European Commission

# Supporting the Green Transition via the EU Industrial Strategy: Opportunities and Challenges for Bioeconomy, through Bio-Based Industrial Systems and Biotechnology in the EU

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*Final Report*

# Supporting the Green Transition via the EU Industrial Strategy: Opportunities and Challenges for Bioeconomy, through Bio-Based Industrial Systems and Biotechnology in the EU

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Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs

2026

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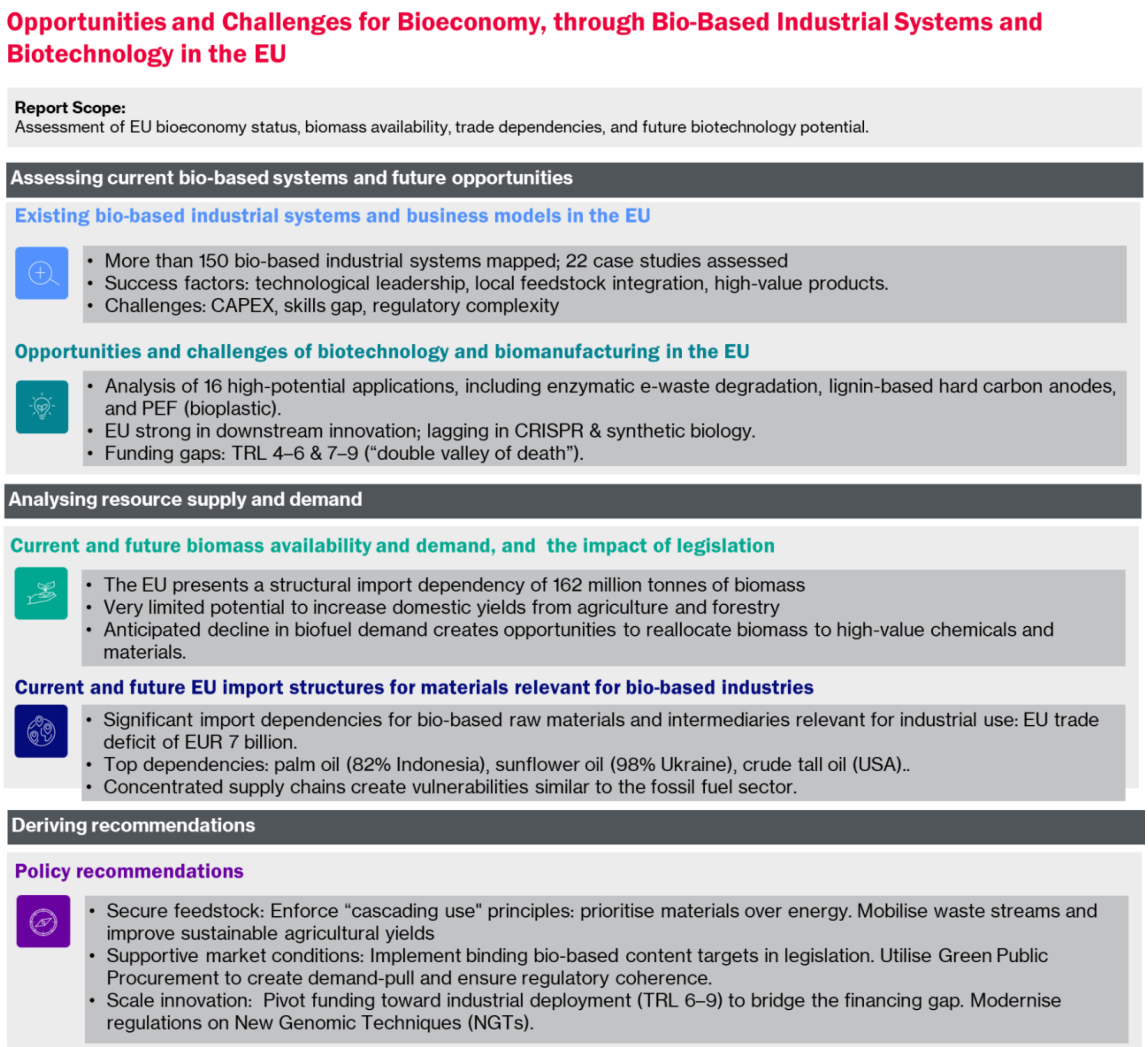
# Abstract

This study examines how bio-based industrial systems and biotechnology can accelerate the EU's green transition and industrial strategy. It focuses on three pillars: (1) mapping and analysing over 150 bio-based industrial systems, including 22 case studies of successful business models; (2) assessing biomass availability, trade dependencies and future supply–demand dynamics; and (3) identifying opportunities and challenges for biotechnology and biomanufacturing.

Findings reveal strong market potential—EU bioeconomy value added reached EUR 812 billion in 2022—but persistent barriers such as high capital costs, skills shortages and fragmented regulations. Biomass analysis shows a structural import dependency of 162 million tonnes in 2022, projected to decline modestly by 2035, while policy-driven scenarios indicate possible supply–demand imbalances under accelerated transitions. Trade analysis highlights critical reliance on a few suppliers for key raw materials, creating strategic vulnerabilities.

Sixteen emerging biotechnologies, including PEF, PLA, lignin composites and enzymatic $CO_2$ conversion, demonstrate robust environmental performance and growth prospects (CAGR up to 26%) but face scale-up and financing gaps. Policy recommendations include securing sustainable feedstock, introducing binding bio-based content targets and bridging innovation funding gaps to strengthen EU competitiveness and autonomy.

# Visual Abstract




Source: Prognos AG/Idea Consult/nova Institute 2025, own elaboration

# Executive Summary

This report examines the role of bio-based industrial systems and biotechnology in supporting the European Union's green transition and industrial strategy. Commissioned by DG GROW, the study provides a comprehensive assessment of the current state of the EU bioeconomy, its future potential, and suggests policy measures required to strengthen competitiveness and sustainability. The analysis covers three main areas: (1) mapping and learning from successful bio-based industrial systems and the identification of future opportunities and challenges, (2) evaluating biomass availability and trade dependencies, and (3) formulating policy recommendations.

**Bio-Based Industrial Systems and Business Models**

The European bio-based industry operates within highly complex value chains that are distinct from conventional industries. The study identified over 150 Bio-based Industrial Systems (BBIS) operating in Europe, narrowed to 50 high-potential systems with Technology Readiness Levels (TRL) of 6 or higher.

Twenty-two case studies illustrate successful business models, highlighting common success factors: companies achieving market viability typically leverage technological leadership in specific biochemicals, maintain strong integration with local feedstock supplies, and focus on high-value-added products that generate sustainable cash flows. Challenges persist, including high upfront investment costs, skills shortages, overlapping certification schemes, and regulatory complexity. A significant distortion in the current market is the policy imbalance that heavily incentivizes the use of biomass for bioenergy and biofuels over biomaterials, affecting allocation decisions.

**Biomass Availability and Use**

The analysis of EU biomass availability indicates a broadly stable but constrained base, with sectoral shifts expected to redefine supply and demand patterns through 2035. Domestic biomass supply in the EU amounted to approximately 925 million tonnes of dry matter in 2022, while demand reached 1,087 million tonnes, resulting in a structural import dependency of 162 million tonnes. Agricultural biomass dominates supply, followed by woody biomass and organic waste.

Agricultural systems in the EU are already highly optimized, and the baseline scenario projects only a modest annual growth rate of 0.04% in crop production. While innovation in breeding and regenerative practices could offer further yield improvements, the expansion of protected areas under biodiversity strategies may reduce the productive land available for agriculture.

The forestry sector faces similar constraints. While woody biomass supply is projected to grow moderately in the baseline scenario, the implementation of stricter conservation policies could reverse this trend, potentially leading to a decline in harvestable volumes by 2035. In the waste sector, organic waste remains an underutilized resource. However, paradoxically, successful waste reduction policies aiming to halve food waste could significantly decrease the total volume of secondary resources available for bio-based applications. On the demand side for biomass, a major structural shift is anticipated. The demand for crop-based biofuels is projected to decline sharply by approximately 5% annually due to the electrification of transport and reduced blending

mandates. This reduction in energy-related demand creates a strategic opening, potentially freeing up biomass resources for high-value material applications and chemicals, provided that policy frameworks support this reallocation.

**Import Structures and Trade Dependencies**

The transition to a bio-based economy does not automatically equate to resource independence. The EU currently runs a trade deficit of over EUR 7 billion in materials relevant for bio-based industries, revealing significant reliance on external markets. Import dependencies are often highly concentrated, creating vulnerabilities comparable to those in the fossil fuel sector. For instance, the EU relies on Indonesia for 82% of its industrial palm oil and on Ukraine for 98% of its technical sunflower oil. Crude tall oil (USA), cellulose acetates (USA), and soya oil (Argentina) represent further critical dependencies.

Five case studies, such as those on phosphorus recycling and polylactic acid (PLA), demonstrate that it is technically feasible to reduce these dependencies through innovation and circularity. However, without supportive measures, domestic production often struggles to compete with cheaper imports. Consequently, diversification of supply chains and the fostering of domestic capacities are identified as essential steps to mitigate geopolitical risks and ensure security of supply.

**Opportunities and challenges of biotechnology and biomanufacturing in the EU**

Sixteen high-potential biotechnological applications were assessed, including PEF, PLA, PHA, lignin-based composites, hemp biorefining, enzymatic $CO_2$ conversion, and microbial biofertilizers. The European Union maintains a strong competitive position in downstream innovations, particularly in biomass valorisation and the development of advanced materials like lignin biocomposites. The sector outlook is positive, with global CAGRs forecasts ranging from 4% to 26% and high-potential applications such as enzymatic e-waste degradation poised to unlock multi-billion-euro markets by 2030. Applications such as lignin-based hard carbon anodes and hemp biorefining are particularly promising for EU leadership. Furthermore, the environmental performance of these emerging technologies is robust; most applications analysed demonstrate clear reductions in greenhouse gas emissions compared to fossil incumbents, with some waste-based biorefineries achieving carbon-negative operations.

Despite these strengths, the EU faces a "double valley of death" in financing. There is a critical lack of funding for the transition from lab to pilot scale (TRL 4–6) and an even more pronounced gap for moving from demonstration to full commercial deployment (TRL 7–9), where projects are capital-intensive and deemed high-risk. Additionally, the EU lags behind global competitors like the US and China in foundational biotechnological platforms, such as synthetic biology and CRISPR applications. This disparity is exacerbated by a fragmented regulatory environment and slow approval processes for biomanufacturing facilities, which creates a risk of innovation leakage and production offshoring

**Policy Recommendations**

To realise the full potential of the bioeconomy, the report recommends a comprehensive and cohesive policy framework.

- Securing Feedstock Availability: Policies must actively support sustainable agriculture to increase domestic yields and mobilize waste streams. Crucially, the "cascading use" principle should be enforced to prioritize high-value material applications over energy use, ensuring optimal resource allocation and utilization.

- Create Supportive Market Conditions: To drive industrial uptake, the EU should implement binding bio-based content targets across relevant product legislation. Green public procurement should be leveraged to create predictable demand-pull, while regulatory coherence must be established to level the playing field between bio-based and fossil-based products. This includes harmonising certification systems and accelerating approval processes for advanced biotechnologies.
- Strengthen Innovation and Scale-Up: Public funding instruments need to pivot toward supporting industrial deployment (TRL 6–9) to bridge the financing gap. Furthermore, a modernization of regulations concerning new genomic techniques (NGTs) is required to ensure the EU keeps pace with global innovation and maintains its technological sovereignty.

# 1 Introduction

The transition towards bioeconomy offers many opportunities for the European Union, promising benefits for a sustainable development, climate neutrality, enhanced industrial competitiveness and increased strategic autonomy. Yet, the strong innovation potential of bio-based solutions also poses challenges—particularly in terms of scalability, competitiveness and market success.

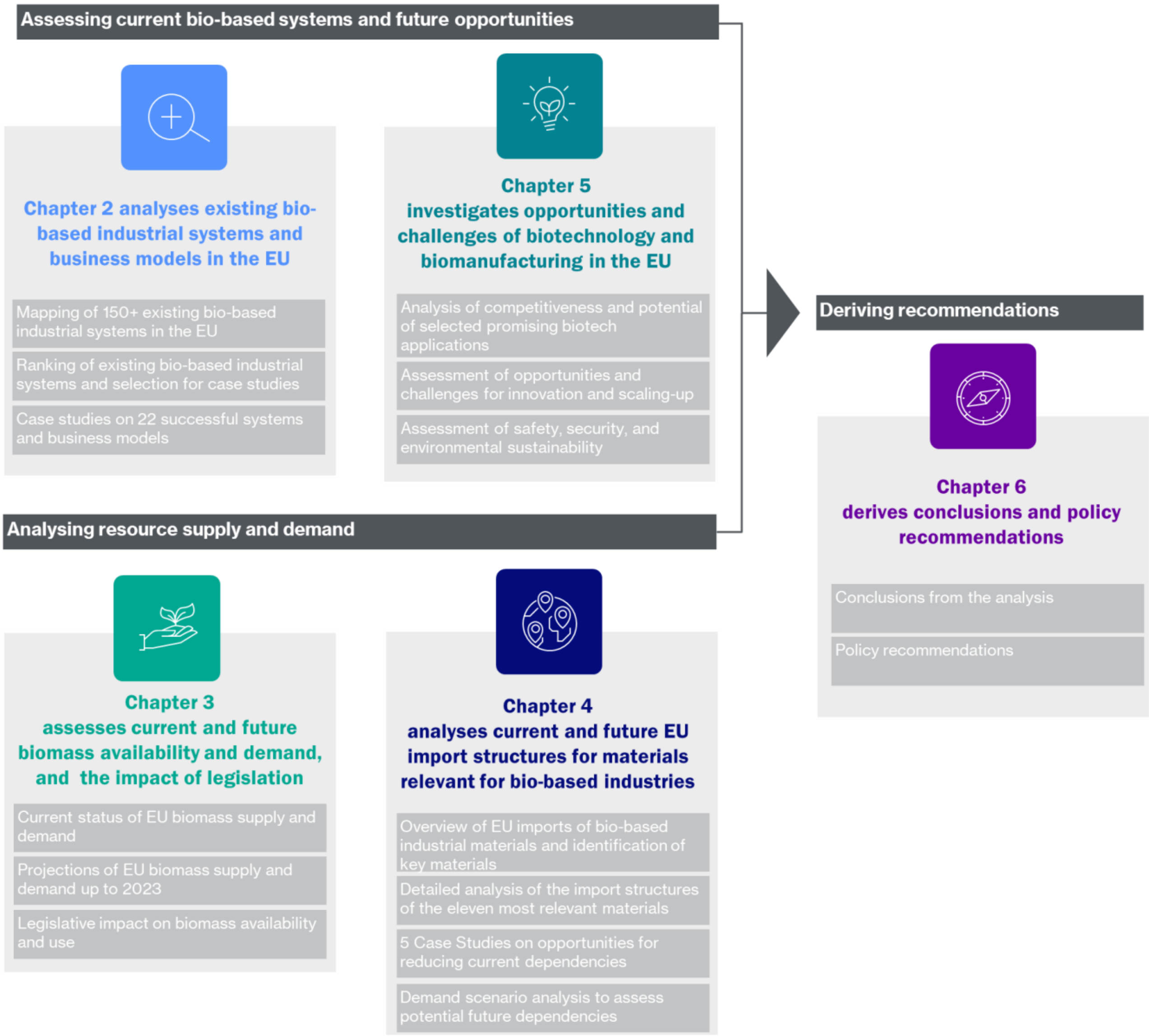
The current political landscape, shaped by the ambitious goals of the European Green Deal and a renewed focus on boosting the competitiveness of EU industries, offers a unique window to establish a coherent and supportive regulatory framework. This is reflected in the recent 2025 update of the EU Bioeconomy Strategy and the introduction of the new Biotech Act, both of which aim to strengthen bio-based and biotech sectors. At the same time, shifting geopolitical dynamics underscore the urgency for the EU to act decisively.

The primary objectives of this study are to identify existing bio-based industrial systems within the EU, learn from successful cases and innovative business models, assess biomass availability and import dependencies, investigate market potentials along with their environmental, social, and economic impacts, examine the legislative landscape, and ultimately develop policy recommendations. By addressing these objectives, the study aims to provide a comprehensive understanding of the current state and future potential of the bio-based economy in Europe.

Figure 1 gives an overview of the design of this study. It comprises three main blocks:

- **Assessing current bio-based systems and future opportunities:** Chapter 2 takes stock of the current situation. It explores the landscape of bio-based industrial systems in the EU, by mapping and ranking current systems in the EU and exploring successful business models based on a range of case studies. Chapter 5, on the other hand, examines the future potential of biotechnology and biomanufacturing within the EU for 16 high-potential applications. The chapter discusses competitiveness and market potentials, opportunities and challenges for innovation and scaling-up; as well as environmental and safety aspects and the role of national regulations.
- **Analysing resource supply and demand:** A critical prerequisite for the bioeconomy is a stable supply of biomass. Chapter 3 focuses on domestic supply. It quantifies the current supply and demand for biomass in the EU and outlines future trajectories. On this basis, the chapter assesses the potential for growth in agricultural and forest biomass and impacts of current policies. Chapter 4 considers imports. It analyses the import structures of key raw materials relevant for bio-based industrial systems based on five key metrics. It further examines selected cases that showcase examples to decrease import dependencies and conducts a scenario analysis to explore future dependencies.
- **Deriving policy recommendations:** Chapter 6 synthesizes the findings from the previous chapters and offers strategic policy recommendations aimed at enhancing the EU's bioeconomy. It emphasises the need for a supportive regulatory framework, investment in research and development, and the promotion of sustainable practices to strengthen the bio-based sector and reduce reliance on fossil fuels.

**Figure 1: Study design**




Source: Prognos AG/Idea Consult/nova Institute 2025, own elaboration

# 2 Understanding successful bio-based industrial systems and business models in the EU

This chapter explores established bio-based industrial systems within the European Union. It outlines the methodology used to map and rank a comprehensive list of existing systems, which is presented in detail in the Annex of this report. Subsequently, the chapter draws insights from 22 case studies of selected successful systems, examining opportunities and challenges for scaling up technologies and products as well as characterising their business models, referencing the business model taxonomy and challenge classification proposed by Bröring and Vanacker (2022). It also assesses barriers to growth and evaluates strategies to enhance the global competitiveness of EU bio-based industries.

*i*

**Key findings**

In comparison to conventional industries, bio-based industry value chains are relatively more complex. Even at the level of case studies, which in this study were formulated around a specific characterising bio-chemical, the companies typically operate in multiple value chains encompassing a system of value chains rather than a particular one. Companies offer their products and processes in a wide array of end-markets. Additionally, variability in feedstock quality and seasonality are typical features as well.

Nevertheless, the EU bio-based industry still has a strong market potential in EU, yet in continuous competition with value chains based on fossil-based feedstocks. In contrast to the latter, the EU bio-based industry contributes to the EU's industrial autonomy and resilience with strong interlinkages with local economies.

Current challenges include i) high upfront investment costs ii) skills shortages and availability of qualified workforce, iii) the administrative burden due to third-party certifications, and iv) the relatively stronger EU policy incentives for bioenergy compared to the incentives for biomaterials.

The selected successful business cases indicate that each company or case has its own business plan to overcome these challenges. Yet a few overarching success factors can be identified such as i) technological leadership for producing and valorising a specific (set of) chemical(s), ii) a strong link with the local economy and feedstock supply, iii) a focus on products and/or processes with high value-added and willingness to pay, generating financially sustainable cashflow, iv) access to equity finance, and v) internal training and skills upgrading of the workforce.

## 2.1 Mapping and selection of bio-based industrial systems in the EU

As a basis for the whole project, the consortium conducted a broad mapping of existing commercial value chains of bio-based chemicals and derived materials in Europe. The objective was to a) obtain a wider impression of the level of operationalisation of bio-based production in Europe and b) to have a basis for the in-depth research of the case study analysis.

To map and select 25 bio-based industrial systems (see Box below) to be researched in depth, a long list of more than 150 bio-based industrial systems was compiled at first, which was subsequently reduced to a list of 50+ high-potential bio-based industrial systems. The long list aimed at collecting as thoroughly as possible companies that presented at least a production facility in the European Union. This means that industries with presence in the EU, but whose production facilities were based outside the EU were not considered and therefore discarded from the analysis. In addition to the geographical limitation, the list was further narrowed down to production process whose TRL is 6 or above. We considered TRL>6 as those production processes where pilot scale demonstrations were successful and no further changes to the production process or end-product were to take place[1]. Whenever possible, a more specific and accurate TRL was assigned to each production process. Finally, certain end use sectors were deliberately excluded from the study, such as fuels, food, feed, and pharmaceuticals, as these areas fell outside the scope of the project, which aimed to concentrate on industrial bio-based systems relevant to materials and chemicals.

**Figure 2: Value chain logic – illustrative**


Source: Own production

The final list can be found in Annex 1.1

[1] Buchner, G. A., Stepputat, K. J., Zimmermann, A. W., & Schomäcker, R., *Specifying Technology Readiness Levels (TRL) for the Chemical Industry*. Industrial & Engineering Chemistry Research, 58(17), 6957-6969, 2019 https://doi.org/10.1021/acs.iecr.8b05693

i

**Definition of Bio-based Industrial Systems**

In this study Bio-based Industrial System (BBIS) refers to the integrated production processes that use renewable biological feedstocks – such as agricultural crops, wood, agricultural residues, forestry by-products, marine biomass, animal-derived materials, bio-waste, biogenic gaseous carbon and microorganisms – to create products, services and materials.

The compilation of the list of industrial bio-based systems (Annex 1.1) involved a comprehensive and systematic process to identify and categorize bio-based industrial systems operating primarily in Europe consisting of four steps:

1. The first step included surveying existing reports from various sources including the 2019 JRC study on the European market for bio-based chemicals[2], the Road-To-Bio[3] project reports, the EU Biorefinery Outlook[4], and several nova-Institute market reports, such as the Bio-based Building Blocks and Polymers Report[5], the report on Carbon Dioxide ($CO_2$) as Feedstock for Chemicals, Advanced Fuels, Polymers, Proteins and Minerals[6], the Biorefineries in Europe report commissioned by CEPI[7]. Other sources included Horizon projects reports from STAR4BBS[8], HARMONITOR[9], SUST-CERT4BIO-BASED, BioReCer[10], 3.-CO and Wood Circus[11] among others. Internal knowledge of the consortium played also a significant role in the compilation of the BBIS, including sources such as the Renewable Carbon News[12] and the Renewable Carbon Companies[13].

[2] Spekreijse, J., Lammens, T., Parisi, C., Ronzon, T. & Vis, M., Insights into the European market for bio-based chemicals, EUR 29581 EN, Publications Office of the European Union, Luxembourg, 2019, https://dx.doi.org/10.2760/18942.
[3] RoadToBio. 'A roadmap to the bio-based chemical industry: Societal, technological, and regulatory challenges and actions to be taken by 2030'. Horizon 2020 Project, 2020. https://www.roadtobio.eu
[4] European Commission: Directorate-General for Research and Innovation, BTG, E4tech, FNR, ICONS and WUR, EU biorefinery outlook to 2030 – Studies on support to research and innovation policy in the area of bio-based products and services, Publications Office, 2021, https://data.europa.eu/doi/10.2777/103465
[5] Skoczinski, P., Carus, M., Tweddle, G., Ruiz, P., Hark, N., Zhang, A., de Guzman, D., Ravenstijn, J., Käb, H., and Raschka, A., Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2023–2028. nova-Institut GmbH, 2024. https://doi.org/10.52548/VXTH2416
[6] Ruiz, P., Skoczinski, P., Raschka, A., Hark, N. and Carus, M., Carbon Dioxide (CO2) as Feedstock for Chemicals, Advanced Fuels, Polymers, Proteins and Minerals – Technologies and Market, Status and Outlook, Company Profiles. nova-Institut GmbH, 2023. https://doi.org/10.52548/HKBS8158
[7] Krause, L., Mrsic, K., Partanen, A., & Plum, M. Innovative bio-based products for a clean transition: A Cepi study on pulp and paper industry biorefineries in Europe (Executive Summary). CEPI, 2024. https://www.cepi.org/wp-content/uploads/2024/09/Cepi_BioRefineries_Executive-Summary_2024.pdf
8 STAR4BBS. 'Sustainability Transition Assessment Rules for Bio-Based Systems'. Horizon Europe Project, European Commission Website, 8 July 2022, accessed 20 November 2025, https://cordis.europa.eu/project/id/101060536
9 HARMONITOR. 'Harmonisation and Monitoring Platform for Certification Schemes and Labels to Advance the Sustainability of Bio-Based Systems'. Horizon Europe Project, European Commission website, 1 June 2022, accessed 20 November 2025, https://cordis.europa.eu/project/id/101060133
[10] BioReCero, 'Biological Resources Certification Schemes'. Horizon Europe Project, 07 June 2022, accessed 20 November 2025, https://cordis.europa.eu/project/id/101060684
[11] Wood Circus, 'Underpinning the vital role of the forest-based sector in the Circular Bioeconomy'. Horizon 2020 Project, 01 November 2018, accessed 20 November 2025, https://cordis.europa.eu/project/id/820892/results
[12] nova-institut GmbH, 'Renewable Carbon News, accessed 20 November 2025, https://renewable-carbon.eu/news/
[13] nova-Institut GmbH, 'Renewable Carbon Companies (RECACO)'. Accessed 21 November 2025, https://renewable-carbon.eu/companies/

2. In addition, targeted searches on the websites of the respective companies were carried out to identify missing information. Despite the broad literature covered in the initial steps, data gaps remained, such as actual and total production capacity in tonnes per year, technology applied and technology readiness levels among others. These data are not openly shared by companies. In addition, other companies are also reluctant to share information on the feedstock and precursor of their processes.
3. In step 3, experts from different associations and companies were interviewed (see Table 1). During this step the preliminary list of, at this point more than 150 BBIS, was presented to all interview partners for them to provide feedback related to the representativeness and comprehensiveness of the list, as well as gaps and quality. The experts also ranked the BBIS in terms of market potential.
4. The final step involved a validation round carried out by experts at the nova-Institute, the European Circular Bioeconomy Fund and the Bio-based Industries Consortium. For the final validation, the preliminarily ranked list containing the 50+ BBIS was shared, feedback was incorporated. The validation process was the last step to confirm the final status of the list of 50 BBIS and confirmed that the ranking was done using a systematic approach by screening multiple factors in order to avoid subjective bias. The final list of 50 BBIS can be found in Annex 1.1.

**Description of the Bio-based Industrial System List**

Each BBIS was categorised based on the primary product of the process. This product was labelled as "Main Product". In addition, the precursor ("Precursor") and the subsequent chemical ("Derivative") of the main product was included. This allows for a more comprehensive understanding of potential industrial linkages across different BBIS. It should be noted that the "Derivative" should not be considered as part of the production process of the company in which is mentioned. In addition to this technical classification, the company name, location country of the production facility was recorded along with potential end-use sector categories, TRL (as mentioned above) and process type.

**Ranking of the Bio-based Industrial Systems**

To select the BBIS for the case studies, a funnel approach was used to ensure the systemic and objective selection and prioritization of industrial systems, with the aim to refine and shorten the list to a maximum of 50 BBIS. The criteria for this analysis considered not only the policy context and economic aspects, such as market potential, feedstock availability, potential for scalability and Technology Readiness Levels (TRL), but also data availability, role of SMEs and aspects related to the contribution of the industrial systems to EU competitiveness, economic resilience and strategic autonomy. In addition, the internal knowledge of the consortium and other external stakeholders (See Table 1) in the bio-based industry was also considered through unstructured interviews. Given that the selected experts belonged to a wide network of cluster organisation, they were able to provide insights into the technological readiness, market dynamics, international competition and scalability of the systems from a broader, more systemic perspective. Based on these evaluations, each system was assigned a potential rating of high, medium, or low, reflecting its ability to become competitive in the bio-based market. This classification was important for understanding which systems were likely to lead the market in the coming years and which were still in the development or exploratory phases.

**Table 1 Overview of overarching interviews**

| Organisation | Focus and scope of the organisation | Interview Date |
|---|---|---|
| Cluster Industrial Biotechnology – CLIB | Industrial biotechnology, new application fields of biotech. | 17 December 2024 |
| EuropaBio | Food, feed, biotech chemicals, plastics, and other bio-based materials (e.g., enzymes and amino acids for food and feed); > 80 members representing together approximately 2500 biotech SMEs | 7 January 2025 |
| Bio-based Circular | Bio-based industrial solutions, sustainable raw materials (e.g. polyesters made with biomaterials), industrial glycol production and other bioplastics, circular bio-based solutions | 9 January 2025 |
| CEFIC/Bio-ChemEurope | Competitiveness of bio-based products, feedstock prices, framework conditions | 24 January 2025 |
| Bio-based Industry Consortium (BIC) | Access to finance for bio-based innovation upscaling, legislative framework for the development of bio-based value chains | 5 February 2025 |

From the final list of 50 BBIS, 25 BBIS were selected to conduct in depth case studies ensuring a wide coverage of end-use sectors and feedstocks. For more details on the final selection process, see the next chapter.

## 2.2 Successful bio-based industrial systems and learnings from successful case studies and business models

### 2.2.1 Overview of case studies and selection process

As described in the previous section, the bio-based industrial systems selected for further in-depth research and compilation into complete case studies was carried out through desk research on the one hand and expert validation on the other. A series of overarching interviews with key organisations representing major European bioeconomy stakeholders was carried out at the beginning of the study.

In addition to validating the long list of bio-based industrial systems and understand the challenges and opportunities the industry faces, these interviews served the purpose to identify successful examples of companies having commercialised bio-based industrial solutions. Based on the validated long list and member organisation volunteering, as well as work previously done by the EC's Knowledge Centre for Bioeconomy, the EU bio-based industry dashboard developed by the JRC and other recent industry reports, 22 case studies covering successful business applications were compiled. The reports and industry insights produced by these organisations provided relevant companies and repositories to search for additional companies, completing the initial longlist of companies presented in the previous section. The final selection of case studies is listed in the table below, together with the application sectors that they cover and can be found in the annexes of this document. Each of the 22 case studies includes a business model description based on the paper by Bröring et al. (2022). This business model approach introduces a bioeconomy-specific typology for bio-based products, processes and integrated services as a starting point for design choices. Business model design is presented as part of a more complex technology system than conventional business model approaches. This business model framework is intended to guide practical business model design in the bioeconomy specifically. Each case study is also accompanied by a factsheet that summarises the product or technology offered by the organisation.

The elaborated case studies provide evidence of the potential of bio-based industrial systems and biotechnology for European industry. The insights gained give anchor points and inspiration for suggestions on how the future development of EU industrial policy and research and innovation could develop. In this section we compiled the main insights in terms of market potential, industrial strengths, challenges, feedstocks and regulations. These insights are designed to support the European Commission in the implementation of new policy initiatives to boost biotechnology and biomanufacturing in the EU and provide input to the review of the EU Bioeconomy Strategy.

Biotechnology is defined here following the updated industrial biotechnology definition set out in JRC139415[14]. It covers the use of enzymes, microorganisms, and/or advanced tools, including genetic engineering, metabolic engineering, precision fermentation, recombinant DNA technology, and synthetic biology, to produce bio-based products.

In Table 2, a company is marked under "Biotech" only if its core production process relies on one or more of these biological mechanisms. Working with bio-based feedstocks alone does not qualify a company for this column. Companies whose processes rely exclusively on conventional chemical transformations, such as hydrolysis, esterification, distillation, hydrogenation, or mechanical fractionation, are not marked under Biotech, even where the feedstocks are biological in origin.

[14] Lowe C.R., Minssen T., Skentelbery C. (2024). Emerging Biotechnologies in Europe: Foresight for Policy. European Commission Joint Research Centre, JRC139415. doi:10.2760/4814109

**Table 2 Overview of Case Studies and applications sectors**

| Case # | Case Study title | Chemicals | Agriculture | Cosmetics | Construction | Automotive | Packaging and Plastics | Textiles | Biotech |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Spider silk through bio fermentation | | | X | | X | X | X | X |
| 2 | Succinic Acid (LUCRA Project) | X | | | | X | X | X | X |
| 3 | Polyhydroxyalkanoates (PHA) | | X | X | | X | X | | X |
| 4 | Terpene synthesis technology | X | | X | X | X | X | | |
| 5 | Biosurfactants | X | X | X | | | | | X |
| 6 | Cellulose and lignin from wood residues and low quality hard wood | X | | X | X | | X | | X |
| 7 | Polylactic Acid (PLA) | | X | | | | X | X | X |
| 8 | Hemp Fibres | | X | | X | X | | X | X |
| 9 | Designed Enzymatic Biomaterials™ (DEB) | X | X | X | X | X | X | X | X |
| 10 | Enzymes | X | X | | | | | X | X |
| 11 | Biodegradable Polymer Green Planet™ (PHBH) | X | X | | | X | X | | X |
| 12 | Yeast for bioethanol production | X | X | X | | X | | | X |
| 13 | Carbon recycling with bio and fossil (waste) feedstock | X | X | X | | | X | X | X |
| 14 | Man-made cellulosic fibers | | | | | | X | X | |
| 15 | Performance ingredients from lignin | X | X | X | X | X | X | X | |
| 16 | Bio-Butanediol (BDO) | X | X | X | X | X | X | X | X |
| 17 | Oleochemicals | X | X | X | X | X | X | | |
| 18 | Terpene- and phenyl-propane-based products | | | X | | | | | X |
| 19 | Ethyl acetate and acetaldehyde from biobased ethanol | X | X | X | | | X | | |
| 20 | Wood based bioproducts | X | | X | X | X | X | X | |
| 21 | 9 decenoate (9-DAME) and 1 decene | X | X | X | | X | X | | |
| 22 | Mass balanced vinyl acetate copolymers and mass balanced silicone polymers | X | | X | X | X | X | | |
| | **TOTAL** | **16** | **14** | **16** | **9** | **14** | **17** | **11** | **14** |

### 2.2.2 Market potential and opportunities

The European bioeconomy represented a value added of EUR 812 billion in 2022 and employed over 17.2 million people[15]. More than 31% of global bio-based production is provided by European bio-based industries, while Europe contributes 17% to global fossil based production[16].

Currently, bio-based plastics account for less than 1% of total plastics production[17]. Conventional plastics maintain a competitive advantage because they continue to receive public subsidies as the fossil fuel industry received EUR 1.24 trillion globally in government support in 2023[18]. This support comes both in the form of direct support for production facilities and indirectly through subsidised oil and gas. In addition, fossil-based feedstocks remain widely available and inexpensive compared to bio-based alternatives[19]. As such, fossil-based plastics benefit from system-level fossil-fuel subsidies that keep feedstock and energy costs below the true social cost of 130 euro per ton of CO2[20]. In the meantime, bio-based plastics benefit from project-bound support in the form of R&D, demonstration and early deployment grants and other funding programmes. Overall, industry data suggests approximately EUR ~5.7 billion in support of bio-based materials/bioplastics projects in Europe since 2014, which is significantly lower than previously mentioned support for fossil-based plastics[21].

Figure 3 presents European market values and forecasts for bio-based chemicals. This data is collected from various sources (Forbes, Grand View Research, Skyquestt, Vantage Market Research, Global Market Insights, Business Research Insights, and Fortune Business Insights) to present a partial market overview of bio-based chemicals covered by the case studies. To ensure comparability across sources, the data points were selected so that the reference years and forecast horizons match each other. It should be emphasised that the resulting overview remains partial. The available studies differ in scope, methodological assumptions, and product definitions, and no single, comprehensive assessment of European bio-based chemical markets at this level of granularity currently exists. While the 2019 JRC Study *Insights into the European market for bio-based chemicals* produces figures for products, it does not cover specifically chemicals as presented in the figure above. Therefore, the figure should be interpreted as an indicative illustration of market coverage and magnitude rather than a definitive or exhaustive forecast.

The most significant growth rate is linked to the European Carbon Capture, Utilization, and Storage (CCUS) market, which was estimated at EUR 0.77 billion in 2024 and is expected to grow to EUR 33.81 billion by 2034.[22] Accounting for 20% of the global polysaccharides market, European

[15] European Commission: Joint Research Centre (JRC) Lasarte-López, J., González-Hermoso, H., Tamosiunas, S., Porc, O., Poranki, N. and M'barek, R., *Jobs and wealth in the EU bioeconomy / JRC – Bioeconomics,* Publications Office of the European Union, Luxembourg, 2025, http://data.europa.eu/89h/7d7d5481-2d02-4b36-8e79-697b04fa4278

[16] Spekreijse, J., Vikla, K., Vis, M., Boysen-Urban, K., Philippidis, G. and M'barek, R., *Bio-based value chains for chemicals, plastics and pharmaceuticals*, EUR 30653 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-32459-1, doi:10.2760/712499, JRC124141.

[17] European Environmental Agency, *Global bio-based plastics production capacity*. Last Accessed 18 April 2024, https://www.eea.europa.eu/en/circularity/sectoral-modules/plastics/global-bio-based-plastics-production-capacity

[18] OECD, *OECD Inventory of Support Measures for Fossil Fuels 2023*, OECD Publishing, Paris, 2023. Retrieved from https://doi.org/10.1787/87dc4a55-en.

[19] CE Delft, *Balanced policy support for bio-based and recycled plastic.* Delft, 2023, https://cedelft.eu/wp-content/uploads/sites/2/2024/12/CE_Delft_240292_Balanced_policy_support_for_bio-based_and_recycled_plastic_def.pdf

[20] Economisch Statistische Berichten (ESB), Mulder, M., J. Bollen, J. Cozijnsen, S. Lomme, F. Rooijers, J.P. van Soest & E. Woerdman, *Europees emissiesysteem bepaalt halen CO2-doelen, fossiele subsidies secundair*, 109(4832), 9 October 2023, p. 12.

[21] Circular Bio-based Europe Joint Undertaking, 'Consolidated Annual Activity Report 2024', Ares(2025)5339564, 3 July 2025, https://www.cbe.europa.eu/system/files/2025-07/CBE-JU-AAR-2024-signed.pdf

[22] Exactitude Consultancy, *Europe Carbon Capture, Utilization and Storage (CCUS) Market – Growth, Trends and Forecast 2024–2034,* Last Accessed 20 April 2025, https://exactitudeconsultancy.com/reports/49514/europe-ccus-market.

polysaccharides are expected to grow from EUR 14 billion in 2023 to EUR 21.7 billion in 2032. The expected growth for enzyme-based polysaccharides is based on high value-added applications in personal care and bio-based packaging, as well as food ingredients and pharmaceuticals.

Enzymes, polysaccharides and chemicals made with CCU feedstock have a significant market value. However, smaller markets such as Polyhydroxyalkanoates (PHAs), Polylactic Acid (PLA) and Succinic Acid are also important chemicals for European bio-based Industries. While valued at EUR 391 million in 2023, the European PLA market is growing quickly, driven by rising demand for sustainable packaging, textiles, and durable goods. The packaging sector is the dominant application for PLA, accounting for 59% of all compostable plastics in 2019[23]. The market for PHA is scaling up rapidly and is projected to grow from 49.04 kilotons in 2025, with Europe accounting for 35 to 47% of it, to 141.58 kilotons by 2030[24]. This projected development suggests both a growing market interest in bio-based plastics alternatives and a growing production capacity in Europe. Europe currently holds around 36.2% of the Succinic Acid market[25]. A related biopolymer, polybutylene succinate (PBS) is estimated to be worth EUR 100 million in 2023 to reach up to EUR 300 million by 2032 at a CAGR of 12%[26]. Double-digit growth rates for both polymers suggest an increasing demand for bio-based succinic acid.

It is noteworthy that currently no comprehensive study on market forecasts for bio-based chemicals at such a granular level exists. While the 2019 JRC Study *Insights into the European market for bio-based chemicals* produces figures for products, it does not cover specifically chemicals as presented in the figure above.

Contrary to conventional markets like steel, cement and concrete or petrochemicals that have longstanding established value chains and stable market demand, bio-based chemicals are newer and their future market uptake is less certain. Market projections and future demand will be heavily influenced by policy changes, incentives and investor sentiment, or risk perception.

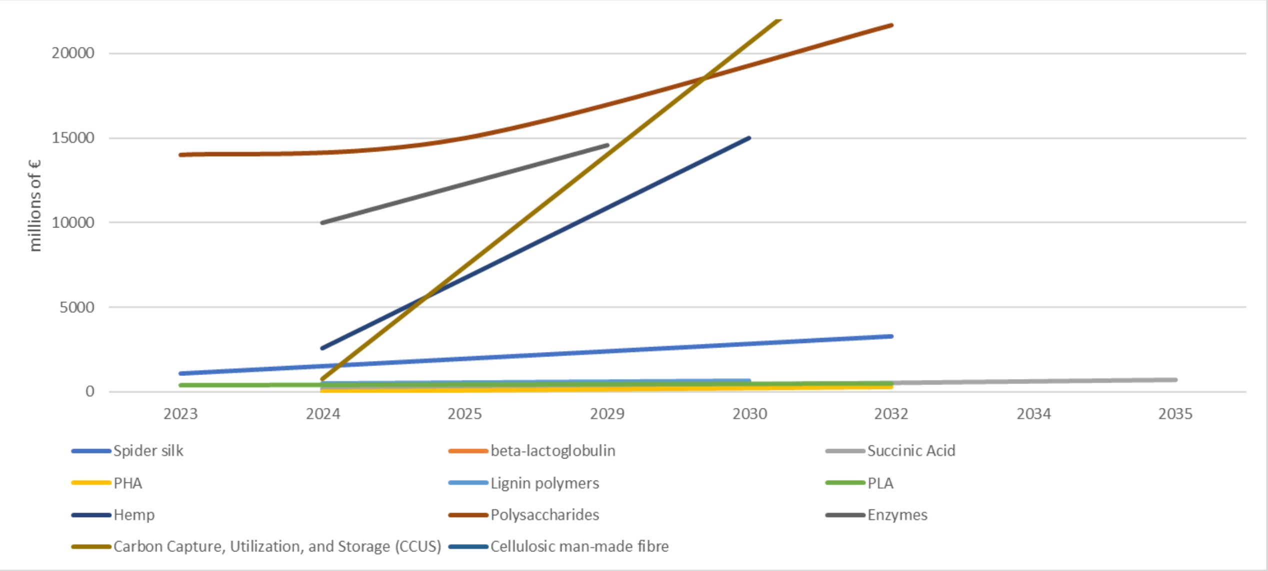
[23] Fortune Business Insights, Polylactic Acid (PLA) Market Size, Share & Industry Analysis, By Application (Packaging, Textiles, Consumer Goods, Agriculture & Horticulture, and Others), and Regional Forecast, 2024-2032, 1 December 2025, Fortune Business Insights, https://www.fortunebusinessinsights.com/polylactic-acid-pla-market-103429

[24] Mordor Intelligence. (2025). *Polyhydroxyalkanoate (PHA) Market – Growth, Trends, and Forecasts (2025–2030),* 10 September 2025, Mordor Intelligence, https://www.mordorintelligence.com/industry-reports/polyhydroxyalkanoate-market

[25] Vantage Market Research, *Succinic Acid Market (Industry Report)*, https://www.vantagemarketresearch.com/industry-report/succinic-acid-market-2569?utm

[26] Global Market Insights. (n.d.). *Polybutylene succinate (PBS) market size, share & global report – 2032*. 4 September 2025, Polybutylene Succinate Market Size, Share & Global Report - 2032

**Figure 3 European Market Forecasts for bio-based chemicals, 2023-2035, in million EUR**




Source: IDEA Consult, based on Forbes, Grand View Research, Skyquestt, Vantage Market Research, Global Market Insights, Business Research Insights, Fortune Business Insights

### 2.2.3 Industrial strengths

**Complete value chain integration**: Companies active in bio-based chemicals are typically involved in several complex value chains. Upstream, this implies that the companies get their feedstocks from a variety of sources and downstream that their products serve several industries simultaneously. This is true for small companies as well as larger, multinational, companies and offers the benefit of a certain degree of resilience to external shocks such as resource scarcity and demand decline due to changing industry needs. Nevertheless, in contrast to conventional value chains, feedstock in bio-based industries is more subject to seasonality and quality variations.

**Ecosystem development for industrial resilience**: because of the interconnected nature of bio-chemical value chains, in times of urgent needs it is possible to leverage stakeholders to answer demand spikes for specific products. Such was the case for ethanol production during Covid for sanitisers. Company 1 reactivated an unused ethanol plant within 11 days, partially thanks to swift public support and cross-border collaboration, partially because of substitution effects in ethanol production through bio-based feedstocks.

**EU industry autonomy**: In the long-term, bio-based chemicals have the potential benefit of making local economies more resilient to external shocks (e.g. climate change induced extreme weather events, wars, trade tariffs and transport disruptions). Interviewed experts, organisations and practitioners stated that, in the short-term, Bio-based chemical production in the EU could benefit from additional support, including mandatory bio-based content targets, green public procurement incentives, and the development and harmonisation of eco-labelling schemes. The European Technical Committee for Standardisation for bio-based products (CEN/TC 411) already provides a framework of standards for assessing bio-based content, sustainability, and life-cycle impacts, which could be further leveraged to enhance consumer trust and comparability across markets. Moreover, the European Commission's Communication on the Sustainable Carbon Cycles

(COM(2022) 682 final) highlights the need to foster the deployment of ecolabelling schemes and promote the uptake of sustainable bio-based materials to strengthen market demand and transparency[27].

With over 800 biorefineries in Europe, which far exceeds the number of fossil fuel refineries in the EU, illustrating the increasing importance of biorefinery deployment[28]. Most of the EU biorefineries, as per the ENEA/JRC biorefinery mapping, are focused on biomaterials (e.g., 507 producing bio-based chemicals and 141 composites/fibres) along with a substantial energy segment (363 liquid biofuels), 177 sites thus product and energy outputs integration (note: facilities can be counted in multiple product categories). At a system level, bioenergy is already providing a significant share of the EU final energy—roughly in the low teens percent—thereby highlighting the extent of energy applications alongside materials pathways.

**Market and application diversification**: Bio-based chemical companies typically cater to a wide array of end-markets. Each segment, such as textiles, packaging and bioplastics, cleaning and personal care, aromas and food ingredients, has its own growth dynamics, regulatory landscape, and customer requirements. This diversification might reduce dependency on any single market, mitigate sector-specific risks, and enable companies to capture emerging opportunities across different value chains.

### 2.2.4 Challenges

**High CAPEX costs**: Large-scale biomanufacturing plants require high upfront investments. Strategic partnerships with larger structure help mitigate risks, however regulation uncertainties increase the investment risks.

**Skills shortage in the EU**: Companies struggle with a shortage of qualified workforce such as for fermentation technicians and bio-process engineers. The European Commission's Employment and Social Developments in Europe (ESDE) 2023 report shows that labour and skills shortages permeate across numerous sectors—including science, ICT, engineering, and STEM, all critical to bioprocess engineering and fermentation roles[29].

**Overlapping certifications**: Companies rely on third-party sustainability certifications (e.g., FSC, PEFC, Responsible Care). These are increasingly important for market positioning and supporting claims of environmental responsibility and traceability. Companies are driven to adopt several sustainability schemes and certifications that cover the same domain but follow different processes. Companies processing wood or timber for instance often need both FSC and PEFC chain-of-custody certifications, even though the end objective of responsible sourcing is shared. Securing multiple certifications brings increased costs for companies in the form of annual audits, administrative processes, and overlapping reporting which duplicate effort without delivering proportional new value.

**Potential competition for biomass use for energy purposes**: Concerning the interrelation of bio-based industries and EU energy demand and hence the link with EU resilience on energy imports

[27] European Commission. (2022). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Sustainable Carbon Cycles (COM(2022) 682 final). Retrieved from COM_2022_682_1_EN_ACT_part1_v4.pdf
[28] IEA Bioenergy, 2025, BioRefinery Plant Portal, accessed 14 November 2025, https://webgis.brindisi.enea.it/bioenergy/maps.php#
[29] European Commission: Directorate-General for Employment, Social Affairs and Inclusion, Employment and social developments in Europe 2023, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2767/089698

and with the climate targets we refer to section 3.1. This chapter quantifies the current EU-27 biomass supply and demand and develops baseline trajectories to 2035. Furthermore, a set of policies potentially impacting biomass supply and demand in the future is analysed and quantified to determine whether supply and demand will be matched or if competition for biomass is expected to become sharper.

A systematic cross-cutting case analysis of the challenges as identified and classified by Bröring and Vanacker (2022) indicates that the top ten challenges encountered in the set of 22 cases are mostly related to regulatory aspects, market related and economic aspects. Specifically, these challenges and their respective categories are presented in the following table.

