Plan

The action plan draws upon the RoadToBio strategy document, which includes detailed information on the drivers for bio-based market growth, as well as the opportunities and barriers to increasing the share of bio-based chemicals in the nine product groups.

Short, mid and long-term actions, between 2019 and 2030, are proposed to address the barriers identified for each product group, and four key stakeholder groups identified for implementing the recommended actions (Figure 2).

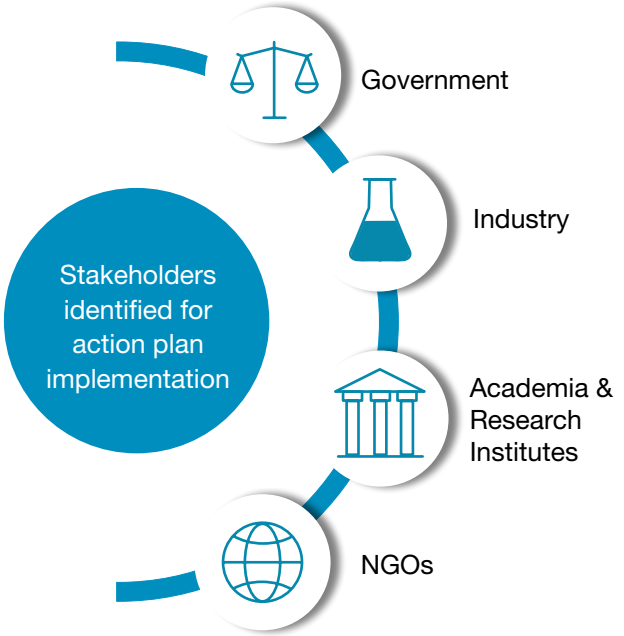


Figure 2: Stakeholders who need to be involved for implementation of the RoadToBio action plan

Several recommended actions require collaboration between stakeholders. For example, actions related to R&D and demonstration-scale projects require collaborative effort by government, academia & research institutions and industry.

Several associations and NGOs, that play or could play a role in the promotion of bio-based products, have also been identified in relation to the product groups, such as NATRUE (True Friends of Natural and Organic Cosmetics), ECPA (European Crop Protection Association), CIRFS (European Man-Made Fibres Association), ESIG (European Solvents Industry Group), and EUBP (European Bioplastics). Further, there are specific chemical industry associations at Member State level, and these associations' bioeconomy-related policy papers and statements have been considered in formulating the roadmap. Some have also provided input during the stakeholder engagement exercise.

Several companies are already active in bio-based chemicals production and promotion, and a few are listed here[5]:

Product group	Key companies or industry players
Cosmetics	Keracol Limited, Clariant Personal Care
Paints & coatings	DSM, Corbion
Agrochemicals	Corteva, Sipcam-Oxon
Surfactants	Ecover, Henkel
Lubricants	Total, PANOLIN AG
Man-made fibres	Sofila, Lenzing
Solvents	Green Biologics Limited, Roquette
Adhesives	VTT, Arkema
Plastics/polymers	Novamont, BASF

Finally, policy makers both at the EU level and within Member States play a key role in the formulation of policies and legislations required to advance the bioeconomy in Europe. Table 1 shows EU policies and initiatives related to the bioeconomy. Refinement and further development of policies will require collaborative input from stakeholders such as industry, academia and NGOs.

Table 1: Overview of the main EU policies relevant to a bioeconomy (Source: European Parliamentary Research Service)

Agriculture	Forestry	Fisheries
• Common Agricultural Policy (CAP)	• New EU forest strategy	• Common Fisheries Policy (CFP) • Blue Growth Agenda

Climate	Circular economy	Research & Innovation
• Europe 2020 Strategy • 2030 climate and energy policy	• Circular economy action plan • Waste legislation	• Horizon 2020 • European Research Area Networks (ERA-NETs) • Joint Programming Initiatives

5 This is not an exhaustive list, and the companies have not been listed in any specific order.

However, there is very limited policy or legislation specifically dedicated to bio-based products besides bioenergy. Though bio-based products and industrial biotechnology have been identified as priority market and technology under initiatives such as the Key Enabling Technologies (KETs) Strategy.

Bioeconomy-related strategies are being developed in several EU Member States and regions. Multiple government departments are involved in the formulation and implementation of these strategies. The European Commission's Knowledge4Policy[6] portal maintains a database of Member State bioeconomy initiatives and related actors (see Figure 3).

Collaboration between companies and associations with an interest in the bioeconomy and relevant government departments, academic institutions as well as fossil-based chemicals industry players will be critical in implementing the RoadToBio action plan. The intention is that the RoadToBio action plan serves as input to the formulation of bioeconomy policies and initiatives at EU and Member State level, and that the actions proposed trigger collaboration between stakeholders.

Collaborations are already underway as illustrated by several H2020 project consortia. But, broader interaction amongst stakeholders is needed to develop the framework for a bio-based industry. There is also a need for further public-private fora and partnerships like the Bio-based Industries Joint Undertaking (BBI JU), and to reinforce existing activities post 2020 as they have had a key role in developing the bioeconomy. The networking and stakeholder engagement activities of RoadToBio have generated considerable interest in this regard among different stakeholders.

Figure 4 provides an overview of the RoadToBio project focus. The following sections provide a summary of the opportunities, barriers and actions required to increase the share of bio-based chemicals in nine product groups in Europe.

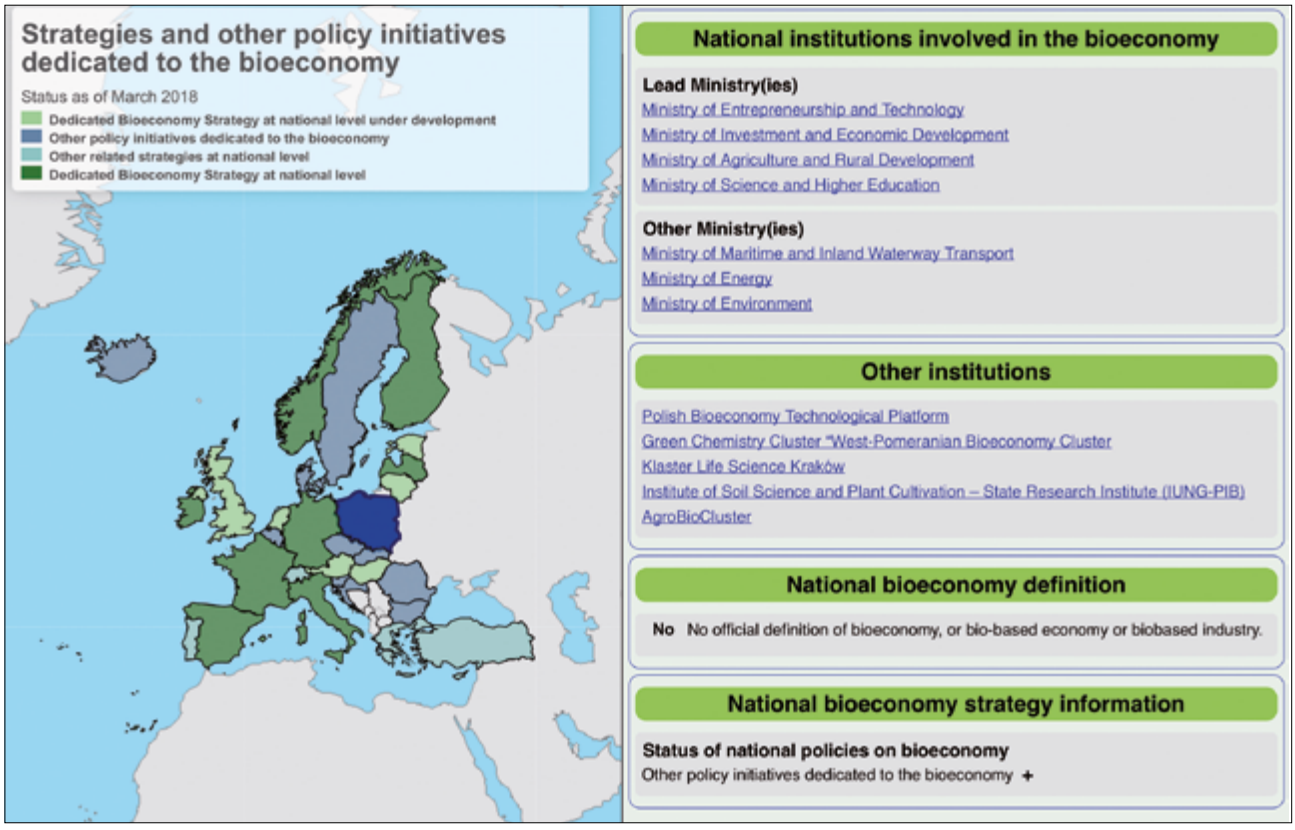


Figure 3: Member State-level bioeconomy strategies and policy initiatives. List in the figure is specific to Poland. Similar information is available for other Member States. (Source: European Commission – Knowledge4Policy)

6 Knowledge4Policy website: https://ec.europa.eu/knowledge4policy/bioeconomy/topic/policy_en.

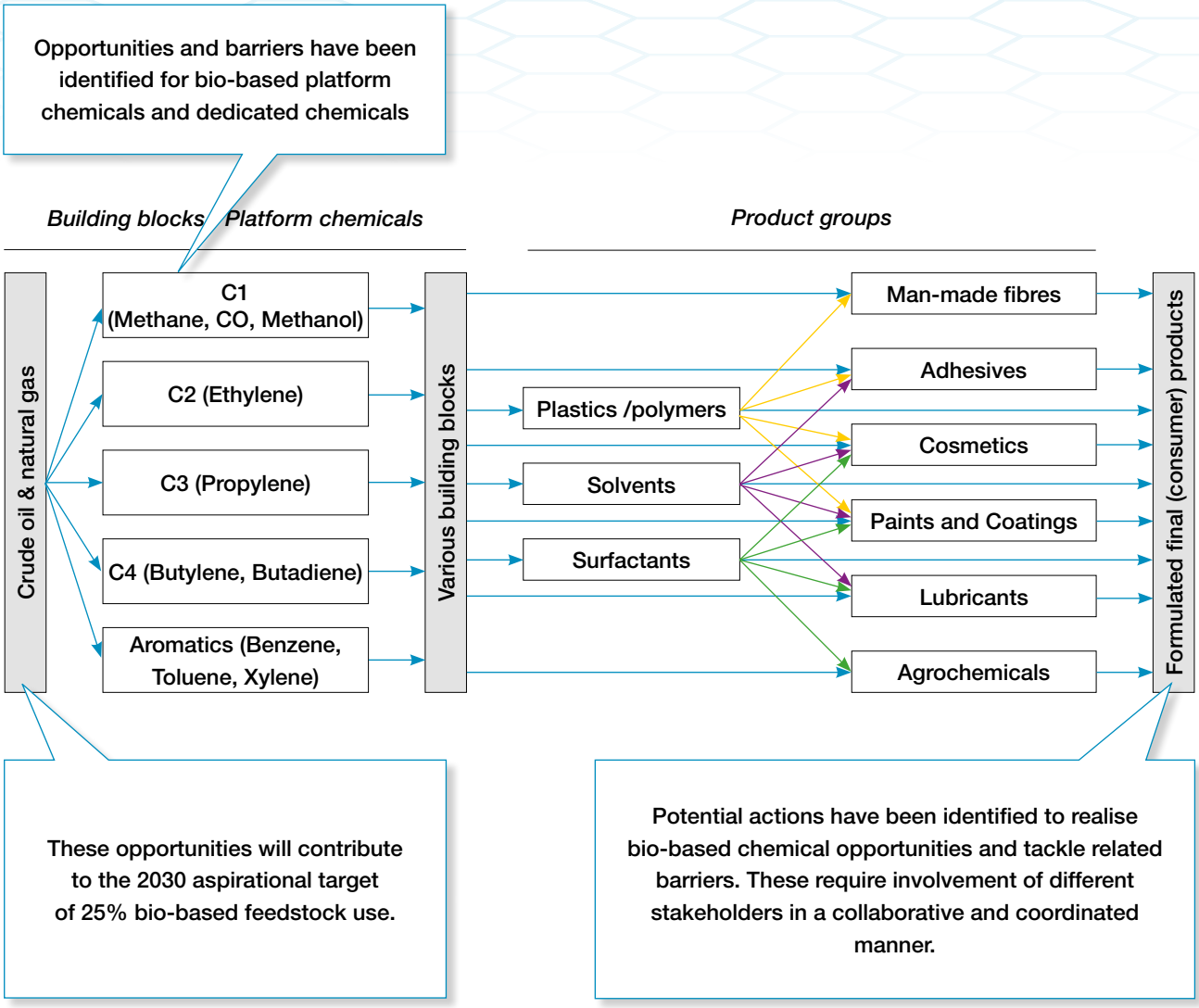


Figure 4: Overview of the RoadToBio project target, product groups and outcome.

