Bio-based plastics - Expert workshop on current state of the art and knowledge gaps

Summary report -
Community of Practice on Bioeconomy

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Abstract

The European Union (EU) supports the reduction of plastic waste and pollution through various policy documents and regulations. In particular, it has defined a policy framework on bio-based, biodegradable, and compostable plastics (COM(2022) 682), as well as a strategy for the development of a circular economy for plastics (COM(2018) 28 final), promoting the increase in recycling and reuse of plastics (Packaging and Packaging Waste Regulation (EU) 2025/40), and targets to reduce single use plastics (Directive (EU) 2019/904). Scientific evidence is particularly needed to clarify specific issues and challenging aspects inherent to bio-based plastics.
Bio–based plastics offer various benefits, such as reduced greenhouse gas (GHG) emissions compared to conventional plastics, improved biodegradability and renewable biomass sources. However, currently their production is more complex and expensive compared to fossil-based plastics, it requires biomass feedstocks for which availability is limited and in competition for land with food crops, with impacts on land use changes and water use. In addition, it can be more difficult to process than conventional plastics, requiring specialised equipment and expertise. These considerations are general and may vary depending on the feedstock and on the production process utilised. The interest for bio-based plastics is growing also regarding the opportunity for innovation brought to the European industrial landscape. In this context, the Knowledge Centre for Bioeconomy (KCB) has organised a workshop framed within a deep dive study of the KCB on bio-based plastics which will include a knowledge for policy brief and further information material.

1. Introduction

The European Union (EU) supports the reduction of plastic waste and pollution through various policy documents and regulations. In particular, it has defined a policy framework on bio-based, biodegradable, and compostable plastics (COM(2022) 682), as well as a strategy for the development of a circular economy for plastics (COM(2018) 28 final), promoting the increase in recycling and reuse of plastics (Regulation (EU) 2025/40), and targets to reduce single use plastics (Directive (EU) 2019/904). The EU policy could further promote sustainability and innovation within the plastic sector, based on sound scientific evidence. Such evidence is particularly needed to clarify specific issues and challenging aspects inherent to bio-based plastics.

Bio–based plastics offer various benefits, such as reduced greenhouse gas emissions compared to traditional plastics, improved biodegradability and renewable biomass sources, such as corn starch, sugarcane, or potato starch.

However, their production is more complex and more expensive compared to fossil-based plastics, it requires biomass feedstocks for which availability is limited and in competition for land with food crops, with impacts on land use changes and water use. In addition, bio-based plastics can be more difficult to process than traditional plastics, requiring specialised equipment and expertise. These considerations are general and may vary depending on the feedstock and on the production process utilised. As a matter of fact, the interest for bio-based plastics is growing also regarding the opportunity for innovation brought to the European industrial landscape.

The Knowledge Centre for Bioeconomy (KCB) is a European Commission initiative on enhanced knowledge management for bioeconomy-related policymaking. It aims at developing a common and robust knowledge base for a sustainable and circular bioeconomy. This workshop is framed within a deep dive of the KCB on bio-based plastics which will include a knowledge for policy brief and further information material.

In the framework of the task A5 "Knowledge analysis, synthesis and dissemination" of the Administrative Arrangement "KCB Support 3" between DG RTD and the JRC, a new KCB topic page on bio-based plastics will be set up by January 2026. Following the 'linked knowledge pyramid' concept , the webpage will include: an intro with the main messages related to the bio-based plastics topic, a 'knowledge for policy brief' synthesising currently available knowledge, facts and figures on bio-based plastics, an "Explore further" section that will include latest data, visualisations, projects and additional selected resources available and a "Latest resources" section with the latest news and publications in the KCB knowledge base, related to bio-based plastics.

In this context, starting in May 2025 the KCB was helped for this task by the expert Karin Molenveld, Programme Manager Renewable Plastics, Wageningen University Research, to draft a state of the art, a knowledge gap analysis and outlook for the bio-based plastics sector, to synthesise such contents and to identify key messages to be included into the above-mentioned knowledge for policy brief.

2. Expert Workshop Organisation

The KCB organised the Expert workshop on bio-based plastics, which took place in Brussels on 26 June 2025 in hybrid modality, in the framework of the Community of Practice on Bioeconomy. Such workshop aimed to gather inputs and views on several aspects related to the bio-based plastics sector: available feedstock, process, current and future market trends, environmental impacts, trade-offs, knowledge gaps and policy needs. With this aim, it targeted around 30 attendees among policy makers, practitioners and researchers working in the bio-based plastics field. 31 participants attended the workshop in person (of which 10 European Commission staff members and 21 external experts from 8 different countries) (**Figure 1**) and 21 attended online (of which 3 external experts and 17 European Commission staff members), ensuring a sufficient variety of expertise and view angles.

