Roadmap for the Chemical Industry in Europe towards a Bioeconomy

Strategy Document

2019

Contributing authors

E4tech: Yamini Panchaksharam, Pragna Kiri, Ausilio Bauen

nova-Institute: Christopher vom Berg, Ángel Puente, Raj Chinthapalli

BTG: Jurjen Spekreijse, John Vos, Swinda Pfau

DECHEMA: Kathrin Rübberdt, Jochen Michels, Lea König

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Acronyms

Acronym	Full form
1G feedstock	First generation feedstock
2G feedstock	Second generation feedstock
3G feedstock	Third generation feedstock
5-HMF	5-Hhydroxymethylfurfural
1,4-BDO	1,4-butanediol
1,4-PDO	1,4-propanediol
ABS	Acrylonitrile Butadiene Styrene
B	Biodegradable
BBI JU	Bio-based Industries Joint Undertaking
BDE	Polybutadiene
BIC	Bio-based Industries Consortium
BPA	Bisphenol A
BTG	Biomass Technology Group B.V.
CAGR	Compound annual growth rate
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
COP	Conference of Parties
CRISPR	Clustered regularly interspaced short palindromic repeats
DDDA	Dodecanedioic acid
DECHEMA	Gesellschaft für chemische Technik und Biotechnologie e.V. (Society for Chemical Engineering and Biotechnology)
E4tech	E4tech (UK) Ltd.
EC	European Commission
ECH	Epichlorohydrin
EEA	European Environmental Agency
EPR	Extended Producer Responsibility
EPS	Expanded polystyrene
ESIG	European Solvents Industry Group

Acronym	Full form
EUBA	European Bioeconomy Alliance
EUBP	European Bioplastics
EVA	Ethylene-vinyl acetate
FA	Fulvic acid
FAME	Fatty acid methyl esters
FDCA	Furan dicarboxylic acid
FDME	Furan dicarboxylic methyl ester
FSC	Forest Stewardship Council
GDP	Gross Domestic Product
GHG	Greenhouse gas
GMM	Genetically modified microorganism
GMO	Genetically modified organism
GPP	Green Public Procurement
HA	Humic acid
HAP	Hazardous air pollutants
HDI	Hexamethyl diisocyanate
HDPE	High-Density Polyethylene
HMDA	Hexamethylene diamine
HP	3-hydroxypropionic acid
kt/yr	kilo tonnes per year
L	Large
LDPE	Low-Density Polyethylene
LE	Low ecotoxicity
LHT	Low human toxicity
LLDPE	Linear Low-Density Polyethylene
M	Medium
MEG	Monoethylene glycol
MEP	Methyl-erythritol 4-phosphate
MeTHF	2-methyltetrahydrofuran
MIBK	Methyl isobutyl ketone
MRL	Maximum residue levels
Mt/yr	Million tonnes per year
MUF	Melamine-urea-formaldehyde

Acronyms

Acronym	Full form
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne. Statistical classification of economic activities in the European Community
NAFTA	North American Free Trade Agreement
NMP	N-methyl-2-pyrrolidone
nova	nova-Institut für politische und ökologische Innovation GmbH
PA	Polyamides
PAOs	Polyalphaolefins
PBS	Polybutylene succinate
PBT	Polybutylene terephthalate
PC	Polycarbonate
PCP	Pre-Commercial Procurement
PDCA	2,5-pyridinedicarboxylic acid
PDI	Pentamethylene diisocyanate
PE	Polyethylene
PEF	Polyethylene furanoate
PEG	Propylene glycol
PEG ester	Polyethylene glicol ester
PET	Polyethylene terephthalate
PF	Phenol-formaldehyde
PH	Protein hydrolysates
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate

Acronym	Full form
PLA	Polylactic acid
PMMA	Polymethyl methacrylate
PP	Polypropylene
PPI	Public Procurement of Innovative Solutions
PPL	Polypropiolactone
PS	Polystyrene
PTF	Polytrimethylene furandicarboxylate
PTMEG	Polytetramethylene ether glycol
PTT	Polytrimethylene terephthalate
PUR	Polyurethanes
PVC	Polyvinyl chloride
R	Recyclability
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
SBR	Styrene-Butadiene Rubber
SBS	Styrene-Butadiene-Styrene Rubber
TOFA	Tall oil fatty acid
TRL	Technology Readiness Level
UAA	Utilised agricultural area
UF	Urea-formaldehyde
UP	Unsaturated polyesters
VOC	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, foresty 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 resouce 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 special 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 considered to be ‘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. • Less toxic or harsh 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.

Executive Summary

The RoadToBio project is funded by the EU under the Horizon 2020 research and innovation programme. It aims to pave the way for the European chemical industry towards a higher bio-based portfolio and competitive success based on the benefits offered by the bioeconomy. The goal of RoadToBio is to create **a roadmap for the chemical industry** with the aspiration to increase the share of bio-based or renewable feedstock to 25% of total volume of organic chemicals raw materials/feedstock used by the chemical industry in 2030. Societal needs in 2030 need to be considered while aspiring for this target. The biomass used for bio-based chemicals should 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). The SIRA is considered as 'guidelines' for the European biorefinery sector.

This roadmap strategy document is intended to provide an evidence-based foundation for the EU chemical industry upon which future policy can be implemented and actions delivered. The way that this report has been prepared is designed to ensure it has credibility with industry, academic, and other stakeholders and is recognised by government as a useful contribution when considering future policy. It will be successful if, as a result, the government and chemical industry in Europe are able to build on the evidence, analysis, key messages and strategic conclusions to increase share of bio-based chemicals whilst 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.

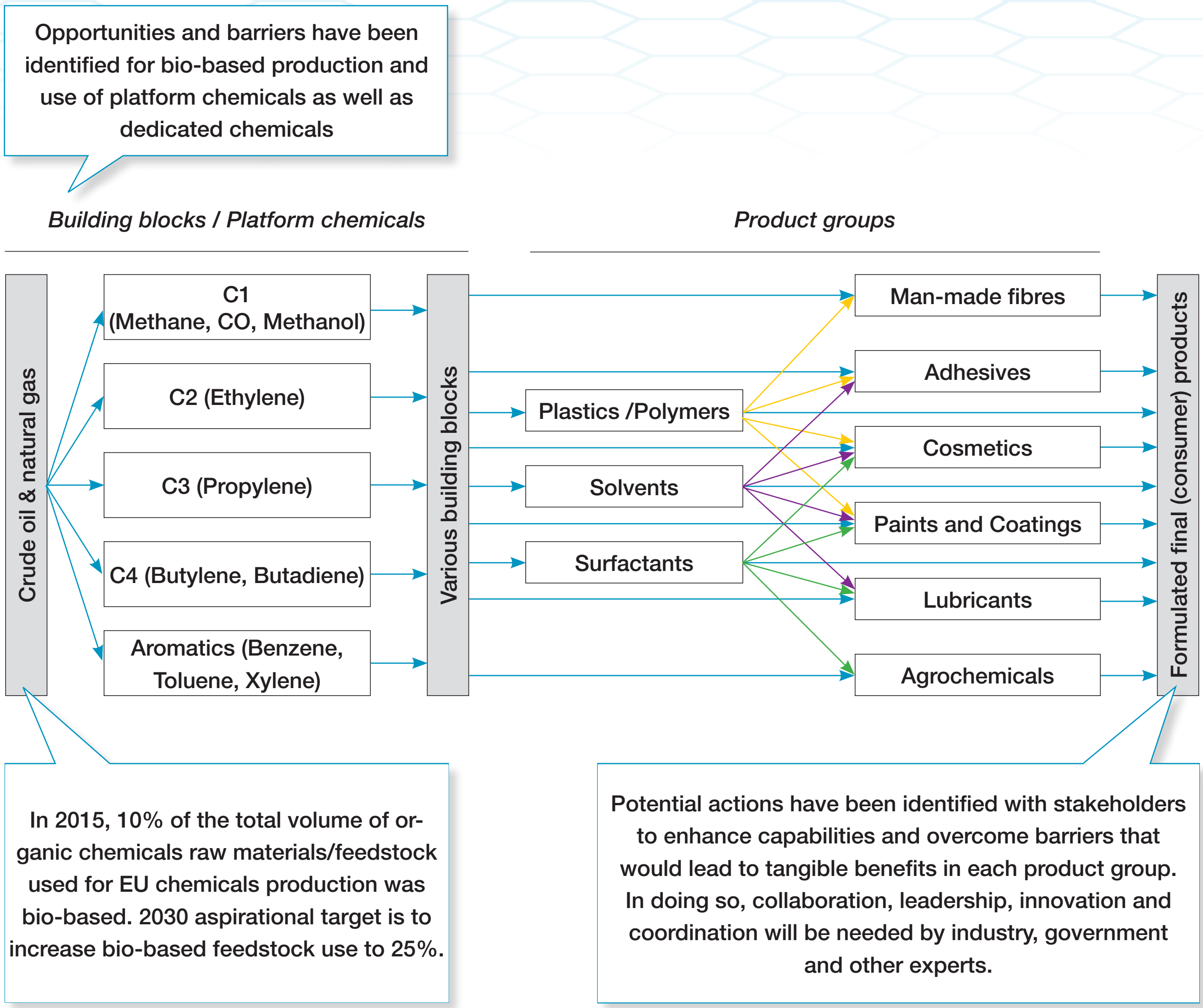


Figure 1: Brief overview of the RoadToBio project target, product groups and outcome

Product group opportunities and roadmap to increased share of bio-based chemicals in the EU chemicals industry

The strategy document includes detailed information on the drive for bio-based market growth, as well as the opportunities and barriers to increasing the share of bio-based chemicals in nine product groups:

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

Short term, mid term and long term actions, between 2019 and 2030, have been proposed for the barriers identified for each product group. Further, stakeholders who need to be involved to execute the actions have been identified.

Following is a summary of the product groups, opportunities and roadmap to increased share of bio-based chemicals.

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 not sustainable.
- 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.

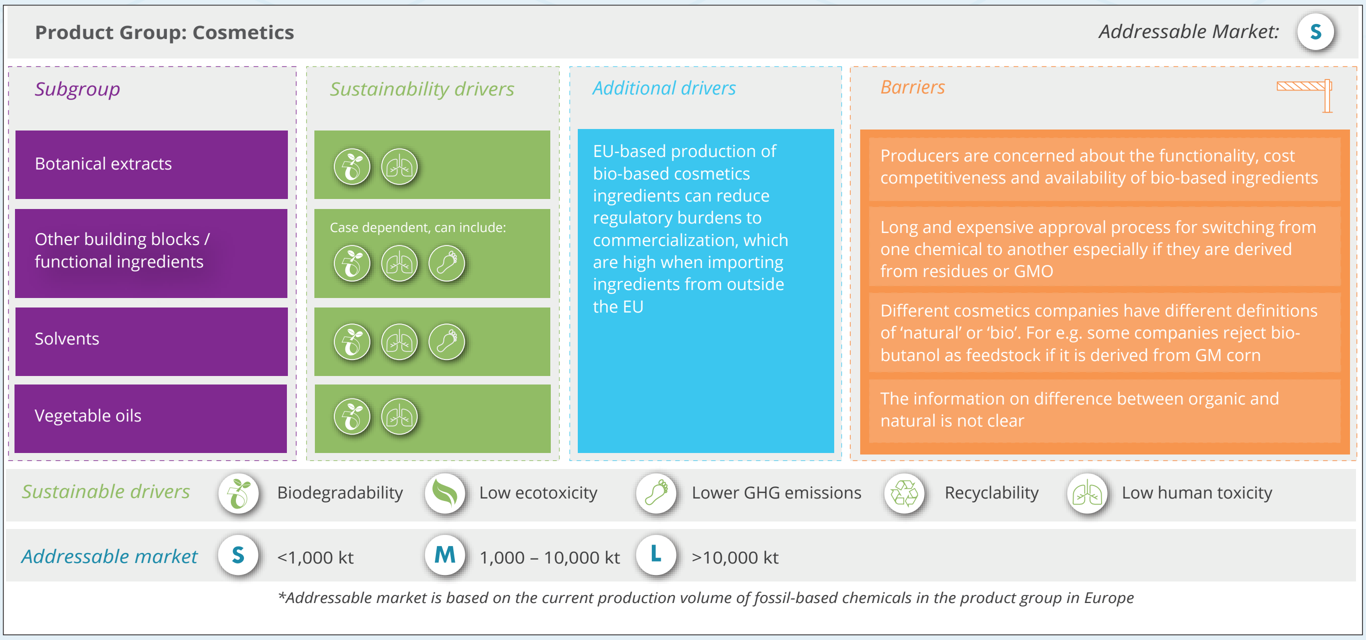


Figure 2: Pictorial summary of the cosmetics product group

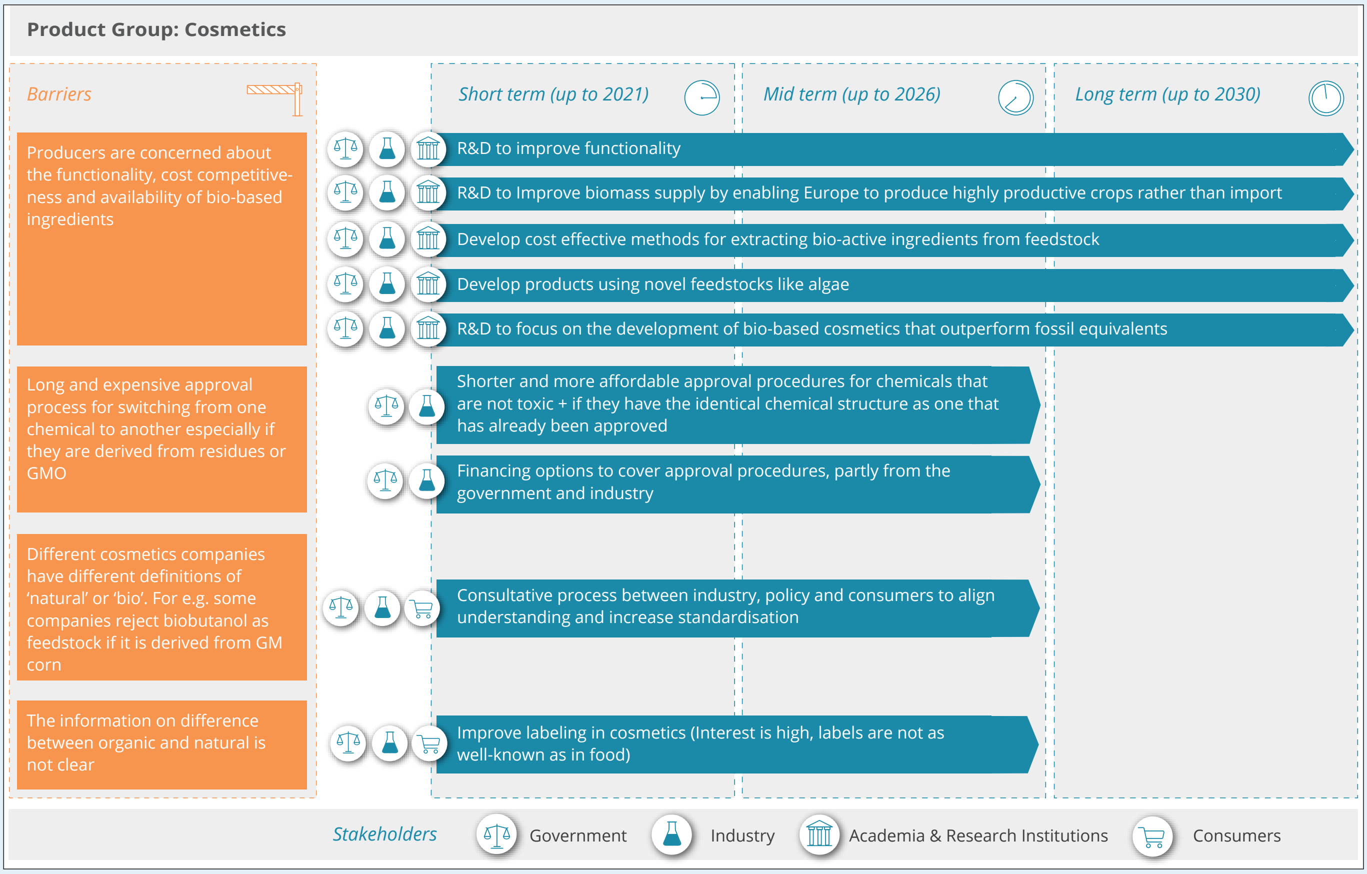


Figure 3: Roadmap to increasing the bio-based share of chemicals in the cosmetics product group

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 (<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 times 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.

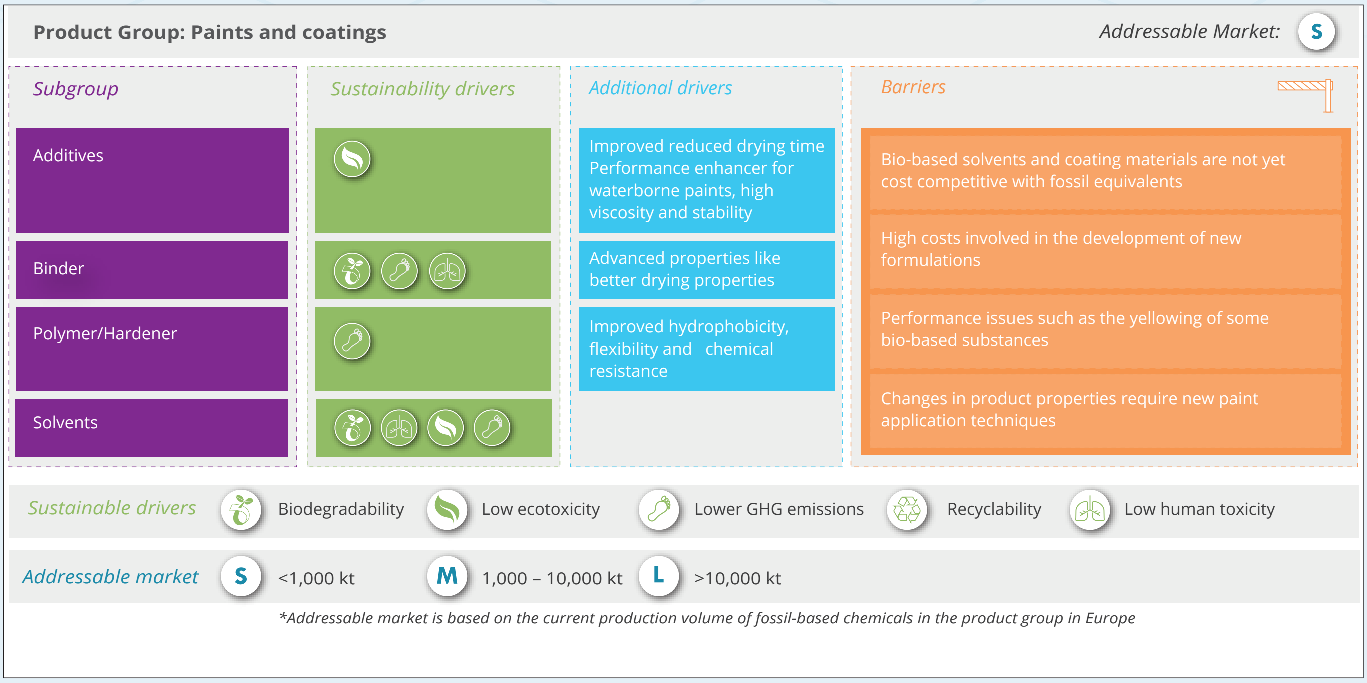


Figure 4: Pictorial summary of the paints and coatings product group

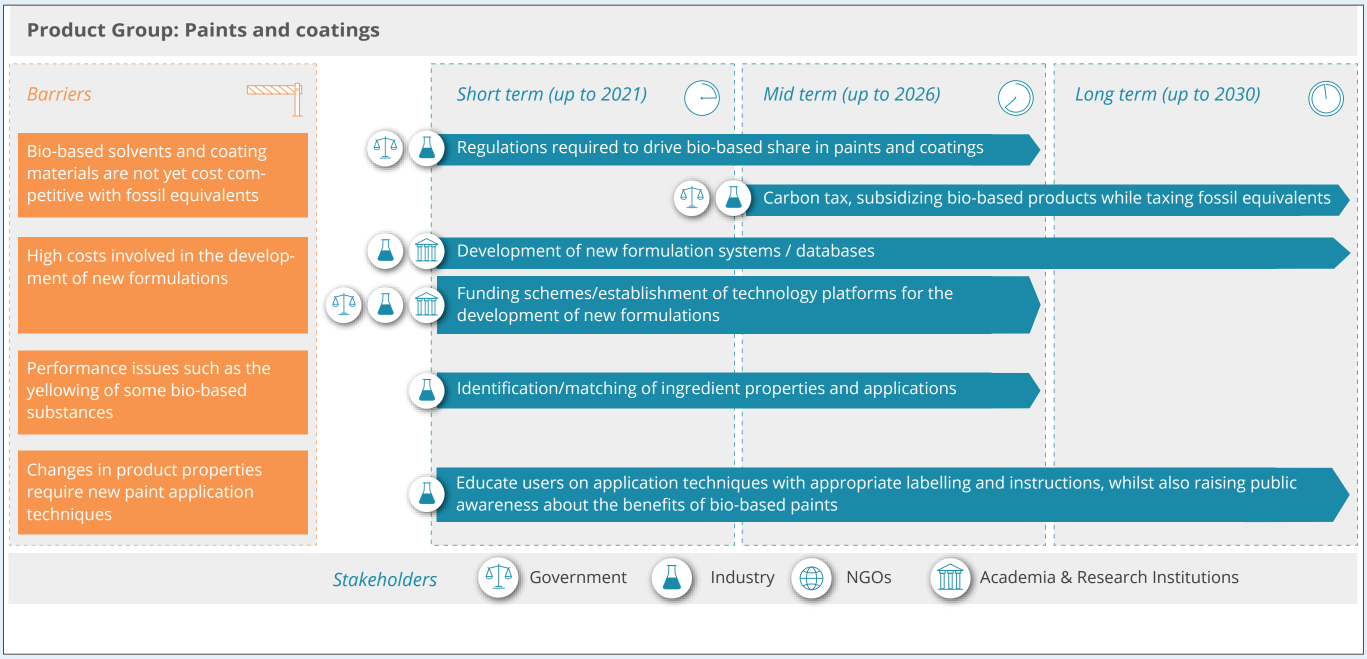


Figure 5: Roadmap to increasing the bio-based share of chemicals in the paints and coatings product group

Agrochemicals[1]

- 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 has to 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

1 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.

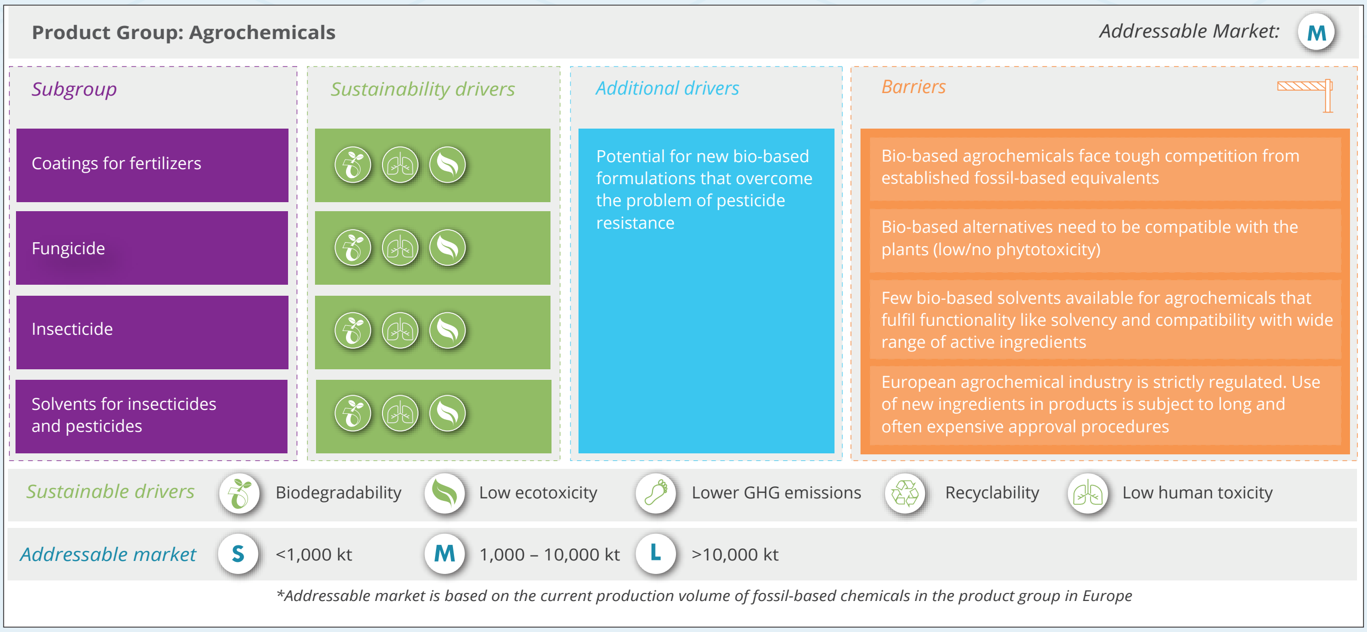


Figure 6: Pictorial summary of the agrochemicals product group

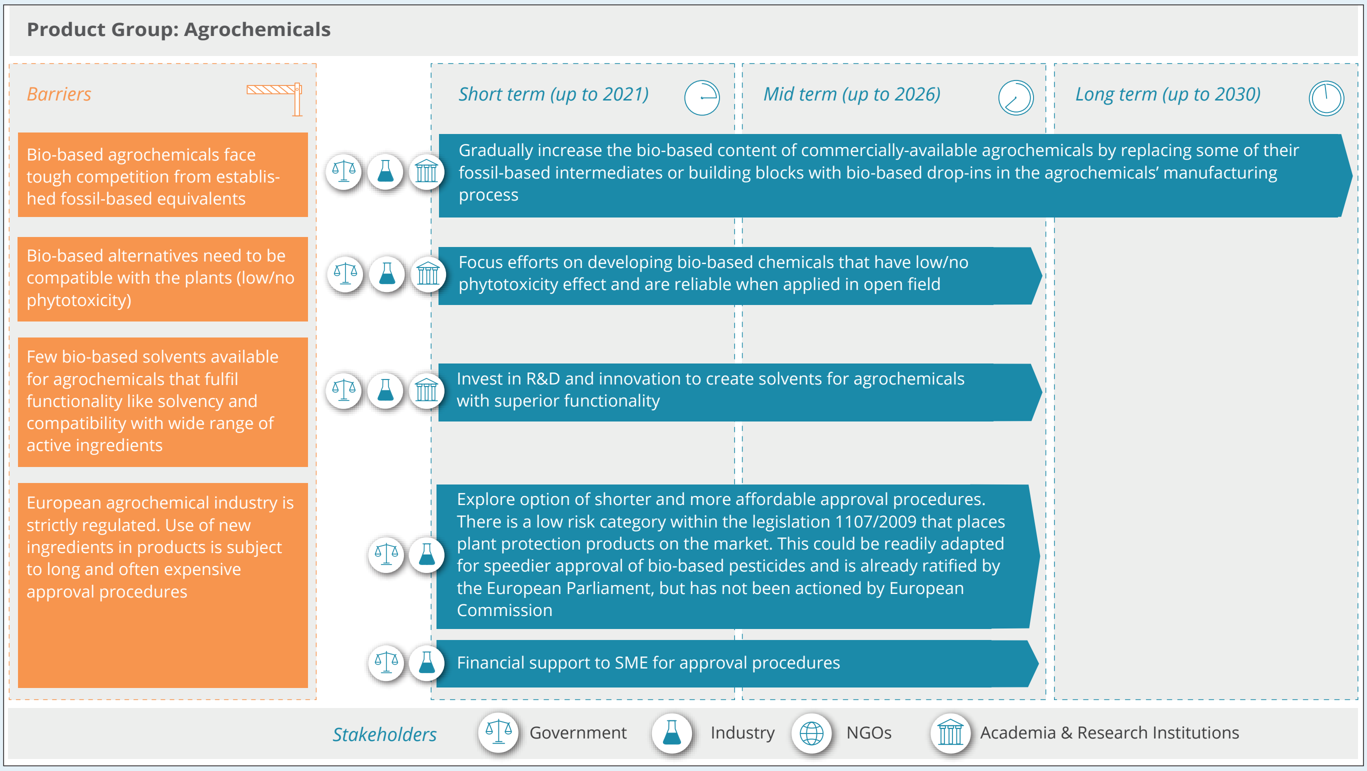


Figure 7: Roadmap to increasing the bio-based share of chemicals in the agrochemicals product group

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 alkyl benzene 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 surfactant 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, as long as 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 surfactants include Evonik, Ecover, Henkel, Saraya, Soliance, Wheatoleo and Nouryon.

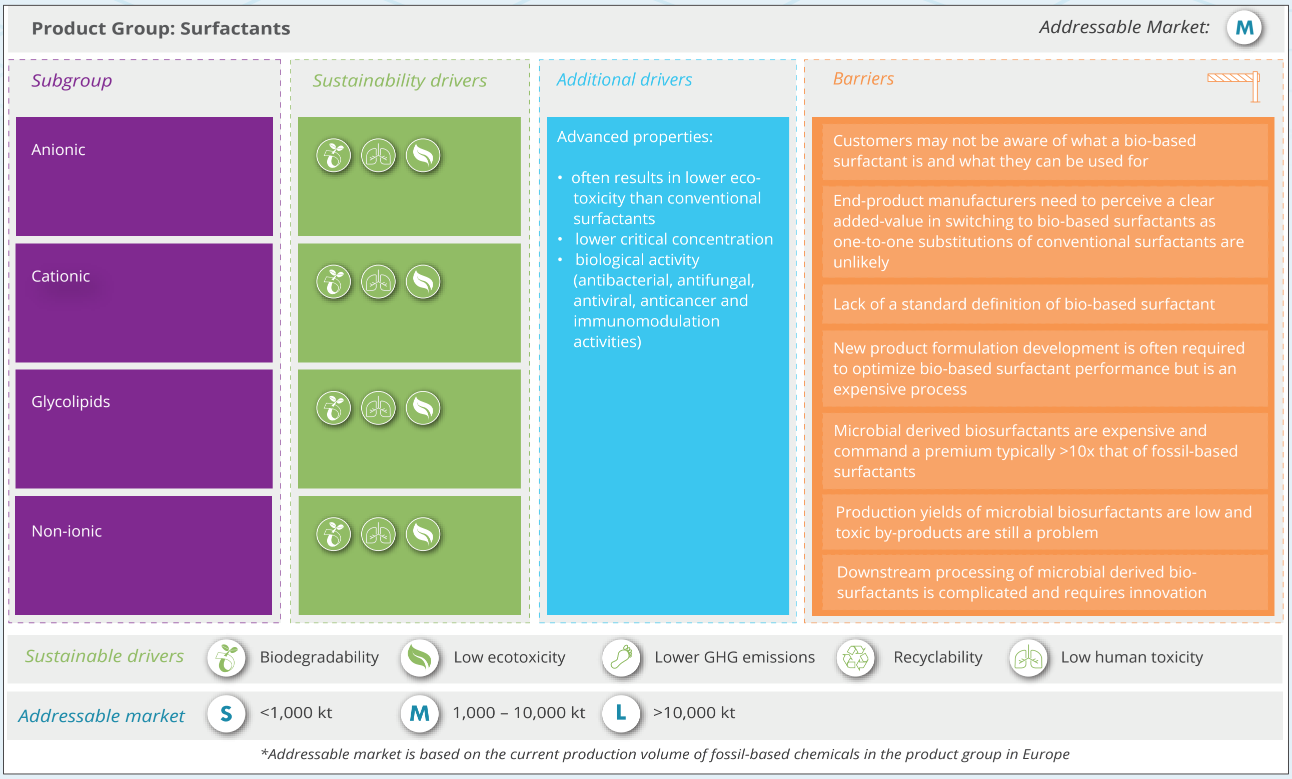


Figure 8: Pictorial summary of the surfactants product group

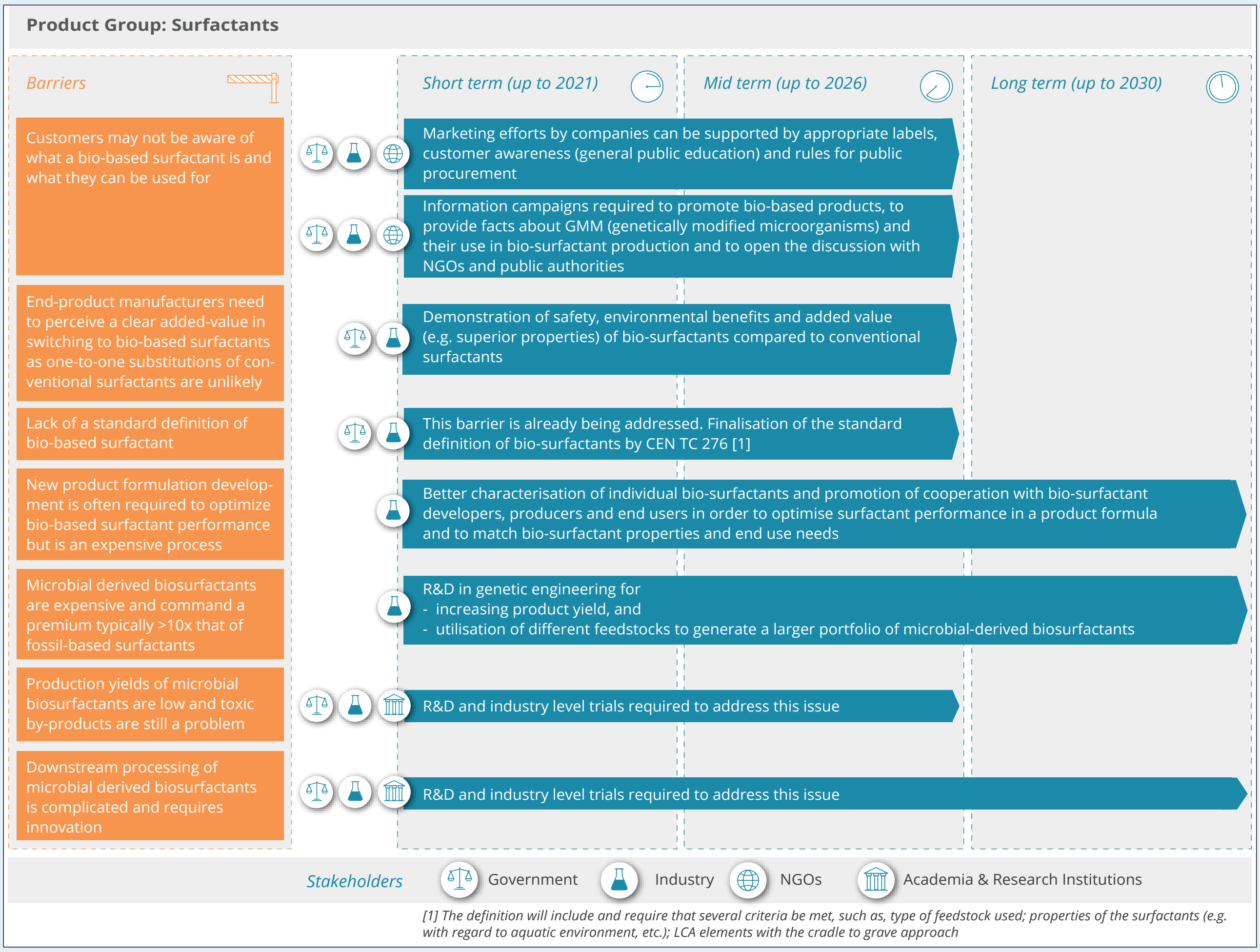
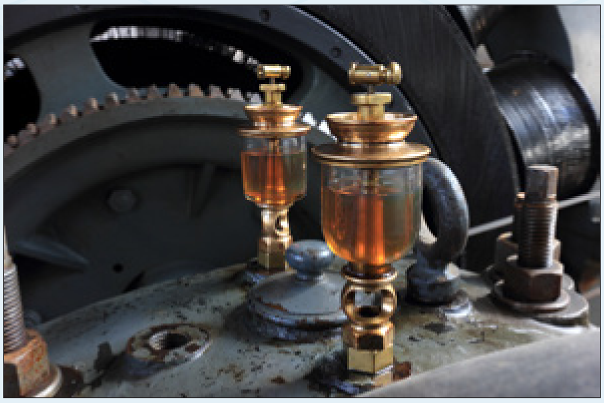


Figure 9: Roadmap to increasing the bio-based share of chemicals in the surfactants product group

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)

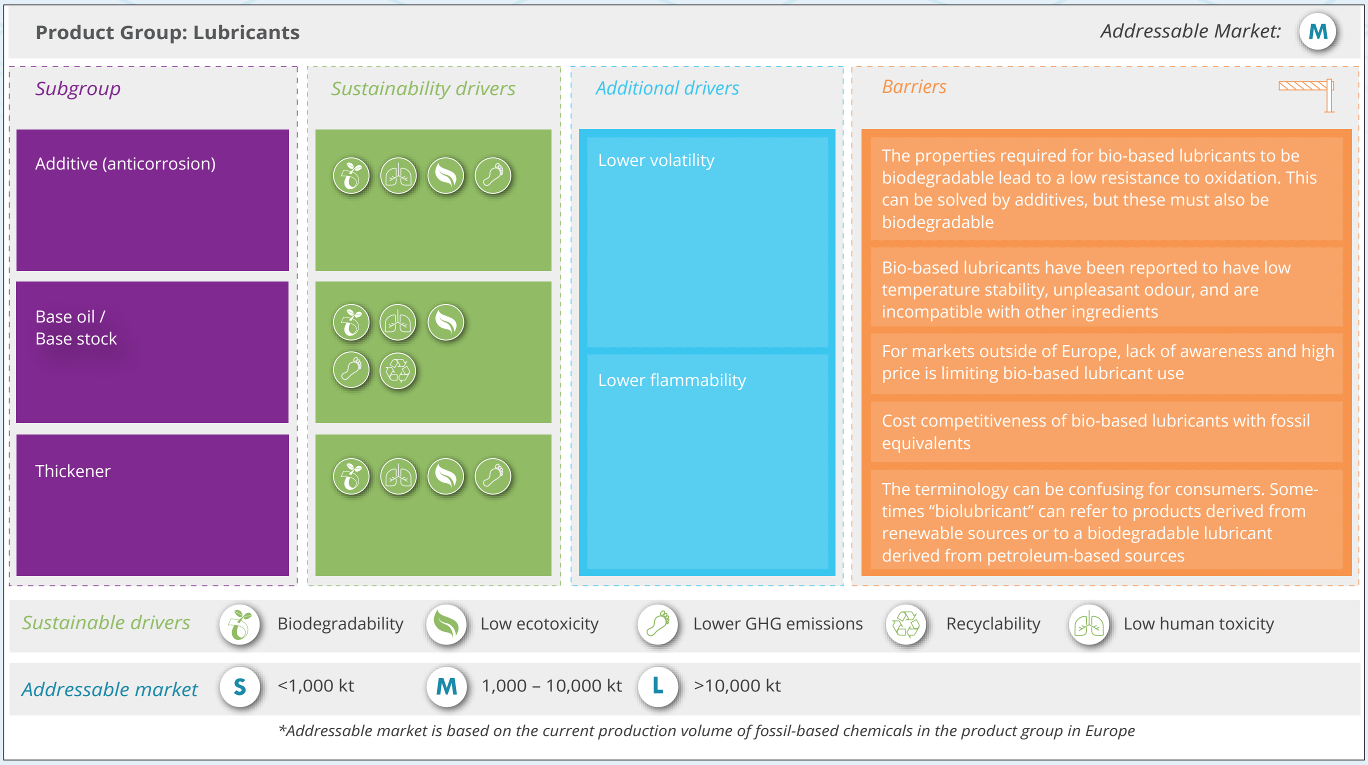


Figure 10: Pictorial summary of the lubricants product group

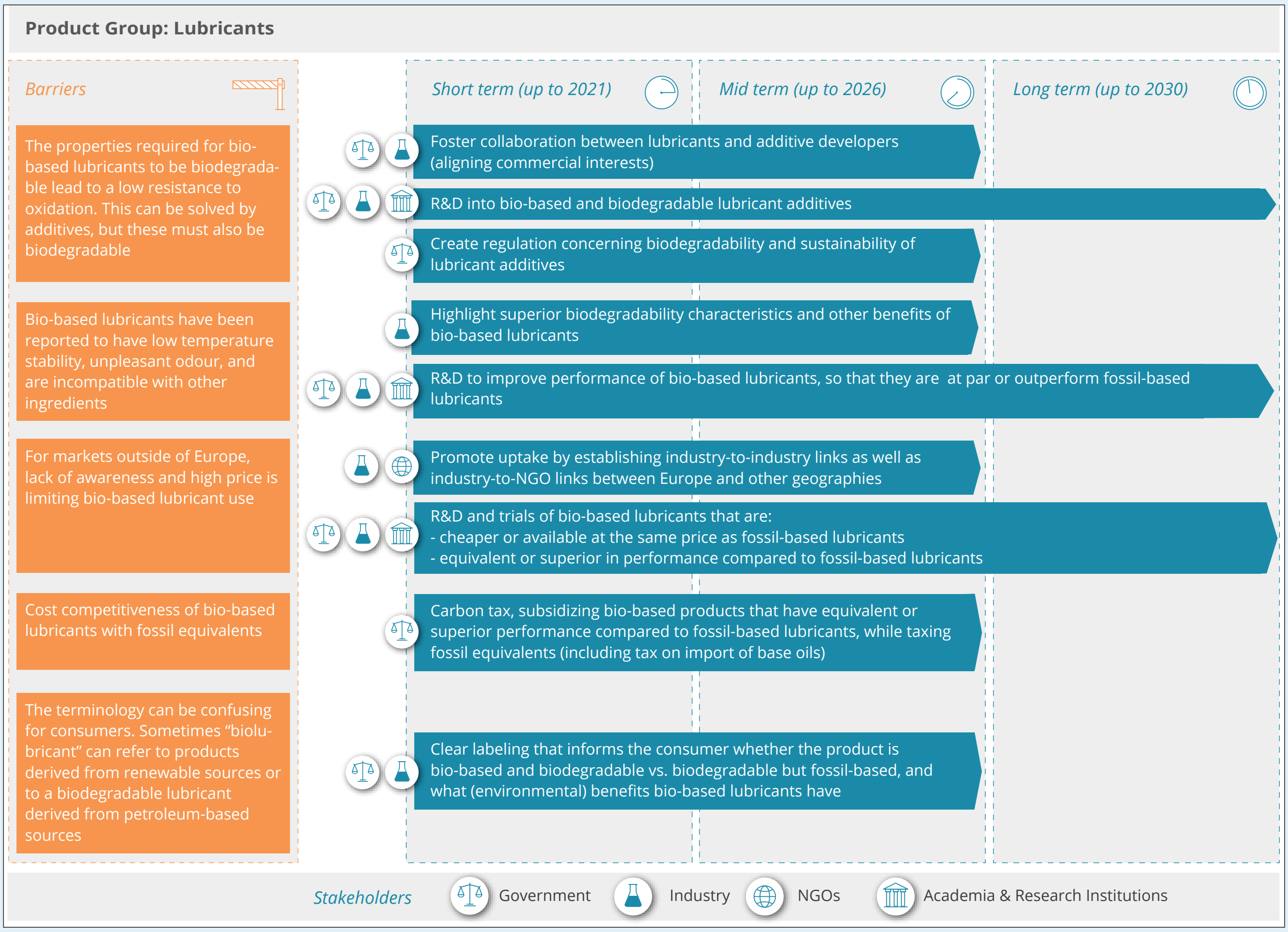


Figure 11: Roadmap to increasing the bio-based share of chemicals in the lubricants product group

Man-made fibres

- Bio-based man-made fibres production in Europe is >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 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, Radici-Group (Radilon® DT 40EP25W), BASF, Solvay, Distrupol, Sateri (viscose), Lenzing (TENCEL™), AlgiKnit

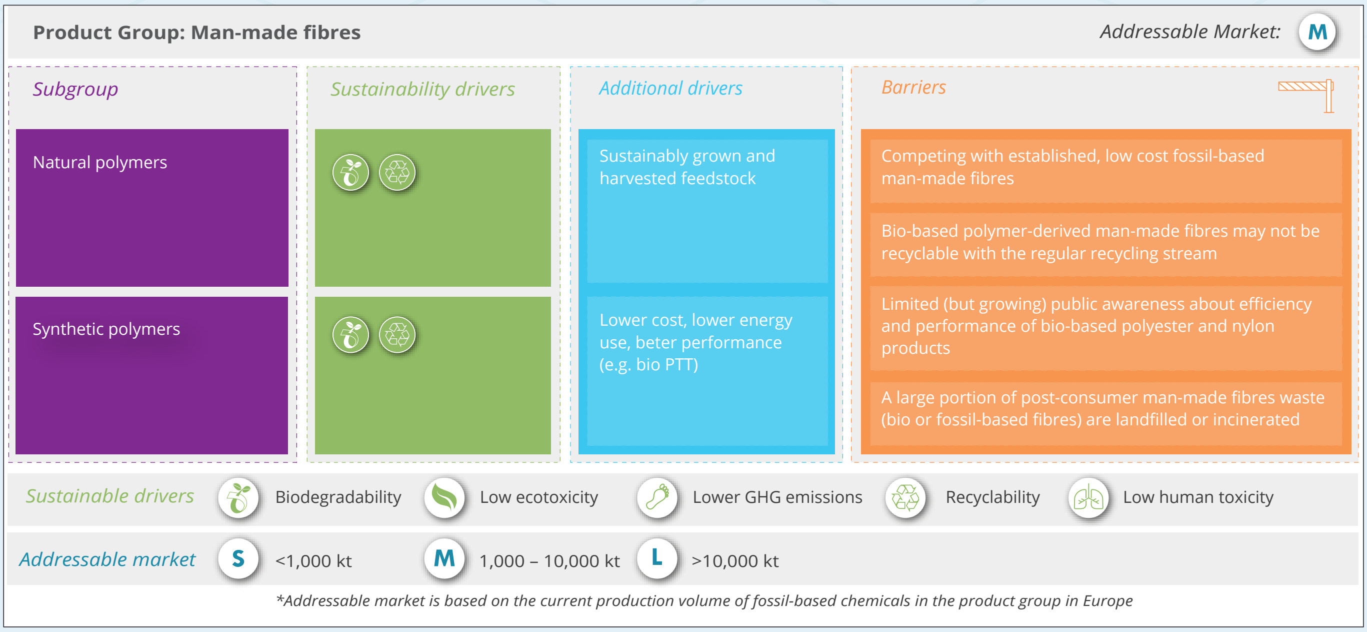


Figure 12: Pictorial summary of the man-made fibres product group

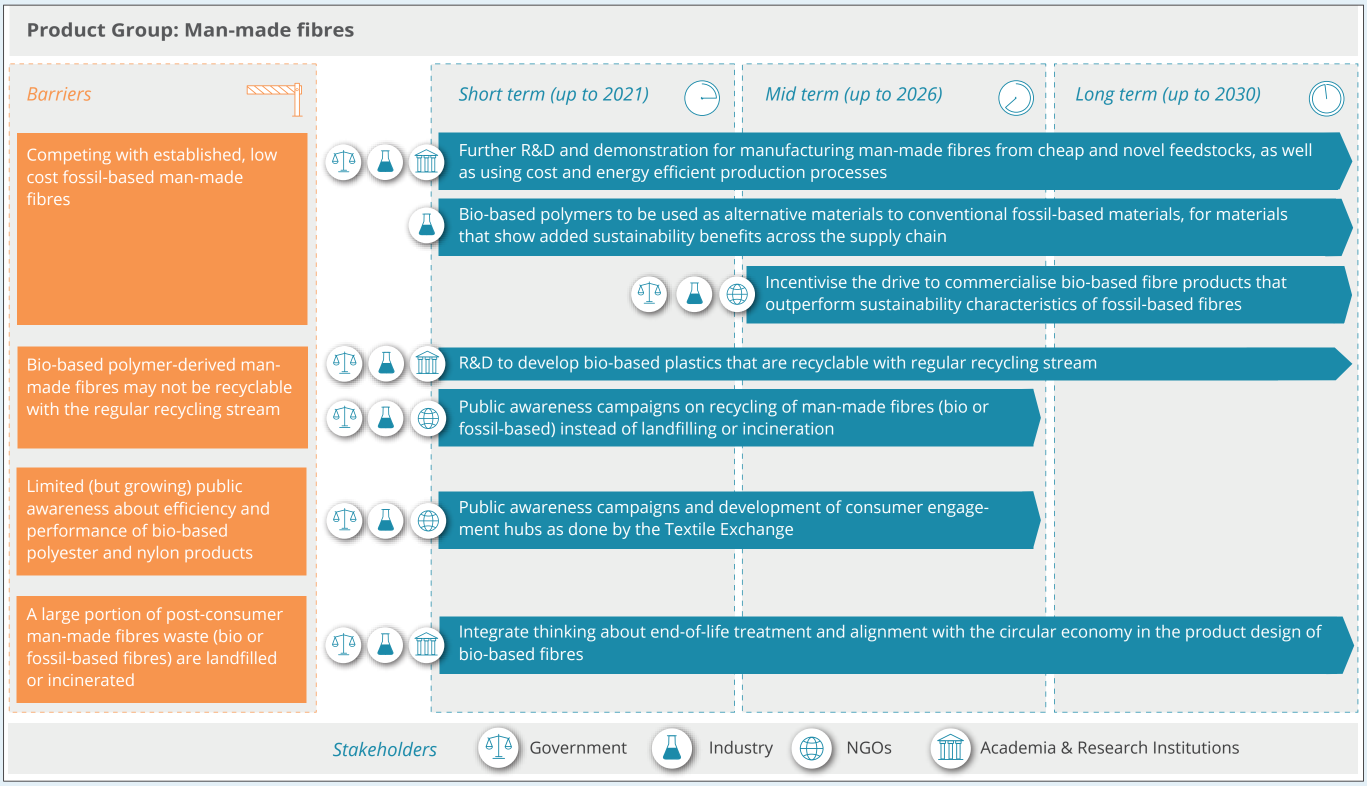


Figure 13: Roadmap to increasing the bio-based share of chemicals in the man-made fibres product group

Solvents

- Bio-based solvents production in Europe is <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 provided that they meet the functionally 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

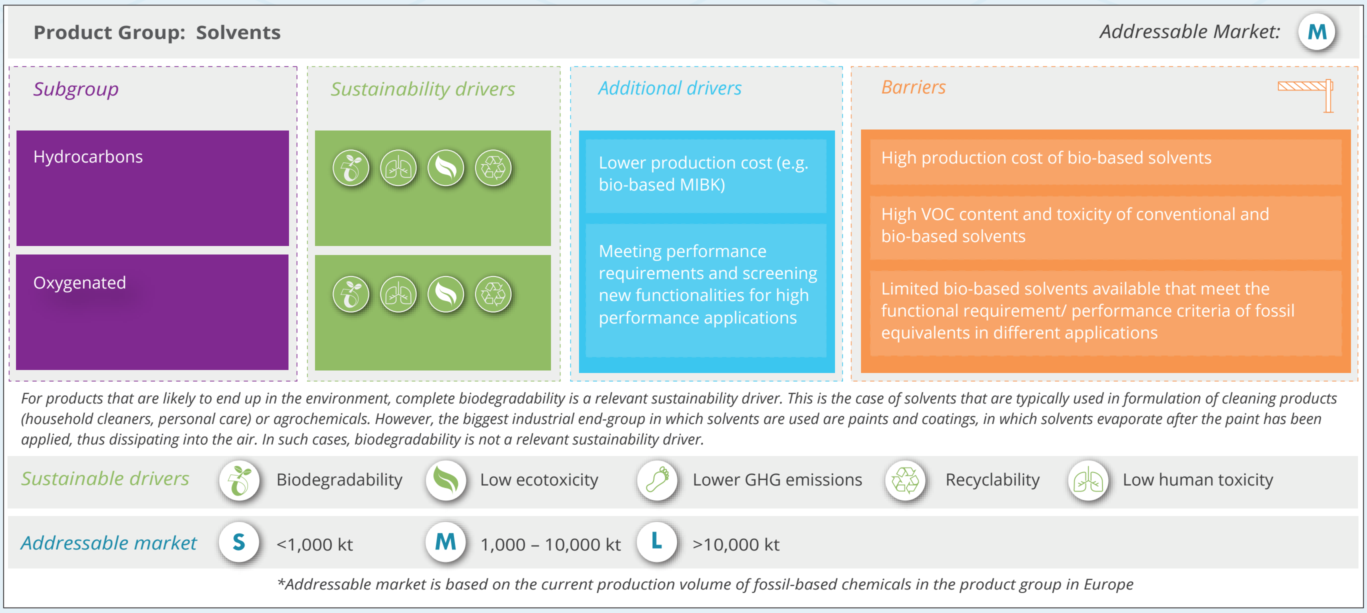


Figure 14: Pictorial summary of the solvents product group

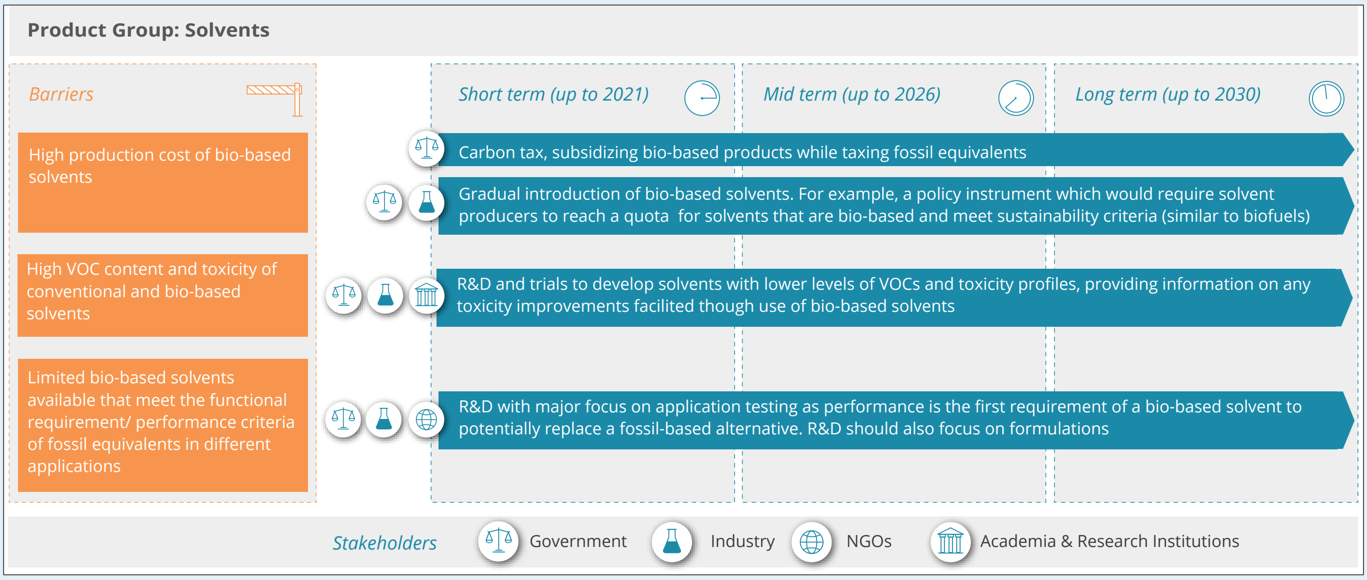


Figure 15: Roadmap to increasing the bio-based share of chemicals in the solvents product group

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 (Finalnd), Arkema (France), Weiss Chemie + Technik (Germany) and Covestro (Germany)

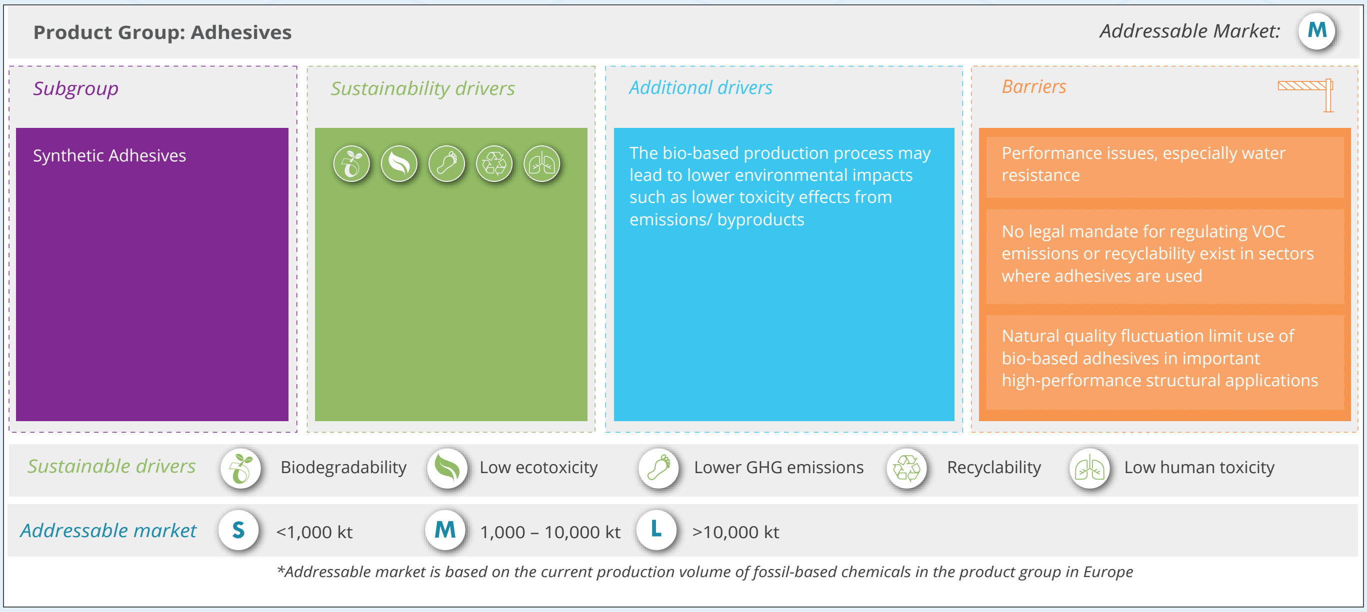


Figure 16: Pictorial summary of the adhesives product group

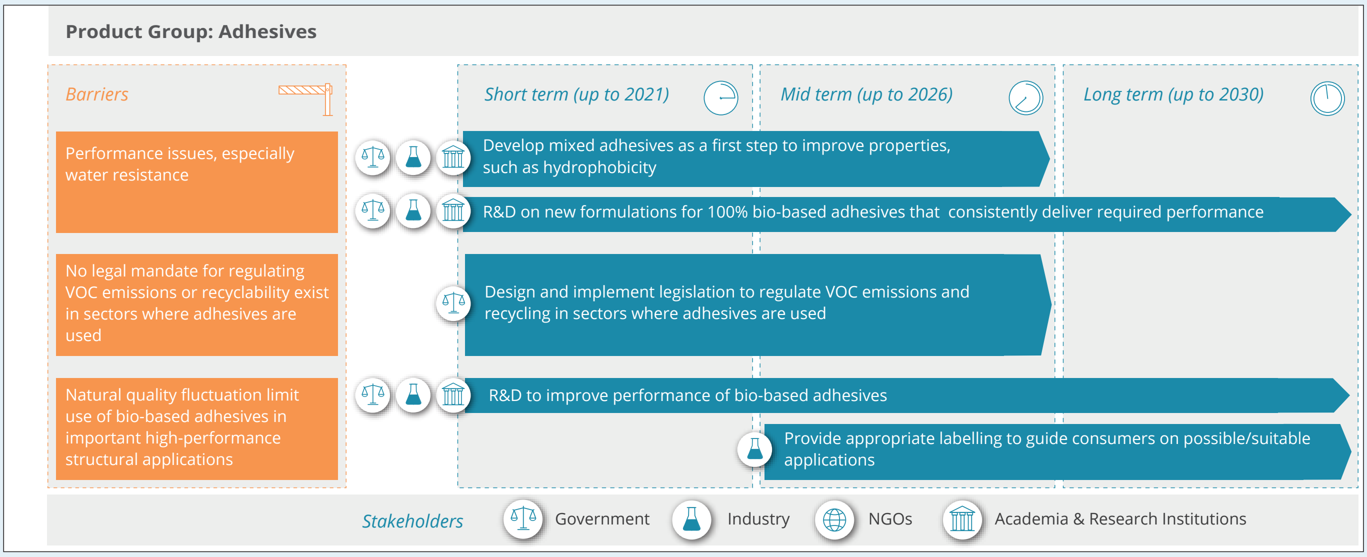
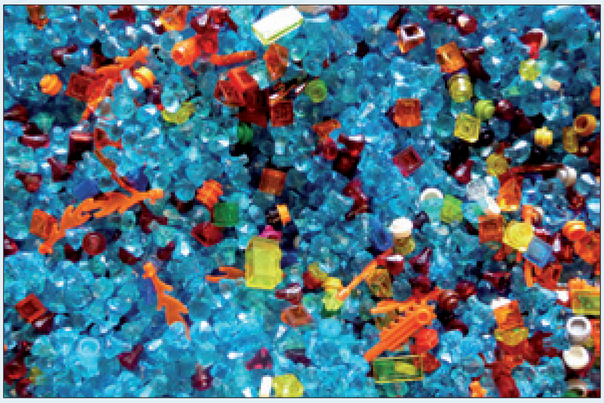


Figure 17: Roadmap to increasing the bio-based share of chemicals in the adhesives product group

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 >1,200 kt/yr, while fossil-based production is ~70,000 kt/yr.