**Table 3 Key challenges identified in the analysed cases**

| Rank | Case frequency | Challenge description | Category |
|---|---|---|---|
| 1 | 22 | Inefficient policies and high transaction costs | Regulatory |
| 1 | 22 | Unclear regulation | Regulatory |
| 2 | 21 | Commercialization and market diffusion | Market |
| 2 | 21 | Misaligned regulation across countries, markets and sectors | Regulatory |
| 2 | 21 | Dominance of existing business models | Organizational |
| 3 | 20 | Low market acceptance and limited customer demand/lack of confidence in the product | Market |
| 4 | 19 | High opportunity costs | Economic |
| 4 | 19 | Trouble achieving economic profitability/process efficiency | Economic |
| 5 | 18 | High costs of EU feedstock | New |
| 6 | 17 | Lack of economies of scale | Economic |
| 7 | 16 | Time consuming security/safety approvals | Regulatory |

| | | | |
|---|---|---|---|
| 8 | 15 | Competition for limited raw materials | Product quality and availability |
| 9 | 14 | Upscaling | Technological |
| 9 | 14 | Difficulty to secure public funding | New |
| 10 | 11 | Lack of capital and financial resources | Economic |
| 10 | 11 | Dependence on subsidies | Economic |
| 10 | 11 | Technological lock-in and path dependent behavior | Organizational |

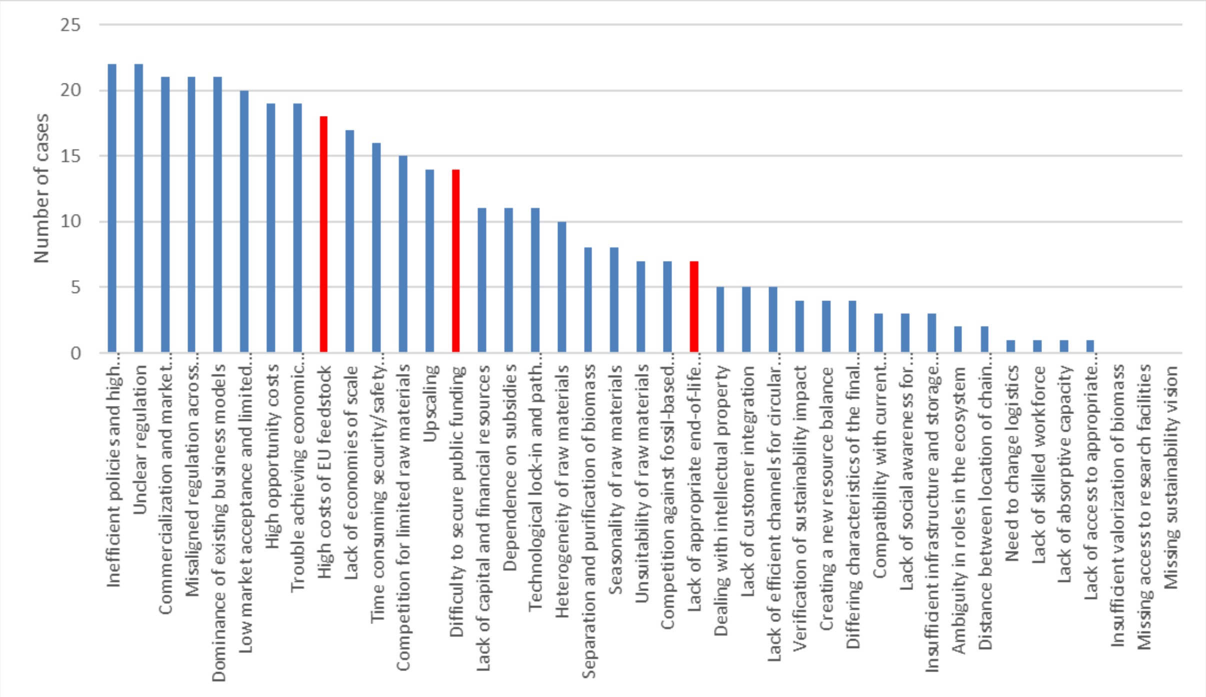
Source: Prognos AG/Idea Consult/nova Institute, 2025,own elaboration based on case studies

However, we also identified three new or additional challenges in the set of 22 case studies which were not found in the Bröring and Vanacker (2022) classification. These are:

- High cost of EU feedstock
- Lack of appropriate end-of-life management systems
- Difficulty to secure public funding.

Figure 4 provides an overview of all the challenges and the respective frequencies ranked from high to low. The frequencies of the newly identified challenges are indicated in red.

**Figure 4 Challenges as defined and classified by Bröring and Vanacker (2022) ranked by frequency in the 22 cases**




Source: Prognos AG/Idea Consult/nova Institute, 2025,own elaboration based on case studies

Every case has its own idiosyncrasies. A challenge for one company can be a driver for business for another. Applying contextual analysis to the cases, Figure 5 provides an overview of the challenges in Bröring and Vanacker (2022) which in the cases were identified as drivers for business activities. The top five challenges that are business drivers at the same time are presented in the next table.

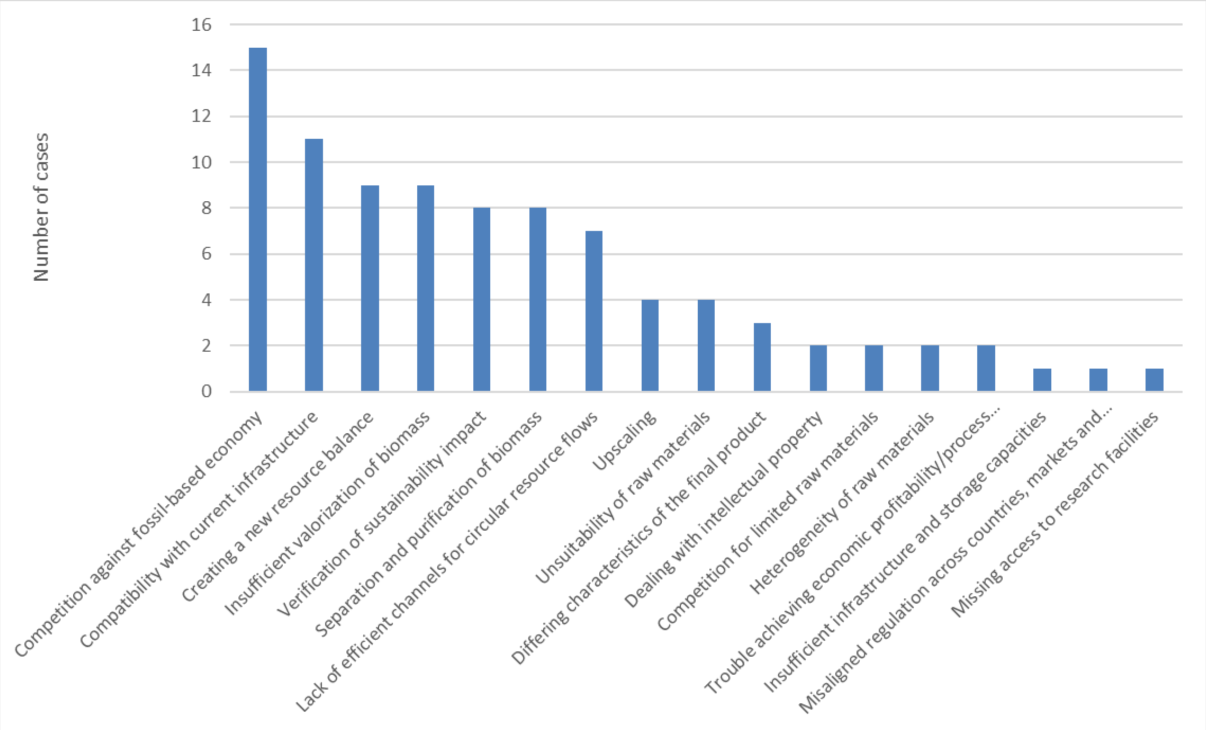
**Table 4 Key drivers identified in the analysed cases**

| Rank | Case frequency | Description | Category |
|---|---|---|---|
| 1 | 15 | Competition against fossil-based economy | Economic |
| 2 | 11 | Compatibility with current infrastructure | Technological |
| 3 | 9 | Creating a new resource balance | Value chain / Ecosystem |
| 3 | 9 | Insufficient valorisation of biomass | Economic |
| 4 | 8 | Verification of sustainability impact | Value chain / Ecosystem |
| 4 | 8 | Separation and purification of biomass | Product quality and availability |
| 5 | 7 | Lack of efficient channels for circular resource flows | Value chain / Ecosystem |

Source: Prognos AG/Idea Consult/nova Institute, 2025,own elaboration based on case studies

This suggests that companies within the bio-based value chain seek to provide solutions to challenges of other companies within the value chain and beyond. Figure 5 provides the frequencies for all the challenges that function as drivers.

**Figure 5 Challenges which have been reported as business drivers ranked by frequency in the set of 22 cases**




Source: Prognos AG/Idea Consult/nova Institute, 2025,own elaboration based on case studies

Evidently these results need to be carefully interpreted given the limited number of cases. Yet the results suggest that the solution to the challenges in the bio-based industry are not only to be sought in the regulatory field, yet businesses themselves create solutions and value added for other companies, and hence reinforce the competitiveness of the entire value chain. Regulatory challenges remain an important action field that is outside the scope of the industry. Addressing these can only help strengthening the EU bio-based industry.

### 2.2.5 Feedstocks

**Production location**: Many companies strategically place processing and fermentation plants close to where the feedstock is grown. In some instances, companies own the surrounding agricultural land operate the farming as well. This can reduce transportation costs and ultimately feedstock costs as well as reducing the carbon footprint related to transport and logistics.

**Incentivised feedstock allocation to biofuels**: Commented on by several companies and highlighted in a June 2025 briefing by the Institute for European Environmental Policy (IEEP), there is a misalignment in EU policy incentives, favouring biomass use for bioenergy, while weaker support exists for biomaterials or land carbon stock maintenance. This divergence drives strategic placement and land ownership decisions by companies seeking to optimise returns[30]. In practice,

[30] Institute for European Environmental Policy (IEEP), Springer K. and Bognar J., *EU bioeconomy in the context of the 2040 climate target*, June 2025, https://ieep.eu/wp-content/uploads/2025/06/Bioeconomy-and-the-2040-climate-target-IEEP-2025.pdf

companies are incentivised to allocate land use to biofuels rather than biomaterials. Indeed, biofuels in the EU benefit from financial incentives—such as a EUR 375 premium per certificate (equating to 10 Gcal), which significantly improves their economic attractiveness relative to alternative biomass valorisation pathways. These built-in premiums underscore why biomass allocations for biofuels can overwhelm those for biomaterials[31].

### 2.2.6 Regulatory considerations

**Complicated regulations inhibiting market developmen**t: Companies may prefer to produce and sell certain products in their portfolio outside of the EU because of complex regulations. These regulations are further listed below and have implications for companies, restricting their ability to procure feedstocks and sell their products for instance. Product approval procedures take a long time compared to other international markets, further adding to the investment uncertainties. The 2024 Draghi Report also describes "inconsistent and restrictive regulations" as barriers to innovation, scale-up and competitiveness[32]The Press Release accompanying the announcement of the Competitiveness Compass further proposes targeted simplification (via the Omnibus Regulation), including specific relief for REACH and broader EU-wide regulatory coherence, to counteract these disadvantages. It also outlines one of its five horizontal enablers as simplification, explicitly stating that the upcoming Omnibus proposal will simplify sustainability reporting, due diligence, and taxonomy[33].

The following table summarises all regulations covered in the case studies, their related challenges and suggested improvements, based on interview outcomes and market insights.

**Table 5 Overview regulations covered in the case studies**

| Regulation / Directive | Case(s) | Challenge and Suggested Improvement |
|---|---|---|
| Renewable Energy Directive (RED II – Delegated Act on Recycled-Carbon Fuels) | Case 13 | *Challenge*: LCA rules require counting 'lost power generation', limiting siting options and profitability. *Improvement*: Adjust LCA rules to enable fair treatment of recycled-carbon fuels and industrial off-gas use. |
| Renewable Energy Directive (RED III) | Case 16, Case 22 | *Challenge*: Quotas and certification frameworks constrain renewable feedstock availability; $CO_2$-based materials often excluded. *Improvement*: Harmonise RED-based certification schemes and allow inclusion of $CO_2$-based inputs. |

[31] European renewable ethanol association - ePURE, *Overview of biofuels policies and markets across the EU-27 and the UK,* November 2020, https://www.epure.org/wp-content/uploads/2021/01/201104-DEF-REP-Overview-of-biofuels-policies-and-markets-across-the-EU-Nov.-2020.pdf

[32] European Commission, *The future of European competitiveness: A competitiveness strategy for Europe (Report by Mario Draghi)*, Publications Office of the European Union, 2024, https://commission.europa.eu/document/download/97e481fd-2dc3-412d-be4c-f152a8232961_en?filename=The%20future%20of%20European%20competitiveness%20_%20A%20competitiveness%20strategy%20for%20Europe.pdf.

[33] European Commission, *An EU compass to regain competitiveness and secure sustainable prosperity*, [Press release], Publications Office of the European Union, Luxembourg, 9 January 2025, https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_25_339/IP_25_339_EN.pdf

| | | |
|---|---|---|
| Single-Use Plastics Directive (SUPD) & ECHA 2012 Polymer Guidance | Case 3, Case 9, Case 10 | *Challenge*: Enzymatically produced biomaterials are classified as plastics; biodegradables gain no recognition.<br>*Improvement*: Classify materials by biodegradability and function, not production process; incentivise compostable PHAs. |
| Packaging and Packaging Waste Regulation (PPWR) | Case 3 | Challenge: Emphasis on recyclability and recycled content mutes demand for compostable bioplastics. Suggested improvement: Introduce recognition and market pull where compostability provides system benefits. |
| ISCC+ / REDcert² Certification Systems | Case 22 | *Challenge*: Lack of mutual recognition between EU-endorsed schemes complicates sourcing and market uptake.<br>*Improvement*: Harmonise and cross-recognise certification systems for mass balance. |
| Green Claims Directive (proposal) | Case 22 | *Challenge*: Fragmented sustainability claims hinder consumer and business uptake.<br>*Improvement*: Establish clear, harmonised rules for verified sustainability claims and PCF reporting. |
| Product & Corporate Carbon Footprint Standards (GHG Protocols) | Case 22 | *Challenge*: Multiple, inconsistent PCF/CCF methods; limited recognition of biogenic −1/+1 credits and recycling benefits.<br>*Improvement*: Adopt harmonised cradle-to-grave PCF rules acknowledging biogenic uptake and end-of-life impact. |
| Net-Zero Industry Act (NZIA) / Clean Industrial Deal | Case 13 | *Challenge*: Project permitting remains lengthy (~5 years) despite new frameworks.<br>*Improvement*: Further streamline and accelerate strategic project permitting and approval procedures. |
| Regulation (EC) No 726/2004 – Sunset Clause for fossil $CO_2$ use in CCU/CCR | Case 13 | *Challenge*: 2041/2025 sunset limits CCU investment horizons, deterring projects.<br>*Improvement*: Provide transitional pathways or derogations for CCU projects with proven decarbonisation outcomes. |
| Corporate Sustainability Reporting Directive (CSRD) (EU) 2022/2464 | Case 16, Case 22 | *Challenge*: Fragmented standards and unclear recognition slow demand for low-carbon certified materials.<br>*Improvement*: Use CSRD to standardise recognition of certified renewable/mass-balance content in reporting. |
| Common Agricultural Policy (CAP) | Case 16 | *Challenge*: No EU-wide sustainability framework for bio-based products tied to land/biodiversity.<br>*Improvement*: Anchor sustainability criteria for bio-based products under CAP using RED III Article 29(2–7) as model. |

Source: Prognos AG/Idea Consult/nova Institute, 2025,own elaboration based on expert interviews and market insights

**Materials vs. food/feed**: Currently only 1.6% of agricultural land in the EU is used for bio-based chemicals, with an increase in use of agricultural residues[34]. The use of bio-based resources for chemical and material applications has a long tradition, both from wood resources as well as from agricultural biomass. The use of starch for the paper industry alone has required millions of tons of feedstock for decades, and Dammer et al. (2023) estimate that other traditional chemical and pharmaceutical uses of food and feed crops generate an annual turnover of EUR 165 billion in the EU.[35] So far, this has not led to an insecure food situation in the EU. In general, the co-utilisation of crops for different purposes – food, feed, materials and energy – is standard in our economy, to ensure the efficient use of previous land resources. Using for example starches and sugars for chemicals, leaves protein-rich by-products that get valorised completely in the feed industry. The strong concern for food security related to the use of crops for anything else than food or feed stems from the food crisis in 2008 that was quickly connected to the increase in biofuels use worldwide, following the strong incentives in the EU and the US. In a scientific background paper, Dammer et al. (2023) investigated the complex interlinkages between the use of bio-based resources and food security and found that the evidence does not show that the use of food and feed crops for materials automatically endangers food security. In addition, they point out a variety of benefits of using sustainable bio-based feedstocks, including the fact that limiting climate change is one of the biggest levers there is for protecting food security.[36]

The relationship between the heavy subsidies for biofuels and the 2008 food crisis is complex. Researchers have found multiple causes for the crisis in 2008, of which biofuels are only one factor.[37] Nevertheless, it makes sense to couple political support to a minimum of sustainability safeguards, such as GHG thresholds and sustainability certification of feedstocks, as defined in the REDIII. Since there is no support for bio-based chemicals, there is no such system for them either.

In conclusion, bio-based industries have been innovating to further increase circularity and should therefore be considered a complementary rather than a competing industry. It would benefit EU companies if the current and complex regulatory environment regarding the use of food crops for industrial applications was revised to further reflect this and incentivise the development of EU bio-based industries.

**Regulatory fragmentation**: Some companies report that fragmented regulatory frameworks in the EU (e.g. for GMOs, bioplastics, etc.) increase compliance costs and slow down the adoption of new technologies. Companies then prefer to move to markets with less regulatory burden to commercialise their products[38].

One company highlighted that although the European Union is in favour of renewable feedstocks, the mass balance certification systems (such as ISCC+ and REDcert[2]) supported by the EU are not yet mutually recognised. Therefore, producers must set up parallel certification and traceability systems in case they get their materials from different suppliers, which not only increases the administrative costs but also makes market uptake more difficult. The company also reported

[34] Carus, M., Porc, O., vom Berg, C., Kempen, M., Schier, F. and Tandetzki, J.: *Is*
there enough biomass to defossilise the chemicals and derived materials sector by 2050, nova-
Institut GmbH (Ed.), Hürth, Germany, 2025-02.
10.7 Mt of dry biomass used for the chemical and derived material industry, of 820 Mt agricultural biomass produced in the EU (for this calculation, glycerol and UCO were removed from the total of 924 Mt agricultural biomass)– European Commission, https://knowledge4policy.ec.europa.eu/bioeconomy/topic/agricultural-biomass_en?

[35] Dammer, L., Carus, M., Porc, O., The Use of Food and Feed Crops for Bio-based Materials and the Related Effects on Food Security. Renewable Carbon Initiative (ed.), Hürth 2023; (Dammer et al. 2023)

[36] Dammer et al. 2023

[37] Dammer et al. 2023

[38] Financial Times, *Tackling Europe's red tape challenge,* [FT Live event]. Financial Times, in partnership with ExxonMobil, 24 September 2024, https://euredtapechallenge.live.ft.com

that discrepancies in greenhouse gas (GHG) counting frameworks are barriers for the commercialisation of renewable materials. It remarked that the GHG Protocol, which supports corporate carbon accounting, does not recognise the biogenic "–1/+1" credit method for carbon uptake in renewable feedstocks. Consequently, companies are not allowed to make emission reduction claims for bio-based inputs, thus, weakening the business case for their utilization and, as a result, less investment in renewable carbon solutions within the EU. The company is hence pushing for the introduction of uniform product and corporate carbon footprint (PCF/CCF) rules that will allow the integration of biogenic and end-of-life impacts to provide accurate sustainability performance of bio-based products.

Another case study offers more proof of the negative impact of fragmented regulations on the slow technology rollout. In this instance, the RED II delegated act requires recycled-carbon fuels to demonstrate at least 70% GHG savings and to include the "lost power generation" in the LCA. The grid restrictions added to this that limit eligibility to plants connected to already decarbonised grids make the framework causing several EU projects to be economically unfeasible. Additionally, the "sunset clause" in Regulation (EC) No 726/2004 limits the industrial applications of carbon capture and utilization (CCU) based on fossil carbon beyond 2041 (or 2025 for power generation), thus, shortening the investment horizons for capital-intensive facilities. In consequence, the company stated that it is choosing to deploy in non-EU markets, like the US and Asia, where there are fewer administrative and regulatory barriers to carbon utilisation projects.

Similar difficulties were voiced by further companies, which are engaged in the development of innovative bio-based polymers and enzymatic materials. They emphasise that the Single-Use Plastics Directive (SUPD) and ECHA polymer guidance treat many biodegradable or nature-identical biopolymers as "plastics" without going by biodegradability or environmental performance. The absence of such factors limits the acceptance of the product in the market and discourages investments in the EU manufacturing sector. The companies contrasted the fragmented EU regulatory environment with the faster regulatory routes available in North America and some parts of Asia, where the classification and approval processes for new bio-based materials are more reliable and less time-consuming.

Together, the findings from the case studies map out a very distinct pattern. On the one hand, the EU sets forth ambitious sustainability objectives but, at on the other hand the lack of coherent and streamlined regulatory frameworks - for certification, accounting, and product classification - that covers the area in a thorough manner, causes uncertainty and imposes cost burdens. Such problems are not only delaying the innovation but also causing bio-based companies who are on the forefront of technology to choose to commercialize their new technologies first in the markets that have less stringent regulations which in turn is resulting in Europe losing its competitive power in the global bioeconomy.

#### 2.2.7 Impact of EU funding

Horizon Europe and related Bio-based Industries Joint Undertaking (BBI-CBE JU) grants for early TRL research projects are considered very useful by companies and research organisations for building consortia and strategic long-term partnerships, creating cross-border, multi-sector networks and sharing the financial risk among stakeholders[39]. Researchers and companies also engage in EU-funded initiatives for the knowledge spillovers and scaling up their activities.

A key barrier for bio-based chemicals remains the so-called “second valley of death”, which is the label attributed to the challenging transition from demonstration to industrial scale deployment. Even if the technology or product is proven at pilot scale, companies struggle to attract private investment for industrial-scale deployment because of high upfront costs (CAPEX), long ROI times and market uncertainties. To solve this, companies combine high equity shares (up to 60%) with public debt and grants. The Innovation Fund is specifically designed to overcome this barrier as well. It provides milestone-based grants covering part of the CAPEX and in some instances part of the early-on OPEX. Even so, it covers between 20 and 40% of the overall costs, highlighting the need to a broader mix of private and public co-financing[40].

Horizon Europe, BBI-CBE JU grants (for early TRL & consortia building) and the blended finance solutions offered by the EIB (loans & guarantees) contribute to the success of bio-based chemical producers. Additionally, being financed by the innovation Fund and being part of the JUs helps companies gain visibility and more importantly credibility towards private investors. Innovation Fund projects with robust business models from the start are particularly attractive to private capital, as experienced by the EU funded ShapingBio project. Private investors want to see industrial know-how and milestone-based management, a clear value chain integration as well as regulatory clarity and cross-border policy alignment to secure long-term competitiveness[41].

#### 2.2.8 Business model findings

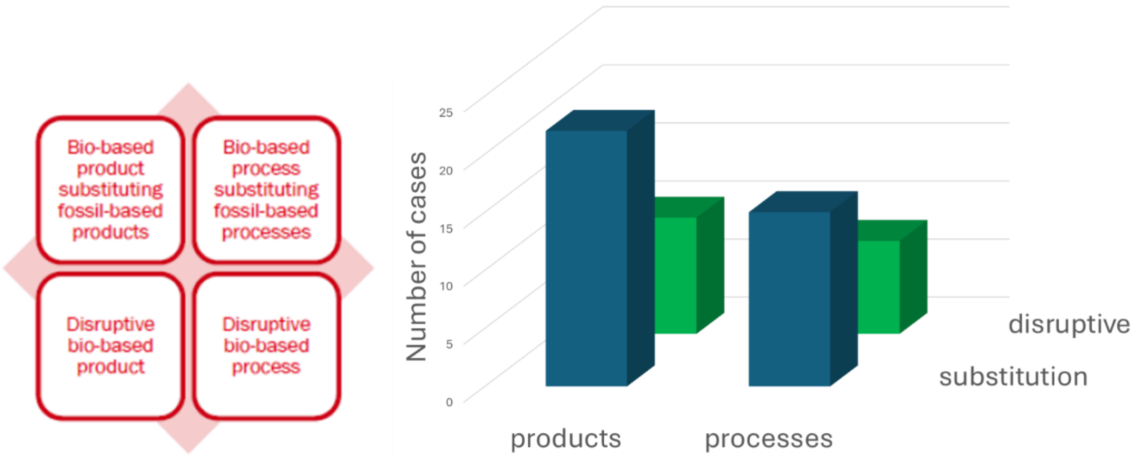
Each of the cases and corresponding business models were classified according to the Bröring & Vanacker (2022) business model classification for bio-based industries[42]. This classification depicts the business models for bio-based industries along two dimensions: i) horizontally: products versus processes and ii) vertically substituting fossil-based products and processes versus disruptive products and processes. Hence four segments can be specified. Figure 6 gives an overview of the number of cases for each segment.

All of the 22 selected business models offer value creation by producing bio-based products substituting fossil-based products. Yet analysing a step further, one can distinguish subgroups as illustrated in Figure 7. A few cases entirely focus only on bio-based products substituting fossil-based products. Examples are case study 16 for bioplastics and biochemicals, and case study 21 for 9-decenoate and 1-decene. Yet other cases cover additional business segments as well. Within this category one can distinguish cases that orient more on the products and include as well disruptive bio-based products such as company 4, company 8 and company 10, while others valorise the fossil-fuel substitution function both in products and processes such as the company 17, company 18 and company 22 cases.

[39] European Commission: European Climate, Infrastructure and Environment Executive Agency, Przadka, A., Aleman, M., Bravo, B., Darida, M. et al., *2025 annual knowledge sharing report of the Innovation Fund – De-risking innovative low-carbon technologies*, Publications Office of the European Union, 2025, https://data.europa.eu/doi/10.2926/9356836
[40] European Investment Bank (EIB), *Investment gaps to achieve sustainable targets in the bioeconomy*. Luxembourg: EIB, 2025, https://www.eib.org/files/publications/20250089-150925-investments-gaps-to-achieve-sustainable-targets-in-the-bioeconomy-en.pdf
[41] Dammer, L., Iffland, K., & Piotrowski, S., *ShapingBio Deliverable 2.4 – Financing and funding conditions for bio-based industries (awaiting approval).* ShapingBio Project, funded by the European Union’s Horizon Europe programme , 2024.
[42] The detailed description of the 22 selected business cases and the corresponding business models is presented in the annexes.

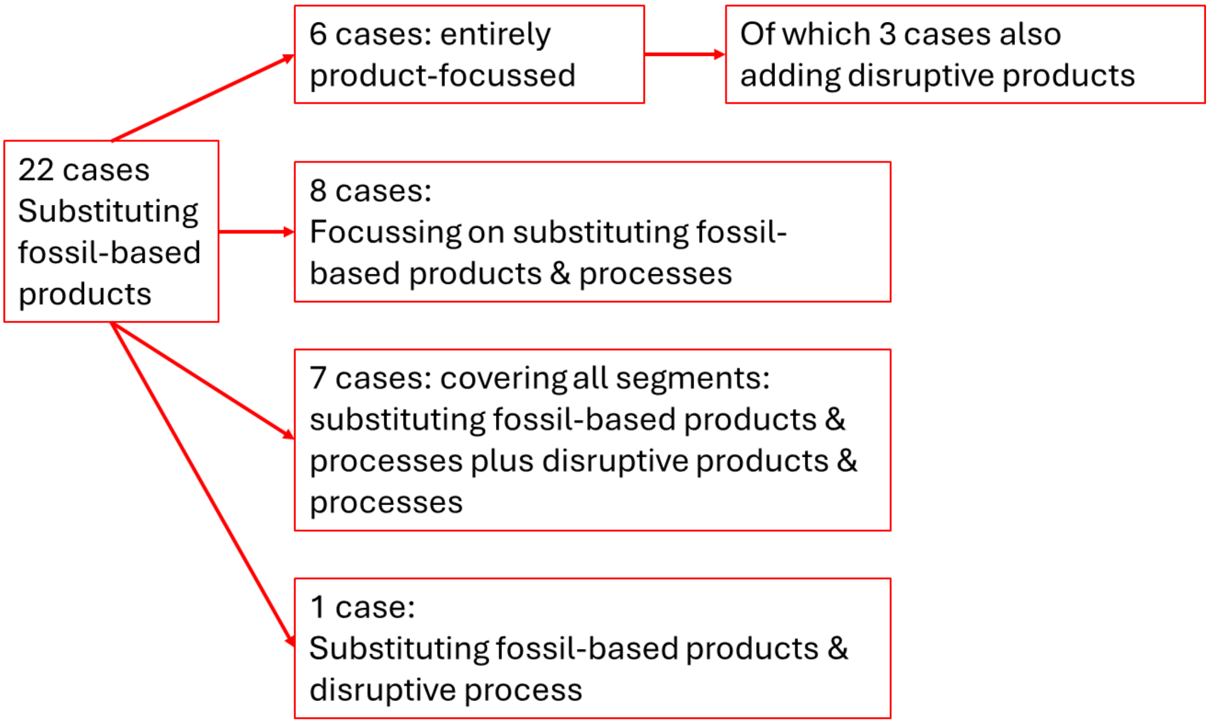
However, seven of the 22 selected cases cover all segments of the Bröring & Vanacker business canvas offering a wider valorisation scope. Examples are company 9 for designed enzymatic biomaterial – polysaccharides, company 1 spider silk obtained by fermentation, and the facility mentioned in case study 2.

**Figure 6 Overview of the number of case studies by category in the Bröring & Vanacker (2022) business model typology**




Source: Case studies and business models as presented in the annex.
Note: Cases may cover more than one segment.

**Figure 7 Case studies classified by combination of segments in the Bröring & Vanacker (2022) business model canvas**




Source: Case studies and business models as presented in the annex.
Note: Cases may cover more than one segment.

# 3 Biomass availability and use

This chapter quantifies the current EU-27 biomass supply and demand and develops baseline trajectories to 2035. Furthermore, a set of policies potentially impacting biomass supply and demand in the future is analysed and quantified to determine whether supply and demand will be matched or if competition for biomass is expected to become sharper.

*i*

Key findings

Agricultural biomass: Systems in the EU are highly optimised, only very little growth of production is expected in the baseline scenario. But with modern agricultural techniques, the use of advanced technologies, innovative breeding and regenerative practices, there is still potential for additional growth in domestic biomass productivity. Soil health and regeneration will also be key.

Forest biomass: Systems in the EU are highly optimised, only very little growth of production is expected as seen in the baseline scenario. Policy impacts reduce production of woody biomass, no potentials for sustainably increasing production were identified.

Organic waste: Overall waste production expected to decrease due to shrinking population, but availability can be improved significantly by separate collection. Policy framework for that is currently lacking. Food waste and other waste reduction targets in stark contrast to policy focus on secondary resources for biomass only.

## 3.1 Biomass availability in the EU: Now and in the future

As data is already available to a certain extent, to avoid duplication, this sub-task builds on and is fully aligned with the scope and methodology of the existing European Environment Agency (EEA) report on biomass availability, titled: "The European Biomass Puzzle: Challenges, Opportunities, and Trade-offs around Biomass Production and Use in the EU"[43], which uses data from the EU Biomass Flows Tool developed by the Joint Research Centre (JRC)[44]

The first section provides an updated overview of current biomass supply and demand in the European Union (EU-27), focusing on agricultural biomass, woody and forestry biomass, and organic waste. The objective was to comprehensively map and quantify the currently available domesti-

[43] European Environment Agency (EEA), *The European biomass puzzle – Challenges, opportunities and trade-offs around biomass production and use in the EU*, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2800/834565
[44] Gurría, P., González Hermoso, H., Cazzaniga, N., Jasinevicius, G., Mubareka, S. et al., *EU biomass flows – Update 2022*, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2760/082220.

cally produced biomass as well as the current demand for biomass across key application sectors, such as food, feed, biofuels, and biomaterials, including chemicals and derived materials. For clarity, in this chapter, “domestic production” refers to biomass produced within the EU-27. “Biomass supply” refers to the total biomass available to the EU market, including domestic production and net trade flows, unless stated otherwise.

In a second step, baseline scenarios for development of EU biomass supply and demand were derived and validated by relevant stakeholders to maximise robustness of the data. The details of the methodology and a full explanation of the respective assumptions for each sub-part can be found in  Annex 3.1 “Methods, assumptions and details for the biomass analysis”.

### 3.1.1 Biomass supply and demand – status quo 2022

**Agriculture**

The updated status quo of domestic agricultural biomass production in the EU-27 for 2022 is based on the most recent data of the EU Biomass Flows Tool developed by the Joint Research Centre (JRC)[45]. The total domestic agricultural biomass production is estimated at 648.8 million tonnes of dry matter (tdm). Within this total, crop production accounted for 466.9 million tdm (72%), by far the largest share, followed by grazing with 93.0 million tdm (14%), and utilised agricultural residues up to 89.0 million tdm (14%). It is worth mentioning that this does not include imported agricultural biomass in any shape or form.

The total agricultural biomass demand in the EU-27 for 2022 was 676.1 million tdm. Demand was dominated by the feed sector (71%), followed by food (19%), biofuels (7%) and bio-based products (3%), including feedstock consumption for chemicals & derived materials, as well as fibres and other uses. The updated status quo of agricultural biomass demand in the EU-27 for 2022 is based again on the most recent update of the EU Biomass Flows Tool developed by the Joint Research Centre (JRC)[46], but updated with latest information on the biofuels sector (JRC data) and bio-based products data, based on surveys and interviews conducted by nova-Institute in 2024 and 2025.

**Woody biomass**

For the status quo assessment of woody biomass production, data is derived from both the FAO[47] and from the Eurostat wood statistics[48]. Both datasets refer to production year 2022 and were harmonised to a consistent unit of million tonnes of dry matter for comparability across biomass categories. Domestic roundwood production in Europe is a key indicator of primary woody biomass availability. In 2022, total domestic roundwood production was estimated at 232.8 million tdm[49]. This includes both coniferous and non-coniferous species and differentiates between industrial roundwood and fuelwood.

[45] Gurría, P., et al., 2022.
[46] Gurría, P., et al., 2022.
[47] Food and Agriculture Organisation of the United Nations (FAO), *Forestry Production and Trade*, FAOSTAT, Rome 2025, accessed January 2025. https://www.fao.org/faostat/en/#data/FO
[48] EUROSTAT, 'Wood products - production and trade', 2023, accessed 03 December 2025, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Wood_products_-_production_and_trade
[49] FAO, 2025.

Industrial roundwood accounted for 168.8 million tdm (73%), while fuelwood contributed 64.0 million tdm (27%), which represents primary wood[50]. Conversion factors from Szarka et al., 2021[51] were used to standardise all data to tonnes of dry matter.

Fuelwood is primarily used for energy generation, whereas industrial roundwood feeds into the paper industry, furniture and construction, and the chemical industry.  The total semi-finished wood material output in the EU amounted to 104 million tdm in 2022. This value reflects the wood contained in finished products rather than the total roundwood input required to produce them, as significant fractions are lost or diverted into by-products and process residues during manufacturing.

- The paper industry consumed 28.1 million tdm primary wood, including chemical wood pulp (21.3 million tdm) and mechanical wood pulp (6.9 million tdm)
- The furniture and construction sector used 74.8 million tdm, dominated by sawn wood (51.8 million tdm) and particle board (12.8 million tdm).

The chemical industry used approximately 1.4 million tdm, primarily in the form of dissolving pulp used for the production of cellulose fibres and cellulose derivates.

Around 52 million tdm arise as sawmill by-products during wood processing (sawdust, wood chips, bark). According to Mantau (2023), around 45% of these by-products are used for energy purposes (23.4 million tdm), while 55% are directed to the material industry (28.6 million tdm) [52]

In addition to primary and secondary resources, the wood-based bioeconomy encompasses tertiary biomass streams. These include recovered wood and recycled paper fibres from waste, as well as residues from the pulp and paper industry, such as black liquor, an important bioenergy carrier.

**Organic waste**

According to Eurostat, a total of 229 million tonnes of municipal solid waste (MSW; in fresh matter, FM) were generated across the EU-27 in 2022[53]. Between 34% and 50% of this waste stream can be classified as biowaste, comprising primarily food waste, garden waste and other biodegradable materials.  This corresponds to an estimated 79 to 115 million tonnes FM of municipal biowaste annually[54] [55]). These amounts of fresh matter correspond to roughly 36 to 52 million t dry matter of organic waste.

Despite its significant potential as a circular resource, only a limited share of this biowaste is currently recovered through material recycling. Data from the European Compost Network indicate that 33 to 48 million tonnes FM of organic waste were separately collected and treated through

[50] Szarka, N., Haufe, H., Lange, N., Schier, F., Weimar, H., Banse, M., et al., 'Biomass Flow in Bioeconomy: Overview for Germany', *Renewable and Sustainable Energy Reviews*, Vol. 150, Article ID: 111449, 2021, https://doi.org/10.1016/j.rser.2021.111449
[51] Szarka, N., Haufe, H., Lange, N., Schier, F., Weimar, H., Banse, M., et al., 'Biomass Flow in Bioeconomy: Overview for Germany', Renewable and Sustainable Energy Reviews, Vol. 150, Article ID: 111449, 2021, https://doi.org/10.1016/j.rser.2021.111449
[52] Mantau, U., Wood Resource Balances – Circular Economy and Cascading, 20 years of Wood Resource Monitoring, Gülzow, FNR, FKZ: 22015918, 2023, https://international.fnr.de/press/news/wood-resource-balances-circular-economy-and-cascading-20-years-of-wood-resource-monitoring

[53] EUROSTAT, 'Municipal waste by waste category, treatment and source [env_wasmun],' Statistical Office of the European Union, last update 15 September 2022, accessed 20 November 2025, https://ec.europa.eu/eurostat
[54] EEA, 2019.
[55] European Compost Network (ECN), ECN data report 2022: Biowaste collection and processing in Europe, 2022, accessed 15. August 2025, https://www.compostnetwork.info/wordpress/wp-content/uploads/ECN-rapport-2022.pdf

composting and anaerobic digestion in 2022[56]. This represents just 15% to 21% of total MSW, or roughly 40% to 50% of the estimated biowaste stream. The remaining volume, approximately 46 to 66 million tonnes FM (around 21 to 30 million tdm), was disposed of in mixed waste streams, predominantly through landfilling and incineration. Compositionally, the biowaste fraction is dominated by food waste, which accounts for approximately 60% of the total, followed by garden waste (35%) and a small share of other organic materials (5%). These proportions are based on estimates from the European Environment Agency[57].

A distribution of organic waste utilisation pathways is assumed, based on available expert knowledge and market reports[58], with shares of 40% for composting, 30% for anaerobic digestion to biogas, 20% for animal feed, and 10% for biochemicals and biofuels. These shares refer to the distribution within the separately collected and treated bio-waste fraction, whereas the figures presented above describe the share of total municipal bio-waste that is collected and treated.

**Imports and exports**

According to the EU Biomass Flow tool[59], agricultural biomass trade covers primary and processed bio-based products of plant and animal origin expressed in physical biomass units or biomass-equivalent terms. Total imports amounted to 158 million tdm, while exports reached 137 million tdm. Net imports were observed for plant products (15.5 million tdm), plant-based food (18 million tdm) and processed products (12.8 million tdm). In contrast, animal products showed net exports of around 26 million tdm in feed equivalent. This suggests that the EU relies on external supply for certain plant-based feedstocks and bio-based products, while trade in animal products is characterised by an export surplus, particularly in dairy, meat and related goods.

For woody biomass, Eurostat data (2025) indicate that the EU exported approximately 9.5 million tdm of roundwood compared with 4 million tdm of imports, corresponding to a net export of about 5.5 million tdm. This reflects the EU's position as a net exporter of unprocessed forest resources, though the overall balance remains moderate in scale. Trade of fuel wood was rather small with 0.5 million tdm imported and 0.2 million tdm exported. For industrial roundwood, the EU imported 3.6 million tdm but exported 9.3 million tdm, reflecting an export surplus.

**Excursus: Impact of the Ukraine war on EU biomass imports**

Since 2022, the structure of EU biomass imports has been significantly impacted by the consequences of the war in Ukraine, particularly within the agricultural and forestry sectors. As the EU was not heavily reliant on Russia or Belarus for agricultural crops like cereals or oilseeds, disruption to the supply chain in these sectors was minimal. However, Ukraine has substantially increased its exports of cereals and oilseeds to the EU thanks to alternative land-based and maritime transport corridors, streamlined customs procedures, and robust EU demand. Consequently, Ukraine has become a key supplier of several agricultural biomass categories, thereby stabilising EU feedstock availability despite the conflict.

In contrast, the impact on woody biomass was more severe. Following EU sanctions and certification withdrawals, imports of sawn wood, wood pellets and semi-finished wood products from Russia and Belarus, which supplied the EU with about 20 million tonnes of wood products before 2022, declined to near zero. The resulting supply gap was partly compensated for by increased

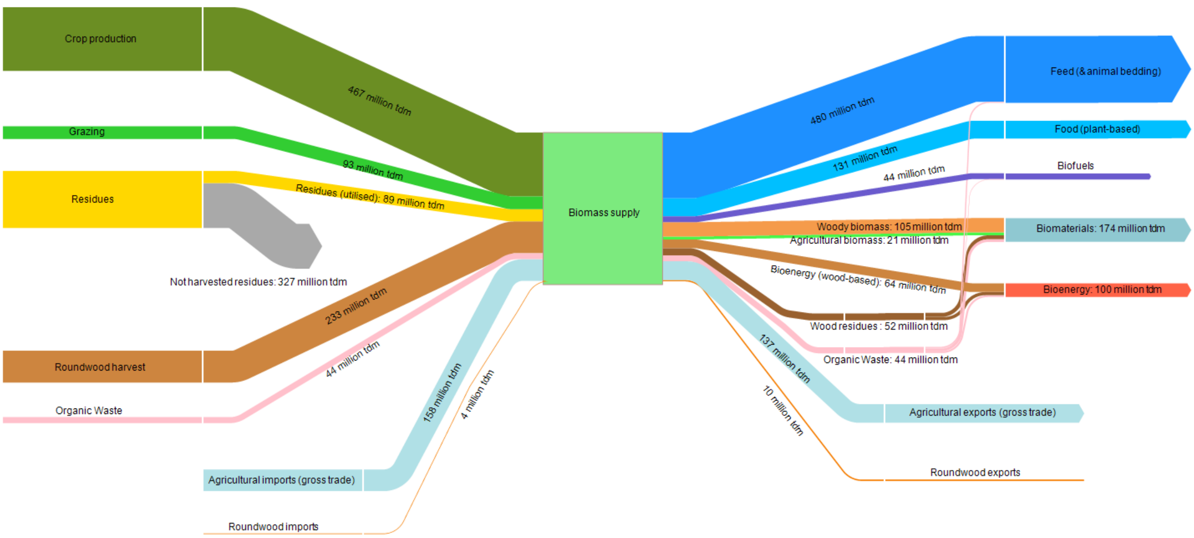
[56] ECN, 2022.
[57] EEA, 2020.
[58] Transparency Market Research, 2024.
[59] Gurría et al., 2022.

intra-EU trade and higher imports from Norway, the United States, Canada, Brazil, China, and Ukraine to a limited extent. While these adjustments have helped to offset the sudden loss of supply from Russia and Belarus, they have not managed to replace former import volumes entirely [60].

Figure 8 shows a complete overview of supply and demand status quo:

**Figure 8 Biomass supply and demand in the EU, 2022 :**

**Biomass Supply & Demand in the EU, 2022 (in million tonnes of dry matter)**




source: Own calculations based on JRC 2025

### 3.1.2 Baseline projections – supply and demand 2022–2035

**Agricultural crops production and demand**

The baseline scenario for agricultural biomass supply projects developments up to 2035 and is based on the relationship between cultivated area and yield for each crop category. Projections draw on official outlook data[61 62]) and independent calculations using historical Eurostat data (2012–2022, Eurostat 2025). Tables with exact factors are located in the Annex. Overall, the baseline scenario projects only a modest increase in agricultural biomass supply from 466.9 to 469.6 million tonnes dry matter between 2022 and 2035, an absolute increase of 2.7 million

[60] EUROSTAT, 'EU trade since 1988 by HS2-4-6 and CN8 [ds-045409]', accessed 20 November 2025, https://ec.europa.eu/eurostat/databrowser/view/ds-045409/default/table?lang=en.

[61] European Commission: Directorate-General for Agriculture and Rural Development, Analysis and Outlook Unit, *EU Agricultural Outlook, 2024-2035*, Publications Office of the European Union, Luxembourg, 2024, https://agriculture.ec.europa.eu/data-and-analysis/markets/outlook/medium-term_en.

[62] OECD/FAO, *OECD-FAO Agricultural Outlook 2024–2033*, OECD Publishing, Paris/FAO, Rome., 2024,https://doi.org/10.1787/4c5d2cfb-en

tonnes dry matter (+0.6% in total), corresponding to an annual growth rate (CAGR) of 0.04% per year.

These results are broadly consistent with predictions of other modelling approaches. The CAPRI model used by RCI & BIC (2025)[63] projects a CAGR of 0.115% for agricultural production in the baseline scenario (2020–2050). Similarly, the OECD-FAO Agricultural Outlook (2024)[64] expects a slightly higher, but still modest increase of 1.6% in EU output by 2033.

The baseline scenario for agricultural biomass demand in the EU-27 is based on sector-specific projections using data from the JRC EU Agricultural Outlook 2024–2035[65] and the RCI & BIC biomass study (2025)[66]. Population decline of -0.2% per year[67] was factored in.

Total agricultural biomass demand is projected to decrease slightly from 676.1 million tdm in 2022 to 645.3 million tdm in 2035 (-0.4% CAGR). Feed and food demand are both expected to decline by 0.2% per year, while biofuels are projected to fall sharply (-5.0% CAGR) due to transport decarbonisation and reduced blending mandates after 2026[68]. Bio-based products demand is projected to grow strongly (+1.4% CAGR), particularly for biogenic feedstock in the chemical and derived materials sector, driven by bio-based material substitution[69]. This suggests a shift from the use of agricultural biomass in biofuels towards bio-based products, as declining fuel demand is offset by growing demand for biogenic feedstock in chemicals and materials.

**Grazing**

Biomass from grazing refers to biomass produced in grasslands that is not harvested, but directly consumed by livestock through grazing. The quantity of grazed biomass is estimated proportionally to the pasture and meadows land area reported in FAOSTAT, applying a factor of 1.8 tonnes of dry matter (tdm) per hectare. According to the EU Biomass Flows Tool[70], the total grazed biomass production in the EU-27 amounted to 92.97 million tdm in 2022.

For the baseline projection, the EU Agricultural Outlook 2024–2035[71] indicates that the area of permanent grassland will remain stable over the projection period, with a compound annual growth rate (CAGR) of 0.0%. Under this assumption, the biomass from grazing is expected to remain unchanged from its 2022 level throughout the baseline scenario period up to 2035.

**Agricultural residues**

Agricultural residues refer to the portion of crop biomass remaining after the primary harvest, such as straw, stalks, husks, and other plant parts. According to the EU Biomass Flows Tool[72], the

[63] Carus, M., Porc, O., vom Berg, C., Kempen, M., Schier, F., Tandetzki, J., Is there Enough Biomass to Defossilise the Chemicals and Derived Materials Sector by 2050? – A Joint BIC and RCI Scientific Background Report, 2025, https://renewable-carbon.eu/publications/product/is-there-enough-biomass-to-defossilise-the-chemicals-and-derived-materials-sector-by-2050-a-joint-bic-and-rci-scientific-background-report/
[64] OECD/FAO, 2024.
[65] European Commission, DG AGRI, 2024.
[66] Carus et al. 2025.
[67] European Commission, DG AGRI, 2024.
[68] European Commission, DG AGRI, 2024.
[69] Carus et al., 2025.
[70] Gurría et al., 2022.
[71] European Commission, DG AGRI, 2024.
[72] Gurría et al., 2022.

utilised agricultural residues in the EU-27 amounted to 88.96 million tonnes of dry matter (tdm) in 2022.