Figure 1: Workshop participants

Source*:* Original photo by the authors

The event, chaired by Andrea Camia of the Knowledge Centre for Bioeconomy Coordination Team, featured a welcome address by Serenella Sala, Hou JRC.D.3 and Rosalinda Scalia, Deputy HoU of DG RTD.B.2 - Bioeconomy and Food Systems.

Martin Policar (RTD.B1) gave an overview of EU-funded research on bio-based plastics, while Maria Teresa Borzacchiello (JRC.D.3) introduced the KCB deep dive study on bio-based plastics, which is going to be released later this year in the form of a policy brief and a new topic page on the KCB website.

Werner Bosmans (ENV.B1) presented to the audience the latest EU policies on bio-based plastics and relations with the upcoming new bioeconomy strategy. Karin Molenveld (Programme Manager Renewable Plastics, Wageningen University Research) described the state of the art on bio-based plastics and key issues at stake, preparing for the discussions in the parallel sessions.

The working tables, facilitated by Karin Molenveld and JRC.D3 colleagues Sarah Mubareka and Giulia Listorti, were set up to discuss in detail four specific topics:

- Material performance and durability vs. costs and economic viability
- Feedstock sustainability – land use and resource competition
- Product sustainability – measuring environmental impacts
- End-of-life management - challenges and solutions

In conclusion, Maria Teresa Borzacchiello (KCB Coordination Team) thanked the participants and invited them to continue to contribute to the debate by replying to the online survey which will remain open for the following two weeks, and to join the Community of Practice on Bioeconomy to stay tuned about future information from the KCB.

The following sections report the main contents presented and discussed during the workshop. The interventions and the working table discussions are synthesised and organised into subsections to facilitate reading, the slides presented are in Annex 2.

3. Welcome address

Serenella Sala, Head of Unit – JRC.D.3 – Land Resources and Supply Chain Assessments

Bio-based plastics is a key topic in the bioeconomy landscape, and has implications for innovation, packaging, and the use of biomass. The Joint Research Centre is working to improve the understanding of the biomass availability. In particular, the JRC Biomass Mandate 10-th years anniversary report on biomass supply and uses [1] highlights the need for more coherent governance and urgent actions to ensure that biomass production and use are compatible with both ecological limits and EU policy goals.

Indeed, there is a growing dependency on biomass and great expectations associated with bio-based plastics, not only to substitute fossil-based materials, but also to ensure the same level of functionality to respond to evolving societal needs.

On the other side, evidence highlights several trade-offs, which need to be carefully addressed to avoid regrettable substitution. The Commission has also developed a framework for safe and sustainable by design chemicals and materials, which aims to ensure compliance with sustainability and safety considerations.

The JRC is working on supporting fair comparisons between fossil-based and bio-based alternatives through lifecycle assessments.

Rosalinda Scalia, Deputy Head of Unit - DG RTD B.2 - Bioeconomy & Food Systems

Plastics are a key material in modern life. They are versatile, light and can be produced at relatively low cost. Their use entails several challenges, such as low recycling rates, environmental pollution, and greenhouse gas emissions. Biodegradable, compostable, and bio-based plastics are seen as a potential solution, but currently, they make up less than 1% of the global plastic market.

The EU has no specific legislation on bio-based plastics, but they are addressed in various directives and policies, like the EU Taxonomy, the Single Use Plastics Directive, the Plastic Carrier Bags Directive, the Packaging and Packaging Waste Regulation. The Commission's 2022 Communication on a policy framework for bio-based and biodegradable plastics guides EU policy making, and a new Bioeconomy Strategy is expected to be adopted by the end of the year.

The current Bioeconomy Strategy, updated in 2018, outlines five objectives: ensuring food and nutrition security, managing natural resources sustainably, reducing dependence on non-renewable resources, mitigating and adapting to climate change, and strengthening European competitiveness and creating jobs.

To monitor progress in achieving the mentioned objectives, the JRC has developed the EU Bioeconomy Monitoring System. The system tracks economic, environmental, and social advancements towards a sustainable bioeconomy.