- Therefore, out of the nine product groups, the addressable market of fossil-based plastics/polymers production in Europe is the largest in the nine product groups (large addressable market is considered as >10,000 kt).

- Diverse bioplastics are being developed that can be drop-ins, compostable and non-biodegradable, 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 plastic should provide adequate labelling to inform customers of types of bio-based plastics to raise awareness about bio-based plastic alternatives 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.

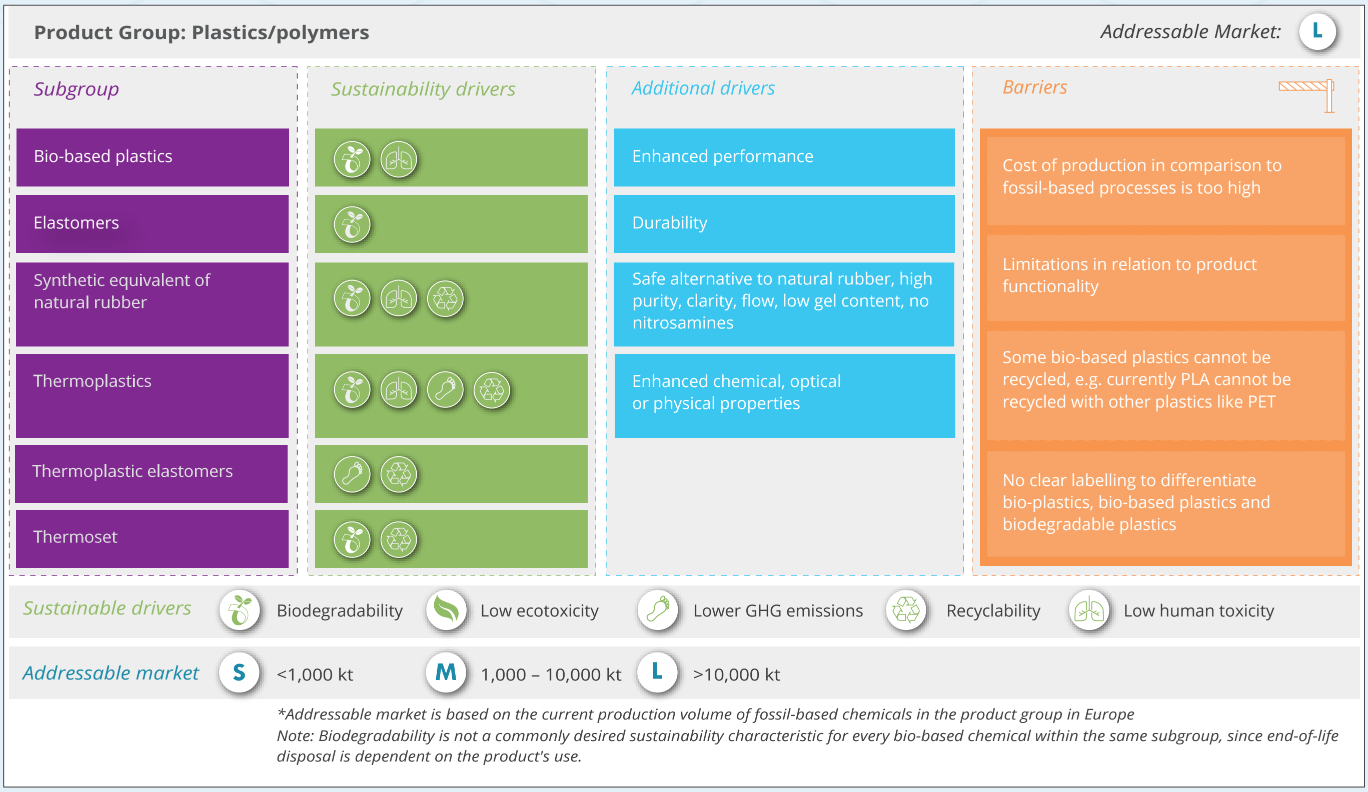


Figure 18: Pictorial summary of the plastics/polymers product group

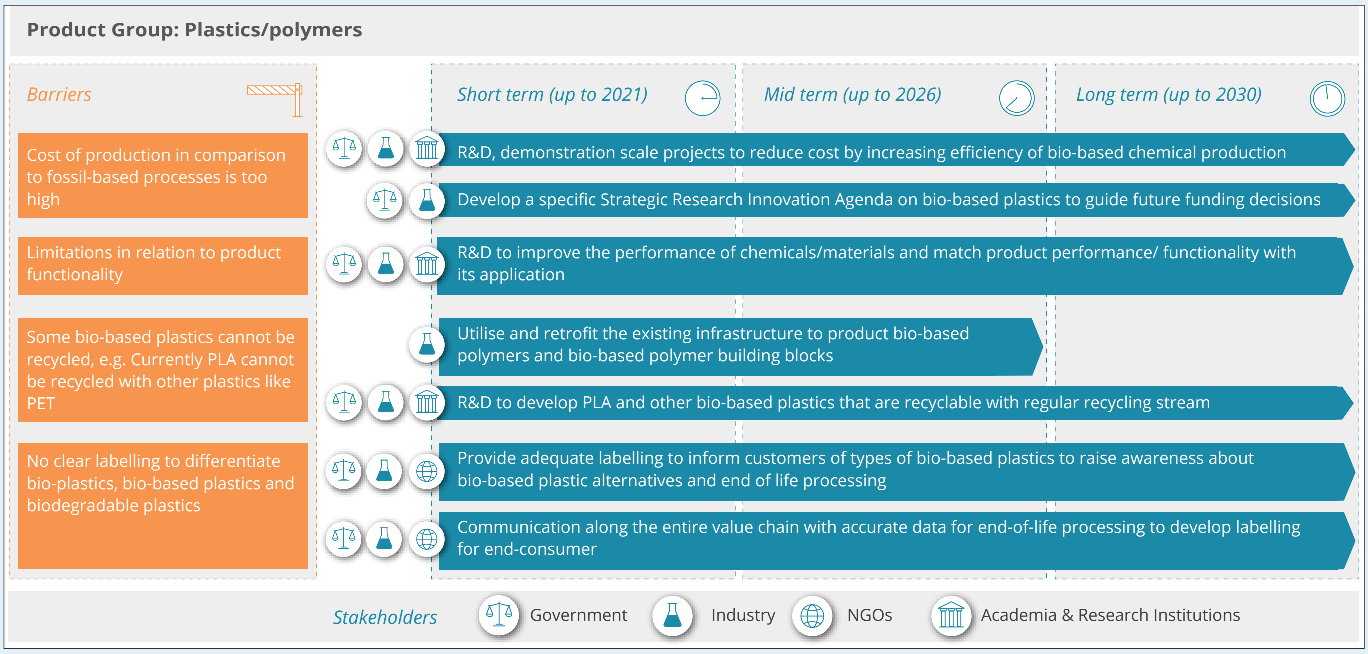


Figure 19: Roadmap to increasing the bio-based share of chemicals in the plastics/polymers product group

General barriers

Besides the product group specific analysis of barriers, some wider issues exist that concern the chemical industry in the bioeconomy. These are referred to in RoadToBio as general barriers. We give an overview of the crucial general barriers and provide some recommended actions to overcome these. The collected set of actions are a result of project-internal 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.

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 20: Summary of the general barriers and recommended actions for all six barrier

1. Introduction

1.1 EU bio-based industry background

The bioeconomy covers all sectors and systems that rely on biological resources (including organic waste), their functions and principles. The European Commission (EC) defines the bioeconomy as, “the production of renewable biological resources and the conversion of these resources and waste streams into value-added products, such as food, feed, bio-based products and bioenergy. Its sectors and industries have strong innovation potential due to their use of a wide range of sciences, enabling and industrial technologies, along with local and tacit knowledge [1].” While biotechnology is at the heart of bio-based processes, health biotechnology and biological medicines are not included in the European Union’s (EU) bioeconomy definition [2].

According to the European Commission’s Joint Research Centre (JRC), in 2015 the bioeconomy in the EU-28 generated ~EUR 2.3 trillion of turnover, which was a 5% increase from 2014 (Figure 1) [3]. Bio-based industries[1] accounted for >EUR 600 billion of this total(3,4). Further, the bioeconomy added EUR 621 billion of value in the EU, representing 4.2% of the EU’s Gross Domestic Product (GDP) and provided employment to >18 million persons in the EU, mainly in agriculture and the manufacture of food and beverages [3]. Bio-based industries employ ~4 million people in the EU (3,4). In 2015, the highest value-added annual growth occurred in the manufacture of bio-based chemicals (excluding biofuels) (+26%), bio-electricity production (+15%) and rubber and bio-based plastics manufacture (+13%), generating altogether an additional EUR 3.5 billion of value added compared to 2014 [2].

Further, it is estimated that one million new jobs could be created in the bio-based industries by 2030 [2]. It is anticipated that the biotechnology sector will play a key role in realising this potential [2].

1 Bio-based industries include: forest-based industries, bio-based chemicals and plastics, paper & paper products, biofuels & bioenergy, bio-based textile sector and pharma

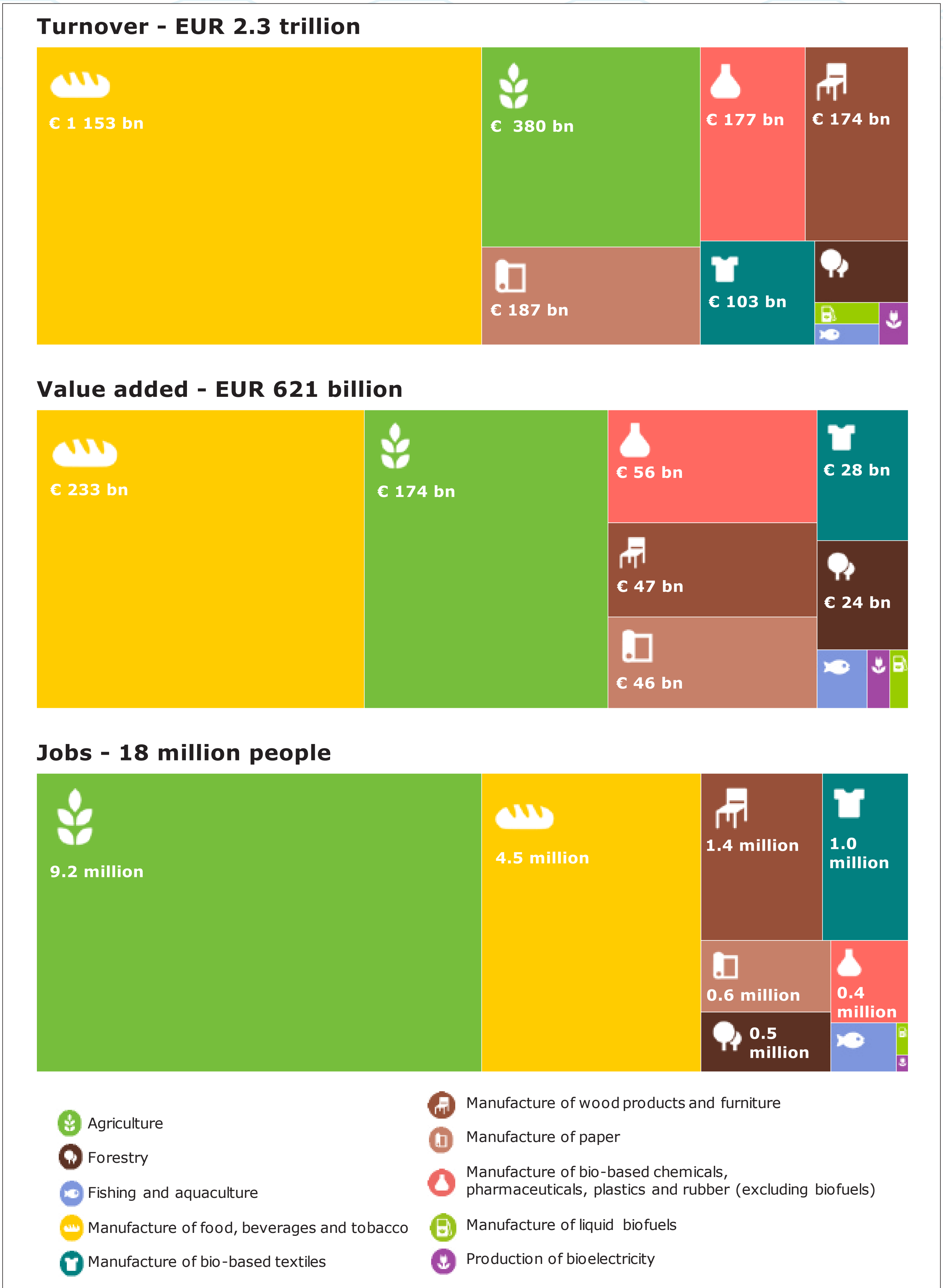


Figure 1: Turnover (billion EUR), value added (billion EUR) and employment (million people) in the bio-based sectors of the EU-28 in 2015 (Source: EC, 2018a - Brief on jobs and growth of the bioeconomy 2009-2015 [3])

1.1.1 Assessing the state and promoting the growth of the EU bioeconomy

The European Bioeconomy Strategy and its Action Plan was developed in 2012, recognising that the bioeconomy plays a central role in addressing several key interlinked challenges [2]. The 2012 Strategy aimed to "pave the way to a more innovative, resource efficient and competitive society that reconciles food security with the sustainable use of renewable resources for industrial purposes, while ensuring environmental protection [2]". The 2012 Strategy highlighted that the bioeconomy's cross-cutting nature offers a unique opportunity to address inter-connected societal challenges, and identified five objectives to which the Strategy and its Action Plan were to contribute: (I) ensuring food security, (II) managing natural resources sustainably, (III) reducing dependence on non-renewable resources, (iv) mitigating and adapting to climate change, and (v) creating jobs and maintaining EU competitiveness [2]. A review of the strategy in 2017 concluded that the 2012 strategy had substantially delivered on its objectives through several actions, which promoted the development of local bioeconomies valuing local resources and adapted to local needs, and the development of several national bioeconomy strategies (with dedicated regional platforms and stakeholder panels) [2]. These include EU Framework Programmes for Research and Innovation (the Horizon 2020 programme) and the launch of the Bio-Based Industries Joint Undertaking (BBI JU), which led to the creation of new bio-based value chains. Following the review, an updated version of the strategy was launched in 2018, which proposes three main action areas:

1. Strengthen and scale-up the bio-based sectors, unlock investments and markets
2. Deploy local bioeconomies rapidly across Europe;
3. Understand the ecological boundaries of the bioeconomy.

1.1.2 The EU chemical industry

The European chemical industry plays a major role in economic development, providing products and materials, and enabling solutions in numerous sectors. With 1.14 million employees and sales of € 507 billion (2016), it is one of the largest industrial sectors and a leading source of direct and indirect employment in many regions [5]. Multiple drivers such as regulations and public pressure have resulted in sustainability and circular economy concepts being adopted by the industry. Figure 2 shows the sectors that are served by the EU chemicals industry.

1.2 Rationale for bio-based chemicals

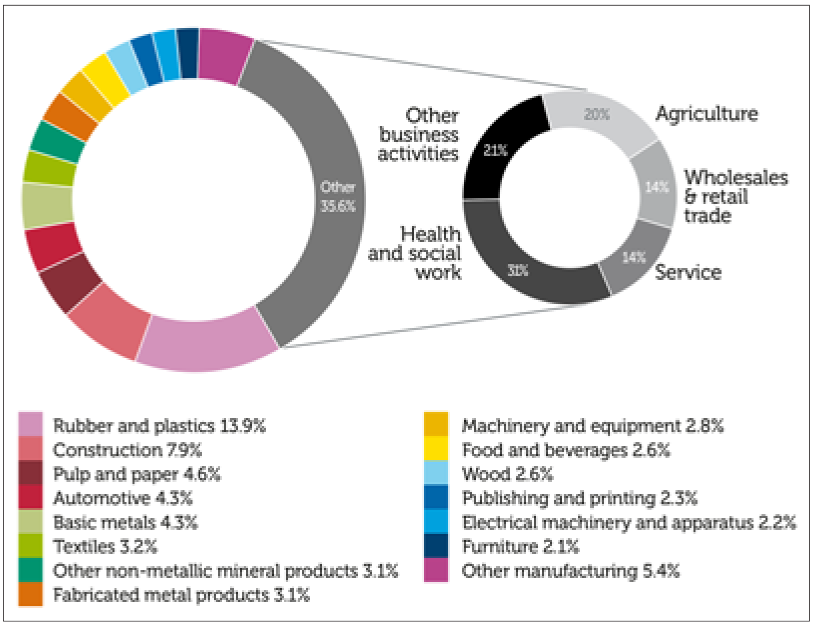


Figure 2: Contribution of the chemical industry to the EU economy – Customer sectors of the EU chemicals industry (Source: Eurostat data (Input Output 2000) and Cefic analysis [5])

The transition to a bio-based economy is powered by several drivers. These include [6];

- the need to develop an environmentally, economically and socially sustainable global economy
- an over-dependency of many countries on fossil fuel imports and therefore their need to diversify energy sources
- the anticipation that fossil fuels such as oil, gas and coal will reach peak production soon
- tackling climate change by taking measures to reduce GHG emissions
- and the need to stimulate regional and rural development.

By replacing fossil-based products with bio-based products (which tend to have a smaller carbon footprint[2]) the chemical industry can make a critical contribution to the EU's climate goals, whilst simultaneously generating new job opportunities in the region [4]. There is potential in major industrial sectors such as chemicals and plastics to replace fossil-based car-

2 Note: not all bio-based products have a smaller carbon footprint when compared to their fossil equivalents

bon with renewable and recycled carbon as raw materials [4]. Sources of renewable and recycled carbon [7] are as follows:

- renewable carbon gained from all types of biomass
- recycled carbon from recycling of already existing plastics and other organic chemistry products (mechanical and chemical recycling)
- recycled carbon from direct CO_2 utilisation of fossil point sources (while they still exist) as well as from permanently biogenous point sources and direct air capture.

The RoadToBio project has focused on renewable carbon gained from biomass.

Globally, governments and private companies are already providing support and investing in the transformation of the chemical industry [8]. Further, most of the large chemical and pharmaceutical producers have sustainability high on their agendas. Many of them are setting targets to improve the sustainability of their products in the mid to long term to 2050[8]. To achieve these targets businesses are improving sustainability in their entire value chains by considering: sustainable feedstock for their products, use of renewable energy in the manufacturing process, and reducing the environmental impact of the product end-of-life and disposal [8].

In the EU, the European Environmental Agency (EEA) has been advising that bio-based and biodegradable alternatives to fossil equivalents should be used where the risk of dispersion into the ecosystem is high, e.g. lubricants, materials that are subject to wear and tear, and disposable products [2].

The raw materials used by the chemicals industry are ~50% organic (fossil and bio-based) and ~50% inorganic (minerals, metals) [9]. The chemicals, plastics and pharmaceuticals sectors include several fully bio-based (e.g. natural dyes and pigments, enzymes, fatty acids) and partly bio-based products [9]. Based on Eurostat data, in 2015, out of 534 products in the NACE Division 20 (*Manufacture of chemicals and chemical products*), 110 products were fully or partly bio-based [9]. Around 40% of these 110 products were 100% bio-based (e.g. tanning extracts of vegetable origin, sorbitol, tall oil), 24% of these products had a bio-based share of at least 10% (e.g. ethylene glycol, carboxylic acid, adipic acid) and the remaining 36% of products had lower bio-based shares (e.g. acetic acid, methanol, epoxy resins) [9]. Most of the products (424 in total) in the NACE Division 20 are therefore non bio-based [9]. Hence, there is potential to increase the share of bio-based in partly bio-based products, and to research and develop methods for manufacturing bio-based versions of fossil-based products.

1.3 RoadToBio project

The RoadToBio project is funded by the EU under the Horizon 2020 research and innovation programme. It aims to pave the way for the European chemical industry towards a higher bio-based portfolio and competitive success based on the benefits offered by the bioeconomy. The goal of RoadToBio is to create **a roadmap for the chemical industry** with the aspiration to increase the share of bio-based or renewable feedstock to 25% of total volume of organic chemicals raw materials/feedstock used by the chemical industry in 2030[3] (4,10). Societal needs in 2030 need to be considered while aspiring for this target. The biomass used for bio-based chemicals should 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). The SIRA is considered as 'guidelines' for the European biorefinery sector.

Cefic estimated that the total volume of organic raw materials/feedstock used in 2015 was around 78.7 million t/yr [10]. Of this, the bulk of the raw materials/feedstock in use comprised of mineral oil derivatives (74%) and natural gas (15%), and a small volume of coal (1%) [11]. The renewable share of the EU chemical industry's raw material use was around 10% in 2015, which is ~7.8 million t/yr [10] (Figure 3). Nearly 70% of the renewable or bio-based raw materials are from vegetable oils and animal fats, sugar and starch, and bioethanol. Other important bio-based raw materials in use are natural rubber, chemical pulp[4], and glycerol. 'Others' include a variety of vegetable waxes, natural resins, tanning agents, proteins, and medicinal plants. Given that several lab-scale and some demonstration-level projects are underway to investigate the use of biomass waste and residues as renewable raw materials for chemicals production, this resource could start featuring as a renewable raw material (along with the others listed by Cefic) in 2030 (12–17).

Research, development and commercialisation of bio-based chemicals/products enables the establishment of a market for bio-based feedstock use in biochemicals production. Feedstock that can be/is used has been assessed for over 500 chemicals and multiple value chains in D1.1 of the Road-

3 Piotrowski, S., Carus, M., Carrez, D., 2016. European Bioeconomy in Figures. nova-Insitute.

4 Chemical pulp is a man-made fibre of cellulose, which is obtained from plant material (95% from wood) and is further processed predominantly in the paper industry. The Kraft process produces chemical pulp.

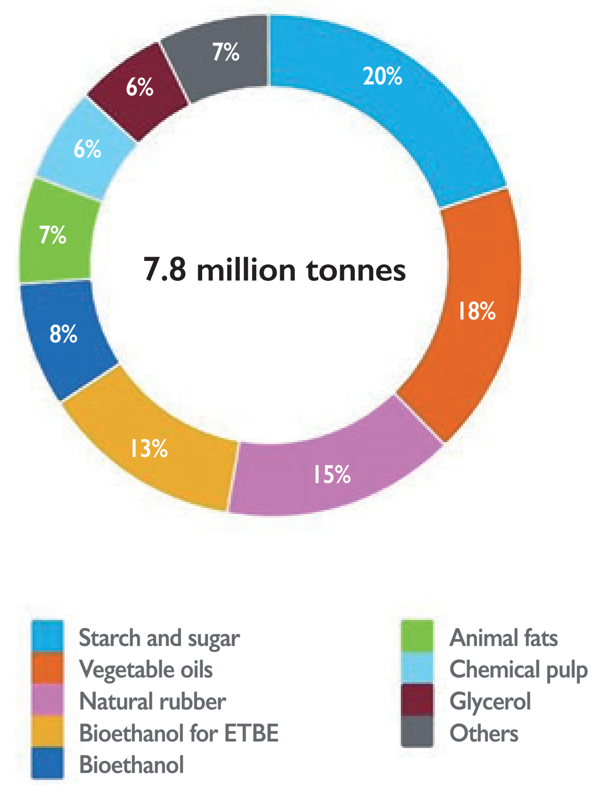


Figure 3: Bio-based raw materials use in the EU chemical industry (Source: Cefic – Facts & Figures 2017 of the European chemical industry) [10]

ToBio project and in more detail in D1.2 for nine chemicals[5]. This report includes a literature-based assessment of barriers associated with the availability of bio-based feedstock for the EU chemical industry as well as supply chain related issues. The nine product groups covered in RoadToBio are adhesives, agrochemicals, cosmetics, lubricants, man-made fibres, paints/coatings, plastics/polymers, solvents, and surfactants (see Annex I for details on how these were chosen for the scope of RoadToBio).

The roadmap will contain the following two main components:

- an **analysis** of the most promising opportunities for the chemical industry to increase its bio-based portfolio, as well as the technological and commercial barriers in regulations and acceptance by society, governing bodies and the industry itself.
- a **strategy, action plan and engagement guide** to overcome the existing and anticipated barriers as mentioned above.

The current document is a draft version of the **strategy** document (deliverable) mentioned above.

5 The nine chemicals covered in D1.2: Ethylene, methanol, dodecanedioic acid (DDDA), 1,4-butanediol, polyhydroxyalkanoates (PHAs), polyethylene furanoate (PEF), lactic acid, furfural, glycerol

2. Scope and approach

This section of the report describes the tasks involved in the RoadToBio project for the development of the roadmap. Additional information detailing how the nine product groups were chosen for the scope of the roadmap are found in Annex I and the findings from other work packages (WP1-WP3) are found in Annex II. Further detail on the methodology are found in Annex III.

2.1 Roadmap Scope and Objectives

The RoadToBio roadmap for the EU chemicals industry toward a bioeconomy is designed to describe the actions needed from all stakeholders (government and policy makers, funding bodies, NGOs, the chemical industry, academia, R&D centres, and commercial entities) to incentivise and facilitate the **use of bio-based feedstocks and intermediates in the chemicals industry** between now and 2030. The roadmap aims to deliver a set of **key messages and actions** for each of the nine product groups in scope to achieve the overarching objectives, set out over time, showing inter-dependencies between them. Along with this, the roadmap will also focus on a set of general barriers that apply to the entire European chemicals industry, and actions that could be taken to address them.

The roadmap is being developed using open literature and market reports in consultation with stakeholders and will be disseminated to a wide audience. In this way, actors already in the sector (and those adjacent) will gain a deeper understanding of the opportunities in this area and the actions that they could take to overcome barriers and to exploit these opportunities. This strategy document details the methodology and analysis used to understand the landscape of various markets within the nine product groups and to establish the drivers towards a greater share of bio-based products within the product groups; reports the status of the current bio-based market and potential for its growth, where there are opportunities and barriers with a suggested action plan encompassing key messages for the range of relevant stakeholders. If this action plan were adopted during the period to

2030, the EU chemical industry could see a shift to a 25% share of bio-based products.

2.2 Roadmap development methodology

The draft roadmap was created using four key tasks, Task 1-4. The diagram in Figure 4 indicates all the steps that have been taken to deliver the final strategy document (the roadmap), which involves five tasks with three stakeholder consultations.

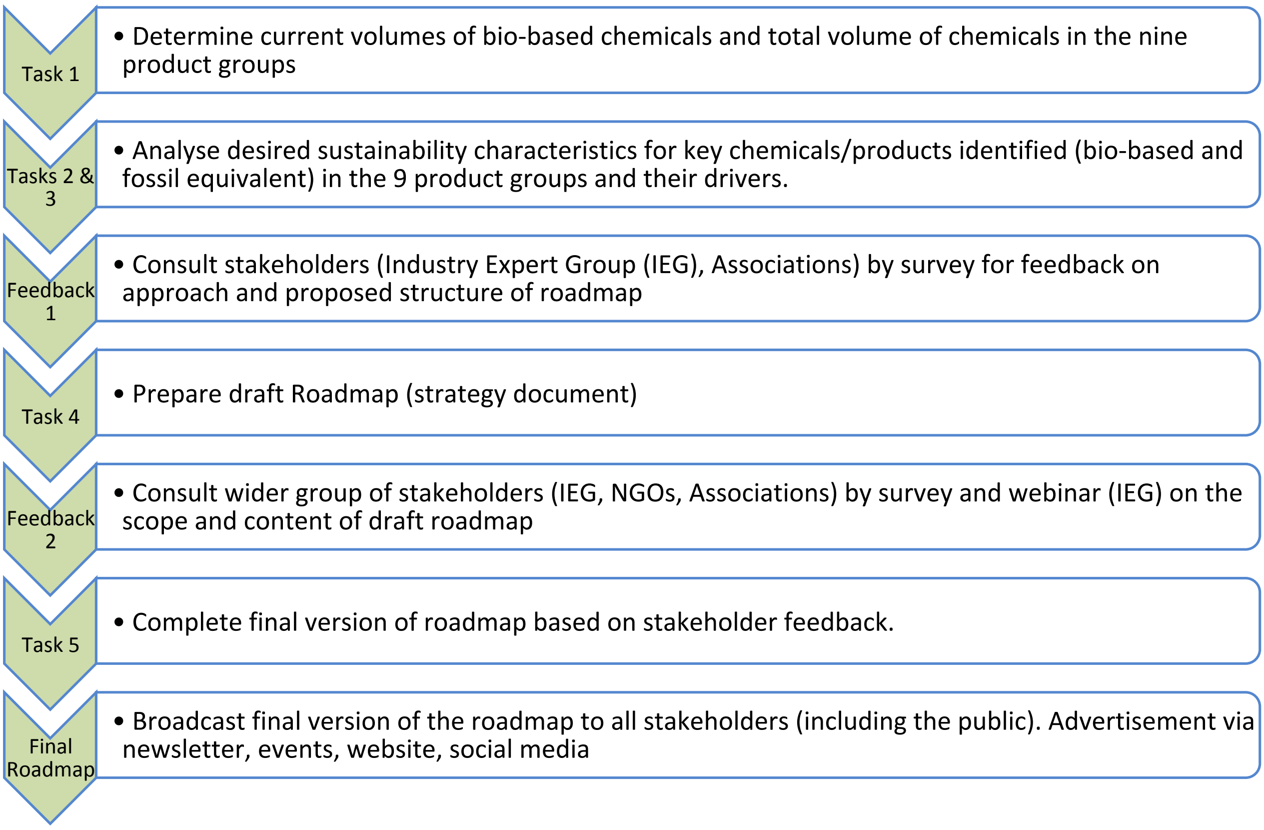


Figure 4: Tasks and steps involved in roadmap development

To make the roadmap as impactful and user-friendly as possible, an approach document to roadmap development was written and circulated to the RoadToBio Industry Expert Group (IEG) and relevant associations, which outlined the proposed structure for the roadmap. The following survey questions were asked:

1. Is the approach to the Roadmap development outlined in this document clear? Is it logical? Is more/less detail needed and, if so, where?
2. Are the criteria for determining the attractive product groups/subgroups/bio-based chemicals the right ones?
3. What do you anticipate being the most important challenges in developing the Roadmap?
4. Are the Roadmap chapters logical and detailed enough?
5. From the explained chapters, which do you find most interesting? Which one is the least significant? Which could we expand upon?
6. Are there any additional elements that you think should be included in the Roadmap?

The feedback from stakeholders was positive with respect to the proposed roadmap structure, analytical techniques used and level of detail intended for the roadmap. They made suggestions of the challenges the consortium might face in generating the roadmap and made suggestions on how to address these. They also highlighted the areas of most interest and desired outcomes, which have helped to formulate the essential actions in the roadmap. Stakeholder's views and comments have been incorporated into this draft roadmap strategy document and will prove an important step to forming the final roadmap.

The fundamental research and analysis to generate a section of the strategy document, Tasks 1-3 was used to identify sub-product groups and bio-based chemicals of interest and most value. Task 1 involved determining the current volumes of bio-based chemicals and the total volume of chemicals in the nine product groups. For each of the nine product groups, Task 2 and 3 involved identifying and understanding the main drivers and desired sustainability characteristics that are met, or are not met, by both the 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 results for each product group are presented in chapter 3 in a table categorising sustainability characteristic (proven and/or desired) of bio-based chemicals and their fossil equivalents in each product group. Table 1 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.

The information gathered in Tasks 2 and 3 with analysis of product group markets and results of D1.1 were used to form a narrative in Chapter 3 to describe the bio-based growth opportunity within each product group, and to determine the actions required by the EU chemical industry to realise bio-based uptake in different product groups with associated benefits (for e.g. increased market share, GHG benefits).

Chapter 3 is the roadmap (Task 4), which will be used to generate the action plan. This is to guide stakeholders to develop and commercialise technologies and to overcome barriers (technical/economic, political, market) to move towards the aspirational target of increasing the share of bio-based/renewable feedstock to 25% of total volume of organic raw materials/feedstock used by the chemical industry in 2015.

2.2.1 Action Plan

This will form a separate deliverable but will be based on the action diagrams in chapter 3 for each product group. Thus, the steps a-d have been implemented in forming this draft roadmap strategy document.

The approach to the action plan of the roadmap is to:

a. Detail any identified barriers (technical, economic, political or societal) to uptake of bio-based chemicals, based on Task 2 and 3 analyses, case studies, analysis of policy barriers and stakeholders' inputs.

b. Present the barriers to be addressed and by which stakeholders.

c. Explain what actions are needed. Actions will be grouped according to the barriers they overcome.

Table 1. Colour coding and "x" marks to indicate sustainability characteristics of fossil/ bio-based chemicals that were selected in the nine product groups for analysis in Chapter 3.

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)

d. Show when these actions should take place by matching actions to timelines in Chevron diagrams. This will allow the identification of critical paths or dependencies, and 'crunch periods' where many actions are required.

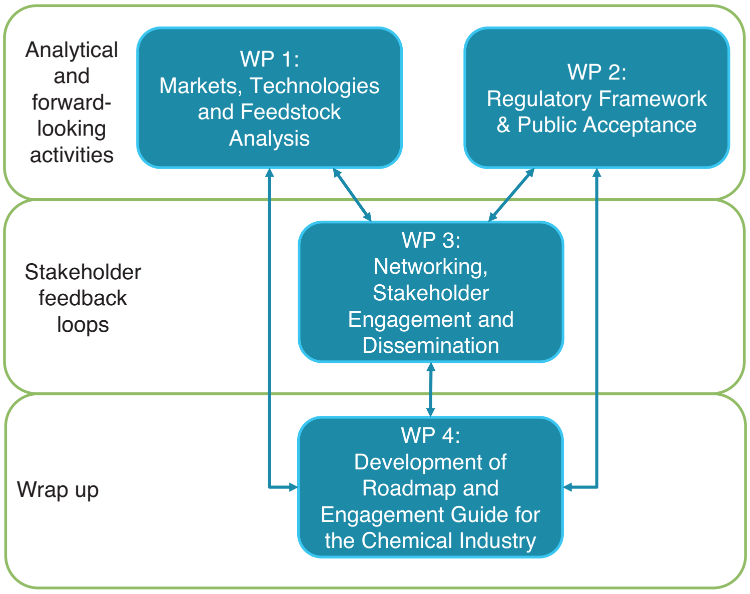


Figure 5: Interaction between Work Packages in RoadToBio

This draft roadmap document (strategy document) will be presented to a group of stakeholders (Consultation 2, see Figure 4) to assess whether the scope of opportunities identified are suitable for the roadmap and whether all possible actions required to overcome barriers have been identified and characterised correctly. Once feedback from the stakeholders has been incorporated into the final roadmap, the actions will be examined from an alternative perspective: the perspective of each type of stakeholder. Action plans will then be devised, consisting of recommended actions for each type of stakeholder in the period 2018-2030. Based on the stakeholder feedback, the final roadmap (including the engagement guide to facilitate the wide spread dissemination of the project outcomes) will be prepared. Details of the engagement guide can be found in Annex III.

2.2.2 Work Packages 1-3

In the RoadToBio project, there have been 4 main work packages (denoted by WP1, WP2 *etc*.):

- **WP1** examined the current status of bio-based products in the chemical industry, and what specific opportunities for growth may lie ahead
- **WP2** looked at the regulatory framework associated with bio-based chemicals and materials, and public perception of these
- **WP3** aimed to strengthen the cooperation between the chemical industry, societal and governmental organisations through dissemination of outcomes and public engagement throughout the project
- **WP4** built upon the findings from the previous 3 work packages to develop a roadmap

The relationship between these 4 main Work Packages is summarised in Figure 5.

Key Observations from WP1 – D1.1:
Overview of opportunities for bio-based chemicals in the chemical industry

- For most of the chemical products there are possibilities to fully or partially replace fossil feedstocks with bio-based alternatives. In 85% of the analysed petrochemical value chains, at least one entry point for a bio-based chemical was found.
- In total more than 1,000 possible bio-based entry points were identified in the value chains of these 500 petrochemical products. Extrapolating this observation leads to the conclusion that every value chain in the chemical industry on average has two entry points for bio-based chemicals.
- Bio-based oxygenates enter the petrochemical value chains further downstream, which means the subsequent value chain will be shorter yet in principle it shows an opportunity for 'smart drop-ins', that make use of oxygen functionalities that are already present in biomass.
- Of the 120 bio-based chemicals studied, only 49 could enter these value chains – those that could not can be considered 'dedicated chemicals'. This means they have specific (often preferential) properties and can potentially replace formulated final products based on their functionality, rather than parts of the chemical value chains.
- The feedstock platforms that came out as most important in this analysis are the sugar platform and the glycerine platform, though it is important to note that other feedstocks may become more important for bio-based chemicals in the future.

Key findings from WP1 – D1.2:
Specific business cases for the introduction of bio-based products in the chemical industry

- In most of the cases, bio-based chemicals have lower greenhouse gas (GHG) emissions compared to their fossil-derived equivalents. Large volume bio-based drop-ins like ethylene, and dedicated polymers such as PEF or glycerol derivatives could lead to significant displacement of fossil-based feedstock and improve the overall carbon footprint of European chemical industry.
- In some cases bio-based products showed improved performance and functionality and relatively lower production costs.
- However, further technology developments and energy optimization of bio-based process are needed to continue reducing GHG emissions and improve the overall sustainability and cost competitiveness of bio-based chemicals.
- A significant driver for dedicated bio-based plastics such as PEF, PLA and PHA is the environmental impact after disposal, where recycling and/or biodegradability are key end-of-life considerations.

Future development of innovative bio-based products should focus on ones that *outperform* traditional fossil-based products *technically*, *environmentally* and in terms of process efficiency – *improved functionality and value* will result in strong end-user drivers. To drive the uptake of bio-based chemicals, *cost optimization* of the entire value chain of bio-based chemicals is required, for example, through increasing the availability of low-cost renewable sugars and technology advances in utilization of waste feedstock.

Summaries of the key findings from previous work packages to demonstrate how they formed the basis the roadmap in WP4 are in the following boxes. Further details of the work involved in each work package are found in Annex II.

Thus, a key input from D1.2 in to the roadmap is the **emphasis on developing bio-based products with superior technical, environmental and cost performance compared to fossil-based products.**

Information from **WP2** was used to understand the regulatory framework associated with bio-based chemicals and materials, and their public perception. More specifically, the goals were to:

- Create an overview of the most important regulatory barriers that hinder the production and market uptake of bio-based chemicals and materials and derive suggestions for overcoming these barriers to be used in the roadmap.
- Understand the public perception of bio-based chemicals and materials, identify potential contributions of bio-based chemicals to societal needs and suggest ways to overcome societal and acceptance barriers
- Identify possible interfaces and synergy potentials between the bio-based sector and the Circular Economy.

Information on deliverables D2.1 – D2.4 were used in the draft roadmap development:

D2.1 – Report on regulatory barriers

D2.2 – Public perception of bio-based products

D2.3 – Public perception of bio-based product – qualitative analysis of stakeholders' concerns

D2.4 – Ways to overcome societal and policy barriers

D2.5 – Concept of bio-based and circular economy *(forthcoming publication)*

Successful development of the roadmap requires the collaboration of experts from the chemical industry, NGOs, governmental bodies, academia as well as the finance sector and brand owners. Hence, the aim of **WP3** is to create awareness about the project and its scope within the chemical industry, relevant up- and downstream industries, governments and administrative bodies, as well as the interested public. Based on this awareness, discussion and networking activities will be initiated to gain insight in the different perspectives, collect contributions to the analysis performed during roadmap development, discuss findings with relevant stakeholders and stimulate the dialogue between relevant stakeholders. Through stakeholder consultations, this work package created buy-in from key stakeholders for the draft roadmap and further consultation with allow refinement of the draft for the final roadmap to be used more effectively by concerned parties.

Further information on WP2 and WP3 is found in Annex II.

3 Current status and drive for bio-based chemicals/products in nine product groups in the EU chemical industry

RoadToBio has focused on nine specific product groups (adhesives, agrochemicals, cosmetics, lubricants, man-made fibres, paints and coatings, plastics/polymers, solvents, and surfactants). The scope and approach described in Chapter 2 and further details on scope and methodology for developing this strategy document can be found in Annex I and II. This chapter (Chapter 3) begins with an overview of volumes of bio-based chemicals or products in each group. This is followed by:

- A product group by group analysis of bio-based chemicals or products that are in use (in those product groups), and reasons for their uptake despite competition from fossil equivalents.

- Identifying the desired sustainability characteristics that are met, or are not met, by both the 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 are 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 sustainability drivers that were considered in the assessment were:

  – Biodegradability, low human toxicity, low ecotoxicity, low GHG and other drivers 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.

- The product group analysis then focuses on the opportunities and barriers identified for uptake of bio-based, and actions that need to be taken to address those barriers.

3.1 Current share of bio-based chemical/products

The current share of bio-based chemicals/products in the nine product groups in the EU chemical industry was estimated in D1.1 of RoadToBio and is presented in Figure 6. The methodology used to calculate these volumes is available in Annex I.

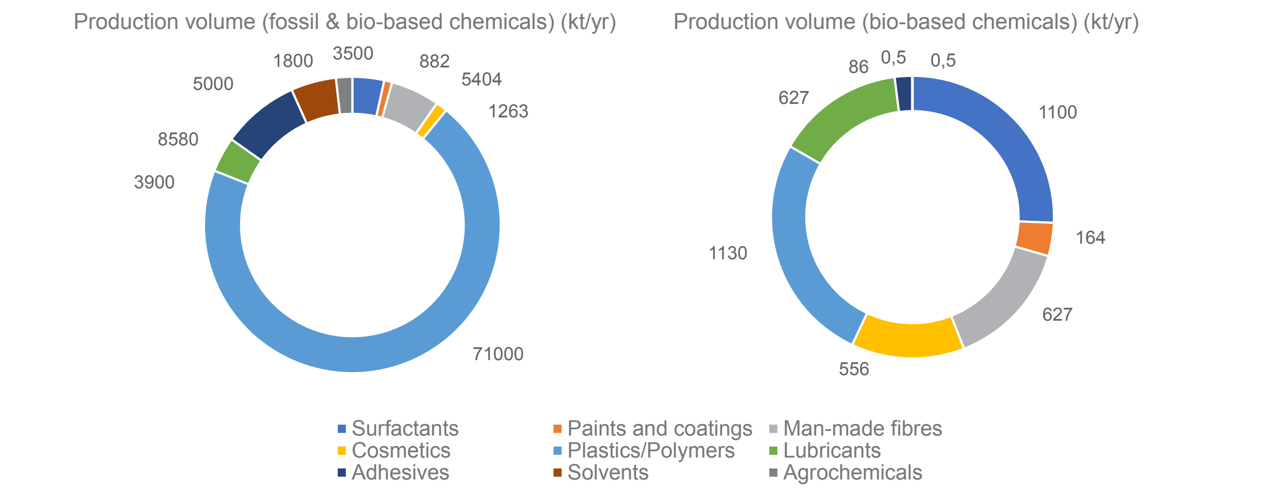


Figure 6. Comparison of volumes of bio-based chemicals and total volumes of chemicals in nine product groups (in kt/yr) in the EU. Reference year: 2015 (Source: RoadToBio D1.1)

Based on these estimates, bio-based chemicals/products make up a little over 4% of the total volume of chemicals/products in these nine product groups. On a product group basis, bio-based share varies as mentioned in Table 2.

Table 2: Percentage share of bio-based in different product groups in the EU

Share of bio-based chemicals (%)	Product groups
<1	Agrochemicals, solvents
1 – 2	Adhesives, plastics/polymers
10 – 30	Man-made fibres, lubricants; paints and coatings; surfactants
>40	Cosmetics

Plastics/polymers comprise the largest volume of chemicals/products among the nine product groups in the EU (71,000 kt/yr). However, the share of bio-based is around 2% for plastics/polymers (1,130 kt/yr). On the other hand, bio-based share is higher in lower volume product groups such as surfactants (31%, 1,100 kt/yr bio-based) and paints and coatings (19%, 164 kt/yr bio-based).

The current production volume of fossil-based chemicals in each product group in Europe has been used to define the 'Addressable market' for bio-based chemicals in those respective product groups. Depending on the production volumes, the addressable market for a product group can be categorised as Small (S), Medium (M) or Large (L). Following is the key:

S	<1,000 kt
M	1,000 – 10,000 kt
L	>10,000 kt

The nine product groups are described in the following section. They are arranged in ascending order of their addressable market.

3.2 Cosmetics

3.2.1 Background

Cosmetics are classified as skin care products, hair care products, colour cosmetics, fragrances and personal care products. Natural substances are substances of botanic, inorganic-mineral (not organic-mineral e.g. mineral oil) or animal origin (except for dead vertebrates) and their mixtures with each other. Inorganic materials like calcium carbonate, carbon black, are not considered bio-based. Different bio-based materials (strictly from biomass and not inorganic materials) have different functionalities. For example, substances extracted from plants and other types of biomass can be used to increase shelf life and protect against UV degradation [1]. Many natural substances have bioactive effects such as preserving, healing, anti-inflammatory or emollient effects [1].

Company marketing strategies have focused on the renewable nature and performance of ingredients in bio-based cosmetics. Cost is not as important a driver in the cosmetics segment, in fact, this sector is able to leverage novel ingredients as a selling point [2]. A recent survey of consumers across Europe revealed that the two major drivers that influence consumers' decision regarding the cosmetics that they purchase are product efficacy and product quality [3]. Other drivers specifically linked to bio-based cosmetics consumption are low toxicity and natural-based properties.

3.2.2 Drive for bio-based market growth

The organic personal care market is expected to grow to US$25.1 billion by 2025 [2]. Grand View Research announced that the global organic beauty market was likely to reach $15.98bn by 2020, as demand for organic skincare, haircare and colour cosmetics drives consumers to look for natural and organic labels [4]. Skincare maintains the top billing in the global organic beauty market and is expected to emerge the most attractive segment with 30.9% share by 2024, followed by haircare [4].

Petro-chemical alternatives never satisfy the natural-based attribute and could potentially be more toxic in comparison. Manufacturers also use popular ingredients from the health and food sectors in cosmetic products [5]. Some examples include baobab, acai, vegetable oils high in omega-3 and omega-7 fatty acids as well as botanicals high in vitamins or protein. All these bio-based ingredients are used in a wide range of applications including skin care, hair care, personal care and fragrances. In addition to product efficacy and quality, the growing market for bio-based cosmetics in the EU is driven by consumers' concern about origin of ingredients and whether they are produced sustainably; and the popularity of Organic and Fair Trade certifications in cosmetics [5]. Consumers are generally able to identify food labels better than cosmetic labels and some of the labels like EU organic leaf are not applied to cosmetics. Further, in terms of private standards, and consumer expectations of natural and organic cosmetics, the origin of the raw material is primarily non-GMO. Private standards also have criteria concerning the processing aids - mostly permitting the use of recombinant enzymes to carry out modification reactions but GMOs are normally prohibited under private standard's criteria to produce cosmetic raw materials themselves.

There is significant focus in private standards and increasingly by manufacturers in particular to also focus on manufacturer using green chemistry principles consistent with sustainable production practices.

The production of cosmetics uses a huge list of different chemicals. Many of these are derived from petroleum and are therefore not sustainable. A far from exhaustive list of petrochemicals used in the cosmetics industry that could be replaced with bio-derived alternatives includes:

Polyethylene glycol, acetone, acetyl esters, acetoin, n-butanol, butyl esters, isopropanol, 1,3-propanediol, propylene glycol, terpenes, terpenoids, organic acids (lactic acid, acetic acid), ethanol.

These building blocks or functional ingredients mainly come in the category of surfactants and solvents. These are covered in detail in sections 3.5 and 3.8 of this report, respectively.

In the area of cosmetics preservatives, petroleum derived preservatives such as parabens, formaldehyde donors and halogenated compounds are being phased out from cosmetics due to growing health issues associated with these products [6]. There is no universal bio-based preserving agent which performs well as the above listed compounds [6]. But few preservatives on Annex V of the EU Cosmetic Regulation, such as ethyl lauroyl arginate, can be made from 100% bio-based building blocks. The industry is actively looking for bio-based substitutes [6]. Sorbic acid and its derivatives, pentylene glycol (from maize or sugar cane) and salicylic acid from *Gaultheria procumbens* (Eastern teaberry) are among potential candidates which could replace fossil-derived and more toxic chemicals [6]. However, most of these bio-based substitutes will have to be used in very high concentrations or volumes to get them to work, and so they would be impractical for most cosmetics [6]. Propylene glycol production from bio-based materials is possible since it involves conversion of glycerine (e.g. lower grades of glycerine from biodiesel production) by hydrogenation to this substance. it is already commonly used in certified natural and organic cosmetics. As such this area of the cosmetics segment represents an opportunity for further development and growth of bio-based chemicals.

The cosmetics industry is strongly regulated in the EU. Cosmetics suppliers (manufacturers/importers/exporters) who would like to place cosmetic products on the EU market have to comply with the following regulations:

- EU Cosmetics Directive 76/768/EEC
- New EU Cosmetic Products Regulation (EC) No 1223/2009
- REACH Regulation (EC) No 1907/2006

However, there still is missing an official regulatory definition to support the claims natural or organic cosmetic product which may be facilitated by improved standardization of raw materials as well.

In the RoadToBio project, the desired sustainability characteristics that are met/not met by selected bio-based cosmetics and their fossil-based equivalents were assessed. The drivers of these sustainability characteristics were also assessed. These are summarised below.

Table 3: Desired sustainability characteristics of cosmetics (bio-based/fossil) and their drivers

Product group	Desired sustainability characteristics	Drivers of sustainability characteristics
Cosmetics	Low human toxicity, less often: biodegradability, low GHG	Legislations, customer and producer driven (voluntary)

Table 4: Sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in the cosmetics product group

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category (Drop-in/smart drop-in/ dedicated)	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Botanical extracts	Botanical extracts (Terpenes) *(bio alternative for PEG wax, paraffin wax)*	100	Dedicated	X	X					9
Vegetable oils	Vegetable oils *(bio alternative for paraffin oils, petroleum gels)*	100	Dedicated	X	X					9
Building block	Lactic acid *(commercial production now is only biobased. Previously produced from fossil-derived acetaldehyde)*	100	Dedicated	X	X	X			The major functionalities of lactic acid range from exfoliant; fragrance ingredient; humectant; pH adjuster; skin-conditioning agent Note: Lactic acid comprises only 1-2% of the final formulation in cosmetics	9 (using 1G feedstock) 3-5 (using 2G feedstock)
Building block	Bio-based succinic acid *(bio-alternative for fossil-based succinic acid)*	100	Drop-in	X	X	X			Formulated for different functions like buffering, neutralizing, emulsification, thickening and stabilizing Note: Succinic acid comprises only 2-4% of the final formulation in cosmetics	9
Building block	Bio iso-butene *(bio alternative for fossil-based iso-butene)*	100	Drop-in	X		X			Improvement of the functional properties that it does not change the texture properties of creams and lotions Note: Iso-butene comprises only 5-10% of the final formulation in cosmetics	6
Solvent	Bio-based acetone (replacement of fossil derived acetone)	100	Drop-in	X		X			Nail polish removal agent and solvent in cosmetic products. In contrast to fossil-based acetone which is produced via the cumene process, bio-based acetone is produced free of aromatics (benzene and phthalate free). These aromatics are toxic to humans and the environment.	9
Solvent	Bio-based ethanol *(bio-alternative for fossil-derived ethanol)*	100	Drop-in	X	X	X			Ethanol is used as solvent in personal care products such as fragrances, colognes, body and hair sprays; as antibacterial agent in mouthwash, astringents	9
Functional polymer	Polyhydroxyalkanoates (PHA) *(bio-alternative for plastic microbeads)*	100	Dedicated	X	X	X			PHAs can be used to prepare microbeads that are used in cosmetics	5-6

Key: B=Biodegradable, LHT=Low human toxicity, Low GHG=Low greenhouse gases, LE=Low ecotoxicity, R=Recyclability

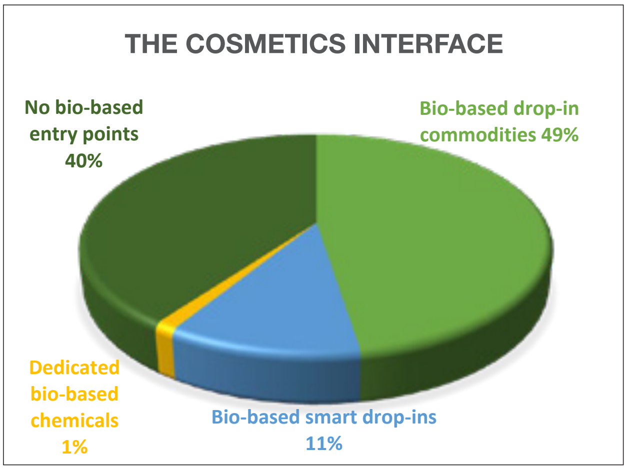
Note: The chemicals/products selected for the analysis are representative of the product group and do not cover the full spectrum of chemicals/products. These representative chemicals/products are either produced in large volumes (thereby dominating the market for that product group) and/or of interest and value due to the functionality they offer.

3.2.3 Opportunities and barriers

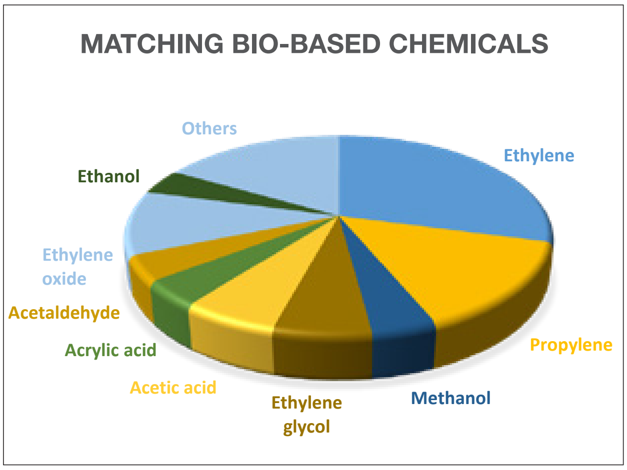
The trend towards green cosmetics reinforces the use of bio-based surfactants, solvents and preservatives. In general, these are less toxic and are biodegradable compared to their fossil equivalents. In case of surfactants, examples would be sorbitol or mannitol esters, but also alkyl polyglucosides and lauryl glucoside [7]. The latter are already used in products like shampoos, bath foams, lotions, and skin care products [7]. That said, surfactants can be used in a wide variety of end-uses ranging from cosmetics to lubricants. When looking only at surfactants used in the personal care market, the numbers are very small compared to the entire surfactants segment (which for example also caters to industrial cleaners and home care products).

Solvents such as acetone and ethanol are key for cosmetics formulations (8,9). In 2018 Green Biologics launched the first bio-based acetone nail polish remover showcasing growing opportunity for bio-based solvents in the cosmetics sector [10].

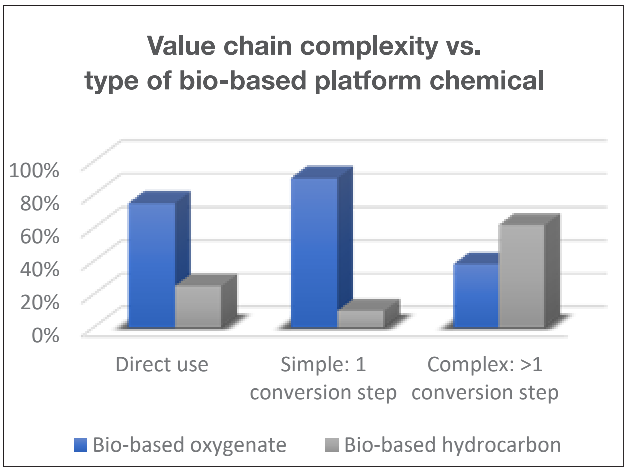
As mentioned earlier, there are very few bio-based cosmetic preservatives available and underperform compared to their fossil equivalents. This also represents an opportunity for further development and growth of bio-based chemicals in cosmetics.



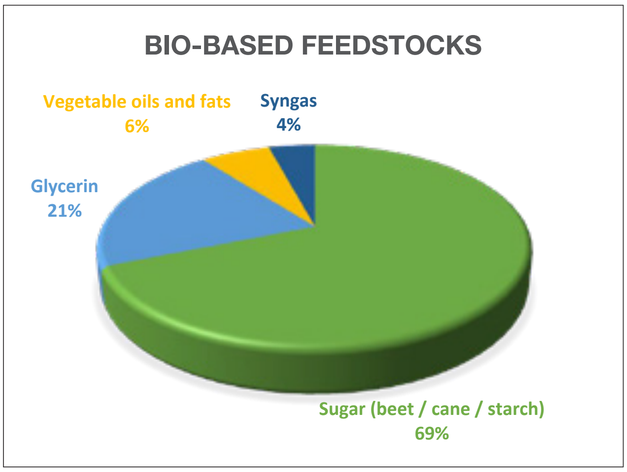
35 petrochemical cosmetics were analysed; at least one potential entry point for a bio-based chemical in the value chain was identified for 60% of the cosmetics, the majority being drop-in commodities.



17 different bio-based chemicals could enter the value chains at 48 potential entry points that were found. Ethylene as well as its derivatives ethylene oxide and glycol, and propylene were common options.



Here also the subsequent pathways from entry point to final chemical were on average shorter for the bio-based oxygenates than for the bio-based hydrocarbons.



The main feedstock platforms that can currently provide these bio-based chemicals are the sugar platform and the glycerine platform.

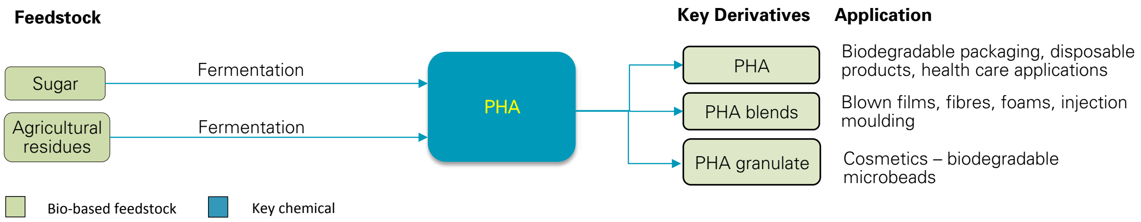
Figure 7: Opportunities for higher bio-based share in cosmetics via use of drop-in bio-based chemicals in the production process.

Opportunities also lie in exploring novel feedstocks as source of bioactive ingredients for cosmetics. Examples include macroalgae (brown seaweed) which is a source of alginic acid that has gel-forming properties [2]. Another example is the use of orange peels as source of pectin which also have gel-forming properties [2]. These two biopolymers (alginic acid and pectin) have been used by the company Keracol for the development of bio-based hairstyle products [2]. Hair sprays and gels contain a film-forming polymer that provides the shine and hold required [2]. Options are limited for consumers looking for bio-based hair sprays or gels that are effective, wash out easily and are flexible enough to use on dry or damp hair [2]. Keracol has also been working on addressing a major drawback of these bioploymers which is that neither dissolve in ethanol [2]. This is an issue for hair sprays that are usually > 50% ethanol [2].

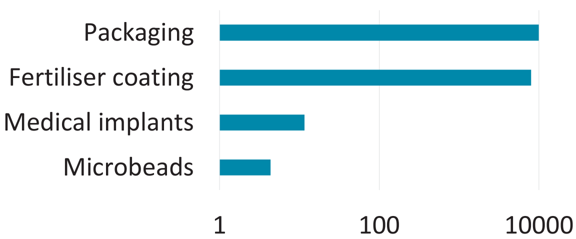
Further, Keracol has partnered with Marks & Spencer to bring to market skincare products containing antioxidants and anti-inflammatory compounds extracted from waste stream of wine production [2]. It should be noted that according to EU law raw material claims (e.g. antioxidant, anti-inflammatory) are not transposed by default to the finished products. This can only be achieved if the finished product is compliant with the Regulation (EC) 655/2013.