The supply of agricultural residues is directly linked to overall crop production levels, as residues are by-products generated in proportion to harvested crops. In particular, cereal straw (including wheat, maize, and rice) accounts for over 80% of total residues. Not all generated residues can be mobilised for other uses, as a substantial share is retained on the fields to maintain soil health, prevent erosion, and support nutrient cycling. In the presented assessment, it is assumed that only around 20% of the total agricultural residues are utilised, with the remaining share left on the fields. This utilisation rate is also applied in the baseline scenario. In line with the projected trends for crop production, the supply of utilised agricultural residues is therefore expected to grow at an annual growth rate of 0.1% between 2022 and 2035, reaching approximately 89.8 million tdm by 2035. These projections are consistent with other studies, namely with the RCI/BIC study[73] and the OECD/FAO report. All sources indicate slight declines in feed and food demand, a strong contraction in biofuels demand (-2.7% to -3.5%), and strong growth in industrial uses (biomaterials).

**Woody Biomass**

Baseline projections for woody biomass supply in the EU indicate a steady upward trend between 2022 and 2035. Based on growth trajectories derived from the JRC study "Simulating future wood consumption and the impacts on Europe's forest sink to 2070"[74], total EU roundwood harvests are estimated to increase from approximately 232.8 million tonnes of dry matter (tdm) in 2022 to around 257.7 million tdm by 2035, corresponding to a compound annual growth rate (CAGR) of 0.86%.

Industrial roundwood, which constitutes the majority of the total harvest, is projected to grow at 0.94% per year, rising from 168.8 to 188.8 million tdm. Fuel wood from forest sources, by contrast, is expected to expand more moderately at 0.60%, reaching 69.2 million tdm by 2035.

On the demand side, projections are based on the RCI/BIC biomass study[75] which uses the TIMBA model developed by the Thünen Institute[76] to simulate wood demand across sectors. The annual growth rates used in this section are derived from these sources but have been applied to the updated 2022 baseline values and may not correspond exactly to the figures published in the original model outputs.

Demand for sawn wood for construction and furniture applications is projected to grow by 0.56% annually, while demand for wood-based panels increases at a faster pace. In particular, fibre board and particle board are expected to grow by 1.34% and 0.48% per year, respectively, reflecting strong demand in building, renovation, and interior design. In the chemical sector, dissolving pulp, which serves as a feedstock for cellulose fibres and chemical derivatives, is projected to grow strongly at 1.94% annually. In the pulp and paper sector, mechanical pulp is expected to

[73] Carus et al., 2025.
[74] European Commission: Joint Research Centre, *Simulating future wood consumption and the impacts on Europe's forest sink to 2070*, Publications Office of the European Union, 2024, https://data.europa.eu/doi/10.2760/17191
[75] Carus et al. 2025.
[76] Thünen Institute, 'Model-based assessments of wood demand using the TIMBA model', Thünen Working Paper 263. Braunschweig: Johann Heinrich von Thünen Institute, 2025, https://www.thuenen.de/media/publikationen/thuenen-workingpaper/ThuenenWorkingPaper_263.pdf

grow by 0.62% and chemical pulp by 1.22%, suggesting a substantial shift toward circular and bio-based packaging materials.

### Organic waste

For the baseline scenario to 2035, it is assumed that per capita generation of organic waste will remain broadly stable in the medium term. As a result, changes in total volumes are expected to stem mainly from demographic developments, in particular the forecasted decline in the EU population from 445.97 million in 2022 to 434.51 million in 2035[77]. This assumption is consistent with a recent European Commission study, which projects that municipal waste generation will remain relatively stable until 2030[78].

By 2035, total municipal solid waste (MSW) generation is projected to fall slightly to around 224 million tonnes FM (roughly 101 million tdm), of which biowaste would account for about 94 million tonnes FM (42.5 million tdm) and non-biowaste around 130 million tonnes. The share of biowaste collected separately is assumed to increase from 42% to 50%, supported by the gradual expansion of collection systems (e.g. food-/biowaste bins), greater public awareness and regulatory measures. This would mean roughly 47 million tonnes FM (21 million tdm) is being separately collected and about 47 million tonnes FM (21 million tdm) remaining in residual waste. As a result, the recycling rate would rise to 17–21% of MSW, equivalent to 38–47 million tonnes FM (about 17-21 million tdm) of organic waste recovered for material use.

No further adjustments have yet been made for potential gains in collection efficiency beyond this moderate improvement, nor for possible changes in treatment pathways. In the longer term, technological advances could allow greater recovery of organic material from mixed waste streams, but such effects remain uncertain.

Overall, the baseline projection points to a slight decline (-3%) in total biowaste volumes between 2022 and 2035, driven largely by demographic change. At the same time, higher rates of separate collection would modestly increase the quantity of biowaste available for recovery and valorisation, particularly through composting and anaerobic digestion.

### Overall results baseline projections

While overall biomass production in the EU is expected to grow slowly, but continuously (Figure 9), demand is expected to decrease in three out of five demand sectors (Figure 10). For food and feed, demand is expected to decline slightly, reflecting dietary shifts towards less meat consumption and improving feed efficiency in livestock systems, while population change plays a minor role. For agricultural-based biofuels, a decline is projected, reflecting the phase-out of crop-based feedstocks for road transport fuels as blending mandates decrease, and road transport becomes increasingly electrified.  This is the main reason for the reduced competition for biomass in the baseline scenario, which could benefit the material uses. Although the production of chemicals from agricultural resources is expected to grow modestly, the use of wood for materials, including cellulose fibres and wood-based chemicals, is expected to grow more significantly.

Based on the supply and demand data and export volumes at 2022 levels, the biomass gap between domestic production and overall demand (domestic use plus exports) across all biomass

[77] European Commission, DG AGRI 2024.
[78] European Environment Agency (EEA), *Reaching 2030's residual municipal waste target: How much waste needs to be prevented or recycled?*, EEA Briefing 09/2023, https://www.eea.europa.eu/publications/reaching-2030s-residual-municipal-waste

categories is estimated at approximately 162 million tonnes of dry matter in 2022. This corresponds to a domestic biomass production of around 925 million tonnes dry matter and a total requirement of roughly 1,087 million tonnes dry matter. Under these conditions, the shortfall is covered through biomass imports, which reached around 162 million tonnes dry matter in 2022 (Figure 8). The agricultural sector accounts for the largest share of this deficit, while woody biomass shows a moderate surplus and organic waste remains partially underutilised.

By 2035, under the baseline scenario and maintaining the assumption of constant export volumes, total domestic biomass production in the EU-27 is projected to increase to around 953 million tonnes dry matter, while overall demand (including exports) is expected to decline to approximately 1,078 million tonnes dry matter. This results in a projected biomass gap of about 125 million tonnes dry matter. In the baseline scenario, this gap is assumed to be closed through corresponding imports. The reduction of the gap compared with 2022 is mainly driven by the projected decline in crop-based biofuels, moderate increases in agricultural yields and wood mobilisation and improved separate collection and valorisation of biowaste. Under the assumptions applied, this development suggests that the EU's import requirement may decrease from approximately 162 million tonnes dry matter in 2022 to around 125 million tonnes in 2035. This would indicate a modest reduction in structural import dependence, although the EU is still expected to rely on external suppliers for a substantial share of its biomass needs.

Since 2022, the availability of woody feedstocks has been constrained by the near-complete halt of wood imports from Russia and Belarus, previously major suppliers of sawnwood, pellets and semi-finished wood products. EU sanctions effectively removed these imports from the market. The resulting shortfall has been largely but not entirely compensated through increased intra-EU trade and additional imports from Norway, the United States, Canada, Brazil, China and, to a limited extent, Ukraine. Nevertheless, the new supply mix remains more fragmented and often more costly, which continues to put pressure on wood-based value chains.

For agricultural biomass, the situation is different. The EU-27 was not structurally dependent on Russia or Belarus for agricultural crops such as cereals or oilseeds, so the direct impact of the war on agricultural imports has been limited. Since 2022, Ukraine has significantly expanded its exports of cereals and oilseeds to the EU via alternative transport corridors, simplified customs procedures and strong EU demand, making the EU an increasingly important outlet for Ukrainian agricultural products[79].

The projected deficit illustrates that the EU bioeconomy will remain structurally dependent on biomass imports, particularly for plant-based feedstocks. While declining biofuel demand temporarily reduces pressure on domestic resources, growing demand for bio-based materials and energy may increase competition in the long term. Under the baseline assumptions, the lower import requirement in 2035 suggests a slightly reduced import dependence, although the EU will still rely on external suppliers for a significant share of its biomass needs.

[79] EUROSTAT, 'EU trade since 1988 by HS2-4-6 and CN8 [ds-045409]', accessed November 2025, https://ec.europa.eu/eurostat/databrowser/view/ds-045409/default/table?lang=en

**Figure 9 Domestic biomass supply in the EU 2022 and 2035 baseline scenario**

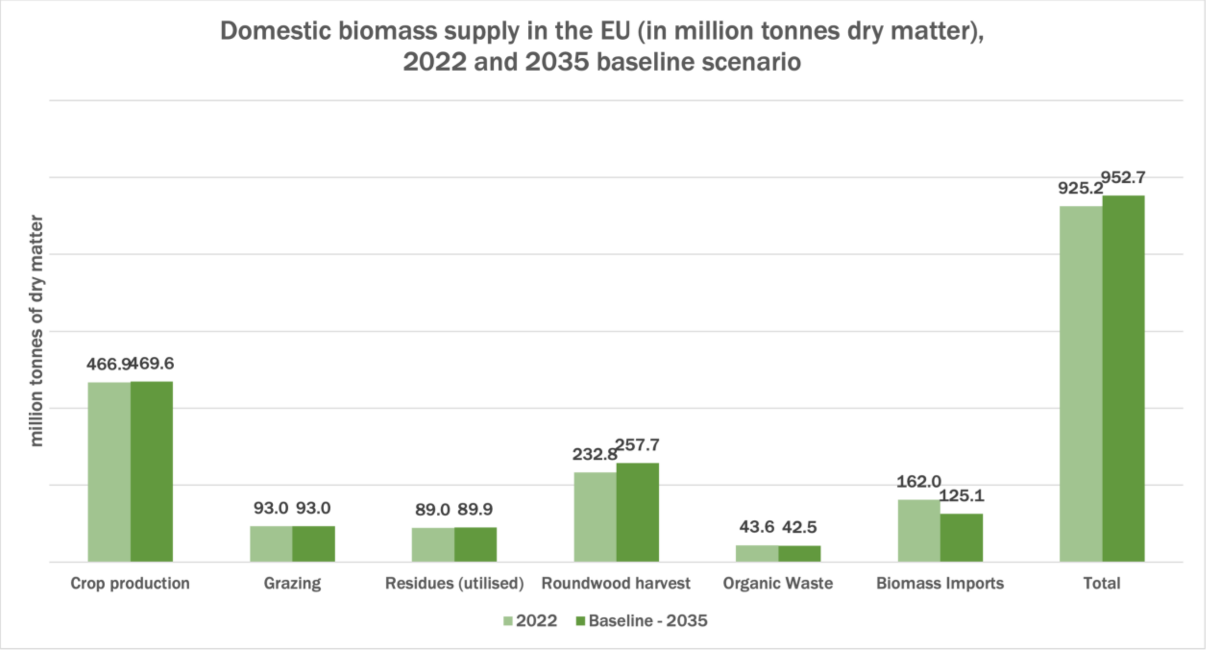
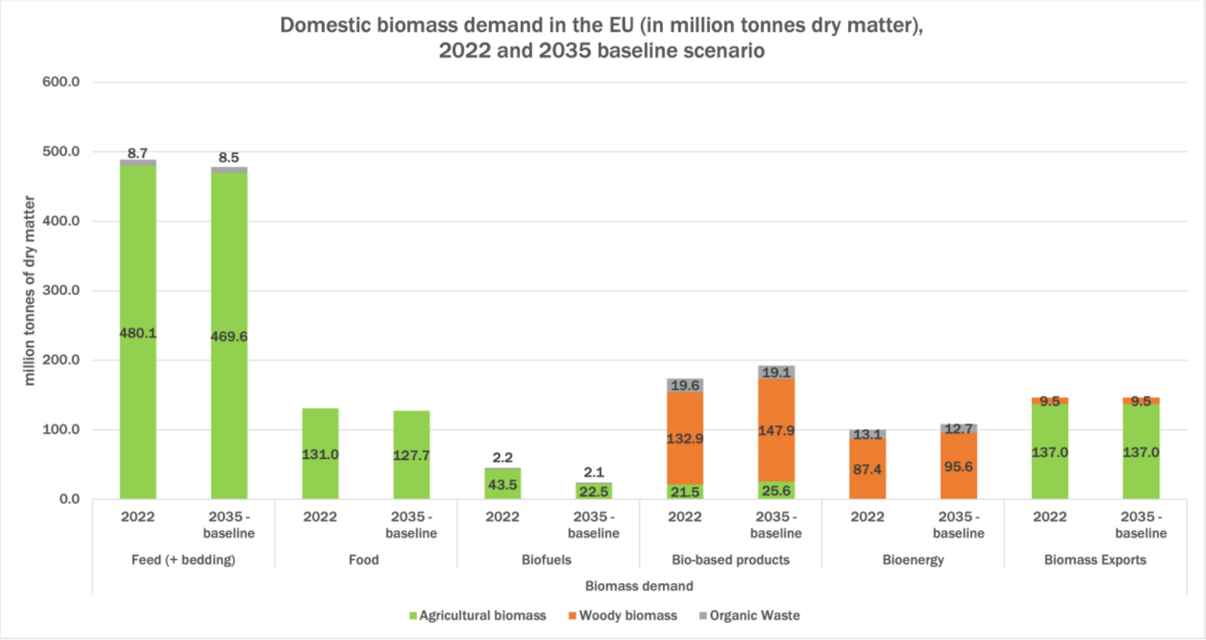



**Figure 10 Domestic biomass demand in the EU 2022 and 2035 baseline scenario**



## 3.2 Legislative impact on biomass availability and use

This section examines how the recent and current EU policy framework shapes the supply and demand of biomass across the agricultural, forestry and waste sectors. This analysis complements the baseline scenario, by contrasting the policy impacts with a business-as-usual development. Typical impacts are additional protected areas that are taken out of production for agriculture or forestry; changes in cultivation such as reductions in fertiliser or pesticide use, increasing regenerative practices; but also improved collection of biowaste, etc.

A thorough keyword analysis of EURLEX sources resulted in the first list of selected policies, which was validated by experts from the consortium and the European Commission. Later, policy documents were screened to extract the relevant policy targets. Only policy targets directly affecting biomass supply and demand were considered of relevance. Indirect targets were discarded. The analysis resulted in a total of 11 policies and 15 quantitative targets that have a direct impact on biomass supply (Table 6 Policy targets and their impact on biomass supply) and a total of 4 policies and 8 targets that have a direct impact on biomass demand (Table 7). A full explanation of how the impact factors were calculated for each policy can be found in Annex 3.1.

### 3.2.1 Policy targets and impacts on biomass production in the EU

**Table 6 Policy targets and their impact on biomass supply**

| | Policy | Target | Land availability | Yield per Area | Biowaste Availability |
|---|---|---|---|---|---|
| 1 | Biodiversity Strategy 2030[80] | 30% land and sea protection | Loss of 3.4 to 8.4 million ha (agriculture and forestry) | No significant impact noted | No direct impact |
| 2 | Biodiversity Strategy 2030[81] | 10% high-diversity landscape features in agriculture | Effective loss of 5.1 million ha (non-productive) | No direct impact, indirect positive ecosystem services possible | No impact |
| 3 | Farm to Fork Strategy[82] | 25% agricultural land under organic farming | No impact (land use shift) | 5-10% yield decrease on organic land; overall 5-10% production decrease | No impact |
| 4 | Farm to Fork Strategy[83] | 50% reduction in pesticide risk and use | No impact | 8-20% yield decrease (with integrated pest management potentially offsetting much) | No impact |
| 5 | Farm to Fork Strategy[84] | 50% reduction in nutrient losses from fertilisers and 20% fertiliser use reduction | No impact | 3-5% yield decrease average | No impact |
| 6 | Vision of Agriculture and Food[85] | Sustainable and resilient EU food system | No impact | efficiency improvements 5-10% yield increase possible through regenerative practices and efficiency | No impact |
| 7 | Waste Shipment Regulation[86] | Regulation of transboundary waste shipments | No impact | No impact | 5-15% increase in usable biowaste through improved retention and quality |
| 8 | EU Algae Initiative[87] | Scale up algae biomass production to 8 million tonnes by 2030 | No impact | Adds alternative biomass source | No impact |
| 9 | Soil Monitoring Strategy[88] | Systematic soil health assessment and restoration | No impact | 2-5% yield increase due to improved soil health | No impact |

[80] Communication COM(2020)380 of 20 March 2020, EU Biodiversity Strategy for 2030: Bringing nature back into our lives. European Commission, 2020, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52020DC0380.
[81] COM(2020)380, EU Biodiversity Strategy for 2030: Bringing nature back into our lives.
[82] Communication COM(2020)381 of 20 March 2020, *A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system*, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52020DC0381.
[83] COM(2020)381.
[84] COM(2020)381.
[85] Communication COM(2025)75, *A vision for agriculture and food: Shaping together an attractive farming and agri-food sector for future generations*, Publications Office of the European Union, 2025, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52025DC0075.
[86] Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006, 2024, *Official Journal of the European Union, L,* 2024/1157.
[87] Communication COM(2022)592, *Towards a strong and sustainable EU algae sector*, Publications Office of the European Union, 2022, https://oceans-and-fisheries.ec.europa.eu/document/download/4d5a28c9-8720-45e7-84f0-b1d076d60a60_en?filename=COM-2022-592_en.pdf
[88] Communication COM(2021)699, *EU Soil Strategy for 2030: Reaping the benefits of healthy soils for people, food, nature and climate*, Publications Office of the European Union, 2021, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0699

| | | | | | |
|---|---|---|---|---|---|
| 10 | New Genomic Techniques Proposal[89] | Facilitate market access for gene edited plants | No impact | 5-15% yield increase with adoption of advanced breeding techniques | No impact |
| 11 | EU Forest Strategy 2030[90] | 30% forest protection including 10% strict | Potential exclusion of 15-20 million ha from intensive harvest | No significant direct impact, harvest intensity lowered | No impact |
| 12 | LULUCF Regulation[91] | Target 310 million tonnes net GHG removals in 2030 | Reduced harvest area by 5-15% (10% typical conservative estimate) | Indirect positive impact via enhanced sequestration | No impact |
| 13 | Farm to Fork Strategy[92] | 50% reduction of food waste at retail and consumer | No impact | No impact | 23.5-34.5 million tonnes food waste reduction (~30% of total biowaste) |
| 14 | Zero Pollution Action Plan[93] | Reduce total waste and halve residual municipal waste | No impact | No impact | 8-23 million tonnes reduction in biowaste (10-20%) |
| 15 | Waste Framework Directive[94] | Obligatory collection of biowaste / recycling targets for municipal waste | No impact | No impact | 10–20 million tonnes of additional biowaste collected (up to 75% of current biowaste volumes) |

Source: Prognos AG/Idea Consult/nova Institute, 2025,own elaboration.[95]

### 3.2.2 Policy targets and impacts on biomass demand in the EU

The policy targets affecting the demand for biomass in the EU are underpinned by the EU-wide target of reaching net-zero emissions by 2050. This was initially presented in the European Green Deal[96] and later ratified and made legally binding by the European Climate Law[97], as well as by its intermediate target of at least 55% reduction in GHG emissions by 2030 presented in the Fit-for-55[98] package. Most quantitative targets impacting the demand for biomass originate in legisla-

[89] Communication COM(2023)411 of 05 July 2023, Proposal for a Regulation of the European Parliament and of the Council on plants obtained by certain new genomic techniques and their food and feed, and amending Regulation (EU) 2017/625. Publications Office of the European Union, 2023, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52023PC0411.
[90] Communication COM(2021)572 of 17 July 2021, *New EU Forest Strategy for 2030*. Publications Office of the European Union, 2021, https://eur-lex.europa.eu/legal-content/de/TXT/?uri=CELEX%3A52021DC0572.
[91] Regulation (EU) 2023/839 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2018/841 as regards the scope, simplifying the reporting and compliance rules, and setting out the targets of the Member States for 2030, and Regulation (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review. Official Journal of the European Union, L 107, 1–28, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R0839.

[92] COM(2020)381, A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system.
[93] Communication COM(2021)400 of 12 March 2021, *Pathway to a Healthy Planet for All. EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil'*, European Union, 2021, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0400.
[94] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, Official Journal of the European Union, L 312, 3–30 , 2008, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0098.
[95] For assumption refer to Annex 3, section 3.3.
[96] Communication COM(2019(640) of 11 December 2019, *The European Green Deal,* Publications Office of the European Union, 2019, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640.
[97] Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999(Regulation No. 2021/1119), Official Journal of the European Union, L 243 (July 9, 2021).
[98] Communication COM(2021)550 of 14 July 2021, *'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality*, Publications Office of the European Union, 2021. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0550

tion from the fuel and energy sector. Since these are already adopted, binding and under implementation, their impacts have been integrated in the baseline scenario above. In order to provide a complete picture, the results are listed below. The full explanations can be found in Annex 3.1.

**Table 7 Policy targets and their impact on biomass demand**

| Policy | Target | Impact on biomass demand |
|---|---|---|
| Renewable Energy Directive (III)[99] | By 2030 42.5% of energy is generated from renewable sources | Expected to stabilise demand but change across sectors, Feed and food biofuels capped. Biomass demand constrained by stringent sustainability criteria (sourcing) and GHG emission savings (climate contribution) to be eligible for State aid and assigned to the Union's renewable energy target. |
| RePowerEU Action Plan[100] (Biomethane Action Plan) | By 2030, a non-binding, indicative 35 bcm of biomethane target | Moderate, prioritizing Annex IX feedstocks, feed and food crops are limited by GHG emissions savings criteria, production to increase by better use of existing feedstock (retrofitting) and expanding the feedstock base. |
| FuelEU Maritime[101] | Sets limits to the GHG intensity of energy used on board of ships (from 2% in 2025 to 80% reduction in 2050). | Moderate to high. Since biofuels are just one of several decarbonisation pathways under consideration, food and feed crops have been excluded. Other options include electrification, hydrogen, non-biological renewable fuels, and methanol and ammonia. |
| ReFuelEU Aviation[102] | By 2050, aviation fuel should contain a minimum share of 70% Sustainable Aviation Fuel | Medium, limited to Annex IX feedstocks, food and feed crops biofuels excluded as other low carbon pathways are prioritized. |

Source: Prognos AG/Idea Consult/nova Institute, 2025,own elaboration

Beyond fuel and energy policy targets, several product-related regulations may include targets that can influence the demand of biomass in the future. The Packaging and Packaging Waste Regulation that entered into force in 2025 has significant potential to introduce specific bio-based content targets in the form of minimum mandatory content of bio-based plastics.  Cumulative impact of policy targets on biomass supply and demand in the EU-27

When all of the impacts discussed above are included in the model of biomass and supply, we see several effects, both decreasing and increasing biomass availability.

[99] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. (2023, October 18). *Official Journal of the European Union, L Series, 2023/2413,* https://eur-lex.europa.eu/eli/dir/2023/2413/oj.
[100] Communication COM(2022)230 of 18 May 2022, *REPowerEU Plan*, Publications Office of the European Union. 2022, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0230.
[101] Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC (Regulation No. (EU) 2023/1805), Official Journal of the European Union, Series L, 234, 48–100, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R1805.
[102] Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation) (Regulation No. (EU) 2023/2405), Official Journal of the European Union, Series L, 2023/2405, https://eur-lex.europa.eu/eli/reg/2023/2405/oj.

### Agricultural crops

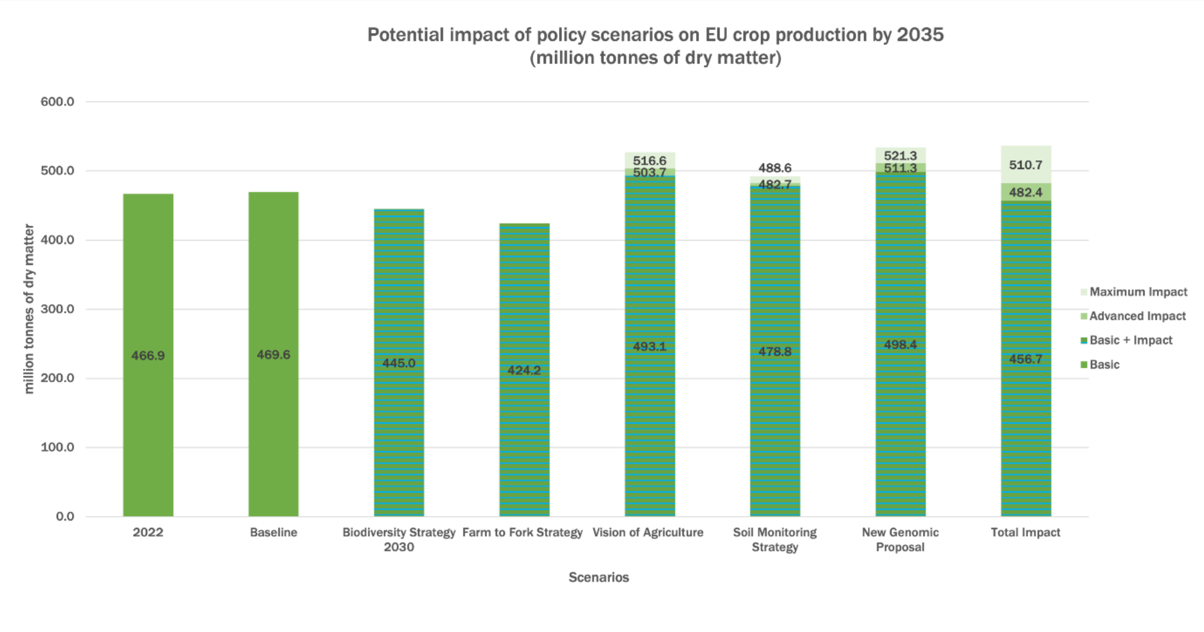
The amount of agricultural land in the EU is expected to decrease as a result of the 2030 Biodiversity Strategy[103]. Both requirements for the expansion of protected areas as well as the increased establishment of high-diversity landscape features reduced productive areas. Taken together, these measures reduce the amount of productive farmland by around 7.9 million hectares by 2035, equivalent to almost 5% of the agricultural land currently in use leading to a clear decrease of agricultural production.

Beside land availability, crop yields (productivity per area) can be strongly affected by EU policy measures. Three measures in particular under the Farm to Fork Strategy[104] may introduce a declining impact on yields. First, the expansion of organic farming from about 10% of land in 2022 to 25% by 2030 is associated with yields that are 20-25% lower per hectare than conventional production. Second, pesticide use is set to be halved. Third, fertiliser use is to be cut by 20% across the sector, but because organic farms do not apply mineral fertilisers, the required reduction for conventional farms is only about 4%, after expansion of organic farming areas.  Taken together, in our analysis the Farm to Fork measures result in an average yield decline of around 6% compared with the baseline.

At the same time, three other policies provide compensating or even positive yield effects. The EU Vision for Agriculture and Food[105] promotes agroecological and sustainable practices and efficiency gains, which could raise yields by 5 to 10%. The Soil Monitoring and Resilience Directive[106][107] targets long-term soil health, with expected gains of 2 to 5%. Crops with yields that are particularly sensitive to soil health, such as potatoes and sugar beet benefit most, while perennials such as olives and vineyards respond more modestly. The New Genomic Techniques[108] proposal supports gene-edited varieties resistant to drought, pests and diseases. Depending on adoption rates, this can increase yields by 5 to 15 percent. Stronger effects are expected in breeding-intensive crops such as cereals and oilseeds, while perennials show lower responses.

[103] COM(2020)380, EU Biodiversity Strategy for 2030: Bringing nature back into our lives.
[104] COM(2020)381, A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system.
[105] COM(2025)75, A vision for agriculture and food: Shaping together an attractive farming and agri-food sector for future generations.
[106] Communication COM(2023)416 of 05 July 2023, Proposal for a Directive of the European Parliament and of the Council on Soil Monitoring and Resilience, Publications Office of the European Union, 2023, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52023PC0416.
[107] Please note that the Proposal for a Directive on Soil Monitoring and Resilience has, as of the 21 November 2025, been approved by the Council of the European Union and the European Parliament but is still not published in the Official Journal of the European Union. See: https://oeil.europarl.europa.eu/oeil/en/procedure-file?reference=2023/0232(COD)
[108] Communication COM(2023)411 of 05 July 2023, Proposal for a Regulation of the European Parliament and of the Council on plants obtained by certain new genomic techniques and their food and feed, and amending Regulation (EU) 2017/625, Publications Office of the European Union, 2023, https://food.ec.europa.eu/document/download/c03805a6-4dcc-42ce-959c-e4d609010fa3_en?filename=gmo_biotech_ngt_proposal_2023-411_en.pdf#page=1.00&gsr=0

**Figure 11 potential Impact of Policy Scenarios**




When combined, the net effect depends on the scenario. In a conservative case, yield reductions from Farm to Fork[109] are largely but not completely balanced by improvements from efficiency, soil and breeding. This results in near-stable biomass availability. In a mid-range scenario, the positive measures more than offset losses, lifting average yields by around 10 to 15 percent compared with baseline trends. In an optimistic scenario with rapid adoption of innovations, cereals could reach around 5.3 tonnes per hectare in 2035, up nearly 20 percent from baseline. Pulses, oilseeds and root crops show similar or larger gains. Perennials improve less, but overall, the policies could not only stabilise but also increase EU biomass supply by 2035.

**Woody biomass**

The baseline projections indicate a steady increase in roundwood production across Europe. However, EU policy measures are expected to reduce the area available for harvesting. The EU Forest Strategy 2030[110] advocates closer-to-nature management and the stricter protection of the EU's 161 million hectares of forest. In this model, it is assumed that around 22 million hectares will be subject to restrictions on intensive harvesting. These figures reflect the model's assumptions about the potential impact of policies on the area of forest harvested.

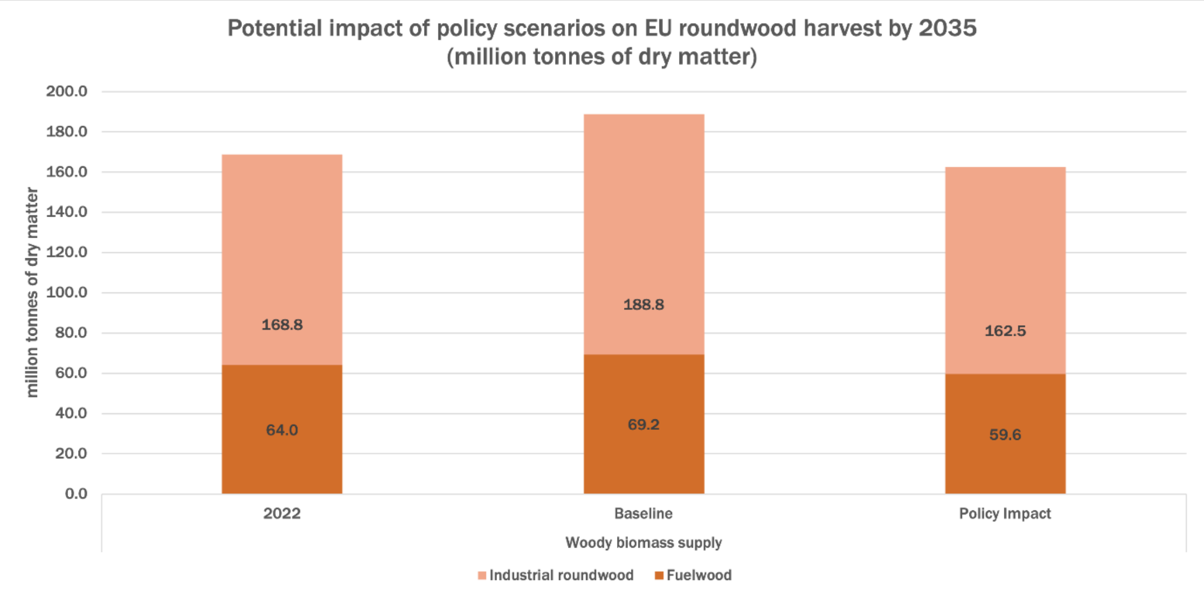
Based on this assumption of reduced harvestable area and applying constant yields, total roundwood production is projected to reach 221.8 million tonnes in 2035, which is 5 percent lower than 2022 levels and about 14 percent below the baseline projection. Industrial roundwood falls to around 162.5 million tonnes, while fuelwood declines to about 59.6 million tonnes.

Overall, EU policies shift the outlook for woody biomass from moderate growth to a decline in available supply by 2035, highlighting a strong trade-off between biomass use and climate and

[109] COM(2020)381, A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system.
[110] COM(2021)572, New Forest Strategy.

biodiversity objectives. At the same time, the decline in primary roundwood supply does not necessarily translate into scarcity for all wood-based products. Circular options such as the recycling of waste wood and paper, as well as greater material use of by-products from sawmills are expected to gain further importance. While recycling rates are already high today, the model assumes a gradual further increase in secondary material use and residue utilisation by 2035, supported by improved collection efficiency and circular bioeconomy measures.

**Figure 12 Woody biomass supply in 2022 and 2035 scenarios**




## Organic waste

Organic waste, mainly food and garden residues, represents one of the largest material streams in municipal waste in the EU. In 2022, the average person generated about 488 kg of municipal waste per year, of which 168 kg (34%) was biowaste. Around 58% of this fraction was collected in mixed waste, while 42% was separately collected for recycling. In total, this corresponds to around 97 million tonnes FM of biowaste generated (44 million tdm), of which 18 million tdm were captured separately and available for composting or anaerobic digestion.

Baseline projections to 2035 assume stable per-capita generation of municipal waste, adjusted for a slightly declining EU population. Under this assumption, total municipal waste falls to around 101 million tdm, of which about 42 million tdm are biowaste. With increasing recycling rates and separate collection, the share of biowaste captured separately is expected to rise from 42% to 50%, equal to 21 million tdm of usable material.

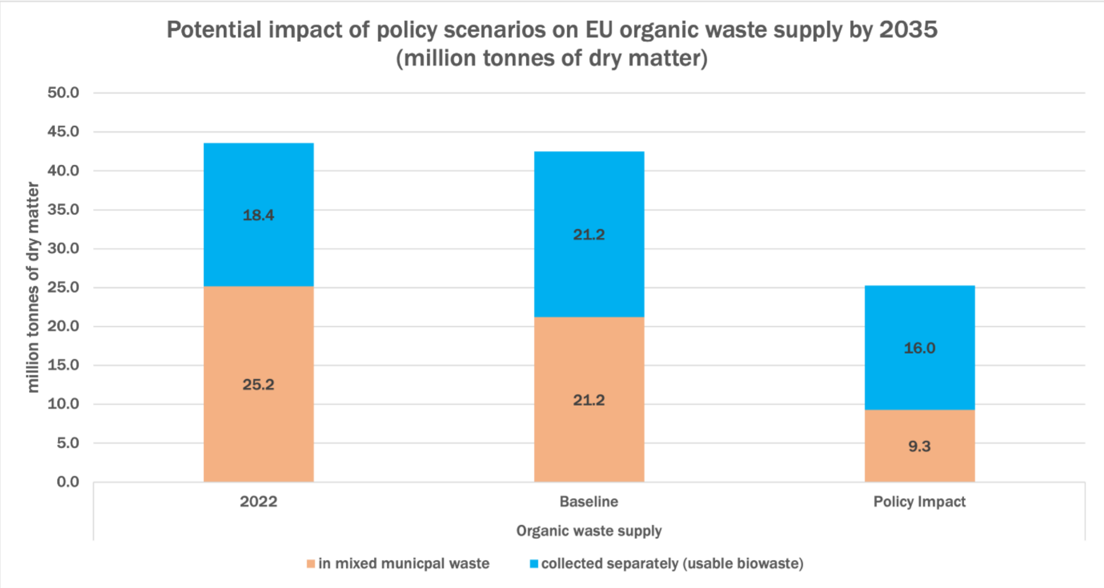
Policy measures are assumed to influence both the overall quantity of biowaste generated and, indirectly the quality of streams of valorisation. Farm to Fork Strategy[111] and Waste Framework Directive[112] primarily aim to prevent food waste by targeting a 50% reduction at retail and consumer level by 2030. Since food accounts for around 60% of municipal biowaste, this reduces

[111] COM(2020)381, A Farm to Fork Strategy for a fair, healthy and environmentally friendly food system.
[112] Directive 2008/98/EC, on waste.

total biowaste by about 30% compared to baseline. By 2035, usable biowaste would drop to about 33 million tonnes FM (15 million tdm). The Zero Pollution Action Plan[113] aims to reduce total waste generation and halve residual municipal waste, lowering usable biowaste to around 28 million tonnes FM (13 million tdm).

On the other hand, the Waste Framework Directive[114] (WFD) requires separate collection of biowaste from 2024 and raises recycling targets for municipal waste to 65% by 2035. This increases capture rates without changing total generation. In the model, the share of separately collected biowaste rises by about 15% compared to baseline, raising usable supply to roughly 14 million tdm. The Waste Shipment Regulation[115] tightens export restrictions and improves intra-EU tracking and treatment. By reducing contamination and keeping more material within the EU, raising usable biowaste availability to around 16 million tdm.

**Figure 13 Organic waste supply in 2022 and 2035 scenarios**



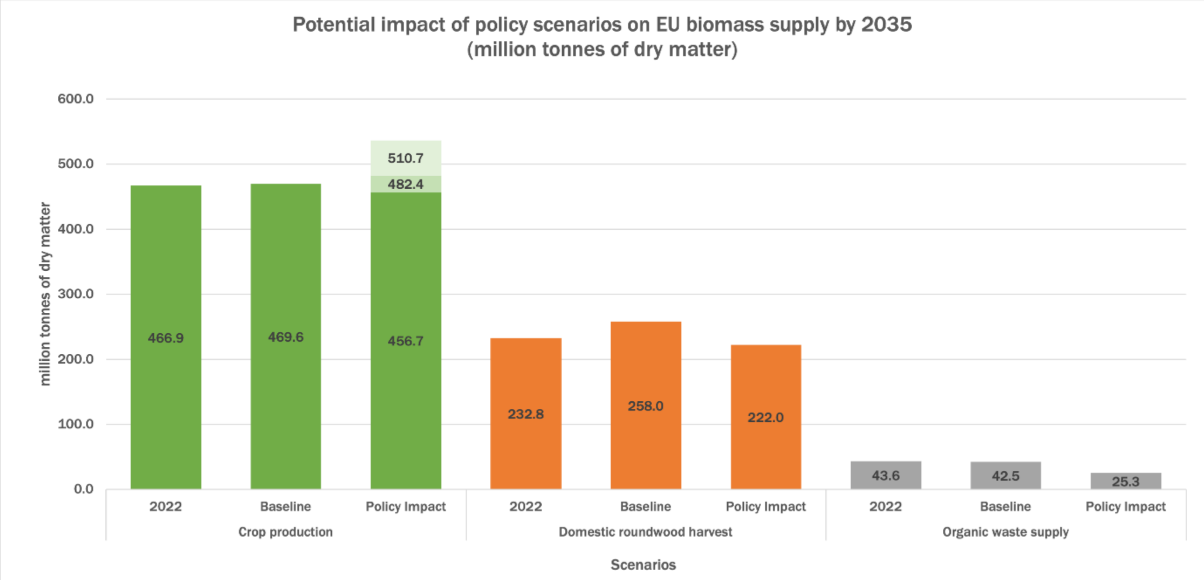

Taken together, the combined impact of these policies reduces the absolute volume of usable biowaste (collected separately) from 21 million tdm in the baseline to about 16 million tdm in 2035, a decline of 25%. At the same time, both the volume of biowaste in mixed municipal waste decreases (due to prevention and waste reduction policies) and the share of usable biowaste within separately collected waste streams increases (through stricter collection rules, higher capture rates and lower contamination). This means that while less waste is generated overall, a larger fraction of it can actually be used for composting, anaerobic digestion and bio-based applications.

[113] COM(2021)400, Pathway to a Healthy Planet for All. EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil.
[114] Directive 2008/98/EC, on waste.
[115] Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipments of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006. (2024). *Official Journal of the European Union, L,* 2024/1157.

### 3.2.3 Summary and conclusion for biomass supply and demand

Comparing the baseline and policy scenarios in the agriculture, forestry, and organic waste sectors reveals varying impact of EU policies on biomass availability.

**Figure 14 Potential impact of policy scenarios on EU biomass supply**




The analysis shows that the EU possesses a broadly stable biomass base, but sectoral shifts will redefine demand and supply patterns and the impact of policy measures can both reduce or increase domestically available biomass.

The moderate growth in supply of agricultural biomass contrasts with the declining food/feed demand and the sharp contraction in biofuels, which is projected by several major studies. It is very worthwhile to note that this is the only sector which may even grow further, depending on the exact impact of policy measures. The highest potential for increasing domestic biomass production was found in the agricultural sector.

The supply of woody biomass will expand moderately according to the baseline scenario, but demand growth – especially for pulp, packaging, and bio-based materials – may create supply pressure. Environmental policies can impact wood harvests even further, if more area is protected. A similar potential for increasing yields as in the agricultural sector was not found.

Organic waste currently is underexploited, but increased collection and treatment could make it a more significant feedstock for circular bioeconomy pathways. However, waste reduction targets are in stark contrast with an overstated potential. Considering the strong focus of recent bioenergy and biofuels policies on these resource streams, this is a very relevant insight. Further bioeconomy policies cannot only rely on secondary resources only – instead, policy needs to address those measures that can sustainably increase the yields of agricultural crops. This will be crucial for long-term availability of biomass in Europe. Correspondingly, it will be key that the use of crop-based biomass will be accepted for industrial material uses of biomass.

Trade dependency on imported biomass remains a structural vulnerability and could intensify as demand for industrial uses rises. More details on this are provided in the subsequent chapter.

**Moving beyond competition and fostering synergies between bioenergy/biofuels and bio-based chemicals and materials**

The analysis of the legislative framework performed here demonstrates that there are very few binding and quantitative targets regarding the supply and demand for biomass in the European Union. With the exception of the biofuels sector and certain renewable energy targets, biomass use and supply remain primarily governed by market mechanisms and indirect incentives, rather than direct regulatory mandates. In contrast to the biofuels sector – which has benefited from comprehensive and coordinated policy support through binding renewable energy targets, dedicated sectoral mandates, and carbon pricing mechanisms – the bio-based materials sector continues to receive only limited policy attention, despite representing substantial opportunities for lower environmental impacts,[116], industrial transition, and fossil resource substitution.[117] [118]

The Renewable Energy Directive (RED) has historically served, and continues to serve, as the principal driver of biomass demand for energy, particularly to produce liquid biofuels and biogas for transport and power generation. Its most recent iteration, the Renewable Energy Directive (RED III)[119], establishes a 45% renewable energy share target by 2030 (which consolidates the Fit-for-55 targets), including sectoral obligations that require the use of biofuels and renewable gaseous fuels of non-biological origin in transport, aviation, and maritime sectors. Legislative acts such as ReFuelEU Aviation[120] and FuelEU Maritime[121] complement the RED III by setting progressively increasing mandates for renewable fuels in these hard-to-abate transport sectors, resulting in fast-growing additional demand for sustainable biomass feedstock throughout the value chain. These binding targets are not only supported by significant financial incentives and market mechanisms (including carbon pricing through the Emissions Trading System[122]) but also offer a stable regulatory outlook that has facilitated the large-scale mobilization of investment and infrastructure development for bioenergy and biofuels[123]

By contrast, the demand for bio-based materials – covering chemicals, plastics, and advanced materials – lacks the same binding policy framework. Efforts have been made at the strategic level to clarify the ambition, such as the 20% renewable carbon target for chemicals and plastics

[116] Zuiderveen, E., Kuipers, K., Caldeira, C., Hanssen, S., Van Der Hulst, M.K., De Jonge, M., Vlysidis, A., Van Zelm, R., Sala, S. and Huijbregts, M., '*The potential of emerging bio-based products to reduce environmental impacts*', NATURE COMMUNICATIONS, ISSN 2041-1723, 14 (1), 2023, p. 8521, JRC127868, https://doi.org/10.1038/s41467-023-43797-9
[117] van Leeuwen, M., Gonzalez-Martinez, A., & Sturm, V., *EU Outlook for Biomass Flows and Bio-based Products*, *EuroChoices*, 22(3), 13-20, 2023, https://doi.org/10.1111/1746-692X.12408
[118] Lehnert, W., & Traum, Y., *The 'new' Renewable Energy Directive (RED III): an overview*, The European Energy and Climate Journal, 12(2), 40-47, 2024, https://doi.org/10.4337/eecj.2024.0001
[119] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources and repealing Council Directive (EU) 2015/652. (2023, October 18), Official Journal of the European Union, L Series, 2023/2413, https://eur-lex.europa.eu/eli/dir/2023/2413/oj
[120] Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation) (Regulation No. (EU) 2023/2405), Official Journal of the European Union, Series L, 2023/2405, https://eur-lex.europa.eu/eli/reg/2023/2405/oj.
[121] Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC (Regulation No. (EU) 2023/1805), Official Journal of the European Union, Series L, 234, 48–100, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R1805.
[122] European Commission, 'EU ETS, EU Emission Trading System'. Commission Website, accessed 20 November 2025, https://climate.ec.europa.eu/eu-action/carbon-markets/eu-emissions-trading-system-eu-ets_en
[123] Lehnert et al., 2024.

set out in the Sustainable Carbon Cycles Communication[124]. However, this target remains non-binding, with no associated legal mandates or implementation measures. The inclusion of certain bio-based material definitions in the EU Taxonomy Regulation[125] has improved recognition of their potential contribution to sustainability goals, but the Taxonomy as of yet offers only indirect investment guidance rather than direct demand-side obligations. Thus, the policy landscape remains highly uneven, resulting in a significant imbalance in the rate and scale of development between the biofuels sector and the bio-based materials sector – a divergence that has led to the systematic diversion of available sustainable biomass resources toward energy applications at the expense of optimal cascading and high-value material uses.[126]

Crucially, this situation stands in tension with the EU's stated commitment to cascade the use of biomass. RED III formally defines the cascading use of biomass as the principle which "aims to achieve the resource efficiency of biomass use by prioritising, wherever possible, the material use of biomass over its energy use, thus increasing the amount of biomass available within the system. Such an alignment is intended to ensure fair access to the biomass raw material market for the development of innovative, high value-added bio-based solutions and a sustainable circular bioeconomy." Yet in practice, the RED III implementation largely interprets cascading through the lens of energy policy objectives, primarily by promoting the use of waste and secondary resources for energy, and by limiting the use of food and feed crops for energy through the seven percent cap on their use for biofuel production. Even though this lessens the competition for biomass compared to previous iterations of the RED, there is still significant support, both for primary biomass as well as for feedstocks found in Annex IX, which are supposed to be waste or residues. The contribution of fuels made from the latter is even counted double towards the quotas, making them especially attractive for the energy sector. Unfortunately, Annex IX feedstocks may also include resources that can be used for chemicals and materials, diverting them from these applications. The material sector, meanwhile, does not benefit from equivalent prioritization or supportive measures and faces persistent competition from subsidized energy uses.[127] [128]

There is a lack of consistent data collection on the quantitative and financial impacts of this imbalance in market support. However, as early as 2014, the nova-Institute collected evidence and statements from 12 companies and industry associations that were struggling in obtaining raw materials due to competition from the renewable energy sector – for feedstocks as diverse as animal fats, vegetable oils, glycerol, residues from forest and agro-industries, agricultural area, tall oil, wood, biowaste, sugar, starch and cellulose.[129] Due to the bioenergy incentives, wood imports

[124] Communication COM(2021)800 of 15 December 2021, Sustainable Carbon Cycles, Publications Office of the European Union, 2021.https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0800

[125] Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088,2020, Regulation (EU) 2020/852, Official Journal of the European Union, L 198, 13–43, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852.

[126] van Leeuwen et al., 2023.

[127] van Leeuwen et al., 2023.

[128] Lehnert et al., 2024.

[129] Carus, M., Dammer, L., Hermann, A., Essel, R., *Proposals for a Reform of the Renewable Energy Directive to a Renewable Energy and Materials Directive (REMD)*, nova paper #4 on bio-based economy 2014, https://renewable-carbon.eu/publications/product/nova-paper-4-on-bio-based-economy-proposals-for-a-reform-of-the-renewable-energy-directive-red-to-a-renewable-energy-and-materials-directive-remd-%E2%88%92-full-version-update/.

into the EU have increased strongly over the last few decades. Depending on the eventual implementation and impact of the EU Regulation on Deforestation-free products (EUDR)[130], it is expected that imports might decrease again – potentially further increasing the competition for domestic feedstock.[131]

Simultaneously, there are many cases in which there are synergies between supported biofuels and other uses of biomass. Subsidized bio-ethanol production may partly also enter the materials sector for further refining into a multitude of chemicals. Bio-naphtha, which can replace fossil-based naphtha in cracker-based chemistry, is a by-product of biodiesel production. And it should also be mentioned that of course there is also demand for bioenergy – mainly fuelwood – which is not subsidized. Damaged wood, residues of wood processing and other types may not even be usable for material purposes. Or even if they are, just from a logistics point of view it is often much easier and possibly economically feasible to use them for energy purposes.