Looking into the latest available data from the EU Bioeconomy Monitoring System, in 2022, in EU-27 almost 500,000 people were employed in the bio-based chemicals and pharmaceuticals, plastic and rubber sectors. The value added by these combined sectors was EUR 94 billion, representing 12% of the total value added of biomass producing and converting sectors.

For the new Bioeconomy Strategy to be adopted this year, it is decisive to get concise policy factsheets that give the ‘big’ and key numbers on structures and trends in the EU bioeconomy in view of all three dimensions of sustainability to underpin the policy debate, because it has to be clarified to what extent can bio-based plastics help solve the sustainability challenges posed by plastics and if they create new ones.

Bio-based plastics are part of the Bioeconomy Strategy, and the EU has strongly supported developing bio-based plastics through ambitious and collaborative research under the Horizon 2020 and Horizon Europe R&I programmes. The benefits of bio-based plastics include reducing reliance on fossil fuels, mitigating environmental damage, and creating new opportunities for farmers and rural communities.

Moreover, the Commission is working on several policy initiatives, including the Life Science Strategy and the EU Startup and Scaleup Strategy, which aim to make Europe a leader in life sciences and a startups powerhouse.

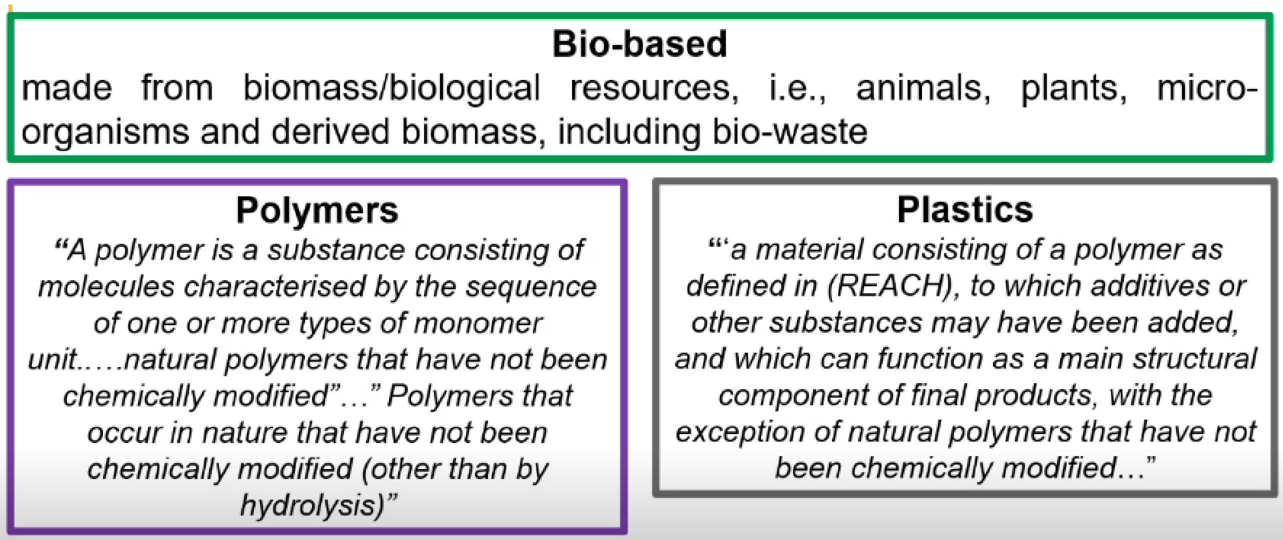
In this context, it is needed to identify the main challenges and prioritise measures to support the development of a sustainable bioeconomy, including scaling up bioeconomy solutions, ensuring strategic autonomy and sustainable competitiveness, and protecting the climate and environment. A key question is whether to encourage Member States to introduce mandatory bio-based plastic content percentages for bio-based plastics, which will guide the discussion on the role of bio-based plastics in the EU's transition to a sustainable and equitable economy.

4. EU funded research on bio-based plastics

Martin Policar, Policy Officer – DG RTD.B1 - Green Transitions

As a scientists' and practitioners' community, it is important to be clear and agree on definitions of the concepts. The term "bio-based" refers to material made from biomass/biological resources (See **Figure 2**).

Figure 2: Definitions as in Reach Regulation (EC 1907/2006)



Source*:* Reach Regulation

Horizon Europe is funding specifically clusters 6 and 4, which deal with food, bioeconomy, natural resources, environment and industry. Under Cluster 6, the Circular Bio-Based Europe Joint Undertaking (CBE-JU) is a key partnership between the EU and the Bio-based Industries Consortium (BIC), with a budget of EUR 2 billion. Under Cluster 4, other partnerships are Made in Europe and P4P Processes for Planet.