Market Volume EU: (ktonne/yr)	Market Volume Global (ktonne/yr)	Price: (€/tonne)	Market growth rate: (%/yr)
Total: 7 Bio-based: 7	Total: 110 Bio-based: 110	4,000 – 5,000	4.9
Source: Estimation based on global demand, 2015	Source: European Bioplastics, 2018	Source: De Hart (2014)	Source: Marketsandmarkets (2017)

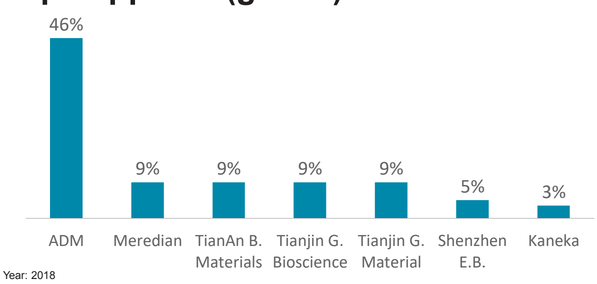
Value chain:



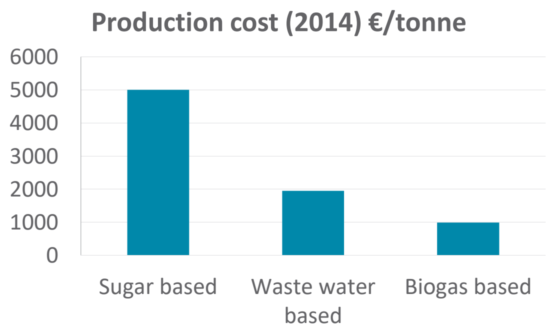
Potential EU demand (per application):



Top suppliers (global):



Costs:



Opportunities and Barriers:

\+ High costs due to feedstock and downstream processing
\+ Specialised equipment needed for processing
\+ Negative connotation due to unsuccessful start ups.

\- Marine biodegradable
\- Well developed technology from decades of research

Figure 8: PHA case study summary

The EU funded project MIRACLES (*Multi-product Integrated biorefinery of Algae: from Carbon dioxide and Light Energy to high-value Specialties*) reported the pilot production of a facial cream that has a fucoxanthin-enriched extract. A full protocol was developed for microalgae extraction and elaboration of the cosmetic product [11].

In addition to sourcing ingredients from plants and alternate feedstocks, cosmetics manufacturers also want assurance that the bioactive ingredients remain available in the final product and last on the shelf [2]. 'Mobile plant processing units' that employ solvent-free Zeta Fraction technology have been used by companies like Ashland, where the unit is driven directly to the field so that plants can be harvested and processed in one step, minimizing the loss of active compounds [2].

D1.1 of the RoadToBio project identified pathways to higher bio-based share within cosmetics *via* the use of drop-in chemicals in the production process of cosmetics. Following is a summary of the results from D1.1.

In addition to identifying bio-based chemicals and their potential entry points in 9 product groups, the RoadToBio project also includes an analysis of nine potentially attractive business opportunities ("sweet spots") for the European bio-based industry (D1.4). The "sweet spots" were chosen by analysing the current landscape of bio-based chemicals and those that have reached an advanced development stage, and hence may represent a potential business opportunity for the European chemical industry. One of the 9 chemicals that was analysed in-depth was PHA (polyhydroxyalkanoates) which is a dedicated chemical used in cosmetics and plastics. Following is a summary of that analysis. Please note that this chemical is not the most representative of the cosmetics product group, but one that was covered in-depth in D1.2 and selected here due to its relevance to this product group.

PHAs derived from biogas or waste water feedstock could have limited application in cosmetics or food sectors due to the general perception that waste-derived PHAs could be contaminated. However low production cost of PHAs from

Table 5: Barriers to bio-based uptake in cosmetics and proposed actions

Barriers	Actions	Actors	Timeline
Producers are concerned about the functionality, cost competitiveness and availability of bio-based ingredients: Cosmetics manufacturers need to have clarity on all three before deciding to switch one or more ingredients with sustainably sourced bio-based ingredients. Costs of bio-based ingredients are often higher to petroleum-based counterparts. Even though costs are not a main driver, lowering the costs would likely lead to an increased growth rate.[7]	R&D to improve functionality	Industry, government, research institutions	Short-long term
	R&D to Improve biomass supply by enabling Europe to produce highly productive crops rather than import; develop cost effective methods for extracting bio-active ingredients from feedstock	Industry, government, research institutions	Short-long term
	Develop products using novel feedstocks like algae	Industry, government, research institutions	Short-long term
	R&D to focus on the development of bio-based cosmetics that outperform fossil equivalents	Industry, government, research institutions	Short-long term
Long and expensive approval process for switching from one chemical to another especially if they are derived from residues or GMO	Shorter and more affordable approval procedures for chemicals that are not toxic + if they have the identical chemical structure as one that has already been approved	Government, policy makers, industry	Short-mid term
	Financing options to cover approval procedures, partly from the government and industry	Government, policy makers, industry	Short-mid term
Different cosmetics companies have different definitions of 'natural' or 'bio'. For e.g. some companies reject biobutanol as feedstock if it is derived from GM corn	Consultative process between industry, policy and consumers to align understanding and increase standardisation	Industry, policy makers, consumers	Short-mid term
The information on difference between organic and natural is not clear	Improve labeling in cosmetics (Interest is high, labels are not as well-known as in food)	Industry, policy makers, consumers	Short-mid term

7 This depends on the raw material - some unmodified natural substances (i.e. not derived naturals) are also food commodities and so costs can be low, and certified natural cosmetics for private labels can still be sold for the same price as conventional products.

waste feedstock could motivate manufacturers to further develop this technology in such a way that it guarantees that the PHAs used in, for instance, food packaging or microbeads do not cause any contamination to consumer products. Thus, its use should be encouraged in any sector.

Barriers identified to bio-based uptake in cosmetics are as follows. There are certain 'generic barriers' such as feedstock availability and cost competitiveness of bio-based products with fossil equivalents, which are applicable to all product groups. These are covered in chapter 4 of the report. These generic barriers may be mentioned in the following table only if there is something very specific about the barrier for the cosmetics product group. Otherwise they are not mentioned in table 5.

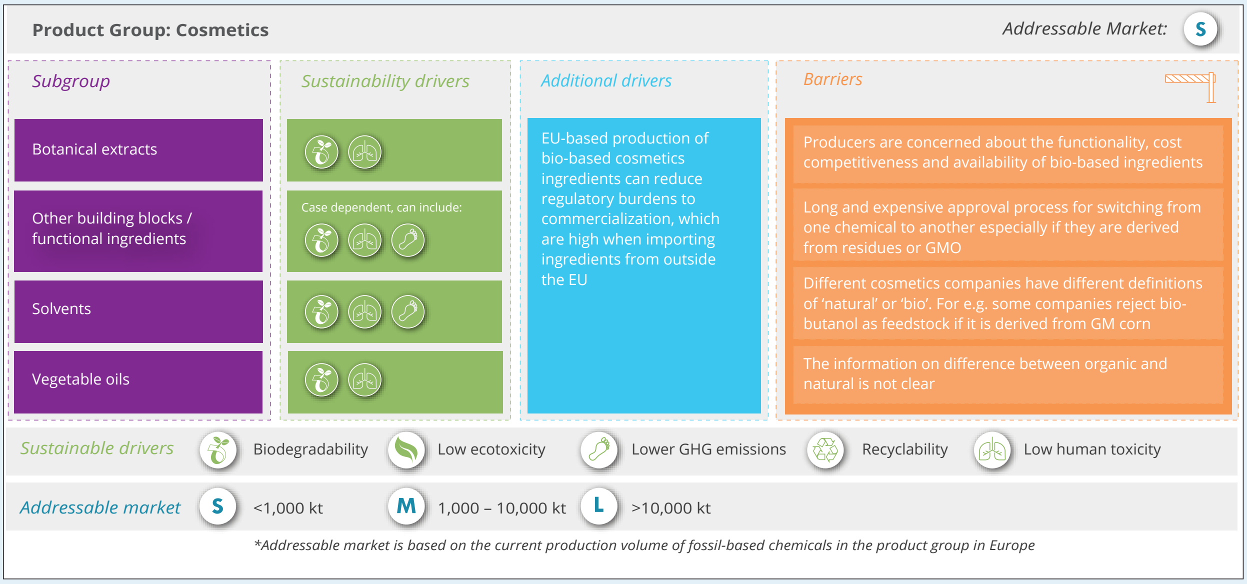


Figure 9: Pictorial summary of the cosmetics product group

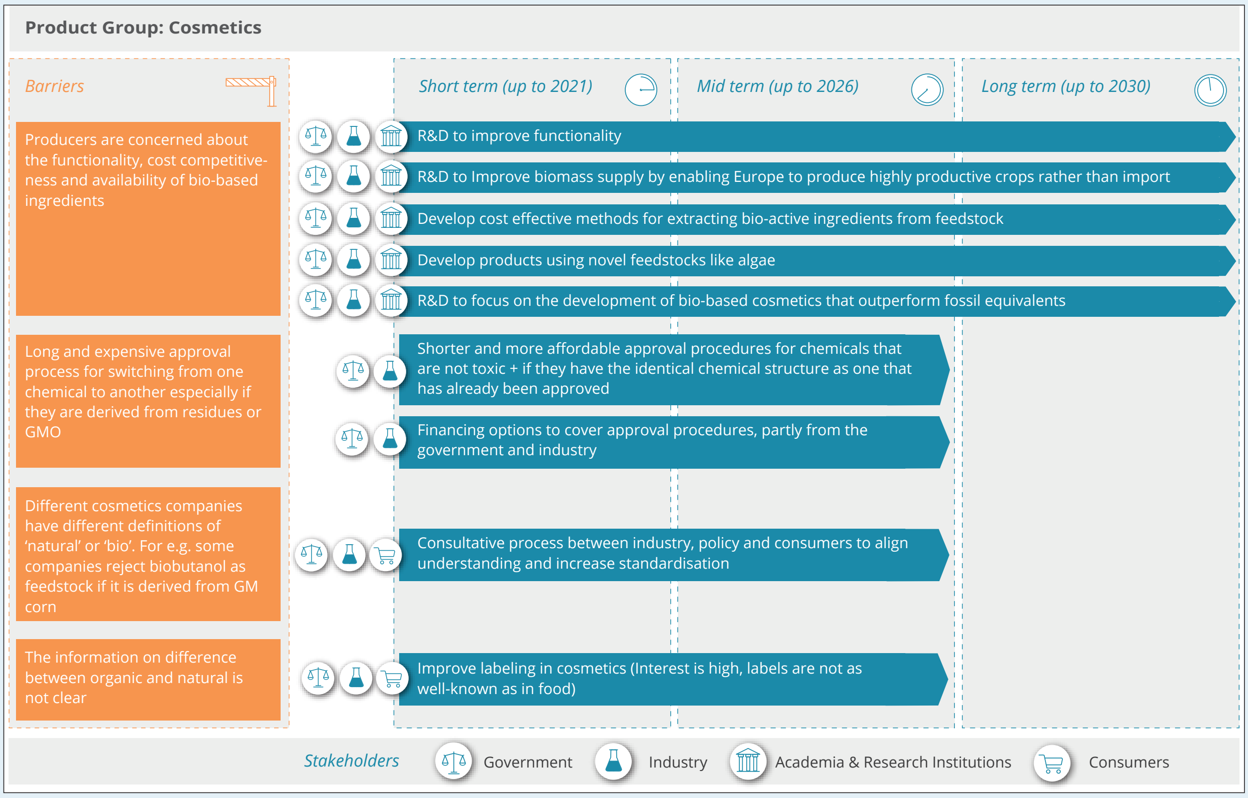


Figure 10: Roadmap to increasing the bio-based share of chemicals in the cosmetics product group

3.2.4 Summary

- 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 not sustainable.
- 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.

Note: Please refer to the summary section for solvents (section 3.8.4) and surfactants (section 3.5.4) as well as they are used in cosmetics formulations.

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3.3 Paints and coatings

3.3.1 Background

Paints and coatings are used in a wide range of applications from interior decoration to anticorrosive coatings on ship hulls that also prevent the settling of mussels.

In general, paints, varnishes and coatings consist of resins (also known as binders), pigments and additives carried in a solvent that evaporates after application. The formulation can vary widely depending on the application. The requirements on the performance and key parameters of paints and coatings strongly depend on the area of application. Typical performance indicators include the desired appearance, ease of application, viscosity, durability, drying times and many more. Especially in the consumer sector, a broad range of application conditions such as temperature and humidity have to be covered. The same holds true for durability considerations – exterior coatings have to withstand UV and rain, corrosion by salt (for e.g. cars in winter or marine vessels) while interior wall paints in some case offer functionalities such as acting as a humidity buffer in bathrooms or being easy to clean such as sanitary wall paint.

Paints and coatings contain the following main ingredients [1]:

Solvents

- **Fossil based solvents:** aliphatic, cycloaliphatic and aromatic hydrocarbons as well as alcohols, glycols, glycol ethers, ketones and esters
- **Bio-based solvents:** lactate esters [2]

Organic Binding agents

- **Fossil-based:** acrylate, methacrylate
- **Bio-based:** Natural resins, drying oils such as linseed oil, alkyd resins and cellulose esters; partially bio-based acrylic binders, dibutyl itaconate or succinic acid as monomer
- **Application:** Alkyd resin lacquers, air-drying building lacquers incl. oil paints, baking enamels, industrial water-thinnable alkyd resin paints, alkyd emulsion paints, reactive thinners from epoxidized vegetable oils and nitrocellulose paints

Additives (only 1% of the formulation)

- Responsible for specific properties such as flow behaviour, gloss, weather resistance, surface tension

3.3.2 Drive for bio-based market growth

The two main groups of bio-based paints are acrylate and urethane systems. Currently 700 kt of bio-based solvents are consumed in Europe, 40% of this for the paints industry. Experts estimate that the potential for bio-based uptake in this product group is very high. Etxeberria forecasts that Europe alone will account for 1 million tonnes by 2020 [3]. This is supported by forecasts suggesting that Europe will see an annual average growth rate (CAGR) of 8.8% over the period 2015 to 2020 in the bio-based solvents segment [3].

Paints and coatings have for some time experienced a trend towards more sustainability. Drivers are the elimination of toxic ingredients, reduction of VOCs to improve and protect indoor and outdoor air quality, reduction of carbon footprint, and an increased use of bio-based ingredients [4].

As in traditional paints the solvent accounts for 40 to 50 % of the product (40% of white gloss (alkyd) paint is solvent, 44% of matt white emulsion paint is solvent), reducing or substituting the solvent is a major sustainability lever (1,5). Increasing pressure from legislations and growing public awareness of environmental and health-related issues are contributing to increased demand for paints and varnishes that contain low levels of solvents or are even solvent-free (3,4). A key regulation relating to solvents is the EU Paints Directive, which limits the Volatile Organic Compound (VOC) content in paints, in order to avoid health issues due to the exposure to VOC and environmental effects of ozone caused by atmospheric reactions involving VOC (6,7). Solvent shares have been reduced and solvents have been replaced by water or by bio-based solvents that emit less VOC.

Another driver towards bio-based ingredients is the desire of producers to become more independent from fossil resources with volatile prices and to prepare for a future when petrochemicals capacity might be shrinking [8].

From the consumer perspective, sustainability guidelines in companies can be a driver for the preferred procurement of bio-based coatings. The "green building" movement has also resulted in increased sensitivity regarding the origin and sustainability of paints and coatings [9].

Currently, research is focusing on new types of binders, testing a wide range of fatty acids and polyols. The immense variety of building blocks and potential combinations offers the perspective of completely new functionalities and performance parameters.

Anti-fouling paints that are used by shipping industry to reduce drag and prevent corrosion often contain compounds such as copper which have ecotoxic effects and are non-biodegradable. 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 – enzyme-based compounds being one such example [10].

In the RoadToBio project, the desired sustainability characteristics that are met/not met by selected bio-based paints and coatings and their fossil-based equivalents were assessed. The drivers of these sustainability characteristics were also assessed. These are summarised below. It should be noted that biodegradability is mostly limited to solvents, as biodegradability of a paint or coating is in general contrary to the expected performance (i.e. longevity and protection against environmental influences).

Table 6: Quantities of renewable raw materials used in paints and varnishes in Germany

Segment	Quantity (t)	Renewable feedstock	Quantity renewable feedstock (t)
Alkyd resins, air drying	>70,000	Oil acids, linoleic acid, linolenic acid, castor oil, soya oil, linseed oil, glycerine	35,000
Alkyd resins, heat-drying	~12,500	Oil acids, linoleic acid, linolenic acid, castor oil, soya oil, linseed oil, glycerine, tall oil, saturated fatty acids	5,000
Oil paints, oil varnishes	~8,500	Linseed oil	5,000
Cellulose nitrate lacquers	>15,600	Cellulose	4,500
Colours based on shellac	~3,500	Shellac, ethanol	1,400
Alkyd paints and water-based paints	>30,000		16,000
Colours. Base modified natural polymers	~3,000	Natural oils	1,000

About 630,000 t of all solvents used in Europe is bio-based [3]; European coatings market is predicted to account for 1 million t of bio-based solvents by 2020 [3].

Table 7: Desired sustainability characteristics of paints and coatings (bio-based/fossil) and their drivers

Product group	Desired sustainability characteristics	Drivers of sustainability characteristics
Paints and coatings	Biodegradability, low human toxicity, low eco-toxicity	• Customer and producer driven (voluntary) • Driven by regulations and labels such as VOC limits, “green building” guidelines

Table 8: Sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in the paints and coatings product group

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Solvent	Bio-ethyl acetate, 2-Butyl acetate, bio-butyl glycol, allyl reactive diluent *(bio alternative for Lactate esters)*	100	Drop-in	X	X		X			9
Solvent	Lactate esters *(replace NMP, acetone and others)*	100	Dedicated	X	X		X		Methyl lactate, ethyl lactate and butyl lactate are readily biodegradable and offer low toxicity and low VOC levels. As a result, they are easy to use and easy to dispose. Solvent for digital inks, coalescing agent for water-based paint	9 (using 1G feedstock, 3-5 (using 2G feedstock)
Solvent	Dimethyl succinate and other bio-based esters *(In combination with other esters, this chemical replaces a wide range of solvents such as N-methyl-2-pyrrolidone, dichlormethylene and more)*	100	Dedicated	X	X	X	X		VOC levels of paints can be reduced by using solvents or coalescing agents based on bio-succinic acid.	9
Solvent	D-limonene *(alternative for xylene, toluene or 1,1,1 trichlor in blends with other inexpensive solvents)*	100%	Dedicated	X	X	X	X		D-limonene is an effective solvent to directly replace the toxic solvent components in existing solvent blends. One example is the 1:1 substitution of d-Limonene in the place of xylene, toluene or 1,1,1 tri-chlor in blends with other inexpensive solvents to make up the balance (mineral spirits, isopropylalcohol, butyl cellosolve, etc.). So long as no water is present, re-formulating may not be necessary in a strictly solvent-based system.	9

Key: B=Biodegradable, LHT=Low human toxicity, Low GHG=Low greenhouse gases, LE=Low ecotoxicity, R=Recyclability
Note: The chemicals/products selected for the analysis are representative of the product group and do not cover the full spectrum of chemicals/products. These representative chemicals/products 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.

Low VOC has not been listed as a separate sustainability characteristic. However, this is an important issue for solvents and is considered under ‘low ecotoxicity’ and ‘low human toxicity’.

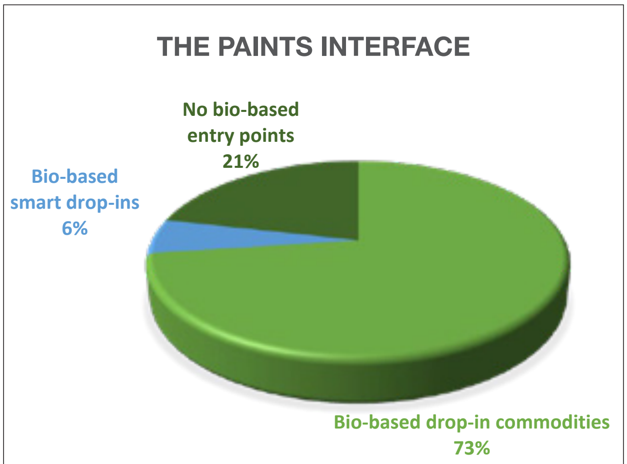
Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Binder	Bio-based alkyd resins containing e.g. succinic acid *(replacing other alkyd resins that are part or fully fossil-based)*	Partly bio-based (% unclear)	Smart drop in		x	x			Preliminary findings suggest that bio-based succinic acid can replace 20-35 % of phthalic anhydride in penta-erythritol alkyd resins with retention of performance; succinic acid is also a "near drop-in" replacement for adipic acid	4-5
Binder	(partly) bio-based polyols as a component for polyesters and polyurethane (from castor oil) *(replacing fossil-based polyols)*	Up to 100	Dedicated	x		x				8-9
Binder	(partly) bio-based acids as a component in polyesters/polyurethane: 1) dibutylitaconate 2) Octadecandioic acid 3) Bio-based 3-hydroxypropionic (3 HP) and acrylic acid 4) Furan dicarboxylic acid *(replacing fossil-derived acids such as maleic acid, phthalic acid, adipic acid)*	48	1), 2), 4) Dedicated 3) Smart drop-in			x			1) Dibutylitaconate will polymerize slower than acrylate and methacrylate monomers, which it is intended to replace. The effect of this can, however, be mitigated by choosing effective comonomers. The wall paints produced using such binders show performances mostly comparable to those of the ones based on fossil fuel-based binders. Chemical resistances of the plant-based paints are somewhat better than those of the fossil fuel-based types, which is attributed to the higher hydrophobicity of dibutyl itaconate compared to butyl acrylate and butyl methacrylate. Acrylate and methacrylate suffer from several drawbacks such as high allergic potential and pungent odour. 2) Properties of octadecandioic acid: Improved hydrophobicity, flexibility and chemical resistance 3) Use of 3 HP and acrylic acid is under development 4) "on the cusp of application"; tendency towards yellowing might limit applicability	1) 7-8 2) 9 3) 4-5 4) 6-8
Polymer/ hardener	Pentamethyl diisocyanate (PDI) as a component for polyurethane *(replacing fossil-derived hexa-methyl diisocyanate (HDI))*	70	Smart drop in			x				9
Additives	Enzyme-based antifouling agent *(replacing fossil-based biocides)*	100	Dedicated				x		AEROZYME™ works by preventing organisms from settling. The product does not kill organisms. Could lead to reduced use of copper in antifouling paints.	9

Note: There are other bio-based alternatives that are used in the paints and coatings industry and are at different TRL levels. However, they do not feature in this table as it is difficult to say which fossil-based chemicals they replace. This is because the functionality of the formulation can change depending on the choice of chemicals. The list of such bio-based alternatives includes: lignosulfonates (for primer binders; TRL 6), lactides (additive that results in improved viscosity and reduced drying time; TRL 6-8), microfibrillated cellulose (additive, performance enhancer for waterborne paints; TRL 7-8)

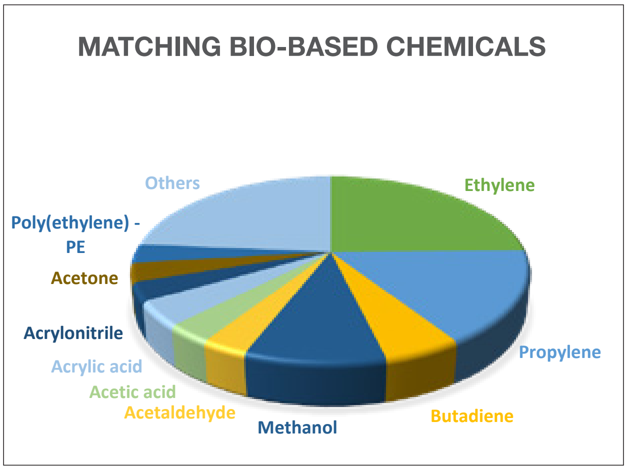
3.3.3 Opportunities and barriers

Deliverable D1.1 of the RoadToBio project identified pathways to higher bio-based share within paints and coatings via the use of drop-in chemicals in their production process. Figure 11 shows a summary of the results from D1.1 [11].

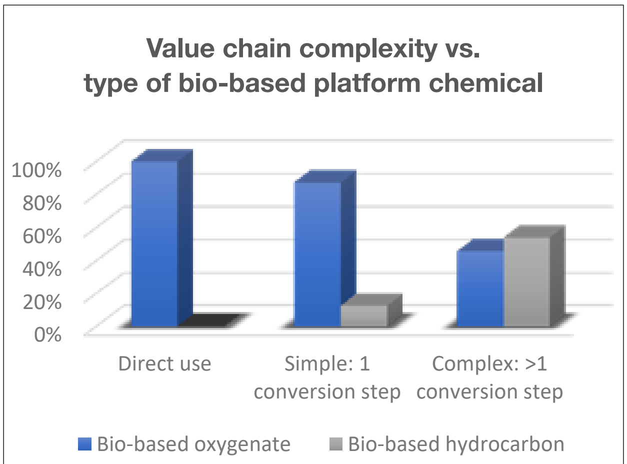
It has to be noted that replacement of fossil solvents by bio-based substances is only one way to decrease the fossil share; replacement by water or reduction of solvent content are also very common strategies. Having water-based paints



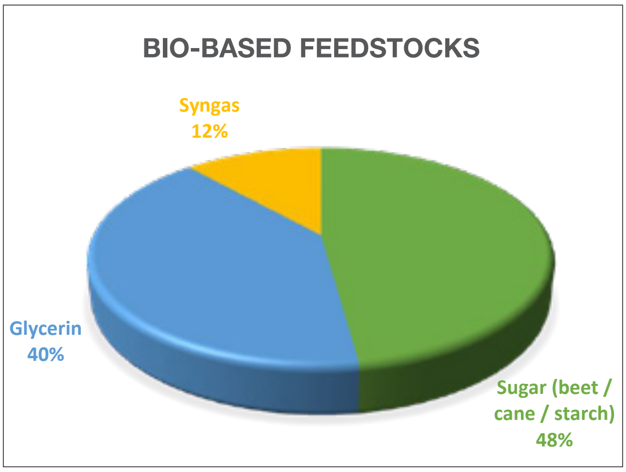
Value chains of 28 petrochemical paints & coating components were analysed; at least one potential entry point for a bio-based chemical was identified for 79% of them, mainly being drop-in commodities.



22 different bio-based chemicals could enter these value chains at 39 potential entry points that were found. Ethylene, propylene and methanol together made up half of the bio-based entries.



As in other groups, some bio-based oxygenates can be applied directly (mainly as solvents), while on average the bio-based hydrocarbons needed more subsequent conversion steps after entering the value chains.



The main feedstock platforms that can currently provide these chemicals are the sugar platform and the glycerine platform.

Figure 11: Opportunities for higher bio-based share in paints and coatings via use of drop-in bio-based chemicals in the production process

and coatings does not automatically imply water solubility of the product. Industry is working on new types of binders which are soluble in water but lead to water resistant coatings [13].

Paints and coatings are complex formulations. A partial or complete replacement therefore rarely follows the idea of a 1:1 switch from an individual fossil component to a bio-based component. However, the development of whole new functional systems where the replacement of a solvent or a monomer leads to the introduction of new components, especially additives. Barriers to bio-based uptake in paints and coatings derive 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 which in turn have to be taught to professional and DIY users of the product [12]. As formulation knowledge is often critical IP of companies, industry might be reluctant to share this knowledge or introduce it into jointly used technology platforms.

On the other hand, as new functionalities of paints and coatings are discussed, researchers and developers in the field see 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 [8].

Barriers identified to bio-based uptake in paints and coatings are as follows. There are certain 'generic barriers' such as feedstock availability and cost competitiveness of bio-based products with fossil equivalents, which are applicable to all product groups. These are covered in chapter 4 of the report. These generic barriers may be mentioned in the following table only if there is something very specific about the barrier for the paints and coatings product group. Otherwise they are not mentioned in the following table.

Table 9: Barriers to bio-based uptake in paints and coatings and proposed actions

Barriers	Actions	Actors	Timeline
Bio-based solvents and coating materials are not yet cost competitive with fossil equivalents	Regulations required to drive bio-based share in paints and coatings.	Government, policy makers	Short-mid term
	Carbon tax, subsidizing bio-based products while taxing fossil equivalents	Government, policy makers	Mid-long term
High costs involved in the development of new formulations [14]	Development of new formulation systems / databases	Industry, academia	Short-long term
	Funding schemes/establishment of technology platforms for the development of new formulations	Government, policy makers, Industry, Academia & Research institutions	Short-mid term
Performance issues such as the yellowing of some bio-based substances	Identification/matching of ingredient properties and applications	Industry	Short-mid term
Changes in product properties require new paint application techniques	Educate users on application techniques with appropriate labelling and instructions, whilst also raising public awareness about the benefits of bio-based paints	Industry	Short-long term

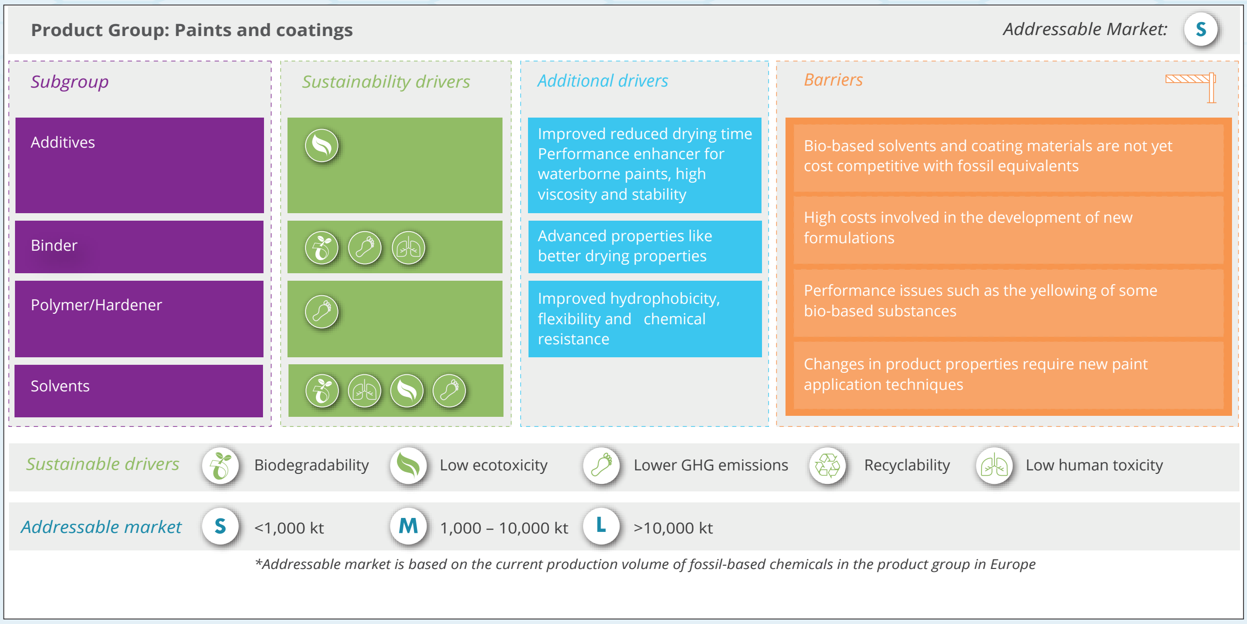


Figure 12: Pictorial summary of the paints and coatings product group

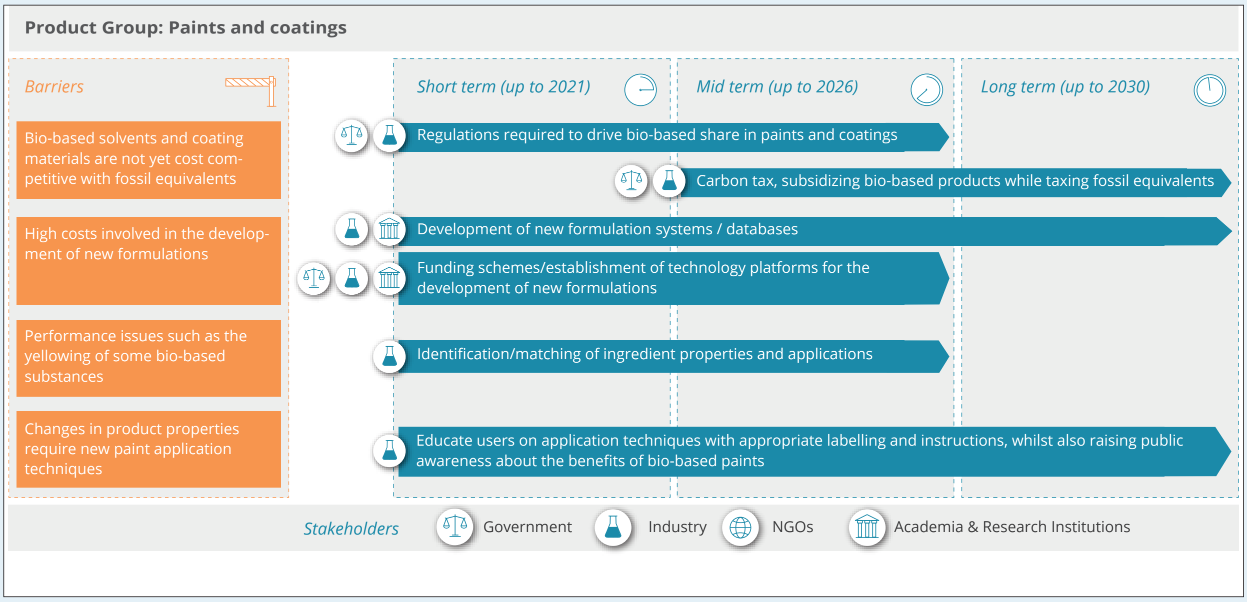


Figure 13. Roadmap to increasing the bio-based share of chemicals in the paints and coatings product group

3.3.4 Summary

- 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 (<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 times, 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.

Note: Please refer to the solvents summary section as well (section 3.7.4).

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3.4 Agrochemicals

3.4.1 Background

Agrochemicals are complex synthetic compounds made in multiple steps to acquire the right functionality. The broad categories of agrochemicals on the market include crop protection products such as fungicides, insecticides, herbicides, nematicides; plant growth regulators, and fertilisers.

The agricultural biologicals market[8] is projected to grow at a CAGR of 13.8% to reach USD 14.65 billion by 2023 from USD 6.75 billion in 2017 [1]. Government regulations supporting use of bio-based products for agriculture and rising global food demand is expected to drive market growth [2]. Agricultural biopesticides have the largest market share followed by bioFertilisers and biostimulants. Biopesticides are anticipated to be the fastest growing market owing to high yield of harvest and improved health benefits [2].

Agricultural biostimulants complement fertilisers and crop protection products

Biostimulants include different substance formulas that are applied to plants or soil in order to adjust and improve the physiological processes of crops, thus making them more efficient [3]. The biostimulants act on the physiology of plants through other means than the nutrients, enhancing the vigour, yield and quality, as well as contribute to the conservation of the soil after cultivation [3]. Biostimulants have been categorised into 7 classes: humic acid (HA) and fulvic acid (FA), protein hydrolysates (PHs), seaweed extracts, chitosan, inorganic compounds, beneficial fungi and bacteria [4]. Biostimulants are increasingly used in worldwide agricultural production and can effectively contribute to overcome the challenge posed by the increasing demand for food [3]. Initially biostimulants were mainly used in organic farming and

8 Agricultural biologicals market includes Biopesticides (Biofungicides, Bioinsecticides, Bionematicides), Biostimulants, BioFertilisers, Agricultural Inoculants, and Biological Seed Treatment

for fruit and vegetable crops with higher added-value [3]. But now they play an increasingly important role in traditional agriculture, as a complement to fertilisers and crop protection products as well as agronomic practices in general [3]. Although biostimulants help increase the share of bio-based in the agrochemicals sector, they are a barrier to development of new biological pesticides as currently there is no regulation of biostimulants. The same strain product can today be used as a pesticide and as a biostimulant. But in the former it costs millions to put the pesticide on the market, while in the latter there is no regulation and therefore cheaper to introduce. This means there is no return on investment for companies investing in a compound for pest control that is also used as a biostimulant because the biostimulant undercuts the pest control product (Lewis, J., pers. comm., Feb. 2019).

Biological seed treatment (microbials and botanicals)

Biological seed treatment is projected to develop into a very important product category by 2023 [1]. Biological seed treatment across the globe is expected to gain momentum as it provides environmental tolerance to seedlings and helps in yield maximization, which encourages farmers to adopt these products [1].

The role of agricultural biological products has become a part of integrated pest management practices (IPM) in developed markets, wherein the biological products are used in combination with new synthetic crop chemistries [1].

Organic farming is on the rise and as of 2016 covered ~7% of the EU UAA (Utilised agricultural area). As of 2016, the number of EU approved low risk or non-chemical substances have doubled since 2009 [5].

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. Biopesticides[9] are natural materials derived from plants or microbes like bacteria. However, the majority of the market is dominated by microbial pesticides. This is a biological organism[10] and not a chemical, and therefore excluded in RoadToBio. In other words, RoadToBio only focuses on biochemical-based pesticides where organic chemistry plays a role.

3.4.2 Drive for bio-based market growth

The market for agrochemicals in general is expected to grow at a steady rate due to increased food demand driven by population growth and rising incomes, as well as increasing rates of soil degradation. CAGR of 4.6% between 2016-2022 [8]. The global market for biostimulants is projected to gain strong growth between 2017-2023 due to their properties such as activating plant physiology, stimulating soil microbial function, and adjusting nutrients and pH in the rhizosphere. Europe is expected to lead this market, followed by the Asia Pacific and North America [1].

Bio-based crop protection products start degrading soon after application resulting in little or no toxic residue [9,10]. However, the drawback is that they need to be applied more frequently in order to be effective [10]. Examples of crop protection products include vegetable or fish oils as well as plant essential oils [11].

As a result of the potential toxicity, often even at very low levels, the application of crop protection products is strictly regulated in Europe [5]. Policy control measures in the EU are driven by the objectives of protecting human health and the environment (consumers, operator safety, protection of water quality and biodiversity) [5]. Following are a few key regulations/policies [5]:

- Directive 2009/128/EC establishing a framework for community action to achieve the sustainable use of pesticides;
- Regulation (EC) No 1107/2009 concerning the placing of plant protection products on the market.
- Directive 2009/127/EC amending Directive 2006/42/EC with regard to machinery for pesticide application.
- Regulation (EC) No 83/98 on the quality of water intended for human consumption (Drinking Water Directive) which stipulates a maximum concentration of 0.1 µg/l (which in practice means the absence) for any single pesticide and its relevant metabolites (maximum of 0.5 µg/l for total pesticides) in potable water;

9 The biopesticides sector is not very diverse, with 75% to 90% of the microbial biopesticides currently available originating from the same bacterium: Bacillus thuringiensis [6,7]. 28% of the biopesticides market is in the EU [7], which can be explained by the long and complex registration processes in the EU [6].

10 Microbial pesticides consist of a microorganism (e.g., a bacterium, fungus, virus or protozoan) as the active ingredient. For example, there are fungi that control certain weeds and other fungi that kill specific insects. These microorganisms by themselves have pesticidal properties and are different from microbes that are used in fermentation processes

- Directive 2000/60/EC establishing a framework for community action in the field of water policy (Water Framework Directive) which identifies a large number of particularly toxic, persistent or bioaccumulative polluting substances in Annex VIII including organophosphate compounds.

In 2017 the company Ecospray developed and registered its garlic extract-based nematicide, Nemguard SC, in the EU southern zone for use in drip irrigation systems on a range of outdoor and protected speciality crops. The active ingredient is exempt from an EU MRL (maximum residue levels) or minimum harvest interval [12].

Mahindra Agri Solutions' patented red green algae-based biological product, Jingo NXG, was introduced in 2016. Jingo NXG performs through receptor activation technology consisting of natural plant growth elicitors that encourage plants to produce growth-promoting molecules [12].

In agriculture, chitosan is used as either a biostimulant or biopesticide depending upon the formulation and the way it is used [18]. Chitosan manufacturing begins by extracting the polysaccharide chitin that is found in several biological organisms [18]. It provides the structural rigidity associated with the exoskeletons of invertebrates and the cell walls of fungi [18]. Chitosan is predominantly extracted from shellfish waste in developing countries and is mainly used in industrial wastewater treatment and in cosmetics [13,19]. This causes inconsistencies in molecular weight and purity and allows the introduction of contaminates such as heavy metals in crustacean-derived chitosan [13]. Responding to increased demand for chitosan from a range of industries, Plater Bio developed a fungal-derived chitosan. The fact that the majority of chitosan on sale globally is made from waste crustacean shells makes it impossible to sell it in countries where animal waste products are restricted or to customers who have vegan/halal/Kosher requirement. Further, it is possible that crustacean-derived chitosan could be an issue for people allergic to seafood if allergens are not removed during the manufacturing process. Plater Bio claims that these will not be an issue for their fungal-derived chitosan. Increased production in Europe will make fungal-derived chitosan more attainable to growers who would not have opted for this usually expensive biostimulant [12]. Further, as chitosan is manufactured from natural polysaccharides it is organically certifiable, allowed to be used as a biopesticide under EU organic regulations, and is exempt from the REACH regulations [18].

Stockton's Regev is a "hybrid" fungicide based on tea tree extract and difenoconazole. It is a new way of controlling diseases in agriculture and is an innovative solution that brings the advantages of a mixture formulation for sustainable agriculture. The product is claimed to be an effective resistance management tool with shorter pre-harvest interval limitations and lower residues than conventional products [12].

Water compatible solvents (good water solubility) and solvents that are not damaging to the plants (low phytotoxicity) are of interest to agrochemical industry. Bio-based n-butanol and isopropanol are often mentioned as solvents which meet these requirements. Partly bio-based agrochemicals include bio-based solvents for pesticides, such as those produced by Corbion, to enhance the pesticides' wetting properties. Corbion's PURASOLV® range are lactate esters, derived from L- and D-lactic acid [14]. (Corbion, n.d.). Lower levels of toxicity to both humans and the environment make bio-based agrochemicals a preferred option over fossil-based chemicals [10].

In the RoadToBio project, the desired sustainability characteristics that are met/not met by selected bio-based agrochemicals and their fossil-based equivalents were assessed. The drivers of these sustainability characteristics were also assessed. These are summarised below.

Table 10: Desired sustainability characteristics of agrochemicals (bio-based/fossil) and their drivers

Product group	Desired sustainability characteristics	Drivers of sustainability characteristics
Agrochemicals	Biodegradability, low human toxicity, low ecotoxicity	Legislations

Table 11: Sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in the agrochemicals product group

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Fungicides	Natural oils and *azadirachtin (bio alternative for fossil-based fungicides)*	100	Dedicated	X	X	X	X		Required for organic farming certification	9
Insecticides	Natural oils and *azadirachtin (bio alternative for fossil-based insecticides)*	100	Dedicated	X	X	X	X		Required for organic farming certification	9
Solvents for insecticides	Esters of lactic acid *(bio-alternative for fossil-based organic solvents such as N-methyl-2-pyrrolidone (NMP) and acetone derivatives)*	100	Dedicated	X	X	X	X		Corbion's PURASOL®	9
Solvents for pesticides	Bio-based isopropanol and n-butanol *(bio-alternative for fossil-based isopropanol and n-butanol)*	100	Drop-in	X	X	X	X		Solvents which provide good solubility and low phytotoxicity.	9
Coatings for fertilisers	Polyhydroxyalkanoates (PHA) *(bio-alternative for Sulphur-based coatings that have a thin layer of organic polymer; and resin-based polymers)*	100	Dedicated	X	X	X	X		PHA can be used as coatings for fertilisers that enable controlled urea release. Italian company Bio-on have demonstrated the use of PHA-based coating for urea in 2018.	5-6

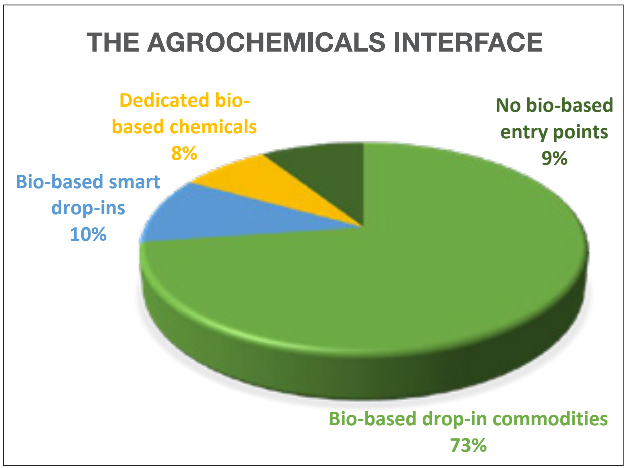
Key: B=Biodegradable, LHT=Low human toxicity, Low GHG=Low greenhouse gases, LE=Low ecotoxicity, R=Recyclability

Note: The chemicals/products selected for the analysis are representative of the product group and do not cover the full spectrum of chemicals/products. These representative chemicals/products 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.

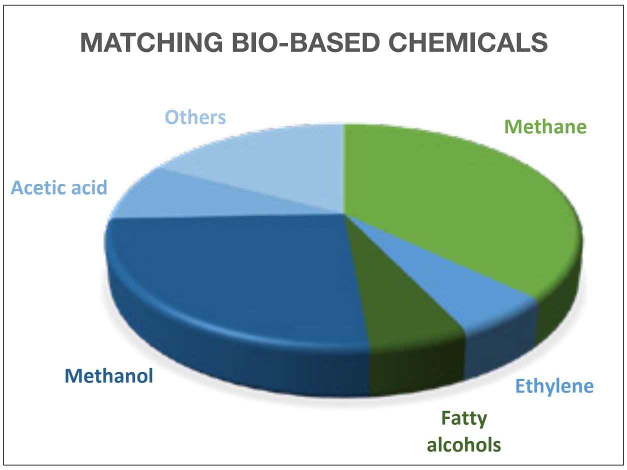
Low VOC has not been listed as a separate sustainability characteristic. However, this is an important issue for solvents and is considered under 'low ecotoxicity' and 'low human toxicity'.

3.4.3 Opportunities and barriers

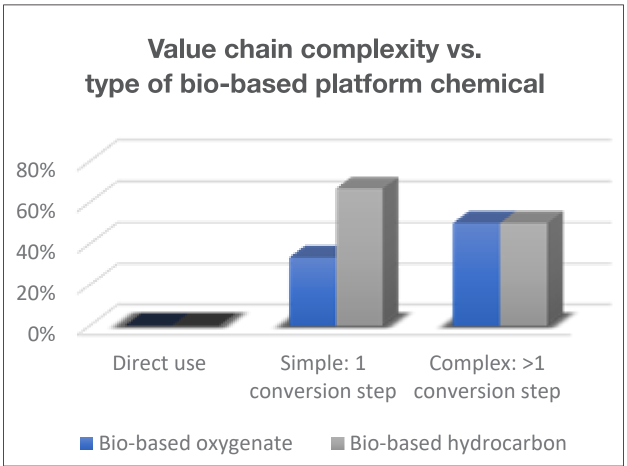
Given the complex synthesis pathways of agrochemicals, the product group will benefit from the use of bio-based platform chemicals in the agrochemicals' manufacturing process. This was investigated in D1.1 of RoadToBio where drop-in opportunities for different agrochemicals were studied, which showed 35 potential entry points for chemical building blocks such as methanol for 11 selected agrochemicals. Following is a summary of the results from D1.1 [15].



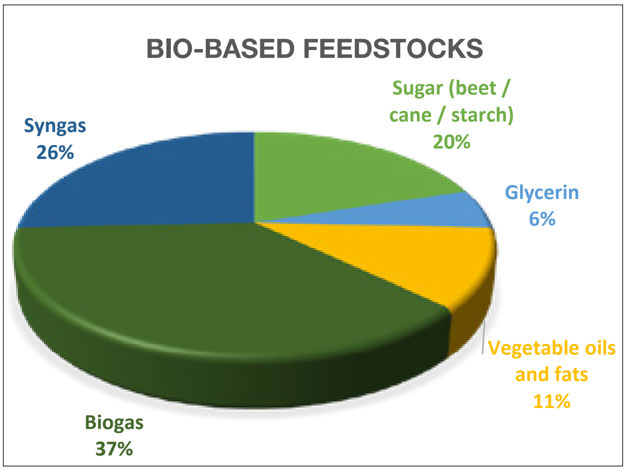
11 petrochemical agrochemicals were analysed; at least one potential entry point for a bio-based chemical in the value chain was identified for 91% of the agrochemicals, the majority being drop-in commodities.



11 different bio-based chemicals could enter the value chains at 35 potential entry points that were found. Methane and methanol were the most prevalent options.



Only 3 of the 35 resulting value chains were simple, in general the agrochemical value chains were very complex, leading to many subsequent conversion steps for both bio-based oxygenates and hydrocarbons to the final agrochemicals.



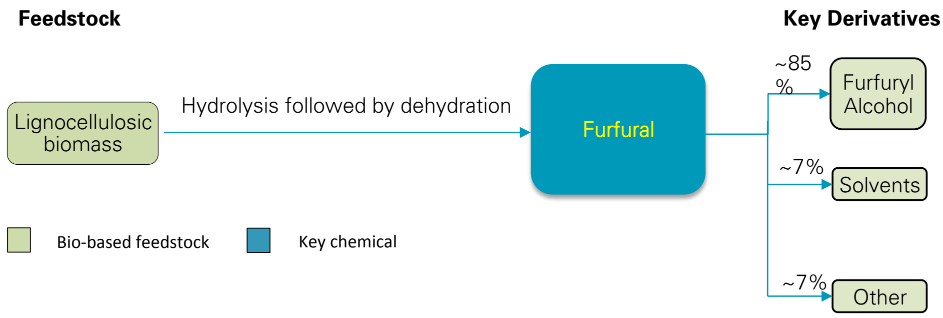
The main feedstock platforms that can currently provide these bio-based chemicals are the sugar platform, the biogas platform, and the syngas platform.

Figure 14: Opportunities for higher bio-based share in agrochemicals via use of drop-in bio-based chemicals in the production process

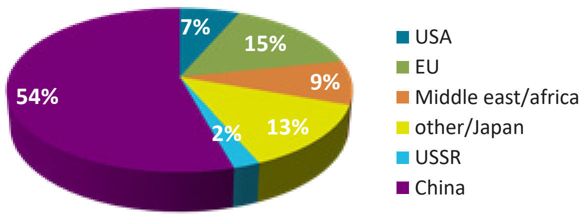
In addition to identifying bio-based chemicals and their potential entry points in 9 product groups, the RoadToBio project also includes an analysis of nine potentially attractive business opportunities ("sweet spots") for the European bio-based industry (D1.2) [16]. One of the 9 chemicals that was analysed in-depth was furfural. Furfural is a bio-based dedicated chemical that is used for preparing fungicides such as nitro substituted furans [16]. The chemical is also used in preparation of adhesives. Furfural was covered in D1.2 of RoadToBio and following is a summary of the analysis [16]. Please note that this chemical is not the most representative of the agrochemicals product group, but one that was covered in-depth in D1.2 and selected here due to its relevance to this product group.

Market Volume EU: (ktonne/yr)	Market Volume Global: (ktonne/yr)	Price per tonne: (€/tonne)	Market growth rate: (%/yr)
Total: 67	Total: 440		
Bio-based: 67	Bio-based: 440	1,550	11.9
Source: DalinYebo (2016)	Source: DalinYebo (2016)	Source: www.nrel.gov	Source: Grand View Research

Value chain:

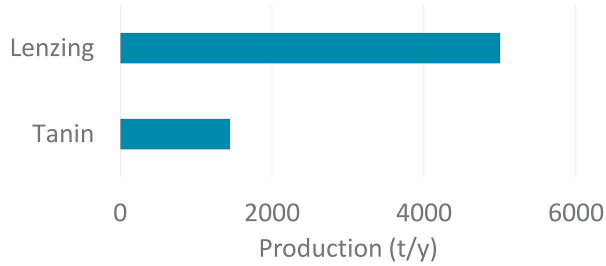


Demand:

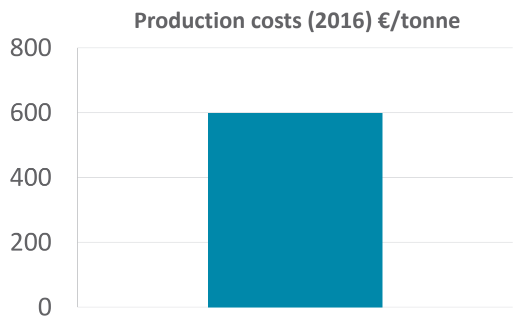


Year: 2016

Supply (EU):



Costs:



Opportunities and Barriers:

+ Use of residual biomass
+ Base compound of a broad portfolio of furan-based chemistry

- Dedicated furfural production requires large amounts of energy
- Furfural production is co-dependent on other biomass conversions
- Handling of hazardous chemicals

Figure 15: Furfural case study summary

In horticulture over 50% of the pesticides used are bio-based in origin and the majority of these are microbial. In agriculture (broad acre crops) less than 5% of pesticides are bio-based. The challenge lies in making bio-based pesticides more reliable in open field and thereby increasing their uptake (Lewis, J., pers. comm., Feb. 2019). In addition to the chemicals, innovation is also required in the technologies that can be used to deliver the chemicals to the crops. For example, the Bee Vectoring Technology has developed a system that uses bees to deliver biopesticides. As the bees leave their hive to forage they pick up trace amounts of product and carry it to the bloom, where it can colonise and outcompete pathogens. The patented system drastically reduces the amount of wasted product and off-target application and can save thousands of gallons of water used in sprays [12,17]. This technology is suitable for horticulture which includes bee pollinated crops, but not for crops such as cereals that are wind pollinated. Other methods include the use of existing drip irrigation systems like Ecospray's Nemguard (garlic-based nematicide) [12].

Barriers to bio-based uptake were identified for each product group, followed by potential actions that can be taken to address those barriers and the time required to do so. There are certain 'generic barriers' such as feedstock availability and cost competitiveness of bio-based products with fossil equivalents, which are applicable to all product groups. These are covered in chapter 4 of the report. These generic barriers may be mentioned in the following table only if there is something very specific about the barrier for the agrochemicals product group. Otherwise they are not mentioned in the following table.

Table 12: Barriers to bio-based uptake in agrochemicals and proposed actions

Barriers	Actions	Actors	Timeline
Bio-based agrochemicals face tough competition from established fossil-based equivalents	Gradually increase the bio-based content of commercially-available fossil-based agrochemicals. This can be done by replacing some of their fossil-based intermediates or building blocks with bio-based drop-ins in the agrochemicals' manufacturing process. The resulting partially bio-based agrochemical should be tested to check that it at least has the same level of performance as the fossil-based equivalent.	Policy makers, industry, academia	Short-long term
Bio-based alternatives need to be compatible with the plants (low/no phytotoxicity)	Focus efforts on developing bio-based chemicals that have low/no phytotoxicity effect and are reliable when applied in open field	Policy makers, industry, academia	Short-mid term
Few bio-based solvents available for agrochemicals that fulfil functionality like solvency and compatibility with wide range of active ingredients	Invest in R&D and innovation to create solvents for agrochemicals with superior functionality	Policy makers, industry, academia	Short-mid term
European agrochemical industry is strictly regulated. Use of new ingredients in products is subject to long and often expensive approval procedures	Explore option of shorter and more affordable 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.	Policy makers, industry	Short-mid term
	Financial support to SME for approval procedures.	Policy makers, industry	Short-mid term

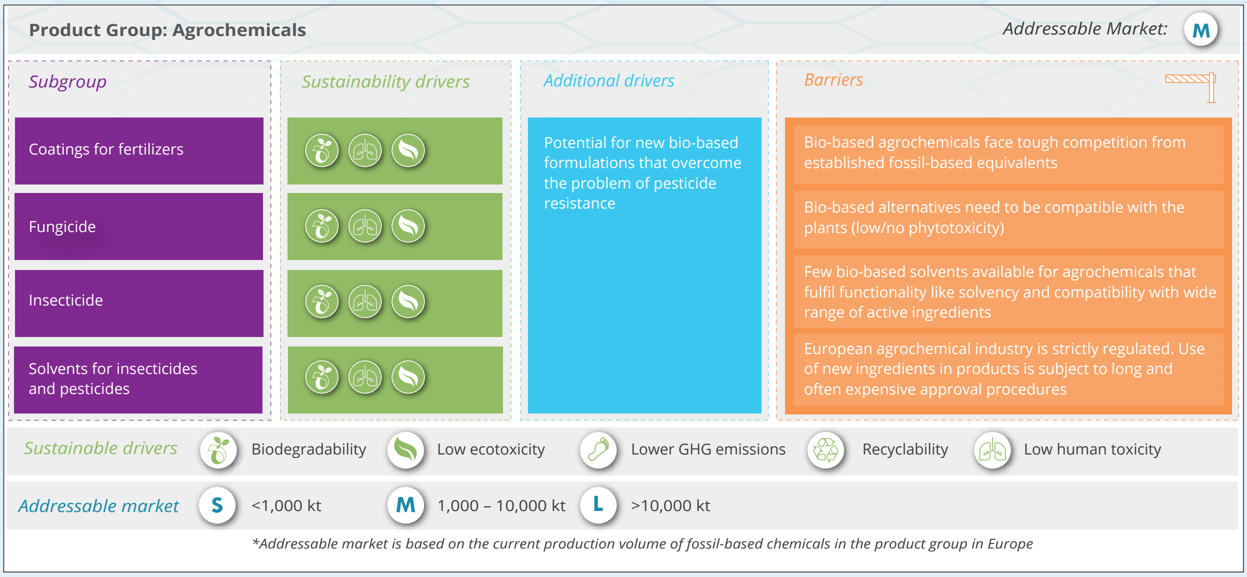


Figure 16: Pictorial summary of the agrochemicals product group

Figure 17: Roadmap to increasing the bio-based share of chemicals in the agrochemicals product group

3.4.4 Summary

- 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 has to 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

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3.5 Surfactants

3.5.1 Background

Surfactants are widely used in cosmetics, personal and home care products as dispersing agents and emulsifiers. The surfactants can be divided in the following subgroups: anionic, cationic, non-ionic and amphoteric surfactants. All of them are produced from fossil and/or bio-based raw materials. The bio-based surfactants are produced as high value products, typically for high-end customer products. Globally, most consumed bio-based surfactants include Methyl Ester Sulfonate (MES) (33.3%), Alkyl Polyglucoside (APG) (25 %), Sorbitan esters and Sucrose esters (combined share of 8%) [1]. Table 13 shows the share of bio-based surfactants in different products/applications.

Table 13: Share of bio-based surfactants in products/applications globally [1]

Application	Share (%)
Household detergent	44.6
Personal care	10.8
Industrial cleaner	6.7
Food processing	5.8
Oilfield chemicals	4.3
Agrochemicals	3.5
Textiles	2.2
Other markets	22.1

3.5.2 Drive for bio-based market growth

The demand for bio-based surfactants will depend strongly on household spending and industrial activity in detergents and cosmetics where environmental concerns are more evident. The development of the detergent and cosmetics industries can be characterised by general economic development and the 2G[11] bio-surfactants market is estimated to grow from EUR 1.3 million in 2013 to approximately EUR 3.1 million in 2030 [2]. In high and low case scenarios, the market value is expected to reach EUR 4 million and EUR 2.2 million respectively [2]. The demand for bio-based surfactants will also depend on whether they meet the consumer requirements of being a 'sustainable' option. If the bio-based surfactant production process uses less water and/or energy and is therefore more 'sustainable' beyond just being bio-based, then the demand for that particular bio-based surfactant will exist.

Europe is currently and expected to remain the largest consumer and producer of bio-based surfactants in 2030 [2].

Due to the advanced product properties the use of bio-based surfactants is possible in a wide range of product applications, however, still as niche products due to their limited cost competitiveness compared to conventional products. The main factors to success of the European bio-surfactant market could be the increased environmental awareness and the opportunities for new product properties at a competitive cost. Bio-based surfactants often offer low ecotoxicity, biodegradability, an independence of fluctuating oil prices, the use of a lower critical concentration compared to chemical surfactants as well as biological activity (antibacterial, antifungal, antiviral, anticancer and immunomodulation activities).

Highest Potential to replace fossil based alkylbenzene sulfonates with MES:

Methyl ester sulfonates (MES) are anionic surfactants that can be made by sulfonation of saturated fatty acid methyl esters, derived from natural fats and oils. MES are used in manufacturing of laundry detergent powders & detergent cakes, where they could replace fossil based alkylbenzene sulfonates, which are a group of the oldest and most widely used fossil-based detergents.

MES are produced by several companies worldwide (China, USA, Japan, Indonesia). The eleven largest producers had a production capacity of > 560,000 MT in 2012 [3]. No producers are mentioned in Europe though Henkel KGaA is known as technology provider. 3.5 million t fossil based alkylbenzene sulfonates have been produced worldwide in 2016 [4].