However, it remains fact that the support system for different uses of biomass is skewed in favour of fuels and energy. To achieve more efficient biomass uses and potentially more cascades, a level playing field for chemicals and materials would be helpful. The revision of the Bioeconomy Strategy aims to promote more support for chemicals and materials in selected lead markets and outlines implementation steps that aim to bridge the valley of death that many innovative products face.

In summary, a balanced and effective policy framework – one that incorporates binding targets, consistent incentives, and robust data infrastructure for bio-based materials alongside energy uses – is a precondition for optimising biomass allocation in accordance with the cascading principle, supporting full circularity, defossilising material cycles, and maximizing socioeconomic value from limited bioresources.

[130] Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023 on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010,2023, Regulation (EU) 2023/1115, Official Journal of the European Union, L 150, 206–247, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32023R1115.
[131] Johnston, C., Guo, J., Prestemon, J., *The European Union Deforestation Regulation: Implications for the global forest sector*, Forest Policy and Economics (Volume 173), April 2025, 2025. https://doi.org/10.1016/j.forpol.2025.103462

# 4 Import structures of relevant raw materials for the bioeconomy in the EU

To sustain its fossil-based industrial economy, the EU has to rely significantly on imports of fossil raw materials. The shift towards a bioeconomy has the potential to reduce existing dependencies, by building up more on own biological resources and by diversifying import relations. However, Europe cannot meet its growing demand for biological resources solely based on own production. As a result, the shift toward bio-based industrial systems carries the risk of creating new import dependencies.

Against this backdrop, this chapter examines trade flows associated with both bio-based industrial systems and fossil-based materials that could be substituted, focusing on import dependencies and global interconnections. Five key dependency metrics are assessed to identify the most critical materials. Additionally, a scenario-based approach is applied to estimate potential future dependencies that may emerge from an intensified transition to bio-based systems. Selected case studies are also presented to illustrate strategies for mitigating import dependencies.

*i*

**Key findings**

- Import dependencies: The analysis reveals significant import dependencies for bio-based raw materials and intermediaries relevant for industrial use. The EU is a large net importer and the EU's imports are often highly concentrated, with a large share of global supply controlled by only a few countries.

- Options for increased domestic use: Many bio-based industrial systems rely on imported biomass feedstock. Shifting from fossil-based to bio-based solutions does not automatically reduce import dependencies. But the case studies demonstrate that it is possible to design bio-based value chains in ways that decrease external dependencies and build on domestic resources.

-

- Case studies illustrate approaches to decrease import dependencies, emphasising the need for policies that support domestic biomass production and innovation in bio-based materials.

## 4.1 Overview of EU bio-based industrial materials imports

The EU is a significant net importer of bio-based industrial materials. Given its dense population and advanced industrial development, this is expected and not inherently problematic. However, trade deficits concentrated in a limited number of key resources—particularly those critical to specific industries—can pose risks to strategic resilience. When such materials are predominantly sourced from one or a few countries, trade dependencies may emerge. These potential dependencies, both for bio-based industrial materials and their fossil-based counterparts, will be examined in the following subchapters.

The EU imports nearly 97 million tons of bio-based raw materials that can be potentially used in industrial processes in 2023 (see Table 8). The value of these imports amounts to approx. EUR 57 billion. It's important to clarify that not the entire volume of these materials is then also used in bio-industrial processes. For example, for starch crops like wheat and maize or oils like palm oil a major share of the imports and use is for food, feed or bioenergy. For starches the share of non-food applications sits at around 44%, primarily for corrugating and paper making[132]. EU exports were 13% lower than the bio-based imports, meaning that the trade deficit in 2023 is at more than EUR 7 billion.

Fossil-based materials are imported into the EU with a greater volume in monetary terms, over EUR 127 billion, but with a lot smaller volume in tons, around 39 million tons. Exports from the EU are often in higher production grades or more valuable materials and therefore the EU exports are even a bit higher than the imports, leaving a small trade profit. The exports in tons on the other hand are a third lower, leaving a trade deficit of nearly 13 million tons.

**Table 8 Trade balance for Bio-based and Fossil-based materials for the EU**

| Origin | Imports in billion EUR | Imports in million t | Exports in billion EUR | Exports in million t | Trade balance in billion EUR | Trade balance in million t |
|---|---|---|---|---|---|---|
| Bio-based raw materials potentially relevant for industrial use | 25.2 | 70.2 | 14.8 | 50.6 | - 10.4 | - 19.6 |
| Precursors | 14.8 | 16.2 | 12.2 | 12.0 | - 2.6 | - 4.2 |
| Platform chemicals | 9.5 | 6.7 | 8.9 | 3.5 | - 0.6 | - 3.2 |
| Pre-products | 7.3 | 3.5 | 13.5 | 16.9 | + 6.2 | + 13.4 |

[132] The European Starch Industry - Starch Europe, 'Starch Europe - Plant-Based Solutions' accessed September 15, 2025. https://starch.eu/the-european-starch-industry/.

| | | | | | | |
|---|---|---|---|---|---|---|
| Fossil-based materials[133] | 127.5 | 39.2 | 128.9 | 26.4 | +1.4 | - 12.8 |

Source: Prognos, 2025, based on Eurostat data.

The bio-based industrial materials are grouped in four types in different value chain positions. Bio-based raw materials potentially relevant for industrial use [134] is the type with the largest import sum in 2023 and by far the largest yearly growth rate since 2019. Of these bio-based raw materials worth more than EUR 25 billion were imported, a growth of over 10% p.a. since 2019 (see Figure 15). In 2019 EU imports of this category were below EUR 17 billion. A comparison with the change rate of the imports in tons, which decreased by around 2% p.a. since 2019, shows a significant increase in import prices in that timespan.

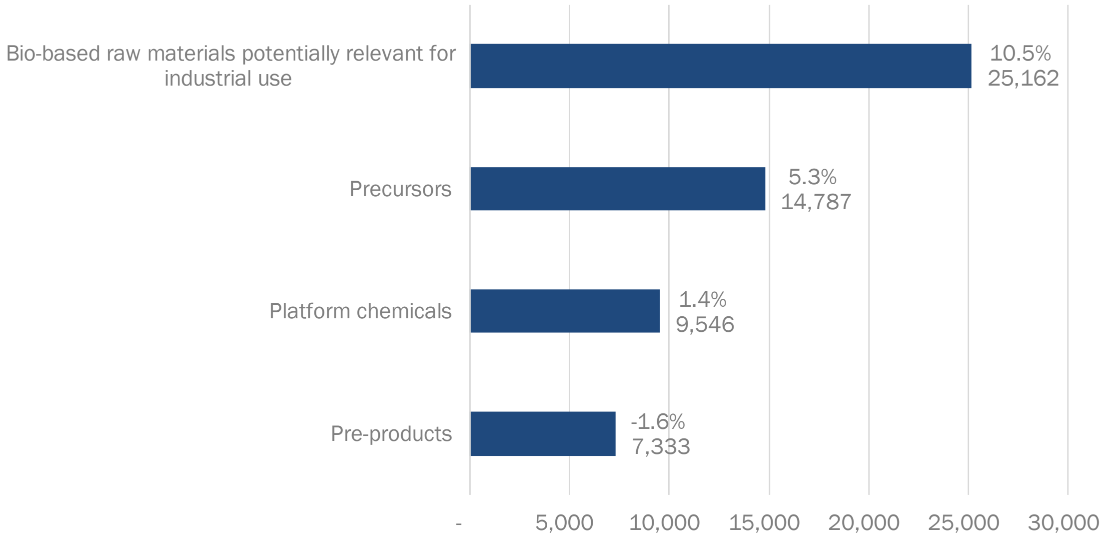
Precursor products are the second largest import type of bio-based materials with nearly EUR 15 billion and a steady growth rate of ca. 5% yearly. But the volume in tons is significantly lower in 2023 than in 2019, only reaching 85% of the volume of 2019. This indicates similar price increases like for bio-based raw materials potentially relevant for industrial use, being directly influenced by higher raw material prices.

Imports of platform chemicals (bio-based and drop-in) reached roughly EUR 10 billion in 2023, only slightly increasing since 2019 in value. Like in the case of precursor materials, the import volume in tons decreased. Pre-products, such as wood-based materials and yarns, however, decreased both by value and by volume. While their import value in euro decreased slightly, their volume in tons was cut more than in half since 2019, amounting to less than 4 million tons in 2019.

Figure 15 Extra-EU Imports of the four types of bio-based industrial resources in million EUR in 2023, with change from 2019 to 2023 in% p.a.

[133] The analysis considers fossil-based materials primarily used for material purposes, as delineated by Chapters 29 (organic chemicals) and 39 (plastics) of the CN classification. From these two chapters, all codes previously identified as inputs to bio-based industrial systems were excluded to ensure that all essential codes relevant for bio-based industries were not categorised as fossil based. The remaining codes were considered under the category of fossil-based materials. Given the size and complexity of the dataset (700+ codes), an exhaustive verification of whether each code is exclusively fossil-based is not feasible; isolated bio-based exceptions may remain. For the materials examined in the in-depth analysis in 4.3 and in the case studies, individual checks were conducted and cross-referenced with the feedstocks listed as key inputs for the identified bio-based industrial systems and considering only those relevant to the study scope (excluding biofuels, bioenergy, food and feed, pharmaceuticals, health, and medical devices).

[134] The category "Bio-based raw materials potentially relevant for industrial uses" considered here as part of the trade analysis must not be confused with the overall biomass considered in chapter 3. The analysis in the present chapter focuses on biomass with a high potential for direct industrial use like the most common crops for starches, sugars and oils whereas the analysis in chapter 3 includes biomass on a much broader scale and for example live animals, milk, cheese, prepared foods and all crops are included. Therefore, the figures do not correspond directly.




Source: Prognos, 2025, based on Eurostat data.

On top of the absolute importance of a material in EU trade, the trade balance and the dynamic, the dependency from individual countries and the political relationship with that country can also play a major role in identifying critical materials. The imports of many of the materials are centred around individual supplier countries in the bio-based industry. Ukraine is the largest supplier of the EU for bio-based raw materials potentially relevant for industrial use with more than a fourth of the imports originating from the country (see Table 9). Especially for mass products like wheat, maize and sunflower-seeds Ukraine is by far the largest supplier of the EU. The high share of the US and Brazil are driven by their dominance in the EU imports of soya-beans. Brazil is also the top supplier in the precursors type with a share of over 17% of the EU imports between all of the materials of this type. The main reason for this high share of Brazil being wood pulp. Ukraine and Indonesia dominate the EU import market for sunflower-seed oil and palm oil respectively.

Further up the value chain, imports of platform chemicals, key materials for bio-industrial processes, primarily originate from the United States, which accounts for nearly 18% of all materials. The USA is a leading supplier of drop-in chemicals such as ethylene and acetic acid. While the largest share of pre-products comes from China, this market is less concentrated compared to the other three categories of bio-based industrial materials. China is particularly significant as a source country for the EU in the yarns and textiles segment.

It is important to note that the table below does include many different materials and trade dependencies are more concentrated for individual materials but differ more in the supplier countries for different materials. The table below therefore does not show a generally low concentration of imports on single countries, but a concentration on different countries for different materials.

**Table 9 Top supplier for the EU in the four types of bio-based industrial resources, 2023**

| Type | Top supplier | Share | Top supplier | Share | Top supplier | Share |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| Bio-based raw materials potentially relevant for industrial uses | Ukraine | 26.0% | United States | 17.3% | Brazil | 16.3% |
| Precursors | Brazil | 17.2% | Ukraine | 14.0% | Indonesia | 12.0% |
| Platform chemicals | United States | 17.7% | Great Britain | 13.7% | China | 8.6% |
| Pre-products | China | 14.8% | Turkey | 9.7% | India | 8.5% |

Source: Prognos, 2025, based on Eurostat data.

Process for analysing EU imports and dependencies

The relevant bio-based and fossil-based industrial materials are defined using the European foreign trade codes of the Combined Nomenclature (CN-codes). The quantitative evaluation is based on the corresponding foreign trade data from EUROSTAT. The EUROSTAT-data was downloaded from the comext-database and the indicator “DS-059322 - EU trade since 2002 by HS2-4-6 and CN8” was used for the data extraction. Using a classification of relevant materials that is available in Annex 4.1: Trade codes of biomass resources and intermediates relevant for bio-based industries, the EUROSTAT data for extra-EU imports by country of origin and extra-EU exports for the years 2019 to the most recent year 2023 are evaluated. The data is available as trade in euro as well as trade in tons. Based on this data, the most important import goods, trends since 2019, the concentration of EU imports on individual supplier countries and the EU's trade balances can be analysed. The analysis of the EUROSTAT-data from the comext-database in combination with the developed classification (Annex 4.1: Trade codes of biomass resources and intermediates relevant for bio-based industries) builds the base for the quantitative assessments in chapters 4.1, 4.2 and 4.3.

Analysis of the global export market using the Prognos ‚world trade model‘

The global export volume of bio-based and fossil-based industrial materials is calculated based on the classification of trade codes using Prognos' own ‘world trade model’. The underlying database are the trade flows between 64 countries, broken down by product group until 2023. The countries included account for around 95% of global gross domestic product. The model is based on the Harmonised System (HS) codes and is compatible with the CN-codes used for EU trade. The global export volumes of the 64 countries provide the basis for identifying alternative supplier countries for materials with strong EU dependencies and information on global market concentration.

Identification and systematisation of bio-based and fossil-based materials

Based on different existing studies and classifications as well as own research, a list of relevant trade codes in the CN classification was compiled. Only codes representing bio-based materials and intermediates that are potentially relevant for industrial use were included.

The list contains more than 600 CN-codes of bio-based materials and intermediates that are relevant for industrial use. On top of that nearly 700 codes with raw materials and intermediates of fossil origin were included for comparison and for the assessment of transformation potentials in fossil-based materials, where promising bio-based alternatives exist. This includes Chapter 29 of the CN classification, which includes 'organic chemicals', and Chapter 39, which includes 'plastics and articles thereof'.

For bio-based codes, the systematisation distinguishes different segments along the value chain. The first segment deals with bio-industrial feedstocks. These include certain crops for starch, sugar and oil production, natural fibres, wood-based raw materials, selected animal-based raw materials and biological waste. Further up the value chain, we look at bio-based intermediates. These are precursors, platform chemicals and pre-products. Precursors are refined products derived from the raw materials, such as sugars or starches. Platform chemicals are the basic building blocks from which a wide range of chemicals and materials can be produced. Examples include methanol, lactate acids and polypropylene. The analysis includes both dedicated bio-based platform chemicals and drop-in materials. The latter are treated as a separate category as trade codes do not allow bio-based drop-in materials to be distinguished from their identical fossil-based counterparts. Finally, we look at selected pre-products like yarns, textiles and wood-based pre-products such as sawn wood.

## 4.2 Identifying the most relevant imported materials and assessing current dependencies

The identification of the most relevant raw materials and intermediates for the in-depth analysis is based on five central indicators as criteria. The selected indicators are aimed at covering multiple aspects for the identification of a critical trade dependency of a bio-based or fossil-based material.
The five indicators on the material level are the following:

1. EU-import value in million EUR
2. Yearly change rate of EU-imports in million EUR from 2019 to 2023 in% p.a.
3. EU trade deficit in million EUR in 2023
4. Herfindahl-Hirschmann-Index (HHI) of global exporters (excl. EU itself)
5. Share of total EU-imports for top 3 supplier countries by value

The '*EU-import value in million EUR*' is the baseline indicator that provides an accurate overview of the most imported materials of the EU. 16 bio-based materials are imported at more than EUR 1 billion in 2023. The most important import materials focus on mass crops like soya beans, maize, rape seeds and wheat. While all having bio-industrial applications, the major shares of these crops are used in food, feed and bioenergy. Wood pulp and wood pellets are also part of the most imported materials, with non-coniferous wood pulp ranking at number three overall. The other two material groups in the most imported materials by value in Euros are drop-in chemicals and oils or fats. Polypropylene, Ethylene and Acrylic polymers are all imported in a volume of more than a billion Euros. The most imported oils and fats are palm oil, sunflower-seed oil and inedible 'yellow grease' (of animal and vegetal origin), all ranking in the top 10 materials. The most imported fossil-based industrial materials include Lactams or articles of plastics with each more than seven billion Euros of EU-imports. Unlike for bio-based materials, fossil-based imports by weight in tons show a very different list of top imports. By weight the most imported material by far is methanol with more than 6.2 million tons of EU-imports in 2023. Methanol is followed by saturated acyclic hydrocarbons and many different plastics like Polyethylene (PE), Polypropylene (PP) and Polyethylene terephthalate (PET).

For the assessment of the criticality of the EU trade dependency of a material a key factor is the dynamic of the imports in the last years. The '*Yearly change rate of EU-imports in million EUR from 2019 to 2023 in% p.a.'* identifies some materials where import values and quantities increased by extremely dynamic rates showing a sign of growing relevance of the material or growing import dependencies. Soya-bean oil for technical and industrial uses has by far the largest average yearly growth rate of bio-based material since 2019, tripling the import value every year. If this trend continues for the next years soya-bean oil for technical and industrial uses will be one of the most imported bio-based materials. Other materials with highly dynamic imports by value in euro are rape seeds, sunflower-seed oil for technical uses, wheat, palm oil and crude tall oil. For fossil-based industrial materials two of the three most imported materials Lactams and saturated acyclic hydrocarbons are also the second- and third-most dynamic growing import commodities by value in euro with growth rates of ca. 45% and 40% respectively.

But the EU also exports huge quantities of some bio-based and fossil-based industrial materials, making high import values and dynamic a less problematic factor as there also exists a significant EU supply. The indicator *'EU trade deficit in million EUR in 2023'* is included to account for industrial materials that are exported and imported in similar quantities and help identify the biggest net import industrial materials. The bio-industrial materials that have the highest trade deficits by value are very similar to the most imported bio-industrial materials in general. The highest net import materials are the crops soya beans, maize and rape seeds. Wheat still being in the top 10 but ranked lower than for total imports. Palm oil and technically specified natural rubber "TSNR" on the other hand being more critical and having one of lowest ratios of exports to imports, as these materials are nearly impossible to produce and therefore also export in the EU. For fossil-based industrial materials the highest trade deficits also mirror the most relevant materials by import value in 2023, except for Methanol. By import value in euro Methanol is only rank 8, but the trade deficit by value is the highest of all bio-industrial materials.

The fourth indicator, the '*Herfindahl-Hirschmann-Index (HHI) of global exporters (excl. EU itself)',* adds the global export market concentration as a factor into the analysis. Where trade dependencies are identified, the global market concentration is a relevant factor for determining if alternative suppliers for diversification are even available at the moment. The Herfindahl-Hirschmann-Index (HHI) is a concentration measure for supplier competitiveness. It is calculated by squaring the market share of each supplier (country) competing within a market and then summing the resulting numbers. Using the HHI for country trade limits the number of suppliers to around 200 countries. The resulting number between 0.005 and 1 is then expressed as a share of 10,000. The HHI therefore ranges from 50 to 10,000, a higher number indicating a higher market concentration. Some plastic polymers like Polypropylene or Polyurethane are for example one of the least concentrated global supply markets of the 100 most relevant materials with HHI-Scores around 1,000. Especially many bio-based materials have a very heavily concentrated global supply market. The highest concentration exists for s-p-f wood, where more than 99% of the exports are from Canada leading to a HHI of 9,810. The market for Brewing or distilling dregs and waste is dominated by the US with a share of 95% and an HHI of ca. 9,000. Natural rubber and manioc exports markets are also very much concentrated on Thailand as a supplier with HHI of ca. 8,600 and 8,300 respectively. Global supply markets are often times less strongly concentrated as the products and chemicals do not have the same clear environmental and outside factors controlling the ability to produce them as some bio-based materials. But it stands out, that for many plastic polymers and especially plastic pre-products or products the export markets often have a significant concentration on China.

To also assess the concentration of the EU-import market the *'Share of total EU-imports for top 3 supplier countries by value'* was included for the selection of industrial materials for the in-depth analysis. EU-imports of bio-based as well as fossil-based industrial materials are generally concentrated on only a handful of supplier countries. For both categories nearly all of the top 100 most imported materials are imported by a share of at least 50% or more by only three supplier countries. At least 90% of the imports for 40 of the top 100 bio-based materials are imported from only three countries. For fossil-based industrial materials 19 of the top 100 materials were imported by a share of at least 90% from only three countries. For bio-based oils like palm oil, sunflower-seed oil, crude tall oil and soya-bean oil the EU-imports are the most concentrated on the top suppliers. Lactams as the most relevant imported fossil-based material by value are also one of the materials, where more than 90% of the imports are from only three countries.
The lowest EU-imports share with around 50% from the top 3 countries are calculated for bio-based materials like cotton, gelatine, raw solid cane sugar, 'yellow grease' and Polypropylene. Fossil-based materials with similar low shares are for example plastic films, tubes, sheets and plates.

For each of the indicators the top 5 materials for bio-based and fossil-based with the highest value were identified. For this step only materials in the top 100 of the most imported (or top 100 of the world export market) of both bio-based and fossil-based materials by value in euro were considered.

The top 5 materials of each indicator constitute two lists (bio-based and fossil-based) of the most relevant materials from the trade perspective. Excluding duplicate appearances of materials in the top 5, both lists consist of 20 most relevant materials. These two lists of the top 20 most relevant materials can be found as the "Identify"-step in Annex 4.2: List of most relevant imported raw materials/intermediates. For every material of these two lists the average ranking in all five indicators in the top 100 of all materials was used to determine an order of relevance from all trade perspectives.

The most relevant bio-based materials were also filtered by the share of bio-industrial use for the selection of the 5 materials for in-depth analysis in the following chapter. All materials with an estimated lower share (~less than half) of bio-industrial use were excluded for this selection. For the fossil-based list of the most relevant materials only materials with an existing promising bio-based alternative were further considered for in-depth analysis. As a second filtering step for both bio-based and fossil-based materials, a comparison with the long-list of potential bio-industrial systems from Task 1 was made. For the in-depth analysis of five bio-based materials, the highest ranked materials that appear at least once as feedstock in this long-list and have a high share of bio-industrial use were selected. For the in-depth analysis of five fossil-based materials, the highest ranked materials that appear at least once as original base chemicals in this long-list of potential bio-industrial systems and have a promising bio-based alternative were selected.

**Table 10 Overview of the five selection indicators (incl. volume in tons) of the 11 most relevant materials**

| **Commodity** | **EU Imports 2023** | | **EU Import dynamics 2019-2023** | | **EU Trade balance 2023** | | **Market concentration by value** | | |
|---|---|---|---|---|---|---|---|---|---|
| Resource bio-based | Value in million EUR | Weight in tons | Change in value in% p.a. | Change in weight in% p.a. | Value in million EUR | Weight in tons | Herfindahl-Hirschmann-Index (HHI) global exports (excl. EU) | Share of EU top-3 supplier countries | EU top supplier country |
| Palm oil, for industrial uses | 1,239 | 1,231,164 | 30.3% | 12.7% | - 1,238 | - 1,230,299 | 5,416 | 100.0% | Indonesia |
| Crude sunflower-seed or safflower oil, for technical or industrial uses | 221 | 265,026 | 64.8% | 53.5% | - 212 | - 253,527 | 5,813 | 100.0% | Ukraine |
| Crude tall oil | 136 | 96,173 | 29.7% | -2.3% | - 136 | - 95,690 | 8,319 | 99.8% | USA |
| Non-plasticised cellulose acetates, in primary forms | 138 | 42,611 | 3.4% | -3.0% | - 135 | - 42,000 | 8,254 | 99.0% | USA |
| Soya-bean oil, for technical or industrial uses | 171 | 159,822 | 237.7% | 205.6% | - 161 | - 152,574 | 1,706 | 99.6% | Argentina |
| Butane-1,4-diol | 159 | 85,505 | 90.7% | 73.6% | -150 | -83,304 | 2,026 | 91,4% | USA |
| Resource fossil-based | | | | | | | | | |
| Lactams | 10,738 | 20,512 | 44.5% | 9.8% | - 816 | 2,947 | 3,806 | 93.1% | Switzerland |

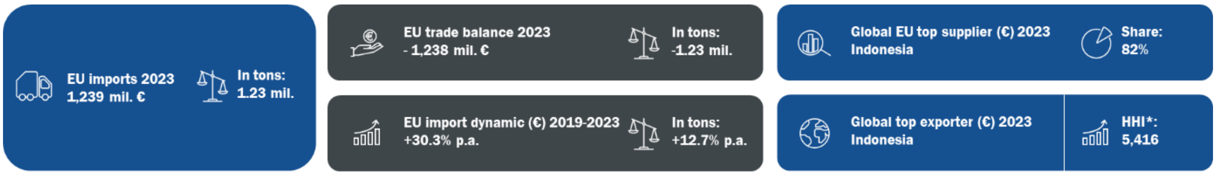
| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Saturated acyclic hydrocar-bons | 766 | 1,606,204 | 0.5% | -4.7% | - 649 | - 1,547,983 | 7,004 | 93.4% | USA |
| Lysine and its esters | 442 | 390,561 | 9.8% | -0.1% | - 401 | - 368,674 | 6,641 | 85.8% | China |
| Polyethylene tereph-thalate, primary forms | 1,295 | 1,197,184 | 6.0% | 4.0% | - 1,090 | - 1,052,266 | 2,935 | 57.2% | Viet Nam |
| Methanol "methyl alcohol" | 1,832 | 6,229,834 | 2.5% | -1.1% | - 1,703 | - 5,885,258 | 2,301 | 58.0% | Trinidad and Tobago |

## 4.3 Detailed analysis of the import structures of the eleven most relevant materials

### 4.3.1 Six most relevant bio-based materials

Palm oil and its liquid fractions, for industrial uses

**Figure 16 Dashboard of the most relevant indicators for Palm oil**




* Herfindahl-Hirschman-Index

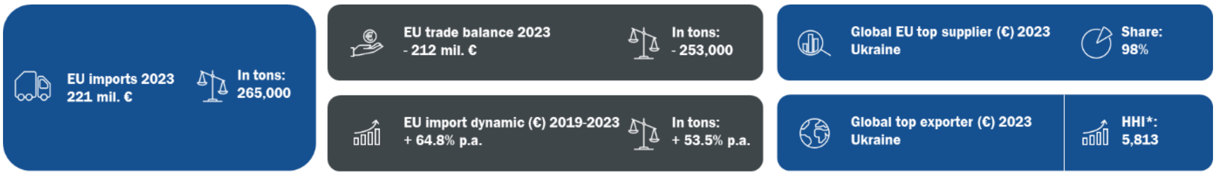
Palm oil is a bio-based oil from palm fruits, widely used in food and industrial products, its fossil-based substitutes include petrochemical-derived lubricants and surfactants. Only the palm oil that is used in industrial or technical processes is analysed here.

Palm oil for technical uses ranks 11th in total Extra-EU Imports of bio-industrial materials by value with more than EUR 1,239 million or by weight more than 1.23 million tons. Palm oil is one of the 10 fastest growing bio-industrial import commodities by value with more than 30% yearly growth from 2019 to 2023. In this period of time the product has increased import prices for the EU, as the volume by weight only increased by 12.7% p.a. The EU does not export palm oil in relevant quantities, that's why the trade deficit is nearly the same as the import value.

The EU imports palm oil for technical uses mainly from Indonesia, the country having a share of 82%. There are only two more countries the EU imports palm oil from, being Malaysia and Togo. Malaysia accounts for nearly the complete rest of the share and from Togo only a negligible amount gets shipped to the EU. For no other bio-industrial commodities the market is concentrated that much on only three or effectively two supplying countries. The global export market for the commodity is similarly dominated by Indonesia (67%) and Malaysia (30%), but at least some other countries like the UAE, USA, Thailand and Turkey are also exporting smaller amounts. The Herfindahl-Hirschman-Index of 5,416 underlines this concentration on only two countries. EU imports could be aimed at also incorporating these other trade partners for palm oil for technical uses to diversify the imports as much as reasonably possible.

## Crude sunflower-seed or safflower oil, for technical or industrial uses

**Figure 17 Dashboard of the most relevant indicators for Crude sunflower-seed or safflower oil**




* Herfindahl-Hirschman-Index

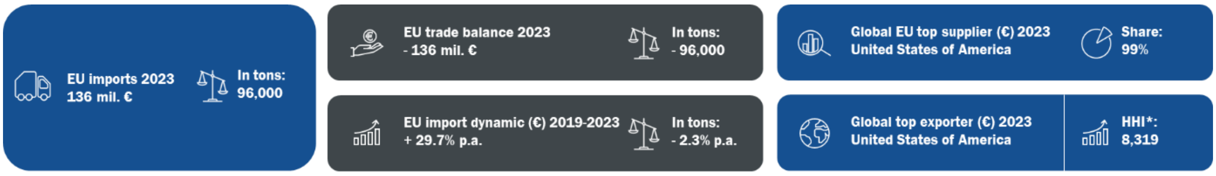
Crude sunflower-seed (or safflower) oil is a vegetable oil from seeds, used technically in coatings and lubricants, fossil-based alternatives are mineral oils. Only the sunflower-seed oil that is used in industrial or technical processes is analysed here.

EUR 221 million of the oil was imported into the EU in 2023 which equals to around 265,000 tons. Sunflower-seed oil is one of the five fastest growing bio-industrial import commodities with a growth of nearly 65% p.a. from 2019 to 2023. The volume by weight increased similarly by nearly 54% p.a. Even though small amounts of sunflower-seed oil were also exported from the EU, the trade deficit amounts to more than 95% of the total import value and weight.

Nearly all (ca. 98%) of the sunflower-seed oil imports originated from one country in 2023, Ukraine. The ongoing Russian invasion of the country seems not to halt or even increase shipments from Ukraine at least for the second year of the invasion 2023. The only other countries with relevant trade to the EU for this commodity are Serbia (1.9%) and Moldova (0.4%). That makes sunflower-seed oil the second most heavily concentrated bio-industrial material on the top-3 import destinations. The global export market is also heavily dominated by Ukraine in 2023, but with the share of the country being "only ca. 75% of the global market and therefore a lot smaller than the share for EU imports. Countries like Argentina (13.8%), Turkey (5.2%) and Moldova (4.1%) play a more important role in the global trade of sunflower-seed oil. The Herfindahl-Hirschman-Index still is rather high with 5,813. Even though factors from the Russian invasion and also geographical proximity could play a role for the higher share of Ukrainian sunflower-seed oil imports for the EU, but either way the incorporation of higher shares of the other three major global exporters in the import mix would increase resilience of the supply chain for this commodity.

Crude tall oil

**Figure 18 Dashboard of the most relevant indicators for Crude tall oil**




* Herfindahl-Hirschman-Index

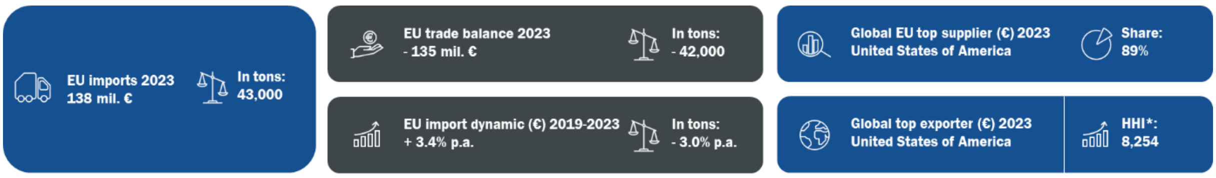
Crude tall oil is a byproduct of wood pulping, used for resins and chemicals and fossil-based analogues are petroleum resins and fatty acids.

Crude tall oil imports have increased in price massively from 2019 to 2023. The imports by value grew by nearly 30% per year, while the imports by weight actually decreased by about 2% per year. The overall imports amount to EUR 136 million or 96,000 tons in 2023. There are nearly no exports from the EU of crude tall oil, so the trade deficit amounts the nearly the same numbers as the imports.

The EU imports of crude tall oil originate almost all from the United States, the country having a share of 99% of the imports in 2023. Turkey, Argentine, Belarus and Russia only contribute with minor shares to the import mix of the EU. Belarus and especially Russia stand out, because imports from these countries plummeted since 2019, with the import by value decreasing in half for Belarus and decreasing by 99% for Russia. The United States on the other hand increased their imports to the EU with an even greater yearly change rate than for the whole crude tall oil import market. The global export market is also dominated by the United States accounting for 91% of the exports in 2023. But Brazil and Canada also have relevant shares in the market with 5.2% and 2.0% respectively. This still results in one of the highest Herfindahl-Hirschman-Indexes of the bio-industrial commodities in 2023 with 8,319. While the options for building up resilience and decreasing dependencies is still limited, the global export market offers at least small opportunities to diversify imports by increase trade with Brazil and Canada.

Non-plasticised cellulose acetates, in primary forms

**Figure 19 Dashboard of the most relevant indicators for Non-plasticised cellulose acetates**




* Herfindahl-Hirschman-Index

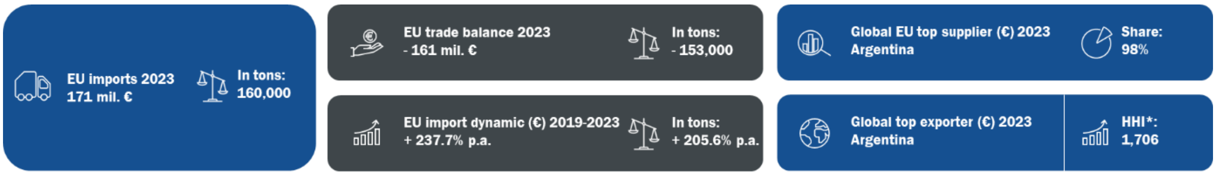
Non-plasticised cellulose acetates in primary forms are a cellulose derivative from wood or cotton, used in films and fibres. Fossil-based alternatives include plastics like PVC or PET.

While the imports for non-plasticised cellulose acetates have only increased by a small yearly rate 3.4% by value from 2019 to 2023, the imports in tons have decreased by 3.0% in the same time. But as there are only marginal exports from the EU itself, the trade deficit is at 98% of the import weight in tons. The total imports amounted to EUR 138 million and 43,000 tons in 2023.

The EU imports as well as the global export market are heavily cantered around the United States and China to a smaller extent. The United States cover roughly 90% of both the EU imports and the global market. China also amounts to nearly the same share for EU imports as globally (8.4% and 9.0%). This US dominance can also be seen in the very high Herfindahl-Hirschman-Index of 8,254 for non-plasticised cellulose acetates. The EU trade therefore already follows global availability in a very clear way. Countries like Japan, India and the UK have smaller shares of the EU imports of this commodity. But the dynamics of the import change since 2019 are very different for the supplier countries. The US-imports grew at a fast pace of nearly 12% p.a., but imports from China (ca. 27% p.a.), India (ca. 44% p.a.) and the UK (ca. 66% p.a.) grew very rapidly. The Japanese share on the other hand decreased significantly by 7.9% p.a. India and the UK are also the only other remaining relevant suppliers on the global market apart from the United States and China. That means the options for diversifying and strengthening the supply chain are limited for the EU.

Soya-bean oil and its fractions, for technical or industrial uses

**Figure 20 Dashboard of the most relevant indicators for Soya-bean oil**




* Herfindahl-Hirschman-Index

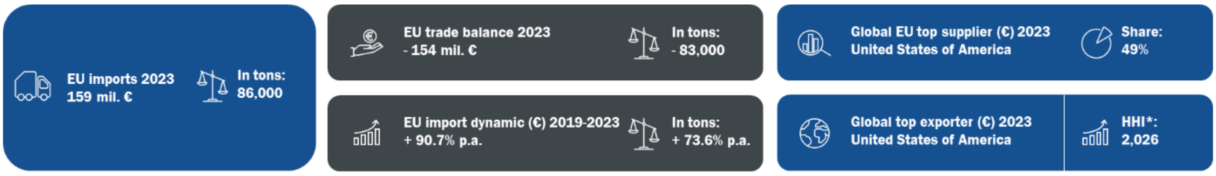
Soya-bean oil is a soy-derived bio-based oil, used in biodiesel, inks and polymers, fossil-based oils are used for similar functions. Only the soya-bean oil that is used in industrial or technical processes is analysed here.

The EU imported EUR 171 million or about 160,000 tons of the commodity in 2023. The exports amount to only around 5% of these volumes, leaving a trade deficit of roughly 95% of the total imports in 2023. Soya-bean oil for technical and industrial uses is by far the fastest growing import commodity of all relevant bio-industrial materials. From 2019 to 2023 the EU imports grew to 130-times the value or about 240% p.a. This is mainly an increase in volume not price, because the import in tons also grew by over 205% p.a.

The main supplier for the EU is Argentina with 98% of the imports by value in 2023. In 2019 Argentina did not yet supply any soya-bean oil for technical and industrial uses to the EU. Ukraine and the UK are the second and third largest suppliers for the EU and did also increase their exports to the EU drastically by 90% and 40% respectively but remaining below the mean growth of the whole commodity. Even though Argentina is also leading the global export market with 33% of the value, the supply is a lot more evenly spread with many other countries. This can also be seen in the only Herfindahl-Hirschman-Index being only in the medium concentration tier of the indicator with 1,706, one of the lowest of all relevant bio-industrial commodities. Brazil and Thailand also supply more than 10% of the world market. Canada, Malaysia, the United States and China each have more than a 5% share in the global market. Apart from Argentina none of the next six relevant supplying countries of the global market are a relevant source for the EU imports. Therefore, there are multiple options to diversify the supply chain of the EU for soya-bean oil and build up resilience.

Butane-1,4-diol

**Figure 21 Dashboard of the most relevant indicators for Butane-1,4-diol**




* Herfindahl-Hirschman-Index

Butane-1,4-diol is a colourless, viscous organic compound (chemical formula $C_4H_{10}O_2$) used mainly as an industrial chemical intermediate. Used mainly as feedstock for manufacturing polybutylene terephthalate (PBT) plastics, polyurethanes, tetrahydrofuran (THF), γ-butyrolactone (GBL), and various solvents and elastic fibers (e.g., spandex). Its fossil-based variante is produced from petrochemical feedstocks, such as acetylene and formaldehyde or through hydrogenation of maleic anhydride derived from n-butane. Butane-1,4-diol can also be produced biotechnologically from renewable sugars via fermentation pathways using engineered microorganisms.

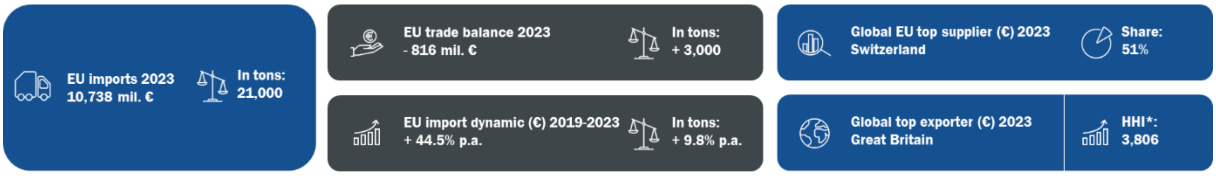
The EU imported EUR 159 million or about 86,000 tons of Butane-1,4-diol in 2023 and does not export significant volumes itself. The trade deficit therefore amounts to around 95% of the total imports in value and weight. The imports of the commodity dynamically increased since 2019 more than 90% p.a. in value and nearly 75% p.a. in weight.

The United States are the biggest supplier of the EU in 2023 and ship around half of the total EU imports of Butane-1,4-diol. Imports from the United States in 2019 were nearly non-existent and therefore are the main driver of the dynamic growth rate. The second largest import origin for the EU is China with around a third of the total imports. Imports from China also increased by over 70% p.a. since 2019, but therefore below the mean growth rate for the commodity. In 2019 China was the largest EU supplier together with South Korea. But the imports from South Korea declined sharply until 2023 by around 37% p.a. and the country is only the sixth largest supplier today. The United States are also the largest global exporter of the commodity, and a large share is supplied to the EU in 2023. The share of global exports for the US is around one third, lower than for the EU imports. There are also three countries that have a significantly larger share of the global export market than for EU imports, being Taiwan, South Korea and Japan. These three countries represent opportunities to diversify suppliers and decrease US and China dependencies.

### 4.3.2 Five most relevant fossil-based materials with promising bio-based alternatives

Lactams

**Figure 22 Dashboard of the most relevant indicators for Lactams**




* Herfindahl-Hirschman-Index

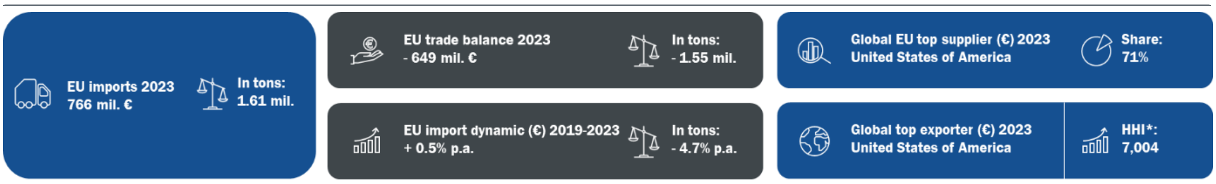
Lactams can be synthesized bio-based (e.g., from sugars, amino acids) or fossil-based (from petrochemicals) and are used in nylon and pharmaceuticals.

Lactams are the most imported fossil-based chemicals by the EU in 2023 by value with EUR 10.7 billion. As they are not mass chemicals, the weight in tons only amounts to 20,500 tons. From 2019 to 2023 EU imports of Lactams increased in price drastically, as the yearly growth by value was nearly 45%, while the yearly growth by volume in tons was “only” ca. 10%. Lactams are therefore also the second fastest growing import commodity of the fossil-based chemicals by value since 2019. The trade deficit stands at EUR 816 million, but the volume shows a trade surplus of ca. 3,000 tons for the EU. Therefore, the EU in general imports higher value Lactams and exports slightly lower value Lactams.

The EU import market is centred around three top suppliers, being Switzerland with 51.0%, the UK with 25.6% and China with 16.5%. These three suppliers account for around 93% of the total EU imports of Lactams. Especially the imports from the UK (ca. 73% p.a.) and China (ca. 117% p.a.) grew more rapidly than the whole commodity imports. Other relevant suppliers for the EU are the United States and India. In global Lactams-market the UK, Singapore and China are the most relevant suppliers. The UK exports more than half of all Lactams globally. The Herfindahl-Hirschman-Index shows a concentration of 3,806, being higher than for a lot of other fossil-based chemicals, but not part of the most concentrated ones. There are limited options for diversification as only Singapore as a top global exporter does not already have a relevant share of the EU imports.

Saturated acyclic hydrocarbons

**Figure 23 Dashboard of the most relevant indicators for Saturated acyclic hydrocarbons**




* Herfindahl-Hirschman-Index

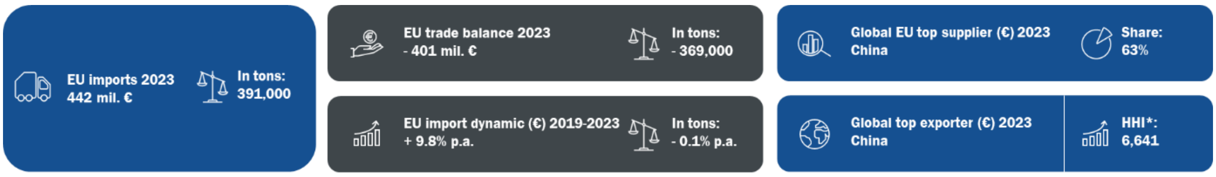
Saturated acyclic hydrocarbons are straight-chain or branched molecules containing only carbon–carbon single bonds (alkanes). Fossil-based sources come mainly from crude oil and natural gas, used as fuels or petrochemical feedstocks. Bio-based alternatives can be produced from biomass, e.g., bioethanol upgraded to alkanes, biogas methane.

The EU imported EUR 766 million or 1.61 million tons of saturated acyclic hydrocarbons in 2023. The imports stagnated by value from 2019 to 2023 and decreased by 4.7% p.a. by volume in tons. The commodity has a significant trade deficit for the EU market of EUR 649 million and 1.55 million tons in 2023. Especially by weight, this is one of the highest trade deficits of all fossil-based chemicals.

The United States are the main EU supplier with a share of 71% of all imports in 2023. The other two countries with significant shares of EU imports are Russia and Norway. In 2019 the shares of these three suppliers were largely different. Russia and Norway were by far the top supplier, with the US only following with a big margin. But the imports from Russia decreased by ca. 32% p.a. or to less than a fourth of the value in 2019 and Norway similarly decreased ca. 22% p.a. or to nearly a third of the weight. The imports from the US on the other hand increased by ca. 65% p.a. and stand at 7.5-times the value in 2023. The global export market is even more strongly dominated by the United States with a share of ca. 83%. The Herfindahl-Hirschman-Index is 2023 one of the highest for all fossil-based chemicals at 7,004. There is no data for Russia for the year 2023, therefore its position cannot be analysed. Canada with ca. 13% of the global trade is a potential option for new suppliers for saturated acyclic hydrocarbons for the EU, as Canada has not yet established itself as a relevant supplier for the EU.

Lysine and its esters

**Figure 24 Dashboard of the most relevant indicators for Lysine**




* Herfindahl-Hirschman-Index

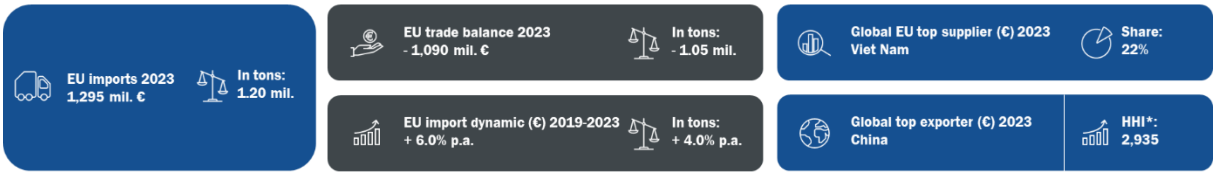
Lysine is an essential amino acid produced biotechnologically through fermentation. Fossil-based analogues are synthetic amino compounds.

Lysine imports of the EU amounted to EUR 442 million and 391,000 tons in 2023. While the value in euro increased by nearly 10% p.a., the volume in tons stayed nearly the same. Lysine-trade is import-heavy and the trade deficit stands in 2023 at roughly 90% of the total imports.

The EU and global top supplier for Lysine is China, with an EU import share of 63%. For this commodity the share of China at the global market is even higher with 81% of Lysine exports. Other big suppliers for the EU are Indonesia, the United States, South Korea and Brazil. Import from Indonesia and South Korea decreased since 2019, while Imports from China grew by nearly 18% p.a. and from the US by ca. 6% p.a. In 2019 imports from Brazil were minimal but grew rapidly, reaching more than 600-times their value in 2023. At the global market stage the same five countries as for the EU are the top suppliers, the main difference being all countries except China have slightly lower market shares than for EU imports.

Polyethylene terephthalate, in primary forms

**Figure 25 Dashboard of the most relevant indicators for Polyethylene terephthalate**




* Herfindahl-Hirschman-Index

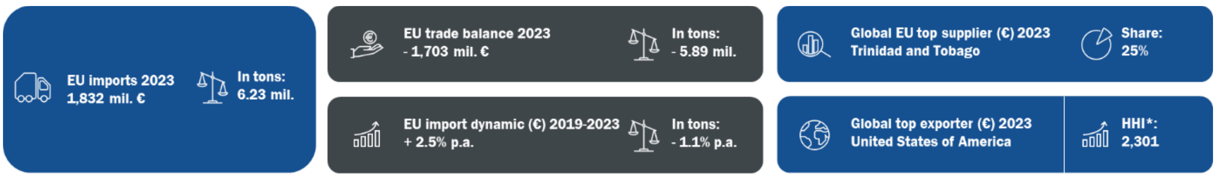
Polyethylene terephthalate or better known with its shortened name PET is typically fossil-based (ethylene glycol + terephthalic acid) but can also be partially bio-based using bio-ethylene glycol.

The EU imported nearly EUR 1.3 billion of PET in 2023, but it is even more relevant when looking at the volume in tons. With ca. 1.2 million tons, PET is one of the most imported fossil-based chemicals by weight in 2023. Imports grew steadily by value (6.0% p.a.) and by weight (4.0% p.a.). Most of the PET imports remain as a trade deficit of nearly EUR 1.1 million or over 1 million tons.