Various topics relate to bio-based plastics and the budget allocated by HE for the period 2021-2025 reached EUR 173.5 million. Altogether, over 110 projects are funded under R&I Framework Programme, including FP6, FP7, Horizon 2020, and Horizon Europe.

The main applications of bio-based plastics include fibre-based packaging, composites, plastics with advanced performances, biodegradable polymers for agriculture and horticulture, and also biodegradable plastics in humanitarian context. Other topics, such as biomanufacturing and biotech (with approximately EUR 100 million), and social innovation (with approximately EUR 220 million), are being introduced into the program.

The EU's mission to restore oceans and waters is also important, with a focus on reducing microplastics by 30% and making the blue economy carbon neutral.

The drivers for R&I programming in bio-based materials include replacing fossil-intensive resources, contributing to climate neutrality and biodiversity and environmental protection, enabling the use of biotechnology and advanced information technologies.

The overall goal is to create a more sustainable and renewable bioeconomy, with benefits distributed equally along the value chain, and to increase the appeal of jobs in agriculture and related sectors.

5. Introduction to the KCB deep dive on bio-based plastics

Maria Teresa Borzacchiello, Knowledge Centre for Bioeconomy – JRC.D.3 – Land Resources and Supply Chain Assessments

The Knowledge Centre for Bioeconomy

The Knowledge Centre for Bioeconomy (KCB) is a European Commission initiative, launched in 2017. The 2018 Bioeconomy strategy recognises a specific role for the KCB in supporting the knowledge base for policymaking and for tracking the progress towards a sustainable bioeconomy. The KCB collects and consolidates knowledge from different sources, identifies and filters relevant information, making it accessible through its website. This one-stop-shop for bioeconomy related information, displays a knowledge library including news, publications, events, datasets and audio-visual contents for more than 5600 curated resources. In addition, the KCB manages a Community of Practice: a network of people who work on a common area, exchange knowledge and views and work together on specific topics. In January 2024 the Community of Practice on Bioeconomy opened up to researchers, practitioners and policymakers from all over Europe and beyond, and it now gathers 270 participants.

The deep dive on bio-based plastics

The KCB is committed to analyse and synthesise knowledge within the bioeconomy domain, to provide high-quality information for better policymaking at European level. In line with this mission, the KCB is collecting and processing data and up to date evidence on bio-based plastics to present and disseminate them through a dedicated webpage, including a knowledge for policy brief, targeting policy makers at EU and national level.

To realise the policy brief on bio-based plastics, in May 2025 the KCB started collaborating with Karin Molenveld, Programme Manager Renewable Plastics, Wageningen University Research.

The workshop included four parallel sessions to discuss the following topics: land use and resource competition, material performance, costs and economic viability, environmental impacts, and end-of-life management.

6. Overview of policy developments on bio-based plastics in EU

Werner Bosmans, DG ENV B.1 - Circular Economy, Sustainable Production & Consumption

The European Commission is working on a series of policy files to implement the European Green Deal, through (i) the Circular Economy Action Plan, aiming to maintain the value of products, materials and resources in the economy for as long as possible, (ii) the new Bioeconomy Strategy, which aims to scale up bio-based sectors within ecological boundaries, and related in particular to plastics, the (iii) European Strategy for Plastics in a Circular Economy, which aims to improve the economics and quality of recycling and curbing plastics waste and littering.

The new Bioeconomy Strategy as a driver for green growth, as an enabler for fossil fuel reduction, and as a booster for rural areas, has been announced by the Competitiveness Compass, the Clean Industrial Deal and the Vision for agriculture and food.

According to recent reports from the JRC [2], the use of biomass is increasing, and in particular for energy. A balance is needed between energy and material use, to make sure sustainability criteria are in place, ensuring resilience of supply, sustainably sourced biomass, and sustainable land and water management practices. The cascading principle should be respected, prioritising material demand, maximising resource efficiency and circularity, prioritising the use of residues and byproducts to extend biomass availability, orienting biomass from bioenergy towards higher value applications.