1. Cosmetics

- The share of bio-based chemicals in cosmetics produced in the EU is about 40%, which is the highest among all product groups that are considered in RoadToBio.
- European consumers' emerging environmental awareness and a growing trend for natural products is driving the uptake of bio-based chemicals in cosmetics. Costs are less important constraints in the cosmetics segment.
- Biodegradability and low human toxicity are the main desired sustainability characteristics in the cosmetics product group. Bio-based products such as botanical extracts and vegetable oils have these key characteristics. However, bio-based solvents such as acetone are toxic and non-biodegradable, thereby presenting an opportunity for development and commercialisation of novel bio-based solvents that are safe to use and dispose.
- Functional ingredients and chemical building blocks used in cosmetics such as preservatives, solvents and surfactants are still mainly derived from fossil feedstock and therefore are unsustainable.
- Low GHG emissions is a desired sustainability characteristic for building blocks such as solvents and surfactants that are used in cosmetics. The bio-based chemicals identified in the sample could lead to low GHG emissions compared to the fossil equivalents.
- By volume of use, botanical extracts and vegetable oils outweigh building blocks like lactic acid and succinic acid. In order to attain higher bio-based share in the cosmetics product group, these two subgroups will play a vital role and therefore should be the subject of further research and product development.
- Bio-based preservatives underperform in comparison to the fossil derived ones. This area of cosmetics presents an opportunity for the development and further growth of bio-based chemicals.
- European cosmetics industry is strictly regulated. Ingredients such as preservatives, UV-filters, nanomaterials or colorants are subject to long and often expensive approval procedures. Other ingredients must be safe for cosmetic use by meeting the requirements of EU legislations (cf. REACH and Cosmetic Regulation)
- Opportunities also exist in using alternate feedstocks like algae, and technology for the extraction and preservation of bioactive ingredients.

Further details about the cosmetics product group can be found here.

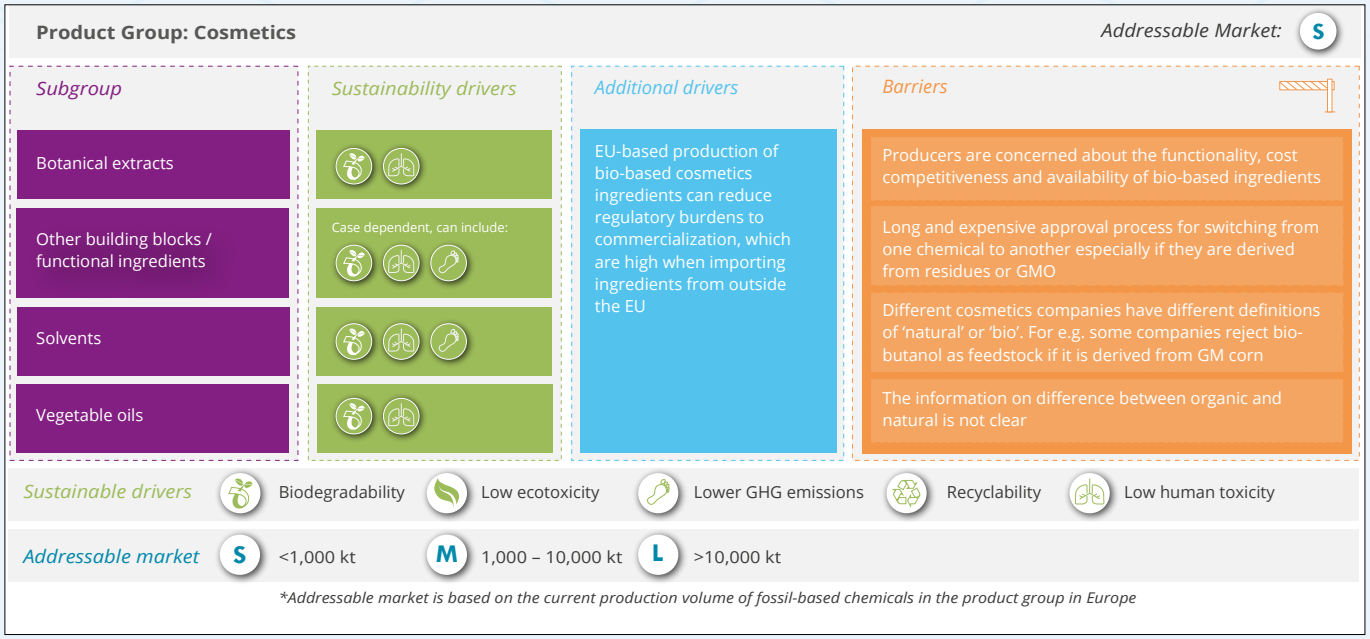


Figure 5: Pictorial summary of the cosmetics product group

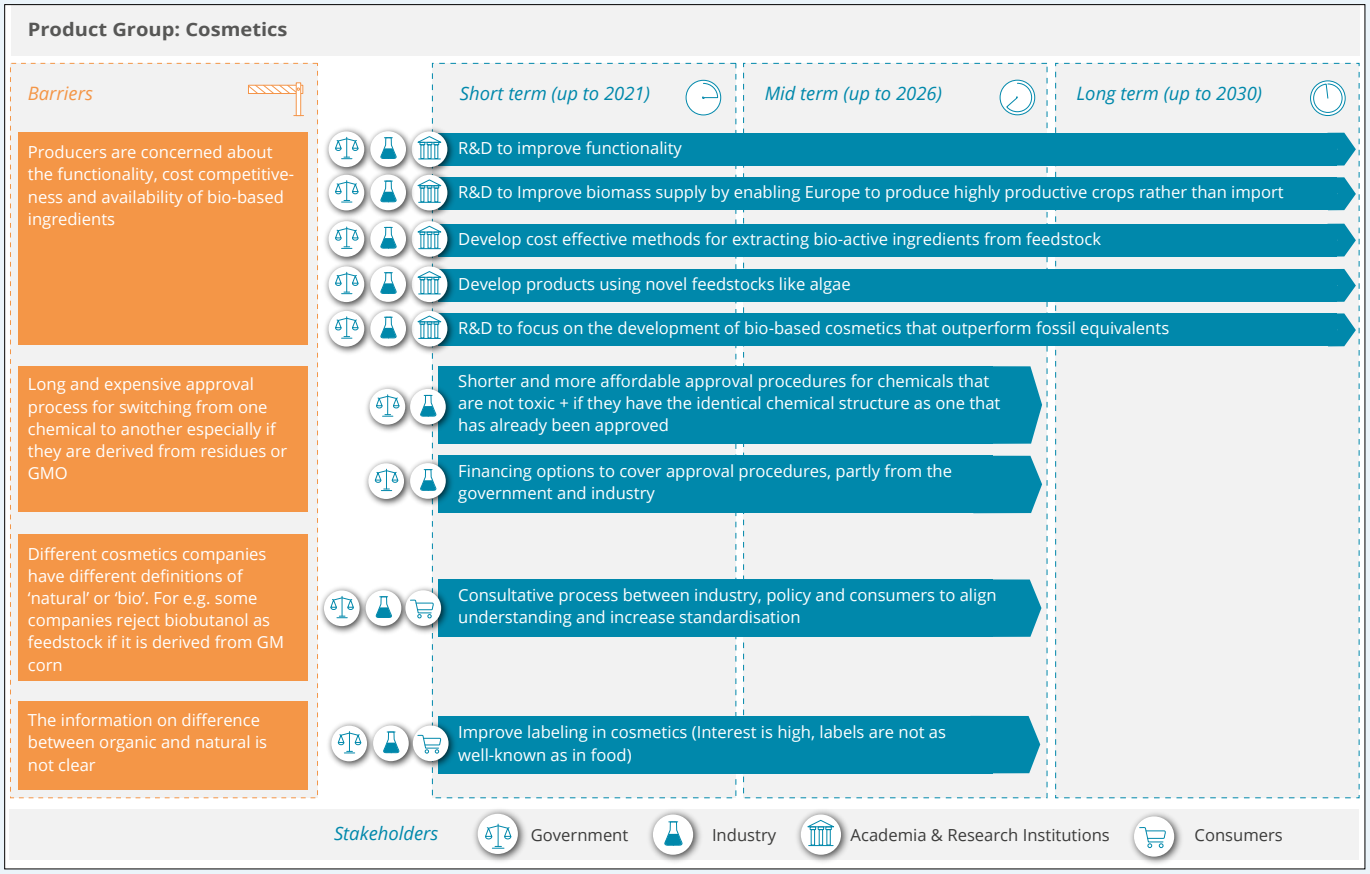


Figure 6: Roadmap to increasing the bio-based share of chemicals in the cosmetics product group

2. Paints & coatings

- There is a trend in paints and coatings towards more sustainable alternatives to fossil-based versions, mainly driven by producers responding to consumer demand for non-toxic, sustainable products.
- The elimination of toxic ingredients, reduction of VOCs to improve and protect indoor and outdoor air quality ("green building" movement) and reduction of carbon footprint are driving forces to an increased use of bio-based ingredients
- Bio-based production of paints and coatings in Europe is ~164 kt/yr, while fossil-based production is ~718 kt/yr.
- The addressable market of paint and coatings in Europe is small (less than 1,000kt) in comparison to the other eight product groups.
- The performance and key parameters requirements of paints and coatings strongly depend on the area of application. Typical performance criteria include the desired appearance, ease of application, viscosity, durability, drying time, etc.
- Barriers to bio-based uptake in paints and coatings result from price and performance issues; the replacement of VOC solvents usually results in shorter drying times, meaning less time to work with the products.
- Significant investment in new formulations is necessary, as well as the development of new application techniques with appropriate instruction guidelines for users.
- There are increased opportunities for bio-based materials that can be combined with functional bio-based additives such as enzymes, anti-microbial peptides, metal binding peptides and many more, to provide new enhanced paints and coatings.
- Paints and coatings are complex formulations. It is rarely possible to exchange one component for another without adjusting the whole formulation. Thus, replacement of one component often requires the development of a completely new formulation. This is a barrier, but also an opportunity for the introduction of new components with new functionalities that might not have worked in "traditional" formulations.
- Driven by the growth of the shipping industry and increasingly strict GHG and environmental regulations, companies are innovating in this space in order to find non-ecotoxic and biodegradable alternatives, such as enzyme-based compounds.