Global trade and EU imports are both not as heavily dominated by a few countries as other fossil- and especially bio-based industrial materials. Viet Nam is the top supplier of the EU with a share of 22% in 2023. Türkiye and Egypt follow with 18% and 17% respectively. The three most important suppliers amount to 57% of EU imports, one of the lowest shares of all relevant fossil-based chemicals. Imports from all three top supplying countries grew from 2019 to 2023 by at least 20% p.a., while especially imports from South Korea and Indonesia decreased significantly. At the global export market China, Taiwan and South Korea remain the three most relevant suppliers. China alone is responsible for 51% of the exports. Even though the Herfindahl-Hirschman-Index is comparatively low at 2,935, the global market is more concentrated than the EU imports.

Methanol "methyl alcohol"

**Figure 26 Dashboard of the most relevant indicators for Methanol**




* Herfindahl-Hirschman-Index

Methanol can be produced bio-based from biomass gasification and biogas or fossil-based from natural gas and coal. It is used as fuel, industrial feedstock, and solvent.

Methanol is the most imported fossil-based chemical by weight in 2023 for the EU. 6.23 million tons or EUR 1.8 billion of the commodity were imported. Even though methanol can be produced in various processes and from various feedstocks, the EU is a massive net importer of it. The trade deficit stands at roughly 95% of the total import figures. But the imports were not dynamic since 2019 but only grew marginally in value by 2.5% p.a. and decreased in weight slightly by 1.1% p.a.

EU Imports for methanol come from multiple core supplying countries without one clear dominant country. With only a share of ca. 58% for the top three import countries, the EU imports are less concentrated than most other fossil-based chemicals. Trinidad and Tobago (ca. 25%), the United States (ca. 20%), Equatorial Guinea (ca. 13%) and Egypt (ca. 11%) are four biggest methanol import origins. Especially imports from the US and Equatorial Guinea had large yearly increases of ca. 20% and 18% p.a. respectively, while supply from Venezuela, Norway and Russia decreased since 2019. Especially Imports from Russia fell massively by nearly 40% p.a. and were at 20% of the level of 2019. But a part of these Russian imports could be represented by the new 5% share of EU methanol imports by “Countries and territories not specified within the framework of intra-Union trade”, where no imports came from in 2019. At the global market the United States are the biggest exporter with a share of roughly 40% of total exports. Malaysia, Chile and Egypt are the other largest exporters. Data from Russia is missing for 2023, that’s why their trade position cannot be analysed. The broad market distribution is supported by a comparatively low Herfindahl-Hirschman-Index of 2,301.

## 4.4 Learnings from case studies: opportunities for reducing current dependencies

### Case study selection

The five case studies were selected to illustrate how value chain transformations can reduce import dependencies and contribute to Europe's open strategic autonomy. The process built on the longlist developed in Task 1, complemented by additional examples identified through desk research (e.g. phosphorus as an inorganic material of strategic importance). Selection was based on two main criteria: (a) trade data analysis from subtask (i), covering import volumes, values, trade deficits and supplier concentration; and (b) policy and strategic relevance, informed by references such as a joint statement of several EU Member States[135], the Critical Raw Materials Act[136], and the JRC study "Insights into the European market for bio-based chemicals."[137]

The chosen cases cover different types of materials and value chains:

- Methanol was selected due to extremely high import volumes and a significant import surplus, combined with its role as a versatile chemical building block for plastics, acetic acid and adhesives.
- Ethylene, one of the most important petrochemical intermediates, was chosen because of very high imports and surpluses, and its strategic designation by EU Member States.
- Phosphorus was included as a critical inorganic raw material essential for fertilizers, highlighted in the Critical Raw Materials Act.
- Polylactic acid (PLA) represents a bio-based plastic that can reduce dependence on fossil-based polymers. Despite being bio-based, Europe still shows high import levels, making PLA relevant both as a case of bio-based import dependency and as a potential substitute for fossil plastics such as PE and PET.
- Maize (biomass feedstock) was selected because of its central role as a sugar source for bio-based industries (e.g. ethanol and PLA). High import volumes underline the potential for new dependencies when shifting towards bio-based production.

Together, these cases reflect different aspects of strategic autonomy: fossil-based imports (methanol, ethylene), critical raw materials (phosphorus), bio-based materials with dual import challenges (PLA), and biomass feedstock dependencies (maize). This mix provides a balanced perspective on both risks and opportunities in transforming European value chains.

### Summary of the case studies

The case studies are presented in the Annex to this report.

**Methanol** ($CH_3OH$) is a key platform chemical used in the production of plastics, paints, solvents, and as a fuel. Currently, it is primarily produced from fossil feedstocks such as natural gas or coal. The EU is highly import-dependent, sourcing large volumes from Trinidad and Tobago, the United States, and Equatorial Guinea, while supply from Russia has declined due to geopolitical

[135] Joint statement of Czech Republic, Hungary, Italy, Netherlands, Romania, Slovakia, Spain and France about the European chemicals industry, The alarming situation of the European chemicals industry, a strategic sector that needs a dedicated "EU Critical Chemicals Act", 2025 Available at: https://presse.economie.gouv.fr/joint-statement-of-czech-republic-hungary-italy-netherlands-romania-slovakia-spain-and-france-about-the-european-chemicals-industry/ (last accessed 09/2025)
[136] European Commission, Critical Raw Materials Act, 2025 Available at: https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en (last accessed 09/2025)
[137] Spekreijse, J. et al., Insights into the European market for bio-based chemicals. Publications Office of the European Union, 2019, Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC112989 (last accessed 09/2025)

tensions. Rising global demand and high energy costs pose additional challenges for the European market.

Sustainable methanol production offers a pathway to reduce import dependency and greenhouse gas emissions. Bio-methanol from organic materials and e-methanol from green hydrogen and $CO_2$ are viable alternatives, with bio-methanol currently the more cost-effective option. Commercial-scale projects, such as a fossil-free biomethanol plant by a European producer, demonstrate the potential to produce renewable methanol domestically. Expanding these technologies can stimulate local economies, create jobs, and support Europe's transition to a circular, low-carbon economy.

**Ethylene** ($C_2H_4$) is a key chemical building block used across industries, from plastics to cleaning agents, with global production exceeding 225 million tonnes annually. EU production currently relies heavily on fossil feedstocks, particularly naphtha and ethane, making the region dependent on imports and vulnerable to supply disruptions. Sanctions on Russia, a major natural gas and petroleum supplier, have highlighted this dependence while contributing to rising energy costs, threatening the competitiveness of the European petrochemical industry.

Bio-based ethylene, produced from renewable ethanol or via carbon capture technologies, offers a viable pathway to reduce fossil fuel dependency and strengthen Europe's chemical sector. While the technologies are well developed and ready for scale-up, market conditions, high production costs, and limited demand for bio-based products remain challenges. Expanding domestic bio-based ethylene production could lower greenhouse gas emissions, create green jobs, and enhance European economic independence, supporting the EU's Green Deal objectives and the transition toward a more sustainable, circular chemical industry.

**Phosphorus** (P) is a critical raw material for European agriculture, with around 85% of global use tied to fertilizers. The EU is highly dependent on imports of phosphorus, sourcing nearly 90% from abroad, mainly from Morocco, Russia, Egypt, Israel and Senegal, while only 5–10% of demand is met domestically. The EU trade deficit, especially in weight is significant. Supply risks are exacerbated by concentrated global markets, export re-strictions from China, and tariffs on Russian imports, alongside rising global demand. This heavy reliance represents a strategic vulnerability for European food security and agricultural competitiveness.

Phosphorus recycling offers a viable pathway to reduce import dependence while delivering environmental and social benefits. Secondary sources such as livestock manure, sewage sludge, and food industry by-products can be processed to recover high-purity phosphorus, with leading European technologies achieving recovery rates above 90%. Initiatives such as Phos4You, SusPhos, and the Schkopau Ash2Phos plant demonstrate that large-scale recovery is feasible. While recycling cannot fully replace imports, it can significantly reduce dependency, lower green-house gas emissions, create skilled jobs, and position the EU as a global leader in circular phosphorus management.

**Polylactic acid** (PLA) is a versatile bioplastic used in packaging, textiles, disposable products, and 3D printing, valued for its biodegradability and potential to replace fossil-based plastics in specific applications. Currently, Europe relies heavily on imports from the US, Thailand, and China, as domestic production remains limited and several planned projects have yet to reach commercial scale. Rising demand for sustainable packaging and consumer goods is increasing PLA import dependency, highlighting the need for domestic PLA production.

Producing PLA from secondary feedstocks, such as food waste, agricultural residues, and woody biomass, offers both environmental and economic benefits. Projects like CIRCLE and WASTE2FUNC are demonstrating industrial-scale conversion of organic waste into lactic acid and PLA, while other initiatives explore forestry side-streams and innovative bioprocessing technologies. Although the technology is mature, scaling up requires supportive policies, incentives, and market conditions. Successfully doing so would enable Europe to reduce PLA imports and additionally reduce import shares of fossil-based imports, especially polyethylene and polypropylene.

**Ethanol** ($C_2H_5OH$) produced from maize and other feedstocks plays a key role as a fuel, beverage ingredient, and industrial intermediate, underpinning chemicals like ethylene, acetic acid, and solvents. Maize (corn) is a cornerstone feedstock for the EU, used primarily for animal feed and industrial processing, including renewable ethanol production. Domestic harvests cover most, but not all, of the EU's needs, leaving the region dependent on imports from countries like Ukraine. Rising industrial demand for ethanol and other maize-based products tightens the maize balance, increasing the EU's exposure to global price fluctuations and supply risks.

Advanced pathways using alternative feedstocks, such as food waste, lignocellulosic biomass, and $CO_2$-rich industrial off-gases, allow Europe to produce ethanol sustainably while reducing reliance on imported maize. European projects demonstrate industrial-scale conversion of residues and industrial emissions into ethanol, while an examined company illustrates efficient production from European maize and wheat, collectively advancing sustainable ethanol supply with reduced greenhouse gas emissions.

**Overarching conclusions from the case studies**

Overall, the European Union's imports of raw materials are often highly concentrated, with a large share of global supply controlled by only a few countries. Phosphorus is a relevant example where around 80% of global trade originates from just five suppliers. Similar patterns can be observed across the other case studies, highlighting the vulnerability of European industries to external dependencies. Across these sectors, it becomes clear that import reliance exposes Europe to price volatility, supply disruptions, and geopolitical risks, while limiting strategic autonomy in critical areas such as agriculture, chemicals, and packaging.

While a full transition from fossil-based to bio-based solutions cannot happen overnight, diversifying feedstocks offers strong potential to gradually reduce import dependencies. The dynamics, however, differ across cases. For phosphorus, feedstock availability is inherently regional. It is largely recovered through sewage sludge recycling, which is processed locally since transporting sludge over long distances is not practical. This means that phosphorus imports can be effectively reduced by increasing recycling efforts. For PLA, the situation is less straightforward. Biomass such as sugar beet or wheat could in principle cover much of Europe's demand, but biomass from other regions is often significantly cheaper, making imports more attractive and domestically grown feedstocks less competitive. As a result, European biomass is less frequently produced and used for PLA production. Stronger incentives and supportive policies will be needed to encourage agricultural production and to support the wider uptake of PLA production in Europe. At the same time, innovative approaches are emerging that substitute primary biomass with waste streams, for example, using food waste as a PLA feedstock. Similar to phosphorus, these resources are sourced and processed regionally. Although still at piloting and small-scale stages, such approaches hold promising potential to reduce import dependency in the future.

For renewable ethanol, Europe already demonstrates large-scale reliance on domestic produced feedstocks. In 2023, ePURE members and other European producers produced 6.4 billion litres of ethanol[138], entirely from crops grown by European farmers. However, current production remains insufficient to meet demand, and imports are still high. Similar to the case of PLA, reducing import dependency of ethanol or biomass (mainly maize) to produce ethanol will require both an increase in domestic production and improved cost competitiveness, supported by targeted policies, incentives, and subsidies where necessary.

To achieve long-term resilience, a diversified mix of primary biomass and secondary feedstocks, such as agricultural residues, food waste, and wood by-products, will be essential. At the same time, resource efficiency through reduction, reuse, and recycling must remain central, as lowering overall consumption is key to reducing dependencies in a meaningful way.

Bio-based solutions have the potential of reducing Europe's import dependencies by making greater use of domestic resources such as biomass, residues, and waste streams. By substituting imported fossil-based inputs with locally available alternatives, the EU can enhance supply security, diversify value chains, and strengthen strategic resilience. Across all five case studies, it is evident that the technological capability to produce bio-based alternatives already exists, from phosphorus recycling to PLA, ethanol, methanol, and ethylene. These projects demonstrate that industrial-scale conversion of biomass and waste is feasible, efficient, and environmentally beneficial, while also creating local economic opportunities. The main opportunity lies in further establishing supportive policies, clear regulations, and robust framework conditions that allow these solutions to compete effectively with fossil-based alternatives and on the other hand to support the growth of European sources biomass that can be used for bio-based materials and products. Promising policy frameworks already exist, such as the revised Urban Waste Water Treatment Directive, which sets targets for phosphorus reuse and recycling, and the EU Single-Use Plastics Directive along with the Packaging and Packaging Waste Regulation, which provide early market signals by promoting bio-based and compostable plastics, including PLA. Establishing further framework conditions have the potential to accelerate the adoption of bio-based innovations, foster circular and low-carbon value chains, and to reduce Europe's reliance on critical imports.

[138] ePure (2024): European renewable ethanol – key figures 2023. Available at: https://www.epure.org/wp-content/uploads/2024/09/240904-DEF-PR-European-renewable-ethanol-Key-figures-2023-WEB.pdf (last accessed 09/2025)

## 4.5 Demand scenario analysis to assess potential future dependencies

This chapter aims to assess potential future foreign import dependencies for bio-based industrial sectors in the EU, under varying growth trajectories and competing biomass demands. The analysis builds on the biomass supply projections provided by the OECD-FAO agricultural outlook. In contrast to Chapter 3, this analysis narrows the focus to selected primary bio-based resources—namely starch, oil, and sugar crops—that are particularly relevant for industrial applications and well represented in the OECD-FAO database. While the scope is also narrower than the ex-post trade analyses presented in Chapters 4.1 to 4.3, it provides a complementary perspective by examining how different demand scenarios may influence the EU's reliance on foreign biomass supplies.

### 4.5.1 Four scenarios on EU demand for biomass

To quantitatively analyse potential future developments and explore these dynamics in the EU bioeconomy, four distinct exploratory demand scenarios were developed. These scenarios are not predictive but rather designed to explore a spectrum of possible futures shaped by key drivers. The analysis is exclusively focused on the demand side, with the OECD-FAO Agricultural Outlook (2024-2033) as a reference point. The core demand drivers considered are:

- Population growth
- Economic factors: GDP per capita, biomass and fossil-based product prices, technological innovation and cost-competitiveness
- Policy & Regulatory Frameworks: Presence and stringency of policy support, such as bio-based content targets or carbon pricing.
- Societal and Environmental factors: Public acceptance and consumer preferences with regards to bio-based solutions. Occurrence of disruptive events due to social or environmental events.

Scenario assumptions for these drivers were developed in an iterative process, considering existing scenario literature, further desk-research and extrapolations of observed trends. Each scenario reflects a distinct trajectory of industrial sector expansion and competing demands from food, feed, and energy sectors until 2050. To align with the scope of the OECD-FAO outlook, changes in biomass demand are then developed for the year 2033, based on the overall scenario vision for 2050. By contrasting these demand pathways with supply projections—both domestic and global—this analysis provides insights into potential mismatches and strategic considerations for future resource planning.

Scenario A: Baseline

The baseline scenario is built on projection data of the OECD-FAO agricultural outlook (2024–2033)[139]. It serves as the reference case against which the alternative scenarios can be compared to. The EU supply is calculated with the 'production'-indicator for the commodities that are part of the overarching trade analysis. These commodities include the categories 'Starches', 'Sugars' and 'Oils & fats'. For the calculation of the demand side, the OECD-FAO agricultural outlook's data of the five demand categories ('Food', 'Feed', 'Crush', 'Biofuel use' and 'Other use') for the

[139] OECD/FAO (2024), OECD-FAO Agricultural Outlook 2024-2033, OECD Publishing, Paris/FAO, Rome, https://doi.org/10.1787/4c5d2cfb-en.

included commodity categories was used. The demand categories 'Feed' and 'Crush' were summarized. The demand category 'Other use' is interpreted as 'bio-industrial' use. The effects of Scenarios B, C and D will be compared to this baseline scenario regarding their impact on the gap between production and consumption including imports and exports.

The OECD-FAO Agricultural Outlook provides a well-established database, making its baseline scenario a robust foundation for analysing the three alternative scenarios. Since the Outlook includes data projections up to the year 2033, the quantitative scenario analysis is aligned with this timeframe, focusing on the initial phase of the broader trajectories leading up to 2050.

**Key demand drivers**: historical trends and established policies

**Influencing Factors & Core assumptions**: continuation of current OECD-FAO projection trends, no disruptive technological or policy changes

Scenario B: High-Tech Development – 'Innovation Era in Biotech'

By 2050, biotechnological innovation has reshaped industrial production systems. Distributed biorefineries are established across arid and coastal regions, utilizing biomass from diverse sources—including agricultural and forestry residues, municipal waste, industrial emissions, and marine algae.[140] Concurrently, AI-guided enzyme design enables the conversion of lignocellulosic residues into carbon-negative materials, including advanced textiles. Economic competitiveness with fossil-based processes is achieved through technological efficiency rather than fiscal intervention.

Advances in synthetic biology—such as lignin valorisation and C1-gas fermentation—combined with AI-optimized catalyst design, significantly reduce bioprocessing costs[141]. Biomass derived from agricultural and forestry residues, municipal solid waste, industrial flue gases, and marine algae constitutes a substantial share of industrial feedstocks.

Regulatory frameworks evolve to expedite the deployment of genetically modified microorganisms and other novel biotechnologies. Urban biomanufacturing, including vertical farming and precision fermentation, facilitates the decoupling of biomass production from traditional rural land use. As renewable energy sources (solar and wind) dominate the energy sector, the cultivation of energy crops declines; biomass is increasingly reserved for high-value material and chemical applications. Simultaneously, cellular agriculture and synthetic protein technologies displace conventional meat production, contributing to reduced land use and greenhouse gas emissions associated with livestock farming[142].

This scenario is driven by the core assumption of accelerated technological advancement. Demand for the bio-based materials in the three commodity categories of the analysis surges in scenario B, where bio-industrial use of the commodities is expected to rise sharply. The overall demand in the 'High-Tech Development' Scenario reaches nearly 7% higher overall volume, mostly in the bio-industrial use category with a significant +70% increase. Bio-industrial demand reaches

[140] EuropaBio, Biomanufacturing: Europe's industrial future, 2025 https://www.europabio.org/wp-content/uploads/2025/02/Biomanufacturing-Europes-Industrial-Future-1.pdf; And Algae-based animal feed market outlook 2025 to 2035, Future Market Insights. Retrieved November 14, 2025, from https://www.futuremarketinsights.com/reports/algae-based-animal-feed-market
[141] Biomaterials on demand with 3D-printing. (n.d.). *World Biomarket Insights*. Retrieved November 14, 2025, from https://worldbiomarketinsights.com/biomaterials-on-demand-with-3d-printing/
[142] Kozicka, M., et al., Feeding climate and biodiversity goals with novel plant-based meat and milk alternatives. Nature Communications, 14(1), 5316, 2023 https://doi.org/10.1038/s41467-023-40899-2

nearly 70 million tons in 2033, up from ca. 43 million tons in 2023. This results in the rapid growth of demand in 2033, surpassing EU production by almost 8%.

**Key demand drivers**: Rapid technological innovation leading to a cost reduction in bioprocessing

**Influencing Factors & Core assumptions**: Breakthroughs in biotechnology (e.g. fermentation, AI-guided designs, GMOs) significantly lower production costs. High public acceptance of novel biotechnologies as a sustainable solution. Regulatory frameworks adapt to fully facilitate innovation.

Scenario C: Policy-Driven Mandate – 'The political shift to bio-based'

By 2050, bio-based materials have become central to industrial strategy, catalysed by a binding Global Plastic Treaty mandating 50% bio-content by 2045. Public policy and consumer sentiment converge to accelerate the transition, with bio-content labelling becoming standard practice. Regulatory instruments—such as fossil carbon taxes (e.g., $150/ton), sector-wide bio-content quotas, and targeted subsidies[143]—drive competitiveness of bio-based alternatives. Brazilian sugarcane ethanol undercuts crude oil, while trade blocs (e.g., EU, Mercosur)[144] form around certified biomass. In regions where renewable electrification lags, bio-based fuels substitute fossil inputs. Tensions emerge over resource allocation, such as palm oil use in Indonesia for bio lubricants versus food, highlighting the food-versus-industry debate.

The shift induces a sharp increase in EU demand for biomaterials and biofuels, outpacing domestic production capacity. Biomaterials alone nearly double their share of EU consumption, while biofuels add further pressure. The resulting supply-demand gap could exceed 11% of total EU demand, equivalent to 63 million tons—comparable to projected import volumes for 2033. Maintaining current import levels would necessitate a drastic reduction in exports, or alternatively a reduction of biomass demand in sectors like energy, transport or feed; otherwise, import volumes must rise significantly to meet internal demand. This underscores the strategic importance of international biomass trade and domestic capacity expansion under the bio-based policy regime.

The dominant driver of Scenario C is the assumption of a stringent, binding policy intervention. In this scenario the demand for biomaterials grows rapidly and reaches nearly double the share of EU production for this demand category by 2033. As biofuels also gain in significance (+30%), this category adds a higher gap to the EU production. The total gap between the domestic supply and the demand of the EU could amount to more than 11% of the total demand or 63 million tons. This is nearly the same amount as the total projected imports in 2033, meaning that imports could only stay at that level if exports are reduced to minimal amounts, or if alternatively, biomass use in sectors like energy, transport or feed are reduced. Otherwise, imports would need to rise significantly to meet EU demand in 2033.

**Key demand drivers**: stringent regulation to facilitate upscaling of the bioeconomy, e.g. via bio-based content targets, fossil carbon taxes or removal of fossil subsidies.

[143] vom Berg et al. 2025; vom Berg, C., Carus, M., Harrandt, J., Policy Proposals for Facilitating the Transition to Renewable Carbon, Renewable Carbon Initiative, 2025 Available at: https://renewable-carbon.eu/publications/product/rci-policy-proposals-for-facilitating-the-transition-to-renewable-carbon-pdf/

[144] Real Instituto Elcano, EU-MERCOSUR: A platform for a new era of transatlantic and intra-regional Latin American integration, 2025, Available at: https://www.realinstitutoelcano.org/en/analyses/eu-mercosur-a-platform-for-a-new-era-of-transatlantic-and-intra-regional-latin-american-integration/

**Influencing Factors & Core assumptions**: implementation of a mandate of bio-based content in materials. Strong political and consumer push towards bio-based alternatives. Economic competitiveness of the bioeconomy is policy-driven, not technology-driven.

Scenario D: Crisis & Retreat – 'Constrained Biomass Pathways'

By 2050, escalating climate impacts—such as prolonged mega-droughts[145], geopolitical tensions over agricultural inputs (e.g., a US-China fertilizer conflict)[146], and emergent crop pathogens[147]—severely disrupt global biomass availability. Grain yields collapse, and wheat exports cease. Governments respond with emergency biomass allocation policies prioritizing food, followed by feed and essential energy. Bio-refineries are decommissioned as feedstocks are redirected to food systems. Public perception turns against bio-based products, associating them with scarcity and hunger. Sustainability targets are abandoned; fossil fuel infrastructure is reactivated to ensure energy security.

The cascading crises lead to a breakdown in international trade and a retreat into national resource hoarding[148]. R&D in bio-based technologies stalls, and only low-tech, resilient biomass applications—such as timber for construction—persist. The collapse of bio-industrial infrastructure marks a reversal of previous bioeconomy progress. This scenario highlights the vulnerability of biomass-dependent systems under compounded environmental and geopolitical stress, emphasising the need for robust contingency planning and diversified resource strategies[149].

This scenario anticipates negative impacts of disruptive environmental and geopolitical events leading to a fundamental shift in priorities. The major demand reduction in Scenario D opens possibilities for an increase in export capacities, as the rapidly declining EU demand clearly falls below EU domestic supply. Only in the 'Food' demand category demand increase, leading to more biomaterials used in this industry. Demand in 2033 for the other categories is significantly above domestic supply and trade included. Especially large capacities would free up in the 'Feed' category. Overall demand would decline to about 80% of EU production. Including the projected import trade deficit, the EU supply is around 100 million tons above demand in this pessimistic scenario. Imports could be massively reduced.

**Key demand drivers**: geopolitical instability, severe climate impacts, resource scarcity

**Influencing Factors & Core assumptions**: crises lead to supply shocks and price volatility. Public perception turns against industrial use of biomass, associated with food security risks. Policy priorisation shifts towards ensuring basic needs like food security

Overview of scenario assumptions

[145] United States Environmental Protection Agency, Climate change impacts on agriculture and food supply, Retrieved November 14, 2025, Available at: https://www.epa.gov/climateimpacts/climate-change-impacts-agriculture-and-food-supply
[146] European Parliament, EU energy security and the war in Ukraine: From sprint to marathon; European Parliament Research Service; 2023, Available at: https://www.europarl.europa.eu/RegData/etu des/BRIE/2023/739362/EPRS_BRI(2023)739362_EN.pdf
[147] Lundberg University, The impact of the pandemic and war on the state of global supply chains. Lund University, 2022, Available at: https://lup.lub.lu.se/student-papers/record/9113645/file/9113647.pdf
[148] International Monetary Fund, Energy transition and geoeconomic fragmentation. IMF, 2023, Available at: https://www.elibrary.imf.org/view/journals/066/2023/003/article-A001-en.xml
[149] Nature, Geopolitical risks and energy transition: The impact of policy uncertainty, Nature, 2024, Available at: https://www.nature.com/articles/s41599-024-03770-3

Table 11 summarises the assumptions taken for the different scenarios in percentages for the different demand categories.

**Table 11 Scenario assumptions for different demand categories**

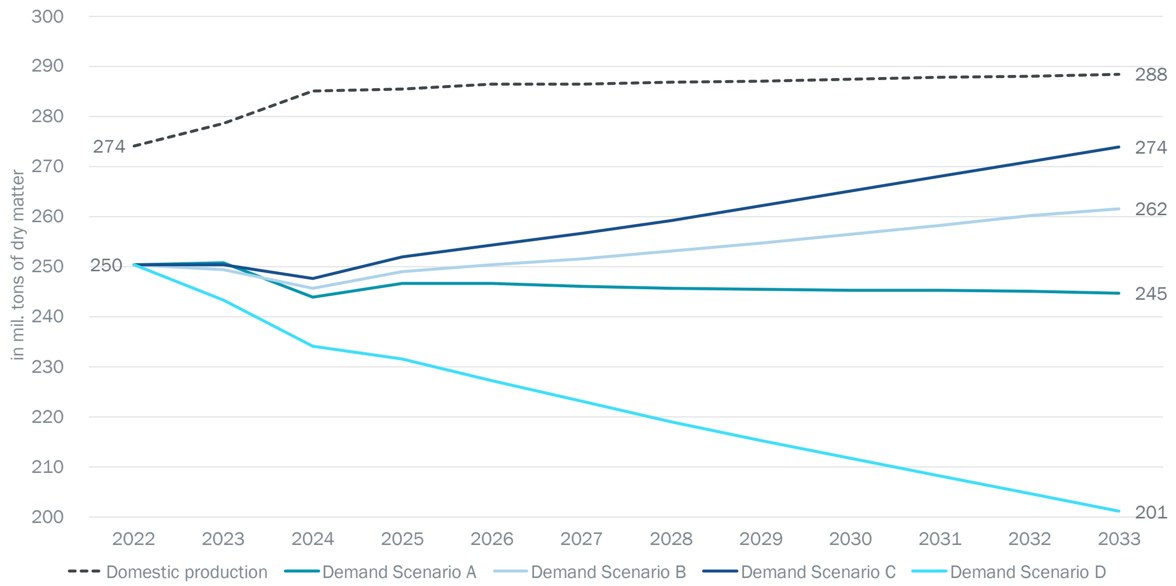
| Category | Scenario A: Baseline | Scenario B: High-Tech Catalyst | Scenario C: Policy-Driven Mandate | Scenario D: Crisis & Retreat |
|---|---|---|---|---|
| Food | +0.4% | +5% | +0% | +10% |
| Feed | -3.0% | -5% | 0% | -30% |
| Biofuels | -8.6% | +5% | +30% | -20% |
| Industrial/Materials | -3.0% | +70% | +80% | -25% |

Source: Prognos AG/Idea Consult/nova Institute, 2025, own elaboration

### 4.5.2 Contrasting future supply and demand for selected commodity groups

**Starches**

**Figure 27 Domestic production and demand scenarios of 'Starches' 2022-2033, in million tons**




Source: Prognos AG/Idea Consult/nova Institute, 2025, own elaboration, based on OECD-FAO and own calculations

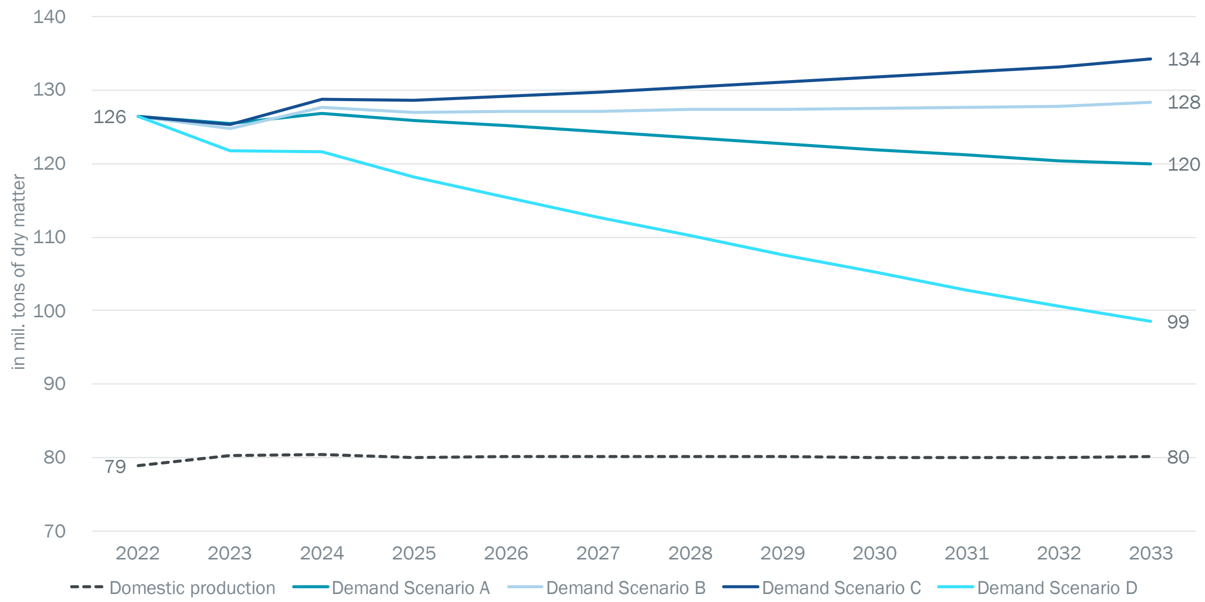
The EU production for ‘starches’ is projected to reach 288 million tons in 2033. When contrasting to the different demand scenarios, the analysis shows that EU domestic supply exceeds demand in all scenarios. The baseline scenario (A) results in a comfortable surplus of approximately

44 million tons. In scenario B (High-Tech Development) and scenario C (Policy-Driven Mandate) demand for starches is higher, reaching up to 10% growth until 2033. However, EU domestic production still remains 15- 20 million tons above demand. Even in these high-demand scenarios Europe would remain a net exporter, albeit exports would have to be lowered to meet increasing demand. In scenario D, by contrast, demand for 'starches' crashes. In 2033, the EU would consume ca. 20% less than in 2022. This would mean an overproduction of 87 million tons compared to the demand.

The global demand for 'starches' rises in the OECD projection by 1.0% p.a. until 2033. Global production does match this growth rate, while global exports are projected to increase by even a bit larger percentage, giving the EU the option to increase imports if needed without creating a significantly more competitive market. India and countries in Africa are increasing their consumption of 'Starches' especially Maize until 2033 dynamically and will struggle to meet the demand with own production. Depending on the scenario, decreasing EU exports and net exporting volume could increase competitiveness on the global market. The biggest domestic producers in 2033 will be the US and China, from which the EU could expand imports in the higher growth scenarios. The EU itself exports significant volumes of 'starches' category in 2023 and projected in 2033, which could be reduced in favour of meeting EU higher internal demand.

**Oils & fats**

Figure 28 Domestic production and demand scenarios of 'Oils & fats' 2022-2033, in million tons



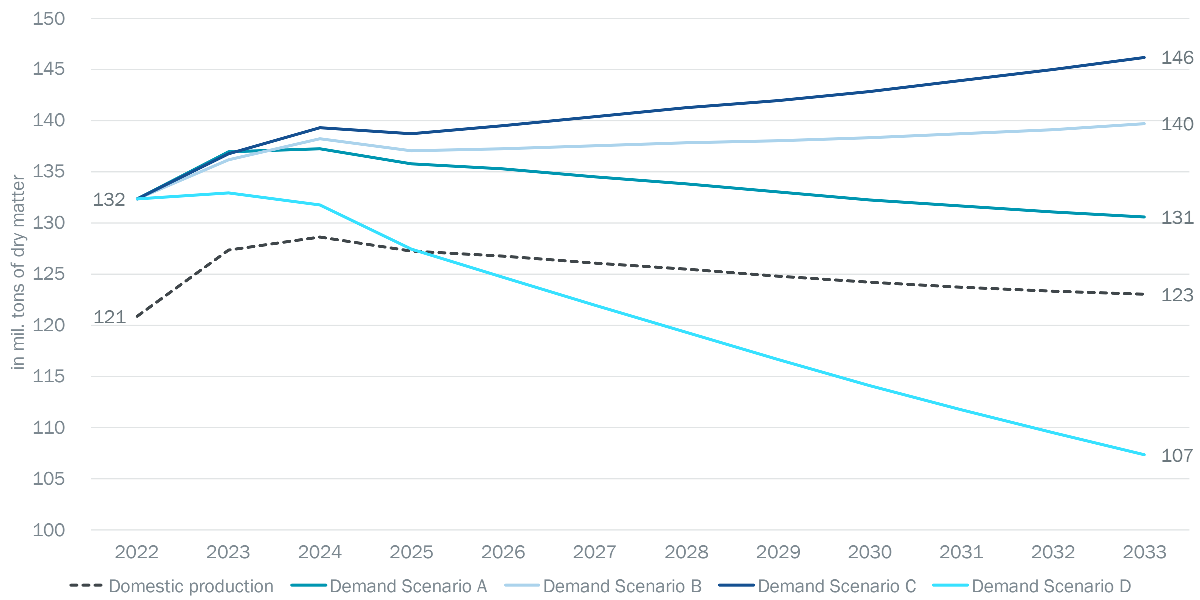

Source: Prognos AG/Idea Consult/nova Institute, 2025, own elaboration, based on OECD-FAO and own calculations

In all scenarios, demand for 'Oils & fats' significantly exceeds EU domestic supply. Although in the Baseline Scenario (Scenario A) demand would slightly decrease below 120 million tons in 2033, stagnating EU-production leaves a gap of 80 million tons. This deficit is compensated with comparatively high imports of 47 million tons with minimal exports. In Scenario B the gap between 'Oils & fats' demand and production increases even more compared to the baseline to nearly 50 million tons. The imports – already high in the baseline scenario – cannot bridge that gap completely, even if the small amount of exports is completely reduced. The pressure on the 'Oils and fats' market in Scenario C is heightened, as the gap between EU production and demand reaches nearly 55 mil tons. In Scenario D on the other hand, the gap closes to just 18 million tons, meaning the high trade deficit could be reduced. The EU would need to cover around 22% less demand with imports.

The EU will need to increase imports from the world market in the short term and if possible, increase own production in the long term. This is possible to a certain extent, according to the supply scenarios in Chapter 3, but will require targeted investment and modernization of the European agricultural sector. The global consumption of 'Oils & fats' increases by 0.8% p.a. until 2033, but exports are projected to only grow by 0.6% p.a., making the global market in the future more competitive. This situation could also increase prices for EU imports, especially as the EU will have to increase imports steadily. The biggest consumers of 'Oils & fats' apart from the EU are China, the US and Brazil. The consumption also increases relatively fast in some commodities in the category for countries Argentina, India and Indonesia as well as African countries. The largest producers are Brazil and China, with Brazil also ranking as the top exporting country. Together they amount to over a third of global production. Brazil also continues to export more than half of their 'Oils & fats' production, while China does export only a fraction of their production. The top exporting countries in 2033 after Brazil are the US and Argentina, all increasing exports above average until 2033. Increased imports by the EU due to rising demands will need to be procured from these export leaders.

**Sugars**

Figure 29 Domestic production and demand scenarios of 'Sugars' 2022-2033, in million tons




Source: Prognos AG/Idea Consult/nova Institute, 2025, own elaboration, based on OECD-FAO and own calculations

For the commodity category ‘Sugars’ the baseline scenario shows just a small gap between EU production and demand in 2033. Imports and exports remain rather low compared to the absolute demand. The demand gap for ‘Sugars’ increases rapidly until 2033 in Scenario B. With already lower exports, even a complete decrease in exports would not be able to make supply and demand match in 2033. Imports also need to increase and the trade deficit will grow. The demand for ‘Sugars’ reaches around 146 million tons in 2033 in Scenario C. This is the largest increase in this Scenario for all three commodity groups. The need for higher imports grows steadily until 2033, as the projected import development could not cover the high demand. In Scenario D the demand for ‘Sugars’ falls below the projected EU production. This leaves a significant production amount that would need to be exported in addition to the current exports.

On the global market the consumption for ‘Sugars’ also increases by roughly 1.2% p.a., with the production growth lagging behind with roughly 0.8% p.a. Even though the gap between production and consumption rises globally, global exports increase by 12.5% from 2024 to 2033. The biggest producers of ‘Sugars’ are Brazil and India, with Brazil also being the largest exporter in the commodity group. India does not export a relevant share of their production right now but is projected to increase its export volumes until 2033. The second largest exporter is Thailand, which will increase their exports by nearly 2.5% p.a. up to the year 2033. The exports of Brazil are projected to grow slower, but still roughly at the pace of the global exports. Competitors for the EU in the global import market will be Indonesia and China, the two largest importers. The consumption of Indonesia will also grow significantly by 2033, increasing the need for additional imports from the global market. African countries also increase their consumption by nearly 3% p.a. until 2033, squeezing the global gap between supply and demand.

### 4.5.3 Conclusions from the Scenario Analysis

The analysis highlights clear differences among the three commodity groups. The EU remains consistently oversupplied in starches, faces persistent and significant import dependence for oils & fats, and holds a near-balanced position in sugars that shifts between deficit and surplus depending on demand scenarios. The two high-demand scenarios B and C lead to significant import needs for oils & fats as well as for sugars, whereas demand decline (scenario D) reduces pressure on oils & fats and creates large surpluses in starches and sugars. Trade exposure amplifies these dynamics. Oils and fats carry the highest risk because global export growth is falling behind consumption, making markets more competitive. Sugars and starches remain more flexible but increasingly contested by fast-growing markets in Asia and Africa. Global competition for imports will intensify across all categories, making proactive sourcing strategies or demand management essential.

**Table 12 Overview of scenario outcomes**

| Commodity | Scenario A (Baseline) | Scenario B (High-Tech) | Scenario C (Higher Demand) | Scenario D (Demand Downshift) |
|---|---|---|---|---|
| Starches | Surplus ~44 million tons | Surplus ~20 million tons; reduction of current surplus in trade balance | Surplus ~15 million tons; balance requires lower exports / higher imports | Surplus ~87 million tons; EU overproduction to be exported |
| Oils & fats | Deficit ~40 million tons; imports ~47 million tons bridge deficit | Deficit ~50 million tons; even zero exports don't close the gap | Deficit ~55 million tons; peak stress on import reliance | Deficit ~18 million tons; reduced import needs |
| Sugars | Deficit ~8 million tons; can be met by imports | Deficit ~17 million tons; imports must rise; zeroing exports insufficient | Deficit ~23 million tons; large increase in imports necessary | Surplus ~16 million tons |

Source: Prognos AG/Idea Consult/nova Institute, 2025, own elaboration, based on OECD-FAO and own calculations

Considering the individual scenarios, the following conclusions can be drawn:

- In the baseline scenario (Scenario A) the pressure on the EU biomaterial market remains similar to 2023, as demands decrease and supply remains steady. The demand for all three biomaterial categories (Starches', 'Sugars' and 'Oils & fats') drops slowly until 2033. The import dependency for 'Oils & fats' is reduced by a small amount but remains high. 'Starches' are heavily exported and are in robust supply, which opens potential for bio-industrial use. The OECD-FAO baseline scenario is rather pessimistic in the projection of the 'Biofuel use' and 'Bio-industrial use' demand, therefore dependencies and production gaps are rather low for bio-industrial materials.
- In Scenario B the gap between demand and supply grows and especially the demand for 'Oils & fats' exceeds the projected production and imports by a significant amount. For 'Sugars' and 'Starches' the EU economy also would need to act by 2033 as the current export and import balance would mean a short supply of biomaterials. Measures could include decreasing exports e.g. for 'Starches' and increasing imports especially for 'Oils & fats'. In the long-term incentivizing higher production especially for 'Sugars' and 'Oils & fats' could also reduce pressure on the import dependencies.
- Scenario C shows an even intensified demand increase until 2033 and effects of Scenario B are highlighted. Especially 'Oils & fats' demand would need to be met in a large share by imports and the import dependency compared to the baseline would increase if no measures were taken until then. The higher demand increase for biofuels means more competition with bio-industrial use for the assessed commodity groups.
- The pessimistic Scenario D for biomaterial demand would ease pressure on the EU's import markets. However, this relief comes at a significant cost: increased reliance on fossil-based fuels and industrial materials. Such a shift would severely hinder progress toward renewable transformation and climate protection goals. Even if the EU could fully meet domestic demand for 'Starches' and 'Sugars' and only require imports of 'Oils & Fats', this would repre-

sent merely a short-term benefit. Moreover, any potential rise in exports of bio-based materials could drive up overall demand—leading to greater imports of fossil-based resources and further undermining sustainability efforts.

In essence, the lessons from this analysis advocate for a proactive approach to building a resilient bioeconomy that leverages local resources. By fostering innovation and encouraging the adoption of bio-based solutions, the EU can not only mitigate future dependencies on imports but also position itself as a leader in sustainable industrial practices. The path forward requires an inclusive strategy that balances economic, environmental, and social considerations, ensuring that the transition to a bio-based economy is both equitable and effective.

# 5 Opportunities and challenges of biotechnology and biomanufacturing in the EU

The European Union is at the forefront of the global transition towards a sustainable bioeconomy, harnessing advanced biotechnological innovations to address environmental, societal, and economic challenges. This chapter aims to analyse the opportunities and challenges related to innovation and scale-up in key biotechnological applications – encompassing sectors, final products, intermediates, and processes – identified as highly promising for the EU bioeconomy, based on stakeholder insights and emerging trends. The chapter is structured as follows. Section 5.1 provides an overview of the 16 selected high-potential applications. Section 5.2 evaluates the competitive potential of these applications and the EU's position within emerging fields. Section 5.3 explores the opportunities and challenges for innovation and scale-up within the EU. Finally, Section 5.4 analyses safety, security, and environmental sustainability.

i

**Key findings**

- **Strong growth outlook**: EU biotechnology and biomanufacturing show significant market expansion potential, with EU leadership in lignin biocomposites and hemp biorefining. While some markets (e.g., PHA) are expected to remain niche, others—such as enzymatic e-waste degradation—are linked to multi-billion-dollar opportunities by 2030. Commercial technologies (e.g., PLA) are approaching cost parity with fossil alternatives and exhibit solid growth forecasts.
- **Sustainability performance**: Most of the 16 analysed biotechnological applications reduce GHG emissions compared to fossil-based alternatives; waste-based biorefineries can even achieve carbon-negative performance. Safety is generally favorable under proper containment.
- **Innovation position**: The EU excels in downstream innovations (biomass valorization, bio-based materials) but lags in foundational platforms (CRISPR, synthetic biology, advanced metabolic engineering). Future research is projected to remain focused on downstream applications.
- **Strategic opportunities**: Global innovation opportunities in synthetic biology, modular bioprocessing, and AI-enabled technologies align with EU climate and circular economy goals. The EU demonstrates strong strategic commitment through overarching policy frameworks (e.g., Bioeconomy Strategy, Circular Economy Action Plan) and substantial public funding (e.g., Horizon Europe, CBE JU, ECBF) to support innovation and scale-up.
- **Persistent challenges**: Key barriers include scale-up and commercialization bottlenecks, financing gaps (the “double valley of death”), regulatory fragmentation and burdens at EU and national levels, offshoring risks, and uneven social acceptance—particularly for new genomic techniques (NGTs).

## 5.1 Overview of 16 high-potential applications

The selection process for the 16 high-potential biotechnological applications focused on identifying novel, emerging, and pre-commercial technologies where biological processes are central rather than conventional chemical or mechanical methods. Technologies were prioritized for their reliance on biotechnology, variety in bio-based products, reduced import dependency for feedstocks, scalability, and alignment with sustainability objectives. Specific attention was paid to applications with strong innovation potential and lower Technology Readiness Levels (TRLs). Applications were identified using authoritative EU references, sector trend reports, and databases like CORDIS[150] and the Horizon Dashboard[151], with additional focus on projects funded by the Bio-Based Industries Joint Undertaking[152] and Circular Bio-Based Europe Joint Undertaking, including flagship examples such as SWEETWOOD[153] and PEFerence[154]. Table 13 provides an overview of the assessed applications (see also Annex 5.1 for a detailed description of the selected technologies).

**Table 13 Overview of the analysed applications**

| Application | Description | TRL |
|---|---|---|
| Enzyme-catalysed $CO_2$ conversion | Enzymatic transformation of $CO_2$ into chemicals and fuels with integrated biotechnological processes | 2–5 |
| Polyethylene Furanoate (PEF) | Bio-based, recyclable polymer with improved properties, using renewable feedstocks | 6–9 |
| Polylactic Acid (PLA) | Biodegradable polymer from plant sources, focus on diversification and integrated processes | 3–9 |
| Polyhydroxyalkanoates (PHA) | Microbially produced biodegradable polymer, optimizing for waste feedstocks and process efficiency | 5–9 |
| Bio-based epoxy resins | Sustainable resins from plant inputs, with multifunctional formulations and waste valorisation | 4–9 |

[150] European Commission, 'CORDIS - EU Research Results'. Publications Office of the European Union, accessed 20 November 2025. https://cordis.europa.eu/
[151] European Commission, 'EU Funding and Tenders Portal', Directorate-General for Research and Innovation, 20 November 2025. https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-dashboard
[152] European Union, 'Circular Bio-based Industries Joint Undertaking (BBIJU)', accessed 20 November 2025, https://www.cbe.europa.eu/
[153] Sweetwood, 'Production and deploying of high purity lignin and affordable platform chemicals through wood-based sugars', Horizon 2020 Project, 30 April 2018, accessed 20 November 2025. https://cordis.europa.eu/project/id/792061/reporting
[154] PEFerence, 'From bio-based feedstocks via di-acids to multiple advanced bio-based materials with a preference for polyethylene furanoate, Horizon 2020, 8 May 2017, accessed 20 November 2025. https://cordis.europa.eu/project/id/744409/reporting

| | | |
|---|---|---|
| Lignin biocomposites reinforced with plant fibres | Composites of lignin and plant fibres, advancing enzyme modification and nanotechnology | 4–7 |
| Mycelium leather | Fungal-based, sustainable leather alternative, innovations in strain and substrate engineering | 6–7 |
| Pretreatment and fractionation of hardwood residues | Efficient separation of woody biomass components using advanced biotechnological methods | 4–8 |
| Lignin-based hard carbon anodes | Battery electrodes made from biomass-derived lignin, focusing on material engineering | 6–7 |
| Enzymatic e-waste degradation | Enzyme-based breakdown of polymers in electronic waste, developing multi-enzyme solutions | 2–6 |
| Hemp biorefining | Complete valorisation of hemp into diverse products using genetic and processing innovations | 6–7 |
| Enzymatic bioremediation | Process using enzymes to degrade pollutants, with a focus on new enzyme discovery and stabilization | 4–7 |
| Microbial biofertilizers | Living microbes to enhance plant growth and nutrient uptake, deploying multi-strain blends and optimized interaction | 1–6 |
| Waste-based microbial-driven biorefinery | Circular integrated systems using microbes to convert waste streams to valuable products | 4–5 |
| Metabolic engineering for high-value chemicals | Advanced metabolic engineering microbes for chemical production using genome editing and scalable processes | 5–7 |
| Plant breeding of non-food crops using CRISPR | Genome editing for improved traits in non-food crops, focusing on DNA-free and precise methods | 3–4 |

Source: Prognos AG/Idea Consult/nova Institute, 2025, own elaboration based on CAGR dataset (see Annex 5.1 and accompanying list of references).