The objectives of the upcoming new bioeconomy strategy will indicatively include:

- Enhance **long-term competitiveness** of the EU economy & strategic resilience
- Ensure **industrial leadership** in addressing climate change, biodiversity loss & pollution
- Lead in the emerging **bio-based economy (*investments*)** & drive biotechnology innovation
- Secure **sustainably supplied biomass** & sustainable production of biological resources for food, materials, energy & services
- Create **green jobs**

These objectives are currently addressed by four pillars:

Pillar I - Increasing resource-efficient & circular use of biological resources

Pillar II - From Lab to Fab, priorities for scaling up

Pillar III - Securing the competitive & sustainable supply of biomass, both domestically & from outside the EU

Pillar IV - Positioning the EU in the rapidly expanding international market

In 2022, the Commission adopted a policy framework on bio-based, biodegradable and compostable plastics (COM/2022/682 final), with the aim to de-fossilise industry, reducing our dependency on fossil resources and meeting our climate neutrality targets, and to create jobs.

There are a number of challenges. Firstly, the bio-based material should not be used to perpetuating single use models, which should be avoided; secondly, the secondary biomass is always to be preferred to the primary one. The cascading principle needs to be integrated, and sustainability criteria should be set up to comply with RED III – for land use and biodiversity, while for GHG, more research is needed. Moreover, biodegradable plastics should be considered only for specific applications where full removal is not possible (e.g. marine fishing nets or mulch films for agriculture).

The Taxonomy Regulation (Regulation (EU) 2020/852) also drives attention on bio-based plastics. In particular, in the Climate Delegated Act (2021), the focus is on plastics in its primary form, looking at the substantial contribution to climate change mitigation. Bio-based plastics is considered a valid option if biomass is compliant with bioenergy sustainability criteria and life-cycle GHG emissions are lower than fossil-based equivalent.

The Environmental Delegated Act (2023) focused on plastic packaging, looking at the substantial contribution to transition to a Circular Economy. Bio-based plastics is a valid option when bio-waste feedstock is used.

These two delegated acts have been extensively commented by stakeholders and are under review.

In February 2025, the Packaging and Packaging Waste Regulation (PPWR) (Regulation (EU) 2025/40) entered into force. Article 8 focuses on bio-based feedstock, whereby by 12 Feb 2028, the EC will review the state of play (and possible legal proposal) of bio-based plastic packaging, considering sustainability requirements, feedstock targets, interplay of recycled content and bio-based targets, updating the definition of bio-based plastics. Linked to that, the Commission is launching three studies on bio-based content targets in products, which will include stakeholder consultations:

- Study on feasibility & impacts of bio-based & other non-fossil content requirements for products, linked to the Communication Building the future with nature: Boosting Biotechnology and Biomanufacturing in the EU
- Circular economy act impact assessment study (part on biobased content targets on 1-3 product groups), as a follow up of the Clean Industrial Deal
- Study for the implementation of article 8 of the PPWR

Overall, the discussion highlighted the complexity of the bioeconomy and the need for careful consideration of the various factors involved in scaling up bio-based sectors. The Commission's plans for a new bioeconomy strategy are seen as important steps towards achieving a more sustainable and circular economy.

7. Bio-based plastics sector and key issues at stake

Karin Molenveld, Programme Manager Renewable Plastics – Wageningen University Research

Introduction to Plastics

Plastics are a type of organic polymer that can be moulded into various shapes during the manufacturing process. This unique property makes them extremely versatile and useful in a wide range of applications. Some of the key benefits of plastics include their lightweight nature, durability, cost-effectiveness, and resistance to chemicals. They can also be designed to be flexible, transparent, and strong, making them an ideal material for many industries.

Historically, the first plastics were derived from renewable sources, such as cellulose. These early plastics were used to replace scarce natural materials like ivory, which was highly valued for its durability and versatility. The use of plastics as a substitute for ivory and other natural materials marked the beginning of a new era in manufacturing, where synthetic materials could be used to create a wide range of products.

The production of plastics really took off during and after World War II, when fossil-based plastics became more widely available. This was largely driven by the need for lightweight and durable materials for military applications, such as parachutes, ropes, and body armour. For example, nylon, a type of polyamide, was used extensively in the production of parachutes and other military equipment. Another notable example is Plexiglas, a type of polymethylmethacrylate, which was used to make aircraft windows due to its exceptional strength, transparency, and resistance to impact.

The choice of raw materials for plastic production has always been largely driven by cost considerations. In the case of nylon, for instance, there are two main types: nylon 11, which is derived from castor oil and is therefore biobased, and nylon 12, which is fossil-based. The decision to use one type of nylon over the other often comes down to the cost of production.