Further details about the paints and coatings product group can be found here.

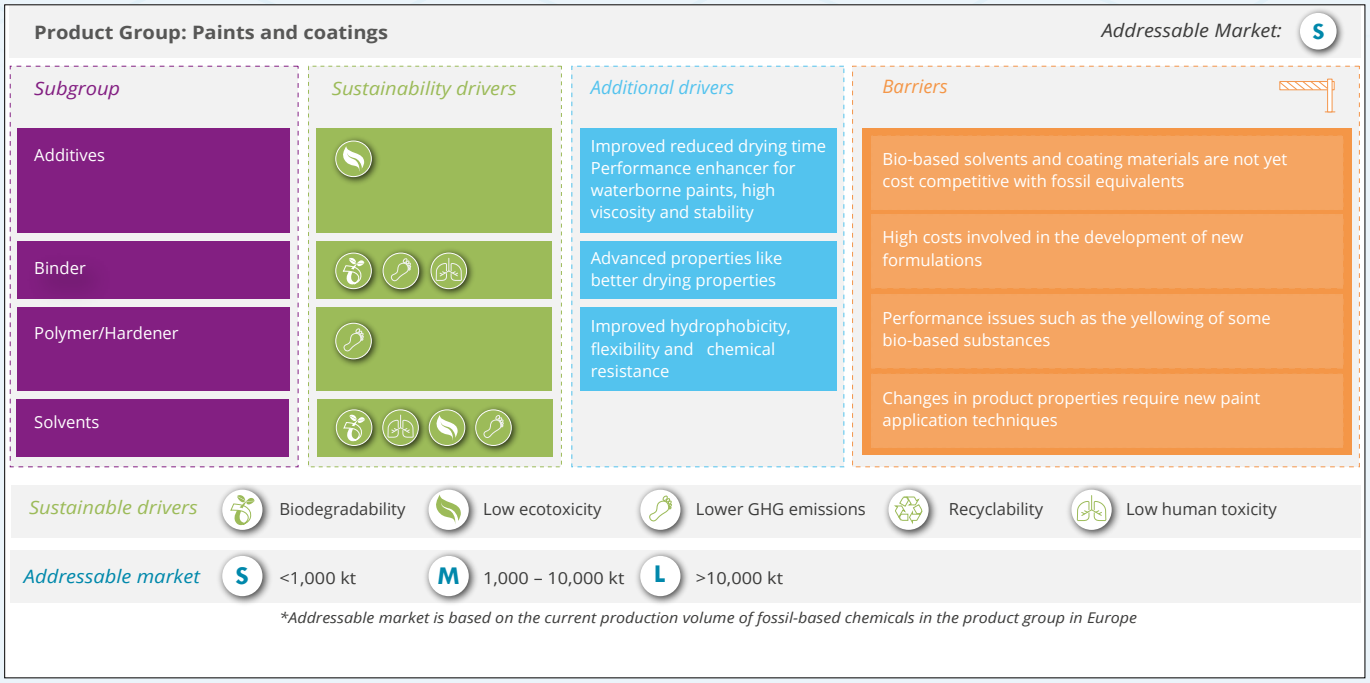


Figure 7: Pictorial summary of the paints and coatings product group

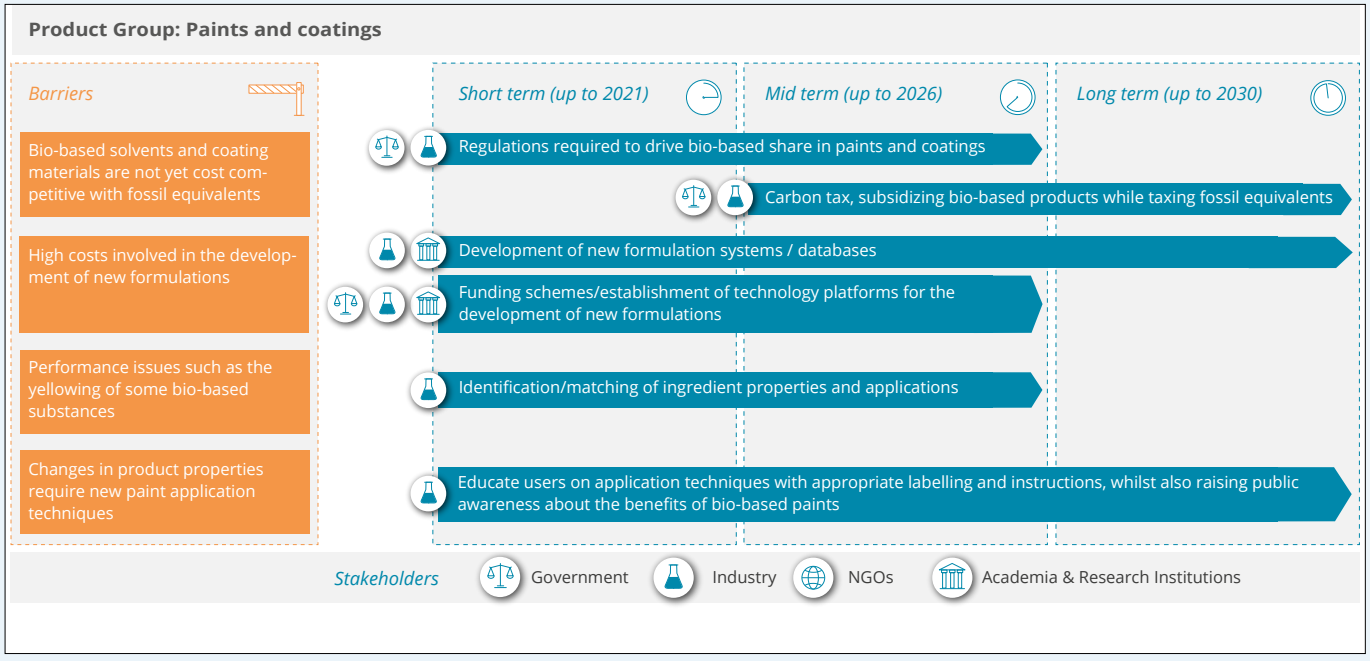


Figure 8: Roadmap to increasing the bio-based share of chemicals in the paints and coatings product group

3. Agrochemicals[8]

- There is a growing market for fertiliser coatings that are bio-based and biodegradable, as well as for biostimulants (including chitosan, seaweed extracts) and biological seed treatment (including botanicals).
- Biodegradability, low human toxicity and low ecotoxicity are the desired sustainability characteristics in agrochemicals. However, the bio-based chemical must at least have the same level of performance as the fossil-based agrochemical.
- Bio-based chemical building blocks such as bio-based lactic acid, methanol and fatty alcohols present an opportunity for converting conventional fossil-based agrochemicals into partly bio-based equivalents. The performance of the latter should be, at least, at par with the fossil-based agrochemicals.
- Bio-based crop protection products start degrading soon after application resulting in little or no toxic residue. However, the drawback is that they need to be applied more frequently in order to be effective. Formulation of bio-based crop protection products can be improved to address this issue.
- New bio-based crop protection products can help address the issue of pesticide resistance in pest populations.
- European agrochemical industry is strictly regulated. Use of new ingredients in products is subject to long and often expensive approval procedures. There is a low risk category within the legislation 1107/2009 that places plant protection products on the market. This could be readily adapted for speedier approval of bio-based pesticides and is already ratified by the European Parliament. However, it is yet to be actioned by the European Commission.
- Key actors of European agrochemical industry include: Syngenta, Bayer Crop Science, Corteva (Dow Agrosciences, DuPont and Pioneer merger), BASF, Sipcam-Oxon.

Further details about the agrochemicals product group can be found here.

8 For RoadToBio, the following agrochemicals were out of scope:
– fertilisers (as they primarily contain inorganic compounds). However, coatings for fertilisers are included in the analysis.
– Microbial agrochemicals such as microbial pesticides. RoadToBio only focuses on biochemical-based pesticides where organic chemistry plays a role.