## 5.2 Analysis of competitiveness and potential of selected high-promising biotechnological applications

This section aims to assess the competitiveness and growth potential of 16 selected biotechnological applications through an integrated approach that combines quantitative and qualitative data from a broad range of credible sources. Market evaluations draw on market intelligence and industry reports and comprehensive datasets provided by the nova-Institute to estimate current and projected market sizes, compound annual growth rates (CAGR), and market entry potential, applying proxy indicators where direct data is unavailable. Innovation performance is analysed using patent data from PATSTAT (2010-2025), publication data from OpenAlex, complemented by LLM-driven classification and filtering to ensure relevance. Funding data and company insights are derived from Crunchbase and validated through automated and manual validation checks to ensure accuracy and timeliness. The data sources and research processes are described in detail in Annex 5.2 to provide full methodological transparency and traceability.

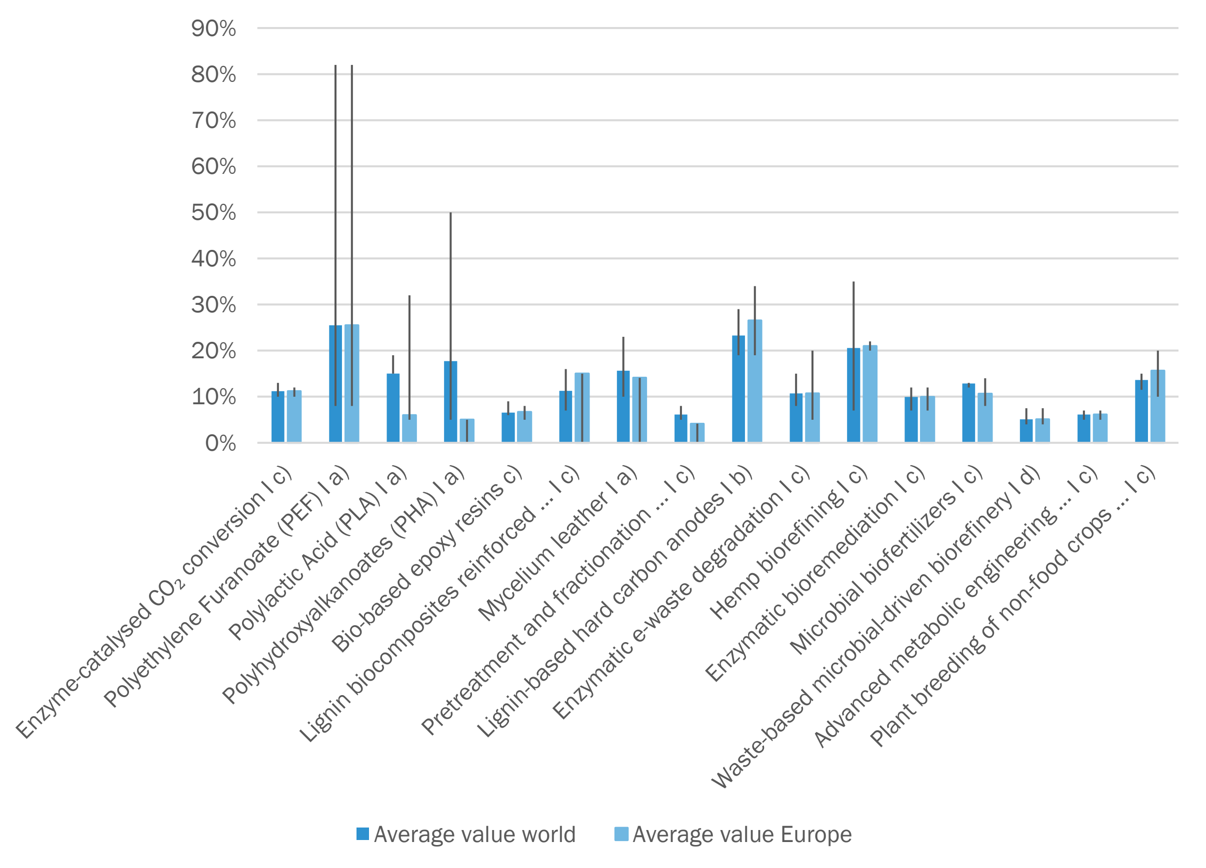
### 5.2.1 Compound Annual Growth Rate (CAGR) and projected market value for targeted applications

Figure 30 (and Annexes 5.3 and 5.4) provide the compound annual growth rates (CAGR) for each application or related markets with a focus on projected trends. The analysis of the CAGR for the 16 targeted applications indicates a strong overall growth trajectory. Across nearly all applications, projected global and European CAGRs lie significantly above general GDP growth and the expected expansion of traditional industrial sectors such as chemicals and plastics (≈3% CAGR). Reported growth rates range from modest, yet still attractive levels of 4–6% to outstanding growth rates above 25%. The lowest projected growth is observed for pretreatment and fractionation of hardwood residues, with a CAGR of around 6% globally and 4% in Europe. At the other end of the spectrum, polyethylene furanoate (PEF) exhibits the highest potential, with a global CAGR of 26%, but an exceptionally wide range of reported estimates (8–82%). Polyhydroxyalkanoates (PHA) also display high but highly uncertain growth dynamics, with reported global CAGRs between 5% and 50%, highlighting both the promise and volatility of this market. For PHA, only a single data point was available (5%) for Europe, because of this, no range is reported.

For most applications, global and European CAGRs are closely aligned, indicating that Europe is expected to broadly mirror worldwide trends. However, Europe-specific data were overall very scarce, and no meaningful European datapoints were available for some applications. In these cases, global data was used as a proxy, specifically for the applications enzyme-catalysed $CO_2$ conversion, PEF, enzymatic bioremediation, waste-based microbial-driven biorefinery and advanced metabolic engineering for microbial production of high-value chemicals.

For the technologies in which Europe-specific data was available, three applications stand out where European growth outpaces the global average: lignin biocomposites reinforced with plant fibres, lignin-based hard carbon anodes, and hemp biorefining. In particular, lignin-based hard carbon anodes are projected to grow at 27% annually in Europe – four percentage points above the global average of 23% – underscoring their strategic relevance for European energy and battery value chains.

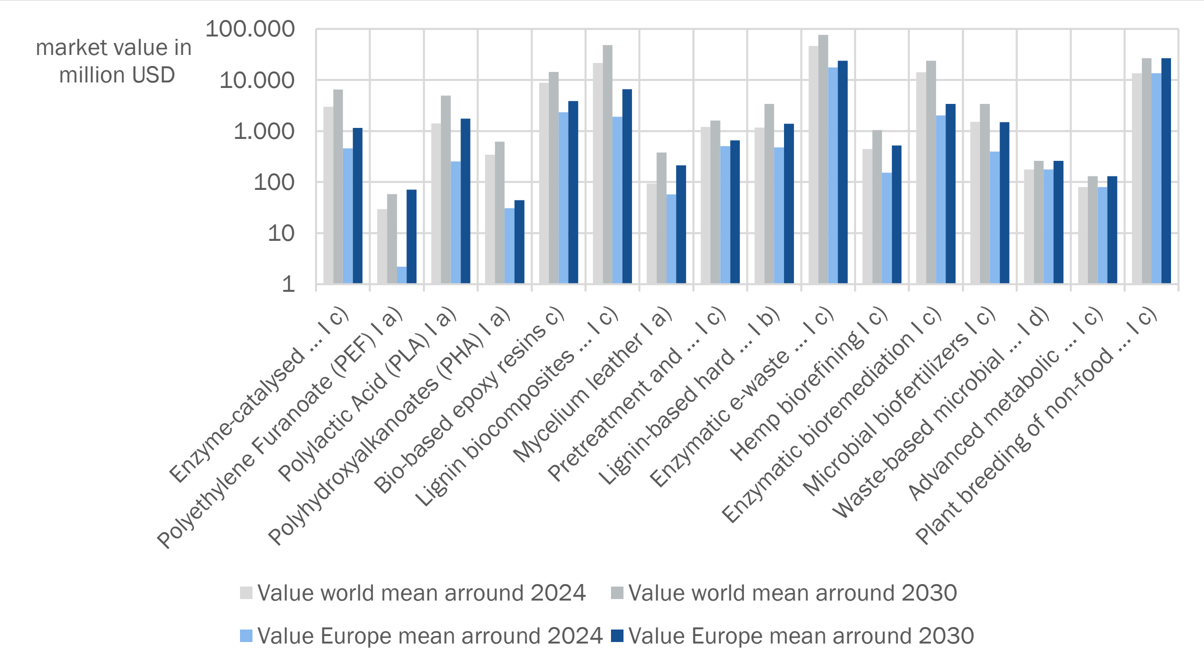
**Figure 30 Potential CAGR for targeted applications* for the timeframe 2024/2025 -2030**




*The CAGR potential is derived using different estimation approaches, depending on the type and quality of information available. For each of the 16 applications, the respective estimation method is indicated by the letters a–c in the heading. These correspond to the following:
a) Sufficient information was available to estimate the CAGR potential specifically for the innovative solution.
b) The CAGR potential is estimated based on the growth rates of the broader technology to which the innovative solution is applied. This represents the market potential that the innovative solution may capture, provided it successfully substitutes conventional alternatives.
c) Due to limited information, the estimated CAGR potential refers to the broader market that the bio-based technology can potentially address.
A detailed explanation is provided in the Annex.
Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on CAGR dataset (see Annexes 5.3 and 5.4 and accompanying list of references).

Figure 31 presents the average global and European market values for 2024 and 2030, while Annex 5.3 provides the corresponding ranges. The projections indicate that the targeted applications offer significant economic opportunities. Some markets remain relatively small in absolute terms – for example, the European PHA market is projected at just USD 44 million in 2029, although global estimates for PHA vary widely, ranging from USD 130 million to USD 1.1 billion in 2030. By contrast, other applications are linked to very large, multi-billion-dollar markets. Enzymatic e-waste degradation, if successfully deployed at scale, could access the European e-waste management market, which is projected to reach USD 38.8 billion by 2030. Similarly, the European bioremediation market is expected to grow to USD 8.7 billion by 2030. As with the CAGR analysis, Europe-specific market values were unavailable for the applications waste-based microbial-driven biorefinery, advanced metabolic engineering for microbial production of high-value chemicals and plant breeding of non-food crops using CRISPR. In these cases, the global market values were used as a proxy. European data availability was overall more limited for all applications. Further research is

**Figure 31 Market values* for targeted applications for 2024/2025 -2030**




*Market value estimates follow the same underlying logic as the estimations for CAGR potential (see figure 30). All values are derived from secondary sources. However, in some cases, different sources were used for CAGR calculations and market value projections when these provided more specific information. As a result, the average CAGR that could be inferred from mean market value projections may differ from the CAGR estimates shown in figure 30. Timeframes differ slightly across sources; detailed periods can be found in the complete dataset in the Annex.

The following estimation procedures were applied:

a) Market values directly reflect the innovative solution when sufficient information was available.

b) Market values are based on the broader application/technology area in which the innovative solution is used. These values represent the potential market the bio-based solution could capture if it proves technologically and economically competitive with conventional alternatives.

c) In cases with limited information, market values refer to a broader market that the bio-based technology could address. If a single market proxy was used, this is indicated in brackets.

d) Where no growth data existed for the general application market, a relevant subset of the market was used as the basis.

Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on market values dataset (see Annexes 5.3 and 5.4 and accompanying list of references).

necessary regarding possible reasons for this limited data availability at European level. Overall, these figures illustrate that even capturing a small share of the overall markets would represent substantial commercial potential.

In summary, the analysis shows that all 16 applications demonstrate attractive growth rates, with several combining high CAGR with access to very large markets. While the most dynamic opportunities are associated with PEF, PHA, and lignin-based hard carbon anodes, the sheer market size of applications linked to waste management and remediation points to strong investment opportunities. Nevertheless, growth ranges vary widely for some applications, underscoring the need for cautious interpretation and further assessment at the level of specific niches and competitive environments.

### 5.2.2 Market entry potential[155]

The investigated applications span a wide range of technology readiness levels. A clear pattern emerges where operational cost competitiveness correlates strongly with technology maturity and especially scale (see Table 14 and Annex 5.5). Commercial technologies like PLA and bio-based ECH already demonstrate closer costs to fossil alternatives[156] [157], with established markets and good growth forecasts. Technologies such as polyethylene furanoate (PEF)[158] and lignin-based hard carbon anodes are now transitioning to commercial production, often offering superior performance (e.g., PEF's barrier properties). Early-stage applications like enzyme-catalysed $CO_2$ conversion currently carry a significant cost premium (1.5-4x fossil alternatives) but hold future potential as carbon pricing evolves. Integration with waste feedstocks consistently improves operational economics. Multi-product strategies, particularly evident in hemp biorefining and waste-based biorefineries, enhance overall operational viability through revenue diversification.

Operating cost analysis reveals three distinct investment categories. Operationally mature applications (PLA, ECH (epoxy resins)) demonstrate established pathways to cost competitiveness through scale and process optimisation. Scaling applications (PEF, hemp biorefining and most of the applications in this study) show possible operational improvement trajectories requiring investment in scale-up infrastructure[159] [160]. Premium-positioned applications (PHAs, mycelium leather) require sustained operational cost reduction or continued premium market positioning[161] [162].

Market entry potential remains high across most applications, supported by regulatory frameworks that increasingly favour bio-based alternatives despite current operational cost premiums. Projected growth rates of 5-24% CAGR across applications suggest market acceptance of moderate cost premiums for sustainability benefits.

Major Takeaways

[155] While significant effort has been undertaken to ensure robustness, this analysis is inherently complex and based on variables with considerable uncertainty. Consequently, its predictive reliability should be viewed as indicative rather than definitive. The findings per application can, in some cases, cover a wide range of end products and production routes, meaning the commercial viability for any specific product may be higher or lower than the general analysis suggests.

[156] Marcon Bressanin, J., Lobo de Mesquita Sampaio, I., Coelho Geraldo, V., Colling Klein, B., Ferreira Chagas, M., Bonomi, A., Maciel Filho, R., & Cavalett, O., '*Techno-economic and environmental assessment of polylactic acid production integrated with the sugarcane value chain*'. Sustainable Production and Consumption, Volume 34, 2022. https://doi.org/10.1016/j.spc.2022.09.009.

[157] Almena, A., Martín, M., 'Techno-economic analysis of the production of epichlorhydrin from glycerol', Computer Aided Chemical Engineering, Elsevier, Volume 38, 2016, https://doi.org/10.1016/B978-0-444-63428-3.50013-8.

[158] Geiselman, Bruce, 'Tapping into PEF's potential', Recycling Today, March 11, 2024, accessed 20 November 2025. https://www.recyclingtoday.com/article/tapping-into-pefs-potential-avantium/

[159] Geiselman, Bruce, 'Tapping into PEF's potential', Recycling Today, March 11, 2024, accessed 20 November 2025. https://www.recyclingtoday.com/article/tapping-into-pefs-potential-avantium/

[160] Michels, M., Brinkmann, A. & Mußhoff, O. Economic, ecological and social perspectives of industrial hemp cultivation in Germany: A qualitative analysis. Journal of Environmental Management, Volume 389, 2025, https://doi.org/10.1016/j.jenvman.2025.126117

[161] Faunalytics, 'Fungi Fashion: The Sustainable Appeal of Mycelium Leather', Faunalytics, 21 November 2023, accessed 20 November 2025. https://faunalytics.org/fungi-fashion-the-sustainable-appeal-of-mycelium-leather/

[162] Bolla, M., Pettinato, M., Francesco Ferrari, P., Fabiano & B., Perego, P., *Polyhydroxyalkanoates production from laboratory to industrial scale: A review.* International Journal of Biological Macromolecules, Volume 310, Part 3, 2025, https://doi.org/10.1016/j.ijbiomac.2025.143255.

- Operating cost parity emerges through scale and integration: Bio-based applications in this study currently carry estimated operational cost premiums of 0.75-6 times the operating cost of conventional alternatives with waste-integrated applications and scale-optimised processes more frequently demonstrating paths to fossil cost parity and with some applications already achieving competitive operational economics.
- Process complexity drives operational premiums: Applications requiring sophisticated processing (PHAs, mycelium leather) face persistent operational cost challenges, whilst simpler bioprocesses approach fossil cost parity through operational optimisation.
- Multi-product strategies enhance operational viability: Integrated biorefineries and multi-output applications (hemp, lignin) demonstrate superior operational economics through diversified revenue streams and complete feedstock utilisation.

**Table 14 Overview of market entry potential of the analysed applications**

| Application | TRL | Cost status (current) | Market potential (expected) |
|---|---|---|---|
| Enzyme-catalysed $CO_2$ conversion | 2–5 | Higher Cost | Good-High Potential |
| Polyethylene Furanoate (PEF) | 6–9 | Higher Cost | High Potential |
| Polylactic Acid (PLA) | 3–9 | More expensive than fossil-based polymers | Good Potential |
| Polyhydroxyalkanoates (PHA) | 5–9 | Higher Cost | Good Potential |
| Bio-based epoxy resins | 4–9 | Similar cost to fossil based | High Potential |
| Lignin biocomposites reinforced with plant fibres | 4-7 | Approaching cost competitiveness or lower cost | High Potential |
| Mycelium leather | 6–7 | Higher cost | Moderate Potential |
| Pretreatment and fractionation of hardwood residues | 4–8 | Cost Unclear | Potential not fully established |

| | | | |
|---|---|---|---|
| Lignin-based hard carbon anodes | 6–7 | Cost Competitive | High Potential |
| Enzymatic e-waste degradation | 2–6 | Higher Cost | Limited Potential |
| Hemp biorefining | 6–7 | Some products are cost competitive or target new niche markets | High Potential |
| Enzymatic bioremediation | 4–7 | Potential to be cost Competitive | High Potential |
| Microbial biofertilizers | 1–6 | Potential to be Cost Competitive | High Potential |
| Waste-based microbial-driven biorefinery | 4–5 | Some (selected) products may be cost competitive with fossil-based equivalents e.g. medium chain fatty acids | Good Potential |
| Metabolic engineering for high-value chemicals | 5–7 | Competitive for some high value (e.g. flavours and fragrances) products only | Moderate Potential |
| Plant breeding of non-food crops using CRISPR | 3–4 | Competitive – is the technique of choice | High Potential |

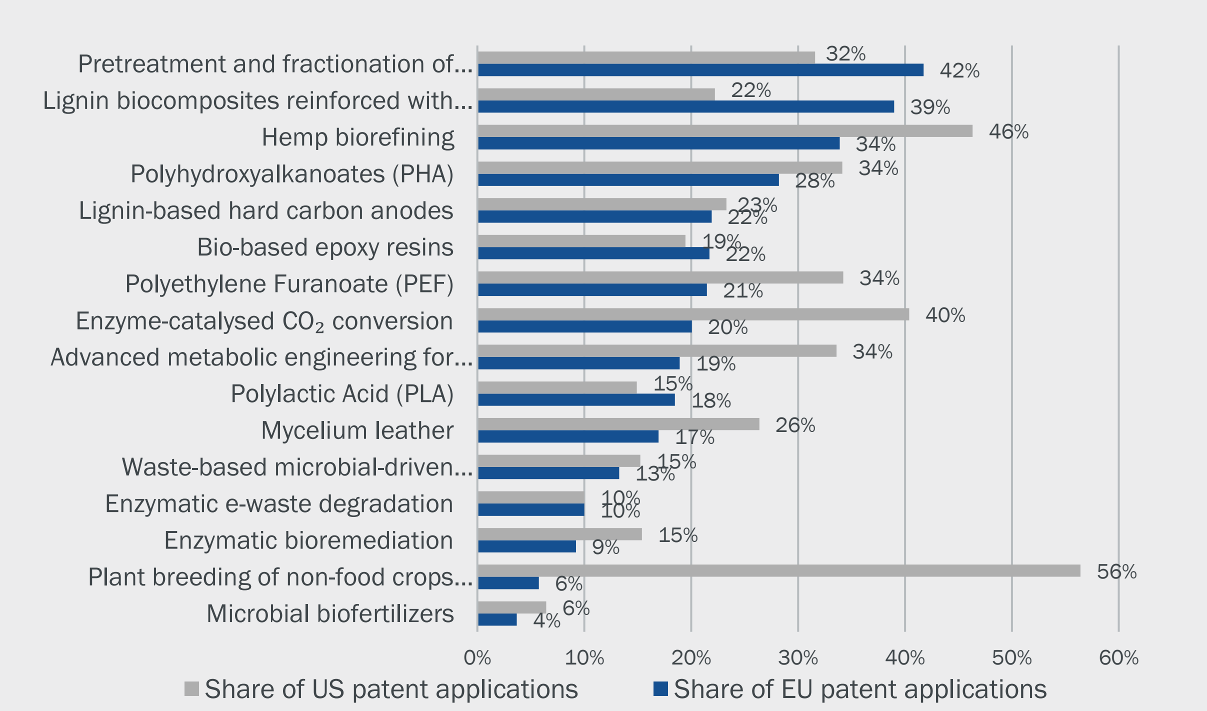
Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on industry reports and nova-Institute data. Full references to the consulted documents and reports are provided in Annex 5.5.

### 5.2.3 Innovation activity and funding

An analysis of the current patent activity and company landscape in the European Union shows that the region has established a strong and visible position within global bioeconomy innovation, as indicated in Figure 32. The European Union demonstrates a differentiated competitive profile across the 16 bioeconomy applications analysed. Patent data since 2010 reveals that Europe's strongest positions lie in technologies linked to biomass valorisation and advanced materials. Applications such as pretreatment and fractionation of hardwood residues, lignin biocomposites reinforced with plant fibres, and hemp biorefining show the highest EU patent shares, with Europe accounting for over 40% of global filings in some cases. These areas underscore the EU's leadership in process and material innovations that support a circular bioeconomy. In contrast, the United States dominates enabling biotechnologies such as CRISPR-based plant breeding, enzyme-catalysed $CO_2$ conversion, and advanced metabolic engineering, where its patent share significantly exceeds that of the EU. This suggests that while Europe excels in downstream applications and material integration, the US maintains an edge in foundational biotech platforms, through these figures should be interpreted with caution given the limitations of patent data as an innovation metric, particularly when comparing across technological fields and jurisdictions. For example, patents related to CRISPR-based plant breeding of non-food crops represent 6% of filings in the EU versus 56% in the US. This discrepancy does not necessarily reflect fewer developments in the EU but rather differences in intellectual property regimes. In the EU, basic biological principles cannot be patented and are instead protected through the Plant Variety Rights (PVR) system, whereas such patents are permissible in the US.

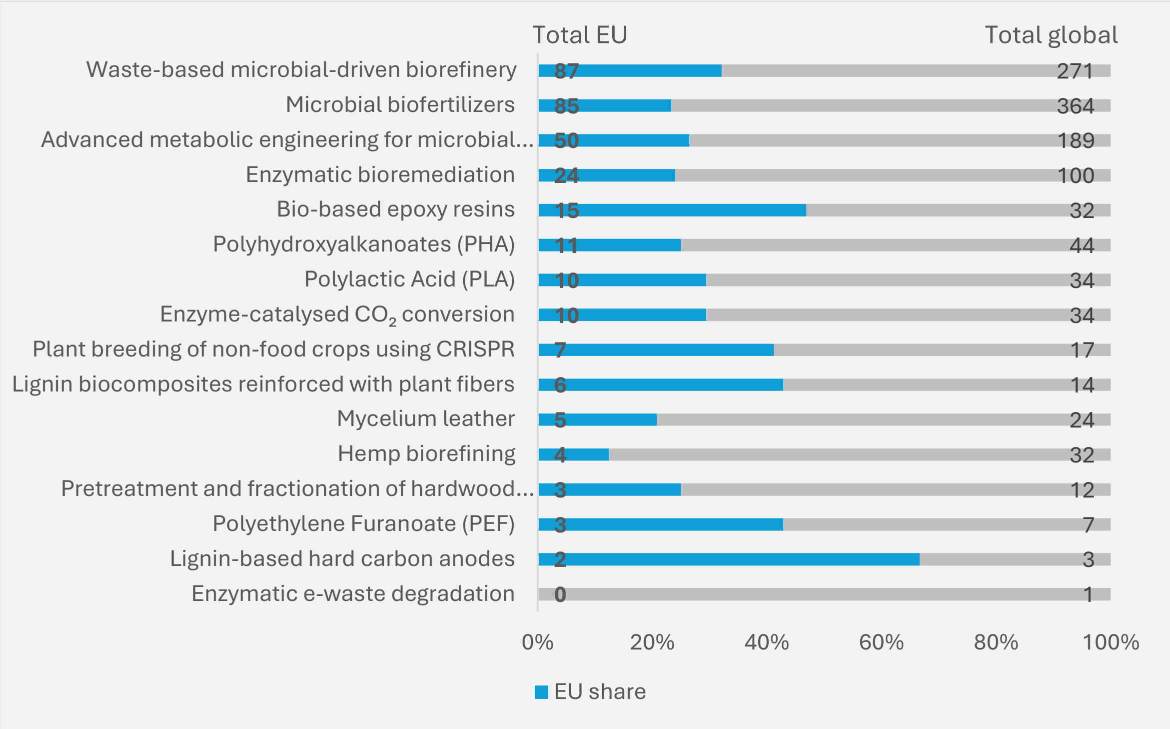
From an innovation ecosystem perspective, as shown in Figure 33, company activity is most pronounced in microbial biofertilizers, waste-based microbial-driven biorefineries, and advanced metabolic engineering, which together host the largest number of firms globally. The EU has a strong presence in these applications, with the highest concentration of companies found in waste-based microbial-driven biorefinery, microbial biofertilizers, advanced metabolic engineering for microbial production of high-value chemicals and bio-based epoxy resins. This breadth of participation suggests a healthy pipeline of SMEs and scale-ups alongside established corporates, although some early-stage technologies – such as enzymatic e-waste degradation and mycelium leather – remain underrepresented in Europe.

**Figure 32 Share of EU and US patent applications (2010-2025)**




Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on PATSTAT data (European Patent Office, June 2025).

**Figure 33 Global and EU company count (2007-2025)**

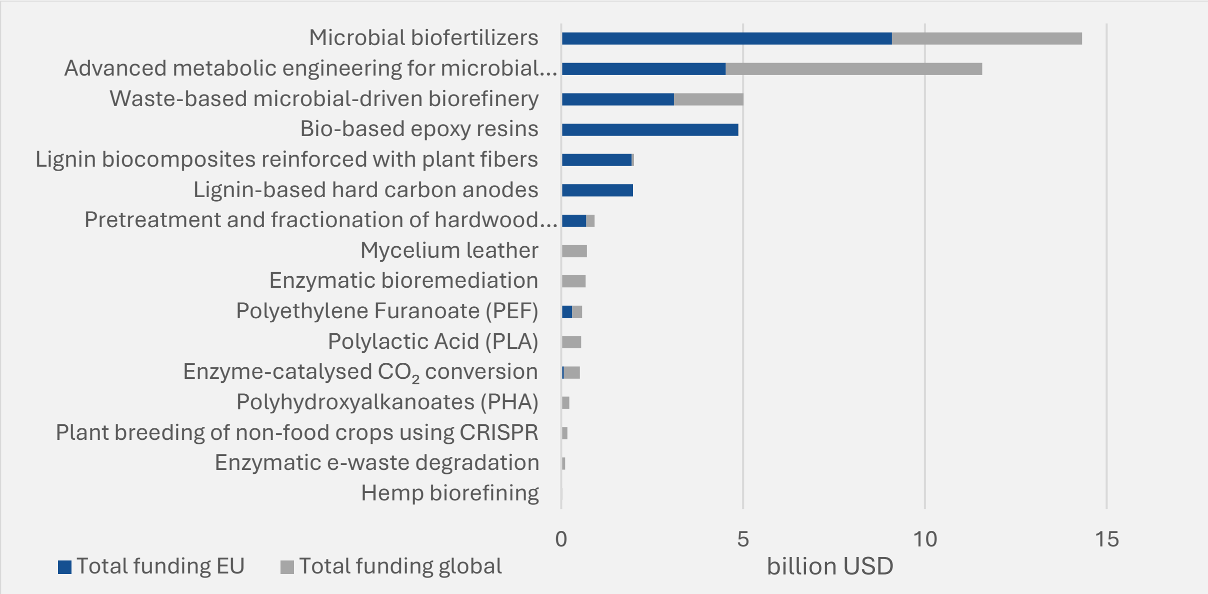



Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on Crunchbase data (accessed May 2025).

Figure 33 summarizes private investment and venture capital flows into innovative bio-based technologies and startups, covering early-stage financing, growth capital, and, in some cases, later-stage scale-up rounds. The analysis is based on funding data sourced from **Crunchbase**, a leading platform for tracking global investment activity. The EU attracts substantial funding in several key areas, particularly microbial biofertilizers, bio-based epoxy resins, and waste-based microbial-driven biorefineries (see Figure 34). These technologies not only receive the highest absolute funding within Europe but also represent a large share of global investment in their respective domains. Notably, lignin-based hard carbon anodes and lignin biocomposites are almost exclusively financed within the EU, highlighting Europe's strategic focus on lignin-derived materials. Advanced metabolic engineering for microbial production of high-value chemicals also receives strong funding, underlining Europe's prominent role in supporting biotechnological innovation.

The current funding landscape reveals a strong position for European companies which collectively attract nearly twice the total investment of their US counterparts. Notably, German companies alone secure more funding than the entire cohort of US companies. However, the EU's funding leadership is partly driven by large-scale investments from a few industrial champions—most prominently Bayer and Evonik Industries, which together account for over USD 13 billion in the dataset. While Bayer does not yet have a finalized product, it actively conducts research and invests in microbial biofertilizers, reflecting a strategic commitment to long-term innovation in the technology. Evonik Industries focuses on advancing precision bio-solutions, accelerating the energy transition, and enabling a circular economy, with specific expertise in metabolic and microbial engineering, strain optimization, fermentation scale-up, downstream processing, and the development of strengthened and modified epoxy resins using copolymers, elastomers, and nanoparticles. It should be noted that the funding amounts represent total company funding; for large, diversified corporations the share attributable to a specific technology as well as the specific company location the investment refers to is therefore often unclear. The concentration of such large funding amounts in a small number of major players highlights both the scale of investment in European industry leaders and the potential influence these companies may have in shaping technology development trajectories in the sector. While this concentration demonstrates the financial commitment of major players, it also introduces dependency risks should corporate strategies shift.

**Figure 34 Funding EU and global (2007-2025)**




Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on Crunchbase data (accessed May 2025).

### 5.2.4 Future potential

To assess the future development potential of the 16 technologies, a publication analysis was carried out using OpenAlex, an open-source scholarly database that offers comprehensive metadata on global research outputs (Annex 5.2 provides a detailed description of the methodology and the selection of publications). Table 15 presents the results of such analysis. The analysis evaluates each technology using two metrics: its current relevance (“Score now”) and its estimated relevance in eight years (“Future score”). To calculate these scores, research publications are first grouped into clusters representing sub-topics. Within each cluster, the share of high-impact publications relative to all research determines the cluster score. These scores are then weighted by the number of publications in each cluster to produce an overall technology-level score. This approach enables direct comparison across technologies and highlights expected changes in relevance over time. To capture both long-term trends and recent momentum, the analysis considers two-time windows: all publications since 2010 for historical perspective and publications since 2021 to identify emerging acceleration.

**Table 15 Future scores weighed by number of published papers (2010–2025 and 2021–2025)**

| Technology | Sum score now | Sum future score 8 years | Sum score now (2021) | Sum score 8 years (2021) |
|---|---|---|---|---|
| Advanced metabolic engineering for microbial production of high-value chemicals | 0.19 | 0.16 | 0.17 | 0.19 |
| Bio-based epoxy resins | 0.37 | 0.41 | 0.32 | 0.43 |
| Enzymatic bioremediation | 0.05 | 0.04 | 0.09 | 0.08 |
| Enzyme-catalysed $CO_2$ conversion | 0.18 | 0.17 | 0.21 | 0.28 |
| Hemp biorefining | 0.13 | 0.11 | 0.10 | 0.11 |
| Lignin biocomposites reinforced with plant fibers | 0.23 | 0.24 | 0.17 | 0.22 |
| Lignin-based hard carbon anodes | 0.28 | 0.32 | 0.26 | 0.36 |
| Microbial biofertilizers | 0.20 | 0.18 | 0.16 | 0.14 |
| Mycelium leather | 0.20 | 0.25 | 0.14 | 0.23 |
| Plant breeding of non-food crops using CRISPR | 0.09 | 0.06 | 0.08 | 0.06 |
| Polyethylene Furanoate (PEF) | 0.33 | 0.33 | 0.24 | 0.29 |
| Polyhydroxyalkanoates (PHA) | 0.15 | 0.15 | 0.14 | 0.20 |
| Polylactic Acid (PLA) | 0.24 | 0.24 | 0.22 | 0.29 |
| Pretreatment and fractionation of hardwood residues | 0.29 | 0.32 | 0.19 | 0.24 |
| Waste-based microbial-driven biorefinery | 0.03 | 0.02 | 0.00 | 0.00 |

Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on OpenAlex data and Prognos-INSIDE-Model (accessed May 2025).

According to the all-papers analysis, bio-based epoxy resins dominate the current landscape with a score of 0.37 and are projected to rise to 0.41, reinforcing their leadership. PEF remains consistently strong at 0.33, indicating stable long-term relevance. Pretreatment of hardwood residues (0.29) and lignin-based hard carbon anodes (0.28) follow closely, both expected to reach 0.32, signalling solid near- to mid-term potential. PLA completes the current top five at 0.24, while mycelium leather, though not yet a leader, is forecast to enter the future top tier at 0.25. Overall, the outlook highlights epoxy resins as clear frontrunners, sustained strength for PEF, and growing momentum for lignin-derived materials and innovative biomaterials like mycelium leather.

In terms of overall momentum in the all-papers analysis, the strongest gains are concentrated in biomaterials and energy solutions. Mycelium leather shows the largest increase (+0.05), followed by bio-based epoxy resins and lignin-based hard carbon anodes (each +0.04), and hardwood pretreatment (+0.03). In contrast, several areas exhibit declining impact, notably advanced metabolic engineering and CRISPR for non-food crops (both −0.03), along with microbial biofertilizers (−0.02). These declines could be due to regulatory constraints in the EU, such as strict limitations on CRISPR applications.

Focusing on where recent research is accelerating the most (since 2021), recent publications reveal a sharp increase in momentum for several technologies. Bio-based epoxy resins show the strongest recent gain (+0.11), followed by lignin-based hard carbon anodes (+0.10) and mycelium leather (+0.09). Enzyme-catalysed $CO_2$ conversion (+0.07) and PLA (+0.07) also demonstrate significant acceleration. When comparing recent momentum to long-run trends, enzyme-catalysed $CO_2$ conversion stands out, shifting from slightly negative long-term growth to strong positive acceleration (+0.08), while bio-based epoxy resins and PLA each add +0.07, and PHA and lignin-based anodes gain +0.06. These patterns indicate that post-2021 research is focusing on new directions, particularly in $CO_2$ conversion technologies and bio-based polymers, signalling emerging innovation opportunities.

## 5.3 Assessment of opportunities and challenges for innovation and scaling-up in emerging biotechnological applications

The objective of this section is to assess the opportunities and challenges faced by key stakeholders across the bioeconomy ecosystem, including industry actors, research institutions, policy makers, funding bodies, and business networks, in their efforts to innovate and scale up the 16 high-potential biotechnological applications summarised in Table 14 and Annex 5.6. The assessment employed a mixed-method approach combining qualitative and quantitative data sources. Primary data were collected through semi-structured interviews, using a structured guideline, with key stakeholders to capture insights on opportunities, such as advances in innovation and scale up, competitiveness, and institutional drivers, as well as challenges including institutional barriers, and scalability constraints. The stakeholders consulted represented a diverse range of actors within the bioeconomy, including business associations and networking organizations, industry representatives from various sectors, and research and academic institutions. The findings from the interviews were systematically triangulated with evidence from EU-funded project datasets, patent analyses, and other secondary sources to strengthen validity and reliability across multiple evidence streams, as detailed in Annex 5.2.

### 5.3.1 Innovation opportunities and challenges

Table 16 (and Annex 5.6) summarizes the findings regarding innovation opportunities and challenges for each of the selected 16 biotechnological applications. Across the 16 technologies, innovation opportunities converge on three major categories. A major innovation opportunity category is feedstock diversification and circularity, with R&D focusing on waste, lignocellulosic residues, side streams and point-source $CO_2$ as inputs (e.g., waste-based microbial biorefineries; enzyme-catalysed $CO_2$ conversion; lignin-based hard carbon anodes derived from hardwood residues). By expanding the range of usable feedstocks, dependency on primary biomass is reduced while circularity and supply security are strengthened. A second category is functional materials innovation for improving material performance and sustainability, and to enable diversification of end applications. This includes, for instance, bio-based polymers (PEF, PLA, PHA) designed for recyclability and compostability, and improved barrier and mechanical properties; lignin biocomposites and lignin-based hard carbon anodes tailored via microstructure engineering; and bio-based epoxies leveraging dynamic covalent chemistry for reprocessing and self-healing. Finally, innovation opportunities converge on process development across most of the 16 technologies to reduce costs, raise yields, and accelerate scale-up. Central to these advances is the integration of key enabling technologies, particularly AI/data science combined with synthetic biology, genetic and metabolic engineering.

Regarding innovation challenges, three persistent constraints can be highlighted. Feedstock heterogeneity remains a core R&D hurdle, with variable waste and residue streams generating inhibitors and quality swings that require tolerant pretreatment, recovery and control, limiting consistency in processing. In many cases, these pre-treatment technologies remain a technical bottleneck, adding another layer of complexity and cost to the value chain. Process robustness is a second barrier, where, for instance, enzyme stability and tolerance, electro-biocatalyst coupling, multispecies consortia viability under real operating conditions still challenge reliable performance at scale. Another challenge is related to performance gaps, with several biomaterials still trailing fossil-based incumbents or requiring reformulation to meet industrial specifications (e.g., PHA mechanical and thermal limits; bio-epoxy chemical resistance; mycelium uniformity; and lignin-based anode microstructure).

**Table 16 Overview of innovation opportunities and challenges for the 16 applications**

| High potential applications/ technologies | Opportunities | Challenges |
|---|---|---|
| Enzyme-catalysed $CO_2$ conversion | $CO_2$ & C1/C2 intermediates (methanol/acetate) as feedstocks for cascaded bioprocesses | Tools, technologies & host systems required for unorthodox/extremophile organisms compatible with $CO_2$ substrates |
| | $CO_2$-to-biopolymer routes as emerging biotech track | |
| | Biofoundry/Data Science to accelerate organism design for $CO_2$ feedstocks & bio-electrocatalytic enzyme cascades fixing $CO_2$ into fine chemicals | Strain optimization for higher yield & productivity |

| | | |
|---|---|---|
| | | Enzyme cascades need tolerant processes for variable inputs<br><br>Robust electro/biocatalytic integration development |
| Polyethylene Furanoate (PEF) | Performance improvements (gas-barrier, thermal resistance, mechanical strength) enabling high-barrier packaging, textiles, automotive<br><br>Advanced FDCA production processes (metal-mediated, metal-free, electrochemical, biocatalytic) for cost efficiency & sustainability<br><br>Design for recycling | High R&D costs and technological complexity of FDCA synthesis from sugars<br><br>Need for efficient catalysts, and optimized polymerization processes |
| Polylactic Acid (PLA) | Feedstock diversification (e.g., waste, CO2), property enhancement (mechanical, thermal)<br><br>Added functionalities (self-healing, self-sensing) for applications in automotive, electronics, additive manufacturing/4D printing, packaging<br><br>Food waste valorisation as promising production route, explored by different stakeholders (e.g., by CIRCLE-Project, TripleW, Sulzer) | Ongoing optimization of fermentation and polymerization processes necessary to reduce production costs, and enhance efficiency<br><br>Mechanical and thermal performance limitations of PLA |
| Polyhydroxy-alkanoates (PHA) | R&D into waste-/side stream fermentation (e.g., BioSupPack-Project)<br><br>Advanced bioprocessing (genetically optimized strains, waste-stream fermentation) to cut costs & support diverse PHA types<br><br>Copolymerization & blending with biopolymers and PHA nanocomposites (graphene, carbon nanofibers) to enhance thermal, mechanical & electrical properties, enabling high-performance applications in e.g., agriculture & medical sectors<br><br>Advanced process technologies to integrate a broader range of sustainable feedstocks | Expensive and complex fermentation leading to high production costs, variable yields from waste feedstocks, and inefficient polymer recovery<br><br>Material limitations (lower tensile strength and thermal resistance than petroleum-based plastics) constrain adoption |
| Bio-based epoxy resins | Functional diversification beyond conventional BPA systems<br><br>Advances in functionalization (flame retardancy, recyclability, shape memory, antibacterial activity) to meet performance & sustainability needs | Feedstock variability (e.g., vegetable oils, lignin, cardanol, algae lipids with inconsistent composition)<br><br>Performance gaps compared to BPA-based epoxies (e.g., lower glass transition temperatures, reduced stiffness, weaker chemical re- |

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| | Dynamic covalent chemistry with reversible bonds (ester, disulfide, Schiff base, Diels–Alder, acetal) enabling closed-loop recycling, self-healing & reprocessing for sustainable thermosets<br><br>Multifunctional systems combining features like flame retardancy with antibacterial, recyclable properties, to open applications in construction, smart materials, and high-performance composites | sistance), and curing agent compatibility issues that can result in incomplete crosslinking and reduced durability |
| Lignin biocomposites reinforced with plant fibers | Lignin engineering to enhance performance (nano/microstructuring, antioxidant/UV, antimicrobial, barrier) & enable new composites<br><br>Process innovations in lignin depolymerisation/fractionation to yield aromatic streams for biocomposites<br><br>Interface optimisation for plant fibres (flax/hemp) and lignin-containing matrices | Consistent performance in fibre composites limited by lignin quality (kraft, soda, organosolv)<br><br>Need improved lignin modification for better compatibility with diverse polymer matrices<br><br>Formulation optimization to balance lignin content in composites |
| Mycelium leather | Selection/genetic optimization of fungal strains, sustainable substrates from waste & improved fermentation/growth to scale production<br><br>Biotechnological and material science advancements improving durability, texture and versatility of mycelium leather, including combinations with other fibres to enhance performance and enable new applications<br><br>Genetic engineering to modify strains to improve properties, reduce pathogenicity, and prevent fruiting/sporulation | Material optimization to achieve uniform quality and reliably to meet required mechanical properties (strength, elasticity, and durability standards across species), improve growth conditions, and post-processing methods<br><br>Improving performance, expanding applications to reduce costs, and scaling production while ensuring consistency |
| Pretreatment and fractionation of hardwood residues | Advanced pretreatment technologies, such as Organosolv variants (acetone-based, hydrotropic, DES) and hybrid processes (steam explosion + organosolv) enabling selective fractionation & high-purity lignin/sugars<br><br>Integration of pretreatment with enzymatic hydrolysis and fermentation of hardwood-derived sugars for downstream valorisation into chemicals, adhesives, carbon materials, and advanced composites | Feedstock heterogeneity (species, seasonality, impurities) complicates reproducibility & needs tolerant, standardised pretreatment<br><br>Tailoring pretreatment to different downstream routes (fermentation, catalysis) adds complexity & cost<br><br>Pretreatments can generate inhibitors (furfural, phenolics, acetic acid) that hinder hydrolysis/fermentation |
| Lignin-based hard carbon anodes | Microstructure engineering during carbonization to optimize spacing/porosity, improving ion storage & cycling stability | Achieving consistent microstructure and porosity in lignin-derived hard |

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| | Hybridization strategies (co-processing lignin with other carbon materials) to enhance performance<br><br>Advances in pretreatment, plant genetic modification & greener processing for higher-quality, sustainable precursors<br><br>AI-driven predictive modelling to optimize the process–structure–performance relationship | carbon, affecting ion-storage capacity and cycling stability<br><br>Optimization of pyrolysis and chemical modification processes required to meet performance targets comparable to conventional graphite |
| Enzymatic e-waste degradation | Advancing enzyme design for higher catalytic efficiency, broader substrate range, and toxicity tolerance<br><br>Applying synthetic biology, genetic engineering, recombinant techniques & nanotechnology to develop efficient enzymes | Complexity of e-waste composition, mixing plastics, heavy metals, and toxic additives inhibit enzyme performance and difficult process design |
| Hemp biorefining | Innovations in decortication & fibre processing to improve efficiency, reduce waste & enhance quality<br><br>Advanced cottonisation of hemp fibres (mechanical/enzymatic) to make fibres softer & diversify applications<br><br>Innovations in automation for precision & scalability, and sustainable processing to cut water/energy use | Requirement of additional processing compared to cotton<br><br>Enzymatic cottonisation faces technical hurdles due to raw material variability |
| Enzymatic bioremediation | Advanced enzyme engineering (laccases, peroxidases, PETases) for higher stability, broader substrate range & immobilization (membrane reactors, bio-electrochemical systems)<br><br>AI tools for predictive modelling of enzymatic degradation | Limited stability & suboptimal catalytic performance of free enzyme systems require major improvement<br><br>Innovation constrained by cost & supply chain hurdles for specialty enzymes |
| Microbial biofertilizers | Development of multi-strain formulations (from single- to multifunctional, multispecies) and soil microbiome-based strategies<br><br>Genetic engineering and synthetic biology to tailor microbial strains, design multi-trait bioinoculants and optimize plant–microbe interactions<br><br>Integration of digital technologies (IoT sensors, AI) to improve precision application & efficiency | Developing stable multispecies consortia needs advanced formulation & precise control, but current encapsulation/carrier systems often fail to maintain viability under diverse field conditions<br><br>Microbial strains lose viability during storage/transport, making shelf-life & consistency a critical barrier |
| Waste-based microbial-driven biorefinery | Advanced microbial engineering, synthetic biology & multi-omics to enable microbes to use heterogeneous waste streams for bioplastics & specialty chemicals<br><br>Enzyme-assisted pretreatment, AI-based process optimization & cascade fractionation to recover multiple products | Feedstock heterogeneity and variability of waste streams difficult microbial process optimization and product consistency |

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| Advanced metabolic engineering for microbial production of high-value chemicals | Synthetic biology & biofoundry platforms with automated DBTL cycles (AI/ML) for rapid strain/pathway design<br><br>Precision fermentation & engineered microbes for novel proteins/specialty chemicals<br><br>CRISPR/Cas & hierarchical engineering to optimize hosts & expand portfolios<br><br>AI-assisted process control & predictive modelling<br><br>Diversification beyond traditional organisms with microbial consortia/community systems for complex conversions | Rational design lacks robustness due to nonlinear, context-dependent metabolic networks, with strategies optimized for model microbes performing poorly in non-model strains and limited automated DBTL platforms |
| Plant breeding of non-food crops using CRISPR | Advanced breeding for climate adaptation & low-input perennial crops (drought-resistant, resilient, high-yield)<br><br>Trends: customized varieties, multi-trait editing, AI-driven breeding, digital phenotyping & blockchain traceability<br><br>Major companies opening rights to genome-editing/breeding technologies & building collaborative platforms to drive innovation | Complex traits governed by multiple genes and shaped by environmental factors make it challenging to identify causal loci and accurately predict the outcomes of genetic edits |

Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on stakeholder interviews and secondary sources. Full references to the consulted documents are provided in Annex 5.6.