The development of plastics like nylon and polyethylene revolutionised industries, and their use became widespread. However, the success of plastics has also led to excessive growth, with over 400 million tonnes of plastic produced annually, expected to double by 2050. Strongest growth is outside Europe, and the share of bio-based plastics is minor. Main applications of plastics are packaging, constructions and textiles. About half of the polymers we use are polyolefins like PP and PE.

Concerns about Plastics

Concerns about plastics started already in the eighties, with worries about waste, pollution, and climate change related to fossil feedstock usage, as well as microplastics and safety concerns. Possible mitigation actions include the development of biodegradable plastics and bio-based plastics, plastics recycling, the use of circularity models, waste hierarchy and even plastics bans, but these alternatives have their own set of challenges (and the transition to sustainable types and use of plastics is very slow).

Current state of plastics

According to the European Court of Auditors [3], nowadays most plastics are still made from virgin fossil fuels, with only about 1% being bio-based. Bio-based and recycled plastics are more expensive, cheap imports slow down plastic transition. The use of fossil fuels for plastic production contributes to greenhouse gas emissions, and the extraction of fossil fuels has environmental and social impacts. The recycling rate for plastics is around 10%, and the use of recycled plastics is limited due to economic and technical challenges. The production of plastics is expected to continue growing, driven by increasing demand from emerging economies.

Why bio-based plastics?

In particular, around 10% of fossil carbon is used as feedstock for chemicals and plastics, while around 7% is used as energy during production. The main use is in bulk polymers like polyolefins and polystyrene and smaller part for engineering plastics, adding up to a 90% share. Due to the energy transition, the relative share of petrochemicals will increase, their costs will increase and their relative contribution to (GHG) emissions will increase.

Alternative carbon sources are needed to allow a growth of the chemical industry and to compensate for inevitable losses during recycling. There are three main options that are being explored.

1. Plastic recycling can be done through mechanical or thermo-chemical means. Mechanical recycling involves sorting and reprocessing plastic products into new products. Chemical recycling like solvolysis implies that polymers are broken up to their monomers that can be reused for polymer production. Thermo-chemical recycling involves using heat and chemicals to break down plastics into feedstocks that can replace nafta.

2. Using bio-based feedstocks means using organic materials such as plants and microorganisms as a source of carbon. There are two main types of bio-based feedstocks: first generation and second generation. First generation bio-based feedstocks are made from food crops such as corn, sugarcane and palm oil, while second generation bio-based feedstocks are made from non-food crops such as switchgrass or agricultural residues.

3. Carbon Capture and Utilization (CCU) involves capturing carbon dioxide from point sources or the atmosphere and converting it into a usable form. This can be done using a variety of technologies, including chemical synthesis and biological processes. Processes to convert CO_2 into chemicals typically require a lot of energy (because of the low energy state of CO_2), and this energy should be preferably renewable.

According to [4] who looked at scenarios of feedstock diversification towards carbo-chemicals, in a market-driven scenario fossil feedstock demand would continue to grow, while in a regulated scenario it would start to decline in favour of alternative feedstock.

General conclusions regarding the feedstock transition highlight several key points. Firstly, reducing the growth of feedstock consumption is essential, and regulation is required to achieve this goal. Additionally, Carbon Capture and Storage (CCS) is necessary to reach climate goals, emphasising the need for a multi-faceted approach to addressing environmental concerns. Efficient feedstock use and processes with low energy demand are also crucial, as they will play a significant role in minimising the environmental impact of feedstock consumption.

As a result of the transition, products are likely to become more expensive, reflecting the increased costs associated with adopting more sustainable practices. Furthermore, losses during recycling are estimated to add up to 50%, highlighting the need for improved recycling technologies and infrastructure. The use of biomass as a feedstock is essential, with an initial focus on first-generation biomass and a gradual shift towards lignocelluloses. This shift will enable efficient feedstock use and help reduce dependence on non-renewable resources.

To facilitate efficient use of biomass feedstock, a shift in the type of products is required, moving away from polyolefins and towards polyesters. This change will involve significant adjustments in production processes and supply chains. Also, implementation of Carbon Capture and Utilization (CCU) (a very expensive process due to its high energy consumption), would require a product shift towards oxygen containing polymers like polyesters. The development and commercialisation of new polymers are time-consuming, typically requiring 20 years to break through and another 20 years to mature, emphasising the need for long-term planning and investment in research and development.