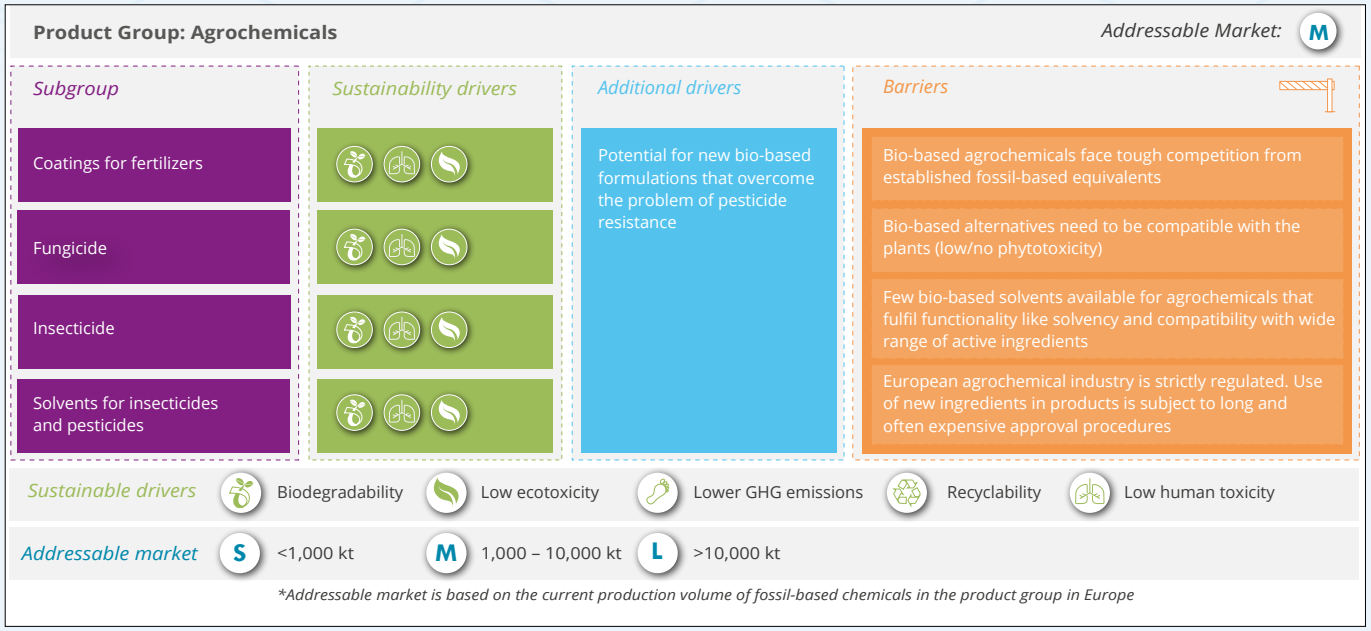


Figure 9: Pictorial summary of the agrochemicals product group

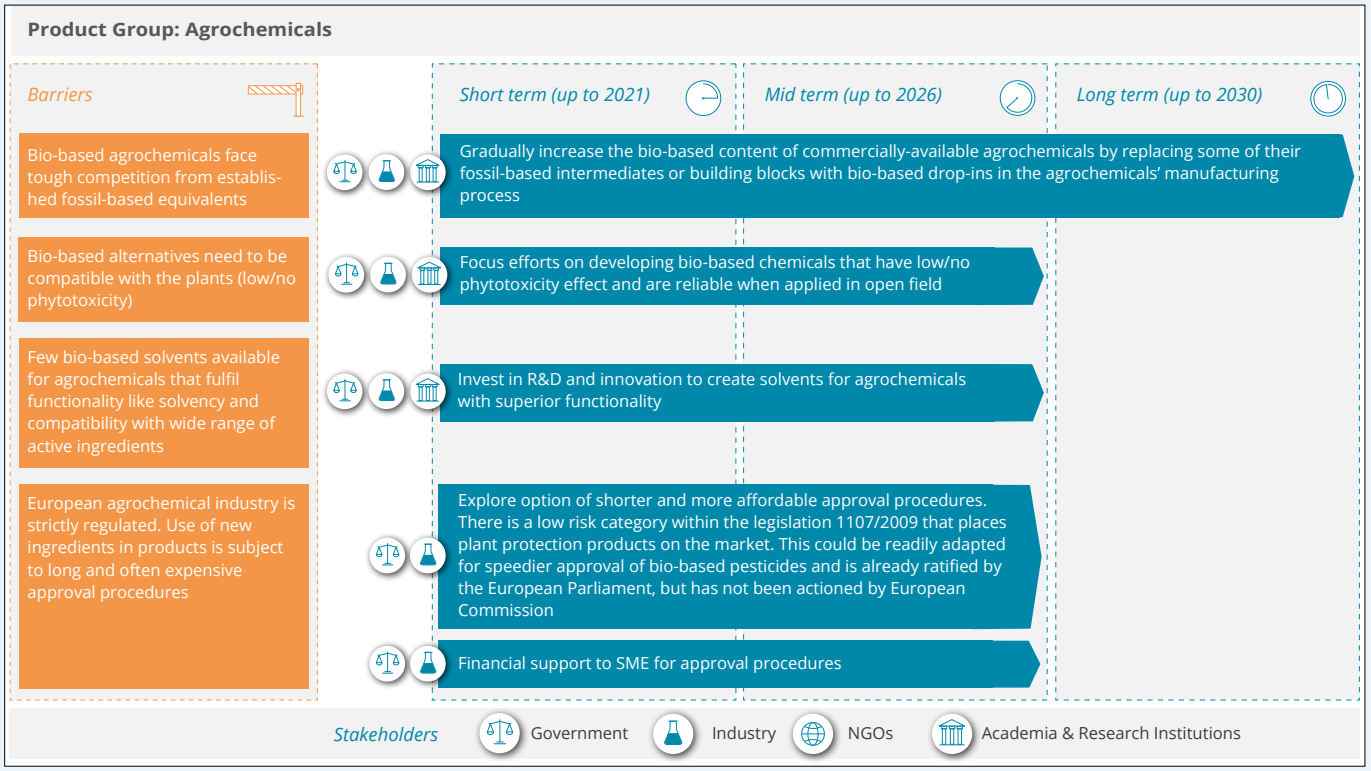


Figure 10: Roadmap to increasing the bio-based share of chemicals in the agrochemicals product group

4. Surfactants

- Bio-based surfactants are produced as high value products, typically for high-end customer products, such as personal care and home care products.
- Methyl ester sulfonate (MES) offers the biggest opportunity to shift from fossil to bio-based surfactants. It could be a bio-based alternative for linear alkylbenzene sulfonate (LAS) and has high potential to be used in cosmetic products.
- The demand for bio-based surfactants strongly depends on household spending.
- There is drive/requirement for clear labelling, so consumers can increasingly opt to buy product using bio-based alternatives.
- The key drivers for bio-based surfactants are their biodegradability, lower human toxicity and lower ecotoxicity, especially in environments where these sustainability characteristics are required.
- Production of bio-based surfactants in Europe is ~1,100 kt/yr, while fossil-based production is ~2,400 kt/yr.
- The addressable market of fossil-based surfactants production in Europe is medium-sized (1,000-10,000 kt/yr) in comparison to the other eight product groups.
- Besides being made from renewable feedstock, the main advantages of bio-based surfactants are possible antimicrobial properties; better performance compared to fossil equivalents which allows to use smaller quantities of surfactants; better foaming properties; higher selectivity for application at lower temperatures, higher pH and salinity; ability to achieve regulatory compliances with regard to (environmental) safety and use of low-cost feedstocks (i.e. fats and oils, sugars).
- Due to the advanced product properties the use of bio-based surfactants is possible in a wide range of product applications (cleaning, personal care, food processing, agrochemicals and textiles). However, these products remain niche due to their limited cost competitiveness compared to conventional products.
- Bio-based surfactants are usually used in end-product formulations where the modification of one component has an impact on the overall composition and performance, which causes additional development costs. This cost barrier could be overcome by targeted support and funded research towards new product formulations. The clear advantage for companies is flexibility in composition, if a certain performance can be ensured.
- Due to the limited number of large-scale producers a secured steady supply of bio-based surfactants is uncertain which creates risk for suppliers like personal and home care producers.
- Key companies producing bio-based surfactant include Evonik, Ecover, Henkel, Saraya, Soliance, Wheatoleo and Nouryon.

Further details about the surfactants product group can be found here.

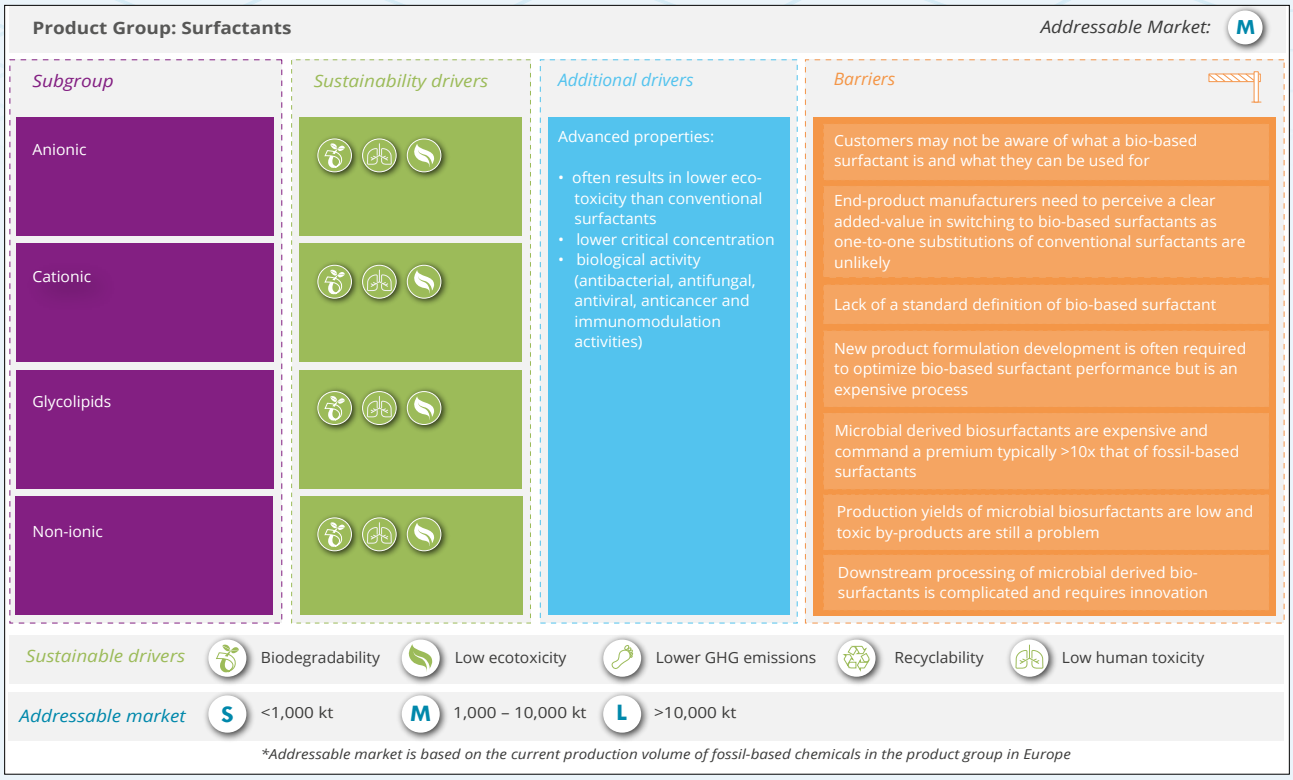


Figure 11: Pictorial summary of the surfactants product group

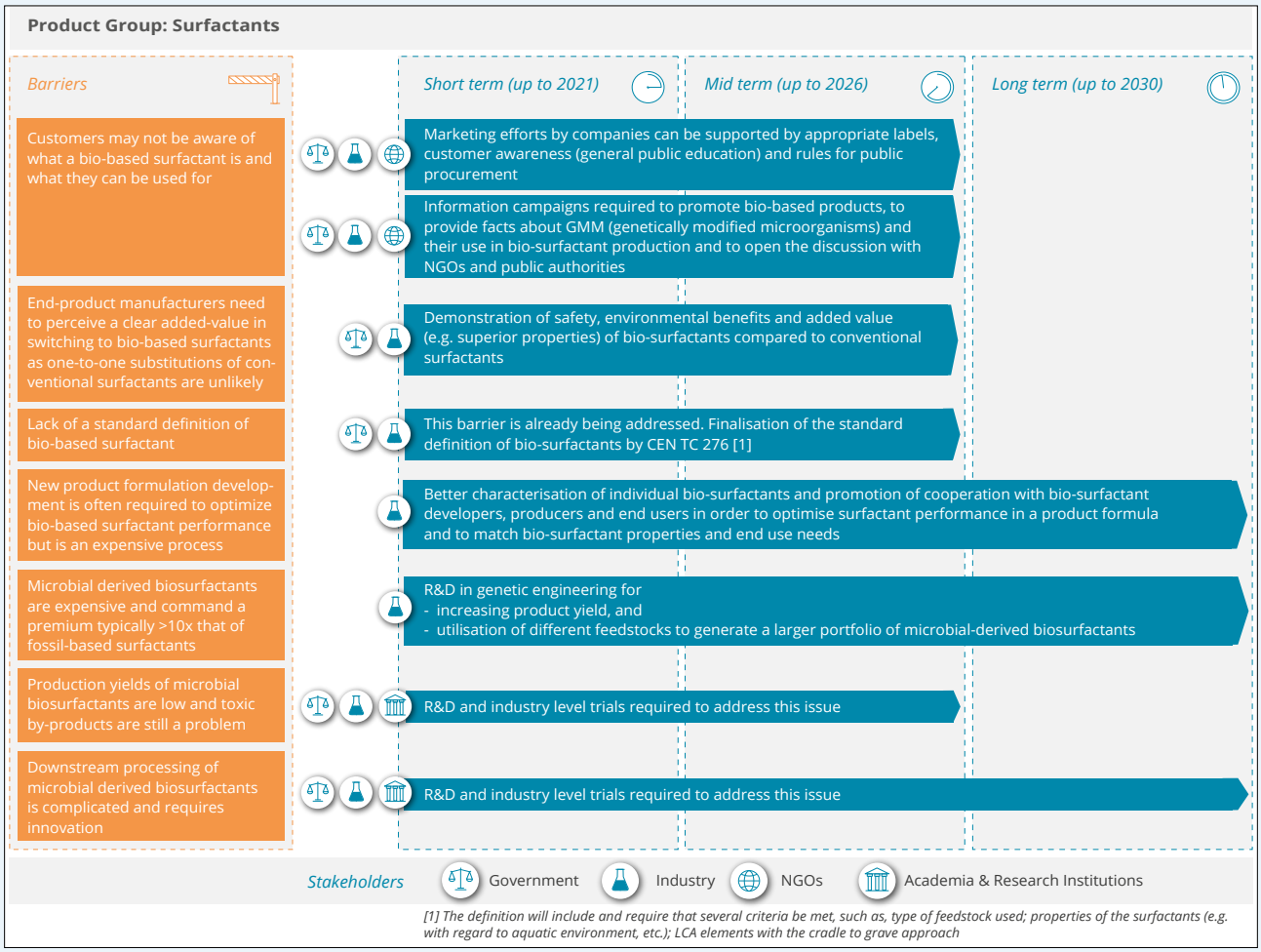


Figure 12: Roadmap to increasing the bio-based share of chemicals in the surfactants product group