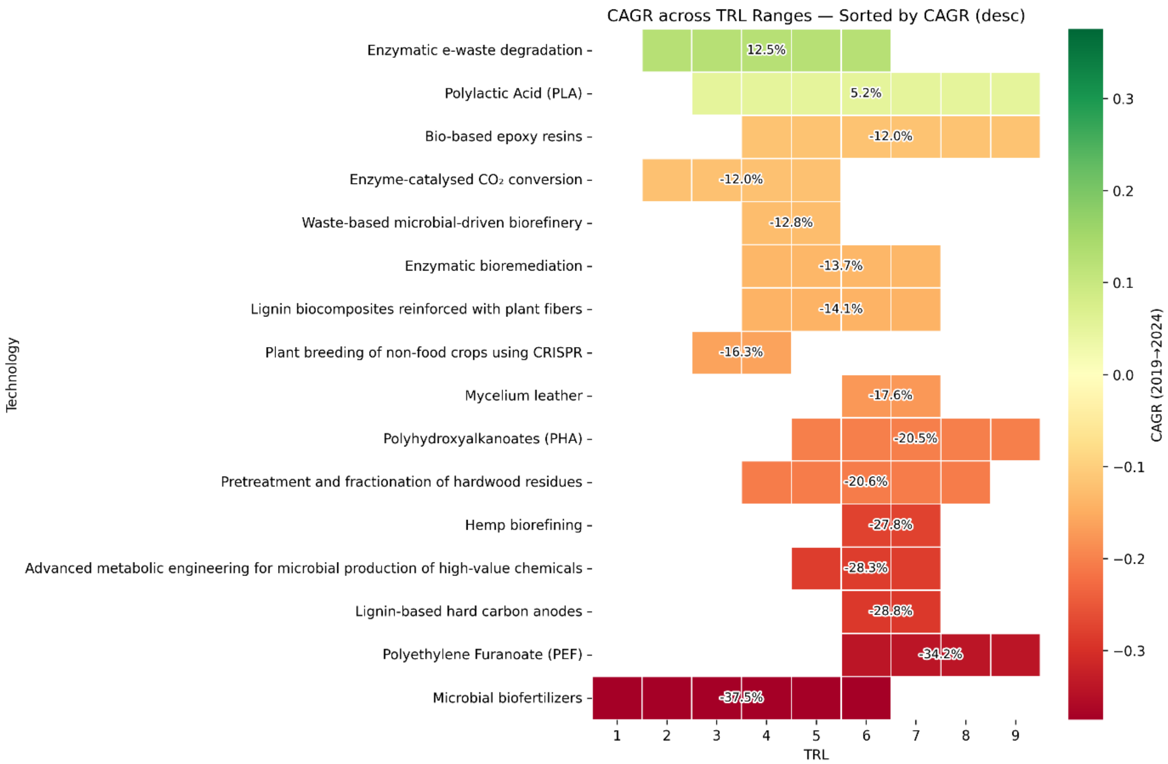
### 5.3.2 Scale up opportunities and challenges

Table 17 (and Annex 5.6) summarises opportunities and challenges for scale up in the 16 selected technologies. Across the 16 technologies, scale-up is being enabled by a growing body of pilot, demonstration and first-of-a-kind plants and associated EU-based infrastructures, which offer pathways from lab to market (e.g., LanzaTech-style CCU references, Avantium's FDCA/PEF, Futerro's PLA biorefinery, CBE JU/BBI pilots for lignin and pretreatment, Stora Enso's Lignode®). Another notable opportunity arises where there is compatibility of the emerging applications with incumbent assets and value chains, enabling retrofit rather than rebuild (e.g., bio-based epoxy monomers that work with current curing agents; PEF's integration with PET recycling; co-location of $CO_2$ conversion with point sources and renewable $H_2$). Furthermore, biofoundry platforms and AI/ML-enabled DBTL cycles are shortening iteration times and supporting scale-out for advanced metabolic engineering and enzyme-enabled processes.

The principal challenges to scale-up are financial and technical. On the finance side, high CAPEX and a persistent financing gap at TRL 4–6 and 7–9 ("double valleys of death") delay first-of-a-kind (FOAK) and commercial plants (e.g., $CO_2$ conversion, bioplastics (PEF, PLA, PHA), pretreatment, mycelium materials, and lignin-derived anodes). Limited access to affordable pilot and demo facilities – particularly for SMEs and start-ups – further delays proof-of-concept and commercialisation. Even where facilities exist, high capital costs prolong time-to-market and deter private investment. On the technical side, scaling and replicating laboratory performance at industrial scale introduce integration and reproducibility hurdles (e.g., achieving target yields and consistent quality at volume, integrating new unit operations and controls). Processes that perform well in controlled environments often face unforeseen difficulties at pilot or demonstration scale. For instance, enzymatic e-waste degradation is slower than chemical methods, complicating investment and upscaling.[163]

Figure 35 shows patent growth rates (CAGR) for 16 bio-based technologies mapped against their TRL ranges, The figure illustrates how patenting activity varies across technology readiness levels, providing insight into innovation and scale-up dynamics in the bioeconomy. Most of the 16 technologies exhibit negative patent CAGR between 2019 and 2024 at mid-to-high TRLs. Decreasing patent trends at mid-to-high TRLs often reflect a shift from invention to scale-up, with technologies having passed proof-of-concept, and the focus of innovation activities turning to engineering, cost reduction, and certification. This trend suggests that challenges are less about early-stage R&D and more about scale up and commercialization hurdles such as high capital intensity, feedstock variability, costly downstream processing, and performance parity with fossil-based incumbents.

**Figure 35 CAGR of patent filings by technology across TRL ranges (2019–2024)**




Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on PATSTAT data (European Patent Office, June 2025).

[163] Khan, S., Alam, F.S. & Borah, D., *Microbial cell factories in the remediation of e-wastes: an insight*. Biotechnol Environ 1, 4, 2024. https://doi.org/10.1186/s44314-024-00003-4

**Table 17 Overview of scale up opportunities and challenges for the 16 applications**

| High potential applications/ technologies | Opportunities | Challenges |
|---|---|---|
| Enzyme-catalysed $CO_2$ conversion | Industrial exemplars (e.g., LanzaTech at steel mills) already operating at TRL 9<br><br>Many enzyme/electro biocatalytic routes are in early development<br><br>Multiple projects, centres and infrastructure (e.g., DTU sister CCU centre, EIC Pathfinder ECOMO project, Evonik and Siemens's pilot project Rheticus) enabling scale up across Europe | Hydrogen integration and specialised fermenter design<br><br>High complexity in scaling biocatalytic processes<br><br>GMP/API-style plants over-engineered and too costly for CCU bioprocesses |
| Polyethylene Furanoate (PEF) | First industrial FDCA production at scale (e.g., Avantium, PEFerence EU project) | High capital intensity with large-scale plants requiring significant upfront investment<br><br>Fragmented supply chains increase risk |
| Polylactic Acid (PLA) | PLA derived from sugar-/starch-rich crops (sugar beet, wheat, cassava, potato, corn, sugarcane) is an established commercial biopolymer with more than five major producers worldwide<br><br>Futerro is currently developing Europe's first fully integrated biorefinery in Normandy, France (€500M investment and production of 75,000t/y)<br><br>Production of non-food feedstocks (agricultural residues, forestry side streams, and food industry waste) demonstrated in pilot projects | Limited existing production capacity in Europe<br><br>High capital/ input costs, and a financing gap between pilot, demo and full-scale plants |
| Polyhydroxyalkanoates (PHA) | Small group of companies successfully developed flagship production facilities, primarily to seed the market and optimise formulations in collaboration with customers<br><br>Since 2024, few producers have demonstrated functional and economic viability with end-users, with scaled production capacities in the range of 10–20 kt per year | Scaling PHA typically takes ~10 years to establish viable production, market entry and approvals<br><br>Limited dedicated capacity and high upfront capital make first-of-a-kind projects hard to finance<br><br>Replicating lab performance at industrial scale (yields, purity, consistency) remains difficult |

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| | | Production costs are still 3-12 times higher than conventional plastics, with feedstock accounting for 40% of the total cost |
| Bio-based epoxy resins | Many bio-based epoxy monomers (e.g., vanillin and eugenol derivatives) compatible with existing curing agents and processes, enabling integration into current industrial workflows (and mass balance approach)<br><br>Scale-up potential for bio-based epoxy resins in coatings demonstrated in EU projects (e.g., Lignicoat for high-bio-content epoxy resins) | Bio-epoxies remain more expensive than petrochemical alternatives<br><br>Complex fermentation/chemical steps (epoxidation, lignin valorisation) and costly scale-up from lab to pilot scale |
| Lignin bio-composites reinforced with plant fibers | CBE JU/BBI projects piloting lignin conversion at TRL 6–7 (e.g., EUCALIVA pilot for polymers/carbon fibres, LIGNOFUN on lignin depolymerisation) | Significant 'valley of death' between pilot scale and full industrial deployment<br><br>Scale-up requires advanced hardware and dedicated infrastructure (lignin fractionation, compounding, continuous processing), demanding substantial capital investment |
| Mycelium leather | Most mycelium-leather technologies at TRL 6–7, with some nearing commercialization<br><br>Partnerships between fashion brands and biotech firms validating viability and accelerating scale-up | Early-stage technology makes scaling difficult and limits high-volume output<br><br>Requires precise environmental control, high capital investment, and often partner-led or outsourced manufacturing |
| Pretreatment and fractionation of hardwood residues | Advanced fractionation technologies at demo to early commercial scale (e.g., Sunburst pre-processing technology, with Fibenol's wood fractionation demonstration plant operating in Estonia at TRL 7–8)<br><br>Pilot-scale integration of pretreatment and enzymatic hydrolysis (TRL 5–7) (e.g., Fraunhofer CBP organosolv pilot combined with enzymatic hydrolysis)<br><br>Cross-border access to EU pilot/demo infrastructures (e.g., BIOMAC OITB, Fraunhofer CBP, VITO LignoValue) enabling scale-up of advanced pretreatment lines (e.g., organosolv, steam explosion, alkaline, and enzymatic systems) | High capital and operating costs make financing first-of-a-kind plants difficult, creating a significant "valley of death"<br><br>Organosolv pretreatment remains costly, energy-intensive, and sensitive to feedstock variability, constraining scale-up and commercialisation |
| Lignin-based hard carbon anodes | Most lignin-based hard-carbon anodes at lab, pilot and early demo stage (TRL 6–7) with active scale-up R&D<br><br>EU pilot/demo projects exploring wood- and biomass-derived carbon for battery anodes, enabling bio-based electronics components | Large-scale production requires major capital investment; pyrolysis, purification and strict QC are costly and slow scale-up, especially for smaller companies |

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| | Stora Enso (Finland) developing lignin-based anodes (Lignode®) | Achieving consistent commercial-scale quality (purity, structure, batch reproducibility) requires complex, R&D-intensive processes<br><br>Hard carbon shows lower initial coulombic efficiency than graphite, reducing first-cycle capacity and overall battery efficiency |
| Enzymatic e-waste degradation | Enzymatic degradation of electronic waste is most advanced for plastic-components like PET and PU and biodegradable devices (TRL 5–7)<br><br>Complex e-waste and PFAS/halogenated compounds remain at earlier stages (TRL 2–4) | Biological processes rely on live organisms, making treatment efficiency and duration hard to predict compared to physical–chemical methods<br><br>Enzymatic activity is highly sensitive to physical factors (temperature, oxygen) and chemical factors (pH, humidity, nutrient availability)<br><br>Maintaining consistent enzymatic activity under fluctuating industrial conditions remains difficult |
| Hemp biorefining | Few processes have reached full commercial maturity (TRL 9), while most advanced processes currently operate at TRLs 6–7, with ongoing R&D to scale them and demonstrate market entry potential | Financial constraints for demonstration and full-scale investments<br><br>Risk-averse investors |
| Enzymatic bioremediation | Pilot-to-field demonstrations under EU Soil Mission and Horizon Europe Cluster 6 calls (e.g., ALL4BIOREM cluster projects) | High cost associated with implementation and scaling of bioremediation technologies |
| Microbial biofertilizers | Most novel microbial biofertilizers based on plant growth-promoting rhizobacteria (PGPR) are still in the early laboratory and initial experimental work (TRL 1–4)<br><br>Few have progressed to prototypes testing and validation under real agricultural conditions (TRL 5–6) | Inconsistent efficacy without optimized carriers/encapsulation and compatibility testing, limiting large-scale rollout<br><br>Infrastructure gaps due to limited fermentation and formulation capacity in parts of the EU |
| Waste-based microbial-driven biorefinery | Single processes such as anaerobic digestion, fermentation, or enzymatic hydrolysis have high TRLs, while their integration with waste valorisation and $CO_2$ in multi-product microbial biorefineries remains at laboratory and validation scale (TRL 4–5) | Firms must coordinate across the value chain to manage feedstock variability and market requirements<br><br>High CAPEX and a “valley of death” between pilot and commercial scale make first-of-a-kind biorefineries financially risky |

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| Advanced metabolic engineering for microbial production of high-value chemicals | Integrated pipelines from biofoundry-driven design to piloting and demonstration with computationally instrumented scale- down/scale-out concepts<br><br>EU-wide pilot and demo infrastructures (e.g., BBEU) to accelerate first-of-a-kind (FOAK) deployments | Difficulties in reproducing optimal conditions from bench to industrial scale, often resulting in performance issues<br><br>Capital scarcity, contractor costs (60–70% of raised funds)<br><br>“Valley of death” at TRL 4–6 acute |
| Plant breeding of non-food crops using CRISPR | CRISPR/Cas-based plant breeding in the bioeconomy is generally TLR 3-4, reflecting proof-of-concept and early experimental validation | Trait expression (e.g., biomass yield, stress tolerance, fibre quality) involves multiple loci and strong genotype–environment interactions, making CRISPR edits for non-food crops harder to scale |

Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on stakeholder interviews and secondary sources. Full references to the consulted documents are provided in Annex 5.6.

### 5.3.3 Competitiveness opportunities and challenges

Table 18 (and Annex 5.6) provides an overview of competitiveness opportunities and challenges in the selected technologies. Competitiveness opportunities are primarily driven by circularity, feedstock diversification and market pull. A major driver for competitiveness is circularity and end-of-life advantages (e.g., recyclability, compostability, degradability and mass balance integration) of bio-based materials (e.g., PEF compatible with existing PET systems; PLA with multiple end-of-life pathways; PHA fully biodegradable; bio-based epoxies designed for recyclability). Another driver is feedstock diversification and local sourcing (e.g., $CO_2$, hardwood residues, lignin, waste streams, hemp), supporting strategic autonomy and shorter supply chains. These factors are coupled with rising consumer demand and uptake by industrial manufacturers of sustainable alternatives creating opportunities for competitive positioning of bio-based materials across packaging, fashion, mobility, and energy storage value chains.

At the same time, competitiveness is constrained by a convergence of barriers spanning scale-up economics, costs, market dynamics, and feedstock. One of the dominant constraints is scaling up economics. First of a kind (FOAK) plants face high CAPEX/OPEX, long timelines, and off take risk, which slows industrialisation across multiple technologies. Access to capital remains a critical bottleneck for scaling and commercialising biotechnological innovations. Despite a strong EU R&D base, many promising technologies fail to progress beyond pilot or demonstration stages reaching deployment on an industrial scale due to limited scale up financing and risk capital availability, capital-intensive high-risk scale-up requirements, long payback periods, and limited track records of emerging bio-based technologies. This contributes to offshoring of production. R&D may be carried out in Europe, but scale-up and manufacturing frequently move abroad due to more favourable investment conditions. The U.S. offers faster regulatory approval, larger unified markets, and greater access to risk-tolerant venture capital, advantages particularly relevant for advanced metabolic engineering of high-value chemicals. Cost competitiveness is another hurdle. Production costs for various applications remain above fossil incumbents, often compounded by high energy inputs and exposure to high EU energy prices (e.g., $CO_2$ conversion, lignin anodes). Economies of scale are rarely reached, keeping unit costs high and slowing industrial uptake. Competitive pressure from lower-cost imports, notably from Asia, further erodes margins (e.g., PLA). On the demand side, in price sensitive segments, customers often resist green premiums (e.g., PEF, PLA, and PHA face limited willingness to pay relative to fossil alternatives). Aesthetic and performance perceptions can deter adoption (e.g., PHA/PLA packaging tint; mycelium leather durability). Furthermore, remaining performance gaps vis-à-vis fossil incumbents slow qualification in demanding applications. Finally, despite feedstock diversification and local sourcing offering competitive advantages, feedstock availability and cost pressures are seen by stakeholders as bottlenecks. Raw materials are often more abundant and cheaper in competing regions, while in Europe, land-use constraints, strict sustainability standards, and competition with other sectors drive up costs. This has hindered domestic deployment of technologies (e.g., most PLA capacity remains outside Europe).

**Table 18 Overview of competitiveness opportunities and challenges for the 16 technologies**

| High potential applications/ technologies | Opportunities | Challenges |
|---|---|---|
| Enzyme-catalysed $CO_2$ conversion | Pairing CCU with renewable hydrogen/electrolysers for cost competitiveness, local/regional production advantages ($CO_2$ not economically shipped), and abundant point-source $CO_2$ streams | Production costs not yet competitive with fossil processes<br><br>High hydrogen demand and energy costs weaken $CO_2$-to-products economics<br><br>Fossil price advantage, Asian import pressure, and EU market fragmentation slow deployment<br><br>Without off-take guarantees, investors hesitation<br><br>Funding/finance constraints: High CAPEX (demo €90–100m); patient capital, off-take guarantees and derisking needed; overheads not fully covered by EU grants<br><br>Feedstock/resource/sustainability constraints: Need constant quality $CO_2$ streams and sufficient renewable energy for electrolysis/AI integration |
| Polyethylene Furanoate (PEF) | High recyclability and circularity, combined with lower carbon footprint compared to PET<br><br>Chemical compatibility with PET enables seamless integration into existing PET recycling systems<br><br>Strong value proposition: superior material properties and circular end-of-life design | PEF faces price pressure from rPET and PLA<br><br>Many consumers resist to pay a premium for sustainable alternatives<br><br>Funding schemes: exclude primary biomass derived from food crops (e.g., food-grade sugars) to avoid competition with food supply |

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| | Growing demand for PEF and other bio-based polymers driven by the shift to sustainable plastics, with PEF fibres approaching performance parity with conventional materials | Strong preference for waste-based feedstocks under EU sustainability frameworks<br><br>Secondary feedstocks have lower conversion efficiency compared to pure sugars, requiring advanced processing technologies, leading to higher CAPEX and OPEX. |
| Polylactic Acid (PLA) | Biodegradable and compostable under industrial composting conditions, recyclable, antibacterial property, and good mechanical and thermal properties to be used for diverse applications<br><br>Multiple end-of-life pathways (including recycling and composting) enhance circularity and market appeal<br><br>Growing demand for bioplastics in the packaging industry contributes to market growth | High CAPEX and investment risk, with limited economies of scale in Europe compared to Asia, raising unit costs<br><br>Sustainability concerns over first-generation biomass slow investment in large-scale PLA plants<br><br>Remains significantly more expensive than fossil plastics, limiting uptake in price-sensitive markets<br><br>Consumer reluctance to pay a premium; aesthetic issues (e.g., slight yellow tint) can reduce perceived quality<br><br>Competitive pressure from Asian producers and imports further reduces European PLA competitiveness |
| Polyhydroxyalkanoates (PHA) | Fully biodegradable and compostable biopolymer (in both marine and soil environments), helps strengthen consumer acceptance and creates market pull for further innovation and deployment | Aesthetic differences (e.g., slight yellow tint seen in PLA or PHA packaging) hinder market adoption by reinforcing perceptions of lower quality<br><br>Around five times more expensive than conventional polyolefins, and many consumers resist paying a premium, especially in price-sensitive segments<br><br>Fragmented EU market due to non-harmonized compostability standards and insufficient recycling infrastructure |
| Bio-based epoxy resins | Growing sustainability requirements across key end-use sectors (automotive, wind energy, construction, electronics) driven by EU Green Deal objectives, increasing demand for high-performance, sustainable and recyclable bio-based epoxy | Production costs for many bio-based epoxy monomers and formulations remain higher than petrochemical counterparts<br><br>Availability of scalable, reliable, and sustainably sourced feedstocks remains a key constraint |
| Lignin bio-composites reinforced | Local sourcing of lignin and plant fibres strengthens strategic autonomy and reduces fossil dependence | Lignin is not a true drop-in replacement, requiring reformulation and validation |

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| with plant fibers | Strong and growing demand for sustainable materials across packaging, automotive, construction, insulation, electronics and other sectors requiring high thermal and mechanical performance | Manufacturers hesitate due to formulation complexity and performance uncertainties, slowing adoption despite rising sustainability-driven demand |
| Mycelium leather | Strong market growth driven by rising consumer demand for sustainable alternatives to natural and synthetic leather<br><br>Increasing adoption of biodegradable, low-carbon materials across fashion (footwear, bags) and emerging uses such as insulation and eco-friendly packaging<br><br>Biodegradable end-of-life potential | Durability and weather resistance still fall short of conventional leather<br><br>Cost premium and limited scale compared to established bovine and synthetic leather supply chains |
| Pretreatment and fractionation of hardwood residues | Hardwood residues and other lignocellulosic by-products serve as strategic feedstocks for bio-based chemicals and materials, creating new revenue streams and supporting circular-economy goals aligned with EU bioeconomy competitiveness priorities | High infrastructure and enzyme costs, costly solvent recovery, and complex feedstock logistics reduce competitiveness<br><br>Fragmented demand for high-quality lignin fractions and lack of standard specifications slow market uptake<br><br>High production costs compared to fossil pathways<br><br>Uncertain demand and low willingness to pay premiums, combined with expensive feedstock, biomass competition, and concerns over long-term availability |
| Lignin-based hard carbon anodes | Provide a sustainable alternative to conventional graphite<br><br>Lignin can be sourced locally and sustainably from forestry residues and pulp-mill by-products<br><br>Lignin is significantly more cost-effective than synthetic or fossil-based carbon sources<br><br>Lignin-derived hard carbon is well suited for sodium-ion batteries, helping reduce reliance on lithium and mitigate critical raw-material risks | Lignin-based anodes struggle to compete with established graphite supply chains, making cost parity and adoption difficult<br><br>Biomass collection and processing infrastructure remains underdeveloped, while high-temperature carbonization (~1400 °C) increases energy use and costs<br><br>High EU energy prices raise production costs, putting European producers at a disadvantage compared to Asian suppliers with cheaper energy, mature supply chains and economies of scale |
| Enzymatic e-waste degradation | Environmental footprint potential vs. conventional metallurgy | Enzymatic processes are often slower than thermal or chemical alternatives |

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| | Demand for secondary critical raw materials | Uncertainty about long-term performance, cost, and reliability of enzymatic e-waste degradation may limit early adopter uptake |
| Hemp biorefining | Carbon negative footprint<br><br>Demand for sustainable materials have positioned hemp as a versatile alternative<br><br>Local sourcing, contribution to EU strategic autonomy<br><br>Diversification of end-use applications, e.g., construction, automotive, packaging, textiles | Price gap: hemp (€1.60/kg) vs cotton (€0.80/kg)<br><br>Price sensitivity in textiles (¢-level matters at scale)<br><br>Economic downturn reduces sustainability priorities |
| Enzymatic bioremediation | Rising environmental pollution from industrial discharge, oil spills, chemical leaks, and agricultural runoff drives demand for effective cleanup solutions<br><br>Sustainable, low-impact alternative to conventional remediation methods (e.g., reduced chemical inputs) | High initial investment for R&D and deployment, particularly for large or heavily contaminated sites |
| Microbial biofertilizers | Eco-friendly alternative with a lower environmental footprint than synthetic fertilizers, improving soil health, biodiversity and water quality<br><br>Microbial biofertilizers align with EU sustainability and sidestream-valorisation goals by reducing mineral-fertilizer dependence and closing nutrient loops, strengthening their market position gegenüber conventional inputs | Higher unit costs compared to chemical fertilizers |
| Waste-based microbial-driven biorefinery | Increased demand in sustainable waste management solutions | High costs limit market competitiveness<br><br>Uneven product quality and consumer/industry scepticism about waste-derived bioproducts can suppress demand and slow commercial uptake |
| Advanced metabolic engineering for microbial production of high-value chemicals | Data-rich biofoundries reduce time/cost<br><br>New production organisms (e.g., extremophiles, community systems) expand design space, potentially improving economics | Scale economics with long timelines (3–10 years) and high CAPEX for pilot/demo/first-of-a-kind plants |

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| Plant breeding of non-food crops using CRISPR | Growing demand for improved non-food crops and advanced breeding methods<br><br>Stricter pesticide regulations increasing demand for low-input, improved crops | High upfront investments |

Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on stakeholder interviews and secondary sources. Full references to the consulted documents are provided in Annex 5.6.

### 5.3.4 Institutional opportunities and challenges

Institutional opportunities and challenges relevant for the 16 technologies are summarised in Table 19 (and Annex 5.6). Across the 16 technologies, the most important institutional opportunities arise where EU institutional frameworks convert climate, sustainability and circularity objectives into innovation promotion incentives, de-risked pathways to scale and explicit demand signals. Public funding, R&D support initiatives and shared EU-wide infrastructures were repeatedly cited by stakeholders as institutional enablers that shorten the TRL progression and de-risk scaling. As shown in Table 20, a broad mix of funding and financing instruments supports different stages of the innovation cycle. Horizon Europe (Cluster 6) finances early-stage R&D, while the Circular Bio-based Europe Joint Undertaking (CBE JU) builds on this by supporting proof of concept for novel bio-based solutions, and the development of sustainable value chains based on biomass, residues, and waste streams. CBE JU also plays a central role in de-risking demonstration and flagship projects, thereby bridging the gap between research, innovation, and market deployment. The European Innovation Council (EIC), Innovation Fund, and InvestEU enable scale-up of breakthrough biotechnologies in line with EU climate and sustainability goals. Investment-oriented mechanisms, such as the European Circular Bioeconomy Fund (ECBF), fill a critical gap at TRL 6–9, targeting bio-based chemicals, packaging, and industrial biotech. Structural funds such as the European Regional Development Fund (ERDF) and European Agricultural Fund for Rural Development (EAFRD) provide regional support for infrastructure and adoption in agriculture and rural areas. EU pilot–demo infrastructures provide risk-sharing and scale-up services that FOAK projects cannot secure from private finance alone.

**Table 19 Overview of institutional opportunities and challenges for the 16 technologies**

| High potential applications/ technologies | Opportunities | Challenges |
|---|---|---|
| Enzyme-catalysed $CO_2$ conversion | EU projects (e.g., $CO_2$SMOS)<br><br>Defossilisation incentives and EU climate targets | Lengthy approvals<br><br>Public opposition to GM/NBT hinder technology uptake<br><br>Complex green hydrogen certification |

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| | | REACH rules, under the Generic Risk Assessment approach, treat enzymes like conventional chemicals creating a risk of disproportionate restrictions or de facto bans<br><br>GMO/NGT approvals and associated risk-assessment burdens |
| Polyethylene Furanoate (PEF) | PPWR creates regulatory incentives for polymers that are recyclable at scale, creating incentives for polymers like PEF | PPWR promotes recyclability but sets no binding bio-based targets, limiting PEF scaling. The EU will clarify position of bio-based content requirements only in 2028 in the frame of the PPWR<br><br>RED II/III bioenergy targets may divert biomass from bioplastics<br><br>EU Taxonomy perceived inconsistency, bio-based plastics can qualify on climate (fossil displacement/biogenic carbon) under the Climate Delegated Act, but are not automatically circular under the Environmental Delegated Act unless they meet recycling/reuse criteria. A product may be eligible for green finance on climate yet fail on circularity, creating uncertainty for companies and investors<br><br>Absence of dedicated NACE codes hinders access to financing<br><br>Regulatory fragmentation, divergent end-of-waste criteria, and no EU-wide composting standards complicate cross-border supply chains; No EU-wide bio-based material targets, thus no predictable demand signal |
| Polylactic Acid (PLA) | PPWR emphasises recyclability for all packaging and introduces mandatory compostability for specific applications under Article 9 (e.g., permeable tea and coffee bags, and sticky fruit and vegetable labels), which supports demand for PLA in targeted niches for compostable material | PLA is treated as plastic under SUPD, so single-use PLA faces all restrictions and compliance obligations with no exemptions<br><br>No binding EU legislation specifically incentivizes bio-based plastics; current frameworks are advisory only.<br><br>Regulatory uncertainty constrains demand and slows scale-up of PLA production in Europe<br><br>PPWR prioritizes recycling/recycled content and compostability is limited to narrow uses constraining demand signals<br><br>For challenges on biomass diversion, EU Taxonomy, NACE codes, regulatory fragmentation, end-of-waste criteria, and EU bio-based material targets, see PEF |
| Polyhydroxy-alkanoates | EU policies promoting circularity/biodegradability, such as the Circular Economy | Under SUPD and ECHA 2012 Polymer Guidance, PHA and enzymatically produced biomaterials are treated as plastics, |

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| (PHA) | Action Plan and the SUPD promotes the use of biodegradable materials, act as drivers for PHA innovation and adoption, although disparities in implementation across member states can hinder its full potential<br><br>PPWR emphasises recyclability for all packaging and introduces mandatory compostability for specific applications under Article 9 (e.g., permeable tea and coffee bags, and sticky fruit and vegetable labels), which supports demand for PLA in targeted niches for compostable material | so biodegradability provides no regulatory relief; all bans, labelling, and EPR obligations still apply<br><br>PPWR prioritizes recycling/recycled content and compostability is limited to narrow uses constraining demand signals<br><br>For challenges on biomass diversion, EU Taxonomy, NACE codes, regulatory fragmentation, end-of-waste criteria, and EU bio-based material targets, see PEF |
| Bio-based epoxy resins | The EU's 2024 ban on bisphenol A (BPA) in varnishes and coatings and the upcoming PFAS restrictions could accelerate the development and market uptake of bio-based epoxy systems | Absence of dedicated NACE codes hinders access to financing<br><br>No EU-wide bio-based targets for materials, thus no predictable demand signal |
| Lignin biocomposites reinforced with plant fibers | EU-funded lignin projects (e.g., LignoMBB, LIBRE) | No EU-wide bio-based targets for materials, thus no predictable demand signal |
| Mycelium leather | EU policies promoting sustainable and circular packaging incentivize the use of mycelium-based materials<br><br>EU-funded programs provide grants for R&D and scale-up | Novel mycelium materials lack clear classification into existing material categories and relevant regulatory frameworks in many jurisdictions<br><br>Ambiguities result in lengthy approval processes, high compliance costs, and delays in market entry |
| Pretreatment and fractionation of hardwood residues | Horizon Europe (Cluster 6; CBE-JU) supports integrated biorefineries and retrofitting existing plants toward higher-value bio-based products, key for de-risking scale-up<br><br>CBE-JU-funded projects (e.g., SWEETWOOD and WOODCELL | Variation in Member States in classifying and handling waste wood/residues (waste vs. by-product, end-of-waste criteria) complicates supply chains<br><br>No mandate/support to advance bio-based chemicals from wood processing<br><br>Strong R&D support exists, but mechanisms to bridge the "valley of death" to market are insufficient<br><br>REACH treats enzymes like conventional chemicals, risking disproportionate restrictions or de facto bans |

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| | | Regulatory fragmentation and divergent end-of-waste rules hinder cross-border operations and EU-wide supply chains |
| Lignin-based hard carbon anodes | EU Battery Regulation mandates carbon footprint disclosure, recycled content, and sustainability criteria for all batteries<br><br>CRMA encourages alternatives to graphite and lithium, favouring bio-based solutions | Compliance with multiple overlapping EU frameworks (Green Deal, the Net-Zero Industry Act (NZIA), the Critical Raw Materials Act (CRMA), and the EU Battery Regulation (2023)) creates complexity and uncertainty for producers. These intersecting requirements often slow down permitting processes and increase administrative burdens for companies seeking to scale up |
| Enzymatic e-waste degradation | EU projects like ENZYCLE and MIX-UP promote enzymatic recycling of hard-to-recycle plastics<br><br>EPR rules in Waste Framework Directive shift collection and processing costs to device manufacturers, incentivizing innovative recycling solutions | REACH rules, under the Generic Risk Assessment approach, treat enzymes like conventional chemicals creating a risk of disproportionate restrictions or de facto bans |
| Hemp biorefining | Hemp liberalisation worldwide are accelerating hemp adoption | "Unequal playing field" compared to fossil-derived materials, and cotton fibre<br><br>Strong R&D support but offer insufficient mechanisms to accelerate commercialization<br><br>No EU-wide bio-based targets for materials, thus no predictable demand signal |
| Enzymatic bioremediation | Zero Pollution Action Plan sets contamination-reduction targets<br><br>EU-supported initiatives, e.g., All4Biorem Cluster with six Horizon Europe bioremediation projects | Classification of enzymes as 'substances of concern' under REACH creates barriers to enzyme innovation and adoption |
| Microbial biofertilizers | EU Fertilizing Products Regulation (FPR) harmonizes rules for microbial biofertilizers, enabling free movement within the single market | FPR covers only a narrow set of microbial biostimulants; most biofertilizers remain under divergent national rules, creating uncertainty and slowing scale-up<br><br>GM strains and engineered biofertilizers require additional risk assessment<br><br>Multi-layered, complex and lengthy authorisations for products slow commercialisation and deter investment |

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| Waste-based microbial-driven biorefinery | EU and national strategies promoting waste valorization and resource efficiency aligned with the EU Circular Economy Action Plan<br><br>EU co-funding derisks pilot/demo runs | Long approval timelines; multiple overlapping regulations for waste handling, bio-based product certification, and emissions<br><br>Regulatory fragmentation and divergent end-of-waste rules complicate cross-border supply chains<br><br>Complex, multi-layered authorizations for biomanufacturing slow commercialization and deter investment<br><br>GMO/NGT approvals and associated risk-assessment burdens |
| Advanced metabolic engineering for microbial production of high-value chemicals | EU co-financed undertakings | EU GMO classification can trigger EFSA reviews<br><br>REACH treats enzymes like conventional chemicals, risking disproportionate restrictions or de facto bans<br><br>Complex, multi-layered authorizations for biomanufacturing slow commercialization and deter investment |
| Plant breeding of non-food crops using CRISPR | EU Horizon initiatives supporting crop innovation for sustainability | ECJ ruling (2018) and strict GMO/NGT rules create long, complex approval processes for CRISPR-edited crops<br><br>Multi-layered authorizations and regulatory uncertainty slow innovation, commercialization, and market growth |

Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on stakeholder interviews and secondary sources. Full references to the consulted documents are provided in Annex 5.6.

**Table 20 Major EU public funding and financing sources for bioeconomy R&D and scale-up**

| **Funding instruments/type** | **Budget** | **Focus areas** | **TRL focus** |
|---|---|---|---|
| Horizon 2020 (2014–2020)/<br><br>Grant | €310 million for SC2[164] (of €80 total[165]) | Supported R&I for food security, sustainable agriculture, forestry, and bio-based industries through Societal Challenge 2.[166] | TRL 1–8 |

[164] European Commission, Research Executive Agency (REA), *EU invests over EUR 310 million in research to support sustainability in agriculture, forestry, marine and bioeconomy*, 2021, https://rea.ec.europa.eu/news/eu-invests-over-eu310-million-research-support-sustainability-agriculture-forestry-marine-and-bio-2021-06-16_en
[165] European Commission, *Horizon 2020*, 2025, https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-2020_en (last accessed 09/2025)
[166] Leibniz Universität Hannover, *Horizon 2020 – EU Framework Programme for Research and Innovation – An overview*, 2018, https://www.uni-hannover.de/fileadmin/luh/content/dezernat4/SG41/Beratung/H2020_Overview_EN_12_2018.pdf (last accessed 09/2025)

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|---|---|---|---|
| Horizon Europe (2021–2027)/<br><br>Grant | €3.2 billion (Cluster 6) (of €93.5 billion total)[167] | Cluster 6 supports R&I in bio-based innovation systems, sustainable food systems, and circular bioeconomy.[168] | TRL 1–8 |
| Bio-based Industries Joint Undertaking BBI JU (2014–2020)/Grant | €822 million[169] | Advanced bio-based materials and technologies from EU biomass; supported flagship biorefineries and industrial demonstration projects.[170] | TRL 5–8 |
| Circular Bio-based Europe Joint Undertaking (CBE JU) (2021–2027)/Grant | € 2 billion[171] | Focus on circular and sustainable bio-based industries using biomass and waste; aims to develop scalable, high-performance bio-based products.[172] | TRL 5–8 |
| European Innovation Council (EIC) (2021-2027) (Pathfinder, Accelerator)/ Grant + Equity | €10 billion for 2021-2027[173]<br><br>Pathfinder: €262 million in 2025<br><br>Accelerator: €634 million in 2025<br><br>(total budget in 2025 € 1.4 billion)[174] | The focus of the EIC is on developing and scaling up breakthrough technologies.[175] EIC Pathfinder (TRL 1–4)[176] and Accelerator (TRL 6–8)177 support disruptive bio-based innovations and scale-up of breakthrough biotech solutions. | Pathfinder: TRL 1–4; Accelerator: TRL 6–8 |

[167] European Commission, Horizon Europe. Research and innovation funding programme until 2027. How to get funding, programme structure, missions, European partnerships, news and events, 2025, Available at: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en (last accessed 09/2025)
[168] European Commission, *Cluster 6: Food, Bioeconomy, Natural Resources, Agriculture and Environment. Policy, strategy, how to apply and work programmes*, 2025, https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/cluster-6-food-bioeconomy-natural-resources-agriculture-and-environment_en#apply-for-funding (last accessed 09/2025)
[169] CBE JU, *A competitive bioeconomy for a sustainable future*, 2022, https://www.cbe.europa.eu/system/files/2022-12/CBE-JU-presentation-Nov-2022.pptx (last accessed 09/2025)
[170] BBI JU, *Bio-based Industries Joint Undertaking*, 2018, https://www.europarl.europa.eu/cmsdata/185349/AAR_2018_BBIJU.pdf.pdf (last accessed 09/2025)
[171] CBE JU, *Circular Bio-based Europe Joint Undertaking*, 2025, https://www.cbe.europa.eu/ (last accessed 09/2025)
[172] CBE JU, *A competitive bioeconomy for a sustainable future*, 2022, https://www.cbe.europa.eu/system/files/2022-12/CBE-JU-presentation-Nov-2022.pptx (last accessed 09/2025)
[173] European Innovation Council, *Commission launches European Innovation Council to help turn scientific ideas into breakthrough innovations*, 2021, https://eic.ec.europa.eu/news/commission-launches-european-innovation-council-help-turn-scientific-ideas-breakthrough-innovations-2021-03-18_en (last accessed 09/2025)
[174] European Innovation Council, *EIC 2025 work programme*, 2024. Available at: https://eic.ec.europa.eu/eic-2025-work-programme_en#factsheets (last accessed September 2025).
[175] European Innovation Council, *About the European Innovation Council*, 2025. Available at: https://eic.ec.europa.eu/about-european-innovation-council_en (last accessed September 2025).
[176] European Innovation Council, *EIC Pathfinder*, 2025, Available at: https://eic.ec.europa.eu/eic-funding-opportunities/eic-pathfinder_en (last accessed 09/2025)
[177] European Innovation Council, *EIC Accelerator*, 2025, Available at: https://eic.ec.europa.eu/eic-funding-opportunities/eic-accelerator_en (last accessed 09/2025)

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| European Circular Bioeconomy Fund (ECBF)/ Equity VC | €300 million[178] | Supports late-stage (TRL 6–9) bio-based companies in sectors such as food, chemicals, industrial biotech, and sustainable materials.[179] | TRL 6–9 |
| European Regional Development Fund (ERDF) (2021-2027)/Grant | € ~226 billion[180] | Supports regional innovation, green transition, and smart specialisation strategies, including bioeconomy development (PO2).[181] | TRL 1–7 |
| European Agricultural Fund for Rural development (EAFRD)[182] (2021-2027)/Grant | € 95.51 billion of which € 8.07 billion under NGEU[183] | Promotes sustainable farming, rural innovation, and adoption of bio-based practices and technologies in agriculture.[184] | TRL 5–8 |
| Innovation Fund (2020-2030)/Grant | € ~40 billion (carbon-price dependent)[185] | Supports deployment of bio-based solutions in hard-to-abate sectors for significant GHG reduction. | TRL 7–9 |
| InvestEU Fund/ Guarantee/Loan/Equity | €26.2 billion total (€9.9 bn for sustainable infrastructure)[186] | Provides capital for sustainable bioeconomy infrastructure and technologies meeting EU environmental criteria. | TRL 8–9 |

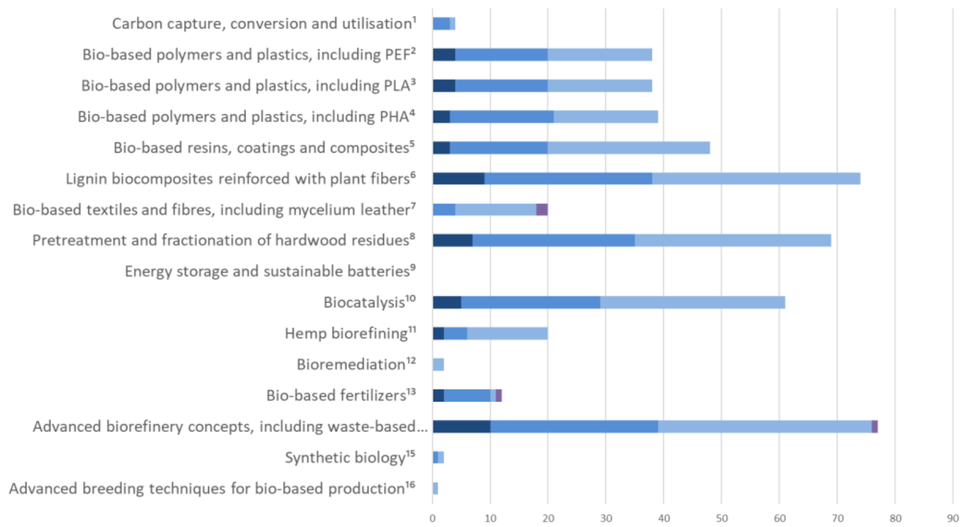
Source: Prognos AG/Idea Consult/nova Institute (2025) based on sources cited in the table (see Reference list for full references).

Figure 36 shows the number of projects funded under CBE JU/BBI JU, broken down by the overarching innovation fields of relevance for the 16 high-potential applications analysed indicating where public investment is currently being directed, which areas are receiving sustained program-

[178] European Commission, *European Circular Bioeconomy Fund (ECBF)*, 2023. Available at: https://circular-cities-and-regions.ec.europa.eu/support-materials/funding-and-financing/european-circular-bioeconomy-fund-ecbf (last accessed September 2025).
[179] ECBF, *Investment criteria*, 2025. Available at: https://www.ecbf.vc/investment-criteria (last accessed September 2025).
[180] European Parliament, *European Regional Development Fund (ERDF)*, 2025. Available at: https://www.europarl.europa.eu/factsheets/en/sheet/95/european-regional-development-fund-erdf- (last accessed September 2025).)
[181] European Commission, *European Regional Development Fund*, 2025. Available at: https://ec.europa.eu/regional_policy/funding/erdf_en (last accessed September 2025).
[182] European Commission, *European Agricultural Fund for Rural Development (EAFRD)*, 2025. Available at: https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/european-agricultural-fund-rural-development-eafrd_en#budget-and-performance (last accessed September 2025).
[183] European Commission, *European Agricultural Fund for Rural Development (EAFRD)*, 2025. Available at: https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/european-agricultural-fund-rural-development-eafrd_en (last accessed September 2025).
[184] European Commission, *European Agricultural Fund for Rural Development (EAFRD)*, 2025. Available at: https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/european-agricultural-fund-rural-development-eafrd_en (last accessed September 2025).
[185] European Commission, *What is the Innovation Fund?*, 2025. Available at: https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/innovation-fund/what-innovation-fund_en (last accessed September 2025).
[186] European Union, *About the InvestEU Fund*, 2025. Available at: https://investeu.europa.eu/investeu-programme/investeu-fund/about-investeu-fund_en (last accessed September 2025).)

matic attention, and which remain less addressed. The CBE JU/BBI JU portfolio shows clear concentration in advanced biorefinery concepts, including waste-based microbial refineries, lignin biocomposites, biomass pretreatment and fractionation, and biocatalysis, which stand out with the highest number of funded projects of relevance. Mid-level attention is given to bio-based resins and polymers (PHA, PLA, PEF, epoxy resins), while hemp biorefining, bio-based textiles, biofertilizers, and $CO_2$ conversion remain more niche. Some high-potential applications, like lignin-based hard carbon anodes, have not been addressed in the scope of the programmes.

**Figure 36 Number of CBE JU/BBI-JTI funded projects by technology**




[1]Covers feedstock gases ($CO_2$, syngas, industrial/biogas, flue gas) with a focus on conversion, utilisation, fixation, enzymatic/biocatalytic routes (FDH, CA, RuBisCO) and biological methanation, [2]Covers PEF/FDCA directly as well as bio-based polymers and plastics, including biopolymers and applications in packaging and performance materials, [3]Covers PLA directly as well as bio-based polymers and plastics, including biopolymers and applications in packaging and performance materials, [4]Covers PHA/PHB/PHBV directly as well as bio-based polymers and plastics, including biopolymers and applications in packaging and performance materials, [5]Covers bio-based epoxies (from lignin, vanillin, cardanol, oils, tannins) for resins, coatings, adhesives, thermosets and composites with natural fibres, [6]Covers lignin and wood-based lignocellulose for composites, resins/adhesives and thermoset applications in pulp and paper contexts, [7]Covers mycelium leather and bio-based textile fibres including MMCFs (viscose, lyocell, modal, rayon), cellulosics and natural fibres (hemp, flax, jute, cotton, wool, silk), [8]Covers wood residues, hardwoods and lignin (kraft, organosolv, lignosulfonate) with focus on pretreatment, fractionation and extraction in pulp, paper and sawmill contexts, [9]Covers energy storage and battery technology, [10]Covers enzymatic processes including biocatalysis, biodegradation, hydrolysis & fermentation, [11]Covers hemp components (fibres, oils, proteins, sugars, bioactives) with focus on extraction/pretreatment, biorefinery concepts, and use in composites, [12]Covers enzymatic/biocatalytic approaches targeting degradation, detoxification and oxidation of pollutants and contaminants, [13]Covers bio-based fertilizers, [14]Covers biorefinery concepts, including cascading use, residue and side-stream valorisation, integrated multiproduct systems and platform chemicals, [15]Covers microbial systems (yeast, E. coli, Bacillus, Pseudomonas) with focus on metabolic engineering, synthetic biology or genome editing, optionally linked to fermentation performance, [16]Covers advanced breeding techniques for bio-based production.

■ Innovation action – flagship ■ Innovation action - demonstration ■ Research and innovation action ■ Coordination and support action

Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on data extracted from the CBE JU project database (accessed August 2025).

In addition to these supply-side enablers, a few EU product-market regulations, in packaging and chemicals, are creating complementary demand signals for selected bio-based products. In packaging, the Packaging and Packaging Waste Regulation (PPWR) in force since February 2025 and applying from mid-2026 prioritises high-quality recyclability and sets mandatory compostability for defined use-cases under Article 9 (e.g., permeable tea and coffee bags, and sticky fruit and vegetable labels). Those provisions create predictable demand for recyclable-by-design biopolymers (e.g., PEF via recyclability-at-scale and compatibility with PET streams) and targeted niches for compostable materials (e.g., PLA, PHA), provided bio-based products are engineered to perform in the relevant end-of-life route and collection systems. In chemicals, the ban on BPA in varnishes and coatings (Commission Regulation (EU) 2024/3190) and upcoming PFAS restriction push markets toward bio-based epoxy systems, accelerating adoption in coatings and composites.