Production routes for bio-based plastics

Starting from biomass, there is a wide range of options for creating plastics.

Over the years, significant advancements have been made in developing **new bio-based plastics**, meaning in the conversion of biomass into fundamental building blocks that can be transformed into plastic polymers. This process allows to create novel, fully bio-based plastics that differ from those derived from fossil fuels.

On the other hand, we can produce **bio-based "drop-in" plastics**, which are chemically identical to their fossil fuel-based counterparts but are partly bio-based. By leveraging chemical processes, we can convert biomass into the precise molecules required for plastic production, effectively replicating the properties of conventional plastics. However, the primary concern surrounding this approach is the cost associated with it. The production process and required infrastructure to produce the required molecules can be substantial, and often biomass is not efficiently used.

Another viable option is to utilise existing installations designed for plastic and chemical production and simply **replace the feedstock with biomass**. This would involve adapting the current infrastructure to accommodate biomass, which has a distinct composition compared to fossil fuels. Biomass has a higher oxygen content and may have other impurities, making it essential to develop new processes that can effectively convert it into a usable feedstock.

All routes require investment in additional installations and require a managed supply chain of biomass.

Requirements for biomass pretreatment add to the cost.

The emergence of **new bio-based plastics** offers several potential advantages. These include the efficient use of biomass, which can be converted into valuable chemicals and materials. Additionally, bio-based plastics can be more cost-effective and have a lower environmental footprint. The production processes for these plastics often require lower energy demand and can be conducted at low temperatures.

New bio-based plastics can also decouple from fuel and energy production, which can provide a more stable supply chain. Furthermore, these plastics can offer new functionalities and specific performance characteristics. They can also be designed to be more recyclable and can be biodegradable or non-persistent.

However, there are also potential disadvantages to consider. These include the need for new production facilities, which could be a significant investment. The development and market introduction of new bio-based plastics can be a long process. New product design and development are also required, which can be time-consuming and complex.

Additionally, new bio-based plastics may have functional differences or disadvantages compared to conventional plastics. Initially, the volumes of bio-based plastics produced may be too low for cost-effective recycling.

Regarding **drop-in plastics**, potential advantages include a faster market introduction due to their known properties and the fact that they can be used in current installations. Additionally, they can be recycled with fossil-based plastics, which can simplify the recycling process. Drop-in plastics also have a lower environmental footprint, specifically in terms of greenhouse gas emissions, compared to their fossil-based equivalents. Furthermore, the production processes for drop-in plastics can require lower energy demand and can be conducted at low temperatures. They can also decouple from fuel and energy production.

On the other hand, the potential disadvantages of drop-in plastics include being more expensive than their fossil-based equivalents. New production facilities are also required to produce drop-in plastics and they do not offer any functional advantages. Additionally, drop-in plastics can result in an inefficient use of biomass.

Certified bio-based plastics can replace feedstock, which allows for the versatile production of different plastic types and grades. They can also have a faster market introduction due to their known properties. Additionally, certified bio-based products can be recycled with fossil-based plastics. They can have a lower environmental footprint, specifically in terms of greenhouse gas emissions, compared to their fossil-based equivalents, although this depends on the biobased content, or the percentage of biomass added. Certified bio-based products are already in operation, for example, using biodiesel produced from vegetable oils.

On the other hand, the potential disadvantages of certified bio-based products include being more expensive than their fossil-based equivalents. They do not offer functional advantages and can result in an inefficient use of biomass. The production of these products requires pretreatment of biomass, which may necessitate the development of new facilities. Post-treatment of pyrolysis oil may also be required, which could involve the construction of new facilities. There is a risk that only limited fossil feedstock replacement may be achieved. The required scales of production can contribute to logistic challenges. Furthermore, changes in current installations may be required in the long term, such as electrification.

In conclusion, bio-based resources are not abundantly available, highlighting the need for efficient conversion processes. The fact that biomass is oxygen-rich suggests that it would be more logical to produce oxygen-containing molecules, which could potentially lead to more efficient and effective use of biomass. However, the use of biomass is likely to lead to price increases, which is an important consideration in the development and implementation of bio-based products and technologies.

Feedstocks for bio-based plastics

According to recent studies[1], the majority of biomass is currently used for feed purposes. In addition to this, the European Union imports approximately 70 Mt of biomass per year for use as feed. The use of biomass for timber, paper, and board is also significant, and it is anticipated that this demand could grow in the future. In contrast, the current use of biomass to produce plastics and chemicals is relatively low, but it is expected to increase. However, using biomass for electricity, heat, and transport applications is not currently considered desirable or realistic.