Kuala Lumpur Kepong Berhad (KLK, Malaysia) mentioned in its recent annual report (2017) a reduced demand of MES, which they relate to the low oil price [5]. This may imply that companies producing detergents are using MES in favour of alkylbenzene sulfonates in (existing) formulations only if this is economic feasible. This demonstrates the advantage of flexibility by switching components in formulations, as long as a certain performance can be ensured. On the other hand KLK saw a surge in demand for MES due to improved environmental protection awareness in some countries [5].

Microbial biosurfactants

Microbial biosurfactants like Rhamno- or Sophorolipids are produced from renewable feedstocks via microbial fermentation. Such biosurfactants can be produced in high yield (typically 400 g/L). Currently microbial biosurfactants are expensive and command a premium typically >10x that of fossil-based surfactants [6]. On the other hand microbial bio-surfactant do often outperform classical surfactants in their different application fields, which could justify higher costs [7].

As microbial biosurfactant manufacture is in its infancy, limited product variation is achievable due to the limitations of the microorganisms used. This is especially true for Rhamnolipids as they are produced by the pathogenic microorganism *Pseudomonas aeruginosa* [2]. However, this fast-evolving area will benefit from genetic engineering, which will allow for the utilisation of a wider feedstock library, which in turn will generate a larger portfolio of microbial derived biosurfactants, and of course allows to produce also Rhamnolipids in non-pathogenic, but genetically modified microorganisms.

Sophorolipids

Sophorolipids are fermented from vegetable oil (and glucose) by a non-pathogenic yeast *Starmerella bombicola*. However, an expensive downstream processing is the major hurdle for sophorolipids market players.

Sophorolipids are produced already on industrial scale. Producing/developing companies are (among others): Evonik, Ecover, Henkel, Saraya, Soliance, Wheatoleo [8]. Sophorolipids are low foaming surfactants with mild antimicrobial properties in addition (anti acne, anti odour). Moreover, indications for antiviral, anti cancer and immunomodeling properties are given [8].

11 Derived from second generation biomass (biomass production not in competition for food and feed)

In the RoadToBio project, the desired sustainability characteristics that are met/not met by selected bio-based surfactants and their fossil-based equivalents were assessed. The drivers of these sustainability characteristics were also assessed. These are summarised below.

Table 14: Desired sustainability characteristics of surfactants (bio-based/fossil) and their drivers

Product group	Desired sustainability characteristics	Drivers of sustainability characteristics
Surfactants	Biodegradability, low human toxicity, low ecotoxicity	Legislations, lower critical concentrations

Table 15: Sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in the surfactants product group

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Anionic surfactants	Methyl ester sulfonate (MES) *[bio-based substitute for linear alkyl benzene sulfonate (LAS) which have global production of 1700 kt/yr]*	Up to 100 (derived from palm and coconut oil) (for special applications rapeseed oil could be used)	Dedicated	X	X		X		MES has far lower price as compared to other conventional detergent feedstocks. MES was the largest consumed bio-surfactant accounting for 33% of the global market in 2013. MES offers the biggest opportunity to shift from fossil to bio-based surfactants. It could be a bio-based alternative for Alkyl benzene sulfonate (LAS) and has high potential to be used in cosmetic products	9
Anionic surfactants	Fatty alcohol ethoxylates (FAE), fatty alcohol ether sulfates, fatty alcohol sulfates *(production has always been partly bio-based because of the bio-based fatty alcohol component)*	Up to 100	Dedicated	X	X		X		Used for home/personal care products. Global production of FAE is ~700 kt/yr	9
Cationic surfactants	Esterquats (EQ) *(new group of surfactants that are derived from bio-based precursors)*	100	Dedicated	X	X		X		Used for home/personal care products	9

Key: B=Biodegradable, LHT=Low human toxicity, Low GHG=Low greenhouse gases, LE=Low ecotoxicity, R=Recyclability

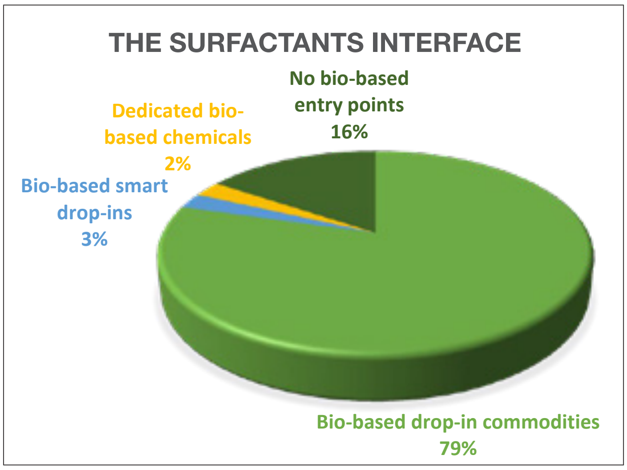
Note: The chemicals/products selected for the analysis are representative of the product group and do not cover the full spectrum of chemicals/products. These representative chemicals/products are either produced in large volumes (thereby dominating the market for that product group) and/or of interest and value due to the functionality they offer.

For all but one bio-based surfactant it is not possible to identify the fossil-based surfactant that they replace. However, all surfactants (fossil or bio-derived) need to have three key characteristics: biodegradability, low human toxicity and low ecotoxicity. Therefore, regardless of which fossil-based surfactants are replaced by the bio-based surfactants, these three characteristics will have to be met by both fossil and bio-derived surfactants.

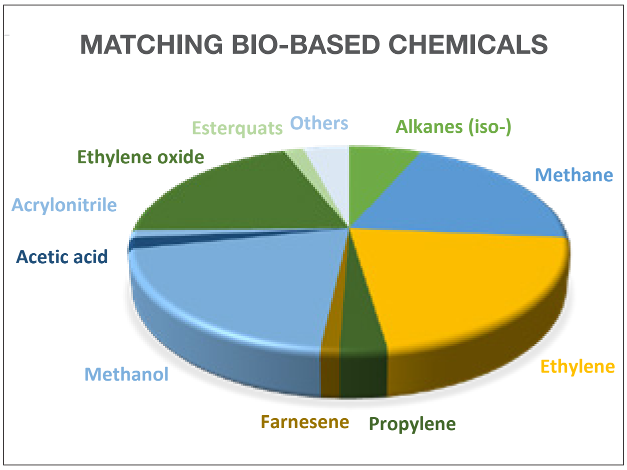
Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Non-ionic surfactants	Alkyl Polyglycosides (APG) *(production has always been fully bio-based)*	100 (derived from sugar and fatty alcohols)	Dedicated	X	X		X		APG was the second largest consumed biosurfactants accounting for 25% of the global demand in 2013. It can be used in cosmetics, biochemicals, food processing, plastic and petroleum industry, textile, printing and dyeing, papermaking and pharmaceuticals. APG has an added advantage of not causing skin irritations. The challenge with APG is to expand the market as only small quantities are required for the application.	9
Non-ionic surfactants	Sorbitan esters [incl. Sorbitan tristearate (STS), Sorbitan monostearate (SMS), Sorbitan monooleate (SMO), Sorbitan trioleate (STO), Sorbitan monopalmitate (SMP), Sorbitan monolaurate (SML)] *(production has always been fully bio-based)*	100	Dedicated	X	X		X		Used in medicine, cosmetics, textiles as emulsifier, stabilizer, thickener, lubricant, emulsifier for oil field etc.	9
Non-ionic surfactants	Sucrose esters (made by esterifying sugar with methyl fatty acids) *(production has always been partly bio-based because of the fatty acid component)*	Upto 100	Dedicated	X	X		X		A sugar-based emulsifying agent for food such as ice cream and candies	9
Microbial biosurfactants/ Glycolipids	Sophorolipids *(new microbial/biotechnological production pathway that is fully bio-based)*	100	Dedicated	X	X		X		Antimicrobial and anti-cancer properties of sophorolipids may enhance application spectra and acceptance	9
Microbial biosurfactants/ Glycolipids	Rhamnolipids *(new microbial/biotechnological production pathway that is fully bio-based)*	100	Dedicated	X	X		X		The natural production organism is pathogenic which poses as a barrier for the uptake of this surfactant class by industry	6-7

3.5.3 Opportunities and barriers

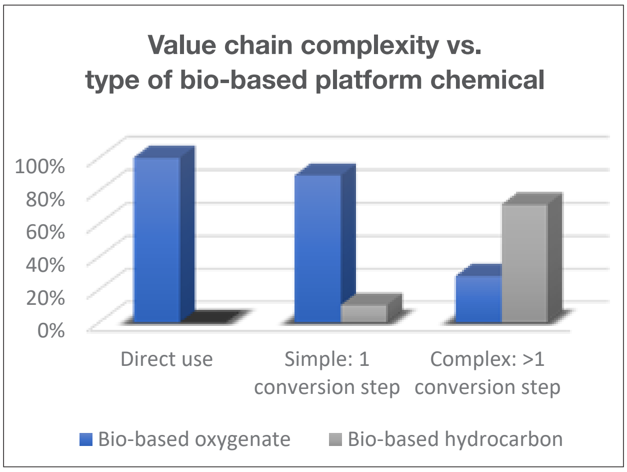
Deliverable D1.1 of the RoadToBio project identified pathways to higher bio-based share within the surfactants market via the use of drop-in chemicals in their production process. Following is a summary of the results from D1.1 [9].



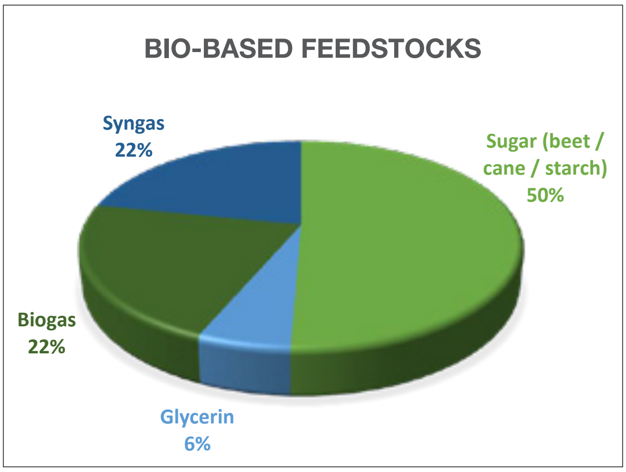
90 different surfactants were analysed; at least one potential entry point for a bio-based chemical in the value chain was identified for 84% of these surfactants.



17 bio-based chemicals from the RoadToBio long-list of 120 chemicals could potentially enter the existing surfactant value chains. Methane, methanol, ethylene and ethylene oxide together are responsible for 80% of these bio-based options.



The bio-based chemicals from the long-list that could be used directly in this case were esterquats. In general, bio-based oxygenates again result in shorter subsequent value chains.



The main feedstock platforms that can currently provide these bio-based chemicals are the sugar platform (providing a.o. ethylene and ethylene oxide), the syngas platform (providing methanol), and the biogas platform (providing methane).

Figure 18: Opportunities for higher bio-based share in surfactants via use of drop-in bio-based chemicals in the production process

The main advantage, additional properties for the end product, also provides the main barrier for increasing the bio-based production volume. Bio-based surfactants are usually used in end products where the modification of one component has an impact on the overall composition and performance [10]. Thus, brand-owners are deterred from switching to an alternative chemical and remain with the conventional surfactant [10]. This barrier could be overcome by targeted support and funded research towards new product formulations. The clear advantage for companies is flexibility in composition, as long as a certain performance can be ensured. Another market-related hurdle is the uncertainty of secured steady supply of bio-based surfactants due to the limited number of large-scale producers [10]. This barrier could also be overcome with targeted investment in research and development or subsidies for large-scale plants.

There are certain 'generic barriers' such as feedstock availability and cost competitiveness of bio-based products with fossil equivalents, which are applicable to all product groups. These are covered in chapter 4 of the report. These generic barriers may be mentioned in the following table only if there is something very specific about the barrier for the surfactants product group. Otherwise they are not mentioned in the following table.

Table 16: Barriers to bio-based uptake in surfactants and proposed actions

Barriers	Actions	Actors	Timeline
Customers may not be aware of what a bio-based surfactant is and what they can be used for.	Marketing efforts by companies can be supported by appropriate labels, customer awareness (general public education) and rules for public procurement. Information campaigns required to promote bio-based products, to provide facts about GMM (genetically modified microorganisms) and their use in bio-surfactant production and to open the discussion with NGOs and public authorities.	Government, industry, NGOs	Short-mid term
End-product manufacturers need to perceive a clear added-value in switching to bio-based surfactants as one-to-one substitutions of conventional surfactants are unlikely	Demonstration of safety, environmental benefits and added value (e.g. superior properties) of bio-surfactants compared to conventional surfactants	Government, industry	Short-mid term
Lack of a standard definition of bio-based surfactant	This barrier is already being addressed. Finalisation of the standard definition of bio-surfactants by CEN TC 276.[12]	Government, industry	Short-mid term
New product formulation development is often required to optimize bio-based surfactant performance but is an expensive process	Better characterisation of individual bio-surfactants and promotion of cooperation with bio-surfactant developers, producers and end users in order to optimise surfactant performance in a product formula and to match bio-surfactant properties and end use needs	Industry	Short-long term
Microbial derived biosurfactants are expensive and command a premium typically >10x that of fossil-based surfactants.	R&D in genetic engineering for increasing product yield, and utilisation of different feedstocks to generate a larger portfolio of microbial-derived biosurfactants	Government, industry, academia	Short-long term
Production yields of microbial biosurfactants are low and toxic by-products are still a problem	R&D and industry level trials required to address this issue.	Government, industry, academia	Short-Mid-term
Downstream processing of microbial derived biosurfactants is complicated and requires innovation	R&D and industry level trials required to address this issue.	Government, industry, academia	Short-long term

12 The definition will include and require that several criteria be met, such as, type of feedstock used; properties of the surfactants (e.g. with regard to aquatic environment, etc.); LCA elements with the cradle to grave approach

Product Group: Surfactants

Addressable Market: M

Subgroup	*Sustainability drivers*	*Additional drivers*
Anionic	Biodegradability, Low human toxicity, Low ecotoxicity	Advanced properties: • often results in lower eco-toxicity than conventional surfactants • lower critical concentration • biological activity (antibacterial, antifungal, antiviral, anticancer and immunomodulation activities)
Cationic	Biodegradability, Low human toxicity, Low ecotoxicity	
Glycolipids	Biodegradability, Low human toxicity, Low ecotoxicity	
Non-ionic	Biodegradability, Low human toxicity, Low ecotoxicity	

Barriers

- Customers may not be aware of what a bio-based surfactant is and what they can be used for
- End-product manufacturers need to perceive a clear added-value in switching to bio-based surfactants as one-to-one substitutions of conventional surfactants are unlikely
- Lack of a standard definition of bio-based surfactant
- New product formulation development is often required to optimize bio-based surfactant performance but is an expensive process
- Microbial derived biosurfactants are expensive and command a premium typically >10x that of fossil-based surfactants
- Production yields of microbial biosurfactants are low and toxic by-products are still a problem
- Downstream processing of microbial derived bio-surfactants is complicated and requires innovation

Sustainable drivers: Biodegradability, Low ecotoxicity, Lower GHG emissions, Recyclability, Low human toxicity

Addressable market: S <1,000 kt; M 1,000 – 10,000 kt; L >10,000 kt

**Addressable market is based on the current production volume of fossil-based chemicals in the product group in Europe*

Figure 19: Pictorial summary of the surfactants product group

Product Group: Surfactants

Barriers	Stakeholders	Measure	*Short term (up to 2021)*	*Mid term (up to 2026)*	*Long term (up to 2030)*
Customers may not be aware of what a bio-based surfactant is and what they can be used for	Government, Industry, NGOs	Marketing efforts by companies can be supported by appropriate labels, customer awareness (general public education) and rules for public procurement	✓	✓	
	Government, Industry, NGOs	Information campaigns required to promote bio-based products, to provide facts about GMM (genetically modified microorganisms) and their use in bio-surfactant production and to open the discussion with NGOs and public authorities	✓	✓	
End-product manufacturers need to perceive a clear added-value in switching to bio-based surfactants as one-to-one substitutions of conventional surfactants are unlikely	Government, Industry	Demonstration of safety, environmental benefits and added value (e.g. superior properties) of bio-surfactants compared to conventional surfactants	✓	✓	
Lack of a standard definition of bio-based surfactant	Government, Industry	This barrier is already being addressed. Finalisation of the standard definition of bio-surfactants by CEN TC 276 [1]	✓	✓	
New product formulation development is often required to optimize bio-based surfactant performance but is an expensive process	Industry	Better characterisation of individual bio-surfactants and promotion of cooperation with bio-surfactant developers, producers and end users in order to optimise surfactant performance in a product formula and to match bio-surfactant properties and end use needs	✓	✓	✓
Microbial derived biosurfactants are expensive and command a premium typically >10x that of fossil-based surfactants	Industry	R&D in genetic engineering for - increasing product yield, and - utilisation of different feedstocks to generate a larger portfolio of microbial-derived biosurfactants	✓	✓	✓
Production yields of microbial biosurfactants are low and toxic by-products are still a problem	Government, Industry, Academia & Research Institutions	R&D and industry level trials required to address this issue	✓	✓	
Downstream processing of microbial derived biosurfactants is complicated and requires innovation	Government, Industry, Academia & Research Institutions	R&D and industry level trials required to address this issue	✓	✓	✓

Stakeholders: Government, Industry, NGOs, Academia & Research Institutions

[1] The definition will include and require that several criteria be met, such as, type of feedstock used; properties of the surfactants (e.g. with regard to aquatic environment, etc.); LCA elements with the cradle to grave approach

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

3.5.4 Summary

- 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 alkyl benzene 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, as long as 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.

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3.6 Lubricants

3.6.1 Background

Lubricants are formulations designed to separate moving parts, thereby minimizing friction and reducing wear. Lubricants consists mostly of a base oil. The properties of the base oil are modified by adding small amounts of different additives [1]. Lubricants are used in various applications in the industrial, automotive, marine and aerospace sectors. The largest consumption of lubricants is in transportation i.e. the automotive, aerospace and marine sectors [11,12]. The increasing number of passenger and commercial vehicles, and growth in the aviation and marine sectors are expected to drive the global demand for lubricants [12]. Bio-based lubricants currently in use include unmodified vegetable oils, such as sunflower oil, rapeseed oil; tall oil fatty acids (TOFA), fatty acid methyl esters (FAME), and fatty acid polyethylene glycol (PEG) esters. Unmodified vegetable oils are mainly used in chainsaws and unmolding applications, while TOFA and the esters are used as engine oils, compressor oils, cooling fluids, aviation fluids and hydraulic fluids [1, 2].

3.6.2 Drive for bio-based market growth

The market for biolubricants mainly exists in Europe and the US [3]. Their market is limited outside US and Europe due to their high costs, which can be double of standard lubricants [3].

However, the need for biodegradable lubricants that are non-toxic has caused the market share of biolubricants to increase [3]. The market value of biolubricants has increased from EUR 1.6 billion in 2011 to EUR 2.3 billion in 2017 [3]. This is expected to grow with a CAGR of 5.4% to EUR 3.0 billion in 2024 [3]. The growth is mainly expected in applications in transportation and manufacturing [3].

The bio-based lubricants market is driven by regulations on total-loss applications or improved performance for certain applications. Total-loss applications are those in which the lubricant is released into the environment during or immediately after use, for example from the use on chainsaws [13]. There are several EU Member States, where bio-based lubricants are compulsory for use in total-loss applications in environmentally sensitive areas [4]. For some applications, e.g. in the automotive industry, bio-based lubricants show high lubricity, which leads to lower quantities used and less noise production. Further properties that make bio-based lubricants a preferred option over fossil equivalents include biodegradability, lower toxicity, lower volatility, and lower flammability. [3, 5, 6, 7]. The use of renewable carbon is rarely mentioned as a driver [7]. On the other hand, bio-based lubricants are associated with a lower stability due to oxidation reactions, bad odours, limitations at low temperature, and low viscosity which can lead to filter clogging [7].

In the RoadToBio project, the desired sustainability characteristics that are met/not met by selected bio-based lubricants and their fossil-based equivalents were assessed. The drivers of these sustainability characteristics were also assessed. These are summarised below.

Table 17: Desired sustainability characteristics of surfactants (bio-based/fossil) and their drivers

Product group	Desired sustainability characteristics	Drivers of sustainability characteristics
Lubricants	Biodegradability, low human toxicity, low ecotoxicity, low GHG, recyclability	Legislations, producer driven (voluntarily)

Table 18: Sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in the lubricants product group

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R[13]		
Base oil/ base stock	Tall oil fatty acids, *[These are bio-based alternatives for Low molecular weight polyalphaolefins (PAOs), Hydrogenated PAOs, phosphate esters, diesters]*	100	Dedicated	X	X	X	X	X		9
Base oil/ base stock	Fatty acid methyl esters (e.g. methyl palmitate, stearate, laurate) *[These are bio-based alternatives for Low molecular weight polyalphaolefins (PAOs), Hydrogenated PAOs, phosphate esters, diesters]*	90	Dedicated	X	X	X	X	X		9
Base oil/ base stock	Fatty acid PEG esters (e.g. polyoxyethylene oleate, palmitate) *[These are bio-based alternatives for Low molecular weight polyalphaolefins (PAOs), Hydrogenated PAOs, phosphate esters, diesters]*	60	Dedicated	X	X	X	X	X		9

Key: B=Biodegradable, LHT=Low human toxicity, Low GHG=Low greenhouse gases, LE=Low ecotoxicity, R=Recyclability

Note: The chemicals/products selected for the analysis are representative of the product group and do not cover the full spectrum of chemicals/products. These representative chemicals/products 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.

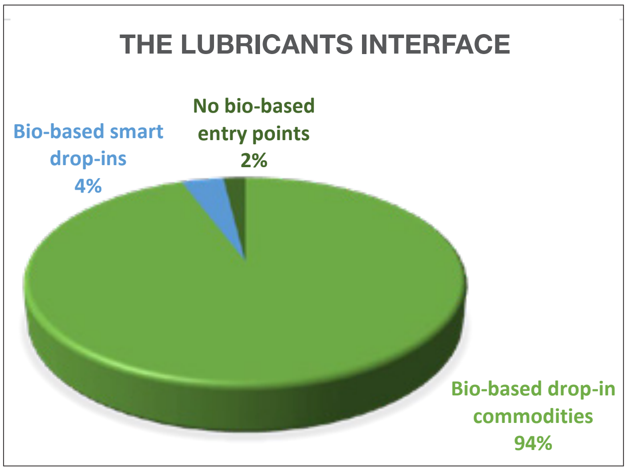
13 Recycling of base oil/ base stock (in lubricants) is done at the production facility. However, it is not possible to recycle lubricants in total loss applications such as when used in chainsaws because it is difficult to collect the lubricants lost during the use phase.

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R[13]		
Base oil/ base stock	Triglyceride oil (soybean, canola, sunflower, corn, castor bean, palm oils) *(bio-based alternative for mineral oils)*	90 to 100	Dedicated	X	X	X	X	X	Advantages: good lubricity, biodegradable. Disadvantages: thermal and oxidative instability, cost	9
Base oil/ base stock	Polyol Esters e.g. neopentyl polyol ester with natural fatty acids *(bio-based alternative for mineral oils/ synthetic base stock)*	~50 to 70	Dedicated	X[14]	X	X	X	X	Advantages: thermal, oxidative, hydraulic, and hydrolytic stability; wide operating temperature range; wide range of viscosities; low volatility; high lubricity; long service life. Disadvantages: diesters can degrade elastomer seals, high cost for polyol esters	9
Base oil/ base stock	Bio-based polyglycols (e.g., bio-based polyethylene glycol, bio-based polypropylene glycol) – made from bio-ethylene oxide feedstock) *(bio-based alternatives for fossil equivalents)*	up to 100	Drop in	X	X	X	X	X	Advantages: biodegradable, good lubricity, high viscosity index, good performance at temperature extremes, hydrolytic stability. Disadvantages: can degrade seals, paints	9
Base oil/ base stock	poly-alpha-olefin (PAO) oils – from bio-ethylene *(bio-based alternative for fossil-based PAOs)*	up to 100	Drop in		X	X	X	X	Advantages: biodegradable (varies), good low-temperature performance, hydrolytic stability, low volatility, good for low-viscosity applications, lower cost than some ester-based oils, hydrocarbon composition similar to mineral oils. Disadvantages: high-viscosity forms have varying degrees of biodegradability	9
Thickener	Simple soap (e.g., lithium or aluminum) made from fatty acids from olive, castor, soybean, peanut or animal/ fish oils reacted with metal hydroxide *(bio-based alternatives for modified clay, carbon black, polyethylene, polyurea)*	Up to 100	Dedicated	X	X	X	X			9
Thickener	Complex soap (commonly based on lithium, aluminum, or calcium sulfonate) made from simultaneous reaction of an alkali with a fatty acid and an inorganic or short-chain organic acid (these may be derived from bio-based feedstock) *(bio-based alternatives for modified clay, carbon black, polyethylene, polyurea)*	Variable	Dedicated	X	X	X	X			9
Additive (anticorrosion)	*Oleochemical based fatty esters (Dodecylene succinic acid and other succinate derivatives) (bio-based alternatives for inorganic thickeners such as Naphthylamine phosphorus containing compounds)*	Variable but up to 100	Dedicated	X	X	X	X			9

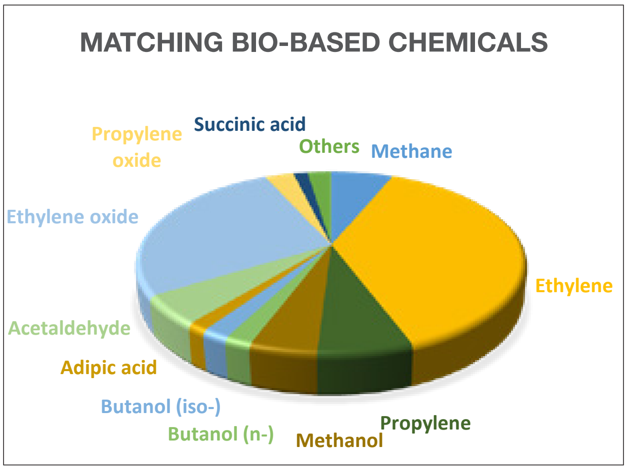
14 Typically, increasing the amount of natural components such as vegetable-based fatty acids helps biodegradability. When synthetic acids and neopolyol alcohols are used, the ester becomes more inert and the rate of biodegradation is reduced.

3.6.3 Opportunities and barriers

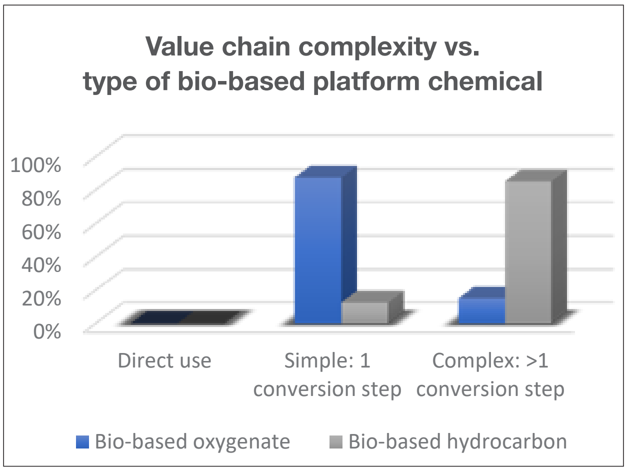
D1.1 of the RoadToBio project identified pathways to higher bio-based share within lubricants via the use of drop-in chemicals in the production process of lubricants. Following is a summary of the results from D1.1 [8].



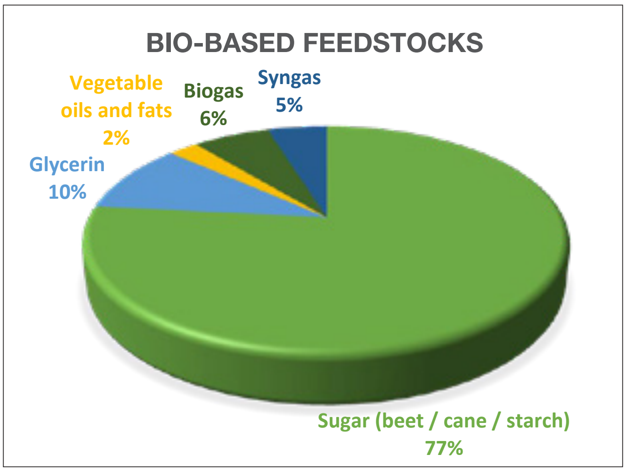
103 petrochemical lubricants were analysed; at least one potential entry point for a bio-based chemical in the value chain was identified for 98% of them, the far majority being drop-in commodities.



15 different bio-based chemicals could enter the value chains at 210 potential entry points that were found. Ethylene as well as its derivative ethylene oxide were the most common options in the value chains to many ethoxylated final chemicals.



Again the subsequent pathways from entry point to final chemical were on average shorter for the bio-based oxygenates than for the bio-based hydrocarbons.

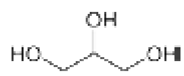


The main feedstock platform that can currently provide these bio-based lubricants is the sugar platform. Important to emphasize is that already many bio-based lubricants exist on the basis of vegetable oils, which were kept out of scope.

Figure 21: Opportunities for higher bio-based share in lubricants via use of drop-in bio-based chemicals in the production process

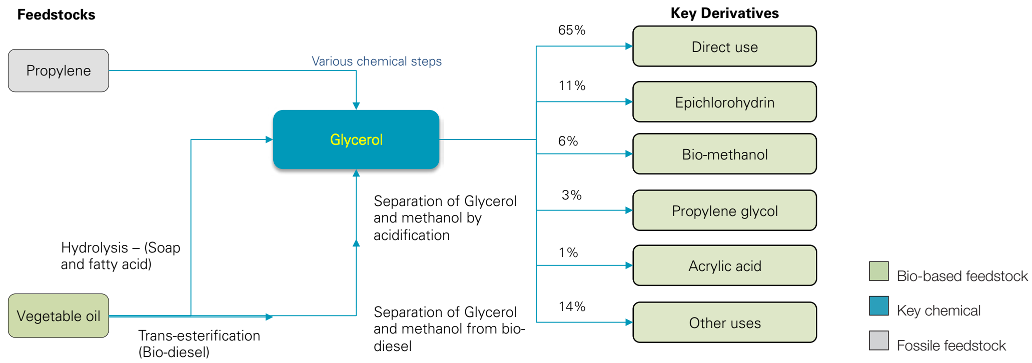
In addition to identifying bio-based chemicals and their potential entry points in 9 product groups, the RoadToBio project also includes an analysis of nine potentially attractive business opportunities ("sweet spots") for the European bio-based industry (D1.2) [9]. One of the 9 chemicals that was analysed in-depth was glycerol. Owing to their recently discovered superlubricity, glycerol-water mixture has been trialled as lubricant between steel surfaces [19]. The current market for glycerol is however mainly in the food and cosmetics industry. Glycerol was one of the chemicals covered in D1.2 of RoadToBio and following is a summary of the analysis [9]. Please note that this chemical is not the most representative of the lubricants product group, but one that was covered in-depth in D1.2 and selected here due to its relevance to this product group.

Smart Drop-in Chemical
Product group: Cosmetics, Lubricants, Solvents

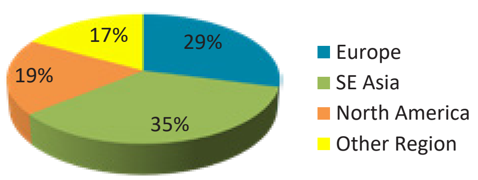


Market Volume EU: (ktonne/yr)	Market Volume Global: (ktonne/yr)	Price: (€/tonne)	Market growth rate (%/yr):
Total: 850	Total: Slightly over 2,900	Crude: 450	6.0
Bio-based: 850	Bio-based: 2,900	Refined: 800-900	
Source: Greenea, 2015	Source: Greenea, 2015	Source: www.nrel.gov and Straathof (2017)	Source: Greenea, 2015

Value chain:

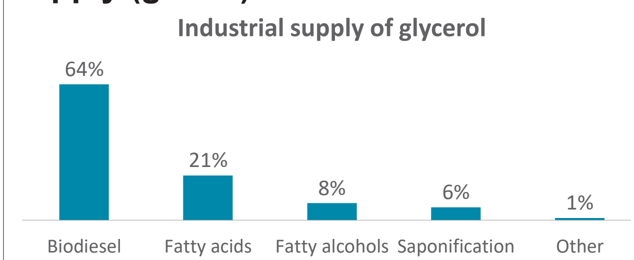


Demand:



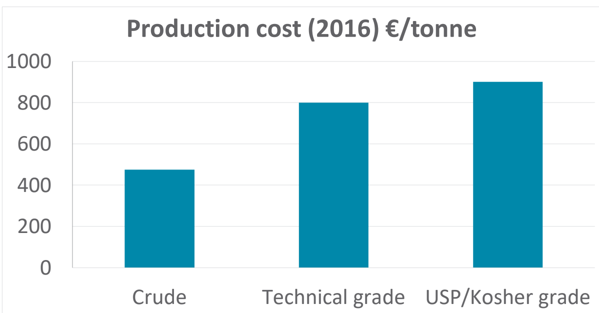
Year: 2014

Supply (global):



Year:2009

Costs:



Opportunities and Barriers:

+ Large application portfolio available and competitively established (e.g. ECH)
+ Glycerol price fall due to biodiesel production opened up the field to new applications

- Supply independent from market demand (Biodiesel production), price is volatile
- Crude glycerol must be purified for many of its applications → higher costs

Figure 22: Glycerol case study summary

It is expected that going forward, the majority of biolubricants will be produced from vegetable oils (rather than animal fats) [10]. The two leading applications of biolubricants are expected to be in metalworking and in hydraulic fluids [10].

Barriers identified to bio-based uptake in the lubricants product group are as follows. There are certain 'generic barriers' such as feedstock availability and cost competitiveness of bio-based products with fossil equivalents, which are applicable to all product groups. These are covered in chapter 4 of the report. These generic barriers may be mentioned in the following table only if there is something very specific about the barrier for the lubricants product group. Otherwise they are not mentioned in the following table.

Table 19: Barriers to bio-based uptake in lubricants and proposed actions

Barriers	Actions	Actors	Timeline
The properties required for bio-based lubricants to be biodegradable lead to a low resistance to oxidation. This can be solved by additives, but these must also be biodegradable.	Foster collaboration between lubricants and additive developers (aligning commercial interests)	Government, industry	Short-mid term
	R&D into bio-based and biodegradable lubricant additives	Academia, industry, government	Short-long term
	Create regulation concerning biodegradability and sustainability of lubricant additives.	Policy makers	Short-mid term
Bio-based lubricants have been reported to have low temperature stability, unpleasant odour, and are incompatible with other ingredients	Highlight superior biodegradability characteristics and other benefits of bio-based lubricants	Industry	Short-mid term
	R&D to improve performance of bio-based lubricants, so that they are at par or outperform fossil-based lubricants	Government, industry, academia	Short-long term
For markets outside of Europe, lack of awareness and high price is limiting bio-based lubricant use	Promote uptake by establishing industry-to-industry links as well as industry-to-NGO links between Europe and other geographies	Industry, NGOs	Short-mid term
	R&D and trials of bio-based lubricants that are: – cheaper or available at the same price as fossil-based lubricants – equivalent or superior in performance compared to fossil-based lubricants	Government, industry, academia	Short-long term
Cost competitiveness of bio-based lubricants with fossil equivalents	Carbon tax, subsidizing bio-based products that have equivalent or superior performance compared to fossil-based lubricants, while taxing fossil equivalents (including tax on import of base oils)	Government, policy makers	Short-mid term
The terminology can be confusing for consumers. Sometimes "biolubricant" can refer to products derived from renewable sources or to a biodegradable lubricant derived from petroleum-based sources.	Clear labeling that informs the consumer whether the product is bio-based and biodegradable vs. biodegradable but fossil-based, and what (environmental) benefits bio-based lubricants have	Industry, government	Short-mid term

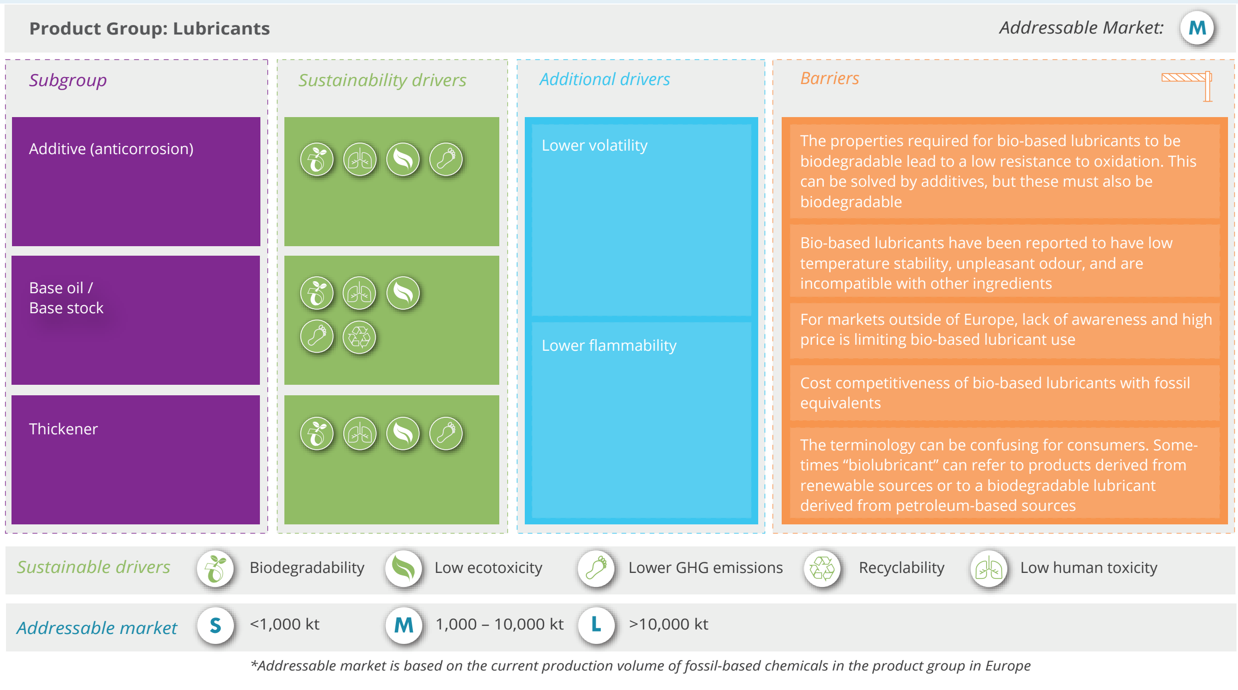


Figure 23: Pictorial summary of the lubricants product group

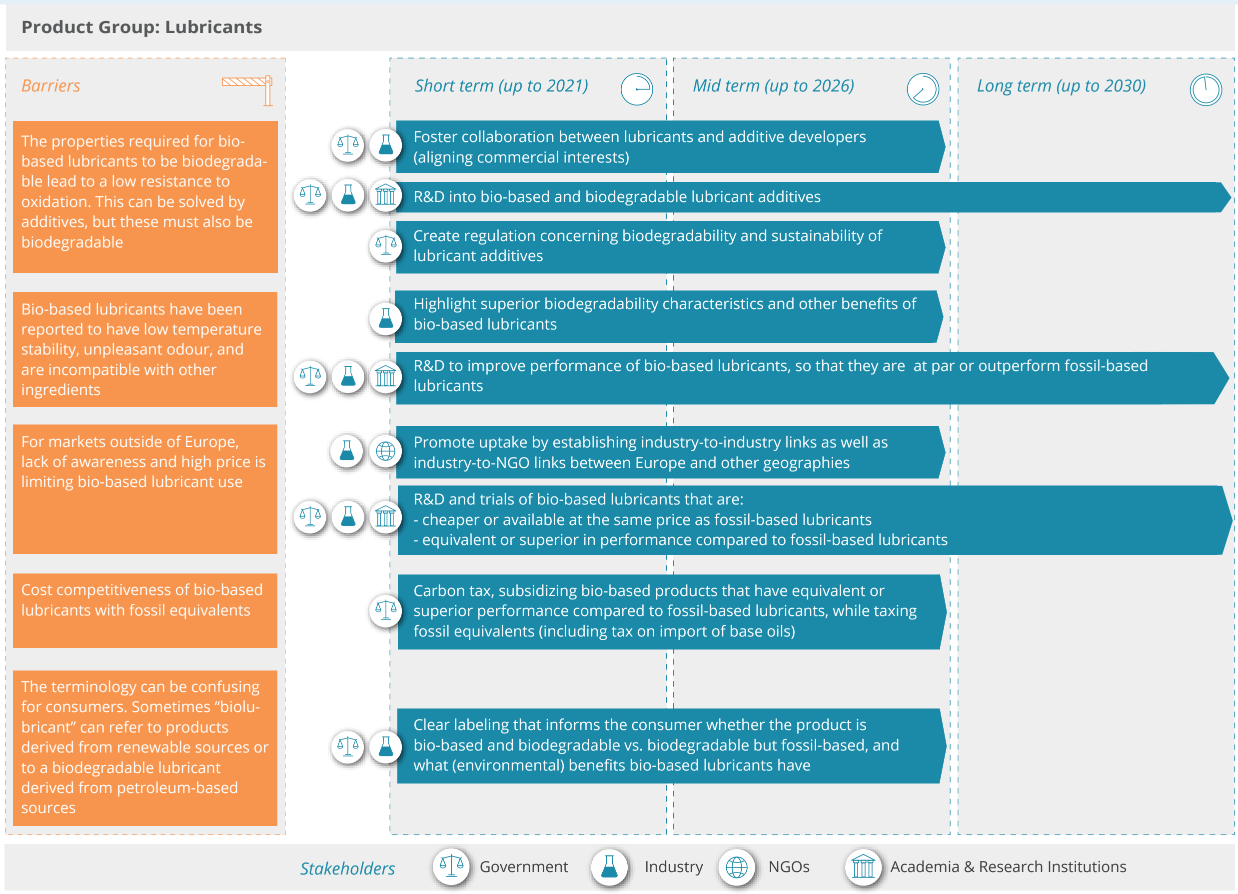


Figure 24: Roadmap to increasing the bio-based share of chemicals in the lubricants product group

3.5.4 Summary

- 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)

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3.7 Man-made fibres

3.7.1 Background

Man-made fibres account for 75% of all fibres produced worldwide, and for 81% in Europe, including Turkey. World production was 69.4 million tonnes in 2016. Depending on the reference year (2015 or 2016), European production was between 4.5 – 5.4 million tonnes [1,4]. Man-made fibres are synthetic fibres based on petrochemicals that dominate the market: polyester (72%), cellulosic, acrylics, polypropylene, polyamide, and elastane (28%) [3]. Their principal end-use is in clothing, carpets, household textiles and a wide range of technical products such as tyres, conveyor belts, fillings for sleeping bags and cold-weather clothing, filters for improving air and water quality, fire-resistant materials, and reinforcement in composites used for advanced aircraft production. Fibres are precisely engineered to give the right combination of qualities required for the end-use in question: appearance, strength, durability, stretch, stability, warmth, protection, easy care, breathability, moisture absorption and value for money. In many cases, they are used in blends with natural fibres such as cotton and wool [1].

Man-made fibres are classified as **organic** or **inorganic fibres**, and organic fibres can be derived by the transformation of **natural polymers** or from **synthetic polymers** [2].

Bio-based man-made fibres commercially available today

Commercially available **man-made cellulosic fibres** that are derived by the transformation of natural polymers are:

- **Viscose**
  Viscose, also known as rayon, is made from cellulose that is derived from wood pulp. It is the most common cellulosic fibre available and is used in manufacturing garments such

as t-shirts, tunics, shirts and dresses. It is also used for linings; in hygienic disposables such as baby wipes and medical dressings; and in reinforcing high speed tyres [2,5,6,7].

- **Modal**
  Modal fibres are derived from beechwood and are made by a modified viscose process. It is used in manufacturing baby and kids wear, lingerie, outerwear; blended with cotton for knits and towels. It can also be blended with spandex and other fibres [2,8,9,10,11,12].

- **Lyocell**
  Lyocell is the third generation of viscose fibres, marketed as Tencel® and is derived from eucalyptus trees. It is used in the manufacture of active wear, clothing for sensitive skin and home textiles such as bedding [2,12,13,35].

- **Acetate, triacetate**
  The term acetate fibres is used to describe fibres made from cellulose acetate. The difference between acetate and triacetate fibres lies in the number of the cellulose hydroxyl groups that are acetylated (75-92% for acetate fibres, >92% for triacetate fibres). Acetate fibres are mainly used in the production of clothing, lining, felts, upholstery, carpets, umbrellas, and cigarette filters. The staple acetate fibres are also used as partial substitutes for wool in the manufacture of fine fabrics and knitwear [2,14,15].

- **Alginate**
  Alginate is a natural polymer that exists widely in many species of brown seaweed. The biological function of alginates is to give strength and flexibility to the algal tissue and regulate the water content in the seaweed. These properties along with the ability to produce fibres from its isomers make Alginate ideal for dressing wounds [2,16].

- **Cupro**
  Cupro (Bemberg®) is a regenerated cellulose fibre derived from cotton linter that has been dissolved in a solution of ammonia and copper oxide. It is similar to rayon, but breathes and regulates body temperature like cotton [2,17,18].

Several man-made fibres are made of **organic 'synthetic polymers'** such as polyester (PET), polyamides (nylon), acrylic/modacrylic and propylene [2]. Biosynthetics are an emerging preferred fibre especially in clothing, footwear, and household brands and retailers due to their use of renewable resources [19]. Current commercially available biosynthetic fibres include:

- Fibres made from **PLA** (**polylactic acid**). PLA is composed of lactic acid which is produced by converting corn starch into sugar and then fermenting it to yield lactic acid. PLA products are comparable with PET. PLA can be blended with cotton as well as wool. Applications include development of improved sutures for medical purposes; in apparel (eg. Ingeo fibre made from PLA); in agricultural applications, wipes, diapers, carpet backing, and compostable geotextiles [19,20,21,22].

- Fibres made from **partially bio-based PTT** (**polytrimethylene terephthalate**). Partially biobased PTT is commonly assigned to the polyester family; however its strict generic class in the United States, awarded by the Federal Trade Commission, is Triexta (a generic class in Europe is currently pending). PTT is made up of two monomer units, 1,3-propanediol and purified terephthalic acid (PTA). A partially bio-based polymer is possible where the 1,3-propanediol is derived from annually renewable plant-based resources (**Bio-PDO**; from corn or other biomass). In the case of DuPont™ Sorona®, the polymer is made up of 37% annually renewable plant-based resources by weight. The end polymer is extruded via a melt spinning process. DuPont™ uses a proprietary polycondensation polymerization process in the production of Sorona®. Bio-based PTT can replace conventional polyester (PET) and Nylon 6 (PA6) in fibre applications [19, 23, 24].

- **Partly bio-based PET (polyester)** is produced commercially by using bio-based monoethylene glycol (MEG) [19,25] MEG constitutes 30% by weight of PET [26]. PET is widely used as material for FMCG containers as well as textiles and fibres [25]. Bio-based PET was majorly used in bottles and accounted for 86.4% of market volume in 2015 [27]. Avantium's project Mekong is a one-step hydrogenolysis process for making a drop-in renewable mono-ethylene glycol (MEG) from glucose. The process is competitive with fossil-based MEG and will address the need for making a greener PET an economic reality [28]. 100% bio-based PET was produced at demonstration scale in 2015 by Virent (in collaboration with Coca Cola), and is the focus of research for Anellotech (funded by Toyota Tsusho) and Origin Materials (in partnership with Danone and Nestle Waters) [29] The end application for 100% bio-PET at this stage is focused on bottles for beverages as the investment is mainly coming from companies such as Coca Cola, Danone, and Nestle Waters. However, Toyota has been exploring the use of bio-PET in vehicles (such as seats, carpets) and apparel along with bottles [30]

- **PA11 (Nylon/Polyamide 11)** is 100% bio-based as it is made from castor oil (sebacic acid) [19,31,32]. Arkema is a global producer of Rilsan®PA11 which is claimed to be the only high performance 100% biosourced polyamide to qualify for the most exacting applications in particular in the electronics, 3D-printing and automotive markets, where it serves as a metal substitute [31]. French spinner

Sofila has used Arkema's Rilsan® PA11 to make Greenfil fibre which is used for making socks [33].

- **Bio-based alternatives to PA6,10 and PA10,12**: Raw materials required to produce PA6,10 are castor oil and 1,6-hexanediamine [34]. It is partly bio-based as 1,6-hexanediamine is still derived via petrochemical route [34]. 1,6-Hexanediamine can be made from bio-based route, but not currently the case for PA6,10 production [34]. Key applications are in monofilaments (used in brushes and filter systems), and automotive applications [34]. PA10,12 is made from castor oil, and has characteristics similar to PA11 and PA12. It is used in automotive and industrial applications [34].

3.7.2 Drive for bio-based market growth

Man-made fibres made of natural polymers i.e. **man-made cellulosic fibres** such as viscose and lyocell have been commercially produced and are in use because of:

- Their functionality (e.g. Lyocell is used for the manufacture of active wear, clothing for sensitive skin and home textiles such as bedding [2,12,13]
- Starting feedstock is renewable, although the process that follows to make it into a usable fibre involves the use of numerous chemicals [2]
- These fibres are biodegradable [7,10,35,36,18,37]

In addition to renewable feedstock, commercially available biosynthetic man-made fibres are in use for several reasons as listed below:

PLA fibres uptake in medical applications such as sutures and implants is attributed to its compostable and resorbable characteristics [22]. The current market for this application is dominated by non-degradable polyester fibre Dacron® [22,38]. The compostable quality of PLA also makes it suitable for the manufacture of geotextiles that are permeable nonwoven fabrics used to separate, filter, reinforce, protect or drain [39]. Fossil-based raw materials that are currently used to manufacture geotextiles are polyester, polyamides, polypropylene and polyethylene [40]. In terms of cost, bio-based production of lactic acid is cheaper than fossil-based lactic acid [41].

Partly bio-based PTT is in use as it can replace conventional polyester (PET) and Nylon 6 in fibre applications [23,19,24]. The market is well established and is expected to grow due to very good market acceptance [42].

Partly bio-based PET (30% bio-based): The mechanical and thermal properties of BioPET are similar to other oil-based PET products [26]. Tests have shown that BioPET can be easily processed and that it is an equivalent substitute of fossil-based PET [26].

PA11 is a 100% bio-based specialty polyamide. It is used on a commercial scale to deliver functional parts that exhibit mechanical properties such as elongation at break, impact resistance, fatigue behaviour, and elastic memory [43].

Table 20: Market growth for bio-based man-made fibres

Man-made fibres	Market growth		Comments
	CAGR %	Forecast period	
Natural polymers/ cellulosic fibres	9.1	2016-2025	The global man-made cellulosic fibre market was valued at USD 20.61 billion in 2015 and is expected to reach USD 48.37 billion by 2025 [44]. The market is mainly driven by the increasing demand of eco-friendly and biodegradable fibre [44].
Polytrimethylene terephthalate (PTT)	*Not specified*	2016-2023	Global PTT demand may increase owing to growing application scope in textile industry (especially carpets) [45]. Shift in preference for developing sustainable polymers from renewable resources owing to depleting petrochemical reserves is likely to drive bio-PTT market [45]. Abundant availability of 1,3-propanediol from glycerol (biodiesel by-product) may positively influence bio-PTT market over the forecast period [45].
Bio PET	44.2	2015-2023	Global bio PET market size was estimated at 496 kt in 2015 and is projected to reach 6.74 million t by 2023 [46]. A large volume of this polymer will go towards packaging (bottles).
High performance polyamides (incl. PA11, PA12)	7.5	2016-2021	The market size for this group is estimated to reach USD 2.51 billion by 2021 [47]. The combined market for PA11 and PA12 is 100,000 t annually [48].

The overall market growth for bio-based man-made fibres is therefore based on the growth forecasted for natural fibres (cellulosics) and bio-synthetic polymers such as bio PET. Table 20 provides details on market growth forecasted by different reports for some of these man-made fibres.

Sustainability in the man-made fibres industry

The man-made fibres industry has been pursuing sustainability initiatives globally such as their adoption and application of the *Responsible Care Programme* [49]. The European man-made fibres industry, represented by CIRFS, supports the fact that man-made fibres production processes and products should be sustainable from cradle-to-cradle, including use and end-of-life [49]. Further, the impact on the environment should be reduced to a minimum [49]. The key elements that have been identified are:

- **sustainably sourced feedstock**
  This applies to both natural and synthetic polymers. In case of natural polymers, FSC certification (Forest Stewardship Council) is an indication of sustainably sourced wood and therefore cellulose [50]. In case of synthetic polymers, there is a drive from the industry to recycle existing products that have reached end-of-life in order to serve as feedstock for new products. For e.g. Aquafil has been recycling discarded fishing nets that leads to PA6 fibres which is then used in textile manufacture [51]. Aquafil and Genomatica recently announced a multi-year agreement to create sustainable caprolactam, a key ingredient to producing 100% sustainable nylon [52]. This will be used for apparel and carpets [52]. Another example is that of the collaboration between Coca-Cola and Ford Motor Company to use bio-PET (30% bio-based) for fabric interior including seat cushions, backs, headrests, door panel inserts and headliners in their Fusion Energi plug-in hybrid demo vehicle [53].

- a **closed-loop manufacturing process** where chemicals that are used get recycled [54].

- **durability** of the product which is influenced by **how consumers use it.** For e.g. in case of textiles, the detergent and softeners used, and temperature at which the wash cycle is set play a role in the wear and tear of the garment [55]. This in turn determines **how long the product can stay in use before being disposed**.

- **proper disposal** of products containing man-made fibres so that **raw material can be recovered** and sent back into the manufacturing process [56]. In case of textiles, several brands have launched “take back” schemes wherein consumers can deposit old clothes at specified locations which then get recycled [57,58,59].

There is **no policy or legislation** where man-made fibre producers have to reduce waste/ increase recycling and/ or increase use of sustainably sourced feedstock within a certain time period. Sustainability adopted so far has been consumer and producer driven. Some textile brands have suggested that although a set target for waste reduction or recycling is beneficial, what would make a difference is:

- Investment in innovation around sustainable fibres for multiple applications as well as recovering fibres from blended fabrics [60]. The issue of ‘microfibres’ being shed from fabric during wash cycles and their entry into the ecosystem also needs further research [61].

- possible policy intervention via the ‘Extended Producer Responsibility’ (EPR) wherein the producer will be responsible for discarded garments/ products containing man-made fibres [60].

Other suggestions made by the CIRFS include:

- explore ways to recover PET feedstock from packaging material which currently is disposed in mixed waste streams [56].

- curb export of reusable waste such as PET bottles to non-EU countries so that the feedstock is available for use here [56]. As the proportion of bio-based PET bottles increases, it will be a loss of potential bio-based feedstock (for the European market) if these used PET bottles continue to be exported.

- promoting a ‘design for recycling’ approach [56]

In the RoadToBio project, the desired sustainability characteristics that are met/not met by selected bio-based man-made fibres and their fossil-based equivalents were assessed. The drivers of these sustainability characteristics were also assessed. These are summarised below.

Table 21: Desired sustainability characteristics of man-made fibres (bio-based/fossil) and their drivers

Product group	Desired sustainability characteristics	Drivers of sustainability characteristics
Man-made fibres	Recyclability, biodegradability	Customer and producer driven (voluntary) *(mainly producer driven)*

Table 22: Sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in the man-made fibres product group

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Synthetic polymers	Bio-based Nylon 6 (bio PA6) prepared from bio-based caprolactam *(bio-based alternative for fossil-based PA6)*	100	Smart drop-in					X	Potentially lower cost compared to fossil-based PA6. Also, lower toxicity as no ammonium sulfate or NOx byproducts. Theoretically, bio-based PA6 should be recyclable like fossil-based PA6. In Jan 2018, US biotech Genomatica has signed a multi-year agreement with Italian nylon producer Aquafil to create sustainable caprolactam	6-7
Synthetic polymers	Bio-based poly(trimethylene terephthalate) (bio-PTT) prepared from bio 1,3-PDO and fossil PTA *(bio-based alternative for fossil-based PA6 and PET)*	27-37	Smart drop-in			X		X	DuPont's Sorona® bio-PTT polymer production uses 30% less non-renewable energy and reduces GHG emissions by 63% compared to production of equal amount of Nylon 6. It is claimed to be cost competitive. Properties of PTT surpass PA6 and PET in fibre applications. Research shows that carpet fibre made with Sorona® can be removed from the carpet backing and recycled at the end of its useful life. However, existing carpet recycling facilities do not accept PTT fiber for recycling today.	9
Synthetic polymers	Nylon 11 or PA11 *(bio-based alternative for fossil-based PA6,6)*	100	Dedicated					X	French spinner Sofila has used Arkema's Rilsan® PA11 to make Greenfil fibre which is used for making socks. PA11 feedstock is castor oil (sebacic acid).	9
Synthetic polymers	Bio-based Nylon 6,6 (bio PA6,6) using bio-based adipic acid and bio-based hexamethylene diamine (HMDA) *(bio-based alternative for PA6,6)*	100	Smart drop-in					X	Rennovia had claimed that production costs for both bio-adipic acid and bio-HMDA were projected to be 20-25% below that of conventional fossil-based adipic acid and HMDA with a significantly lower per-pound capital cost. Rennovia filed for bankruptcy in 2017 so current claim on this advantage is not clear. However, Genomatica is still working on bio-based adipic acid and HMDA.	6-7

Key: B=Biodegradable, LHT=Low human toxicity, Low GHG=Low greenhouse gases, LE=Low ecotoxicity, R=Recyclability

Note: The chemicals/products selected for the analysis are representative of the product group and do not cover the full spectrum of chemicals/products. These representative chemicals/products 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.

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Synthetic polymers	Bio-based Nylon 6,10 (PA6,10) using bio-based sebacic acid and fossil HMDA *(this is conventional method of PA6,10 production)*	60 *(100% is possible)*	Dedicated						60% bio-based PA6,10 is commercially produced by companies such as BASF, Solvay, Distrupol. 100% bio-based PA6,10 is possible using bio-based sebacic acid and bio-based HMDA but is still not produced in this way. Bio-based HMDA is being manufactured by Genomatica but not at commercial scale	9
Synthetic polymers	PA 6,12 *(commercial scale production is already part bio-based)*	60 *(100% is possible)*	Dedicated						Example of 60% bio-based PA 6,12 that is commercially available: Radilon® DT 40EP25W 100% bio-based PA6,12 is possible using bio-based HMDA and bio-based DDDA but is still not produced in this way.	9
Synthetic polymers	100% bio-based PLA *(bio-based alternative for fossil-based PET)*	100	Dedicated	**X**[15]					PLA is not recyclable. Therefore, there is an issue with recycling PLA with PET recycling stream. FIBFAB H2020 project is focusing on industrial application of PLA fibre (2017-2019)	6-7 (for fibre)
Synthetic polymers	Partially bio-based PET using bio-based monoethylene glycol (MEG) *(bio-based alternative for fossil-based PET)*	30	Drop-in			**X**		**X**	Commercially produced for partially bio-based PET bottles used by Coca Cola. Application of this bio-based polymer in the fibre market has been demonstrated by the Ford Motor Company where the polymer has been used for fabric interior including seat cushions, backs, headrests, door panel inserts and headliners in their Fusion Energi plug-in hybrid demo vehicle.	9 (for bottles) 6-7 (for fibre)
Synthetic polymers	Bio-based PET *(bio-based alternative for fossil-based PET)*	100	Drop-in					**X**	Demonstration scale production for Coca Cola using bio-based p-Xylene from Virent. The process involves bio-based MEG (from sugarcane ethanol) and BioFormPX (-xylene) from beet sugars. p-Xylene accounts for 70% of PET by weight.	6-7

15 PLA is not biodegradable under normal conditions. However, it is compostable in a controlled industrial compost facility.