5. Lubricants

- Environmental concerns are the leading drivers for bio-based lubricants. However, bio-based lubricants must meet the performance requirement of the application.
- In total-loss applications the trend towards bio-based lubricants is driven by regulations.
- All five sustainability characteristics (biodegradability, low human toxicity, low ecotoxicity, low GHG, recyclability) are required for lubricants.
- Most lubricating oils are mineral based and are derived from crude oils. Lubricants production costs are affected by crude oil prices.
- Bio-based lubricants have superior biodegradability characteristics compared to fossil derived alternatives.
- Bio-based drop-ins, such as succinic acid, adipic acid, propylene oxide, ethylene oxide building blocks provide an opportunity for the European lubricant industry to increase the bio-based content of its products.
- The global market value of bio-lubricants in 2025 is expected to reach 3 billion, with the major growth expected in transport and manufacturing applications.
- Some of the companies that are actively involved in bio-based lubricants market include: Total (e.g. transformer oil ISOVOLTINE BIO VE, calcium soap grease BIOMERCAN RS, textile lubricants such as LISSOLFIX APZX 225), Renewable lubricants Inc. (e.g. bio-based motor oil Bio-SynXtra™), PANOLIN AG, Environmental Lubricants Manufacturing, Inc. (e.g. ELM 85W140 Multi-Purpose Gear Lubricant), BioBlend Renewable Resources, LLC (e.g. BioFlo FG food grade lubricant).

Further details about the lubricants product group can be found here.

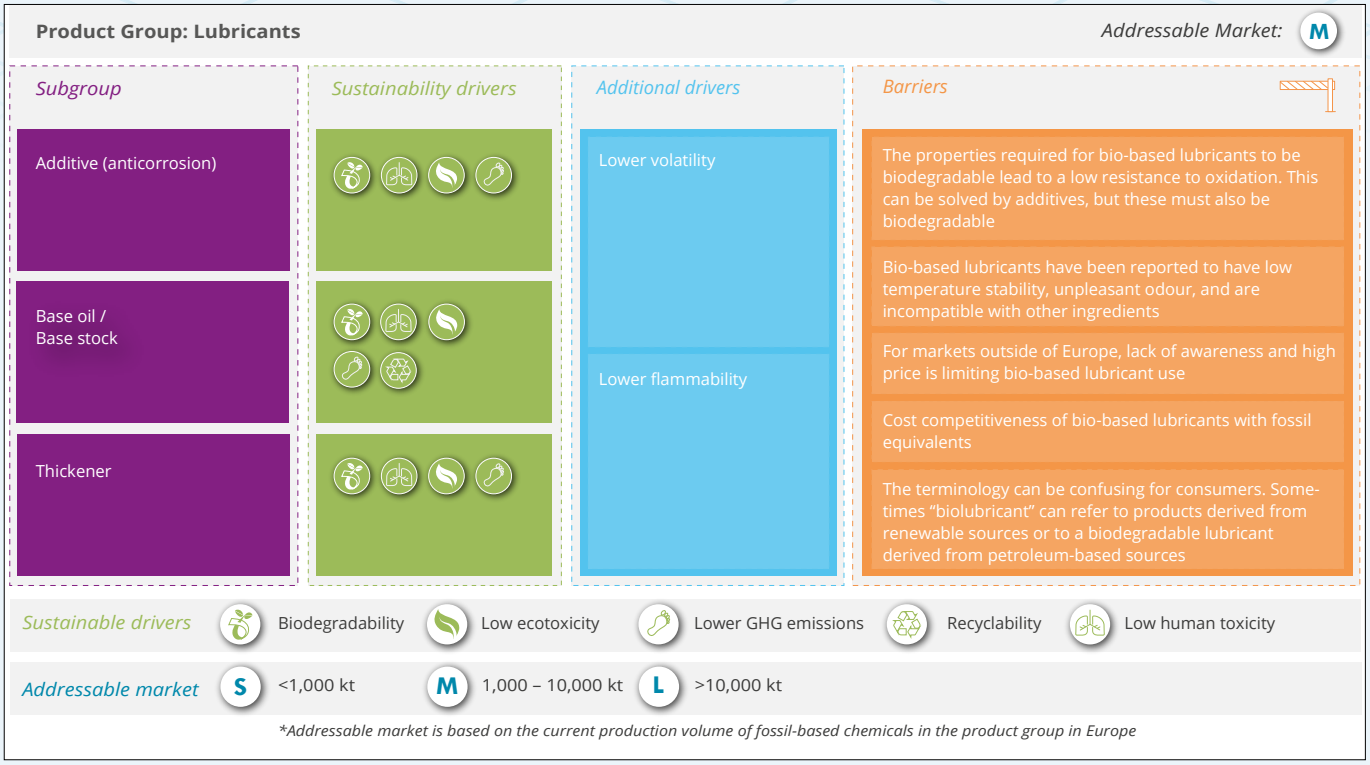


Figure 13: Pictorial summary of the lubricants product group

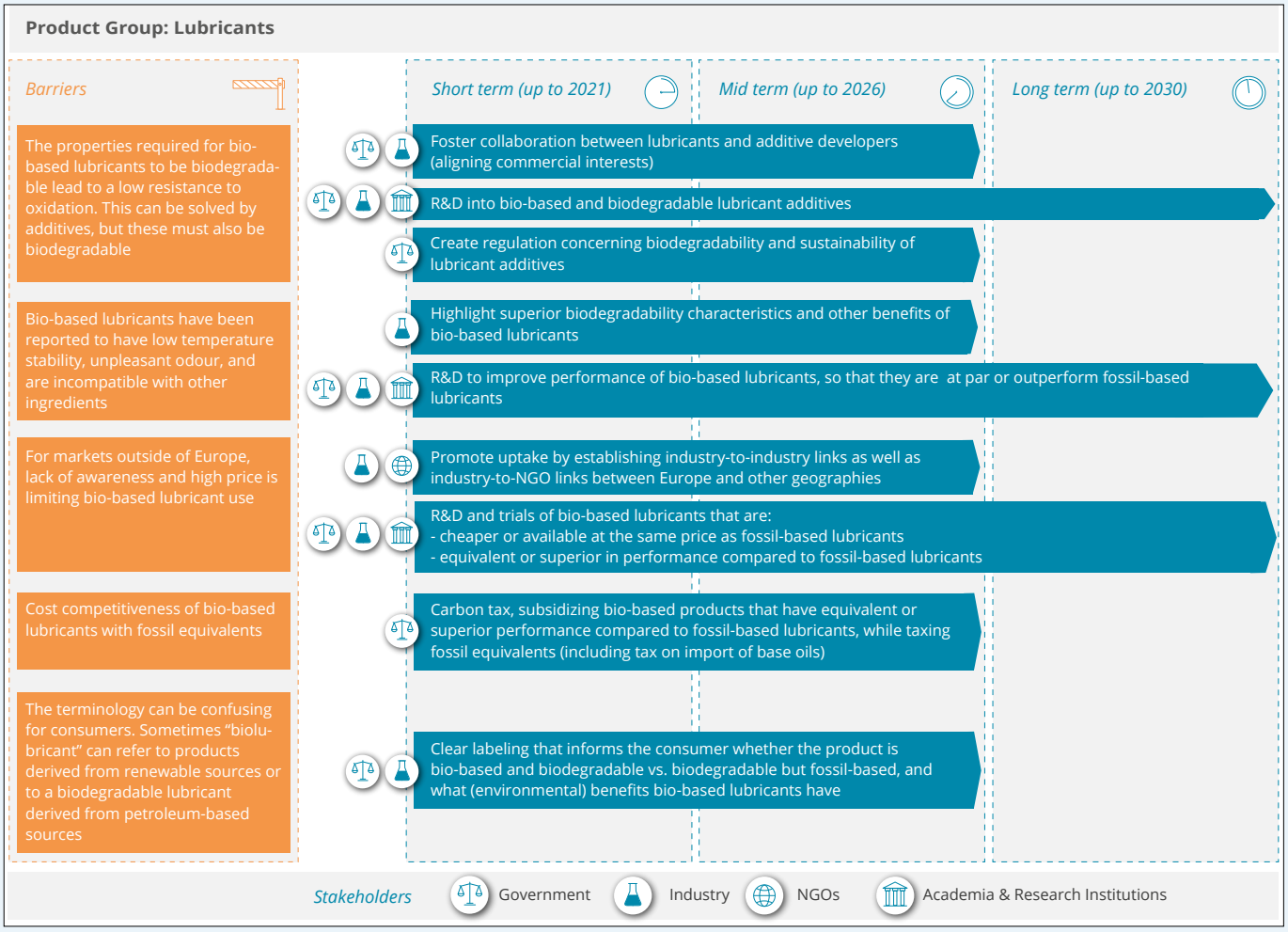


Figure 14: Roadmap to increasing the bio-based share of chemicals in the lubricants product group

6. Man-made fibres

- Bio-based man-made fibres production in Europe is more than 600 kt/yr, while fossil-based production is ~4,800 kt/yr.
- The addressable market of fossil-based man-made fibre production in Europe is medium-sized (1,000-10,000kt) in comparison to the other eight product groups.
- Consumer demand and initiatives by producers have driven the increase in the use of bio-based and recycled feedstock, as well as sustainability across the man-made fibres supply chain.
- Recyclability is the sustainability characteristic that all conventional and several bio-based alternatives have. However, recycling is not easy in case of blends such as fabric made of polyester and cotton with a small percentage of elastane. Another example is of PLA which cannot be recycled with PET in established recycling infrastructure. Therefore, there is scope for further R&D in recycling techniques for different fibres.
- There is a drive to make conventional plastics such as PET and nylon biodegradable by adding 'additives'. While these additives are available on the market, the claims of biodegradation rarely pass rigorous testing and review. However, it does show that biodegradability is considered important for synthetic polymers when they approach end-of-life and cannot be recycled anymore.
- The production of some biosynthetic fibres could potentially result in low GHG emissions and some have low toxicity effect.
- Some bio-based fibres, such as bio-PTT, can be produced at lower cost compared to their fossil-based equivalents, and have properties that surpass fossil-based equivalents in fibre applications.
- There are several bio-based man-made fibres that are still at research and demonstration scale. Further R&D and industrial trials are needed to bring these fibres to commercial scale. Example of an ongoing projects in Europe is FIBFAB (H2020 project) on PLA fibre.
- Some of the companies that are actively involved in bio-based man-made fibres market include: DuPont (Sorona®), Sofila (use Arkema's Rilsan®), Aquafil, RadiciGroup (Radilon® DT 40EP25W), BASF, Solvay, Distrupol, Sateri (viscose), Lenzing (TENCELTM), AlgiKnit.