Notwithstanding these institutional enablers, stakeholders also emphasised institutional challenges that limit demand pull and hinder innovation, scale-up, and industrialisation. Annex 5.6 sets out the main barriers by technology, while in the following cross-cutting institutional barriers and their implications are highlighted:

- **Perceived regulatory inconsistency:** A major issue is the perceived inconsistency of regulations. For example, an inconsistency emerges from how the EU Taxonomy applies different rules to bio-based plastics under its two Delegated Acts. The Climate Delegated Act[187] treats bio-based plastics as contributing to climate goals because they reduce fossil resource use and store biogenic carbon.[188] In contrast, the Environmental Delegated Act for the circular economy focuses on recycling and waste reduction, so bio-based plastics are not automatically considered circular unless they also meet recycling or reuse criteria – even if they are renewable or compostable. This inconsistency means a product can qualify as sustainable and eligible for green finance under one environmental objective but fail under another, creating uncertainty for companies and investors about eligibility for green finance. The absence of dedicated NACE codes for bio-based products compounds access-to-finance hurdles.
- **Chemicals regulation not calibrated to bio-based enablers:** Current REACH rules, especially under the Generic Risk Assessment approach, treat enzymes like conventional chemicals creating a risk of disproportionate restrictions or de facto bans. This hazard-based approach ignores their biological origin, low exposure risk in controlled industrial settings, and central role as critical enablers for industrial biotechnology. This is flagged as a barrier for the several of the 16 technologies in which enzyme-intensive pathways are central (e.g., enzymatic bioremediation, enzymatic e-waste degradation; enzyme-catalysed $CO_2$ conversion).
- **Member-State regulatory fragmentation:** Fragmentation of regulations among Member States creates major challenges for innovation scale up and commercialisation according to stakeholders. One example is divergent end-of-waste criteria among Member States for wood residues and other side-streams and a lack of EU-wide home-composting standards, which complicate cross-border operations and the development of EU-wide supply chains for PLA/PHA/PEF, waste-based biorefining, and lignocellulosic pretreatment. EU-wide end-of-waste criteria cover only a few materials, while most materials rely on national end-of-waste decisions and procedures that vary markedly across Member States, resulting in inconsistent classification of identical streams and legal and operational uncertainty for secondary materials traded cross-border.
- **Regulatory complexity and long approval timelines:** In the EU, multi-layered, complex and lengthy authorisations for biomanufacturing facilities and products slow commercialisation and deter investment. Compared to more agile regulatory environments in other markets, these regulatory hurdles lengthen time-to-market, raise financing risk, and delay scale-up, effects repeatedly noted by stakeholders across several of the 16 technologies, e.g., advanced metabolic engineering, plant breeding of non-food crops using CRISPR, waste-based microbial biorefineries, microbial biofertilizers, and lignin-based hard carbon anodes. In some cases, this has prompted firms to shift commercial plants to jurisdictions with faster, more predicta-

[187] European Commission, *Official Website*, December 16, 2025. Available at: https://commission.europa.eu/index_en; https://finance.ec.europa.eu/regulation-and-supervision/financial-services-legislation/implementing-and-delegated-acts/taxonomy-regulation_en; pm-bbcp-framework-he-workshop-23jan24-002.pdf.

[188] "Renewable Carbon News, *Why the EU's Taxonomy Climate Delegated Act Correctly Lists Bio-Based Plastics as 'Green Investments'*, June 8, 2022. Available at: https://renewable-carbon.eu/news/why-the-eus-taxonomy-climate-delegated-act-correctly-lists-bio-based-plastics-as-green-investments/.

ble regulatory pathways (e.g., the U.S. or China). As a result, as highlighted by various stakeholders, the EU increasingly risks forfeiting the economic and strategic value of biotechnological innovations that have been largely developed within its own research and development base.

- **GMO/NGT approvals and associated risk-assessment burdens:** Strict rules on genetically modified organisms (GMOs) represent another critical bottleneck. Advanced metabolic engineering for microbial production of high-value chemicals, enzyme-catalysed $CO_2$ conversion, CRISPR-based non-food crop breeding, and engineered microbial strains – even in closed industrial systems such as enzyme production – are subject to burdensome approval procedures, slowing down innovation in fields with high potential for the EU bioeconomy. For instance, under the ECJ 2018 ruling, organisms obtained by mutagenesis deploying CRISPR fall under GMO rules, triggering the full deliberate-release and market-authorisation approvals.
- **Resource-allocation challenges:** While the Renewable Energy Directive (RED II/III) explicitly adopts the cascading use of biomass to minimise distortive effects on raw-material markets, in practice, stakeholders report that bioenergy targets and incentives can pull biomass feedstocks into energy uses, potentially reducing availability for higher-value applications such as bio-based plastics (e.g. PLA, PHA, PEF) or bio-based chemicals.
- **Public funding gaps at scale-up:** While early-stage R&D is comparatively well supported by EU programmes, capital for pilot, demonstration and industrial-scale facilities remains limited. Two funding gaps persist. The first “valley of death” (TRL 4–6) is often underserved, too advanced for most public research funding, yet still too risky for private investors. The second “valley of death” (TRL 7–9), where capital-intensive, first-of-a-kind scale-up projects lacks de-risking instruments (patient capital, guarantees, revenue support)[189]. As a result, many high-risk ventures struggle to mobilise the blend of grants, soft loans and risk-sharing needed to reach commercial scale. Small and medium-sized enterprises (SMEs), which drive much of Europe’s innovation, face additional barriers due to limited internal capacity to navigate complex multi-agency funding schemes and to structure bankable scale-up packages. Infrastructure gaps compound the problem. Pilot plants, demonstration facilities, and modular bioprocessing infrastructure are unevenly distributed across Europe, limiting the ability to test and validate industrial processes.
- **Conflicting policy priorities limit market pull for bio-based plastics:** Conflicting policy signals currently limit market pull for bio-based plastics. The PPWR places primary emphasis on design for high quality recycling and recycled content, while compostability is confined to narrowly defined applications such as permeable tea and coffee bags and sticky labels on fruit and vegetables, and there are no near-term binding targets for bio-based content, a combination that weakens incentives for PLA and PHA beyond those niches. At the same time, the SUPD explicitly treats bio-based and biodegradable items as plastics, with no blanket exemptions from bans, consumption reduction measures, labelling, and EPR obligations. Coupled with divergent national waste collection practices that often exclude compostables from organic bins, these reduce demand clarity. Unlike energy, where RED II/III set binding targets and create predictable demand, materials have no EU wide targets for bio-based carbon content. The current policy framework for bio-based/biodegradable/compostable plastics is advisory and focuses on conditions of use rather than volumes. Taken together, the recyclability-first emphasis of PPWR, SUPD’s equal treatment of bioplastics and the absence of short-term bio-content targets constrain demand signals for PLA/PHA outside the specific PPWR compostability cases, limiting near-term market uptake. Public procurement can also be a power-

[189] European Investment Bank Advisory Services. (2017). *Access-to-Finance Conditions for Investments in Bio-Based Industries and the Blue Economy*. Prepared for DG Research and Innovation, European Commission. Luxembourg: European Investment Bank. Retrieved from https://www.eib.org/files/pj/access_to_finance_study_on_bioeconomy_en.pdf (last accessed 09/2025)

ful demand lever for bio-based products, but it remains largely underused in the EU. By contrast, the U.S. BioPreferred® program couples mandatory federal purchasing for USDA-designated bio-based product categories with a voluntary certification creating predictable demand[190].

#### 5.3.5 Social acceptance and public perception

Social acceptance of the 16 biotechnological applications varies with public visibility. Social acceptance issues are most pronounced for technologies with high public visibility, such as bio-based plastics and CRISPR-based plant breeding, where societal concerns and social acceptance sensitivity are particularly strong. For instance, the social acceptance of CRISPR-edited crops and processes faces public resistance and remains closely tied to the broader GMO debate, focusing on the potential for unintended genetic effects, even when food production is not involved. The 2018 ruling of the European Court of Justice (ECJ) determined that plant breeding of non-food crops using CRISPR falls under the 2001 EU GMO Directive, meaning that CRISPR-edited crops without foreign genes are regulated in the same way as GMOs with foreign genes/transgenic GMOs. This strict regulatory approach reinforces public perceptions of risk. Bioplastics are high-visibility applications, where social-acceptance challenges are readily identifiable. Confusion by the public around recyclability, compostability and biodegradability leads many to perceive PLA, PHA, and PEF as equivalent to fossil-based plastics. This is further reinforced by the SUPD classification of bio-based and biodegradable items as plastics. As public discourse increasingly associates plastics with pollution and microplastics, bio-based plastics are often rejected alongside conventional ones, even when they offer lower environmental impacts. Visual differences, such as a slight yellow tint in PLA or PHA packaging, further reinforce perceptions of lower quality or hygiene. Although such characteristics do not impact functionality, they influence consumer preference.

By contrast, less visible applications – such as enzymatic e-waste degradation, bio-based epoxy resins, and lignin biocomposites reinforced with plant fibres – attract little public attention and currently face fewer acceptance barriers. These less consumer-facing innovations are instead primarily constrained by regulatory complexity and technical challenges rather than societal concerns.

## 5.4 Assessment of safety, security and environmental sustainability

The objective of this section is to provide a comprehensive assessment of environmental sustainability, safety, and risk dimensions across 16 selected applications Each application was assessed in terms of climate impact, energy, land and water use, and, where meaningful information was available, resource efficiency. Risk and safety aspects were analysed by examining process safety (conditions and chemicals), product safety (toxicity/biocompatibility), and exposure pathways (worker and environmental). A systematic desk review and an AI-driven automated web search with reasoning capabilities were conducted to identify data sources for this task. The

[190] “BioPreferred | Mandatory Federal Purchasing”, 2025. https://www.biopreferred.gov/BioPreferred/faces/pages/MandatoryFederalPurchasing.xhtml.

sources were analysed, results were cross-checked, supplemented and the most relevant findings are integrated in the report. The results for the environmental impacts' categories are summarised in Table 21 and in detail in Annex 5.7. Unless otherwise specified, each application was benchmarked against conventional fossil-based systems to provide a comparative perspective. The results for the risk and safety assessment are summarised, together with all references, in Section 5.4.2 and Table 22 directly.

### 5.4.1 Environmental sustainability

Table 21 provides an overview of the quantitative indicators extracted for the comparison of environmental performance. The choice of reference point varies across applications, reflecting both differences in data availability and in the maturity of the technologies (e.g. varying TRLs). In some cases, the benchmark is a specific use case, while in others it refers more generally to the conventional application.

Across the portfolio of applications analysed, most applications show lower cradle-to-gate GHG footprints than their conventional counterparts, with the advantage generally increasing when renewable electricity or heat is used, thereby also contributing to fuel independence and alignment with European Power-to-X-strategies. Notable outliers at current maturity are enzymatic e-waste degradation and advanced metabolic engineering for microbial production of high-value chemicals (biobutanol case), which at present exhibit higher carbon intensity due largely to elevated energy demand; the engineered cyanobacteria route consumes roughly 4–13× more primary energy per unit of output than the fossil pathway, which typically remains <1 MJ/MJ butanol (see Annex 5.7. By contrast, waste-based, microbial-driven biorefineries can achieve near energy self-sufficiency and are potentially carbon-negative when integrated with waste heat/energy recovery. These patterns reinforce a strong energy– carbon footprint correlation across applications: where process energy demand is reduced or decarbonized, GHG performance improves accordingly.

Land use impacts are minimal for roughly half of the applications, especially those built on side-streams (e.g., lignin-based materials, hardwood residues pretreatment) or waste valorisation. The conspicuous exception is PEF (versus PET in 250 ml bottles), where land occupation is reported at about 7× the conventional alternative; this reflects current bio-based feedstock sourcing and could be moderated with feedstock shifts and yield improvements. PLA also entails non-trivial land footprints (1–3 $m^2$ per functional unit where relevant), consistent with primary agricultural inputs (see Annex5.7).

Water use shows a mixed picture. Approximately half of the applications consume less water than the reference, while several polymer routes consume more. PLA's blue-water footprint is ~3–4× PET, and PEF's water depletion is ~1.5× PET (see Table 21 and Annex 5.7). In contrast, mycelium leather and microbial biofertilizers tend to use less water than their benchmarks, and waste-based biorefineries can offset higher water needs by integrating wastewater reuse.

**Table 21 Overview environmental performance of the 16 applications**

| Application | Reference point/example | Climate impact | Energy use | Land use | Water use |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Enzyme-catalysed $CO_2$ conversion | Enzyme-enhanced $CO_2$ absorption (carbonic anhydrase + MDEA solvent) vs. conventional MEA-based capture | - 9% | - 3,50% | - | 133% water depletion |
| Polyethylene Furanoate (PEF) | PEF vs. PET 250ml- bottles | -33% to -74% | -44% | 700% | 148% |
| Polylactic Acid (PLA) | General | Up to -70% when renewable energy is used | ~ -35% | Around 1-3 m2 compared to none | 300 to 400% blue water footprint |
| Polyhydroxyalkanoates (PHA) | General | From equal to up to -67% | -47% | - | - |
| Bio-based epoxy resins | Bio-based liquid epoxy raisins LER) vs. average petrochemical-based LER | -13/14%;<br><br>up to - 50% reductions in general | -11/12% | Minimal | - 15/16% |
| Lignin biocomposites reinforced with plant fibres | General; climate impact range for general use of lignin with fossil-based alternative; lignin-based carbon fibres renewable vs. base case for energy use | Between 0% and -90%;<br><br>-32% for lignin based-carbon fibres vs. glass fibres | - 49% | - | up to -40% |
| Mycelium leather | Mycelium leather vs. synthetic PU/PVC leather & vs. animal leather | - 67-85% vs. synthetic PU/PVC leather, up to - 98% vs. animal leather | Less energy vs. both options, not quantified | Minimal | -58% vs. animal leather |
| Pretreatment and fractionation of hardwood residues | Compared to fossil-based systems | Up to -50-80% | Approaching energy self-sufficiency is possible | Minimal | High water use, recycling of solvents is important |
| Lignin-based hard carbon anodes | Sodium ion battery with hard carbon anode made | +- 0% (all in the same ranges 50-64 lower and 120-140 kg | Low net emissions | Low, as lignin is harvested as a byproduct | - |

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| | of lignin vs. anode made of phenolic resin & vs. LIB | CO2eq/kwh upper value) | when using clean energy | | |
| Enzymatic e-waste degradation | Enzymatic vs. hydrometallurgical and pyrometallurgical processes | Enzymatic can potentially be lower, but is currently higher | Enzymatic uses smaller energy input over longer time | Land use is not studied | Enzymatic uses most water |
| Hemp biorefining | Natural fibre composites compared to glass fibre composites (1); hemp vs. traditional cotton (2) | - 53- 77% (1) | -83% energy required (1) | - 50- 67% (2) | - 50-80% (2) |
| Enzymatic bioremediation | Oil-polluted soil using a bio-stimulation approach with bioremediation compared to soil remediated by using diesel oil | - 20-35% | - 48-57% | Less land use | Less water use |
| Microbial biofertilizers | Compared to synthetic biofertilizers | - 90-95% | - 44-72% | No significant land use | Less water use |
| Waste-based microbial-driven biorefinery | General | Potentially carbon negative | Potentially energy self-sufficient around 85% more energy generation | Minimal | More water use but can integrate wastewater reuse |
| Advanced metabolic engineering for microbial production of high-value chemicals | Engineered cyanobacteria biobutanol vs. Butanol with the fossil reference | 127% | Around 400- to 1300% more energy demand | Minimal | Comparable water use |
| Plant breeding of non-food crops using CRISPR | CRISP chicory compared to conventional chicory | - 11-14% | -14% | Slightly less land use | Slightly less water use |

Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on environmental performance dataset (see Annex 5.7 and accompanying list of references).

### 5.4.2 Risk and safety

Table 22 summarizes the findings regarding safety and security for every application. Overall, the bio-based and bio-enabled pathways tend to be safer at the point of use and in routine operation than many fossil incumbents: lower operating temperatures/pressures, reduced use of carcinogenic/toxic reagents (e.g., elimination of BPA in several bio-epoxy systems), and materials with lower inherent toxicity or improved biodegradability (e.g., PHA, mycelium leather). Where risks rise, they are manageable and well-characterised: solvent handling in hardwood pretreatment, bioprocess containment for engineered microbes or enzyme production, dust exposure in fibrous plants, and additive selection in biopolymers. For certain emerging routes (e.g., enzymatic e-waste degradation), scale-up risks are more about process reliability, water management, and complete degradation than acute chemical hazards.

**Table 22 Overview of safety and risk considerations for the 16 applications**

| Application | Safety and risk |
|---|---|
| Enzyme-catalysed $CO_2$ conversion | Enzymatic processes are generally considered safer than conventional $CO_2$-conversion technologies, as they operate at ambient temperatures and pressures, reducing the risk of explosion or thermal runaway[191]. Enzymes are non-toxic and biodegradable, thereby avoiding hazardous solvents or metal-based catalysts[192]. When microbes or genetically modified enzymes are employed, bioprocess safety protocols apply, and standard hydrogen safety measures remain essential if hydrogen is used as a reductant. Operational challenges include enzyme stability and cofactor regeneration, although advances in enzyme engineering and immobilisation are helping to address these bottlenecks[193]. |
| Polyethylene Furanoate (PEF) | PEF demonstrates strong potential for safe use in food packaging, as its monomers have been assessed as safe and it shows low additive migration[194]. However, certain production processes – particularly those involving microwave technologies or UV exposure, raise concerns regarding thermal and UV stability, which may pose challenges for packaging applications[195]. In addition, the use of metal and enzyme-based cata- |

[191] Rouf. et al., *CO2 hydrogenation to formate by immobilized formate dehydrogenase: Challenges and opportunities*. International Journal of Hydrogen Energy, Volume 142, 2025, P. 1067-1074, Available at: https://doi.org/10.1016/j.ijhydene.2024.12.492., 2025.
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[195] Bello, M. et al, Bio-Polyethylene Furanoate Production in Latin America as a Response to the Current Needs for Sustainable Food Packaging. *J Polym Environ* 33, 1792–1813, 2025. https://doi.org/10.1007/s10924-025-03530-7; Sanders, J.H. et al., Bio-based Polyethylene Furanoate: Production Processes, Sustainability, and Techno-Economics. *Advanced sustainable systems*, Volume 8, Issue 11, 2022, https://doi.org/10.1002/adsu.202400074

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| | lysts in Bio-PEF synthesis can lead to issues such as dark coloration, reduced stability, and potential toxicity[196]. While organic enzyme catalysts represent a possible alternative to mitigate these drawbacks, their complex production and relatively low catalytic efficiency currently limit their practical application. |
| Polylactic Acid (PLA) | PLA is approved for food contact by both EU and U.S. authorities and contains no BPA, phthalates, or styrene, making it safer than many conventional plastics.[197] However, research has shown that bioplastics, including PLA, can exhibit in-vitro toxicity levels comparable to those of conventional plastics, highlighting the importance of chemical safety and additive use in the design of safer and more sustainable plastic alternatives[198]. |
| Polyhydroxyalkanoates (PHA) | PHAs are biocompatible, non-toxic, and free of harmful leachates, avoiding many of the health risks associated with synthetic plastics [199]. They degrade into natural substances without leaving persistent pollution or microplastics, thereby reducing long-term risks to ecosystems and human health. While solvent extraction – particularly when chloroform is used – requires strict safety controls[200], PHAs generally need fewer additives, which are typically bio-based and low in toxicity. A remaining challenge lies in ensuring proper waste handling to fully realise their environmental and safety benefits. |
| Bio-based epoxy resins | Conventional epoxy resins often contain hazardous substances such as bisphenol A (BPA) and epichlorohydrin (ECH), which pose health and environmental risks due to their toxicity during handling and use[201]. Bio-based alternatives frequently eliminate BPA, thereby reducing associated health concerns and typically exhibiting lower volatile organic compound emissions.[202] Many of these resins are derived from by-products such as glycerol or lignin, which also helps to avoid competition with food resources. |
| Lignin biocomposites reinforced with plant fibres | Lignin-fibre biocomposites are generally safer than conventional petrochemical composites, as they rely on fewer toxic inputs –for example, adhesives with lower formaldehyde content that reduce VOC emissions[203]. Lignin char formation can enhance fire resistance,[204] although the material remains combustible and requires protection from moisture and UV exposure to prevent degradation during use. With appropriate design considerations, these composites are well suited for non-structural or semi-structural applications. |

[196] Bello, M. et al., 2025.
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| Mycelium leather | Mycelium leather has a very low toxicity profile, as its production is based on biological processes that do not require heavy metals or hazardous tanning agents.[205] Compared with both synthetic and animal leather, it demonstrates lower impacts across all toxicity categories[206]. It is also safer for workers and end-users, as it contains no harmful residues. |
| Pretreatment and fractionation of hardwood residues | The process involves handling high temperatures, and in some cases, high-pressure equipment, as well as either corrosive acids or flammable solvents, depending on the pretreatment method[207]. The use of flammable solvents introduces fire and explosion hazards, requiring robust explosion-proof equipment and continuous monitoring[208]. |
| Lignin-based hard carbon anodes | From a manufacturing perspective, lignin-based anodes can be produced using fewer hazardous chemicals, enhancing workplace safety and reducing environmental risks[209]. The water-wash process primarily involves only biomass and water. In contrast, graphite mining and synthetic graphite production require reagents such as hydrofluoric or sulfuric acid and can generate toxic byproducts[210]. |
| Enzymatic e-waste degradation | Enzymatic e-waste degradation offers a high level of safety. It does not involve toxic fumes, high temperatures, or molten phases, which enhances worker safety[211]. Air pollution is minimal, and the risk of contaminating water or soil is low because the process is contained and gentle[212]. Overall, the process is stable, slow, and easy to control or halt if necessary. The main consideration is to ensure complete degradation, as incomplete processing could leave behind toxic residues[213]. |

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[213] Directory, Sustainability, “E-Waste Bioremediation → Term”, Prism → Sustainability Directory, Oktober 3, 2025. https://prism.sustainability-directory.com/term/e-waste-bioremediation/#:~:text=,Phytoremediation%2C%20for.

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| Hemp biorefining | Hemp-based materials are generally non-toxic and do not produce harmful off-gassing. Their production processes are typically safer than those in oil refineries or chemical plants, as they do not involve extremely hazardous chemicals, reducing the risk of accidents[214]. However, hemp fibre dust can pose respiratory hazards, so dust control measures and personal protective equipment are necessary[215]. |
| Enzymatic bioremediation | Enzymatic bioremediation offers a high level of safety, as it does not involve live pathogens or extreme chemicals. Enzymes operate under mild conditions, minimizing the risk of toxic exposure, accidents, or fires[216]. Being biodegradable and non-infectious, the proteins are safe to handle, and the process generates only minimal emissions[217]. There is no risk of organism release or genetic material spread, as the enzymes used are non-living. |
| Microbial biofertilizers | Microbial biofertilizers are generally safe when produced and applied according to recommended guidelines. They enhance safety for farmers by reducing chemical handling and for consumers by lowering chemical residues in food[218]. Key safety measures focus on maintaining biological integrity: ensuring that only the intended beneficial microbes are applied, avoiding contaminants, and keeping microbial populations within environmentally safe levels[219]. Current evidence indicates that biofertilizers made from well-characterized strains do not pose significant risks to human health or ecosystems. |
| Waste-based microbial-driven biorefinery | Waste-based microbial biorefineries introduce additional safety, health, and security considerations compared to traditional waste management[220]. Yet. there is a significant risk of bacterial, viral, or pathogenic contamination, so the waste must be thoroughly treated, such as through sterilization or sanitization, before or during the biorefinery process[221]. These biorefineries combine biological hazards with the risks typical of chemical plants. Therefore, safety management must address both aspects by implementing good biocontainment practices alongside standard chemical process safety measures. |
| Advanced metabolic | Risk assessment follows established guidelines for genetically modified organisms (GMOs), with industrial strains typically evaluated under EPA or EFSA frameworks. The current consensus is that properly contained engineered microbes do not require stricter regulation than conventional organisms[222]. To date, no |

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| engineering for microbial production of high-value chemicals | major incidents have been linked to industrial GMO production, and the technology is generally considered safe when biosafety standards are applied. Security risks are mitigated through custody controls on genetic materials and by using non-pathogenic chassis[223]. In practice, the chemical safety benefits from avoiding hazardous reagents often outweigh any novel biological risks. |
| Plant breeding of non-food crops using CRISPR | No increased risks have been scientifically established for genome-edited crops compared to conventional breeding methods[224]. In fact, conventional breeding can introduce far more random mutations without undergoing regulatory safety checks. Beneficial traits such as drought tolerance or improved nitrogen-use efficiency may enhance environmental safety by reducing irrigation or fertilizer requirements. However, traits that promote monoculture or chemical dependence could have negative impacts if mismanaged. Environmental risk assessments therefore also consider whether an edited crop could present greater risks of invasiveness or cross-breeding than its conventional counterparts[225]. |

Source: Prognos AG/Idea Consult/nova Institute (2025), own analysis based on sources cited in the table (see Reference list for full references).

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# 6 Conclusions and policy recommendations

## 6.1 Conclusions

The status of bio-based industrial systems in the EU reveals a complex landscape characterized by significant potential and notable challenges. Successful case studies highlight that while the bio-based sector competes with fossil-based value chains, it plays a crucial role in enhancing the EU's industrial autonomy and resilience through strong ties to local economies. Key lessons drawn from these cases emphasise the importance of technological leadership, effective feedstock management, and the development of high-value products that meet market demands. Furthermore, the challenges of high initial investment costs, skills shortages, and administrative burdens underscore the need for targeted policy support and funding initiatives. By fostering innovation and collaboration, the EU can leverage successful bio-based systems to drive economic growth, reduce environmental impacts, and create a sustainable industrial future.

With regards to highly promising emerging biotechnological applications, the study set out to generate evidence on the opportunities and challenges related to innovation and scale-up. The analysis confirms that biotechnology and biomanufacturing in the EU hold significant growth potential, with the EU mirroring worldwide growth trends, while demonstrating leadership in applications such as lignin bio composites and hemp biorefining. While some technologies, such as PHA, are likely to remain niche, others – most notably enzymatic e-waste degradation – could open multi-billion-euro markets by 2030. Some more mature technologies like PLA are approaching cost parity with fossil-based alternatives, signalling readiness for broader market adoption. These trends underscore the major potential of these high potential applications.

Sustainability emerges as a core advantage of the 16 high potential applications. Most of the applications analysed deliver clear greenhouse gas (GHG) reduction benefits compared to fossil-based counterparts, and waste-based biorefineries even offer the potential for carbon-negative performance. This reinforces the strategic role of biotechnology in achieving EU climate neutrality and circular economy objectives.

From an innovation perspective, the EU demonstrates strong capabilities in downstream applications, such as biomass valorisation and bio-based materials, supported by robust patent activity. However, it lags in foundational biotechnological platforms, including CRISPR, synthetic biology, and advanced metabolic engineering. This imbalance suggests that while the EU is well-positioned to capture value in applied markets, its long-term competitiveness could be constrained without strategic investment in enabling technologies. Strengthening these capabilities is essential to avoid dependency on external innovation ecosystems and to maintain leadership in transformative biotechnologies. Opportunities in synthetic biology, modular bioprocessing, and AI-enabled technologies align closely with EU policy priorities, including the Bioeconomy Strategy and Circular Economy Action Plan. The EU’s strong strategic commitment, combined with substantial public funding through programs such as Horizon Europe, CBE JU, and ECBF, provides a solid foundation for innovation and scale-up.

Despite these favourable conditions, persistent structural challenges remain. Scale-up and commercialization bottlenecks, financing gaps – the “double valley of death” – and regulatory fragmentation across EU and national levels continue to hinder progress. Additional risks include the offshoring of production due to higher regulatory burden in the EU in comparison to other regions, as well as uneven societal acceptance, particularly for new genomic techniques (NGTs). Addressing these barriers will require coordinated EU and national actions.

The study also examines biomass availability in the EU, which is a central prerequisite for fostering bio-based industries. The analysis shows that the EU possesses a broadly stable biomass base, but sectoral shifts will redefine demand and supply patterns and the impact of policy measures can both reduce or increase domestically available biomass.

The moderate growth in supply of agricultural biomass contrasts with the declining food/feed demand and the sharp contraction in biofuels, which is projected by several major studies. It is very worthwhile to note that this is the only sector which may even grow further, depending on the exact impact of policy measures. The highest potential for increasing domestic biomass supply was found in the agricultural sector.

The supply of woody biomass will expand moderately according to the baseline scenario, but demand growth, especially for pulp, packaging, and bio-based materials, may create supply pressure. Environmental policies can impact wood harvests even further, if more area is protected. Organic waste currently is underexploited, but increased collection and treatment could make it a more relevant and significant feedstock for circular bioeconomy pathways. However, waste reduction targets are in stark contrast with an overstated potential. Considering the strong focus of recent bioenergy and biofuels policies on these resource streams, this is a very relevant insight. Further bioeconomy policies cannot only rely on secondary resources only, instead, policy needs to address those measures that can sustainably increase the yields of agricultural crops. This will be crucial for long-term availability of biomass in Europe. Correspondingly, it will be key that the use of crop-based biomass will be accepted for industrial material uses of biomass.

Regarding the competition between energy and material uses of biomass, the analysis clearly shows that binding, quantitative policy targets only exist for the energy production, shifting the demand to this sector for years now. To fully support circularity and gain the most value our of limited bio-based resource a balanced and harmonised policy framework based on the cascading principle is necessary. While strengthening domestic biomass supply is essential, a thriving European bio-based industry will also need to rely on imported resources. Trade analysis reveals structural vulnerabilities and critical dependencies in the EU's supply of imported raw materials and intermediates relevant for bio-industrial applications. This dependency on a limited number of supplier countries for key resources presents risks, especially as global demand for bio-based materials continues to grow.

Establishing reliable and diversified supply chains will be crucial, yet challenging, given the high concentration of global markets among a few supplier nations. For resources with elevated supply risks, case studies demonstrate strategies to reduce import dependence. These examples underscore the importance of policies that promote domestic biomass production and foster innovation in bio-based materials.

The biomass analysis, together with the trade and scenario assessments, indicates that Europe remains both an importer and exporter of specific biomass categories. The EU has never been fully autonomous in this regard; rather, it maintains well-established trade relations within global markets. Whether feedstock demand is met through domestic crops or imports depends not only on theoretical availability but also on critical factors such as quality requirements and, most importantly, price. Consequently, the allocation of feedstock between domestic and imported sources is determined by a complex interplay of parameters that could not be comprehensively assessed within the scope of this study.

The results show that under a business-as-usual scenario, biomass production in Europe will increase only marginally. If industrial biomass use expands, part of this growth may be offset by a decline in biofuel demand in the analysed scenarios. Nevertheless, overall demand for domestically produced biomass is expected to rise. This will either increase existing import requirements—particularly for oils, fats, and sugars—or reduce the quantities available for export, such as starch. To enhance capacity and maintain flexibility in responding to fluctuating biomass demand, the EU should prioritise innovation aimed at sustainably increasing agricultural yields and improving land-use efficiency (see Section 6.2.1 on feedstock security). Such measures would enable the EU to adapt to diverse future scenarios while safeguarding ecosystems. Regarding the question of whether scaling up bio-based industries will increase or decrease dependence on raw material imports, the findings do not allow for a definitive yes-or-no conclusion. However, when compared to the EU's extremely high import dependence on fossil resources[226] the bioeconomy offers significantly greater flexibility and potential to expand domestic biomass production than fossil fuels do.

In summary, the EU bioeconomy stands at a pivotal moment. The opportunities are substantial, but so are the challenges. Strategic, coordinated action is essential to ensure that Europe not only captures the economic benefits of biotechnology but also leverages its sustainability advantages to meet climate and circular economy goals.

## 6.2 Policy recommendations

Efforts to scale up the EU's bioeconomy and strengthen its global competitiveness must be embedded in a comprehensive, coherent, and forward-looking policy framework, rather than pursued through isolated measures. The recommendations presented in this chapter outline actions across key areas, which should be aligned in a prioritized and integrated roadmap: securing sustainable biomass and reducing trade dependencies, fostering market formation, and driving innovation, with particular emphasis on accelerating scale-up and commercialization. Policy coherence and synergy are essential to avoid fragmented or competing initiatives. Current and forthcoming initiatives – such as the EU Bioeconomy Strategy, Biotechnology Act, and Circular Economy Act – must be aligned to create a supportive and predictable environment for investment and innovation. Furthermore, timely action is critical to secure the EU's leadership in the global bioeconomy. Acting now will accelerate progress toward climate and circularity objectives, strengthen industrial competitiveness, and attract long-term investment to Europe.

### 6.2.1 Secure and reliable feedstock availability

Securing a sustainable and sufficient feedstock supply is a key prerequisite for scaling Europe's bio-based industries. Waste and residues play a crucial role as sustainable feedstocks, and their efficient use must be maximized through improved collection, processing, and valorisation. However, even with full utilization, they cannot meet current and projected demand alone. Diversified strategies –including sustainable primary biomass – are indispensable. At the same time, Europe faces competitive disadvantages from high raw material costs (e.g., sugar) which risk pushing bio-

[226] 95% for oil, 88% for gas and 53% for coal, see IEA Bioenergy, *Implementation of bioenergy in the European Union – Update, 2024*.https://www.ieabioenergy.com/wp-content/uploads/2025/01/CountryReport2024_EU27_final_v2.pdf].

based production outside the EU. Policy has been taken to address the feedstock challenge, by enabling sustainable agricultural production, diversifying sources, and ensuring competitive access for EU industries.

1. Boost sustainable biomass through modern agriculture

The biomass supply scenario analysis has shown that agricultural systems offer the greatest potential to expand sustainable domestic biomass supply. Policy should promote modern agricultural techniques, regenerative practices, facilitate the application of state-of-the-art breeding methods and soil health measures. Most of the policies analysed above are not yet binding, but on strategic level. It will be important to demonstrate determination and to create more long-term planning security by adopting binding legislation. Measures include adopting product-based criteria for certain NGT plants, and CAP-linked incentives that tie payments to measurable soil health KPIs and regenerative practices. In addition, targeted incentives could enable farmers to produce sustainable feedstocks for non-food uses, such as sugar beet and starch-rich crops, backed by long-term, reliable policy frameworks. Specific support could include direct payment programmes, investment grants, and long-term market certainty instruments. Social acceptance challenges and restrictive third-party labels on NGTs/GMOs must be addressed through clear labelling strategies and communication campaigns.

2. Accelerate electrification to reduce biomass competition

The growing trend toward electrification of transport is a key lever to reduce competition for biomass and ensure its optimal use. Policy should provide a clear regulatory framework to create functioning markets for electrification, while supporting transition pathways for existing biofuel refineries through refurbishment and repurposing. Energy policies must also be aligned with Land Use, Land Use Change and Forestry (LULUCF) objectives, as the emissions from bioenergy are considered there. A phased and predictable transition is essential to give industry confidence, avoid stranded assets, and safeguard biomass for high-value industrial uses, such as chemicals and advanced materials.

3. Mobilise waste feedstocks for climate targets

Analysis of policy targets shows that organic waste availability is limited, yet current objectives for biomethane and sustainable aviation fuels (SAF) rely heavily on these resources. To maximize their contribution, the EU should establish clear End-of-Waste criteria for biowaste and ensure full implementation of collection and recycling obligations. At the same time, the waste sector remains fragmented and structurally locked-in, partly due to existing incineration infrastructure. Regulatory reforms are needed to remove these barriers, promote circularity, and enable waste streams to flow toward advanced bio-based production.

4. Enable complementary crop use for high-value biomanufacturing

Industrial biomanufacturing should not be limited to waste streams; plant-derived sugars from starch- and sugar-rich crops remain critical carbon inputs. Policy should allow the use of all sustainable biomass types for material applications, while enforcing land-use impact assessments and cascading use principles – prioritising food and feed first, industrial materials second, and energy last. Complementary use of food crops in a circular and resource-efficient manner can help increase feedstock availability without compromising food security. EU policies, including the Renewable Energy Directive (RED III), should avoid imposing caps on industrial use of plant sugars. This could also be an important line of support for European farmers, offering additional outlets of products in times of declining food markets and fostering innovation and resilience. Support measures could include investment grants for sugar extraction facilities and R&D programs to improve process efficiency.

5. Strengthen supply chain resilience and diversification

While measures should prioritise the production and use sustainable domestic biomass Europe is a globally interconnected trade partner and will remain dependent on imports to meet its increasing demands for biomass feedstocks. The analysis has shown significant supply risks associated with the concentration of imports from a limited number of supplier countries. Strengthening the resilience of import supply chains is key to secure supply. The EU should develop strategies to secure and diversify its supply chains for critical bio-based and fossil-based materials. This includes establishing trade agreements with a broader range of countries, which may involve quotas with reduced tariffs for selected feedstocks, such as in the Mercosur-EU agreement. Further measures should support the development of alternative suppliers, such as diversification and reshoring incentives. Emphasis should be placed on materials where the EU has a high dependency on imports, such as palm oil, soybeans/soybean oil, crude sunflower oil, and crude tall oil. Furthermore, bio-based innovations can help address challenges related to critical raw materials such as phosphorus, graphite, and lithium. For example, lignin-derived hard carbon has been shown to be well suited for use in sodium-ion batteries as an alternative to lithium-ion batteries (see Table 18 p. 103-4), thereby reducing the need for graphite as an anode material and decreasing reliance on lithium, while mitigating broader critical raw material risks. The EU should therefore further advance the development of alternative bio-based phosphorus sources, as well as promising approaches such as lignin-based anode materials for next-generation battery technologies.

#### 6.2.2 Supportive market conditions for bio-based industrial systems

For Europe's bioeconomy to scale, innovation support must be matched with supportive market conditions. Today, fragmented regulations, inconsistent definitions, higher costs and stricter sustainability requirements compared to fossil-based industries undermine competitiveness and deter investment. The priority is to create predictable demand, harmonized rules, and clear go-to-market pathways. This includes regulatory coherence, market-pull measures such as green procurement, such as the BioPreferred® program established in the US, and a level playing field with fossil-based products. Only with long-term certainty and fair market conditions will Europe attract large-scale investments and secure industrial capacity in bio-based systems.

6. Create lead markets and demand-pull for bio-based products

The EU should move to feasible and mandatory rules that create more predictable, long-term demand and viable business opportunities for bio-based investments over a 15–20-year horizon. This means converting high-level goals into binding market-pull mechanisms that de-risk scale-up and commercialization providing stronger competitive opportunities for EU-based bio-based industries compared to other regions. First, binding bio-based content targets should be integrated into in all relevant product legislation (e.g., Packaging and Packaging Waste Regulation – PPWR, Ecodesign for Sustainable Products Regulation – ESPR, End-of-Life Vehicles Regulation – ELVR), with realistic but ambitious timelines and coverage beyond niche applications. In parallel, the EU should identify "lead markets" based on transparent criteria (e.g., high substitution potential, emissions abatement, strategic resilience) and back them with mandatory green public procurement (GPP) criteria that prioritize bio-based content. Complementary instruments can further strengthen this framework. Regulatory sandboxes should allow companies to test innovative products and business models, while recognition of mixed feedstocks and mass balance approaches will enable diverse manufacturing configurations to contribute toward targets. Time-bound incentives, such as capacity-reservation contracts or guaranteed offtake agreements, can help bridge the green-premium gap while scale economies develop. Public funding should also be tied to market readiness. Support for first-of-a-kind (FOAK) and commercial-scale plants should be conditional on credible go-to-market strategies, including offtake agreements and compliance with GPP or bio-based thresholds to ensure that capital support is matched by demand creation. Finally, ensure feedstock security for prioritized lead markets. If needed, temporarily allow first-generation feedstocks under robust sustainable-sourcing frameworks, while scaling regenerative supply and advanced biomass to balance environmental and industrial needs.

7. Ensure regulatory coherence and a level playing field for bio-based products

Building a competitive bioeconomy requires a predictable and coherent regulatory framework that reflects the distinct nature of bio-based industries and removes structural advantages for fossil incumbents. This starts with clear definitions and classifications: the EU should adopt a common definition for bio-based sectors and update statistical systems. Current NACE codes do not distinguish bio-based from fossil-based production, making it difficult to track investment and growth. A practical solution is to introduce sub-codes or tags within existing categories, an approach consistent with Eurostat's approach to emerging sectors like renewable energy. Life-Cycle Assessment (LCA) methodologies should also be adapted to account for bio-specific factors (e.g., carbon cycling, biogenic carbon, land-use and co-product credits) and not default to fossil baselines. Regulatory alignment is essential. EU Taxonomy criteria for bio-based plastics should be harmonized across climate and circular economy objectives by aligning the Climate Delegated and Environmental Delegated Acts so that bio-based plastics meeting strict sustainability criteria are recognized under both objectives[227]. Compliance processes must become simpler and more consistent. Certification schemes should be harmonized and stripped of unnecessary add-on requirements that go beyond legal obligations, reducing costs and complexity for businesses. At the same time, regulatory inconsistencies that that block innovation and scale-up need to be addressed for instance, align REACH processes (e.g., enzyme assessments under Generic Risk Assessment) with the EU Bioeconomy Strategy to avoid inadvertent bans on enabling technologies. Similarly, fix product-classification asymmetries (e.g., under the Single-Use Plastics Directive – SUPD) so that industrially produced but sustainable chemicals, such as, for instance, biopolymers are not penalised relative to chemically identical "natural" counterparts. Legal frameworks should also codify recognition of mass-balance approaches across horizontal and sectoral legislation, ensuring flexibility in feedstock integration. To create a level playing field, fossil-based products must be subject to equivalent sustainability reporting and transparency requirements, correcting the current asymmetry where bio-based products face higher compliance costs. Legislation should implement the cascading-use principle to prioritize high-efficiency, high-value biomass applications, complemented by biomaterial targets comparable to existing bioenergy objectives. Finally, where justified by climate and resilience goals, preferential conditions – such as targeted

[227] This need for alignment is reinforced by the European Commission's recent statement in the Stakeholder Consultation Synopsis Report, which confirms that the Commission is considering revisions to the EU Taxonomy Delegated Acts to properly recognise sustainable biomanufacturing and other bio-based economic activities as key enablers of the green transition. See European Commission, *Commission Staff Working Document – Stakeholder Consultation – Synopsis Report. Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Strategic Framework for a Competitive and Sustainable EU Bioeconomy*, SWD(2025) 895 final, Brussels, 27 November 2025. Available at: https://environment.ec.europa.eu/document/download/1b42ec76-984d-4de1-a66c-f8b062058ad6_en?filename=SWD_2025_895_1_EN_rapport_de_synthese_part1_v4.pdf

incentives or mandates – should be considered for strategic bio-based products, balancing sustainability with industrial competitiveness to prevent investment leakage outside the EU.

### 6.2.3 Innovation ecosystem and scale-up

To strengthen EU competitiveness and attract investments in bioeconomy, the Bioeconomy Strategy must support the acceleration of the transition from research and development to market deployment. While continued support for research and early-stage development remains essential, the policy focus should increasingly shift toward rapid scale-up, enabling large-scale investments, and addressing regulatory and feedstock challenges to ensure that bio-based products reach the market and deliver measurable impact. The strategy should be inclusive, supporting both transformative and disruptive biotechnological innovations and fully bio-based value chains, as well as incremental improvements and substitution of fossil feedstocks in conventional industries.

8. Address scale-up bottlenecks and financing gaps (“double valley of death”)

Europe’s bio-based sector faces two systemic scale-up challenges: moving from pilot to demonstration (TRL 4–6) and from first-of-a-kind plants to early commercial deployment (TRL 7–9). While support for research and early development remains important, the priority must shift to industrial deployment and commercialization, with a stronger focus on the second “valley of death,” where capital-intensive projects struggle to secure financing. To close this gap, EU policy should prioritize TRL 6–8 for industrialization and ensure TRL 9 is supported through dedicated instruments such as InvestEU and the European Circular Bioeconomy Fund. Other key actions include expanding open-access scale-up infrastructure, guided by a gap analysis to identify technology areas where capacity is lacking, providing patient and risk-sharing finance for FOAK projects through blended instruments that crowd in private capital. Beyond that, implement systemic reforms to improve access to growth capital, as outlined in the European Parliament’s June 2025 Blueprint,[228] while adopting short term measures to bridge the gap, such as pooling Member State resources into large-scale venture and growth equity funds, and incentivizing corporate investment through tax credits or co-investment guarantees. However, funding alone will not close the scale-up gap. Financial measures must be complemented by regulatory and market actions: streamlining permitting, introducing green public procurement and bio-based labelling, fixing LCA and finance rules, and ensuring sustainable feedstock supply.

9. Strengthen EU foundational biotechnological capabilities in emerging platforms

The EU lags the US and China in foundational biotechnological platforms such as CRISPR, synthetic biology, and metabolic engineering. Future and existing frameworks – such as the Biotech Act, the Net-Zero Industry Act (NZIA), and the Bioeconomy Strategy – must explicitly support biotechnology innovation to keep pace with global innovation and secure Europe’s competitiveness in the global bioeconomy. The EU should finalize a risk-based framework for New Genomic Techniques (NGTs) that extends beyond plant breeding to cover microbial engineering, synthetic biology, and metabolic pathway design – core enablers of the bioeconomy. This framework should classify products by risk rather than process, enabling faster, lighter approvals for low-risk edits (e.g., CRISPR-based changes without foreign DNA) while maintaining strict oversight for complex constructs. It should also move beyond the current contained use/deliberate release dichotomy.

[228] “Breaking Barriers: A Blueprint for Capital Markets Integration in the European Union”, July 8, 2025. https://www.euronext.com/en/news/breaking-barriers-blueprint-for-capital-markets-integration-european-union.

EFSA's recent scientific opinion reinforce this shift, concluding that cisgenesis and many site-directed mutagenesis outcomes do not introduce new hazards compared with conventional breeding and that genome editing can reduce unintended modifications, thus supporting proportionate, product-focused oversight rather than blanket treatment under legacy GMO rules[229]. On intellectual property, we recommend ensuring patent protection for genuine NGT-based technical inventions (e.g., specific edited traits, methods), while pairing this with safeguards (e.g., transparency, breeders' exemptions, and monitoring) to prevent lock-in and maintain access. This is essential to incentivize R&D, promote disclosure, and sustain Europe's competitiveness, particularly as global competitors (e.g., US, China) operate under strong IP regimes. Consistent with stakeholder analyses from the European Patent Attorneys' Institute (epi) and AIPPI, an across-the-board patent ban would likely depress disclosure and R&D incentives, and plant variety rights alone cannot substitute for patents on technical traits or methods[230]. A balanced approach therefore addresses legitimate concerns about lock-in and affordability through targeted fixes rather than blanket exclusions, while avoiding innovation flight, reduced private investment, and greater dependency on foreign technologies. Other actions include launching mission-driven R&D programmes and building on initiatives such as IBISBA (Industrial Biotechnology Innovation and Synthetic Biology Accelerator) and scaling with national nodes to develop a pan-European network of biofoundries and pilot plants. Complementary measures should stimulate market uptake and investment. These include demand-side incentives such as green public procurement and capacity-reservation contracts, as well as targeted financing instruments to close scale-up gaps.

10. Promotion and funding for R&D initiatives for domestic bio-based materials

Policy should prioritize R&D projects that convert domestic biomass, residues, and waste into industrial inputs such as methanol, ethylene, and polylactic acid (PLA). Grants should be tied to realistic feedstock supply plans, with funding criteria that include feedstock risk assessments, land-use impact evaluations, and alignment with strategies to bridge the "valleys of death" in scale-up. Public-private partnerships, tax incentives, and EU programmes – such as the CBE JU, InvestEU, and Important Projects of Common European Interest (IPCEI) – should support both early-stage pilots and first-of-a-kind (FOAK) projects. Trade-offs between high-yield crops and biodiversity-protected niche crops must be carefully managed to ensure sustainability and resilience. An inclusive transition strategy is essential. Achieving net-zero by 2050 will require multiple technological pathways, including incremental substitution of fossil feedstocks in conventional industries, not only fully bio-based value chains. Supporting partial substitution can deliver faster emissions reductions while new dedicated bio-based facilities scale up.

[229] Mullins, Ewen, Jean-Louis Bresson, Tamas Dalmay, Ian Crawford Dewhurst, Michelle M Epstein, Leslie George Firbank, Philippe Guerche, u. a., "Updated Scientific Opinion on Plants Developed through Cisgenesis and Intragenesis", EFSA Journal, Bd. 20, Nr. 10, Oktober 1, 2022, S. e07621. https://doi.org/10.2903/j.efsa.2022.7621.
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# 8 Annex

The Annex to this report shows detailed findings of the analysis provided in separate files. The headings below give an overview of the annexes.

## Annexes for Chapter 2: Mapping, Case Studies and Factsheets on Bio-Based Industrial Systems

Annex 2.1: Longlist of bio-based systems

Annex 2.2: Case studies on successful systems (including the business cases)

Annex 2.3: Factsheets (collated together)

Annex 2.4: Comparative Challenges Case Table.xlsx

## Annexes for Chapter 3: Details for the Biomass Analysis

Annex 3.1: Methods, assumptions and details for the biomass analysis

## Annexes for Chapter 4: Details on the Trade Analysis and Case Studies

Annex 4.1: Trade codes of biomass resources and intermediates relevant for bio-based industries

Annex 4.2: List of most relevant imported raw materials/intermediates

Annex 4.3: Case studies on approaches to decrease import dependencies

Annex 4.4: Details on demand scenario analysis

## Annexes for Chapter 5: Detailed documentation of opportunities and challenges of EU biotechnology innovation and scale up

Annex 5.1: Overview of selected 16 high-potential applications

Annex 5.2: Methodological approach for chapter on opportunities and challenges for 16 biotechnological applications

Annex 5.3: Detailed dataset of CAGR and market values estimates by application

Annex 5.4: Detailed description of CAGR and market values estimates by application

Annex 5.5: Summary of cost of production by application

Annex 5.6: Overview of key opportunities and challenges

Annex 5.7: Analysis environmental indicators by application

Annex 5.8: Detailed datasets of EU and EU-27 bioeconomy policy frameworks

Annex 5.9: Analysis of EU and national regulations and enabling frameworks

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