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Synthetic polymers	Waste methane-based PHAs (polyhydroxyal-kanoates) *(bio-based alternative for fossil-based PET and polypropylene)*	100	Dedicated	X				X	Bio-based PHAs from waste biogas via a microbial process has demonstrated by Mango Materials. Properties of PHAs are similar to polyester and polypropylene. PHAs are biodegradable unlike PET and polypropylene.	6-7
Synthetic polymers	PTF (polytrimethylene furandicarboxylate) is a novel polyester made from FDME (furan dicarboxylic methyl ester) and Bio-PDO™ (1,3-propanediol) *(bio-based alternative for fossil-based PET)*	100	Dedicated					X	Current focus of DuPont for PTF is in production of bottles as PTF has 10-15 times the CO_2 barrier performance of traditional PET plastic. However, PTF can be used for fibre and engineering polymer production as well.	5
Synthetic polymers	PEF (polyethylene furanoate) using bio-based 2,5-furan-dicarboxylic acid (FDCA) and bio-based MEG *(bio-based alternative for fossil-based PET)*	100 *(70 if fossil MEG is used)*	Dedicated			X		X	PEF can be used for mak-ing fibre for carpet facing and textiles. 25% of PEF is used for fibre applica-tion. Based on patent application filings, Toray is the leader in using PEF in fibre applications, followed by P&G and DuPont. Production of PEF from FDCA has environmental advantages, reducing the non-renewable energy use by 51-58% compared to PET, and producing GHG emissions of 1.4 – 2.1 tCO_2/ t-product compared to fossil PET emissions of 3.8–4.4 tCO_2/ t-product (a saving of ~60%). PEF is produced at pilot scale by Avantium using the 'YXY' technology.	7
Synthetic polymers	Bio-polypropylene using used cooking oil or sustain-ably sourced vegetable oils *(bio-based alternative for fossil-based polypropylene)*	20	Drop-in					X	There is a nascent market for bio-based polypropyl-ene but the focus appears to be on packaging and commodities like furniture (e.g. collaboration be-tween IKEA and Neste in June 2018)	7-8

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Synthetic polymers	Partly bio-based elastane fibres using polytetramethylene ether glycol (PTMEG) *(bio-based alternative to fossil-derived elastane)*	70	Smart drop-in			X		X	Bio-based 1,4-BDO (via glucose-derived succinic acid) is converted to tetrahydrofuran (THF) used as a monomer in the production of PTMEG, which is used in the manufacture of polyurethane fibres (Spandex), cast and TPU elastomers, and high-performance copolyester-polyether elastomers. These materials are used in various sectors such as clothes, sportswear, automotive, aviation. Cost of production of bio-based 1,4-BDO via fermentation is 15-30% lower than fossil and competitive at low oil prices of $45/bbl range. Bio-based BDO can offer significant GHG emissions savings compared to the fossil route (~70%). EC-funded project ECO-LASTANE validated the following products: Samples of formulated polymer chips and extruded and spun synthetic fibre monofilament of 70% bio-based elastane and 100% bio-based polyester. Invista's bio-based Lycra (elastane) is derived from bio-based 1,4-BDO which uses corn as feedstock.	7
Natural polymers	Cellulose-based fibres: Viscose, lyocell, modal, acetate/triacetate, cupro *(commercial scale production has always been bio-based)*	100	Dedicated					[16]	Producers are focusing on making the supply chain more sustainable. This includes sustainable sourcing of feedstock (FSC certified wood for cellulose production), closed-loop production process (as seen in lyocell fibre production), reducing quantity of used fabric entering landfill. Recycling of natural fibres, including cellulose fibres, is now being done at demo scale using the re:newcell chemical recycling method. However, this is not done globally today and most cellulose fibres end up in landfill	9

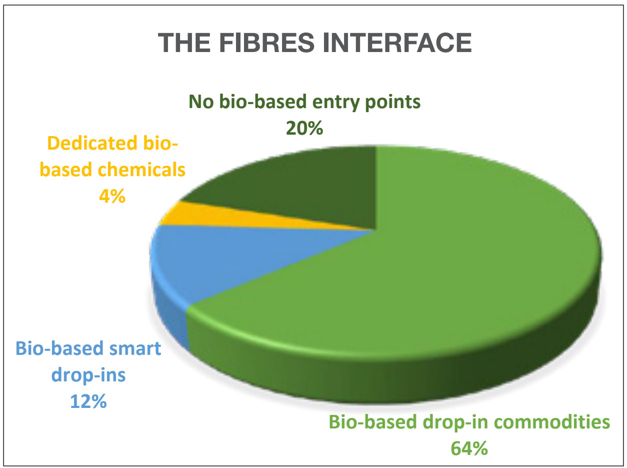
16 Recycling of natural fibres, including cellulose fibres, is now being done at demo scale using the re:newcell chemical recycling method (https://renewcell.com/). However, this is not done globally today and most cellulose fibres end up in landfills

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Natural polymers	Algae-derived fibres (from brown seaweed): alginate *(commercial scale production has always been bio-based)*	100	Dedicated		[17]				US-based AlgiKnit make bio-yarn from macroalgae such as seaweed and kelp via the biopolymer alginate. The recently completed EU 7^{th} Framework project MIRACLES was an industry driven R&D&I project that aimed at developing economically feasible biorefinery concepts for production of specialties from microalgae, such as biopolymers. The focus was on thermoplastics *Solanyl*® and thermosetting materials *Touch of nature*® but opens the prospect for investigating the use of such biopolymers in man-made fibre production	9

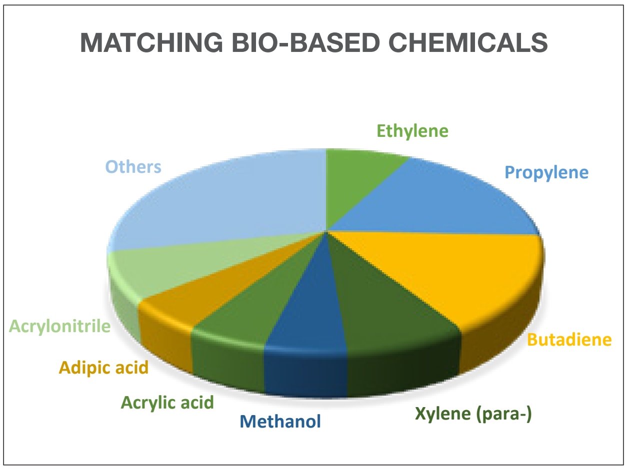
17 Alginate biopolymer is non-toxic and used for wound dressing

3.7.3 Opportunities and barriers

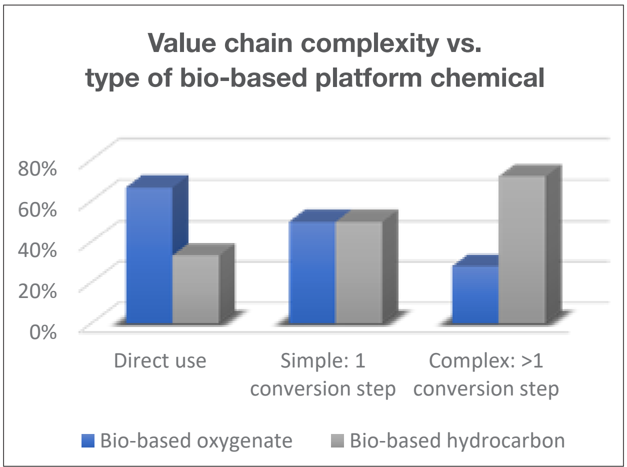
D1.1 of the RoadToBio project identified pathways to higher bio-based share within man-made fibres via the use of drop-in chemicals in the production process of these fibres. Following is a summary of the results from D1.1 [4].



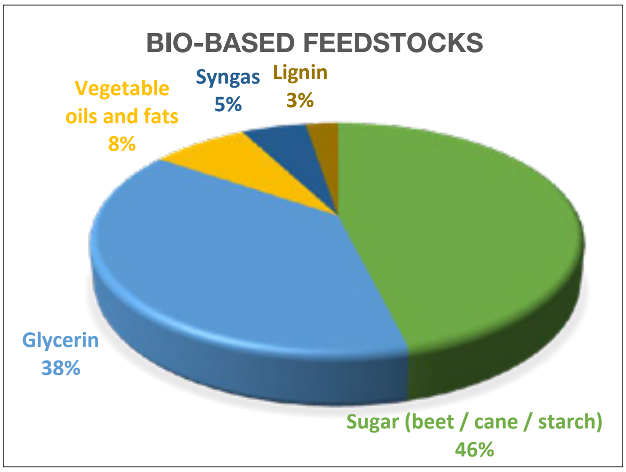
25 petrochemical man-made fibres were analysed; at least one potential entry point for a bio-based chemical in the value chain was identified for 80% of them, the majority being drop-in commodities.



19 different bio-based chemicals could enter these value chains at 39 potential entry points that were found. No single bio-based chemical stood out as far as with other product groups; propylene and butadiene were the most common options.



The bio-based chemicals that could be directly used were in this case all polymers, so in this case it was difficult to compare the remaining complexity of the value chains after the bio-based chemical entry. Some specific examples such as adipic acid were able to reduce the value chain complexity



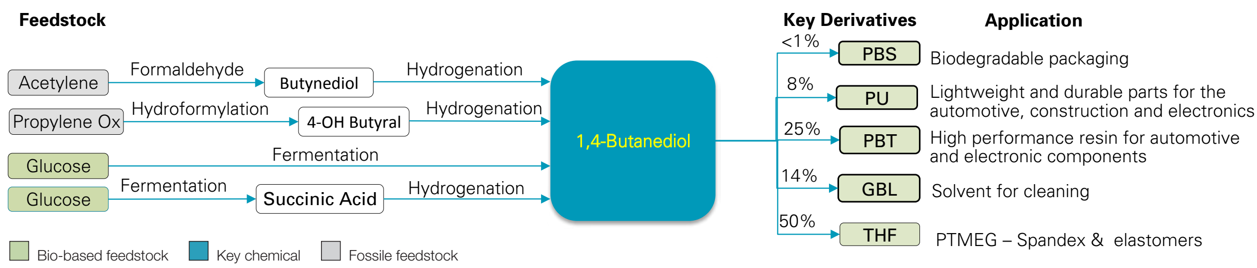
The main feedstock platforms that can currently provide these fibres are the sugar platform and the glycerine platform. Again the already bio-based options (e.g. cellulosic fibres) were out of scope.

Figure 25: Opportunities for higher bio-based share in man-made fibres via use of drop-in bio-based chemicals in the production process

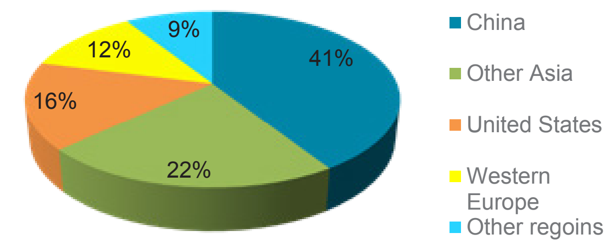
In addition to identifying bio-based chemicals and their potential entry points in 9 product groups, the RoadToBio project also includes an analysis of nine potentially attractive business opportunities (“sweet spots”) for the European bio-based industry (D1.2) [41]. One of the 9 chemicals that was analysed in-depth was bio-based 1,4-butanediol (1,4-BDO) which is a smart drop-in chemical mainly used in the manufacture of Tetrahydrofuran (THF) [41]. THF is used as a monomer in the production of PTMEG (Polytetramethylene Ether Glycol), which is used in the manufacture of polyurethane fibres (Spandex), cast and TPU elastomers, and high-performance copolyester-polyether elastomers [41]. These materials are used in various sectors such as clothes, sportswear, automotive industry, and aviation. 1,4-BDO was covered in D1.2 of RoadToBio and following is a summary of the analysis [41]. Please note that this chemical is not the most representative of the man-made fibres product group, but one that was covered in-depth in D1.2 and selected here due to its relevance to this product group.

Market Volume EU: (ktonne/yr)	Market Volume Global: (ktonne/yr)	Price: (€/tonne)	Market growth rate: (%/yr)
Total: 240 Bio-based: 30 Source: Novamont (2017) capacity, not yet production, Novamont	Total: 2,000 Bio-based: 30 Source: Technon OrbiChem (2016) capacity, not yet production, Novamont	1,750 Source: ICIS (June 2017)	7.7 Source: Grand View Research (2018)

Value chain:

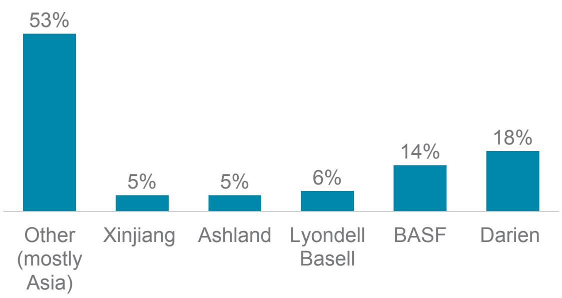


Demand:

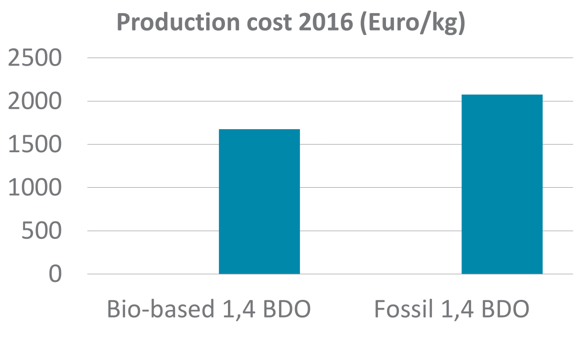


Year: 2016

Top suppliers (global):



Costs:



Opportunities & Barriers:

+ Bio-based route has significant reduction of GHG emissions
+ Bio-based 1,4 BDO is cost competitive at industrial scale
+ Growing demand for sustainable fibre in Europe and US

- 1,4 BDO price is still affected by supply/demand balance
- Bio-based 1,4 BDO is not produced at commercial scale

Figure 26: 1,4-butanediol case study summary

Focus so far for commercial production of biosynthetic fibres has been on 1G (first generation) feedstocks such as starches, sugars, and lipids derived from corn, sugarcane, sugar beets, and plant oils. [1] Various technologies are under development to produce biosynthetic fibres from 2G feedstocks (second generation) such as biomass and waste from agriculture, forestry, food waste; and 3G feedstocks (third generation) such as algae, fungi, enzymes, and bacteria. [1] While many of the alternative feedstocks have been piloted at concept level, they are not yet commercially available. [1]

Barriers identified to bio-based uptake in man-made fibres are as follows. There are certain 'generic barriers' such as feedstock availability and cost competitiveness of bio-based products with fossil equivalents, which are applicable to all product groups. These are covered in chapter 4 of the report. These generic barriers may be mentioned in the following table only if there is something very specific about the barrier for the man-made fibres product group. Otherwise they are not mentioned in the following table.

Table 19: Barriers to bio-based uptake in man-made fibres and proposed actions

Barriers	Actions	Actors	Timeline
Competing with established, low cost fossil-based man-made fibres	Further R&D and demonstration for manufacturing man-made fibres from cheap and novel feedstocks, as well as using cost and energy efficient production processes	Industry, government, academia	Short-long term
	Bio-based polymers to be used as alternative materials to conventional fossil-based materials, for materials that show added sustainability benefits across the supply chain	Industry	Short-long term
	Incentivise the drive to commercialise bio-based fibre products that outperform sustainability characteristics of fossil-based fibres	Industry, government, NGOs	Mid-long term
Bio-based polymer-derived man-made fibres may not be recyclable with the regular recycling stream.	R&D to develop bio-based plastics that are recyclable with regular recycling stream.	Industry, government, academia	Short-long term
	Public awareness campaigns on recycling of man-made fibres (bio or fossil-based) instead of landfilling or incineration	Industry, government, NGOs	Short-mid term
Limited (but growing) public awareness about efficiency and performance of bio-based polyester and nylon products	Public awareness campaigns and development of consumer engagement hubs as done by the Textile Exchange	Industry, government, NGOs	Short-mid term
A large portion of post-consumer man-made fibres waste (bio or fossil-based fibres) are landfilled or incinerated	Integrate thinking about end-of-life treatment and alignment with the circular economy in the product design of bio-based fibres	Industry, government, academia	Short-long term

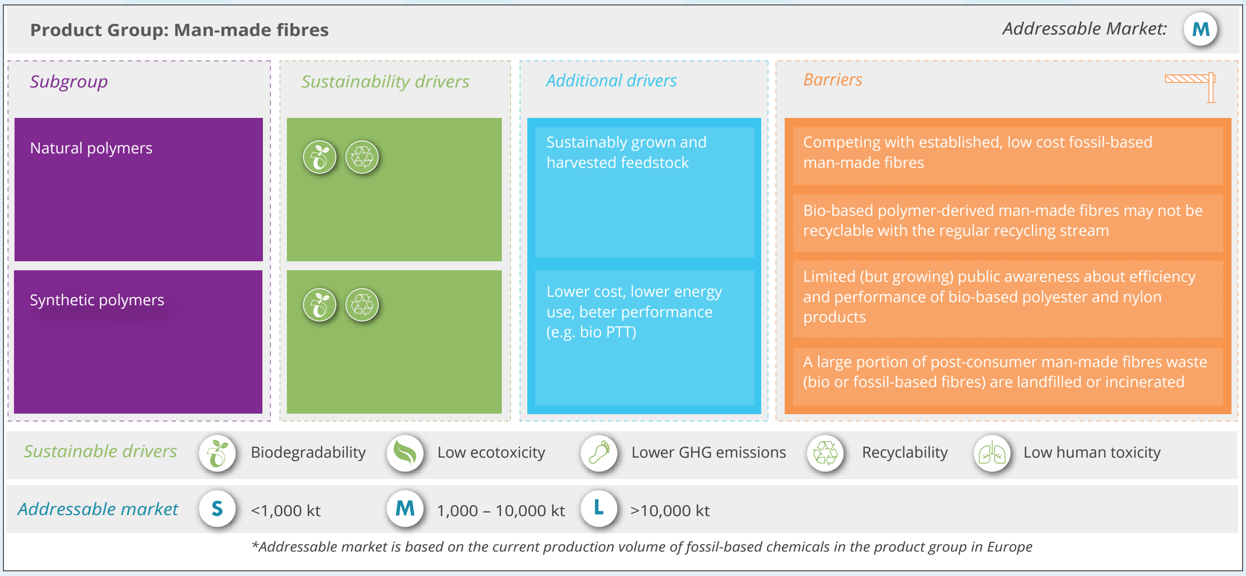


Figure 27: Pictorial summary of the man-made fibres product group

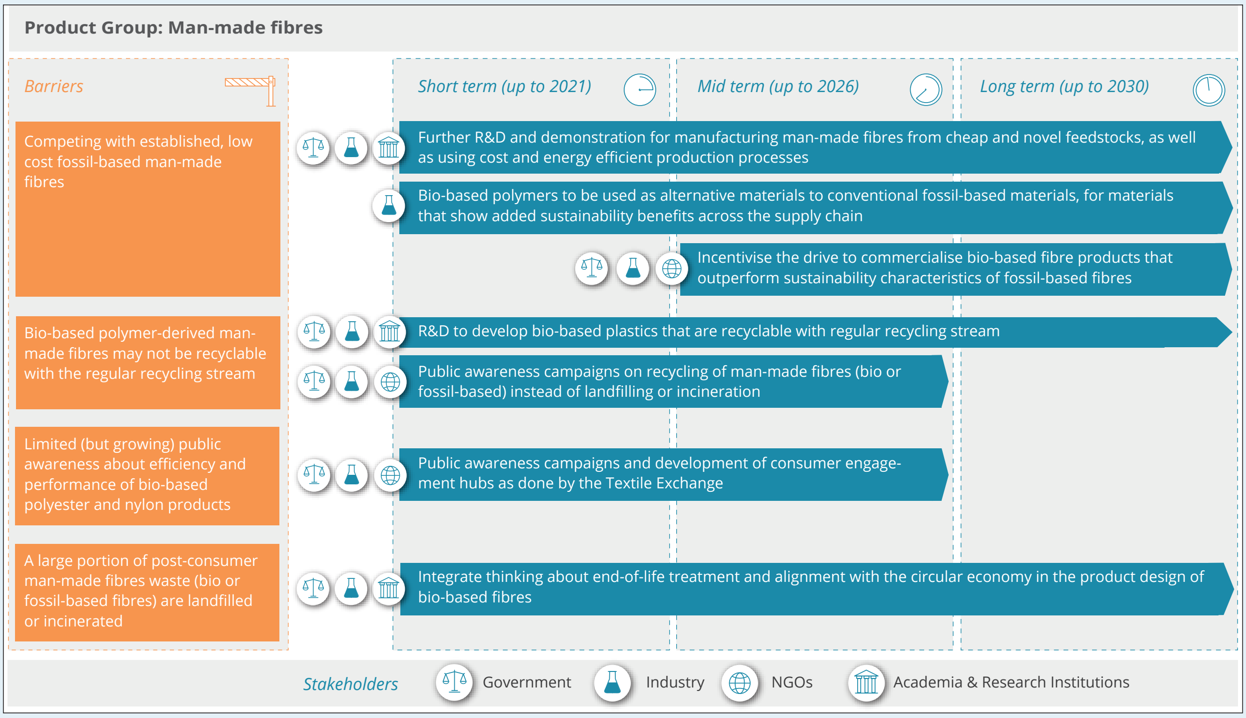


Figure 28: Roadmap to increasing the bio-based share of chemicals in the man-made fibres product group

3.7.4 Summary

- Bio-based man-made fibres production in Europe is >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 (TENCEL™), AlgiKnit

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3.8 Solvents

3.8.1 Background

Solvents are used widely in coatings, adhesives, industrial and domestic cleaning products, and many types of manufacturing [1]. The purpose of the solvent in a formulation or process is to dissolve other substances, either to allow them to mix and perform their function effectively (e.g. to disperse the pigment in a paint) or remove them from a surface (e.g. a paint stripper). The principal reason why solvents are of great environmental concern is that they are used in vast quantities. Solvents account for about 80–90% of the total mass used in any organic reaction. The industry depends on solvent-based organic synthesis, but it is difficult and expensive to dispose safely of the ocean of waste solvent left behind [2].

Having a low environmental impact is necessary for a product or process to be sustainable, but it is not on its own sufficient for it to be so; it must also be a commercial success [3]. There are a number of examples of technically excellent processes that have been introduced, only later to be withdrawn due to commercial pressures [3].

Important sectors where solvents are used include paints and pharmaceuticals [4]. The solvent is often the major component of a formulation, a reaction, or an extraction [4]. Therefore, a significant shift from non-renewable chemical dependence can be achieved with the use of bio-based solvents. The choice of solvent has a strong influence on the rate of reactions and substrate solubility, and the role of a solvent in a paint or coating formulation is different to that of a solvent used to facilitate the synthesis of an active pharmaceutical ingredient [4]. Because of this, many different solvents are used across a variety of applications, and a large diversity of bio-based solvents is required [4].

3.8.2 Drive for bio-based market growth

The current solvent market is ~ 20 million t/yr and worth tens of billions of US dollars annually to the global economy [4]. European solvent production provides about 25% of the worldwide market, with annual bio-based solvent use in the EU projected to grow to >1 million t/yr by 2020 [4].

According to Allied Market Research, the bio-based solvents market is expected to register a CAGR of 4.3% in the period of 2015–2020 [5].

There is a range of bio-based solvents derived from corn, soyabean and other renewables that are currently used in the market either as drop-in or dedicated replacement of the fossil derived solvents. These include:

n-Butanol, ethanol, ethyl lactate, butyl acetate, isopropanol, isobutanol, ethylene glycol, some derivatives of levulinic acid, cyrene, glycerol [6,7,8,9].

Driven by government regulations and concerns regarding environmental preservation and depletion of natural resources, the bio-based solvents industry has faced an exponential rise in demand and a push towards the development of innovative green solutions [1]. These solvents, among which bio-acetone and bio-ethanol, are an effective and low-cost alternative to conventional solvents [1].

Generally, uptake of bio-based solvents is driven by the EU policy on VOC emissions and by REACH [4,10,15]. Those bio-based alternatives which meet the criteria of low toxicity and low VOC, comparing to the fossil counterpart, are likely to be considered as valid alternative providing that they meet the functionally requirements of the solvent in specific applications.

In other cases, bio-based solvents are being used as an alternative to petrochemical solvents in those applications or industries where renewability is a strong driver, providing that safety and performance criteria are met by the bio-based solvent.

There are useful tools such as the solvent selection guide and interactive tool developed by the CHEM21 consortium for classical and less-classical (including bio-derived) solvents, including its formulation and scope [11]. User can also rank a solvent not included in the list according to the guidelines outlined in the CHEM21 publication [11].

Members of the European Solvents Industry Group (ESIG) have been contributing to the standardisation process at the European level, working with policymakers and other stakeholders to develop evidence-based frameworks [12]. The European Committee for Standardization (CEN) published the first product standard for bio-based materials (EN16766:2017: Bio-based solvents – Requirements and test) in November 2017 [12]. Each country taking part in the CEN had to implement it at national level by publishing an identical national standard or by endorsement by May 2018 [12].

The European Commission, which financially supported the development, strongly encourages public procurers and industry to use this standard and its referenced test methods for biological content and sustainability [12].

In the RoadToBio project, the desired sustainability characteristics that are met/not met by selected bio-based solvents and their fossil-based equivalents were assessed. The drivers of these sustainability characteristics were also assessed. These are summarised below.

It must be noted, that for solvents, apart from the desired sustainability characteristics, solvent performance is the most important requirement that a bio-based solvent will have to meet, as it is the key determining criterion in choosing a solvent for a specific application. Solvent selection is system-dependent, the solvent must meet both the performance criteria of the product and be suitable for the desired method of application. Solvent performance is characterized by the physical properties of the solvent itself, as well as by the resulting physical properties of final formulation. Solvent replacement is not a straightforward process. In general, replacements will have both advantages and disadvantages that should be taken into consideration. In the end, the best solvent system for a desired application must always be based on specific application trials.

Table 24: Desired sustainability characteristics of solvents (bio-based/fossil) and their drivers

Product group	Desired sustainability characteristics	Drivers of sustainability characteristics
Solvents	Low human toxicity, low ecotoxicity, biodegradability, recyclability	*Legislations*

For products that are likely to end up in the environment, complete biodegradability is a relevant sustainability characteristic. 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 characteristic.

The bio-based solvents identified as potential replacements for fossil-based solvents have to be considered as representative examples from evidences and claims found from desk research. As such they refer to its performance in specific applications (see references for Table 25 at the end of the chapter) and, therefore, indicate an opportunity for bio-based solvents. However, it must be noted that further investigation, on a case by case basis, is required to verify that the replacement of fossil-derived solvents with bio-based solvents is technically feasible and economically viable or can be further generalised to applications in which the same bio-based replacement and conventional solvent are considered.

Table 25: Sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in the man-made fibres product group

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Hydro-carbons	Bio-based xylene *(bio-based alternative for xylene)*	100	Drop-in	X				X		6-7
Hydro-carbons	D-Limonene *(identified as bio-based alternative for xylene)*	100	Dedicated	X	X	X	X	X	In terms of performance, D-limonene is the next best substitute for xylene. But these solvents still retain some level of toxicity, their odours may become overpowering during prolonged exposure and they can be incompatible with some of the mounting media. D-Limonene solvents also dry very slowly compared to xylene and they often leave an oily residue.	9
Hydro-carbons	Bio-based toluene *(bio-based alternative for toluene)*	100	Drop-in	X				X	**LHT and LE are desired sustainability characteristics**, however toluene does not fulfil this requirement.	6-7
Hydro-carbons	Bio-based *n*-propyl propionate *(identified as bio-based alternative for toluene in some coating applications)*	100	Dedicated	X	X[18]		X	X	*n*-Propyl propionate is a low-odour, medium-evaporating, non-HAP[19] ester solvent with has shown good solvency and versatility in some coating applications. In particular, *n*-propyl propionate was selected as the primary replacement in a two-component polyurethane clearcoat formulation. **LHT and LE are desired sustainability characteristics**, however toluene does not fulfil this requirement. On the other hand, *n*-propyl propionate (fossil or bio-based) enables preparation of lower VOC coatings.	6-7
Oxygenated	Bio-based ethanol, D-limonene *(identified as bio-based alternative for n-hexane as extraction agents in some applications)*	100	Dedicated	X				X	For instance, ethanol and D-limonene have been reported as good performing extraction agents of triglycerides in rapeseed oil extractions.	9

18 Fossil or bio n-propyl propionate helps in the preparation of lower VOC coatings

19 HAP = Hazardous Air Pollutants

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Oxygenated	Bio-based 2-methyltetrahydrofuran (MeTHF) *(identified as bio-based alternative for n-hexane as extraction agent in some applications)*	100	Dedicated	X	X[20]	X		X	MeTHF was selected and experimentally compared to *n*-hexane in terms of yield, selectivity, kinetics, energy consumption and economic impact. This aim was achieved with good results, at both lab scale and pilot scale, in terms of oil quality, extraction quality and extraction speed. There are good indications that the substitution might not induce a significant operating overcost. MeTHF can, as well, serve as a substitute for some chlorinated solvents in some applications. Manufactured by Pennakem Europa SAS.	9
Oxygenated	Bio-based acetone *(bio-based alternative for acetone)*	100	Drop-in	X				X	Green Biologics is the largest commercial supplier of renewable acetone (c3-one™) which is produced through fermentation of sugars from renewable feedstocks, resulting in a high purity, renewable solvent for personal care, extraction and coating applications. One shown advantage of bio-based acetone. in contrast to fossil-based acetone (via the cumene process), is that it is produced free of aromatics (benzene and phthalate free).	9
Oxygenated	Bio-based methyl isobutyl ketone (MIBK) via bio-based acetone *(identified as bio-based alternative for fossil MIBK)*	100	Drop-in	X				X	Lower production cost (i.e. raw materials cost, process cost, etc.), of bio-based MIBK compared to to the petroleum-based method.	9
Oxygenated	VertecBio™ ELSOL® KTR2 *(identified as bio-based alternative for fossil MIBK)*	100	Dedicated	X		X	X	X	20 – 30% more efficient in viscosity reduction than MIBK	9

Key: B=Biodegradable, LHT=Low human toxicity, Low GHG=Low greenhouse gases, LE=Low ecotoxicity, R=Recyclability

Note: The chemicals/products selected for the analysis are representative of the product group and do not cover the full spectrum of chemicals/products. These representative chemicals/products 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.

Low VOC has not been listed as a separate sustainability characteristic. However, this is an important issue for solvents and is considered under 'low ecotoxicity' and 'low human toxicity'. Further, it should be noted that solvents can be recovered and recycled in some sectors and applications but not in others.

There was no strong evidence in publicly available literature that solvents are driven by low GHG criteria. Other sustainability characteristics such as low toxicity (human and environment), recyclability and biodegradability are desired sustainability characteristics for both fossil and bio-based solvents. Where there was evidence claiming that the production process of a bio-based solvent resulted in lower GHG emissions compared to fossil routes, an 'x' has been recorded under 'Low GHG' for that solvent

20 It is reported that "a general limit of 20 mg/(kg•day) and a maximum concentration of 2% of MeTHF or (cyclopentyl methyl ether) CPME would not be expected to contribute to any toxicity potentially exhibited by an active pharmaceutical ingredient containing these solvents" (https://pubs.acs.org/doi/10.1021/op100303c)

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Oxygenated	Bio-based ethyl acetate, butyl acetate, *n*-butanol, isopropanol, ethanol, isobutanol *(identified as bio-based alternatives for fossil equivalents)*	100	Drop-in	X	X[21]		X[22]	X		6-7 (for ethyl acetate) 8-9
Oxygenated	Lactate esters *(identified as potential replacement for N-methyl-2-pyrrolidone -NMP-, acetone and others in custom blends and formulations for paint stripping and degreasing applications)*	100	Dedicated	X	X	X	X	X	Methyl lactate, ethyl lactate and butyl lactate are readily biodegradable and offer low toxicity and low VOC levels. As a result, they are easy to use and easy to dispose. Solvent for digital inks, coalescing agent for water-based paint.	9 (using 1G feedstock, 3-5 (using 2G feedstock)
Oxygenated	Bio-based ethylene glycol (MEG) and propylene glycol (PEG) *(identified as bio-based alternative for fossil-based MEG and PEG)*	100	Drop-in	X	X[23,24]	X	X	X	Bio-based ethylene glycol also known as bio-MEG is produced from bio-ethanol and currently used as drop-in alternative for fossil MEG in production of polyethylene terephthalate (PET) bottles (Coca Cola). Bio-based propylene glycol (1,2-propanediol) route from bio-based glycerol is under development.	8-9
Oxygenated	Bio-based tetrahydrofuran THF *(identified as bio-based alternative for fossil-based THF)*	100	Drop-in	X				X	Bio-based THF is produced by dehydrating bio-based 1,4-butanediol (1,4-BDO).	8-9
Oxygenated	Cyrene® *(identified as bio-based alternative for N,N-dimethylformamide and N-methyl-2-pyrrolidone – NMP)*	100	Dedicated	X	X		X	X	Circa is producing Cyrene® using cellulosic wastes. Cyrene® is currently being produced at a 50 tonne scale plant. Cyrene has been shown to be effective in a range of applications including graffiti removal, as a solvent for synthesis, for dispersion and for dissolving polymers such as polyethersulphone. Cyrene performance needs to be evaluated on a case by case basis. **LHT and LE are desired sustainability characteristics**, however *N,N-dimethylformamide and N-methyl-2-pyrrolidone* do not fulfil this requirement.	8-9

Note: There is a sub-product group on halogenated solvents. This does not feature in the table above as the drive is towards phasing out this group of solvents. So, alternatives from the hydrocarbon or oxygenated solvents subgroups will need to be identified that could provide same functionalities as that offered by halogenated solvents.

21 Except isobutanol

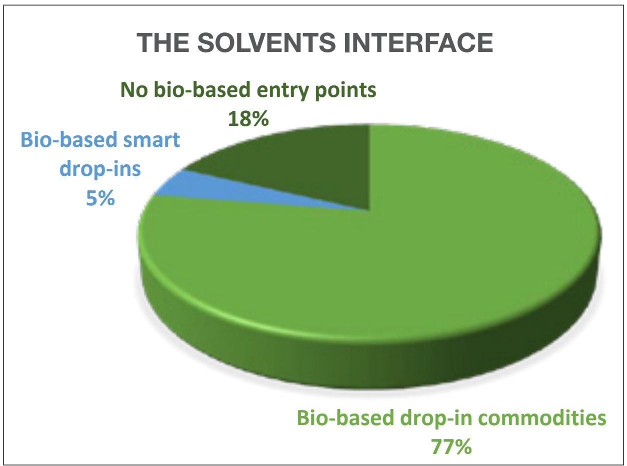
22 Except isobutanol

23 MEG has low toxicity but it has been reported that "Field studies in the vicinity of an airport have reported toxic signs consistent with ethylene glycol poisoning (oxalate crystal formation), fish kills, and reduced biodiversity. These effects cannot definitively be ascribed to ethylene glycol. (http://www.who.int/ipcs/publications/cicad/en/cicad22.pdf)

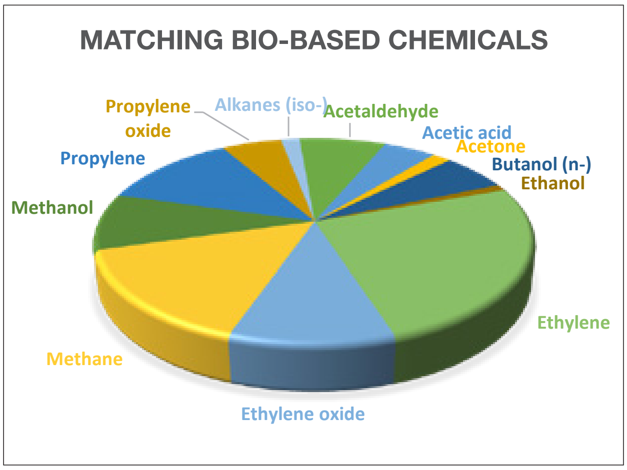
24 When discharged into the environment frequently (as reported in airports via aircraft de-icing fluids) PEG can accumulate in soil and lead to groundwater contamination

3.8.3 Opportunities and barriers

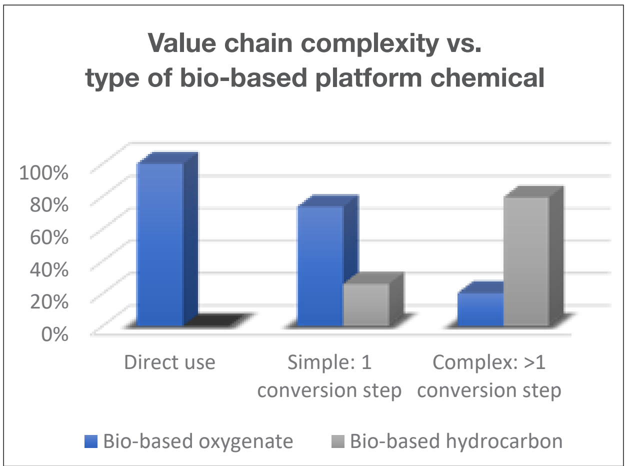
Deliverable D1.1 of the RoadToBio project identified pathways to higher bio-based share within solvents via the use of drop-in chemicals in the production process of solvents. Following is a summary of the results from D1.1 [13].



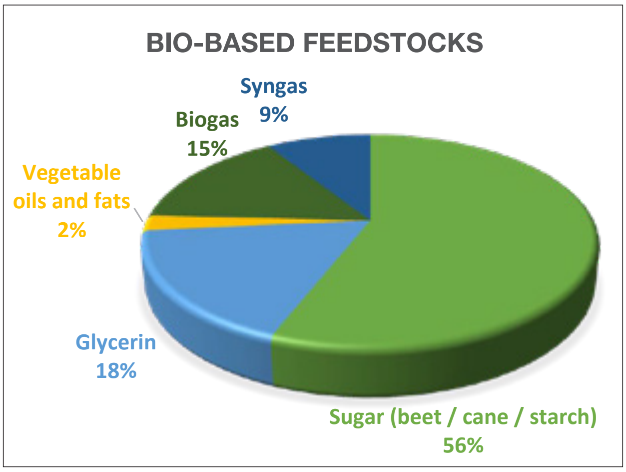
135 petrochemical solvents were analysed; at least one potential entry point for a bio-based chemical in the value chain was identified for 82% of the analysed petrochemical solvents.



14 bio-based chemicals from the long-list were responsible for all the potential entry points in the value chains.



In general, bio-based oxygenates can enter the solvent value chains further downstream than bio-based hydrocarbons, while two bio-based oxygenates are direct (smart) drop-in replacements for a final product (iso- and n-butanol).



The main feedstock platforms that can currently provide these bio-based chemicals are the sugar platform, the glycerine platform, and the biogas platform.

Figure 29: Opportunities for higher bio-based share in solvents via use of drop-in bio-based chemicals in the production process

In addition to identifying bio-based chemicals and their potential entry points in 9 product groups, the RoadToBio project also includes an analysis of nine potentially attractive business opportunities ("sweet spots") for the European bio-based industry (D1.2) [14]. One of the 9 chemicals that was analysed in-depth was lactic acid. Lactic acid is a dedicated chemical that is used in solvent formulations such as lactate esters. It's main use is however in the production of polylactic acid (PLA) for biodegradable packaging. Lactic acid was covered in D1.2 of RoadToBio and following is a summary of the analysis [14]. Please note that this chemical is not the most representative of the solvents product group, but one that was covered in-depth in D1.2 and selected here due to its relevance to this product group.

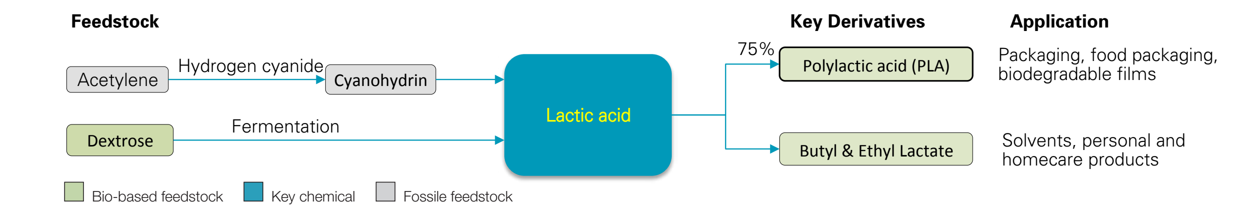
Market Volume EU (ktonne/yr):
Total: 120
Bio-based: 120
Source: 2016, CNBC & Grand View Research

Market Volume Global: (ktonne/yr)
Total: 1,200
Bio-based: 1200
Source: 2016, CNBC & Grand View Research

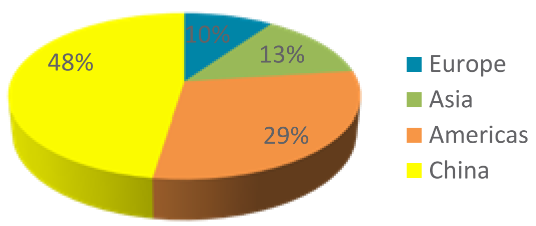
Price PLA: (€/tonne)
Given for PLA – key derivative of lactic acid
2,600
Source: Plastics insight (October 2017)

Market growth rate (%/yr):
15.5
Source: 2016, CNBC & Grand View Research

Value chain:

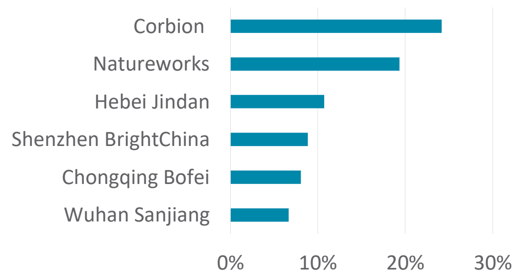


Demand:



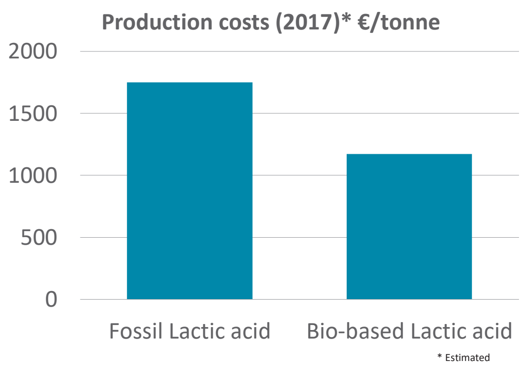
Year: 2016

Top suppliers (global):



Year: 2016

Costs:



Opportunities & Barriers:

+ Bio-based lactic acid is more sustainable than fossil based – uses less energy and it does not use harmful chemicals in the production process
+ Bio-based production of lactic acid is more cost-effective
+ Bio-based route can produce pure stereo isomers which are used for production of PLA

- PLA- polymer of lactic acid competes with cheaper fossil based plastics
- PLA needs to be recycled separately from other plastics streams
- PLA needs industrial composter and higher temperature to degrade

Figure 30: Lactic acid case study summary

Barriers identified to bio-based uptake in solvents are as follows. There are certain 'generic barriers' such as feedstock availability and cost competitiveness of bio-based products with fossil equivalents, which are applicable to all product groups. These are covered in chapter 4 of the report. These generic barriers may be mentioned in the following table only if there is something very specific about the barrier for the solvents product group. Otherwise they are not mentioned in the following table.:

Table 26: Barriers to bio-based uptake in solvents and proposed actions

Barriers	Actions	Actors	Timeline
High production cost of bio-based solvents	Carbon tax, subsidizing bio-based products while taxing fossil equivalents	Government, policy makers	Short-long term
	Gradual introduction of bio-based solvents. For example, a policy instrument which would require solvent producers to reach a quota for solvents that are bio-based and meet sustainability criteria (similar to biofuels)	Policy makers, industry	Short-long term
High VOC content and toxicity of conventional and bio-based solvents	R&D and trials to develop solvents with lower levels of VOCs and toxicity profiles, providing information on any toxicity improvements facilited though use of bio-based solvents.	Scientific & educational institutions, industry, government	Short-long term
Limited bio-based solvents available that meet the functional requirement/ performance criteria of fossil equivalents in different applications.	R&D with major focus on application testing as performance is the first requirement of a bio-based solvent to potentially replace a fossil-based alternative. R&D should also focus on formulations.	Scientific & educational institutions, industry, government	Short-long term

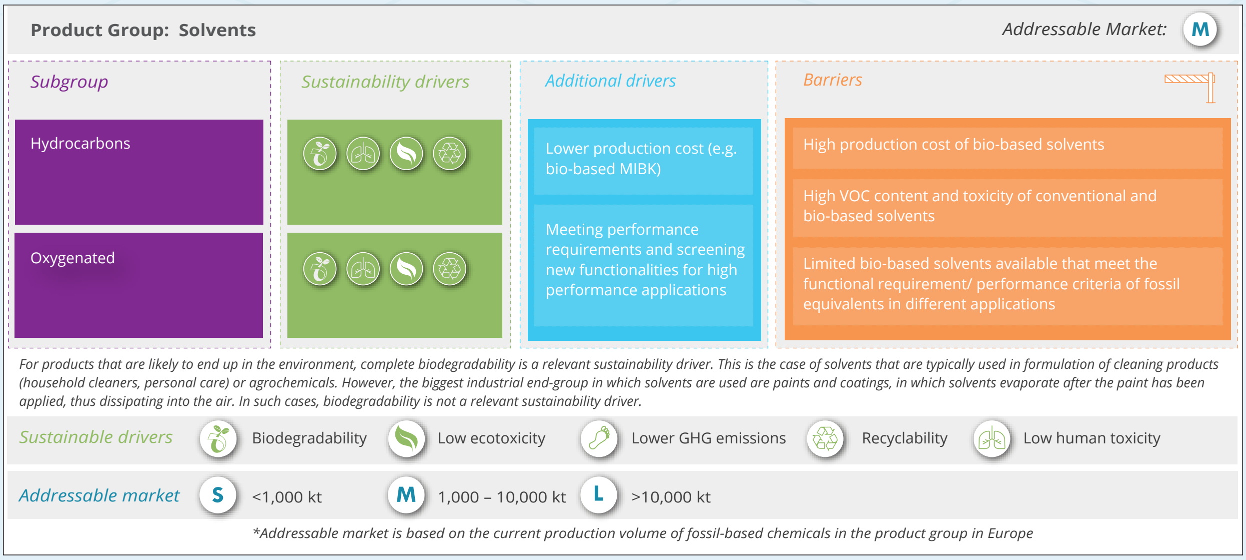


Figure 31: Pictorial summary of the solvents product group

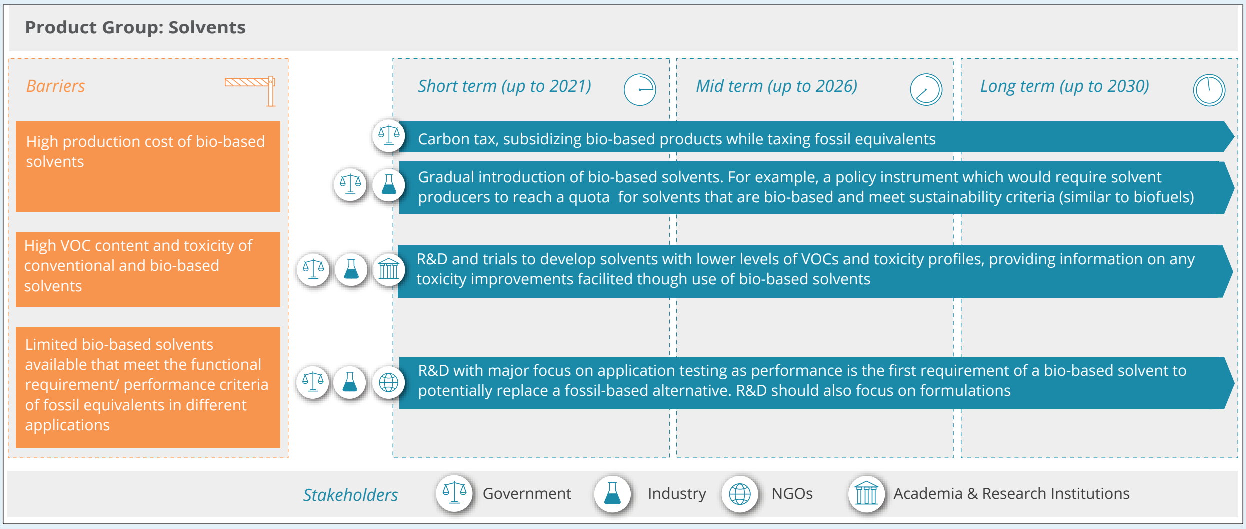


Figure 32: Roadmap to increasing the bio-based share of chemicals in the solvents product group

3.8.4 Summary

- Bio-based solvents production in Europe is <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 provided that they meet the functionally 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

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3.9 Adhesives

3.9.1 Background

Adhesives are typically classified by its origin: natural or synthetic [1]. In RoadToBio the product group adhesives focuses only on the synthetic ones. Therefore, natural adhesives, starch, casein, or other animal glues are excluded from the analysis. Synthetic adhesives consist of a combination of a solvent or mixture of solvents and a polymeric resin. Additives such as plasticizer are typically added to the formulation. In this regard, the identification of drivers and barriers in the development of bio-based adhesives comprises the analysis of their main components, solvents and polymers, which are at the same time product groups of RoadToBio.

A number of bio-based raw materials are available for the production of renewable adhesives and sealants. These include succinic acid and other diacids, natural oil polyols, CO_2-based polyols, bio-based isobutanol and 1,4-butanediol, bio-based isocyanate alternatives, furan dicarboxylic acid (FDCA) and esters, bio-based epichlorohydrin (ECH) [2].

3.9.2 Drive for bio-based market growth

Adhesives used for paper, board or wood products are often made from fossil-based raw materials making the final product non-biodegradable or difficult to recycle [3]. The most common synthetic fossil-based adhesives are based on phenol-formaldehyde (PF), epoxy resins, urea-formaldehyde (UF), melamine-urea-formaldehyde (MUF) and polyurethanes. However, crude oil price fluctuations and environmental legislation have directed attention to bio-based materials. 5-Hydroxymethylfurfural (5-HMF) is currently being researched as an economically and ecologically interesting substitute for formaldehyde in the synthesis of phenolic resins (PF), melamine resins (MF) and urea resins (UF). Several investigations have been targeted toward using lignin in formulation of formaldehyde-free wood adhesives. Other potential bio-based adhesives are based on polyhydroxyalkanoates (PHA), polylactic acid (PLA), polyamides (PA) and starch ester which can be used as replacement for ethylene-vinyl acetate (EVA) resins (hot melt adhesives).

Traditionally, renewable starch-based adhesives have been used as glues, e.g. for corrugated board, but the application areas have been limited due to poor water resistance and high water content of the adhesive formulations [3]. The market for vegetable oil-based polyester polyols, which are also used for polyurethane (PU) manufacture, continues to grow, with improvements achieved in performance [2]. There is a growing interest in alternative bio-based diacids and diols [2]. Advances are being made in the area of bio-based isocyanates, such as pentamethylene diisocyanate (PDI) and aliphatic polyisocyanates [2]. Bio-based epichlorohydrin (ECH), which is prepared from bio-based glycerine/glycerol generated during the production of biodiesel, can be used in the synthesis of epoxides, useful in the preparation of adhesives and sealants based on epoxy resins [2].

The following table shows typical bio-base replacements for different components (incl. additives) in adhesives.

Table 27: Bio-based replacements for adhesive components [4]

Components	Fossil-based	Bio-based
Polymers	• Ethylene vinyl acetate • Polyolefins • Block copolymers	• Soy protein • Starch esters • Polylactide • Polyamide
Tackifiers	• Hydrocarbon resins • Aromatic hydrocarbons • Aliphatic hydrocarbons	• Pine rosin • Terpenes • Citrus
Waxes	• Paraffins • Naphthenes	• Soy • Castor • Dimerized fatty acids

The market for bio-based adhesives and sealants is expected to register a CAGR of 4.49% during the forecast period, 2018 to 2023 [7].

The global bio-based adhesives market is witnessing strong growth, due to the high growth of biotechnology industry, stringent environmental regulations for petrochemical-based adhesives, increase in cost of storing hazardous substances, and the fluctuations in the prices of petro-based ingredients [5]. Moreover, the increased number of end-use industries and technological advancements in the biotechnology sector are also supporting the growth in demand for bio-based adhesives [6]. Among the various applications of bio-based adhesives, the packaging and paper segment held the largest share in the global market in 2015, and it is anticipated to retain its dominance during 2016 – 2022 [5]. The growth in demand for bio-based adhesives for packaging and paper application is attributed to the increasing compliance for bio-based and environment friendly products [5]. The other key application segments of bio-based adhesives include construction, wood, medical and personal care [5]. A high demand for bio-based adhesives is predicted in all these application segments during the forecast period [5].

In the RoadToBio project, the desired sustainability characteristics that are met/not met by selected bio-based adhesives and their fossil-based equivalents were assessed. The drivers of these sustainability characteristics were also assessed. These are summarised below.

Table 28: Desired sustainability characteristics of adhesives (bio-based/fossil) and their drivers

Product group	Desired sustainability characteristics	Drivers of sustainability characteristics
Adhesives	Low human toxicity, low ecotoxicity, recyclability, biodegradablility, low GHG	*Legislations, customer and producer driven (voluntary)*

In case of adhesives, by '**recyclability**' it is meant that if an adhesive is used to stick a label to a bottle then it should not cause a problem with recycling that bottle when using regular recycling infrastructure. This is a desired sustainability characteristic for both fossil and bio-based adhesives.

Table 29: Sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in the adhesives product group

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R[25]		
Synthetic adhesives	Bio-based polyurethane *(bio-based alternative for fossil-based polyurethane)*	1-60	Smart drop-in			X			Building blocks include pentamethylene diisocyanate (Desmodur® eco N 7300), bio-succinic acid (*DaniMer* adhesive based on bio-based 1,4-propanediol (1,4-PDO) / succinic acid) Performance of bio-based polyurethane is same as that of its fossil equivalent. The bio-based production process may lead to lower environmental impacts such as lower toxicity effects from emissions/byproducts.	9
Synthetic adhesives	Bio-based dodecanedioic acid (DDDA) *(bio-based precursor to polyurethane adhesives) (bio-based alternative to fossil-based DDDA)*	100	Smart drop-in	X					The production of DDDA poses no health issues due to its low vapour pressure (no VOC emissions) and is not genotoxic or mutagenic. The only potential VOC emissions from the process originates from the ethyl acetate used for the purification	8
Synthetic adhesives	5-HMF *(bio-based precursor for lignin-HMF resins. It could potentially replace phenolics where phenolic resins are used.)*	100	Dedicated			X		X	Several investigations target to use lignin in formulation to produce 100% bio-based lignin-HMF resins. Performance of 5-HMF needs to be tested	3-4
Synthetic adhesives	Bio-based epichlorohydrin (ECH) *(bio alternative for fossil-based epichlorohydrin which is a precursor to epoxy glues)*	100	Smart drop-in			X			Glycerol is the building block. Performance of bio-based epichlorohydrin is same as that of its fossil equivalent. The bio-based production process may lead to lower environmental impacts such as lower toxicity effects from emissions/byproducts.	9
Oxygenated	Bio-based ethanol, D-limonene *(identified as bio-based alternative for n-hexane as extraction agents in some applications)*	100	Dedicated	X				X	For instance, ethanol and D-limonene have been reported as good performing extraction agents of triglycerides in rapeseed oil extractions.	9

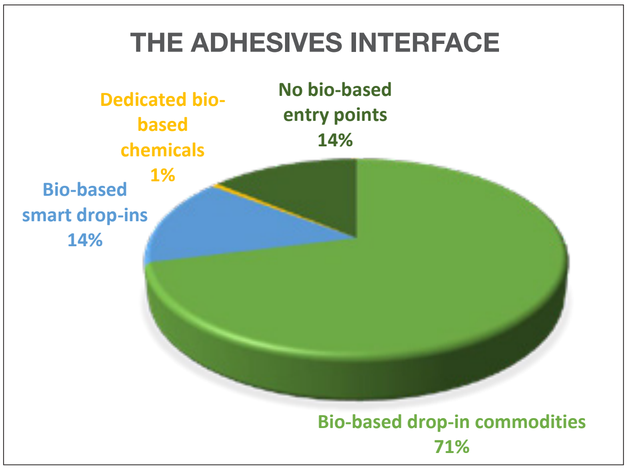
Key: B=Biodegradable, LHT=Low human toxicity, Low GHG=Low greenhouse gases, LE=Low ecotoxicity, R=Recyclability

Note: The chemicals/products selected for the analysis are representative of the product group and do not cover the full spectrum of chemicals/products. These representative chemicals/products 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.

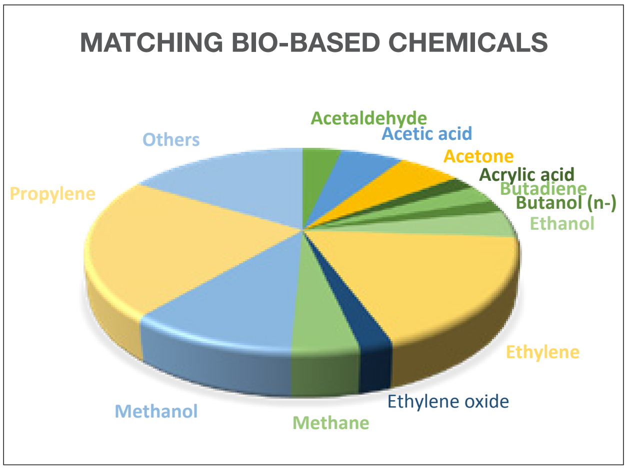
25 In case of adhesives, by 'recyclability' it is meant that if an adhesive is used to stick a label to a bottle then it should not cause a problem with recycling that bottle when using regular recycling infrastructure. This is a desired sustainability characteristic for both fossil and bio-based adhesives.

3.9.3 Opportunities and barriers

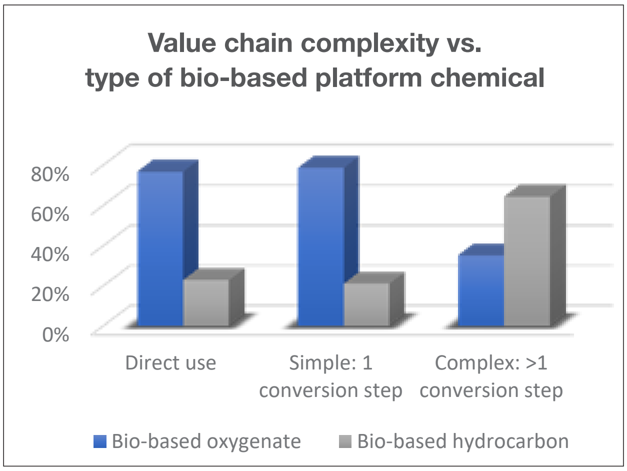
D1.1 of the RoadToBio project identified pathways to higher bio-based share within adhesives via the use of drop-in chemicals in the production process of adhesives. Following is a summary of the results from D1.1 [8].



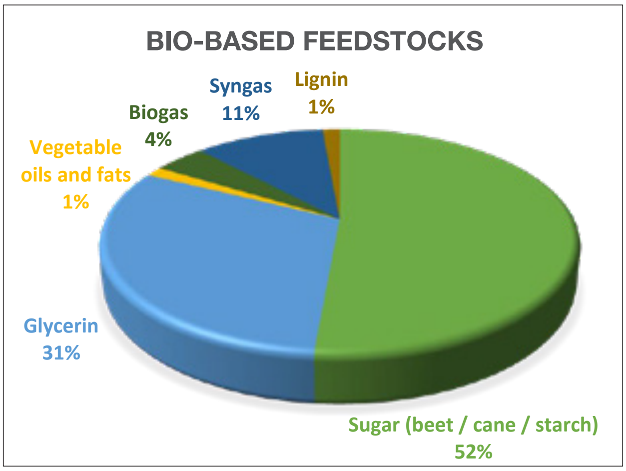
58 petrochemical adhesives were analysed; at least one potential entry point for a bio-based chemical in the value chain was identified for 86% of the adhesives, the majority being drop-in commodities.



30 different bio-based chemicals could enter the value chains at 142 potential entry points that were found. Ethylene, propylene and methanol were the most prevalent options.



The analysis of the complexity of the remaining value chains showed that, in general, bio-based oxygenates can enter the adhesives value chains further downstream than bio-based hydrocarbons, leading to less subsequent conversion steps.



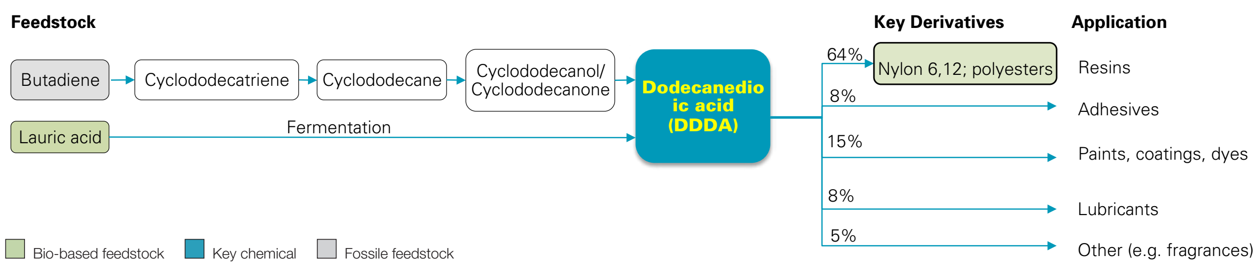
The main feedstock platforms that can currently provide these bio-based chemicals are the sugar platform, the glycerine platform, and the syngas platform.