Further details about the man-made fibres product group can be found here.

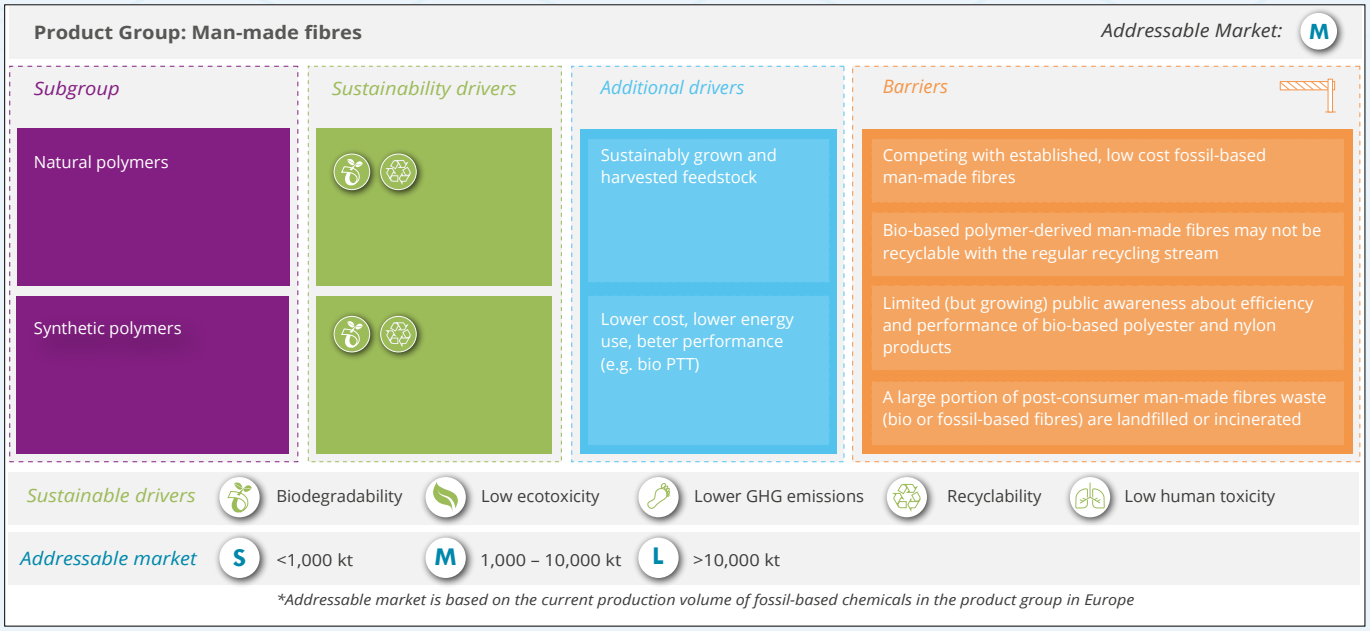


Figure 15: Pictorial summary of the man-made fibres product group

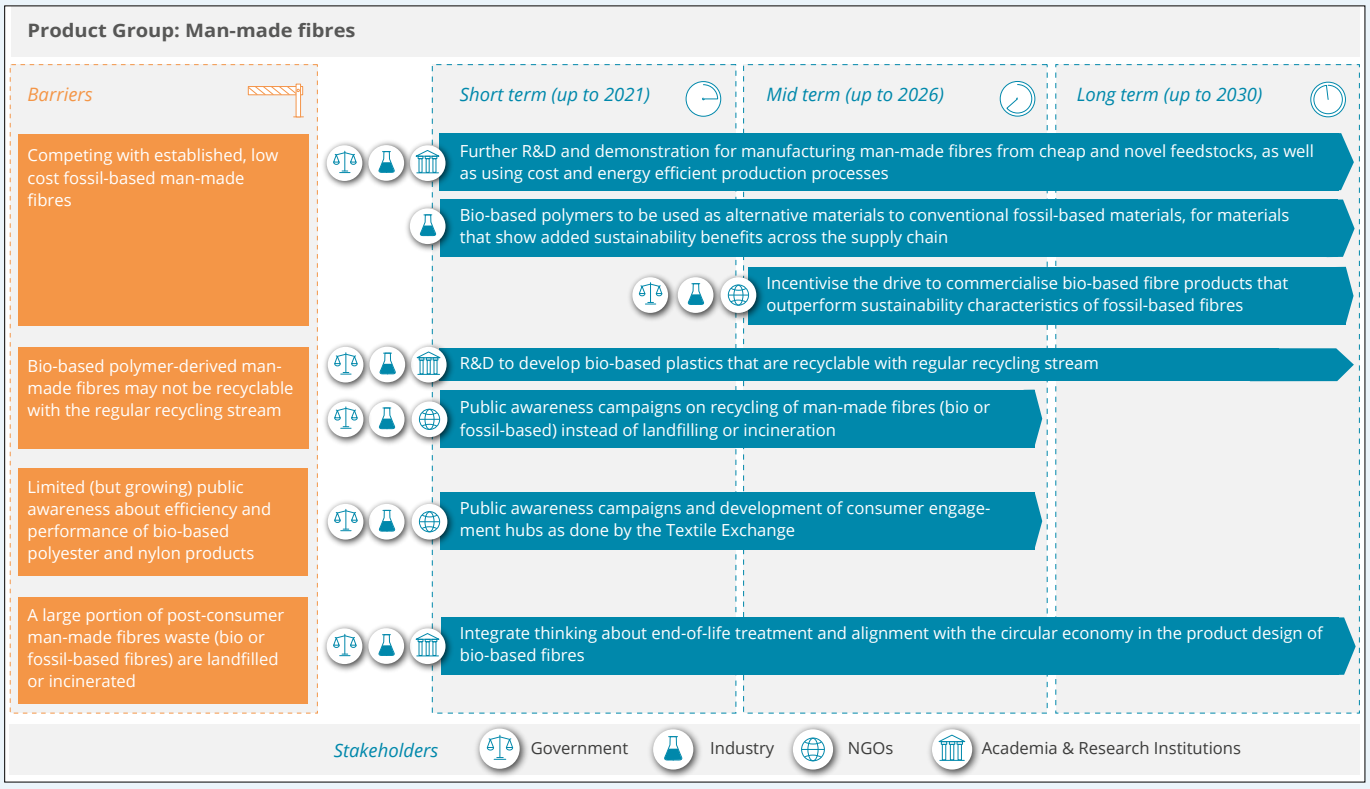


Figure 16: Roadmap to increasing the bio-based share of chemicals in the man-made fibres product group

7. Solvents

- Bio-based solvents production in Europe is less than 0.5 kt/yr, while fossil-based production is ~5,000 kt/yr. The addressable market of fossil-based solvents production in Europe is medium-sized (1,000-10,000kt) in comparison to the other eight product groups.

- The uptake of bio-based solvents is driven by the EU policy on VOC emissions and by REACH. Those bio-based alternatives which meet the criteria of low toxicity and low VOC, compared to the fossil-based counterpart, are likely to be considered as valid alternative if they meet the functional requirements of the solvent in specific applications.

- Conventional and bio-based solvents identified are biodegradable (some more than others), and there is concerted effort from the industry to recover and recycle solvents where possible. This is driven by legislation that aims to reduce the adverse impact of solvents (VOCs) on human beings and the environment. It should be noted that solvents can be recovered and recycled in some sectors and applications but not in others.

- Industries are taking as many steps as possible to remain competitive, by reducing waste and recycling spent solvents. It is very important for producers, especially the ones who are using solvents for extraction, to be able to recycle and reuse the solvent. Extraction is a common processing step in chemical, food, pharmaceutical and mining industry.

- For products that are likely to end up in the environment, complete biodegradability is a relevant sustainability driver. This is the case of solvents that are typically used in formulation of cleaning products (household cleaners, personal care) or agrochemicals. However, the biggest industrial end-group in which solvents are used are paints and coatings, in which solvents evaporate after the paint has been applied, thus dissipating into the air. In such cases, biodegradability is not a relevant sustainability driver.

- Many ‘dedicated’ bio-based solvents included in this analysis claim to have low toxicity effects compared to fossil equivalents.

- The production of some identified bio-based solvents has been reported to release less GHG emissions compared to fossil equivalents.

- Bio-based solvents need to meet the functional requirement of the fossil equivalents that they intend to replace in different applications. There is significant scope for R&D and demonstration scale projects to develop a wide range of bio-based solvents and formulations that can be used in different applications.

- Some of the companies actively involved in the bio-based solvents market include: Cellulac, BioAmber, Green Biologics, DuPont-Tate & Lyle, Pennakem Europa SAS, Circa, Roquette, Cargill, Solvay-Rhodia.

Further details about the solvents product group can be found here.

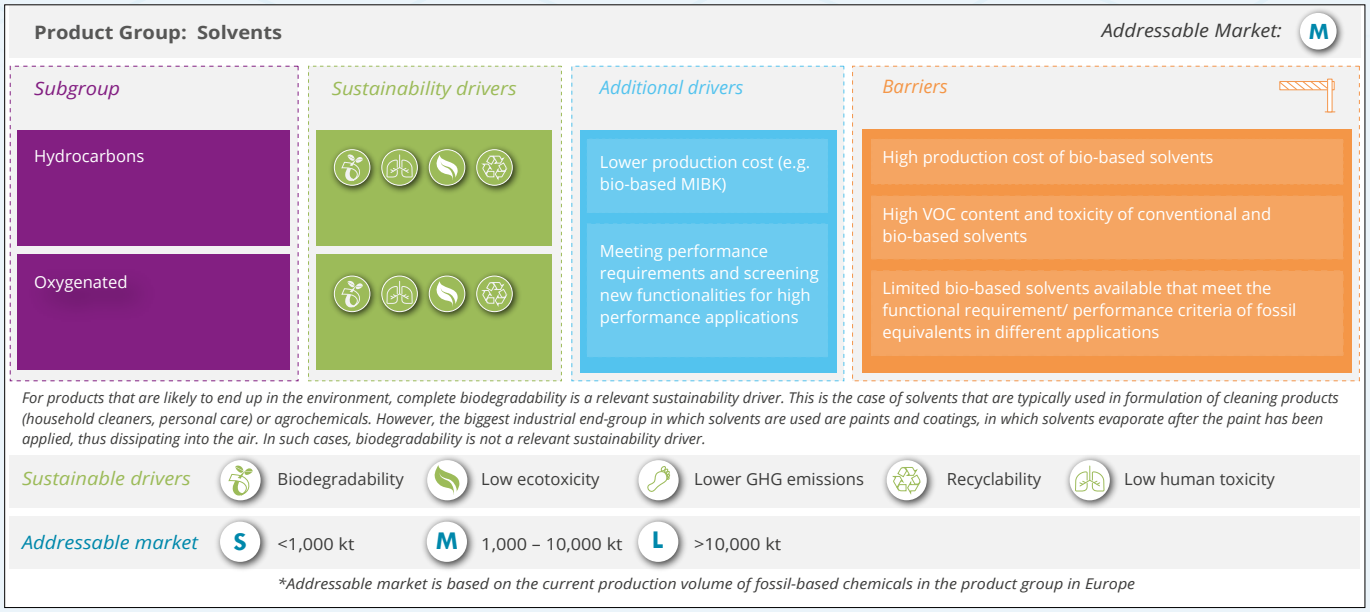


Figure 17: Pictorial summary of the solvents product group

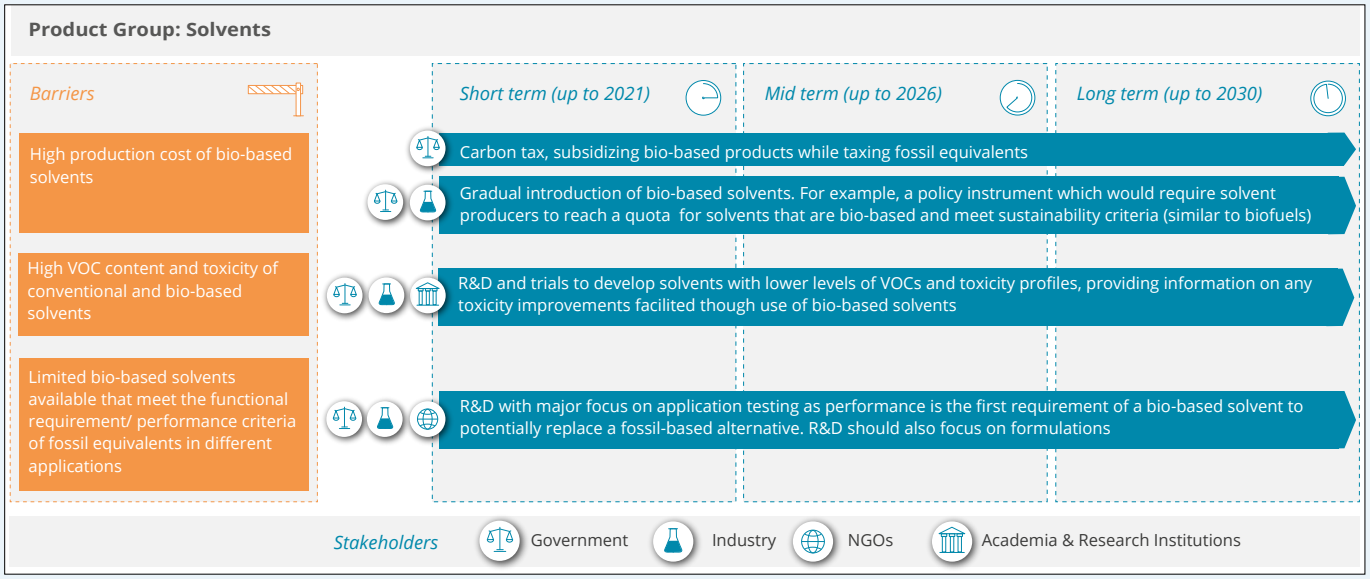


Figure 18: Roadmap to increasing the bio-based share of chemicals in the solvents product group

8. Adhesives

- Production cost is an important driver in the adhesives segment.
- The key sustainability driver is to reduce human toxicity by lowering VOC (especially for the wood building industry which is one of the most significant markets for adhesives).
- Environmental and health concerns related to formaldehyde create a major opportunity for the development and growth of bio-based chemicals which could replace formaldehyde. Bio-based 5-HMF and lignin derivatives are among the most promising candidates.
- A range of bio-based raw materials such as diacids, diols and natural polyols building blocks are available as a drop-in or dedicated replacement of fossil-based building blocks for adhesives and sealants.
- Keeping suitable mechanical properties while reducing the emission of VOCs is the key development and innovation trend in the adhesives segment.
- Bio-based alternatives must deliver the desired mechanical performance characteristics and water resistance requirements in adhesives. Meeting these requirements may initially rely on the development of mixed bio and fossil-based adhesives.
- Legislation may lead to accelerating the transition from synthetic adhesive to bio-based adhesives by regulating the presence of VOCs and the presence of recyclable materials, especially in the building industries.
- Some companies active in the development of new bio-based adhesives are: VTT (Finland), Arkema (France), Weiss Chemie + Technik (Germany) and Covestro (Germany).

Further details about the adhesives product group can be found here.

Figure 19: Pictorial summary of the adhesives product group

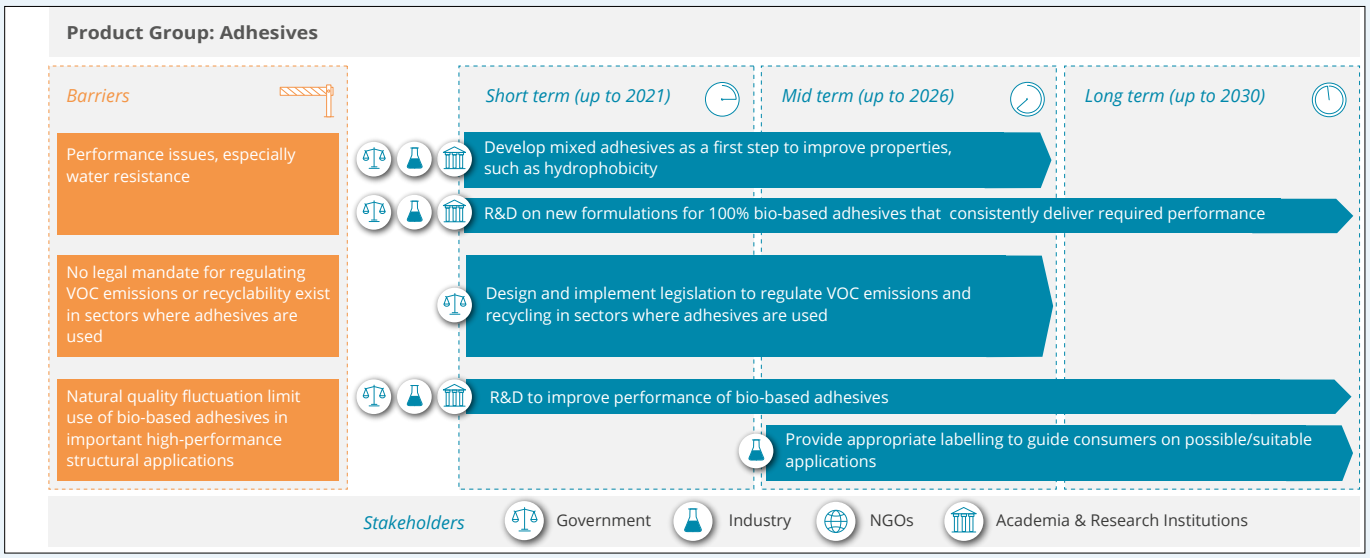
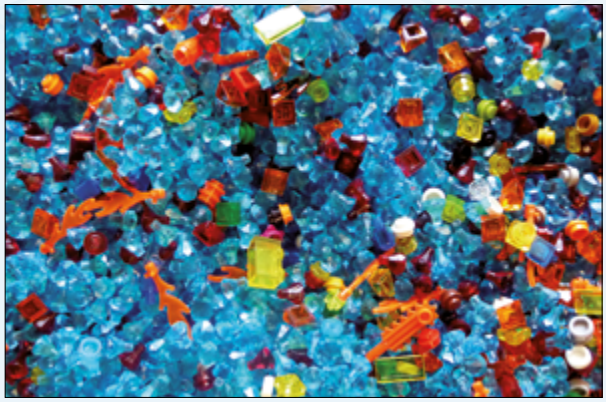


Figure 20: Roadmap to increasing the bio-based share of chemicals in the adhesives product group

9. Plastics/polymers



- The trend towards bio-based plastics is driven by changing consumer demands with increased awareness of environmental impacts of the plastics industry.
- To make plastic products more resource efficient and to reduce GHG emissions, the emphasis is on increasing the use of renewable feedstock using lower energy processing, while reducing the dependency on fossil resources.
- Several innovative small and large companies are responding to consumer demands towards a more sustainable plastics economy. These companies have made substantial investments in R&D for bio-based plastics designed with the circular economy in mind, e.g. PLA, PEF and bio-PTT.
- Bio-based production of plastics/polymers in Europe is more than 1,200 kt/yr, while fossil-based production is ~70,000 kt/yr. The addressable market of fossil-based plastics/polymers production in Europe is the largest when compared with other product groups.
- Diverse bioplastics are being developed that can be drop-ins and compostable, but few are truly biodegradable.
- Some bio-based plastics listed meet the desired sustainability characteristic for low GHG emissions, which is a key driver for thermoplastics. Low human toxicity is an important driver for some thermoplastics used in healthcare and food packaging, e.g. bio-PVC.
- Recyclability is the sustainability characteristic that most conventional plastics and their bio-based alternative plastics already possess. However, some bio-based plastics, such as PLA and PHAs cannot be recycled with current well-established recycling infrastructure and there is evidence that recyclability is a desired sustainability characteristic of these bio-based plastics. Therefore, further R&D in product development and recycling techniques is required to ensure that recyclability does not compromise performance.
- Bio-based drop-ins may not be compostable/biodegradable but would be recyclable – otherwise, biopolymers might conflict with recycling goals. Non-biodegradable biopolymers could also contribute to carbon sequestration.
- Biodegradability is considered an important end-of-life life pathway, especially when recycling is no longer technically possible. Additives are available that could increase the rate of biodegradation in treated plastic products, though claims need to be appropriately verified.
- Producers of bio-based plastics should provide adequate labelling to inform customers of types of bio-based plastics and end-of-life processing.
- Although TRLs for some the bio-based plastics listed are already at 9, there are some that require further R&D (including investment) and industrial trials to improve technical properties and reduce production costs to successfully grow at commercial scale.
- Some of the leading manufacturers are Genomatica, Versalis, Cargill, Synbra Technology, Novamont, BASF SE, Natureworks, Corbion, Braskem, Secos Group, Biome Technolgies, FKuR Kunststoff, Innovia Films, and Toray Industries.

Further details about the plastics/polymers product group can be found here.