Figure 33: Opportunities for higher bio-based share in adhesives via use of drop-in bio-based chemicals in the production process

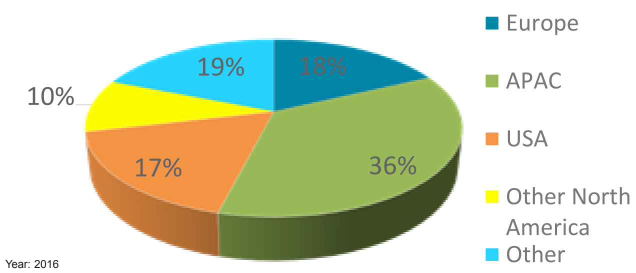
In addition to identifying bio-based chemicals and their potential entry points in 9 product groups, the RoadToBio project also includes an analysis of nine potentially attractive business opportunities ("sweet spots") for the European bio-based industry (D1.2) [9]. One of the 9 chemicals that was analysed in-depth was bio-based dodecanedioic acid (DDDA). DDDA is a smart drop-in chemical that serves as a bio-based precursor to polyurethane adhesives. It is also a key chemical used in coatings. This chemical was covered in D1.2 of RoadToBio and following is a summary of that analysis [9]. Please note that this chemical is not the most representative of the adhesives product group, but one that was covered in-depth in D1.2 and selected here due to its relevance to this product group.

Market Volume EU: (ktonne/yr)	Market Volume Global: (ktonne/year)	Price: (€/tonne)	Market growth rate: (%/yr)
Total: 11 Bio-based: n.a. Source: Crystal market research (2014)	Total: 59 Bio-based: n.a. Source: GlobeNewswire (2016)	5,200 Source: Biofuels Digest (2018)	5.5 Source: GlobeNewswire (2016))

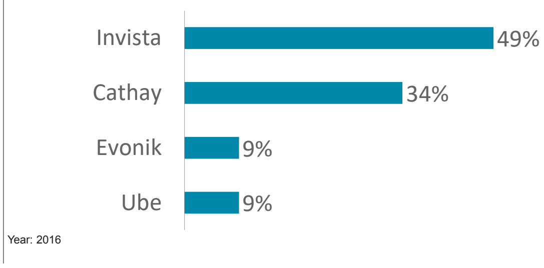
Value chain:



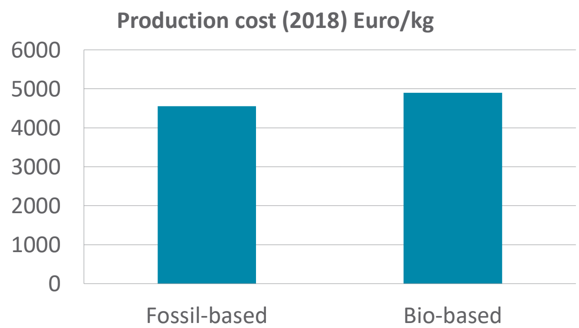
Demand:



Top suppliers (global):



Costs:



Opportunities and Barriers:

+ Less steps from starting material to product (smart drop-in)
+ Demand for bio-based resins
+ High performance applications (polyamides)
+ Well developed technology

- Negative image of palm kernel oil

Figure 34: Dodecanedioic acid (DDDA) case study summary

The main barriers for the development of bio-based adhesives are based on performance: like their mechanical properties, especially water resistance, that confer a disadvantage in many applications. A first step to improve these properties will rely on the development of mixed adhesives. A mixed adhesive is an adhesive exhibiting both bio-based compounds and synthetic compounds.

The market evolution closely depends on both research advances and legislation. Research advances offer new possibilities of development of bio-based adhesives by providing new molecular extraction from biomass or new chemical formulation. In the same way, governments play a crucial role for the development of both the bio-based adhesive market and the associated technologies. Legislation may lead in 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, the main objective being the reduction of the emission of VOCs while keeping suitable mechanical properties for structural applications that require high mechanical strength.

Barriers identified to bio-based uptake in adhesives are as follows. There are certain 'generic barriers' such as feedstock availability and cost competitiveness of bio-based products with fossil equivalents, which are applicable to all product groups. These are covered in chapter 4 of the report. These generic barriers may be mentioned in the following table only if there is something very specific about the barrier for the adhesives product group. Otherwise they are not mentioned in the following table.

Table 30: Barriers to bio-based uptake in adhesives and proposed actions

Barriers	Actions	Actors	Timeline
Performance issues, especially water resistance	Develop mixed adhesives as a first step to improve properties, such as hydrophobicity	Industry, academia, policy makers	Short-mid term
	R&D on new formulations for 100% bio-based adhesives that consistently deliver required performance	Industry, academia, policy makers	Short-long term
No legal mandate for regulating VOC emissions or recyclability exist in sectors where adhesives are used	Design and implement legislation to regulate VOC emissions and recycling in sectors where adhesives are used	Policy makers	Short-mid term
Natural quality fluctuation limit use of bio-based adhesives in important high-performance structural applications	R&D to improve performance of bio-based adhesives	Policy makers, industry, academia	short-long term

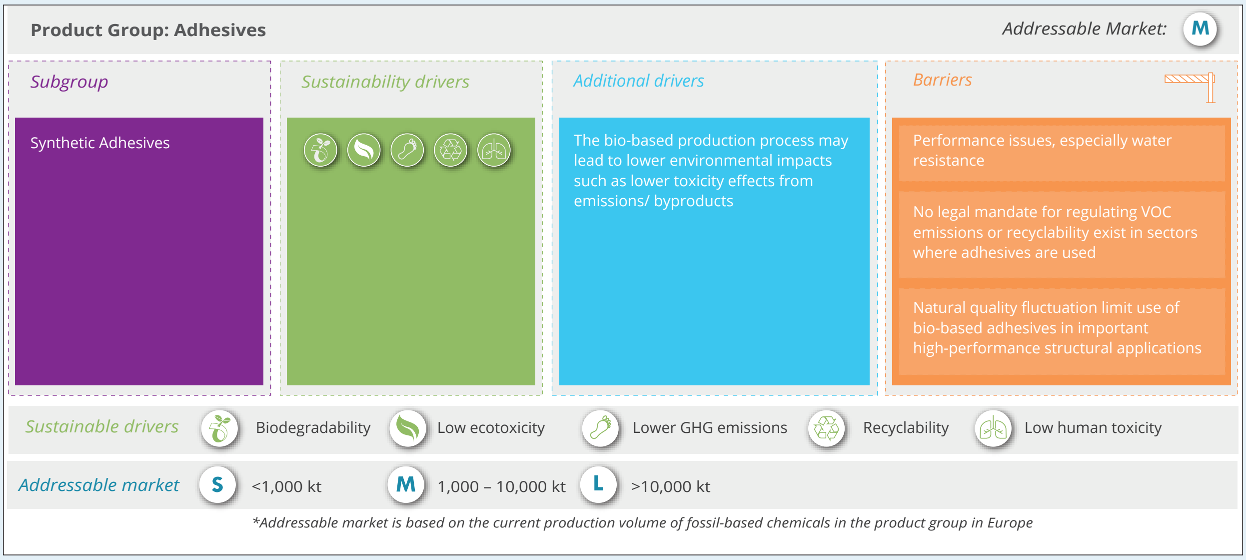


Figure 35: Pictorial summary of the adhesives product group

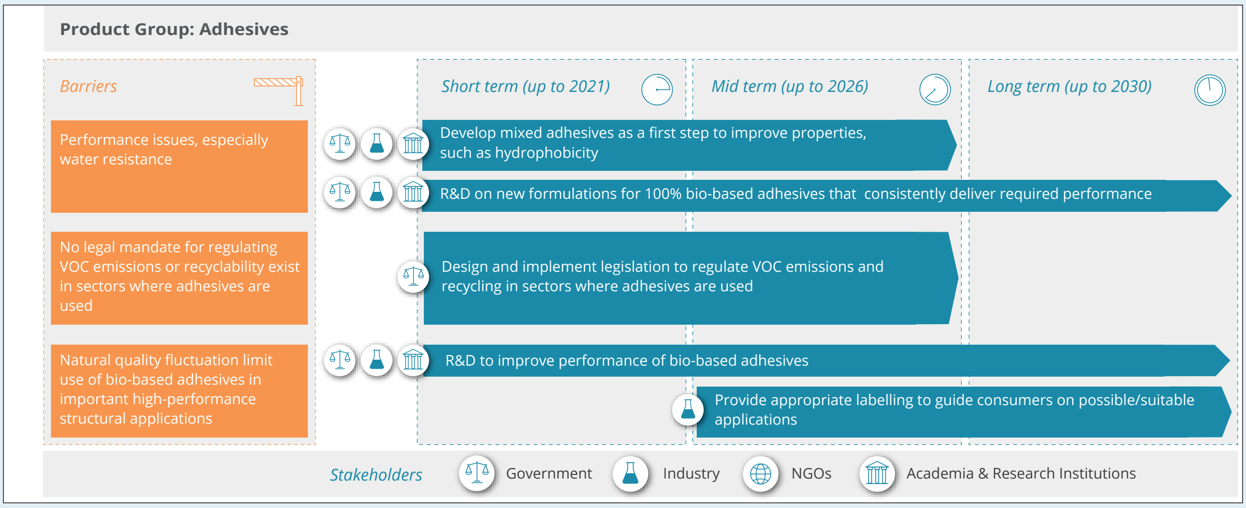


Figure 36: Roadmap to increasing the bio-based share of chemicals in the adhesives product group

3.9.4 Summary

- 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).

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3.10 Plastics/polymers

3.10.1 Background

The plastics industry can be split into three categories: thermoplastics, thermosets and elastomers, each with specific and different performance requirements, ranging from highly robust and durable to readily degradable, for example. Approximately 335 million tonnes of plastic produced annually in the world (2017). Since 1950 to 2015, global demand for plastics was at 8.6% CAGR and is expected to continue to grow at a CAGR of 5.3%. Industry researchers have predicted aggressive growth projections [1]:

- 5.3 % global plastics growth from 2013 and 2020 – Transparency Market Research.
- Global plastics market value of US$654 billion by 2020 – Grand View Research
- Global antimicrobial plastic market to grow by 10% to US$3.6 billion by 2020 – MarketsandMarkets.
- Engineering resin and polymer alloy/blend market to grow from US$38 billion to more than US$48 billion by 2020 – BCC Research.

Growth of major end-use industries such as packaging, construction and automotive, particularly in emerging markets of China, India and Brazil is expected to remain a key driving factor for global plastic demand in 2020 [2]. In addition, the need for high performance thermoplastics driven by the automotive industry to reduce overall vehicular weight and gain fuel efficiency is expected to increasingly influence market growth. Volatile raw material prices coupled with growing environmental concerns around plastics sustainability and end-of-life disposal is now posing serious challenges to market stakeholders. To overcome these challenges, leading industry players have been actively investigating the route to develop bio-based alternatives to conventional, fossil-derived plastics.

Thermoplastics are divided broadly into commodity and engineering plastics. Commodity plastics are generally characterized by their low price and properties (such as low durability) for applications that do not require the use of additives, reinforcing fillers, fibres or polymer blends. Engineering plastics are much more robust and more expensive. Typically, they are used in niche and demanding applications in contrast to the large volume single-use markets occupied by commodity plastics. Commodity plastics account for approximately 80% of all thermoplastics. Major applications are in flexible films for bags and wrapping, cutlery, bottles, food trays and other single-use applications.

Examples of **thermoplastic materials** are:

Commodity Thermoplastics	Engineering Thermoplastics
• Polystyrene (PS) • Polyvinyl chloride (PVC) • Polypropylene (PP) • Polyethylenes (PE) (Linear Low-Density Polyethylene (LLDPE), Low Density Polyethylene (LDPE) And High-Density Polyethylene (HDPE))	• Polycarbonate (PC) • Polyethylene terephthalate (PET) • Polybutylene terephthalate (PBT) • (Polyamides or Nylons – the latter are covered in section 3.6 of this document on man-made fibres)

There is overlap in some commodity/engineering markets, where commodity resins such as PP, acrylonitrile butadiene styrene (ABS) and engineering resins, such as PET, can compete depending on the applications and level and type of modification required. High performance plastics occupy the smallest section of the thermoplastics category, though show the highest growth rate and command high prices [3]. As the commodity materials market grows, pressure increases on price. Ultimately, based on performance within specific market sectors, price and volume begin to plateau.

Thermoset materials account for approximately 30% of the total global market [3], which include unsaturated polyesters (UP), phenol-formaldehyde (PF), polyurethanes (PUR) and epoxy/polyepoxide resins. The main thermoset end-use markets include plywood adhesives, furniture/bedding, building & construction, automotive, consumer products and electronics. Unsaturated polyester resins and polyurethanes account for the two biggest types of thermosets in this market followed by phenolic and epoxy resins.

Polyethylene (PE) is the leading product segment for plastics and accounted for 34.9% of total market volume in 2013 [1]. PE is used in high volumes across various industries such as film and sheet, injection moulding, blow moulding and pipe manufacturing. Increasing PE capacity addition, particularly in the Middle East and Asia Pacific has led to overcapacity in the market which has seen the prices decline. PET is expected to be the fastest growing product segment for plastics, at an estimated CAGR of 8.5% from 2014 to 2020 [1-3].

Plastics production is led by Asia with almost 50% of the global production; China alone accounts for 28% of global plastics production. In comparison, Europe accounts for 18% and North American Free Trade Agreement (NAFTA) totals 19% of global plastic production [1-4]. Major multinational corporations dominate the thermosets market across the value chain, which include Arkema, BASF, Asahi Kasei Chemical Corp., Bayer AG, Chevron Phillips Chemical Company LLC, Sinopec, Dow Chemical Company, Eastman Chemical Company, and LyondellBasell Industries. The growing demand for thermosets from emerging economies like Brazil, Russia, India, and China (BRIC) is expected to drive the market. The North American market for thermosets is primarily driven by the regulatory initiative to reduce automobile weight by 50% by 2020 in order to cut fuel consumption. North America and Europe are the most mature markets for plastics but is predicted to see continued growth driven by innovation in sustainable plastics and bio-based polymers [2].

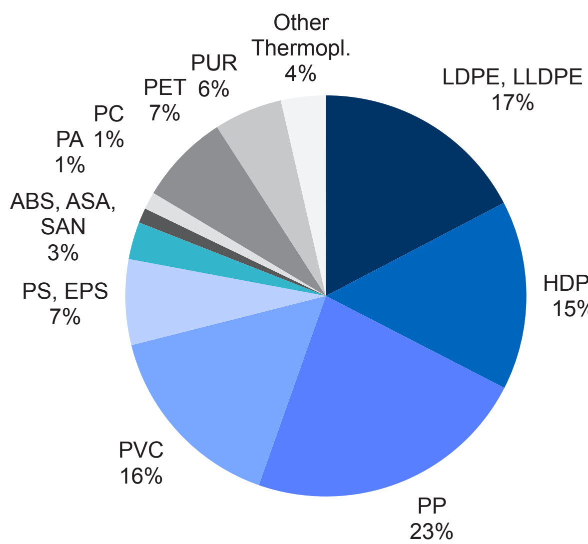


Figure 37: Global plastics demand in 2015
(Source: Plastics Europe)

PlasticsEurope is a leading pan-European association and represents plastics manufacturers active in the European plastics industry. In 2017, the European Commission confirmed it would focus on plastics production and use and work towards the goal of ensuring that all plastic packaging is recyclable by 2030, an initiative labelled "Plastics 2030". PlasticsEurope association aims to support this initiative to transform Europe into a more circular economy and resource efficient economy. In a press release titled "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A European Strategy for Plastics in a Circular Economy." dated 16th January 2018, it is stated that, "The EU is best placed to lead the transition to the plastics of the future. This strategy lays the foundations to a new plastics economy, where the design and production of plastics and plastic products fully respect reuse, repair and recycling needs and more sustainable materials are developed and promoted) [5].

Europe's 2012 Bioeconomy Strategy [6] addresses the production of renewable biological resources and their conversion into vital products, such as bio-based plastics, as well as bio-energy. The strategy is needed to ensure that fossil resources are replaced with sustainable bio-based alternatives as part of the transition to a low-carbon circular economy. Its main purpose is to streamline existing policy approaches that are currently under review, which will provide a good opportunity for new political drive toward bio-based plastic products. European Bioplastics (EUBP), as part of the European Bioeconomy Alliance (EUBA), an informal alliance of 12 leading European organisations representing sectors active in the bioeconomy in Europe, has formulated specific policy asks for the revision of the EU Bioeconomy Strategy to help stimulate the uptake of bio-based products in strategic sectors (e.g. packaging, automotive, coatings, construction, cosmetics, energy, Fertiliser, homecare, pharmaceutical and textiles industries).

The desired sustainability characteristics mentioned about vary between each plastic product, dependant on its application. For example, biodegradability is not found to be a strongly desired characteristic for durable plastics/polymers used in construction, though recyclability or low human toxicity could be stronger desirable sustainability characteristics for the plastic/polymer material. Matched, though ideally enhanced, product performance to currently traded fossil-based equivalent products is also a key desired sustainability characteristic/driver to bio-based plastic research and development.

Table 31: Desired sustainability characteristics of plastics/polymers (bio-based/fossil) and their drivers

Product group	Desired sustainability characteristics	Drivers of sustainability characteristics
Plastics/polymers	Biodegradability, low GHG, recyclability, toxicity,	*Legislations, customer and producer driven (voluntary) (mainly producer driven)*

3.10.2 Drive for bio-based market growth

Bio-based plastics are those that are made wholly or partially (>5%) from biomass, typically starches, oils or cellulose and lignin. In the scope of the RoadToBio project bio-based plastics are defined as those that are typically made from these 1G (first generation) feedstocks, 2G feedstocks (second generation) such as biomass and waste from agriculture, forestry, food waste such as plant and animal oils; 3G feedstocks (third generation) such as algae, fungi, enzymes, and bacteria. However, post-consumer recycled plastics (even if wholly or partially of bio-based origin) that are upcycled are considered part of the circular economy (than bioeconomy), therefore are not detailed in this report.

The bio-based plastics industry is a small but rapidly growing section of the overall EU plastics industry. In 2017, bio-based plastics represented around one percent of approximately 320 million tonnes of plastic produced annually in the world. Driven by sustainability drivers, demand is rising and with more sophisticated bio-based polymers, applications, and products emerging. In 2016, the bio-based plastics market stood at 6,333 kilotons, and is expected to grow at a CAGR of 23.1% in terms of volume from 2017 to 2025 to reach 39,746 kilotons by 2025 [7]. However, functionality is of utmost importance and it is unlikely that customers will compromise on functionality for higher sustainability. Thus, producers often must consider trade-offs between production costs and sustainability (meaning that more sustainable solutions are usually more expensive).

Bio-based plastics are extensively used in the production of rigid packaging. However, the level of technical complexity involved in bioplastics packaging is high. The adoption of bioplastics in rigid packaging was the highest in 2016 and is expected to grow at the same pace throughout 2025 [7]. For example, the commercialization of co-extruded double or multiple layer film products has gained momentum in recent years. This bio-based plastic can also be used in the development of durable products, such as those in portable electronic devices and phone casings; in sporting shoes, ski boots; and interior trim and spare wheel covers [4-7].

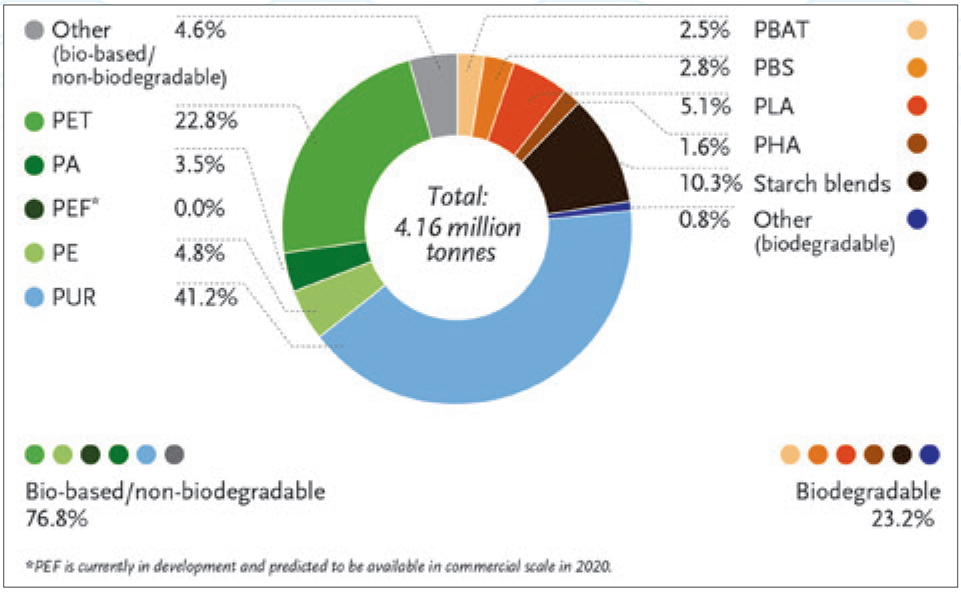


Figure 38: Global production capacities of bio-based plastics in 2018 (by material type).
(Source: nova-institute report for European Bioplastics association [3])

of the region is expected to provide growth opportunities for the bioplastics market in the Asia-Pacific region.

The market is segmented based on type, application, and region. Based on type, market is classified into biodegradable and non-biodegradable plastics (Figure 39). **Biodegradable plastics** are segmented into polylactic acid (PLA)[26], polyhydroxyalkanoates (PHA), polyesters, starch blends, and others, which includes cellulose acetate and others. **Non-biodegradable bio-based plastics** are segmented into bio-PA (polyamide), bio-PE (polyethylene), bio-PET (polythene terephthalate), and others (Bio-PTT, Bio-PUR, and epoxies). Based on application, the market is divided into rigid packaging, flexible packaging, textile, agriculture & horticulture, consumer goods, automotive, electronics, building & construction, and others.

Germany, Italy, and the UK are the major countries involved in the development and production of bio-based plastic in Europe. Some of the leading manufacturers are Novamont S.p.A., BASF SE, Natureworks LLC, Corbion N.V., Braskem, Secos Group Ltd., Biome Technolgies Plc, FKuR Kunststoff GmbH, Inno*via* Films Ltd., and Toray Industries Inc. European Associations in association with the government implement environmental policies to promote sustainability and bio-degradability. This trend is expected to be a significant driving factor for the growth of the bioplastics market in Europe. Asia-Pacific is anticipated to grow at the significant CAGR from 2017 to 2025 [4-8]. The large population base

The use of renewable feedstock in combination with biotechnology processing enables the production of new plastics with novel properties and enhanced performance. A notable example of a bio-based plastic is the Coca-Cola PlantBottle®. The PlantBottle® is a biobased version of the common plastic PET drinks bottle. Under the PlantBottle® brand, Coca-Cola have distributed over 35 billion packages and have the ambition to convert all new PET plastic bottles, to PlantBottle® packaging by 2020 [9]. Another example of successful commercialisation is bio-based polyethylene (PE) produced by the Brazilian company Braskem. Petrochemical polyethylene is the world's largest volume plastic and is used in numerous applications from plastic bags to shampoo bottles. Bras-

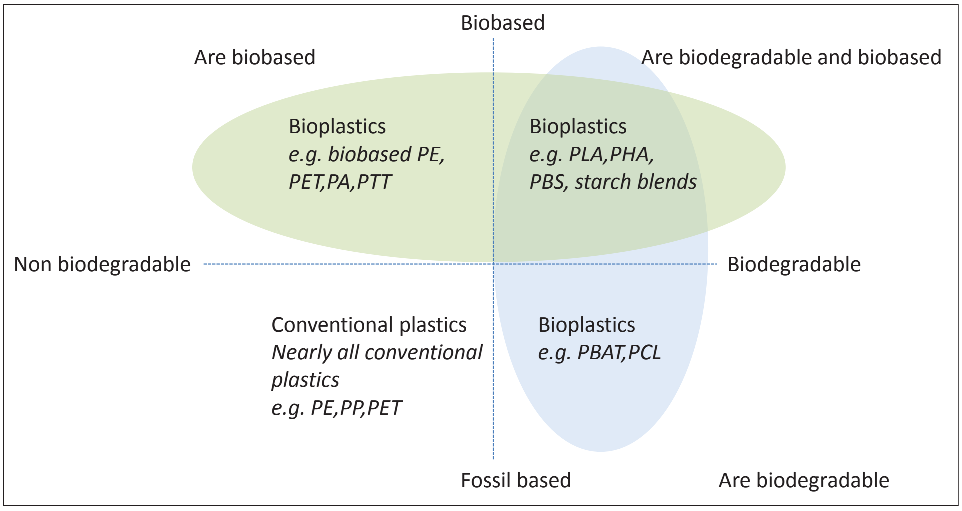


Figure 39: Plastics market can be segmented based on type, application, conventional or bio-based, and biodegradable or non-biodegradable plastics [4]

26 PLA is not biodegradable under normal conditions. However, it is compostable in a controlled industrial compost facility.: http://www.biosphereplastic.com/biodegradableplastic/uncategorized/is-pla-compostable

kem's bio-based polyethylene came to prominence recently through Lego's decision to use the plastic in the production of its moulded trees and plant bricks [10].

As bio-based products are produced from plants that have sequestered atmospheric carbon dioxide during their growth, they can help reduce carbon dioxide emissions associated with fossil-based plastic and contribute to climate change mitigation. For example, bio-based polyethylene resin produced by Braskem sequesters 2.15 tonnes of CO_2eq. for every tonne of resin produced i.e. it acts as a carbon sink. In comparison, the production of traditional oil-based polyethylene emits 1.83 tonnes of CO_2eq. [11].

Biome Technologies, the parent company of Biome Bioplastics, received further government funding as part of its £6 million programme to use industrial biotechnology techniques to produce a new range of highly sustainable polymers. Biome are working towards making bio-based polymer building blocks (specifically PDCA or 2,5-pyridinedicarboxylic acid) at pilot scale that would tackle the plastic waste challenge, while delivering functionality that competes with traditional oil-based plastics. These bio-based building blocks, or monomers, will be used in the production of compostable and recyclable polymers suitable for flexible packaging applications such as pouches, that are not currently recyclable. The resulting products will then be tested by a leading UK brand [12].

Most bio-based plastics have the same product characteristics as their traditional oil-based equivalent. For example, bio-based PET is identical to fossil-based PET. However, simply because a bio-based plastic is made from natural resources doesn't mean it is biodegradable. Bio-based plastics can be just as durable as oil-based plastic. Bio-based plastic with improved barrier properties for gases (e.g. carbon dioxide and oxygen) can lead to a longer shelf-life of packaged products. Synvina's recylable PEF [13] offers a significant advantage to the packaging industry in comparison to alternative bio-based plastics or barrier materials. Moreover, it also offers a higher mechanical strength, thus thinner PEF packaging can be produced and fewer resources are required. PEF is suitable as the main component or as a barrier layer in cups and trays, flexible packaging as well as bottles for carbonated and non-carbonated soft drinks, water, dairy products, still and sports drinks, alcoholic beverages as well as personal and home care products. An important challenge for the growth of bio-based plastics is the communication of sustainability drivers and credentials to raise awareness, social acceptance and uptake of bio-based plastic products. Therefore, the entire value chain must ensure accurate knowledge transfer to the brand-owners to make correct and poignant labelling for the end-consumer to understand any positive environmental impact of their choice to purchase a bio-based plastic product.

Table 32: Sustainability characteristics (proven and/or desired) of bio-based chemicals and their fossil equivalents in the plastics/polymer product group

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Elastomer	Bio-polybutadiene (bio-BDE) (alternative to fossil-based polybutadiene)	100	*Smart drop-in*					X	Versalis and Genomatica have fine-tuned a sustainable process to make bio-BDE from renewable feedstocks. In 2016, the two partners announced successful pilot-scale production of bio-BDE. The partners use a microorganism designed by Genomatica to produce 1,3-butanediol (1,3-BDO); Versalis then dehydrates the 1,3-BDO to BDE, to then make rubber from bio-BDE. This approach is a cost-effective, readily-deployable commercial-scale process now around the world.	9

Key: B=Biodegradable, LHT=Low human toxicity, Low GHG=Low greenhouse gases, LE=Low ecotoxicity, R=Recyclability

Note: The chemicals/products selected for the analysis are representative of the product group and do not cover the full spectrum of chemicals/products. These representative chemicals/products 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 low GHG characteristic is colour coded according to the evidence found to claim that the production process or lifecycle analysis has a lower carbon footprint, using less energy to generate products. Biodegradability maybe a sustainability characteristic for specific bio-based chemicals in a sub-product group in particular application, though may not be applicable for other applications using the same sub-product group material.

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Synthetic equivalent of natural rubber	Bio-polyisoprene *(alternative to fossil-based polyisoprene - synthetic equivalent of natural rubber (hevea brasilienesis rubber)*	100	*Smart drop-in*	X	X			X	Companies developing bio-based isoprene processes have altered several enzymes in the biosynthetic pathway (isoprene is produced naturally from plants through methyl-erythritol 4-phosphate pathway i.e. MEP pathway in the chloroplasts of trees and plants) to increase both the rate of production and the overall yield of isoprene. In healthcare, Cariflex™ bio-polyisoprene products are safe alternatives to natural rubber, which can cause life-threatening allergies in users of surgical gloves, and a versatile option for manufacturing applications that require the high tensile strength and tear resistance of natural rubber, without the impurities that cause discoloration, odor and allergic reactions. bio-polyisoprene combines the key qualities of natural rubber (good mechanical properties and hysteresis) with high purity, clarity, flow, low gel content, no nitrosamines and no natural rubber proteins.	9
Thermo-plastic	Bio-polyethylene terephthalate – bio-PET (alternative to fossil-based polyethylene terephthalate, PET)	20-30	*Drop-in (bio-PET)* *Dedicated (polyethylene furanoate, PEF – alternative to conventional PET (see below))*			X		X	Products made from bio-PET have the same qualities as regular PET (functions, weight, appearance, recyclability). Recycled PET and bio-PET can be used in bottles or in other applications e.g. fibers for the polyester industry. Bio-PET is one of SCG Chemicals Eco Products and is used by leading global drinks manufacturers such as Coca-Cola (Japan).	9
Thermoset	Bio-polyurethane – bio-PUR *(alternative for fossil-based polyurethane, PUR)*	5-70	*Drop-in*					X	Cargill BioOH® polyols and polymers are soy-based, industrial ingredients for bio-PUR flexible slabstock foam, automotive molded, carpet, and coatings. Bayer MaterialScience has commercialised a range of polyol products for use in PUR with renewable content of up to 95% based on natural oils. The greatest technical challenge is maintaining a high renewable content in the polyol and bio-PUR without compromising characteristic polyurethane properties. High-costs are a limitation. soybean oil-based polyols can offer between 40% and 100% bio-based content, resulting in soy oil-based PUR that can have bio-based content between 5% and 60% for flexible and rigid foams. With castor oil, the polyol can have a bio-based content of 30-100%, allowing for the PUR to have a bio-based content between 22% and 70%.	9

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Thermo-plastic	Bio-polyethylene – bio--PE *(alternative to fossil-based polyethylene.)*	100	*Drop-in (bio-PE)* *Polylactic acid PLA is a dedicated bio-based alternative that can be used to replace fossil-based polyethylene.*			X		X	In 2010, Braskem introduced drop-in I'm green™ polyethylene made from sugarcane ethanol on the market and has been expanding its product range ever since. Producing high-density polyethylene (HDPE) and linear low-density polyethylene (LLDPE) on an industrial scale, they are currently developing a green low-density polyethylene (LDPE). Conventional PE and bio-PE have the performance characteristics and require the same processing machinery, so there is no investment necessary. Bio-PE is more expensive than traditional PE but competitive with other biopolymers. Braskem are commercial suppliers of bio-PE to the LEGO group.	9
Thermo-plastic	Bio-polypropylene – PP (alternative to fossil-based polypropylene)	35	*Drop-in (bio-PP)* *Polyhydroxy-alkanoates are dedicated bio-based chemical alternative to traditional PP.*			X		X	Production cost is a limitation. Capital costs for fermentation routes are significantly lower compared with gasification routes. The logical route for Braskem was to leverage their R&D and capital investment in the bio-PE plant to extend to the production of bio-PP. IKEA and Neste are now able to utilize renewable residue and waste raw materials, such as used cooking oil, as well as sustainably-produced vegetable oils in the production of plastic products. The pilot at commercial scale starts during winter of 2018. It will be the first large-scale production of renewable, bio-based polypropylene plastic globally. Terralene® PP 3509 is a bio-based material optimized for injection moulding applications. The processing and application characteristics of this material can be entirely compared to those of PP based on fossil materials. Terralene® PP 3509 offers a high flowability which is necessary e.g. to produce complex components and products with long flow paths.	8

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Thermo-plastic	Bio-polyvinylchloride – bio-PVC (alternative to fossil-based polyvinyl-chloride, PVC)	Unknown	*Smart drop-in*		X	X	X		In 2007, Solvay Indupa, an affiliate of Solvay, had announced to enter the bio-based PVC market, with ethylene partially derived from sugarcane and chlorine derived from brine. A plant of 120 kilo tons per year of bio-PVC capacity was envisioned with Latin America as the initial target market. However, due to an announcement of rise of bio-polyethylene costs by Braskem, the project initiation was paused. BioVinyl compounds incorporate phthalate-free DOW ECOLIBRIUM™ bio-based plasticisers, which are manufactured using plant byproducts by Dow Electrical and Telecommunications (Dow E&T), a unit of The Dow Chemical Company. These are designed to be incorporated into polyvinyl chloride (PVC) compounds used to make wire insulation and jacketing. They are made of 100% renewable feedstocks and can help cable manufacturers and original equipment manufacturers (OEMs) to reduce greenhouse gas emissions by 40% when used as a replacement for traditional PVC plasticizers.	6
Thermo-plastic	Bio-based foams – bio-PS	100	*Dedicated* (dedicated chemical polylactic acid (PLA) is used to make a bio-polystyrene foam as an alternative to conventional fossil-based polystyrene)	X		X		X	Synbra Technology's BioFoam® is a PLA based foam that is comparable to conventional expanded polystyrene (EPS) It looks similar in structure and has similar properties to EPS. The raw material for BioFoam consists of biopolymers made of vegetable materials and is biodegradable. BioFoam can industrially composted at high temperatures under the influence of moisture and bacteria. It is durable and suitable for long-term use in major technical and packaging applications. VTT has developed a foam-formed cellulose-based material that is an attractive alternative to EPS. The material is based on 100% renewable material (wood pulp) and can be recycled in the same way as cardboard.	9
Thermo-plastic elastomers	Bio-based styrene copolymers (bio-based alternative to conventional Acrylonitrile Butadiene-Styrene (ABS) & SAN copolymers)	Up to 50%	*Smart drop-in*			X		X	Versalis is developing bio-BDE within its other proprietary rubber and plastics downstream technologies such as SBR (Styrene-Butadiene Rubber), SBS (Styrene-Butadiene-Styrene Rubber) and ABS (Acrylonitrile Butadiene-Styrene). Polymer blends containing poly(lactic acid) (PLA) and acrylonitrile butadiene styrene (ABS) with high bio-based content (50%) were made by extrusion and injection molding.	7

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Thermo-plastic	Bio-isosorbide polycarbonate – bio-PC (bio-based alternative to fossil-based polycarbonate)	100	*Dedicated*		X				Roquette's POLYSORB® isosorbide is a diol that can be used as a monomer in polycarbonates synthesis. It is a safe alternative to bisphenol A (BPA) has excellent optical properties (low birefringence and excellent light transmission), chemical & UV resistance and high surface resistance, notably scratch resistance. Mitsubishi Chemicals use this bio-based monomer to polymerise into DURABIO™, a bio-based polycarbonate resin. It exhibits high transparency, excellent ductility and higher resistance to impact, heat, & weather when compared with conventional BPA-based polycarbonate resin. Additional benefits include ease of coloring as it can be simply mixed with pigment to create glossy, high reflective surfaces.	9
Thermo-plastic	Bio-polymethyl methacrylate – bio-PMMA (bio-based alternative to fossil-based PMMA)	50-100	*Smart drop-in*			X	X	X	Convention PMMA synthesis from petrochemical feedstock results in production of harmful by-products and various wastes identified as environmental threat. Altuglas International's, a subsidiary of Arkema, new Plexiglas® Rnew bio-based resins, compounded alloys of Altuglas International's PMMA and NatureWorks LLC's IngeoTM biopolymer, bio-based alloys offer exceptional performance characteristics that stem from the synergistic effect of compounding two completely miscible polymers, Plexiglas® and Ingeo biopolymer. The resultant Plexiglas® Rnew alloys feature lower processing temperatures, greater melt flow properties (suitable for low temperature converting, therefore resulting in a lower carbon footprint due to a lower energy consumption), and reduced carbon footprint.	9
Bio-based plastic	Polylactic acid – PLA (bio-based alternative to polyethylene (PE), polypropylene (PP) and polystyrene (PS).	100	*Dedicated*	X [27]		X			PLA is 100% bio-based and industrially compostable. Its physical properties can replace fossil-based PS and can be modified to replace conventional PE or PP. It has performance benefits like petrochemical-based plastics but is biodegradable by composting. Produced by numerous companies worldwide, with NatureWorks as market leader, PLA is the most well-established bio-based polymer. PLA can already be found at near-comparable prices to fossil-based polymers. Total Corbion, one leading producer of lactic acid, will build its first PLA plant in the coming years in Thailand.	9

27 PLA is not biodegradable under normal conditions. However, it is compostable in a controlled industrial compost facility.

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Bio-based plastic	Polyethylene furanoate – PEF is a bio-based alternative to fossil-based PET	100	*Dedicated*			X		X	PEF is referred as the next generation polyester with high potential to replace polyethylene terephthalate (PET), a durable fossil-based polymer. PEF offers numerous benefits compared to PET, such as, superior barrier performance as well as mechanical and thermal properties; high glass transition temperature and lower melting point; recyclable and hence reduced carbon footprint. It cost competitive at industrial scale. Avantium has entered into a joint venture with several companies such as The Coca-Cola Company, Danone, and ALPLA for the development and commercialization of PEF.	7
Thermo-plastic	Bio-polybutylene terephthalate) – bio-PBT (bio-based alternative to fossil-based polybutylene terephthalate)	Partially, % unknown	*Smart drop-in*					X	Toray Industries Inc. has successfully made a partially bio-based PBT (polybutylene terephthalate) using 1,4-butanediol (BDO) made with Genomatica's bio-based process technology. Toray PBT Resin TORAYCON® (polybutylene terephthalate) is a polyester-based thermoplastic engineering plastic with excellent electrical properties and chemical resistance. PBT is the second largest use for BDO, accounting for about 29% of all BDO worldwide, or about 700,000 tons per year as PBT compound.	9
Thermo-plastic	Bio-polybutylene succinate – PBS (aka 'Bionolle') (bio-based alternative to fossil-based PBS	100	*Dedicated*	X					PBS is a biodegradable polymer made by reacting succinic acid with 1,4-butanediol. DSM and Roquette's Biosuccinium™ can make the polymer partly or even 100% bio-based. Myriant's bio-succinic acid is a true drop-in replacement for petroleum-based succinic acid, enabling manufacturers to produce a truly bio-based, biodegradable polymer.	9
Bio-based plastic	Polyhydroxyalkanoate – PHA (bio-based alternative to thermoplastics)	100	*Dedicated*	X		X			PHA are produced through a fermentation process mainly by specific bacteria. PHA structures can include rigid thermoplastics, thermoplastic elastomers and grades useful in waxes, adhesives and binders. Properties range from elastomeric to resins as stiff as nylon 6 or polycarbonate.	9

Sub-product group	Bio-based chemicals identified	% of bio-based content in the chemical identified	Category Drop-in/ smart drop-in/ dedicated	Sustainability characteristics					Comments	TRL
				B	LHT	Low GHG	LE	R		
Bio-based plastic	Polyhydroxybutyrate – PHB (bio-based alternative to thermoplastics)	100	*Dedicated*	X	X	X			Polyhydroxybutyrate (PHB) offers many advantages over traditional petrochemically derived plastics. It possesses better physical properties than polypropylene for food packaging applications and is completely nontoxic. The poor low-impact strength of PHB is solved by incorporation of hydroxyvalerate monomers into the polymer to produce polyhydroxybutyrate-co-valerate (PHBV), which is commercially marketed under the trade name Biopol.	7
Bio-based plastic	Bio-polypropiolactone – bio-PPL (bio-based alternative to conventional, petroleum based polymers, including polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET))	100	*Dedicated*	X		X			Novomer's bio-polypropiolactone-high molecular weight (PPL-HMW) is a biodegradable polymer with attractive mechanical and physical properties that make it suitable for packaging and other thermoplastic applications. PPL is advantageous for its barrier properties, biodegradability, and reduced environmental impact.	7

3.10.3 Opportunities and barriers

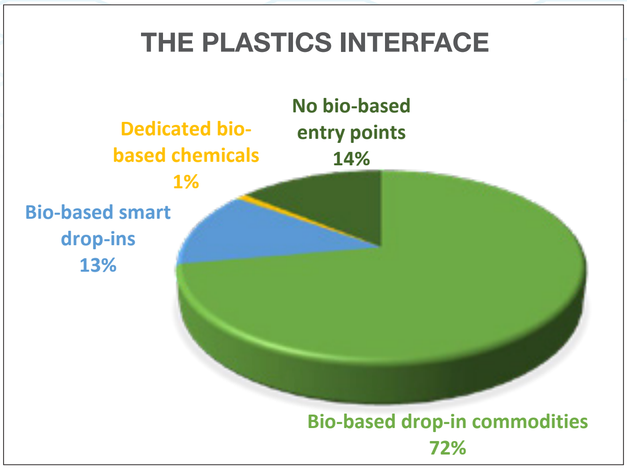
The global bio-based plastics production capacity is set to increase from ~4.2 Mt/yr in 2016 to approximately 6.1 Mt/yr in 2021. Packaging remains the largest field of application for bio-based plastics with almost 40% (1.6 Mt/yr) of the total bio-based plastics market in 2016. There is an increase in the uptake of bio-based plastics materials in many other sectors, including consumer goods (22%, 0.9 Mt/yr) and applications in the automotive and transport sector (14%, 0.6 Mt/yr) and the construction and building sector (13%, 0.5 Mt/yr), where technical performance polymers are being used [3-8].

The “Bio-based content certification scheme” is the European certification scheme that enables independent assessment of claims about the bio-based content of products based on the European standard EN 16785-1 [14]. This certification scheme has been developed and validated by a broadly composed group of European stakeholders (e.g. companies active in biopolymers, bio-based chemicals, bio-based plastics, natural rubbers, paints/coatings, certification bodies, procurers).

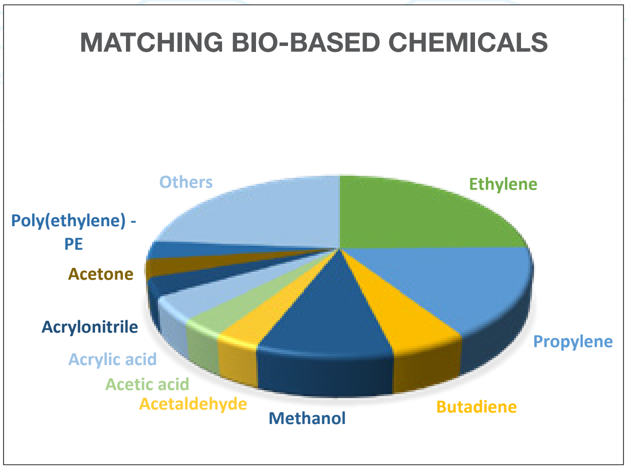
Bio-based, non-biodegradable plastics, such as polyurethanes (PUR) and drop-in solutions, such as bio-based PE and bio-based PET, are the main areas of growth, with PUR making up around 40% and PET over 20% of the global bio-based plastics production capacities. More than 75% of the bio-based plastics production capacity worldwide in 2016 was bio-based, durable plastics. This share will increase to almost 80% in 2021. Production capacities of biodegradable plastics, such as PLA, PHA, and starch blends, are also growing steadily from around 0.9 million tonnes in 2016 to almost 1.3 million tonnes in 2021. PHA production will almost quadruple by 2021 compared to 2016, due to a ramp-up of capacities in Asia and the USA and the start-up of the first PHA plant in Europe [3-8].

With a view to regional capacity development, Asia will further expand its role as major production hub. In 2021, more than 45% of bio-based plastics will be produced in Asia. Around a quarter of the global bio-based plastics production capacity will be located in Europe [1-4].

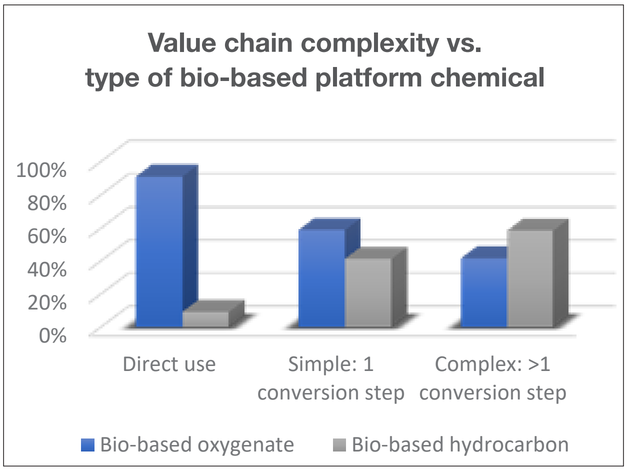
D1.1 of the RoadToBio project identified pathways to higher share of bio-based chemicals within plastics *via* the use of drop-in chemicals in the production process of plastics. Following is a summary of the results from D1.1.



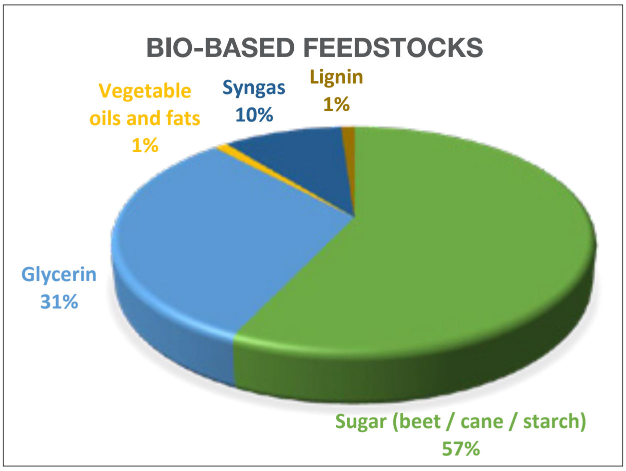
43 petrochemical plastics were analysed; at least one potential entry point for a bio-based chemical was identified for 86% of them, the majority being drop-in commodities, while also quite some smart drop-in options were present.



28 bio-based chemicals could enter these value chains at 93 potential entry points that were found. Ethylene, propylene and methanol again made up half of the bio-based entries together.



Like with the man-made fibres, the bio-based oxygenates that can be applied directly in this product group are all polymers, of which some bio-based options had a shorter production chain, while for some there is not much difference.



The main feedstock platforms that can currently provide these fibres are the sugar platform and the glycerine platform.

Figure 40: Opportunities for higher bio-based share in plastics and polymers via use of drop-in bio-based chemicals in the production process

In addition to identifying bio-based chemicals and their potential entry points in 9 product groups, the RoadToBio project also includes an analysis of nine potentially attractive business opportunities ("sweet spots") for the European bio-based industry (D1.2). One of the 9 chemicals that was analysed in-depth was ethylene, which is a key drop-in chemical used in plastics/polymers (e.g. HDPE, LDPE, PET, PVC). The following is a summary of that analysis.

Drop-in Chemical

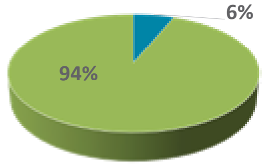
$H_2C{=}CH_2$

Market Volume: (ktonne)
Global: 150
Europe: 21
Bio-based: 200 (Brazil)
Year: 2016

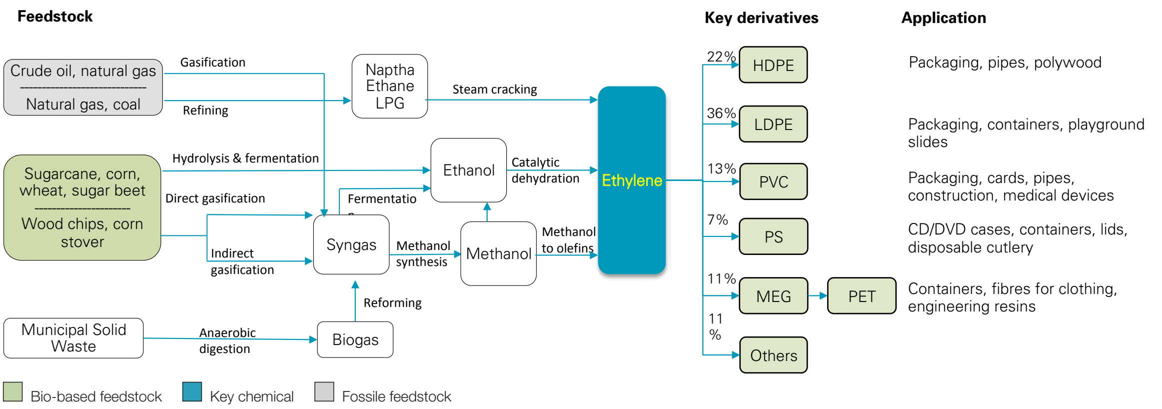
Price: (€/tonne)
Bio-based[1]:1,650
Fossil: 630-990
[1] From Sugarcane, Brazil
Year: 2016

Market growth rate (% per year):
1,0

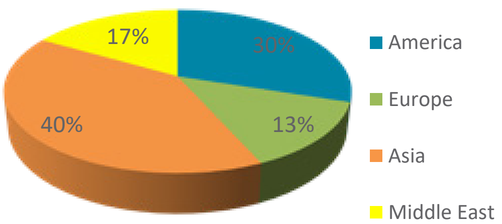
Potential contribution to EU chemical industry



Value chain:

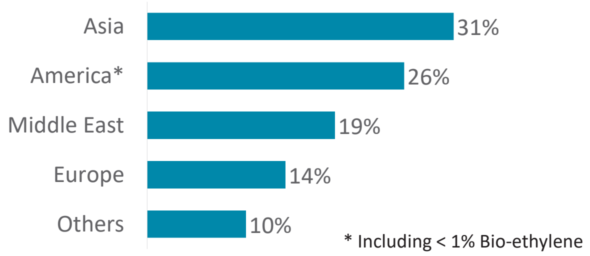


Demand:



Year: 2016

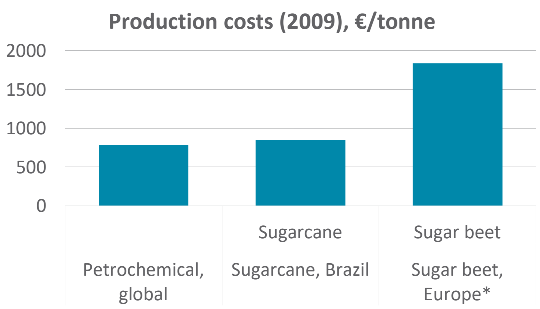
Supply:



Year: 2017

* Including < 1% Bio-ethylene from Braskem, Brazil

Costs:



* Estimated

Potential and Barriers:

\+ Bio-based ethylene from sugarcane has become increasingly efficient and competitive.

\+ Biochemical or thermochemical conversion of lignocellulose could enlarge the feedstock availability with minor impact on food production.

\- Biomass availability in Europe and the price gap with petrochemical ethylene could present barriers

\- Second generation bioethylene is not comercially avilablefeedstocks.

Figure 41: Ethylene case study summary

Barriers identified to bio-based uptake in the plastics and polymers product group are as follows. There are certain 'generic barriers' such as feedstock availability and cost competitiveness of bio-based products with fossil equivalents, which are applicable to all product groups. These are covered in chapter 4 of the report. These generic barriers may be mentioned in the following table only if there is something very specific about the barrier for the plastics and polymers product group. Otherwise they are not mentioned in the following table.

Table 33: Barriers identified to bio-based uptake in plastics/polymers

Barriers	Actions	Actors	Timeline
Cost of production in comparison to fossil-based processes is too high	R&D, demonstration scale projects to reduce cost by increasing efficiency of bio-based chemical production	Industry, policy makers, academia	Short-long term
	Develop a specific Strategic Research Innovation Agenda on bio-based plastics to guide future funding decisions	Policy makers, industry	Short-long term
Limitations in relation to product functionality	R&D to improve the performance of chemicals/materials and match product performance/functionality with its application	Industry, policy makers, academia	Short-long term
Some bio-based plastics cannot be recycled, e.g. Currently PLA cannot be recycled with other plastics like PET	Utilise and retrofit the existing infrastructure to product bio-based polymers and bio-based polymer building blocks	Industry	Short-mid term
	R&D to develop PLA and other bio-based plastics that are recyclable with regular recycling stream	Industry, policy makers, academia	Short-long term
No clear labelling to differentiate bio-plastics, bio-based plastics and biodegradable plastics	Provide adequate labelling to inform customers of types of bio-based plastics to raise awareness about bio-based plastic alternatives and end of life processing	Policy makers, industry, NGOs	Short-long term
	Communication along the entire value chain with accurate data for end-of-life processing to develop labelling for end-consumer	Policy makers, industry, NGOs	Short-long term

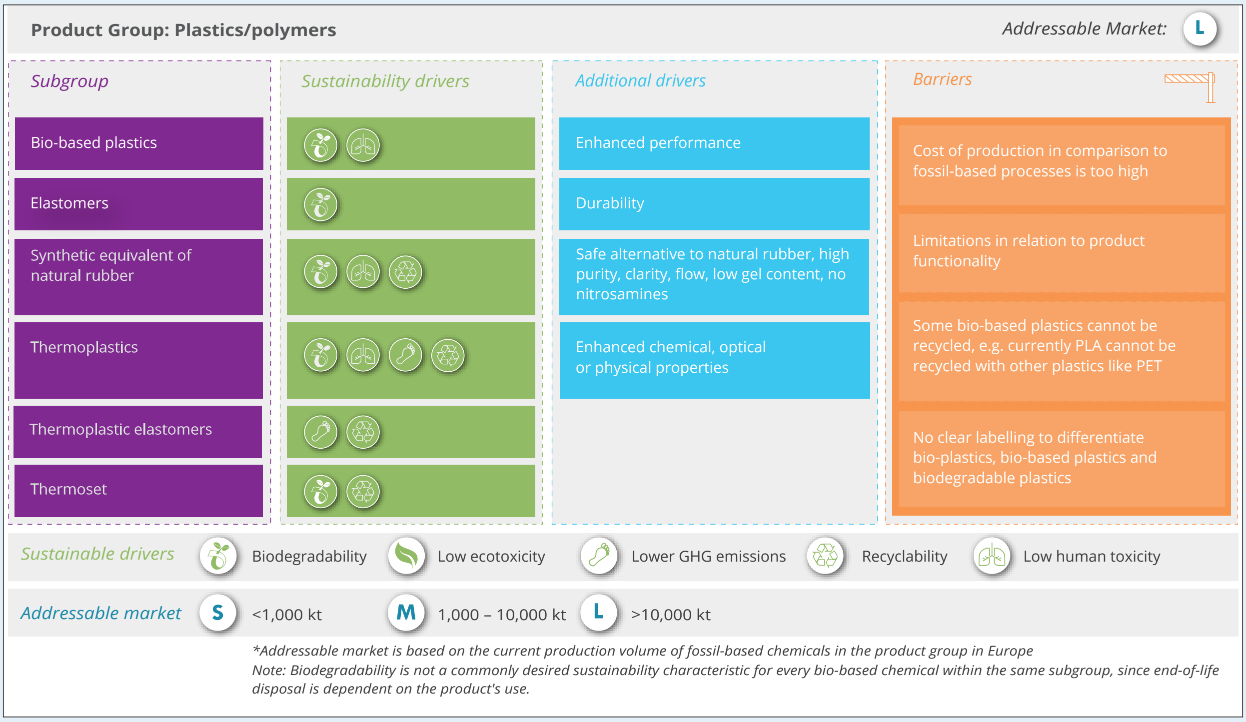


Figure 42: Pictorial summary of the plastics/polymers product group

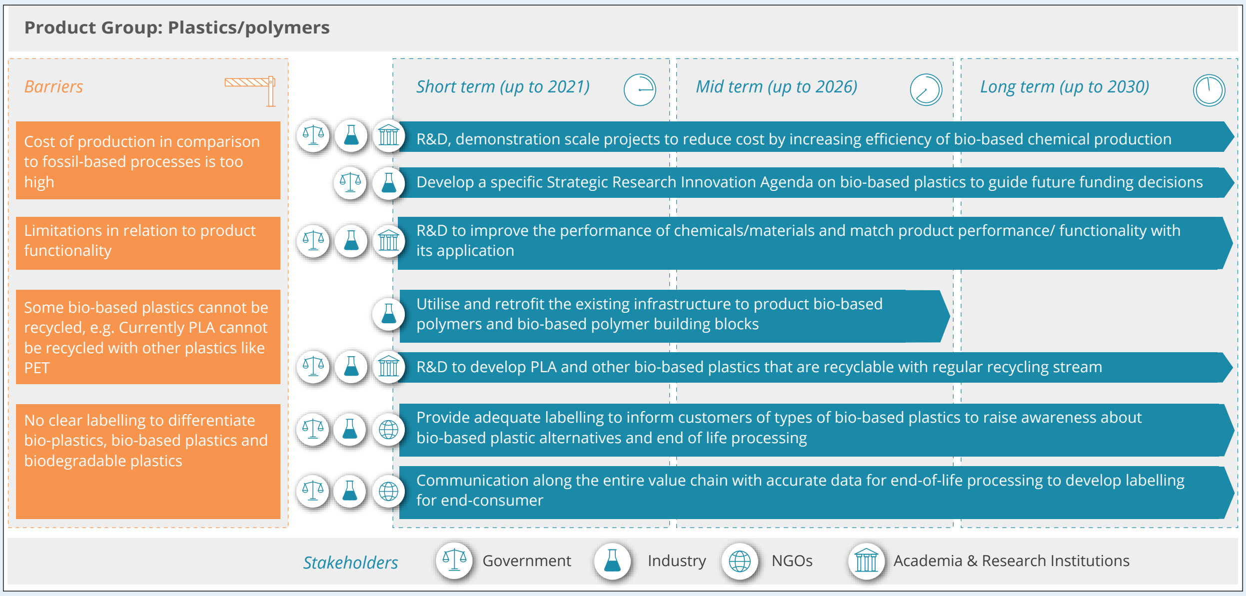


Figure 43: Roadmap to increasing the bio-based share of chemicals in the plastics/polymers product group

3.10.4 Summary

- 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 >1,200 kt/yr, while fossil-based production is ~70,000 kt/yr.
- Therefore, out of the nine product groups, the addressable market of fossil-based plastics/polymers production in Europe is the largest in the nine product groups (large addressable market is considered as >10,000 kt).
- Diverse bioplastics are being developed that can be drop-ins, compostable and non-biodegradable, but few are truly biodegradable.
- Some of 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 plastic should provide adequate labelling to inform customers of types of bio-based plastics to raise awareness about bio-based plastic alternatives 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.

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

The progress towards a bio-based economy is slower than expected by its proponents. This is also true for bio-based chemicals. To provide a solid foundation for the roadmap, develop a better understanding of issues in the bioeconomy, and accelerate deployment and commercialisation, RoadToBio identified and summarised general barriers that impede increased utilisation of bio-based resources in the chemical and material industry.

The complex situation for bio-based chemicals and materials can be summarised in a competition triangle as shown in Figure 44. The chemical and material use is competing with bioenergy for biomass not used for food or feed, but due to the support system for bioenergy the prices for biomass and land have greatly increased. This makes access to biomass for chemical and material use more expensive, which is not compensated for by support measures. When looking at competition with fossil resources, the petrochemistry is subject to heavy taxes for energy applications but not for fossil-based chemical or material applications. Consequently, the chemical or material use of biomass is in competition with the petrochemical industry without any supporting measures. On contrary, the increased biomass prices are not counterbalanced by taxes on fossil carbon sources. New bio-based industries must therefore develop in the face of well-established and long-optimised mass production industries.

RoadToBio focuses on the EU chemical industry and its share of bio-based resource use. Besides the product-group specific analysis of barriers in Chapter 3, some wider issues exist that concern the chemical industry's role in the bioeconomy. In this chapter, we refer to these as general barriers. We give an overview of the crucial general barriers and provide some recommended actions to overcome these. The collected set of actions are a result of project-internal discussions, stakeholder discussions and feedback, as well as recommendations from other EU projects or strategy documents.

To provide some structure, 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 and investment
6. Research and development.

For each category, we have collected several barriers and recommend actions that could provide a viable strategy to remove or overcome the respective barrier.

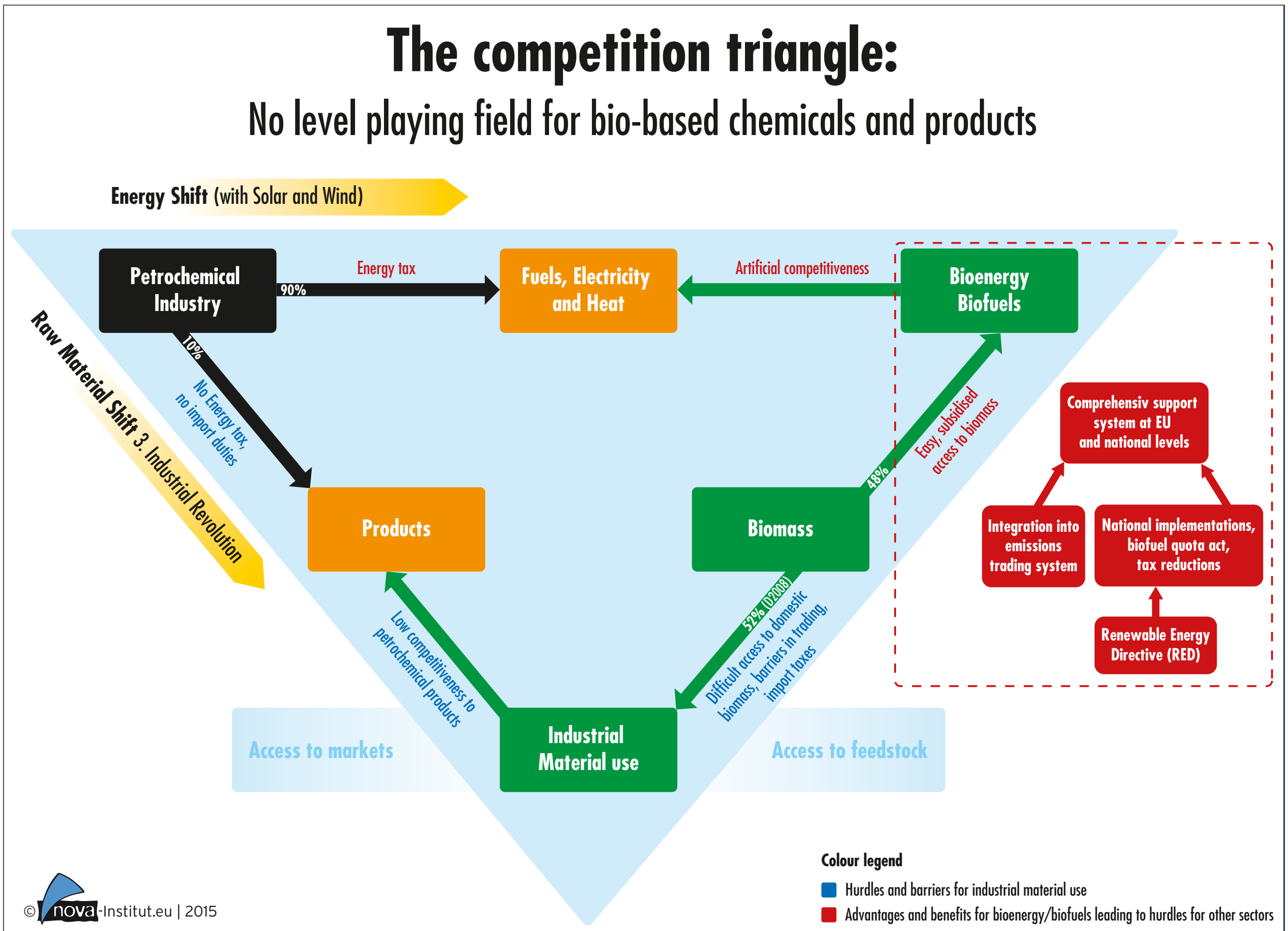


Figure 44: The competition triangle for bio-based chemicals and products (Source: nova-Institute 2015)

4.1 Barrier Group: Access to feedstock

A commonly known barrier for the bio-based economy in the EU, and often the first among barriers mentioned, is limited access to cost-efficient feedstocks for consistent large-scale production of bio-based chemicals and materials. There are two reasons for this. First, availability of biomass in general can be constrained for industry purposes: Covering food and feed demand is the first priority of biomass supply. In combination with seasonal fluctuations and weather dependence, the amount and quality of biomass available at cost-competitive levels for industrial purposes can fluctuate significantly. Second, within industrial processes, incentives exist to utilise the biomass for bioenergy purposes, while no similar incentives are available for biomass utilisation for chemicals, materials or products.

4.1.1 General barrier: Low availability of biomass

In 2013 the biomass harvested and used in the EU was 806 Mt in dry matter (578 Mt agriculture, 227 Mt forestry, 1.5 Mt fisheries and aquaculture, 0.03 Mt algae). Overall including trade and grazing, the EU uses more than 1 billion tonnes of dry matter of biomass each year. Considering both domestic supply and trade, agriculture (65.5%) is the largest supplier of biomass in the EU-28, followed by forestry (34.2%) and fishery (0.4%) [56].

It is estimated that approximately 50% of biomass is used for feed and bedding, primarily for livestock production. The next significant demand for biomass is for bioenergy (19.1%), closely followed by bio-materials (18.8%). But chemicals only make up a tiny fraction within the bio-materials category, the overwhelming majority is covered by solid wood products and wood pulp [56, 2].

In case of the chemical industry, biomass can either be converted into new functional materials and chemicals or into drop-in intermediates that replace platform chemicals. For most of the biomass conversion pathways today, oils and sugar play a central role. Sugar is the preferred feedstock for production of short chain chemicals, while vegetable oils, animal oils and fats are ideal for chemicals which consist of long chains, such as lubricants and paints. Palm and soya oil are among the main feedstocks used in the EU's oleochemical sector [57].

In a study by Wageningen University, the biomass requirements of the EU chemical industry were calculated if a portion of petroleum-based chemicals and materials were to be replaced [58, 57]. Based on that study, a **replacement of 20% of petroleum-based chemicals and materials in 2020 would require 34 Mt/yr of biomass, and for a replacement of 30% in 2030 at least 50 Mt/yr biomass are required.** The study considered corn and sugarcane for the analysis (1G feedstocks). Further, it was estimated that 18 Mt/yr of bio-based polymers and 17 Mt/yr of intermediate bio-based chemicals could be produced by 2030 [57, 58].

Many stakeholders have singled out the availability of cost-efficient feedstock as the most important barrier, as the raw material costs determine the economic feasibility of the value chain. Several issues add up to this situation: Costs of feedstock are generally higher in Europe because of higher labour and operating costs, climatic conditions and regulations. The seasonality of biomass cropping leads to a natural fluctuation of feedstock availability and quality, which is a difficulty for the continuous requirements of industry processes. Furthermore, collection, storage and distribution of biomass are still underdeveloped – the local character of biomass supply and expensive long-distance transport requires innovative and possibly local solutions [25]. Companies also consider space requirements for a large-scale bio-based economy problematic, in times where land is increasingly considered a limited good. In the following, we summarise recommendations and learnings from the BIO-TIC project, from the Commission Expert Group on bio-based products, Working Group "LMI evaluation" [19], from stakeholder input and from feedback within the RoadToBio project.

Recommended action: Increase yield of existing biomass production

An elegant solution to increase biomass availability would be to increase the yield of existing biomass production – thus avoiding additional land use demand. The potential is there: The High Level Expert Forum of the FAO [26] stated back in 2009 that *"the potential to raise crop yields even with the existing technologies seems considerable"(FAO, 2009).*

There are two technology fields we would like to highlight for increasing crop yield: genetically modified organisms (GMO), or crops in this case, provide opportunities to improve productivity and quality of the crops for increased land-efficiency – potentially in combination with increased sustainability. GMOs are a controversial topic: with long-term effects unknown, the protection of human health and environment should always be ensured, and in some application fields of chemistry, GMO might be considered particularly critical (e.g. in cosmetics). In addition to this, European legislation is slow, expensive, requires labelling and the recent ruling of the European Court of Justice on the much-noticed CRISPR gene editing technique classified any organism modified by this technique as GMO, resulting in very strict conditions under which the technology can be applied. In comparison to other regions of the world, with more liberal regulations towards GMO, plant biotechnology in the EU is subject to much stricter rules. These rules will impact plant breeding and plant biotech in Europe, particularly applied-research projects and the introduction of improved crops in Europe. Scientists have lately released several position papers urging the law to be changed in the short term, and one of their key issues is that the ruling on CRISPR is likely to discourage start-ups and small biotech companies [27].

An alternative is the application of increased knowledge and modern technology in agriculture: Precision farming and high-tech like artificial intelligence, robots and drones can support an agricultural transformation towards higher yields with less resource consumption. Vertical farming is an alternative that can offer agricultural production in or close to cities, using urbanised land. Based on the knowledge collected in recent decades, the use of efficient and sustainable farming practices such as intercropping should be encouraged, which can help in reducing soil erosion and improving soil fertility, maintaining or improving farming efficiencies and yields. Intercropping also provides farmers with flexibility to decide anew every year based on the changing agricultural price structures, enabling them to adapt to the liberalised agricultural legislation of the EU. A concrete action in that regard could be to approach farmer associations and discuss how to best implement modern technology and today's knowledge into practice.

Recommended action: Identify and establish new sources of feedstock

There are still large opportunities for using dedicated non-food energy crops grown on marginal land as well as the residues of existing feedstocks, such as, lignocellulosic materials from forests, agricultural residues and food or bio-waste. These so-called second generation feedstocks are favoured by public and policy makers as routes that do not compete with food production or land use, but there is often a lack of knowledge about how much of these wastes can be utilised and at what prices, in particular without adversely impacting upon other markets [25]. For these topics, a closer harmonization with the circular economy concept and with the waste system, in particular the Waste Framework Directive, could increase the availability of wastes and residues as feedstocks and shape the concept of a circular bioeconomy. The RoadToBio deliverable D2.5 "The bio-based and the circular economy" [59] goes into further detail how the chemical industry connects bio-based and circular concepts. In order to develop and establish new feedstock sources, the following actions can be recommended:

- (Continue to) investigate novel feedstock opportunities:
  - Within agriculture, more than half the globally harvested dry mass consists of **agricultural residues and inedible biomass,** such as cereal and legume straw; shoots of tuber, oil and sugar; vegetable crop stalks, leaves and shoots; and fruit and nut tree prunings. A major barrier to increasing the use of agricultural and forestry residues are the costs associated with adapting harvest logistics, which are often higher than costs of primary fossil materials. Also, residues are an important factor for soil quality and need to remain on the field to a certain extent in order to avoid the depletion of nutrients. Local biorefining systems that smartly match residue supply and material demand need to be developed, as the wide dispersal of residues does not fit the economies of scale of the existing industrial oil-based production system [60].
  - Municipal solid waste contains **food waste**, which is a potential feedstock for the bio-based chemistry – signifying a high amount of fermentable materials which are mixed up with non-fermentable materials, which are thus difficult to access.
  - According to recent insights from the S2Biom[28] project, the amount of available **lignocellulosic** biomass in the EU by 2030 is estimated to be at least around one billion tonnes [61]. How¬ever, as mentioned above, the biomass types that are currently used by the chemical industry are mainly sugar (from sugar beets and starch-crops) and vegetable oils such as rapeseed, soya and palm oil. Switching to other types of feedstock proves difficult both from a technical and an economic perspective
  - Marine streams: The oceans offer large opportunities for the cascading use in the bioeconomy. These include for example the use of fisheries discards (~40% of caught fish), algal biorefineries, seaweed farming, multi-use of marine space in off-shore platforms, zero-waste and circular aquaculture, new products from jellyfish, new pharmaceuticals from marine ecosystems. Stakeholders mentioned algae in particular as a promising feedstock choice for the future. The BBI-JU also supports a number of algae-based projects for the bioeconomy, e.g. the ABACUS project [62], the VALUEMAG project [63] or the MAGNIFICENT project [64]. The results of several previous projects, however, also give reason for some caution of expectations. The utilisation of alger is not easy and so far quite costly.
- Empower primary producers:
  - Enable producers to make informed decisions on the use of their residues [25]
  - Ensure that producers are receiving a fair price for collecting waste that can be used as a 3rd generation feedstock [25].
  - Actively involve producers as stakeholders
  - At a workshop, RoadToBio stakeholders also mentioned the option to empower primary producers. It was referred to the US Biomass Crop Assistance Program [65], which provides funds to farmers and forester landowners that grow and harvest "nonconventional" biomass. Examples are perennial crops or agricultural and forestry residues, which are intended to be used for energy and bio-based products in biomass conversion facilities. A similar system could be established in the EU, e.g. via the Common Agricultural Policy.
- Specifically for bio-based plastics in waste collection and recovery systems: They have the potential to replace fossil-based plastics, but require improved volumes and logistics as well as additional research for their recycling (low volume, potential problems for other plastics recycling, anaerobic digestions of bioplastics into biogas) as well as regulatory steering and support to reduce reluctance from recycling stakeholders fearing higher costs [19]
- Focused research and development towards cascading use and utilizing of currently unused waste streams. There are several EU projects ongoing that focus on the utilization of such waste streams: Some examples are the Lifecab project [28], the Embraced project [29] and the Agrimax project [30].

28 S2Biom - Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe, www.s2biom.eu

- If in the future, demand in biofuels starts to decrease gradually as the decarbonisation of transport advances, feedstock might become available for the chemical industry in order to increase its biomass supply without the need for more arable land [34].

Recommended action: Consider first generation biomass for material uses

While the Renewable Energy Directive pushes biomass for energy use, the chemical industry shows tendencies to, at least publicly, avoid promoting the utilisation of food crop biomass for chemicals or materials. Concerns remain regarding the sustainability impacts of using first generation (food) crops for anything other than food or feed applications and in fear of refuelling the arguments of the food vs. fuel debate. Instead, the focus is often entirely put on the above mentioned second and third generation crops. But analyses show that food crops often have high land efficiency, deliver additional by-products (which could also be used for chemical products) and can act as a buffer in times of crop failure. In other words, these crops usually provide more biomass per hectare than other renewable feedstocks, and their competition for arable land is counterbalanced by the excellent land efficiency of first generation crops (especially sugar beet) and protein-rich coproducts (especially wheat and maize) [31].

At the same time, there is room for expanding opportunities to use this biomass for high value products in ways that do not compromise global food needs. A good example is sugar: When comparing commonly cultivated plants, sugar beet and sugar cane excel with an unsurpassed yield and per-acreage-efficiency. As of 2018, there is a global excess production of sugar (for example due to the end of the sugar quota in Europe), while consumption of sugar in society is trending down. The resulting sugar surplus could be picked up by the European chemical industry at competitive prices, but the industry is reluctant to do so, potentially missing out on a large bio-based feedstock. A recent, comprehensive sustainability assessment shows that first generation sugars are feasible for a sustainable resource strategy in Europe's bio-based chemical industry and results clearly indicate that the negative image of first generation feedstocks portrayed in the public discussion and the concerns of certain stakeholders are in no way founded on scientific evidence [31].

Nevertheless, the chemical industry continues to shy away from first generation biomass, reluctant to rekindle the competition with food and the public discussion. Of course, a safe food supply will always be the first priority. But with higher land-use efficiency and new technologies like vertical and urban farming, which do not compete with existing land use, but rather add to land availability, it seems counterproductive to focus exclusively on less efficient biomass alternatives like residues and wastes. Though, non-edible second-generation biomass should be used as a developing cornerstone for the future. When sufficient supply capacity and flexibility is given, food crops can cover both the food/feed demands and deliver valuable assets efficiently to the chemical industry.

Recommended action: Increase efficiency of biomass supply chains

In comparison to fossil feedstock, the logistics of bio-based feedstock can be more demanding: Fluctuation of seasonal harvest, changing level of quality, and difficulties to properly collect, store and transport biomass must be considered, and are currently lacking across much of Europe. There is a need to understand how this can be optimised:

- Although the EU has supported several research projects on biomass mobilisation (e.g. S2Biom, SIMWOOD, INFRES, LogistEC, EuroPruning), infrastructure and routes for mobilisation of waste and residues are currently lacking across much of Europe and there is a need to understand how this could be optimised. The well-established logistical chains within the forestry industry and for straw collection in Denmark might offer insights and learnings. [25]

- With digitalisation advancing, biomass supply chains can become more efficient, especially with improvements on feedstock-related information, in distribution and with ensuring a continuous feedstock supply. ICT-BIOCHAIN is a BBI-JU project that commenced in 2018 with the main objective to identify opportunities for ICT to increase the efficiency of biomass supply chains in the bio-based industry [66]. This way, the project can play a key role in making Europe's bio-based supply chains more efficient and contributing to several objectives of BIC's Strategic Innovation and Research Agenda (SIRA) for 2020 and 2030 [4].

- Establish a platform for feedstock suppliers, logistic partners, consumers (in this case the chemical industry) to optimise the use of the raw materials. On such a platform, feedstock suppliers (farmers, refiners) can offer their (refined) biomass to local logistics partners to take over its transport and the chemical industry players indicate their demands and purchase intentions. Such a platform would lead to a faster and more efficient use of resources.

- Again, empowering primary producer is an option that could be explored: Purchase guarantees could ensure a steady income for the primary producer and a constant biomass supply for the chemical industry – but whether farmers could be convinced to commit to such purchase guarantees in times of a liberalised Common Agricultural Policy (CAP) remains to be explored.

Recommended action: Develop biorefineries

In a biorefinery, biomass is transformed into a spectrum of valuable products such as chemicals, materials, feed and fuels, electricity and, as a by-product, heat. Biorefinery concepts aim to utilise biomass to the fullest extent, but also apply specific technologies to isolate components, prevent waste, and optimise logistics and value chain aspects. The European Commission has encouraged biorefineries to adopt a cascading approach that favours highest value-added and resource efficient products over e.g. bioenergy [67].

The Bio-based Industries Consortium (BIC) and nova-Institute have developed a poster that maps the commercial biorefineries in Europe as of 2017. In total 224 biorefineries have been mapped. Biorefineries are developed with the intention to process more diverse raw materials, including agricultural, forestry and marine biomass resources. An ideal biorefinery could process a wide range of biomass into a spectrum of marketable products and energy, like feed, fibres, bulk and fine chemicals, fertilisers, biofuels, power and heat. By combining different products in a highly integrated production process, available sources of biomass can thus be used more effectively [60].

Currently, there are a number of projects with a focus on biorefineries, but such complex biorefineries do not exist as of yet. The already mentioned Embraced project aims to demonstrate, in a relevant industrial environment, a replicable, economically viable and environmentally sustainable model of integrated biorefinery based on the valorisation of the cellulosic fraction of post-consumer absorbent hygiene products (AHP) waste in producing bio-based building blocks, polymers, and fertilisers. If functional, it would provide an example for how biorefineries can support the circular economy, close the cycle of raw materials and minimise the use of primary resources.

Despite progress being less than envisaged, biorefineries are still often cited as having potential to play a key role in providing more refined biomass. They can deliver a variety of bio-based products to the chemical industry and at the same time provide the opportunity for joining bio- and circular economy principles, especially when using second-generation feedstocks from outside the food and feed sector.

4.1.2 General barrier: Non-level playing field

For bioenergy and biofuels there are strong supportive policies in effect, such as the Renewable Energy Directive (RED) [18] or Member State incentives. Currently, the use of biomass for material purposes is only encouraged by small and isolated incentives, resulting in a situation where the use of biomass for bio-based products is disadvantaged compared to its use for energy production [19]. This is in contrast to studies claiming that the material use of biomass usually leads to 4-9 times higher-value products and 5-10 times more employment when compared to energy use [20]. The incentives of the RED lead to a state in which several biomass sources are significantly more readily accessible for bioenergy and biofuels compared to bio-based chemicals and materials, leading to market distortions and disadvantages for value creation, employment and innovation in the EU.

Recommended action: Establish a balance between the different uses of biomass

The idea of a balance between bioenergy, biofuels and bio-based products, referred to as "a level playing field", is discussed extensively throughout Europe and multiple acknowledgments of its importance are made in strategies published at EU level, by some Member States and regions. But as already mentioned, the current policy situation and in particular the focus on increased renewable energy in the EU lead to a distortion, which directly contradicts the desired "policy neutrality in access to biomass for different purposes"[21].

The 2012 European Bioeconomy Strategy, its update in 2018 [2], and the Circular Economy Package all encourage a cascading use of renewable resources, with several reuse and recycling cycles. The RED, and also the updated RED II, provide incentives to the energy use of biomass, either directly incinerated or transformed as a biofuel. But once the biomass has been used for energy, it can no longer be reused or recycled. While the RED is undeniably highly important to achieve the climate and energy targets of the EU, it shifts biomass towards use in energy applications. This contradicts the idea of an optimised cascading use: where possible, biomass should first be utilised for chemicals, materials and products, kept in the loop for as long as possible, and only afterwards be finally used for energy. This may not always be feasible, and there are also potential benefits e.g. from commercial development of cellulose-to-ethanol plants, where a scaled-up economy could also provide cellulosic ethanol as a building block for bio-based chemicals and materials. But could the same support not also be provided to biomass utilisation outside of energy use? Just recently, the International Energy Agency (IEA) called for a level playing field in the policy landscape [22].

Two potential pathways for action must be considered:

1) Align the incentives for biomass utilisation so that material purposes receive the same benefits as bioenergy. This could be achieved by opening up the RED for material use, making bio-based chemicals and materials accountable for the renewables quota of each Member State. The idea has been further discussed in papers by nova-Institute [23] and the OECD [24] but did not gain traction in policy making until now. The upcoming RED II, which will be valid up until 2030, does not include any such aspects. It therefore appears unlikely that this option will be of any relevance until the end of the scope of the RoadToBio project.

2) Incentivise the cascading use of biomass. This option would explore and develop higher-value applications of biomass and support them by various means so that they can be competitive to the direct biomass use for bioenergy. Following the above-mentioned higher-value products and employment benefits, as well as circular economy thinking, there are many valid reasons for a prioritisation of material use over the direct energy use. A potential lever to incentivise cascading use could be fostering the development of biorefineries by subsidising non-energy outputs. Stakeholder feedback also suggested regulations (or the removal of regulations) as an option.

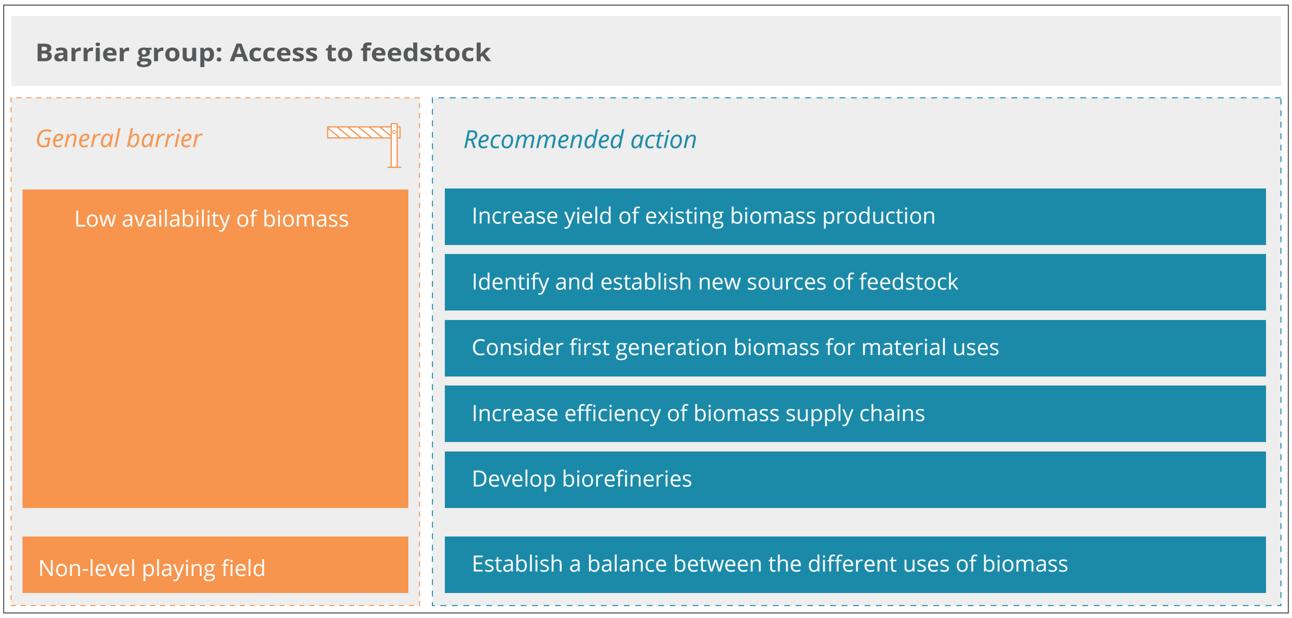


Figure 45: Summary of the general barriers and recommended actions for the barrier group access to feedstock

4.2 Barrier Group: Competition with established fossil industry

The chemical industry is a long-established and highly optimised industry. Yet there is consensus that the chemical industry must become sustainable. A switch to an increased production of renewable chemicals is desired, yet there are too few incentives to push the chemical industry to actively pursue the switch. Given that established methods are proven to work economically and technologically, why switch? Long-term societal needs for sustainable development indicate that maintaining the existing fossil-based dominated status quo is not an option and a switch towards sustainability and circularity needs to happen. Of course, hurdles to achieving these goals exist, for example, higher production costs or technological immaturity of bio-based production processes of chemicals. However, there is room to manoeuvre around these hurdles without directly targeting them, for example, by artificially increasing the competitiveness or enforcing mandatory use of a bio-based alternative. This can be particularly interesting in the case of bio-based drop-in chemicals: once these start to compete with the fossil-based counterpart, a switch could be initiated where the bio-based drop-in chemical ties seamlessly into the existing infrastructure.

Therefore, providing incentives to the chemical industry in order to more actively pursue the switch could go a long way. These incentives could come from regulation, i.e. politically mandated instruments that the chemical industry would have to comply with. A good example here is the renewable energy policy of the EU, which develops a long-term plan to increasingly decarbonise our energy and transport segments. Of course, organic chemistry itself cannot be decarbonised. To this end, the nova-Institute recently proposed a different concept focusing on renewable (including recycled) carbon sources for the chemical industry, either coming from biomass, carbon recycling, or direct carbon capture from air. Alternatively, the chemical industry itself could actively push for voluntary incentives that support a switch. Of course, this loops back to the established and optimised processes and beckons the question "Why should anyone voluntarily opt in for a switch?", especially if it is costly and disadvantageous in the short term. Switching towards bio-based and sustainable solutions might perhaps be better considered a long-term investment: It allows to prepare for future changes in regulation and policy - climate change is high on the agenda and the recent Conference of Parties (COP) in Katowice 2018 [32] has agreed on a set of rules how countries will follow the goals of the Paris agreement [33]. Investing into bio-based chemicals will help to prepare to these foreseen developments and mitigate risks to the business. Such self-initiative could also help to change the public perception of the chemical industry and turn it into an integral part of daily life, something desirable and accepted in the eyes of society. Finally, taking the initiative might provide the chemical industry with the agenda to actively design and shape the incentives and the overall development towards increased sustainability – not simply dictated by regulations and policies from the top, but rather in close collaboration.

4.2.1 General barrier: Bio-based alternatives not cost-competitive

When comparing bio-based drop-in chemicals with their fossil-based counterparts, the typical key barrier is higher production costs for the bio-based option. This lack of cost-competitiveness is a result of several of the other barriers mentioned in this document (e.g. low TRL, high development costs, high feedstock costs) but it is a critical barrier for the chemical industry. If a bio-based chemical has a cheaper, fossil-based counterpart, it requires particularly good or highly specific reasons to still opt to produce the bio-based alternative. The following recommendations directly target the cost-competitiveness of bio-based to fossil chemicals:

Recommended action: Implement market-pull instruments

Market-pull instruments are policy instruments that aim to achieve their objective by increasing demand for products or services. Such pull mechanisms are often designed to overcome market failures and catalyse innovation by setting incentives for participants to achieve a specific goal. They can be a potent instrument to promote and establish the bio-based chemical industry. At the same time, they need to consider that simply because a product is bio-based, it does not necessarily become more sustainable. Market-pull instruments should therefore not focus on bio-based materials alone but consider additional attributes like increased sustainability or lower GHG emissions – desirable sustainability characteristics.

Some exemplary tools exist in other countries, e.g. the BioPreferred Federal Procurement Preference Program (https://www.biopreferred.gov/BioPreferred/) operated in the United States, which mandates "affirmative public procurement practices". Public procurement from the EU would send a strong signal and work as a market-pull mechanism to stimulate the growth of bio-based products. The EC's Expert Group for Bio-based Products published 15 recommendations in 2016 for an increased uptake of bio-based products [35], but implementation has so far proven difficult.

An alternative could be to politically set up rewards for chemicals and plastics with low greenhouse gas emissions or specific labels that indicate the share of bio-based carbon in a product. One example for such a system is the Renewable Chemicals Production Tax Credit program that was recently introduced in Iowa [68].

Stakeholder feedback towards market-pull instruments was partly critical, mostly because they artificially enable competitiveness of the supported products or services, but only as long as the support exists. RoadToBio Stakeholders agree that continued research and development on bio-based chemicals is essential towards truly competitive products on the free market. While this statement might be true, we would like to point out that in times of climate change targets and sustainable development goals, we might simply not have the time to wait for necessary breakthroughs in R&D. In a world with clear political goals (reduce GHG emissions, increase sustainability and circularity) market-pull instruments can be highly effective instruments to steer the overall economic development towards these goals.

Another often cited argument is that some market-pull instruments are difficult to implement on a regional level, like in the EU, due to potential disadvantages on the global markets. Therefore, such instruments would have to be implemented on a global scale, which seems unattainable in the current complicated political setting. We would like to argue against this opinion: The RED is a well-functioning EU market-pull instrument, and even a carbon tax, currently often and widely discussed in different forms and also mentioned in the next recommended action "reduce fossil-based feedstock support", could be implemented on a European level. Products manufactured in the EU would then be taxed, but the tax would be returned if the product is exported outside of the EU. Whereas products manufactured outside of the EU would have to pay the tax once they are imported into the European market.

The following list is a set of interesting market-pull instruments, which policy makers could use to stimulate the switch towards a chemical industry that uses renewable carbon instead of fossil-based carbon. The current options for renewable carbon are bio-based carbon, recycled carbon and carbon directly from atmospheric CO_2. For more explanations on the concept of renewable carbon confer to reference [34].

- Quotas: Establishing quotas of renewable carbon in "drop in" products in the chemical and plastics industries (e.g. 30 per cent of all polypropylene must be made from renewable carbon by 2030) [34]
- Reporting: Obliging companies from the chemical and plastics industries to issue an annual report about the percentage of renewable carbon used in their production processes [34]
- Certificates and labels: Development of certificates and labels which indicate the share of renewable carbon [34]
- Tax credits for the sequestration, storage and utilisation of CO_2 [34]
- Tightening of environmental requirements for chemicals [34]
- Binding targets for the use of renewable carbon in the chemical and plastics industries [34]
- Tradeable biotickets (producers of bio-based chemicals / materials receive a bioticket and can sell these tickets to fuel producers, who then use it to fulfil their renewable energy obligations) [34]
- Public Procurement as part of a general policy to procure sustainable and environmentally friendly products, or using more innovative instruments, such as PCP (Pre-Commercial Procurement), PPI (Public Procurement of Innovative Solutions), or GPP (Green Public Procurement) [34,35]
- Political preference of chemicals and plastics with low greenhouse gas emissions [34].

Recommended action: Reduce fossil-based feedstock support

The fossil-based industry receives comprehensive support from governments, often as instruments to support national industries and connected jobs. A recent study by researchers at the Overseas Development Institute (ODI), Oil Change International (OCI), the International Institute for Sustainable Development (IISD), and the Natural Resources Defense Council (NRDC) identified that, despite promises by G7 and G20 members to phase out fossil fuels and tackle climate change, at least US$100 billion goes into the support of production and consumption of oil, gas and coal. Many countries are currently largely targeting to end public finance of coal mining, but other fossil fuel areas continue to receive new subsidies [69].

In many cases, bio-based alternatives are also subject to much stricter regulations, e.g. when having to fulfil certain sustainability criteria. This creates strong advantages for the well-established fossil industry and increases the difficulty for the bio-based industry to establish a foothold. In order to ease the entry burden for the bio-based industry, the following actions should be considered:

- **Discontinuation of any funding programmes in the fossil domain.** As mentioned above, the G7 states alone pay more than 100 billion dollar a year for promoting and using oil, gas and coal [36]. This included $81 billion in fiscal support through direct spending and tax breaks; and $20 billion in public finance on average per year in 2015 and 2016. Whitley et al. [69] recommend to publish comprehensive fossil fuel subsidy reviews and then establish country-level plans for fossil fuel subsidy phase-out.
- **Higher costs for CO_2 emissions:** The German chemical industry association („Verband der chemischen Industrie e. V., VCI) has committed itself to a globally uniform pricing of CO_2 emissions, at least in the G20 countries, which are responsible for 80% of global emissions. This would establish a "polluter pays" principle in relation to climate change and provide strong incentives for producers to switch towards less emission-intensive processes. Costs for CO_2 emissions could be either raised via uniform CO_2 prices, e.g. set via the Emission Trading System (ETS) or by the implementation of a CO_2 tax.
- **Taxation of fossil carbon** in chemicals and plastics (not CO_2 emissions): An alternative idea for the organic chemistry or material industry, where taxes are not put on the CO_2 emissions, but instead on the raw materials containing fossil carbon. This would provide a simpler system than calculating CO_2 emissions via life cycle assessment.

Currently, the implementation of a CO_2 tax is frequently mentioned as necessary by many stakeholders and international momentum and political will to impose such a CO_2 tax is increasing. The 2018 IPCC report "Global warming of 1.5°C" mentions CO_2 tax as the most effective climate policy and among economists there is great unanimity that carbon pricing is 'the only way in which global warming can be effectively prevented' [70]. Even a petrochemical giant like Shell is proposing the introduction of a CO_2 price. There is also quite a bit of movement to be identified: The environment and energy ministers of nine German federal states have stressed their demand to the federal government to introduce a minimum price for CO_2 emissions. French President Emmanuel Macron has demanded a minimum CO_2 price of 30 €/t – currently the CO_2 price in the ETS is rising but still below Macron's minimum price [34], with prices fluctuating around 21-22 €/t in March 2019. A combination of carbon tax and higher ETS costs could form a strong instrument to force a reduction of CO_2 emissions. These would likely be realised by a several actions, e.g. upgrading older technology, increasing efficiencies, improving capture of waste gas streams and changing to feedstocks with reduced CO_2 emissions, such as bio-based feedstocks.

4.2.2 General barrier: Lower performance of bio-based alternatives

The modern bio-based economy, in particular the biotechnological field, is a comparatively young field. Many processes and bio-based products are still in development, sit at low TRLs or have been only quite recently introduced to the market and are still learning, adapting and optimizing. As a result, the actual performance of the bio-based chemical or material might be lower in comparison to an established, fossil-based alternative. In the end, the critical question always is: Will the bio-based option in the long run be able to compete with the existing alternatives? If the relevant actors are convinced that this is the case, then further R&D is required, continuously testing, adapting, changing and improving the bio-based chemical products to improve its performance and efficiency.

Recommended action: Continue and expand R&D
This recommended action is of course a well-known and often repeated one. But it is also essential to the bio-based economy: Being the aforementioned relatively young field, progress is often achieved by trial and error until a viable solution is found. But following this path, the bioeconomy will be able push its own boundaries step by step, investigating novel ideas, upscaling new technologies, standardising processes and increasing the possible applications and the competitiveness of the new developments. And although research and development often require years of work and dedication, and it is therefore less relevant for a 2030 roadmap, the recommendation is clear: continue and expand on R&D – more specific recommendations on are detailed in the last Barrier Group: Research and Development: in this chapter.

Recommended action: Industry-driven or voluntary incentives
There are a number of reasons for the industry to develop and implement voluntary incentives:

- They allow to harmonise methodologies, assessments and evaluations
- They enable positive communication to convey an improved image of the chemical industry
- They enable the chemical industry to actively shape the transformation process towards a sustainable, circular economy. With clever long-term planning, this can help to avoid disruptive regulations (e.g. bans).

How these voluntary, industry-driven incentives could look and how they could be implemented are questions that go beyond the scope of the RoadToBio project, but we hereby introduce three ideas:

Create a collaborative platform for promising bio-based chemicals: The chemical industry could come together to create a combined collaborative platform for bio-based chemicals that are promising for the future. In order to save time and to avoid duplication or contradictory developments, the platform could be offered as an annual/regular/periodic event by BIC. These events could be used to form collaborations, find relevant partners, learn from others and design aligned and concerted communication and marketing strategies.

Annual ranking or reporting about fossil-based or bio-based share in the portfolio of companies in the chemical industry: This action would develop an annual report that shows either the fossil-based or bio-based share of all companies willing to be involved, similar to how it is practiced in terms of sustainability or GHG emissions (e.g. GHG Protocol). The annual report could become a document that first attracts companies in the chemical industry putting a larger focus on improving their sustainability, showcase annual progress of the participating companies and in the mid- to long-term put pressure on companies that are not willing to participate and disclose their portfolios.

Develop harmonised approach for sustainability assessment: For an increasing variety of feedstocks and products the environmental performance is being determined. But, so far, there is no coherent European framework for the environmental performance assessment of chemicals, materials or products. This hinders the environmental benchmarking of bio-based alternatives, which can be a strong incentive and advertisement for market introduction and uptake.

Many further ideas are possible, e.g. to introduce voluntary targets for bio-based products. Stakeholder feedback focused largely on sustainability assessment by lifecycle assessment (LCA), where more harmonised approaches could lead to simpler processes and improved comparability. For example, product category rules for important fossil and bio-based products could be compiled to calculate comparable LCAs. Other suggestions were to develop an integrated toolkit that covers all three pillars of sustainability by techno-economic analysis, LCA and social criteria risk management.

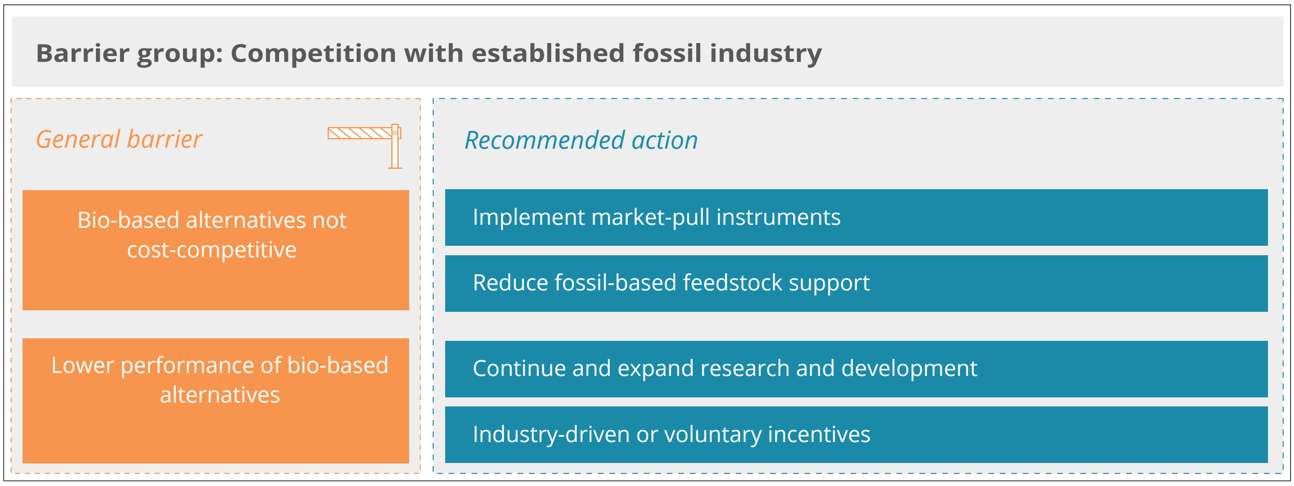
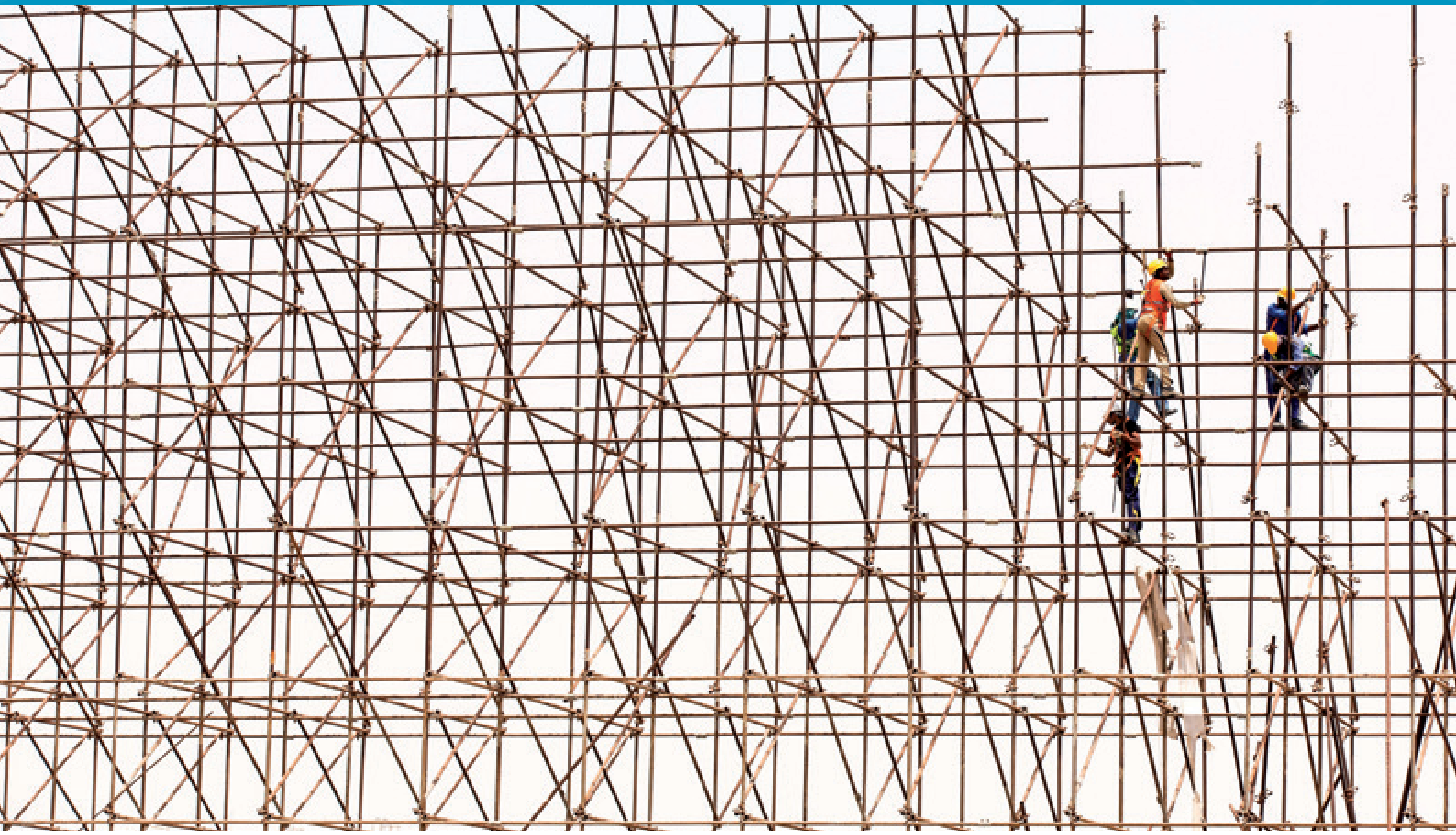


Figure 46: Summary of the general barriers and recommended actions for the barrier group competition with established fossil industry

4.3 Barrier Group: Policy and regulatory framework



The number of relevant legislative acts that impact the bioeconomy is high, but often these documents are designed with focus on a different topic. Take, for example, the Common Agricultural Policy (CAP), centrepiece for the agricultural policy in the EU, which focuses on food, environment and countryside. But at the same time, agriculture is the most important raw material provider of the bioeconomy. There is currently no specific EU legislation supporting bio-based chemicals and materials. Many existing policies hamper market uptake of bio-based chemicals and materials either because they were designed with a different goal in mind (e.g. the RED) or because the bio-based economy, as a new market field, simply was not considered when the legislation was originally drafted. This was investigated in further detail in the RoadToBio deliverable D2.1 “Report on regulatory barriers” [71], where several EU legislations and how they create barriers for the bio-based economy were investigated.

In the final stakeholder workshop in February 2019, it was remarked that the Nagoya Protocol on Access and Benefit Sharing [72] and its implementation should be mentioned as an additional hurdle because of the insecurity they create. The Nagoya Protocol sets out obligations to take measures in relation to access to genetic resources, benefit-sharing and compliance.

As a result, even though the EU updated it’s bioeconomy strategy just months ago (October 2018), a coherent and harmonised policy concept is still missing, and existing sectorial policies and funding mechanisms still exist, to an extent, in isolation [25].

The European Commission Directorate-General for Research and Innovation stated in its 2017 review of the bioeconomy strategy [37], that progress on the issue of regulatory framework for the development of new markets for the bioeconomy has remained limited. The 2018 Updated Bioeconomy Strategy confirms these findings, but notes that relevant measures are currently proposed in the Circular Economy Action Plan, e.g. amendmends to the waste legislation to increase availability of quality bio-waste [2]. In the 2017 "stakeholder manifesto", the European Bioeconomy Stakeholders Panel notes that, "for the bioeconomy to continue to develop in a sustainable way in Europe, a coherent, transparent and predictable policy making process is essential. Removing regulatory uncertainty will encourage innovators and entrepreneurs to invest in the development of new or improved bio-based products" [38]. This manifesto emphasises the need for coherence of the European Bioeconomy Strategy with other EU policies, especially in the field of Circular Economy, agriculture, forestry, energy and climate [2]. A favourable policy environment should include:

- Stable and predictable policy environment
- Clear targets
- Appropriate long-term remuneration
- A minimisation of non-financial regulatory barriers

According to a recent analysis of the Pugatch Consilium, the overall message is, "inputs equal outputs". Economies that tend to have stronger environments with all enabling policy factors in place tend to see higher levels of biotechnology outputs. Adopting a pragmatic, long-term approach, focused on getting the policy environment right, is key to reaping the economic and social benefit of biotechnologies [39].

4.3.1 General barrier: Lack of policy harmonisation

Regulations are often neither consistent nor harmonised. As an example, consider lignins. Lignins are a defensive structure mechanism of plants, providing them with protection against microbes. Existing standard biodegradability tests only accept carbon dioxide and hydrogen gas generation as standard degradation products, but lignin degradation pathways are more complicated, producing more by-products that are difficult to measure and characterise. Therefore, lignins are not considered as biodegradable, even though you can find them anywhere in forests and soils, where they play an important part in the formation of soil organic matter. For this reason, lignins can be purchased commercially as soil conditioners but when a certain product group that ends up in the soil requires biodegradability, lignins are excluded. Regulation that refers to biodegradability standards, as for example the recent fertiliser regulation, does not consider such exceptions from the norm even though these deviations can provide advantages for the ecosystem in which they would end up.

The EC identified that "there was a clear indication of a need for a space where regular and strategic international cooperation at multi-partner level can take place with a focus on building policy coherence and on exploiting synergies between countries and regions taking into account existing mechanisms". In this respect, the International Bioeconomy Forum was set up in 2018 to develop a global policy dialogue on selected aspects of the bioeconomy through international co-operation for coherent, joint and impactful delivery of the world bioeconomies on the Sustainable Development Goals (SDG), align research funding programmes and increase co-operation and international awareness of the central role of bioeconomy.

Recommended action: Harmonisation of standards, regulations and policies

The harmonization of policies will be a continuous long-term process. The recommendations regarding this barrier are therefore largely what is already considered best-practice – but these should be continuously monitored and repeated. The fifth "Building the bioeconomy" report [39] provides some guidance:

First, regulatory policy should be coordinated within governments, with regular dialogue and stakeholder consultation as a formalised part of the process. This is especially true for cross-cutting and newly emerging issues, with coordinated actions that draw on the expertise of numerous government ministries and bodies. Most of these and other issues are already part of the "Better Regulation Agenda" of the EU, but implementation is often lacking.

Second, the design and application of new or existing regulations should not lose sight of the impact on long-term national objectives (large topics are sustainability and climate change) and the regulations impacts on other areas than its intended target area. For example, if all sectors must fulfil sustainability criteria for biomass, while only some sectors receive incentives, the other sectors will suffer from additional hurdles.

Regulators should constantly ask themselves how an existing or proposed piece of regulation would help, or hurt, the wider efforts of developing and building a competitive bioeconomy. In this sense, administrative burdens on research and industry should be continuously identified and removed, innovation should be enabled through non-discriminatory, market-based incentives. Of course, it can be difficult to obtain neutral and comprehensive knowledge of all aspects to be considered. Transparency in terms of lobbying and a stronger involvement of impartial experts could go a long way to reduce one-sided influences on policy making.

It appears that the lack of harmonization between regulations is often remarked, but actually providing specific recommendations on what needs to be changed proves a lot more difficult. We recommend to further identify specific changes and adaptations to the existing regulations that help to remove existing barriers. In that regard, RoadToBio Deliverable D2.1 could prove as a viable starting point, but further regulations should also be considered in detail, e.g. the mentioned Nagoya protocol or regulations on a national or regional level. The STAR4BBI project focuses on standards and regulatory framework and intends to establish a coherent, well-coordinated and favourable framework for the bio-based economy in Europe [73].

4.3.2 General barrier: Limited long-term reliability

Developing new chemical processes and taking them out of the lab into a commercial plant requires patience and dedication, often over a timeline of years or decades. Uncertainty is a central obstacle preventing investment, market introduction and establishment of innovations. It can arise due to several factors – money can become an issue, the process upscaling might prove problematic or even impossible – but for bio-based chemicals and materials, the political framework is a dominant factor causing uncertainty, especially when a specific policy instrument is only guaranteed for a (rather short) time frame. Often, governments change within a couple of years and new governments may stop or even turn around regulations from their predecessors. In order to secure investment and increase confidence in the industry to dedicate towards developing new chemical processes, a stable long-term policy setting can go a long way, providing clear targets and a predictable policy environment.

Recommended action: Provide stability and reduce risks through long-term policy

Designing policies to foster innovation in biotechnology is not an easy task. A key factor can be a stable and reliable policy framework that reduces risks for actors in the innovation chain. This can be achieved by clearly designing a long-term goal, which can then be used as guidance for designing new and adapting existing policies. If policies are long-term based, risks are both reduced and can be better quantified, enabling better justified investment planning. A good example in that regard are the renewable energy goals of the EU and the clear targets of renewable energy in the transport sector that must be achieved by 2030. For the bio-based economy, clear targets and goals might be difficult to define, but a long-term vision to produce bio-based chemicals, materials and products can instil confidence. For example, bio-based chemicals and materials could be placed prominently in long-term strategies regarding climate and health protection. Also, flagship or lighthouse projects that cover whole product value chains can provide successful examples, learnings and best practices that further reduce risk and uncertainty.

4.3.3 General barrier: Registration, Evaluation, Authorisation and Restriction of Chemicals – REACH

Considering the stakeholder feedback within RoadToBio, one of the more frequent responses to key barriers is the REACH regulation process, which is considered one of the most comprehensive chemical regulations in the world [40]. It places the burden of proof on companies and puts the responsibility for understanding and managing risks on manufacturers and importers. In general, REACH is valid for all chemical products and makes no differentiation between fossil-based or bio-based chemicals. Effects caused by REACH are therefore true for all chemicals, but we would like to point out a few points of particular relevance to the bio-based chemistry [74].

First of all, in some cases REACH has positive regulation effects for bio-based chemicals and can act as a market-pull instrument, e.g. in cases where the bio-based alternative provides an advantage in human toxicity. On the other side, it also creates some barriers: The process of **admitting new chemicals into the EU market is a difficult and expensive procedure.** Bio-based chemicals and materials are often new products not previously registered under REACH and are thus required to follow the registration process. Preparing this process is not trivial and challenging for small and medium-sized enterprises (SMEs). Furthermore, when innovations in bio-based chemistry are developed outside of traditional chemistry companies, research institutes, start-ups and smaller companies often suffer under a **lack of awareness** about REACH. Finally, chemicals can be exempt from the REACH regulation, but various stakeholders, who are active in this industry, stated that the rules for these exemptions appear to be confusing, pointing to a **lack of homogenous definition which materials are exempt** from REACH.

Recommended action: Guidance, clarification and support for regulation on bio-based products

Many small and medium-sized companies perceive REACH as a hurdle and often do not have enough knowledge about the consequences that the regulation can have on their own business situation. Since June 2018, even smaller quantities of manufactured or imported phase-in (i.e. already on the market before REACH entered into force) substances between 1-100 tonnes a year have to be registered. This can be often relevant for drop-in chemicals. Dedicated chemicals on the other hand are often non-phase-in substances and have to be registered anyway.

For aspects like the scope and applicability of REACH exemptions, it is important that better clarifications are provided which give companies insight into their duties and show what possibilities are available to use exemption clauses. The more complex issues, such as those concerning substance identity and resource recovery from waste, require attention from policy makers. Details about the borders between waste, which is covered by specific legislation, and the substances and products which fall under the remit of REACH, need to be more clearly defined [41].

The following recommendations are a result of the REACH REFIT evaluation in 2017 [21]:

- Support compliance by SMEs
- Updates of registration dossiers
- Further simplification of the authorisation process
- Ensuring a level-playing field with non-EU companies
- Further aligning REACH with other EU legislation like waste, industrial policy strategy and the circular economy

Barrier group: Policy and Regulatory framework

General barrier	*Recommended action*
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 Restriction of Chemicals – REACH	Guidance, clarification and support for regulation on bio-based products

Figure 46: Summary of the general barriers and recommended actions for the barrier group policy and regulatory framework

4.4 Barrier Group: Public perception and societal challenges

The visibility of bio-based products in the market and their perception by the public is key to successful market development: Changing the economic processes towards a bioeconomy requires public acceptance, but also the active contribution of many different actors in society. At the heart of many recent policy initiatives is the understanding that the outcomes of current economic value chains do not fit the needs of society as a whole. In these cases, public policy aims to start economic transitions – for instance to a bio-based and a circular economy, but also towards greater regional cohesion [42].

4.4.1 General barrier: Lack of information, understanding and expertise

RoadToBio Deliverable D2.2 [46] identified that information on the benefits of bio-based products is often not readily available and that the wider public only has limited understanding of the bioeconomy. This lack of information is perceived as a barrier for an increased uptake of bio-based products. While environmental credentials are not commonly the central argument for purchase, most consumers are concerned about the environmental performance of a product. While bio-based products do not always have a clear overall environmental benefit, they often perform better with regard to climate change and the emission of greenhouse gases because fossil resources are avoided. Consumers like to see proof of such attributes and it is thus usually advantageous to inform consumers about the environmental impact of a bio-based product in comparison to a conventional counterpart.

The lack of understanding in the public also highlights a deeper-rooted problem: It not only inhibits the communication possibilities between producers and the general public, but also indicates a lack of expertise in the field of bioeconomy. The Updated Bioeconomy Strategy 2018 notes that graduates are needed, who not only have in-depth knowledge in a certain domain, but also an understanding of the broader bioeconomy and its emerging fields [2].

Recommended action: Improve labels and standards

Labels are a great tool to convey key information to consumers and the wider public. They make the advantages of a product clear to the end consumer in a very simple and understandable way. For bio-based chemicals, several sustainability characteristics like human toxicity, GHG emissions, biodegradability, ecotoxicity are valid selling points, as well as the renewable feedstock itself. That said, the labelling situation for bio-based chemicals and materials is difficult: there are many labels on the market, some of which are not very well established, and most are not recognised by end consumers. The Updated Bioeconomy Strategy 2018 [2] recommends a two-fold approach:

1) Ensure the availability of comparable data on environmental and climate performance in order to fairly assess the performances of different products and materials. Such environmental assessments are usually based on life cycle assessments, which in turn require high quality life cycle inventory datasets relevant to bio-based materials. This recommendation is in line with the recommendation to develop a harmonised approach for sustainability assessment that we mention under 4.2.2, where we suggest it as an idea where the industry could voluntarily take the lead. That said, for the intention of communication, cooperation with NGOs and governmental bodies would improve credibility

2) Leverage the environmental performance information to boost the market of bio-based products by promoting and developing existing standards and labels, for example the EU Ecolabel. Regarding the last issue, developing the EU Ecolabel, the Open-Bio project (2013-2016) has collected comprehensive information and developed a set of recommendations [75]. The relevant Open-Bio reports are not public but available to the European Commission and other policy makers.

Recommended action: Promote education and training across the bioeconomy

The bioeconomy not only suffers under a lack of information for the wider public, but also under a lack of expertise in the European work force. Reports indicate that especially in the sector of biomass supply, there is an ongoing rate of evaporation of skilled work personnel, which has to be matched by new recruitment (e.g. reference [43]). On a shorter term, updating vocational training to cater to the specific needs for on the job training in the bioeconomy seems to be an essential instrument to develop the sector. Making the job of a farmer more attractive is highly challenging at a time of increasingly stark competition and declining prices for agricultural goods.

In order to embed the bioeconomy into society, it should receive overall higher visibility in education and training. This could already start at school level, where updated curricula could increasingly include the topics sustainability and bioeconomy, to generate a general understanding of and interest for the topic. Furthermore, university degrees with specific consideration for the skillsets required in the bioeconomy could be developed to cater the growing job market. In that regard, the Updated Bioeconomy strategy encourages Member States to "integrate dedicated curricula and training programmes in the bioeconomy areas in the education and training systems" [2].

4.4.2 General barrier: Low awareness of bio-based products

As part of the RoadToBio project, we closer investigated societal barriers towards an increased bio-based economy. One key conclusion was that the general public has a low level of awareness and little specific knowledge about bio-based products. Understanding of product characteristics and environmental impacts is mostly missing and consequently misconceptions occur. Literature review and expert interviews led to the conclusions that these misconceptions and unrealistically high expectations can lead to a reduced public acceptance of bio-based chemicals and products. Other important barriers to public acceptance of bioeconomy and biotechnology is fear of the unknown, based on a limited knowledge of science in general and a fundamental lack of understanding of biotechnology and chemistry specifically. This vacuum of information is currently being filled with stories about the more controversial developments, namely GMO and biofuels, thus creating immediate emotive associations that will need to be overcome.

Recommended action: Design and implement a visible and coherent communication strategy on the bioeconomy

To the public eye, the chemical industry is often first and foremost connected to industrial emissions and environmental pollution, summoning a rather negative public image. Bio-based chemicals, materials and products can support societal efforts towards reduced greenhouse gas emissions and a change towards a circular economy. But, conveying this message to the wider public has proven difficult and requires a more visible and coherent communication strategy.

Back in 2016, the Commission Expert Group Working Group on LMI evaluation gave the recommendation to “Design and implement a communication strategy involving all partners in the value chain and all other stakeholders to achieve coherent messages on bio-based products“ [19]. At the same time, they noted that a visible and coherent communication strategy on the bio-based economy has not been observed to date.

That said, more information does not necessarily mean higher acceptance. Many people consider bio-based products to be more sustainable than fossil counterparts, but that is not always the case. In that regard, the RoadToBio project has developed a set of key messages [44] that can be used as a starting point for communication strategies and that recommend to avoid focusing on the term bio-based when communication with the wider public, instead focusing on other advantages. Clear and concise key messages are a way of controlled communication that effectively bring home your message and minimise potential misinterpretations. For the chemical industry, key messages can be an important part of conveying the benefits of bio-based chemicals, materials and products to their customers and at the same time help to avoid misunderstandings. A number of EU and BBI projects are working on communication and perception topics of bio-based products, for example BIOWAYS [76], Biobridges [77] or BioCannDo [78].

Recommended action: Improve participatory processes and network building

Changing the economic processes requires acceptance, but also the active contribution of many different actors in society. Broad stakeholder and public engagement can be an important tool to form new networks and to realise the potential of the bio-based and circular economy [42]. Increased inclusion of stakeholders and the public will at the same time lead to higher acceptance and greater understanding of the bio-based economy. The BioSTEP project has developed the following key recommendations to improve participatory processes and the network building underlying economic transitions [79]:

1. Support small and medium-sized enterprises in the creation of new networks
2. Facilitate involvement of civil society in bioeconomy and circular economy debates
3. Increase public awareness and engagement with the bio-based and circular economy
4. Design and implement effective instruments for stakeholder and public engagement
5. Provide opportunities for participation in the development, implementation and evaluation phases of bioeconomy and circular economy

Recommended action: Improve social acceptance for the use of agricultural products in the chemical sector

The societal and political acceptance for main agricultural products (such as wheat, corn or sugar beet) to be used as biomass feedstock in the chemicals sector will determine how well the chemical industry can realise a switch to bio-based resources. Biomass use seems to undermine food security, but in-depth analyses show that they rather contribute to a reliable supply of food (e.g. [45]). As already mentioned, stakeholders of the chemical industry are still sceptical and cautious about utilising first generation crops. But when there is evidence that the utilisation of food crops for chemicals and materials actually supports a consistent food supply, a potential win-win situation is wasted because of the (not wholly informed) public opinion. Advocating and informing about the high land efficiency of food crops and how they provide multiple benefits when used in chemistry can induce a shift towards a more favourable disposition.