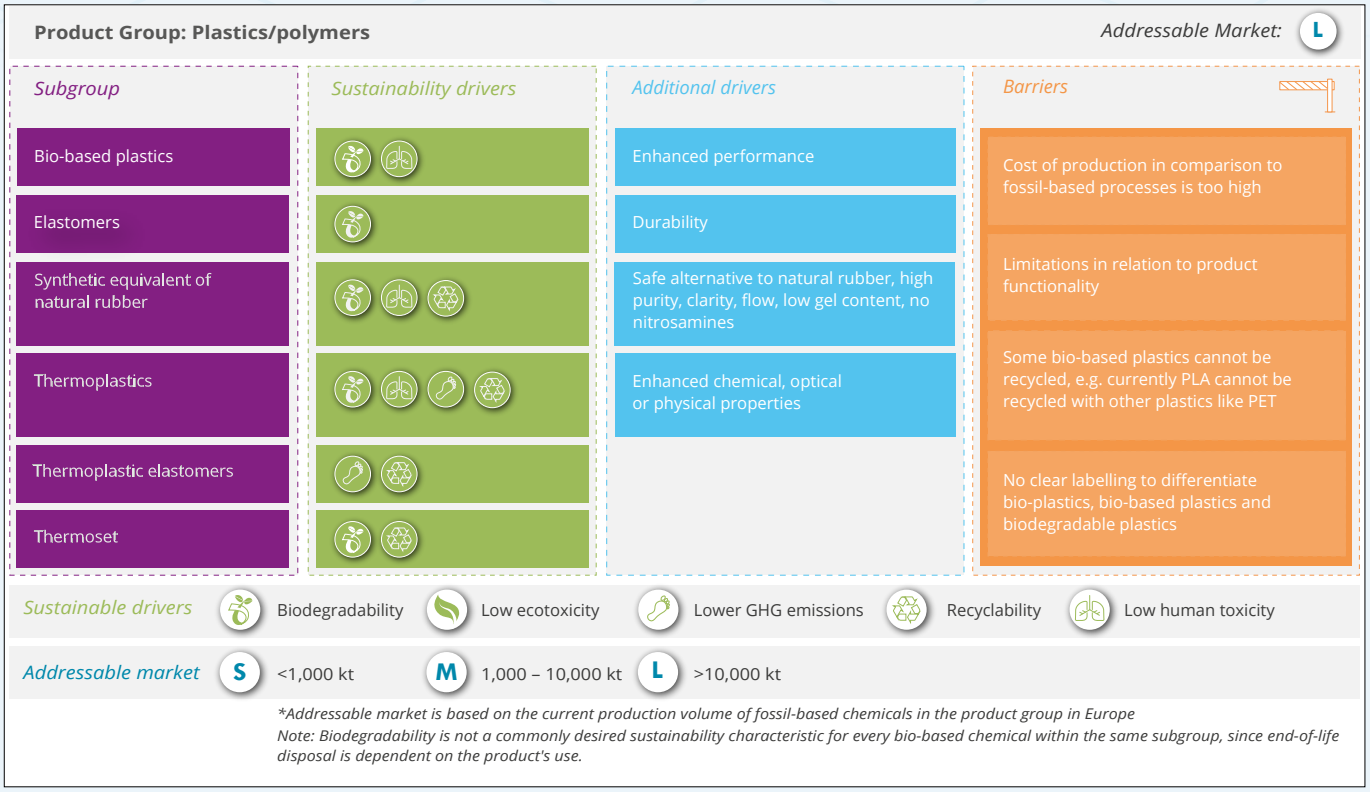


Figure 21: Pictorial summary of the plastics/polymers product group

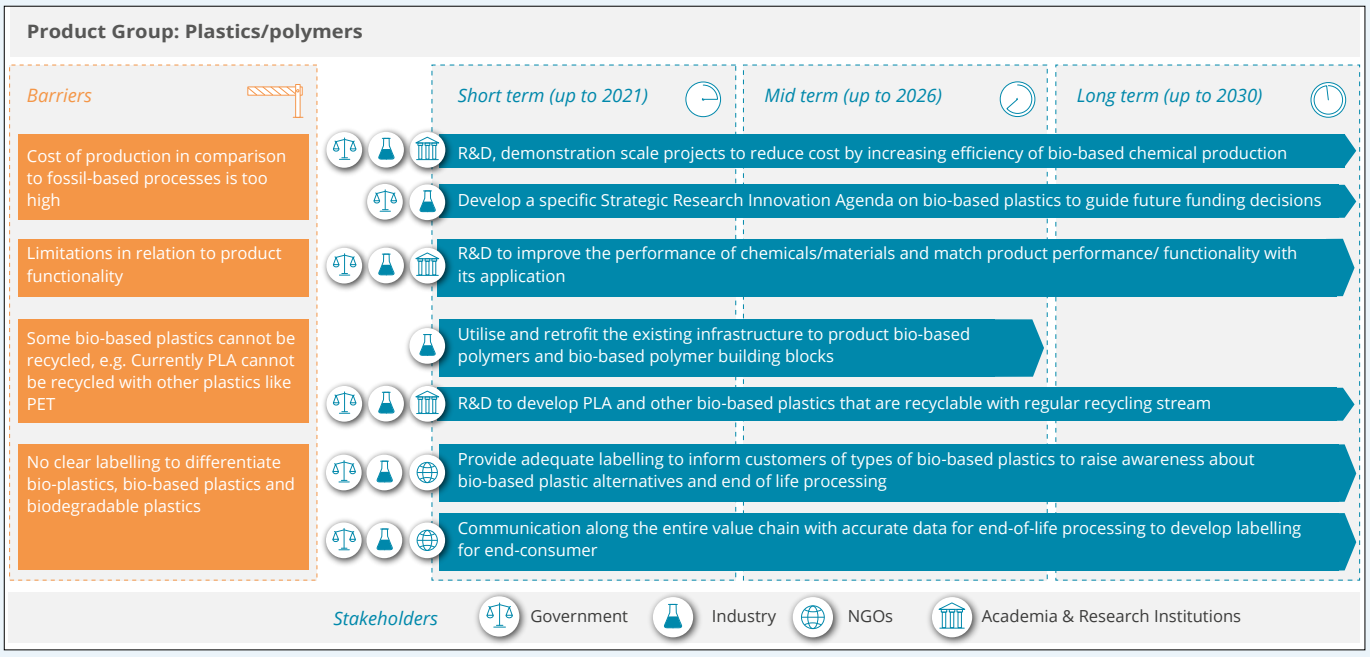


Figure 22: Roadmap to increasing the bio-based share of chemicals in the plastics/polymers product group

General barriers for bio-based chemistry and the bio-based economy

Besides barriers specific to different product groups, there are a wider range of general barriers that concern bio-based products and the bioeconomy. We provide an overview of the general barriers and recommended actions to overcome these. The set of actions are a result of internal project discussions, stakeholder discussions and feedback, as well as recommendations from other EU projects or strategy documents.

We classify the general barriers to increasing the bio-based share in the chemical industry into six main categories:

1. Access to feedstock
2. Competition with established fossil industry
3. Regulatory barriers
4. Societal barriers
5. Markets, Finance & Investment
6. Research & Development.

Further details about the general barriers and recommended actions can be found here.

General barriers - summary

Barrier group	*General barrier*	*Recommended action*
Access to feedstock	Low availability of biomass	Increase yield of existing biomass production
		Identify and establish new sources of feedstock
		Consider first generation biomass for material uses
		Increase efficiency of biomass supply chains
		Develop biorefineries
	Non-level playing field	Establish a balance between the different uses of biomass
Competition with established fossil industry	Bio-based alternatives not cost-competitive	Implement market-pull instruments
		Reduce fossil-based feedstock support
	Lower performance of bio-based alternatives	Continue and expand research and development
		Industry-driven or voluntary incentives
Policy and Regulatory framework	Lack of policy harmonisation	Harmonisation of standards, regulations and policies
	Limited long-term reliability	Provide stability and reduce risks through long-term policy
	Registration, Evaluation, Authorisation and Evaluation of Chemicals – REACH	Guidance, clarification and support for regulation on bio-based products
Public perception and societal challenges	Lack of information, understanding and expertise	Improve labels and standards
		Promote education and training across the bioeconomy
	Low awareness of bio-based products	Design and implement a visible and coherent communication strategy on the bioeconomy
		Improve participatory processes and network building
		Improve social acceptance for the use of agricultural products in the chemical sector
	Unrealistically high expectations	Promote trust in bio-based products to transform negative associations
Markets, Finance and Investment	Limited availability of funding in the early stages	Fund for green investment
	Limited support for scale-up	Use of Open Access pilot plants to avoid high scale-up costs
		Early viability assessment for SMEs
	Limited access to finance for start-ups and SMEs	New tax models to facilitate market entry for SMEs
		Strengthening the communication channels for European start-up funding
Research and Development	Ongoing need for funding	Deploy additional, targeted financial instruments
		Improve access to finance for Research and Development
	Limited guidance and direction in Research and Development	Maximise impact of available EU Research and Innovation
	Limited understanding of ecological boundaries and innovation adaption and diffusion	Enhance knowledge on biodiversity, ecosystems and the bio-based economy

Figure 23: Summary of the general barriers and recommended actions

Annex A: RoadToBio project deliverables

The action plan draws upon information and analysis in the RoadToBio strategy document (deliverable D4.2 – download) which in turn is based on analysis of publicly available literature and results of interim deliverables of the RoadToBio project (listed below).

Work Package 1 **Markets, technologies and feedstocks analysis**		Work Package 2 **Regulatory framework & public acceptance**	
D1.1: Bio-based opportunities for the chemical industry	Download	D2.1: Report on regulatory barriers	Download
D1.2: Case studies on potentially attractive opportunities for bio-based chemicals in Europe	Download	D2.2: Public perception of bio-based products	Download
Article: Bio-based drop-in, smart drop-in and dedicated chemicals	Download	D2.3: Public perception of bio-based products – Qualitative analysis of social stakeholders' concerns	Download
		D2.4: Ways to overcome societal and policy barriers	Download
		D2.5: Concept of bio-based and circular economy	Download

We have also published an engagement guide which includes 3 factsheets:

- Readers' Guide (Download)
- Communication guide (Download)
- Key messages
  The aim of this guide is to help engage a wide range of stakeholders for implementing the roadmap. (Download)
  (Deliverable D4.4)

Project-related presentations and newsletters are also available on the RoadToBio **website**.

Annex B: Sustainability characteristics

The sustainability characteristics that were considered in the assessment were:

biodegradability, low human toxicity, low ecotoxicity, low GHG and other characteristics such as recyclability.

Renewable feedstock is the only sustainability characteristic which directly links to bio-based chemicals and as such indicates the drive for bio-based chemicals in all product groups.

For each of the nine product groups the consortium identified the desired sustainability characteristics that are met, or are not met, by both bio-based products and the fossil-based equivalents that were selected for the analysis. The chemicals/products selected for the analysis are representative of the product group as they are either produced in large volumes (thereby dominating the market for that product group) and/or of interest and value due to the functionality they offer.

The percentage of bio-based content in key chemicals/products and TRL they are at were collected as evidence of drive towards becoming more or completely bio-based in nature. The evidence-based assessment also involved identifying whether the drive for sustainability (including renewability) came from chemical producers or customers/end-users, and whether the drive was voluntary or imposed by policy/regulations.

The results for each product group are presented in chapter 3 of the strategy document in a table categorising sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in each product group. Table 2 shows the categories used to classify these sustainability characteristics, using colour coding and "x" marks to assess sustainability characteristics of bio-based chemicals in relation to their fossil counterpart..

Table 2: Colour coding and "x" marks to indicate sustainability characteristics of fossil/ bio-based chemicals that were selected in the nine product groups for analysis

Sustainability characteristics (B, LHT, Low GHG, LE, R)	Desired characteristics	Offered by conventional/ fossil-based chemicals	Offered by bio-based chemicals
	Yes	Yes	No
x	Yes	Yes	Yes
	Yes	No	No
x	Yes	No	Yes
x	Limited evidence suggesting this is a desired characteristic for the product group		Yes
	Limited evidence suggesting this is a desired characteristic for the product group		No

(B=Biodegradable, LHT=Low human toxicity, Low GHG, LE=Low ecotoxicity, R=Recyclability)

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Disclaimer

The RoadToBio project consortium has taken due care in the preparation of this report to ensure that all facts and analysis presented are as accurate as possible, within the scope of the project. However, no guarantee is provided in respect of the information presented and the consortium is not responsible for decisions or actions taken on the basis of the content of this report.

The consortium has used an evidence-based approach for the analysis and has relied on publicly-available information in reports. However, the consortium has not verified the completeness and/or accuracy of the information contained in publicly-available reports cited in this document.

Download the full strategy document here:
https://www.roadtobio.eu/strategy_document

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