4.4.3 General barrier: Unrealistically high expectations

This barrier ties into the previous two barriers about lack of information and low acceptance, but we think it is useful to highlight it specifically. Consumers link various associations and connotations with bio-based products, which are largely related to environmental aspects, personal benefits and product properties. Various studies show people assume that bio-based production is aimed at finding environmentally friendlier solutions. This results in a positive attitude towards bio-based products, but also brings with it the problem of high expectations towards them. Furthermore, some common misconceptions prevail, such as the assumed link between bio-based and organic products or the assumptions that all bio-based products are biodegradable or recyclable. These high expectations and misconceptions bring with it the danger of disappointment, and consequentially a negative consumption decision, if bio-based products do not possess the expected characteristics [46].

Recommended action: Promote trust in bio-based products to transform negative associations

General misconceptions and valid concerns can be removed or addressed, on the one hand through education and, on the other hand, through promotional and public relations activities of the industry. A good opportunity would be to publish successful case studies. The positive connotations described above could provide inspiration, for example consumers' preference for regional or local production and waste reduction etc. Environmental connotations may be addressed through informing the consumer about the results of a life cycle assessment. This must be carried out at the product level, making it an expensive instrument, but at the same time provides proof of the sustainability performance of a bio-based product.

Trust can be further improved by working with trusted sources, for example NGOs, research institutes and the media, and by establishing product branding for a bio-based product (or product series) at the end consumer market. Here, the already mentioned labels and standards related to bio-based products would ensure additional accountability and foster consumer's trust.

Barrier group: Public perception and societal challenges

General barrier	*Recommended action*
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

Figure 47: Summary of the general barriers and recommended actions for the barrier group access to feedstock

4.5 Barrier Group: Markets, Finance and Investment

To secure investment in new bio-based products or processes is often a challenge and particularly so for SMEs. This is due to particularly high investment costs for the establishment of biotechnological processes. The average financing requirement for GreenTech start-ups is reported to be 200,000 € compared to 35,000 € for non-green start-ups [47].

The EU has a strong interest in promoting innovative developments in the field of bio-based products. For this purpose, numerous investment instruments have been established to directly support new project ideas as well as companies. The EU financial instruments support bio-based industry projects and enterprises are shown in Figure 44 and Figure 45, which show the different opportunities for companies to access solutions to support their growth. Companies may use financial instruments based on forms of debts or equity.

To this extent, InnovFin[29] and EFSI[30] offer products suitable for innovative companies in the bio-based sector, to support their growth. In general, equity and debt instruments may be combined with grants contracted to the same company.

An overview and a detailed description of which projects and companies could be supported at which stage and by which financial instrument can be found in the BIC report "Access to EU financial Instruments" [48]. Additional to these instruments and in order to support the development of bio-based innovations, in 2014 the EU launched the private-public BBI JU partnership with a budget of EUR 3.7 billion for 2014-2020. The bioeconomy pillar in Horizon 2020 has been reinforced with a total budget of EUR 3.85 billion[31]. Several member states have introduced specific funding programmes, for example Germany, Italy and the Netherlands.

29 InnovFin, a set of financing tools like loans, guarantees or equity-type funding for research and innovation projects

30 The European Fund for Strategic Investments (EFSI)

31 This financial envelope could exceed EUR 7 billion when also considering other actions under Horizon 2020 which are not labelled „bioeconomy" per se and which support - in an indirect manner – the development of the bioeconomy (Ref. 2)

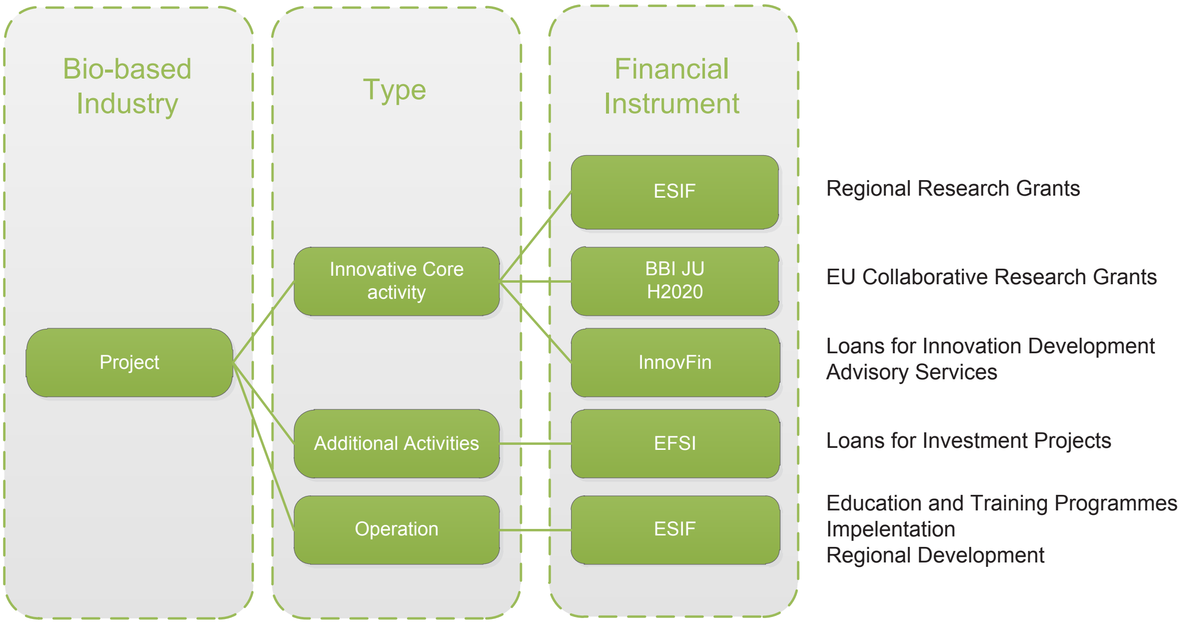


Figure 49: Financial solutions for bio-based Industry projects

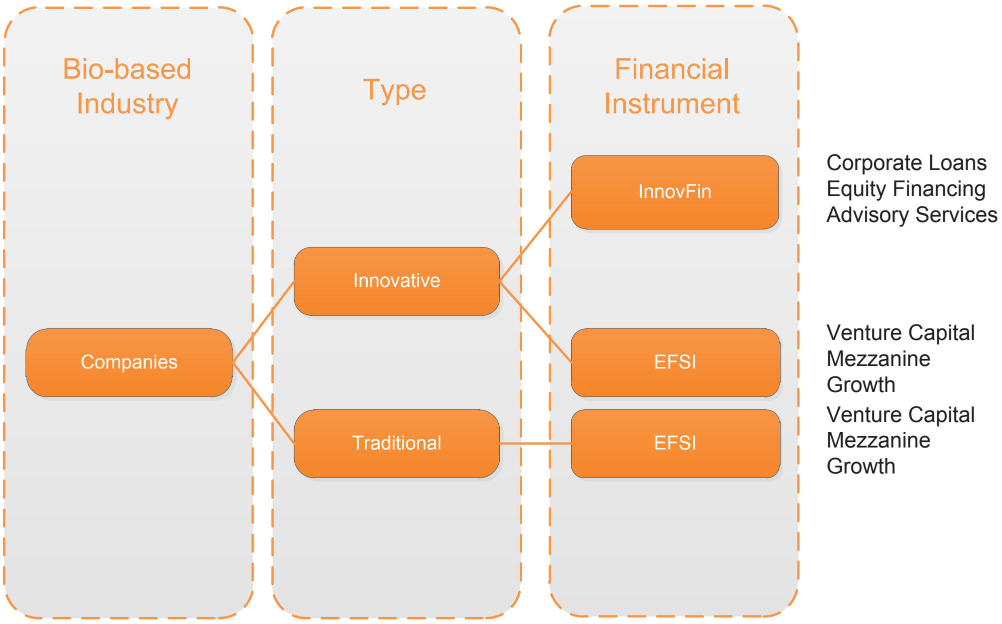


Figure 50: Financial solutions for bio-based Industries

This is due to the necessary development of innovations rather than adapting existing technologies. Within the framework of the RoadToBio project, expert interviews were conducted with various investors, (business angels, venture capitalists and other private investors) active in the financing of green business. It was established that in particular the following hurdles hinder the establishment and growth of bio-based businesses:

- Limited availability of funding in the early stages,
- Limited support for scale-up,
- Limited access to finance for start-ups and SMEs
- High investment risk

The interviews with the experts have shown that the current financing options are already well received, but that there are still some barriers hindering the market launch of bio-based products.

4.5.1 General barrier: Limited availability of funding in the early stages

The increase in the bio-based share is strongly driven by innovations. It is not only a challenge to establish a cost competitive process, but also to integrate the new chemical into existing products and to change formulations, especially in the case of dedicated chemicals. Investment sums are high, and timescales rather long compared to other fields such as FinTechs[32]. Established early stage investors often cannot offer the investment sums required, while for classic venture capitalists, the timeline is too long. High investments in this area are necessary but unfortunately insufficiently available at present.

Recommended Action: Fund for green investment

To help overcome the limited availability of funding in the early stages the establishment of a dedicated fund is recommended with a focus on lower TRL levels. Such fund could be jointly financed by industry and the public sector and would invest in the developments of desired technologies that would be market ready in 10-20 years. To finance future projects in the bio-based sector, the Bio-based Industries Joint undertaking could be continued or a similar fund could be set up to advance research and development in the field of bio-based products and thus make alternative materials competitive.

Financing via venture capital would also be conceivable. This has already started. On the advice of InnovFin Advisory study, the Circular Bioeconomy Investment Platform (CBIP) has already been established as a tool, as announced in the updated EU Bioeconomy Strategy of 2018. This Euro 100 million fund will provide access-to-finance by de-risking innovative projects vis-à-vis private investors, leveraging EU funds to help mobilise private investments in them [49].

Additionally to that companies could be stimulated to increase the bio-based share in its product portfolio this proposition must be made more attractive. To achieve this, we propose two options: On the one hand, a sustainability assessment of the companies could be taken into consideration when awarding a public procurement contract and one criterion could be the share of bio-based products.

On the other hand, legislative financial support could be measured by the bio-based share, thus increasing the attractiveness of bio-based production. With this procedure, however, it should be evaluated exactly what effects this has on SMEs in order to avoid discrimination. One idea here is to limit this support to certain product groups

4.5.2 General barrier: Limited support for scale-up

Scale-up is usually the most difficult step in an innovative process, and often referred to as a “valley of death”. Scaling up a process from lab or demo scale to a pilot plant is expensive, and the risk of failure (and thus loss of the invested money) is high. Actions to support these scale-up processes can help to reduce the risk and increase the willingness for investors and companies to invest. Incentives for the conversion of production plants and industrial processes into bio-based could also help to reduce the costs for scale-up activities due to reduced infrastructure investment costs.

Recommended Action: Use of Open Access pilot plants to avoid high scale-up costs

Another way to handle the limited support for scale-up is to avoid the high costs and to resort to external service providers. Europe-wide open access pilot plants are available for this purpose. As pilot- and demo equipment is very expensive and requires specific expertise, open access infrastructures are the most cost-effective manner to support the deployment of industry-driven innovations in the market. In order to ensure transparency here and to make the required service available to the plant operator, the main goal of the BBI-funded project Pilots4U [50] is to map all existing open access pilot and demo-infrastructures across Europe (further information: www.pilots4u.eu)

Recommended Action: Early viability assessment for SMEs

In some cases, hurdles for scale-up could have been avoided if a viability assessment (economic, environmental, social) had been performed at an earlier stage, allowing for adjustments in early process development. It might therefore be helpful to support SMEs at an early stage in their business to check which limitations and conditions are connected to their process in order to avoid delays or even failure at the scale-up stage. The experts would welcome it if this were done through a special fund managed by the European Commission or BBI or a similar model. Another idea could be according to the experts, one simple way to support SMEs in particular could be to emphasise in projects funding even more that the participation of small and medium-sized enterprises is expressly welcomed in the consortium or is even a prerequisite for the promotion of the project.

32 This financial envelope could exceed EUR 7 billion when also considering other actions under Horizon 2020 which are not labelled „bioeconomy“ per se and which support - in an indirect manner – the development of the bioeconomy (Ref. 2)

4.5.3 General barrier: Limited access to finance for start-ups and SMEs

The current financing structure, particularly in terms of taxes, puts SMEs at a particular disadvantage in the area of green start-ups. This increases the investment risk, lowers the attractiveness for investors and thus the chances of success for smaller companies to launch a new (bio-based) product.

Recommended action: New tax models to facilitate market entry for SMEs

The investment experts interviewed in RoadToBio stated that it is more difficult for start-ups in particular to establish themselves on the market due to, for example, high tax disadvantages for start-ups, although they are responsible for the innovations. E.g. only 4% of the green start-ups set up in Germany are in the field of renewable raw materials and materials. Investors stated that this was due to the fact that there are, among other things, tax disadvantages for start-ups. The government, but also the EU, therefore, has a responsibility to minimise this tax discrimination. This could take the form of tax relief for the first two years until the start-up has established itself on the market.

Recommended action: Strengthening the communication channels for European start-up funding

At both national and international level, there are numerous possibilities for promoting innovative and new start-ups, from support during the development phase to assistance in finding funding and support via the EU. Unfortunately, feedback from new start-ups has shown that they are often unaware of these funding opportunities and therefore do not make use of this service. For this reason, it should be examined whether existing funding systems are inadequate or whether they “only” need to be made more transparent in order to to inform start-up founders about their opportunities.

A further possibility to strengthen the establishment of SMEs is to introduce students in bioeconomy topics to entrepreneurship skills and opportunities at an early stage, though voluntary or obligatory curriculum offerings. The lectures could cover the development of business ideas, market analyses, business plans up to promotion instruments, which enable the students to plan the establishment of an enterprise. Universities and research institutes could also be given greater support during the spin-off phase in order to turn the ideas and developments from research into business ideas more quickly.

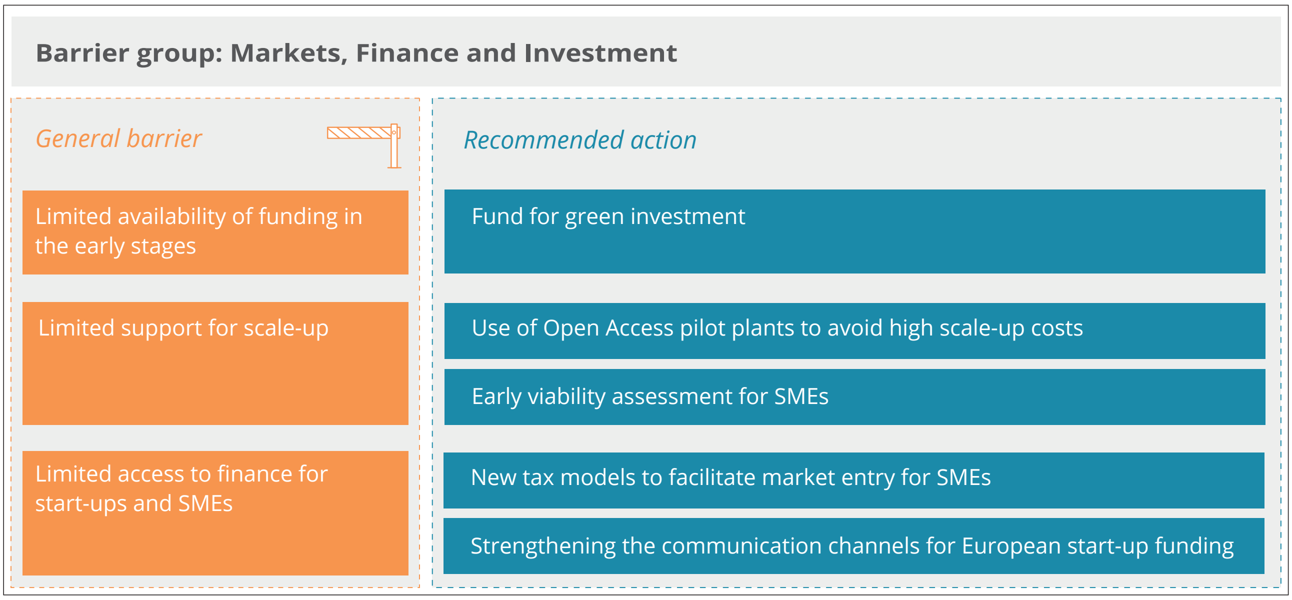


Figure 51: Summary of the general barriers and recommended actions for the barrier group markets, finance and investment

4.6 Barrier Group: Research and Development

The bio-based economy has a continuously high demand for innovation and fights against low TRLs and high development costs. The updated European Bioeconomy Strategy highlights the following statement as one of their most mentioned feedbacks [2]:

"the European Bioeconomy Strategy and the Action Plan should further support strategic Research and Innovation. This latter is crucial for providing solutions to the challenges of our time. It delivers on citizens' priorities, as embodied in the Sustainable Development Goals and in the Paris Agreement on fighting climate change, on growth and jobs, and to solve the global challenges we face today and will face tomorrow. Moreover, Research and Innovation determines the productivity and competitiveness of our economy: about two-thirds of Europe's economic growth over the last decades was driven by innovation."

4.6.1 General barrier: Ongoing need for funding

Access to finance is in general more difficult in Europe than in other regions of the world for several reasons – the funding landscape is fragmented, administrative processes are complicated and decision-making processes are comparably long [35].

Available funding has increased for innovation and even for demonstration and flagships or lighthouse projects in Europe (Horizon 2020 and BBI JU). The European Investment Bank (EIB) offers additional opportunities, for example via InnovFin, a set of financing tools like loans, guarantees or equity-type funding for research and innovation projects. Furthermore, new instruments were established to enable Member States and regions to co-invest in projects – One example would be the five European structural and investment funds (ESIF) [51], through which the EU invests in local and regional projects that contribute to job creation.

Recommended action: Deploy additional, targeted financial instruments

In addition to research and innovation grants under Horizon 2020, the EU will deploy a targeted financial instrument – the EUR 100 million Circular Bioeconomy Investment Platform (CBIP) – to de-risk private investments in sustainable solutions. This will build on and reinforce synergies with on-going and future EU initiatives, such as the Capital Markets Union, the InvestEU Programme, the Common Agricultural Policy and the ETS Innovation Fund [2].

Recommended action: Improve incentives and access to finance for R&D

Access to finance is highly important in enabling technological developments, especially for bringing them to pilot stages. Tax incentives for industrial R&D could be helpful to strengthen market-oriented research and development outside the official EU and member states' programmesAlso, a dedicated task-force within the EIB could be created to facilitate access to finance for the bio-based economy, e.g. through less complex and shorter procedures for identified priority projects. In the Energy Union Package, it is envisaged that the future European Fund for Strategic Investments (EFSI) should be used as a new funding instrument for major infrastructure projects [52]. Stakeholder feedback pointed out that a healthy pipeline of programmes across ALL technology readiness levels should be maintained, from early stage projects to upscaling towards commercialisation. It was furthermore mentioned that only comparatively few funding opportunities for development of processes between TRL 4-6 seem available, to go from lab scale to a first demonstration.

4.6.2 General barrier: Limited guidance and direction in R&D

To shape the future towards the intended direction and for Europe to grow in a sustainable way, not only stronger, but also more impactful investments in research and innovation are necessary. Research and innovation boost Europe's productivity and competitiveness and are crucial for sustaining our socio-economic model and values. In a swiftly changing world, Europe's success and global position depends ever more on our ability to transform excellent scientific results into innovations that can have a real impact on our economy and quality of life [53]. While the EU and other institutions define focus areas for research, more specific guidance and directions for R&D should still be encouraged. Participatory approaches could also be increased: stakeholders of the chemical industry showed interest in instruments or networks where they can better voice their own thoughts and demands in R&D, provide input and guidance to research and highlight urgently required focus topics.

Recommended action: Maximise impact of available EU Research and Innovation

Besides increasing the access to and the actual amount of funding, it is therefore useful to focus on maximizing the impact of the research and innovation landscape in Europe. There are still many technological and innovation challenges to be solved along the way to a sustainable and competitive, bio-based chemical industry. A strong document to take guidance from is BIC's Strategic Innovation and Research Agenda (SIRA) – bio-based value chains are at the heart of SIRA [4]. In the Agenda, four key pillars are defined in order to further push innovation for the bio-based economy. These are: biomass feedstock, optimised processing, innovative products and market-uptake.

4.6.3 General barrier: Limited understanding of ecological boundaries and innovation adaption and diffusion

In the recently Updated Bioeconomy Strategy, one of the three defined main action areas is to understand the ecological boundaries of the bioeconomy. To quote: "However, it is necessary to move beyond research and innovation and have a strategic and systemic approach to the deployment of innovations to fully reap the economic, social and environmental benefits of the bioeconomy. Such an approach should bring together all actors across territories and value chains to map the needs and actions to be taken. It will require addressing the systemic challenges that cut across the different sectors, including synergies and trade-offs, to enable and speed up the deployment of circular economy models. And this approach will have to make the most of all tools and policies available; exploiting synergies with other EU and national funds and instruments, in particular the Common Agricultural Policy, Common Fisheries Policy as well as the cohesion policy and Financial Instruments under the InvestEU Programme" [2].

Recommended action: Enhance knowledge on biodiversity, ecosystems and the bio-based economy

For the bioeconomy to deliver on sustainability, the EC states that it is necessary to better understand and measure its effects and impacts on the ecological boundaries of our planet. This is required to develop the bioeconomy in a way that attenuates pressures on the environment, values and protects biodiversity and enhances the full range of ecosystem services [54]. That said, bio-based alternatives substituting fossil resources usually are advantageous in relation to climate change, which is the largest threat to biodiversity.

An interesting approach to explore could be the innovation systems perspective: It's concept stresses that the flow of technology and information among people, enterprises, and institutions is key to an innovative process. Innovation systems particularly contain the interactions between the actors needed in order to turn an idea into a process, product, or service on the market. In other words, innovation is a collective activity and takes place within the context of a wider system. This wider system is called "the innovation system", and the success of innovations is to a large extent determined by how the innovation system is build up and how it functions [55].

The Technological Innovation Systems (TIS) framework, which as the name indicates looks at specific technologies, can give some guidance on how to tackle innovation challenges in the bio-based economy. By considering seven functions that refer to key processes contributing to generation and diffusion of innovations, it focuses on key processes that are highly important for large-scale sociotechnical change. Unravelling and describing these functions for a specific bio-based value chain or cluster in the chemical industry could offer valuable insights to identify why innovations fail to enter the market.

Barrier group: Research and Development

General barrier	*Recommended action*
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 52: Summary of the general barriers and recommended actions for the barrier group research and development

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 Restriction 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 53: Summary of the general barriers and recommended actions for all six barrier

5 Closing Remarks

This roadmap strategy document is intended to provide an evidence-based foundation for the EU chemical industry upon which future policy can be implemented and actions delivered. The way that this report has been compiled is designed to ensure it has credibility with industry, academic, and other stakeholders and is recognised by government as a useful contribution when considering future policy. It will be successful if, as a result, the government and chemical industry in Europe are able to build on the evidence, analysis, key messages and strategic conclusions to increase share of bio-based chemicals whilst 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.

6 References

For chapters 1 and 4:

References for Chapter 3 can be found at the end of each section.

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Annex I:
Calculation of share of bio-based chemicals in the 9 product groups

The European chemical industry is extremely complex, therefore it is impossible to create a single map that covers all value chains in the entire industry. Given that the goal of this task was to investigate the interface between existing value chains and bio-based products, nine product groups were selected that cover a range of different NACE classes and Prodcom groups and with that a significant part of the chemical industry. The selected product groups were:

- **Adhesives**
- **Agrochemicals**
- **Cosmetics**
- **Lubricants**
- **Man-made fibres**
- **Paints/Coatings/Dyes**
- **Plastics/Polymers**
- **Solvents**
- **Surfactants**

NACE (Nomenclature of Economic Activities) is the European statistical classification of economic activities. NACE groups organizations according to their business activities. Statistics produced on the basis of NACE are comparable at European level and, in general, at world level in line with the United Nations' International Standard Industrial Classification (ISIC).

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

Focus was laid on one subgroup in the NACE classification, division 20 – Manufacture of chemicals and chemical products, which is also covered by Prodcom.

On that basis, the current bio-based portfolio of the different product groups was estimated through a mixture of Eurostat data, literature and market analysis. An initial longlist was created, which included products/chemicals that currently beat TRL≥6 and show potential for the chemical industry in terms of market value. Please note that these numbers are estimations based on the various sources and market analysis and can therefore not be considered to be 100% accurate. In the following you will find the main sources and NACE classes that were considered as a starting point, for each of the 9 product groups:

1. Surfactants: NACE Class 20.41 – Manufacture of soap and detergents, cleaning and polishing preparations. Dechema paper is the main source, which is based on BASF numbers.

2. Paints, Coatings and Dyes - NACE Class 20.12: Manufacture of dyes and pigments). According to available numbers for the considered NACE codes, non TiO2 dyes add up to around 19%, and based on the "Handbook of Natural Colorants" we estimated the current share to be around 10-15%.

3. Man-made Fibres - Direct data from European man-made fibres association was taken. Only cellulosics are considered as bio-based and their share is around 11%, no polyester.

4. Cosmetics. Based on market research by Kline and company, which states an overall market share of -72 billion for cosmetics, with natural cosmetics having a share of -4.5 billion. This is roughly 6% of the total share. The volume is then calculated based on an average price.

5. Plastics and Polymers – NACE Class 20.16: Manufacture of plastics in primary forms. Additionally, data from European Bioplastics was used (total plastics production around 50 million tons, bioplastics slightly above 1 million ton) to estimate a bioplastics share of 2% in Europe

6. Lubricants – Different sources from the lubricants industry, e.g. Kline, Salimon et al. 2014, Grand View Research 2016 (see PDF document). Based on these sources, the bio-based lubricant share is around 1.5% in Europe.

7. Adhesives – NACE class 20.52: Manufacture of glues. Overall, three distinctly different components (solvents, plasticisers and polymers) were analysed. For the total segment of adhesives, the bio-based percentage is less than 1%. In case of some glues (Casein glues, Bone glues, Glues based on starches), it is a 100%. Numbers are very difficult to obtain, and are therefore just an estimation based on primary industry information from experts.

8. Solvents – For solvents there is no commercial bio-based solvent except rarely ethanol and 1,4-butanediol. The capacities of these productions are known – Ethanol is available on worldwide databases, nova tracks 1,4-butanediol. Overall, the share of bio-based chemicals is less than 0.05%.

9. Agrochemicals – NACE class 20.20 – Agrochemical products. Bio-based agrochemicals products make up less than 0.5% of overall market, when we do not consider microbial pesticides and microbial Fertilisers. These microorganisms are not considered to be bio-based. Numbers are very difficult to obtain, and are therefore just an estimation based on primary industry information from experts.

Annex II:
Further information on Work Packages 1-3

In the RoadToBio project, there have been 4 main work packages (denoted by WP1, WP2 etc.):

- **WP1** examined the current status of bio-based products in the chemical industry, and what specific opportunities for growth may lie ahead
- **WP2** looked at the regulatory framework associated with bio-based chemicals and materials, and public perception of these
- **WP3** aimed tostengthen the cooperation between the chemical industry, societal and governmental organisations trhough dissemination of outcomes and public engagement throughout the project
- **WP4** built upon the findings from the previous 3 work packages to develop a roadmap

The relationship between these 4 Main Work Packages is summarised in Figure 48:

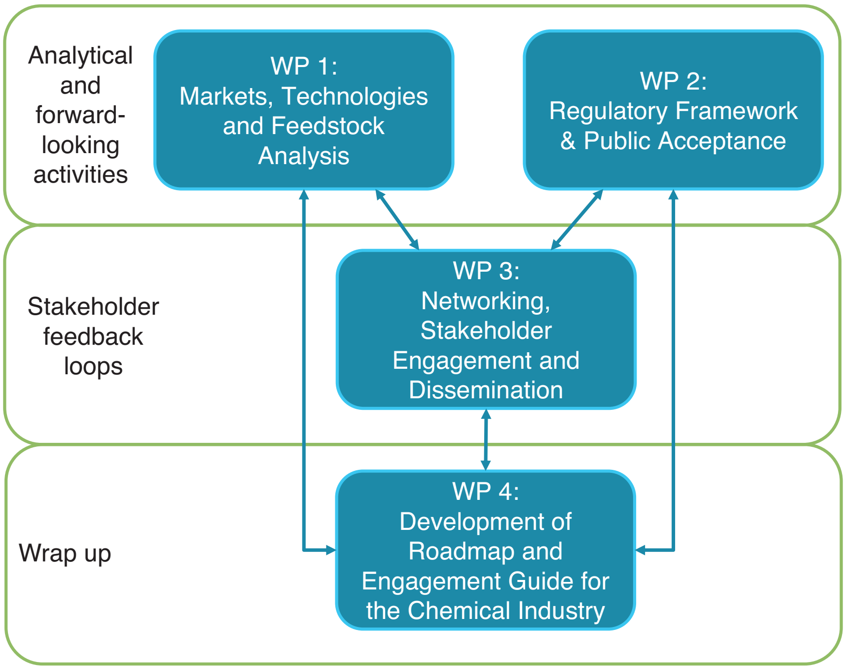

Figure 53: RoadToBio work packages

This section of this document aims to summarise the key findings from previous work packages to demonstrate how they formed the basis the roadmap in WP4.

6.1.1 WP1

The overall objective of this work package was to create a sound fact-base for the preparation of the roadmap, consisting of:

- An overview of the current status of the development of bio-based technology platforms at demonstration or commercial scale, as well as an overview of the parts of the chemical industry where bio-based products can play a role;
- The priorities of the chemical industry when developing new products or markets;
- On the basis of the above, a long-list of opportunities for the chemical industry including how these bio-based products can compete with fossil-based ones;
- Business cases of specific and relevant examples of potential bio-based products by the chemical industry.

Overview of opportunities for bio-based chemicals in the chemical industry

A report providing a high-level overview of the opportunities for bio-based chemical feedstocks and intermediates in the chemical industry was created as the first key deliverable (D1.1: Bio-based opportunities for the chemical industry) in the RoadToBio project. This report summarised the analysis of a significant sample of the value chains that currently exist in the European petrochemical industry and covered the value chains of more than 500 petrochemical final products in total, across nine different product groups.

Key Observations

- For most of the chemical products there are possibilities to fully or partially replace fossil feedstocks with bio-based alternatives. In 85% of the analysed petrochemical value chains, at least one entry point for a bio-based chemical was found.
- In total more than 1,000 possible bio-based entry points were identified in the value chains of these 500 petrochemical products. Extrapolating this observation leads to the conclusion that every value chain in the chemical industry on average has two entry points for bio-based chemicals.
- Bio-based oxygenates enter the petrochemical value chains further downstream, which means the subsequent value chain will be shorter yet in principle it shows an opportunity for 'smart drop-ins', that make use of oxygen functionalities that are already present in biomass.
- Of the 120 bio-based chemicals studied, only 49 could enter these value chains – those that could not can be considered 'dedicated chemicals'. This means they have specific (often preferential) properties and can potentially replace formulated final products based on their functionality, rather than parts of the chemical value chains.
- The feedstock platforms that came out as most important in this analysis are the sugar platform and the glycerine platform, though it is important to note that other feedstocks may become more important for bio-based chemicals in the future.

Specific business cases for the introduction of bio-based products in the chemical industry

The second deliverable from this work package (D1.2: Case studies on potentially attractive opportunities for the bio-based chemicals in Europe) was an analysis of nine specific business cases for the introduction of bio-based products in the chemical industry. Some of the results have been used in Chapter 3.

Key findings from this evaluation

- In most of the cases, bio-based chemicals have lower greenhouse gas (GHG) emissions compared to their fossil-derived equivalents. Large volume bio-based drop-ins like ethylene, and dedicated polymers such as PEF or glycerol derivatives could lead to significant displacement of fossil-based feedstock and improve the overall carbon footprint of European chemical industry.
- In some cases bio-based products showed improved performance and functionality and relatively lower production costs.
- However, further technology developments and energy optimization of bio-based process are needed to continue reducing GHG emissions and improve the overall sustainability and cost competitiveness of bio-based chemicals.
- A significant driver for dedicated bio-based plastics such as PEF, PLA and PHA is the environmental impact after disposal, where recycling and/or biodegradability are key end-of-life considerations.

Future development of innovative bio-based products should focus on ones that *outperform* traditional fossil-based products *technically, environmentally* and in terms of process efficiency – *improved functionality and value* will result in strong end-user drivers. To drive the uptake of bio-based chemicals, *cost optimization* of the entire value chain of bio-based chemicals is required, for example, through increasing the availability of low-cost renewable sugars and technology advances in utilization of waste feedstock.

Thus, a key input from D1.2 in to the roadmap is the **emphasis on developing bio-based products with superior technical, environmental and cost performance compared to fossil-based products.**

6.1.2 WP2

In this Work Package, the aim was to understand the regulatory framework associated with bio-based chemicals and materials, and their public perception. More specifically, the goals were to:

- Create an overview of the most important regulatory barriers that hinder the production and market uptake of bio-based chemicals and materials and derive suggestions for overcoming these barriers to be used in the roadmap.
- Understand the public perception of bio-based chemicals and materials, identify potential contributions of bio-based chemicals to societal needs and suggest ways to overcome societal and acceptance barriers
- Identify possible interfaces and synergy potentials between the bio-based sector and the Circular Economy.

Deliverables:

D2.1 – Report on regulatory barriers [Month 12]

D2.2 – Public perception of bio-based products [Month 6]

D2.3 – Public perception of bio-based product – qualitative analysis of stakeholders' concerns [Month 12]

D2.4 – Ways to overcome societal and policy barriers [Month 15]

D2.5 – Concept of bio-based and circular economy [Month 21]

Table 34. Summary of identified regulatory barriers

Key legislative	Identified barrier
RED	Higher demand and higher prices for biomass
RED	Contested feedstocks
RED	Result: Non-level playing field
RED	Ambiguous incentives
WFD	Non-uniform classification of materials as waste, residue or coproduct.
WFD	Use of gasification, pyrolysis, etc. to produce materials from waste not counted as recycling
WFD	Usage of waste for chemicals requires regulatory work
REACH	Difficult & expensive procedure of admitting new chemicals
REACH	Lack of awareness about REACH
REACH	Lack of homogenous definition which chemicals are exempt from REACH
REACH	Lack of guidance for SMEs
CAP	High costs of bio-based feedstock
CCT	Global price disadvantage
CCT	Competitive disadvantage vs. petrochemicals
CCT	Uncertainty for long-term investments
GMO	Mandatory labelling of GMO products
GMO	Slow and expensive approval procedure
EU ETS	CCU processes not eligible for ETS credits
EED & EBPD	General lack of fair regulation & standardisation for new bio-based options, but barriers in construction are often rather specific, as indicated for insulation materials.

Regulatory barriers hindering production and uptake of bio-based products [D2.1]

The goal of this deliverable was to assess existing regulatory barriers that hinder the production and market uptake of bio-based chemicals and materials.

Since the bio-based economy cuts through many other sectors, a multitude of policy areas were analysed (waste regulation, biofuels and bioenergy, import tariff regimes, chemical regulations, the Common Agricultural Policy). This gave an overview of the most important EU-wide regulatory barriers due to EU legislations, which hinder the production and market uptake of bio-based chemicals and materials in Europe (Table 7). Although the table lists all barriers, these differ largely in impact. For example, the non-level playing field caused by the Renewable Enery Directive (RED) has a greater influence on the bio-based chemistry and material sector than mandatory labelling of GMO products. Deliverable 2.1 provides and understanding the contextual framework of the regulatory barriers to enable strategic recommendations to how to overcome these barriers – a key input to develop the final roadmap of the RoadToBio project in Work Package 4.

Analysis of existing research on public perception [D2.2]

In this deliverable, the analysis revealed four general common themes relating to public perception of bio-based products: awareness and knowledge, associations and connotations, consumption decision and willingness to pay, information and labels.

Awareness and knowledge
The relatively low level of awareness of the existence of bio-based products (around 50%), lack of knowledge about product characteristics and misconceptions are all barriers for further market development of bio-based products, if the fact that they are bio-based is to be the unique selling point. In some cases, producers might want to market their products as bio-based, in others, they may choose to simply advertise a lower price or better properties.

Associations and connotations
Studies show people assume that bio-based products are more environmentally friendly, resulting in a positive attitude towards bio-based products, but also brings with it the problem of high expectations towards them. Furthermore, some common misconceptions are prevailing, such as the assumed link between bio-based and organic products or the assumptions that all bio-based products are biodegradable or recyclable. These high expectations and misconceptions bring with it the danger of disappointment, and consequentially a negative consumption decision, if bio-based products do not perform as expected.

Buying decision and willingness to pay
The work showed that around two thirds of participants prefer bio-based products over conventional products (given no other restrains, like a difference in price), but only 12% have ever consciously chosen bio-based products over conventional ones, though this group has the potential to grow further.

Analysing the motives of consumers more closely shows that consumers generally drawn to environmentally friendly products also have a more positive attitude towards bio-based products and are willing to pay more for them. Most consumers, however, are relatively unaffected by the fact that a product is bio-based, with personal benefits being far more important in the consumption decision. This shows that the fact that a product is bio-based is only of real importance to a niche market.

Information and labels
Most participants thought that information on the benefits of bio-based products is not readily available, with some noting it as a barrier to bio-based product being the preferred choice.

Labels were mentioned as being more effective to present detailed information than textual information. A multitude of ecolabels exist in Europe, but few of them are specific enough for most bio-based products. Creating a label specifically for bio-based would be a costly exercise, after which it may take a very long time before a label is known to consumers, if ever.

It seems doubtful that those labels focussing specifically on the fact that a product is bio-based (these do exist, without a focus on environmental aspects) would be convincing for a general public, since many participants were not convinced purely by the fact that a product was bio-based. It is seen merely as an added value next to other product properties and impacts, thus it is important to emphasise the attributes that are of personal benefit for the consumer.

The view of Social Stakeholders on public perception [D2.3]

The goal of this deliverable was to broaden the insights from D2.2, considering not only the perception of consumers, but also additional societal stakeholders relevant for overall public perception. Interviews were held with staff of 11 NGOs and 8 policy makers. This allowed the fine-tuning of the recommendations from D2.2.

Communication strategies:
Communication should not only focus on the fact that a product is bio-based, but highlight personal benefits, added values (like improved performance) and positive impacts. If the fact that a product is bio-based is the unique selling point, communication should be clear about characteristics and impacts, to avoid disappointment due to high expectations and misunderstandings.

Consumer knowledge level:
Issues regarding the bioeconomy and bio-based products are too complex to expect laypeople to fully comprehend, while even experts differ greatly in opinion. To tackle this, responsibility for information could be shared better between producers and consumers, not expecting consumers to understand what bio-based means and what consequences it has. Thus, policy-making and communication could focus on making it easy for society to move in the right direction.

Environmental impacts:
On the one hand, NGOs state that bio-based products should always provide environmental benefits and the desire for proof of environmental impact is generally great. On the other hand, provision of proof is relatively hard to realise, especially for smaller producers, because it requires very cost-intensive analysis on a case-to-case basis. Policy makers experience it as a barrier that there is no coherent framework to assess the environmental performance of bio-based products, but it is not realistic that simple rules of thumb can be developed for the great variety of products. Finally, even though consumers are interested in environmentally friendly products, the fact that a product is bio-based, and its specific environmental impact are mainly relevant to a niche market.

Strategies for further development of bio-based products:
To integrate bio-based products in a circular economy, producers of bio-based products could collaborate with the waste treatment sectors and policy makers to develop improved waste strategies. For example. it should be made as easy and clear as possible for the consumer in what bin to dispose of bio-based products and packaging materials.

Ways to overcome societal and policy barriers [D2.4]

In this deliverable, the project has developed a set of key messages and recommendations for the chemical industry. Both shall play a part in overcoming the previously identified regulatory and acceptance hurdles. We have also incorporated societal needs, as defined in the UN's Sustainable Development Goals, to which the chemical industry can contribute to.

Based on the identified barriers and needs, we started to work on identifying actions that can be recommended. This included for example intensive literature review, discussion with other projects on similar topics, internal discussions and short questionnaires to interested stakeholders. In June, a first set of recommendations was presented to our Industry Expert Group, and based on their feedback, the recommendations were further refined and polished.

For the final deliverable, we have split the recommendations into:

- Key messages about bio-based chemicals, materials and products
- Recommendations to overcome policy barriers
- Recommendations to overcome societal barriers, including recommendations on communication

Both key messages and recommendations are built up the same way: First, a central sentence is intended to function as a "key" message or recommendation, summarizing the main argument in one short and concise statement. Second, each statement is then backed up by further information and clarification.

The key messages are intended as an instrument for the chemical industry to address target audiences in their communication about bio-based chemicals, materials and products. They can be customized by each stakeholder to highlight product characteristics and tailor-fitted to the respective audience. Examples would be consumers along the entire value chain of the chemical industry. Below you can see the first key message:

#1 – Any chemical or material made from fossil oil and gas can be made from biomass

Many chemicals, materials and daily life products are made from fossil resources (e.g. plastics, synthetic fibres, washing detergents or solvents). The fossil resources (oil and gas) were originally biomass and are the result of a million-year long process. We can speed up or by-pass this process, so that any fossil-based ingredient can be replaced by renewable resources or residues from land and sea.

In the current bioeconomy, bio-based chemicals and materials partly or fully replace fossil-based ones.

The message is designed in a way that supports communication with the wider public. The message in the header is what we consider a useful fact to share with the public, while the provided additional information helps to shape the argument.

With the recommendations we aim to provide the chemical industry with ideas and approaches how to tackle the barriers we have identified in prior studies. We have decided to split the recommendations into a "policy barrier" and a "societal barrier" part, partly because addressing them requires approaching different stakeholder groups. Below, is one of our recommendations for the societal barriers:

#3 – Communication: focus on and highlight advantages, positive impacts and innovative functionalities

Consumers primarily care about direct advantages and positive impacts of products and do not necessarily care if a product is bio-based or not. Communication should therefore not focus on the fact that a product is bio-based (only), but highlight personal benefits, added value and other positive impacts; in relation to its costs.

Creating added value (and proving it) can be challenge for bio-based products, but also an opportunity: if it exists, it can be used for communication and marketing strategies. Producers can strive for added value in innovation and design of bio-based products and use this as a selling point, rather than just focusing on the fact that the product is bio-based.

The difference to the above key message is, that we now give a direct recommendation to the chemical industry. We identified as one societal barrier that consumers only care little about whether something is bio-based or not, and therefore recommend focusing on other aspects of the product, for example reduced greenhouse gas emissions, increased sustainability or maybe even better product properties.

In summary, the key messages provide a basis to start developing communication tools/campaigns in favour of bio-based chemicals, materials and products and should be specifically tailored, dependent on the organization that wants to use key messages and the target audience of that organization. The recommendations have been developed to highlight different avenues which the chemical industry could pursue in order to tackle regulatory and societal barriers that hamper a higher share of bio-based resources in organic chemistry.

The RoadMap will suggest methods to overcome both the regulatory and societal barriers to increasing the production and up-take of bio-based products, based on the understanding developed in this Section. For example, acknowledgment of the fact that consumers may not be able to fully grasp the complex sustainability issues associated with the bio-based products means that solutions need to be developed to ensure communication and marketing of these products does not burden the consumer with too much or too complex information. Recommendations for different target groups will be provided in a visually attractive and easy to use manner in the engagement guide. Similarly, the key messages will be presented, which can be used as a tool by the chemical industry to facilitate communication to their clients. Furthermore, guidelines on how to communicate with different audiences will be developed.

6.1.3 WP3

The aim of this work package is to create awareness about the project and its scope within the chemical industry, relevant up- and downstream industries, governments and administrative bodies and NGOs as well as the interested public. Based on this awareness, discussion and networking activities will be initiated to gain insight in the different perspectives, collect contributions to the analysis performed during roadmap development, discuss findings with relevant stakeholders and stimulate the dialogue between relevant stakeholders.

Deliverables:

D3.1 – Website [Month 3]

D3.2 – List of relevant stakeholders in industry, government and NGOs per topic [Month 6]

D3.3 – Community of experts / contact list receiving regular newsletters and invitations for workshops/events [Month 6]

D3.4 – Monthly newsletter to the network [Month 7-18]

D3.5 – Webinars on findings and examples [Month 8-20]

Successful development of the RoadToBio Roadmap requires the collaboration of experts from the chemical industry, NGOs, governmental bodies, academia as well as the finance sector and brand owners, who need to work together with industry players along the value chain, develop joint strategic concepts for the short term and to resolve barriers to commercialisation of bio-based products. Throughout the development of the roadmap, a dialogue between institutions was established and maintained, to tailor the roadmap so that it has the highest achievable impact. These networks need to be maintained beyond the roadmap publication, so that any issues that might occur in the development of a bio-based chemical industry can be readily resolved.

Over 200 stakeholders in various stakeholder groups from many European countries are already involved in the development of the roadmap, through different engagement formats including workshops, interviews, webinars or 1-to-

1 discussions. Members of the stakeholder network come from a total of 23 countries, 39 % from Germany, 17 % from Belgium (primarily European associations) and 11 % from the Netherlands. These are categorised in a total of 7 groups, as follows:

- Chemical industry
  (from feedstock providers to consumer product producers as well as brand owners)
- Experts from the finance sector
- Academia
- Associations
- NGOs
- Governmental bodies
- Broader public

40 % of the network members are based in industry, 24 % in associations and 14 % in academia. The smallest group with 6 % represents governmental bodies. However, all relevant value chain positions are represented within the stakeholder groups in more or less equal shares.

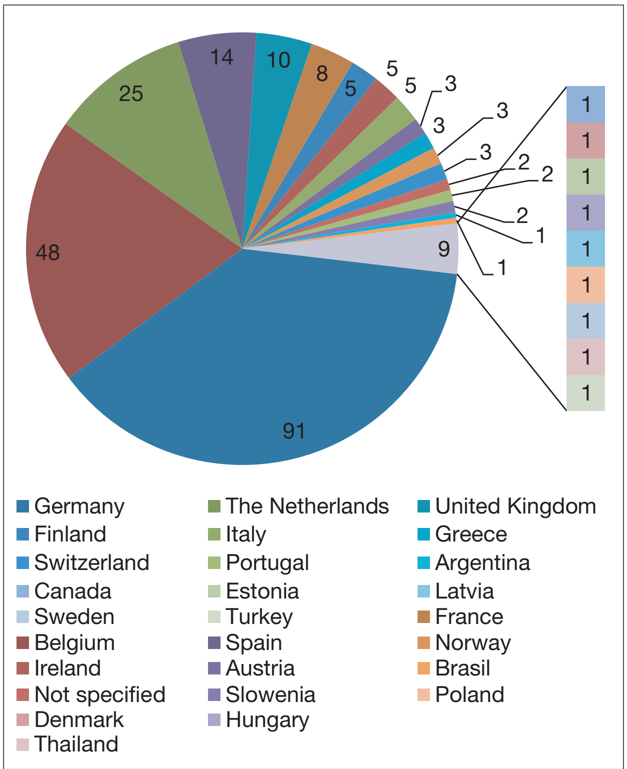

Figure 54: Stakeholder participation by country

The Roadmap has potential to reach wide audiences with high impact. It will include different opinions of producers and consumers through an unbiased, credible voice. The challenges faced by individual institutions can be overcome through collaboration, for which this Roadmap aims to outline and address to the appropriate groups of stakeholders.

To reach the target share of 25% bio-based chemicals in the organic chemical industry, it is of utmost importance to include stakeholders of the entire value chain from feedstock, bio-intermediate, platform chemicals, to the final consumer product. For statistical purposes, many of the stakeholders are assigned to several production steps, since their portfolio often covers a wider part of the value chain.

In two workshops, two webinars and 30+ individual interviews, expert stakeholders from various fields were as asked for their opinions on several topics, for example, what criteria

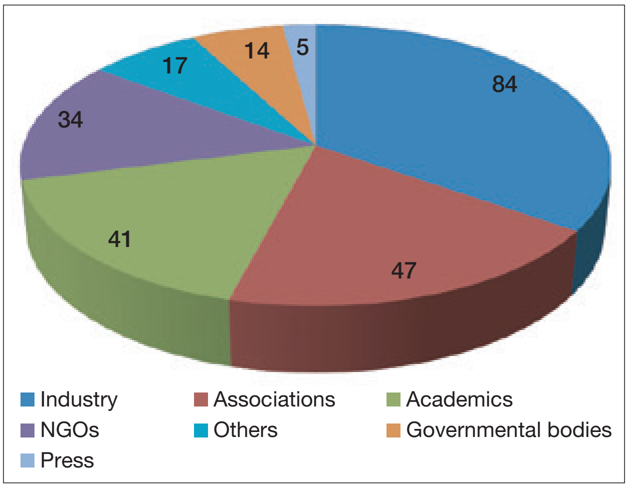

Figure 55: Stakeholder participation by type of organisation

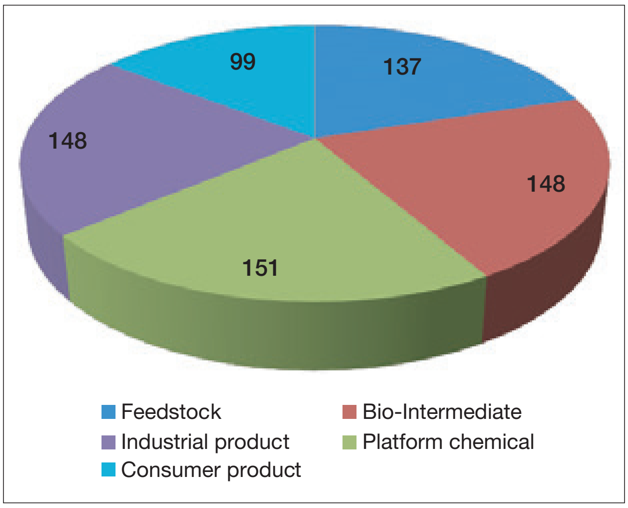

Figure 56: Stakeholder participation by value chain position

are important to them to rank business cases, or what they think the public perception of bio-based products is. A selection of their statements will be included in the final Roadmap. A survey was conducted on key barriers and hurdles perceived by the industry that could make market entry more difficult or prevent markets from expanding.

In addition, the consortium presented the RoadToBio project at a dozen or so events and conferences to discuss the main topics of the roadmap. Most recently, the scope and approach of the roadmap was sent to selected stakeholders from the chemical industry as well as different associations to seek feedback on the content now in the early stages of the development of the final documents.

Annex III:
Further information on Roadmap Methodology & Structure

The **first task (Task 1)** analysis provided a baseline for the current share of bio-based products in EU industrial products. Figure and graphs generated from Task 1 are presented in Chapter 1. This task involved:

a. Determined the share of different product industrial products in the EU Chemical Industry – by volume

b. Determined the current share of bio-based chemicals in each product group – by volume

The **next steps (Task 2 and 3)** determined where growth in *established* and *new* bio-based products can be achieved to meet the 25% target. **Task 4** (developing the roadmap) involved formulating a narrative using data obtained in tasks 2 and 3 to describe the opportunity for bio-based chemicals in the different product groups and what needs to happen to increase their share.

To determine the potential contribution of established bio-based chemicals (**Task 2**), we:

a. Evaluated the status of bio-based chemicals in different product groups (see Figure 1 and Task 1)

b. Investigated whether there is potential for further growth in established bio-based chemicals

c. Assessed the barriers preventing the growth of these bio-based chemicals

d. Determined what actions can help further growth

Task 2 involves answering the following questions:

1. Which bio-based chemicals are used and for what intermediate or end-use application (per product group)?

2. Why are bio-based chemicals used instead of a fossil equivalent?

3. How has the use of the bio-based chemical grown and what is the outlook?

4. What are the barriers to future growth of these bio-based chemicals? How can they be addressed?

To establish the potential contribution of new bio-based chemicals (**Task 3**), we:

a. Evaluated the potential of introducing new bio-based chemicals in the product groups, including
   I. Identifying which of the nine product groups to focus on for the Roadmap
   II. Identifying which bio-based chemicals categories to focus on: drop-in, smart-drop-in, or dedicated

More specifically this involved an evidence-based approach to determine:

I. Volumes i.e. product groups or sub-product groups with highest volumes.
II. Drivers for bio-based chemicals and their strength (legal/regulatory; voluntary- or customer-driven; voluntary- or producer-driven; cost reduction or other incentives).
III. Number of bio-based entry points i.e. identify the product groups with a high share of bio-based entry points.
IV. The number or volume of bio-based chemicals/products which could add value in production (smart drop-in) or in the end product (sustainability or performance improvement).
V. The TRL level of bio-based chemicals.
VI. Barriers to entering the bio-based market and how to overcome these.
VII. Benefits arising from the transition from fossil-based to bio-based production in terms of market share, GHG benefits and local jobs

The drivers for bio-based chemicals in each of the nine product groups will be assessed according to whether:

- It meets the desired sustainability characteristics (driver, e.g. renewable feedstock) of the product group.
- Is a drop-in, smart drop-in or dedicated bio-based chemical.
- It offers any additional advantages to meeting the sustainability drivers identified (e.g. cost saving or enhanced performance).
- Relevant information is available in Deliverable D1.1: Bio-based Opportunities for the EU Chemical Industry, see figure 4.

The formulation of the Roadmap (Task 4) will consist of collating the information gathered in all tasks into a document with an action plan and scenarios to achieve a 25% share of bio-based chemicals in the European Chemicals Industry. The final roadmap will:

a. Detail any identified barriers (technical, economic, political or societal) to uptake, based on Task 2 and 3 analyses, case studies, analysis of policy barriers (WP2) and stakeholders' inputs.
b. How the barriers can be addressed and by whom.
c. What actions are needed.
d. When these actions should take place.
e. Indicative level of funding which includes measures needed to enable the financial viability of the business cases / scenarios.

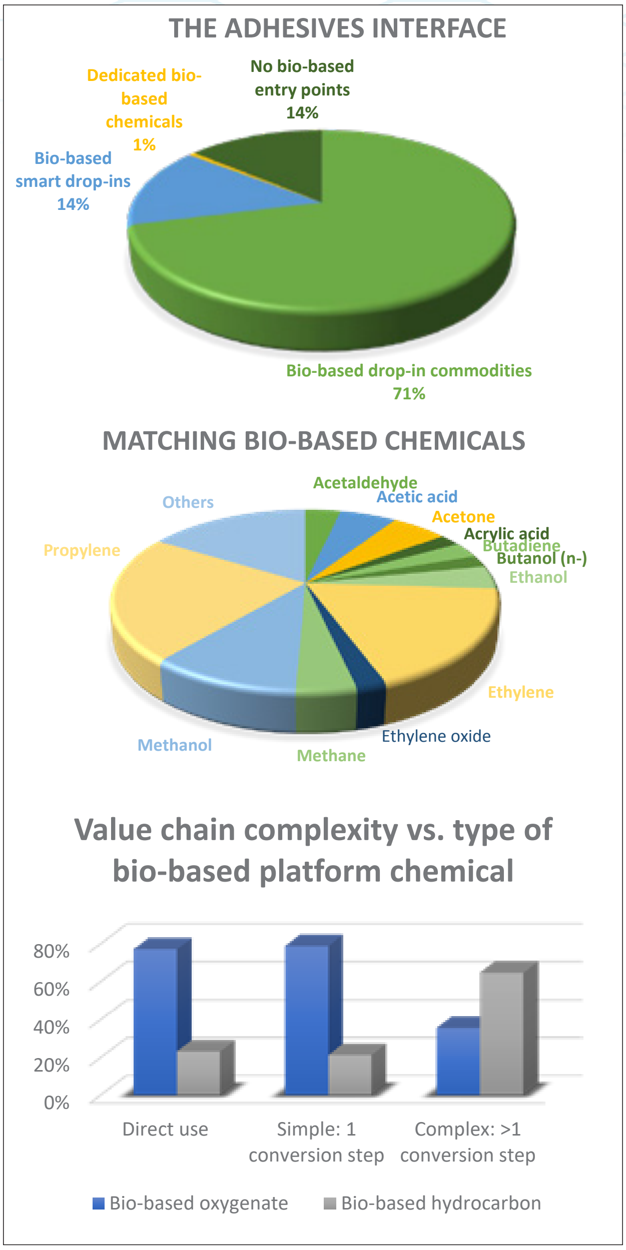

Figure 57: Data from deliverable D1.1: Analysis of bio-based chemicals potential of nine product groups.

Roadmap Structure

This section gives an overview of the format of the Roadmap as three documents – Strategy Document, Action Plan and Engagement Guide. For each document, we shortly introduce the intended audience, the envisioned format and an overview of the envisioned content of each of these documents.

The development of the Roadmap comprises of two components, which will lead to the formulation of three documents:

1) An analysis of the most promising opportunities for increasing the bio-based portfolio, and the technical, commercial, regulatory and social barriers to doing so.
   - This work was completed in the first year of the project to date. Related Deliverables have been published on the RoadToBio webpages (www.roadtobio.eu) and are describes in Annex II.
   - The tasks involved have been described above (Task 1-4).

2) Development of the Roadmap as a Strategy Document, Action Plan and Engagement Guide to achieve the increased bio-based portfolio and for overcoming the existing and anticipated barriers.
   - This component will be synthesised into three documents:
     - Strategy Document
     - Action Plan
     - Engagement Guide
   - The three documents are described in more detail below.

6.2 Strategy Document

Intended audience: parties interested in the details of our work, methodologies, specific data etc.
Format: Classic text document
Content:

- Background information, including statistics on the current EU Chemical Industry landscape
- Details on the product groups and how they were chosen
- Identified opportunities and the benefits that could arise from exploitation. Case studies (as supporting evidence).
- Identified barriers and risks, including policy and societal barriers and how they can be addressed
- A generic innovation journey approach, detailing how the identified barriers could be overcome
  - An example is shown Section 4 of this document.
- Detailed Action Plan – realistic timescales for targets to be met and who can act to achieve these target
  - This section of the Strategy Document will be summarised as a separate document (Action Plan), detailed below.

6.3 Action Plan

Intended Audience: different stakeholder groups (e.g. industry, policy makers, NGOs)
Format: Slides containing Chevron diagrams for different stakeholder groups with references to relevant background information in the Strategy Document
Content:

- Introduction of how to read / use the Action Plan document
- Brief description of steps that have been taken to develop the Action Plan
- Actions required that are specific to each group of stakeholders.
- Chevron diagrams showing the flow of actions to be carried out for various stakeholder groups with links/references to the opportunities, benefits and barriers detailed in the Strategy document.
- A timeline for actions – details on what needs to be done, by when and by whom.

6.4 Engagement Guide

Intended Audience: The Chemical Industry and Policy makers
Format: Factsheets directed as different stakeholders.

Content:

- The benefits of engaging with the Roadmap.
- Key messages from the overall Roadmap and guidance on how to use these for the relevant chemical industry stakeholders to communicate to customers and the broader public.
- Summary of opportunities, barriers, and recommendations.
- Recommendations on which stakeholders should be made responsible to ensure the Roadmap is being delivered by the timescales identified in the Action Plan.

A first set of recommendations and key messages based on analysis of policy and societal barriers (work carried out in the first year of the RoadToBio project), aimed at the EU Chemical Industry, have already been formulated and have been reviewed by the Industry Expert Group.

The approach to the engagement guide of the roadmap is to:

a. Define communication objectives

b. Define target groups (primarily the Chemical Industry and policy makers, secondary (indirectly through the Chemical Industry) Consumers, Citizens, Specialised media, Standardization bodies, etc.

c. Provide a summary of opportunities and barriers, and formulate actionable recommendations

d. Develop key messages,
   - Relating to the benefits of bio-based products for society (building on research done in WP2, detailed in Annex II)
   - On the role of the Chemical Industry in implementing the Roadmap in order to realise these societal benefits (a translation of the Chevron diagrams into key messages)
   - On key barriers, articulating the role of key stakeholders in removing them (building on research done in WP2, detailed in Annex II)

e. Provide guidance to stakeholders how to use these key messages to communicate to the pre-defined secondary target groups (see b.)

f. Identify communication channels, including e.g. social media - Identify communication formats (e.g. story telling) and communication products (e.g. leaflets, press releases)

g. Provide recommendations on which stakeholders should be made responsible to ensure the Roadmap is being delivered by the timescales identified in the Action Plan.

ROAD TO BIO

CONSORTIUM

DECHEMA
Gesellschaft für Chemische Technik
und Biotechnologie e.V.

btg
biomass technology group

E4tech
Strategy | Energy | Sustainability

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Bio based Industries
Consortium

BIO-BASED INDUSTRIES
Public-Private Partnership