When considering the use of biomass, the type of biomass is an important factor to consider. Certain sources of biomass are more abundant than others, with (ligno)cellulose, sugar, and starch being among the most available. For example, sugar beets and sugarcane can yield around 10-15 t/Ha, making them relatively abundant sources of biomass. On the other hand, oils and fats are scarcer, with palm oil (not produced in Europe) yielding around 3.3 t/Ha and rapeseed oil yielding around 0.7 t/Ha. However, the current uses of biomass in 2023 do not accurately reflect the relative abundance of these different sources, suggesting a potential mismatch between the available biomass resources and how they are being utilised.

The most used biomass sources are sugars and starches, which are primarily utilised in fermentation processes and account for around 50% of the total usage. Additionally, Polyhydroxyalkanoates (PHAs) can be produced from a variety of sources, including sugars, vegetable oils, and organic waste. However, waste vegetable oils are mainly being used to produce biodiesel, rather than being converted into PHAs or other biobased products.

As general remarks, lignocellulosic agricultural side streams, as they are, are not well suited to produce chemicals and plastics. This is because they require additional processing and treatment to be converted into a usable form. Therefore, there is a need for technologies that can make these side streams available to produce chemicals at scale.

It is also worth noting that non-food crops, such as those used for fiber and wood, are often standalone crops and not side streams. Additionally, it's desirable to avoid using these crops for energy production. Instead, they can be used for their original purpose, such as producing fiber and wood.

The production of food and non-food products is interrelated, as they often require the same crops. For example, protein-rich fibrous co-products can be used as feed for livestock, while the main crop can be used for food or non-food purposes. An example of this is cereal production, where the plant-based proteins can be used for food, the carbohydrates can be used for chemicals and plastics, and the fibrous co-products can be used as feed for livestock.

Bio-based plastics market

The development of biodegradable plastics and bio-based plastics has driven significant attention in recent years. Initially, biodegradable plastics were developed, but later, bio-based plastics emerged as a distinct category. In fact, bio-based plastics are not necessarily biodegradable.

The current market for bio-based plastics is expected to experience significant growth in the next five years, with production anticipated to double. The main drivers of this growth are expected to be several key bio-based plastics, including Polylactic Acid (PLA), Polyhydroxyalkanoates (PHA), Polyethylene (PE), and Polypropylene (PP). These are expected to play a major role in the expansion of the market. Additionally, it is worth noting that the global production of bioethanol for biofuel is currently around 135 Mt per year, providing a context for the scale up of the bio-based plastics market.

The current applications of bio-based plastics are varied, but some areas stand out as major users of these materials. Packaging is the main application, together with fibres, where their use is driven by functional requirements. In the agricultural sector, biodegradable plastics are typically used. Additionally, polyamides (PA) have a large share of applications in the automotive industry.

The growth of bio-based plastics is limited by several factors. One of the main limitations is economics, as bio-based plastics often have a competitive disadvantage and lack incentives, making them less attractive than traditional fossil-based plastics. However, this economic limitation has not affected the relative success of biodegradable bio-based plastics in areas or specific applications where there is no cheap fossil-based alternative available.

Another factor limiting the growth is the development time required for new products. It can take up to 20 years for a new bio-based plastic to break through and become established, and an additional 20 years for it to mature and reach its full potential.

Bio-based plastics are often used because they offer specific advantages, rather than as a direct replacement for conventional plastics. They are used in specifically designed products that take advantage of their unique functionality.

When considering the properties of bio-based plastics, it's noted that there is a wide range of fossil plastics with very different properties, which raises the question of whether it's possible to categorise properties as "good" or "bad". Instead, it's suggested that properties are simply different and suited for specific applications.

However, some general observations can be made about bio-based polyesters. For example, they are mainly polyesters that are more susceptible to hydrolytic degradation, which can affect their performance and durability. Additionally, bio-based polyesters tend to have a higher density compared to polyolefins, which can add to their costs. Bio-based polyesters also have different processing characteristics compared to conventional plastics. They often have low melt strength, high melt viscosity, and a low crystallization rate, which can impact their processing and manufacturing. These differences in properties and processing characteristics need to be considered when working with bio-based polyesters and designing products that utilise these materials.

End of life options

The end of life of plastics poses two main challenges. The first challenge is **recyclability**, which is complicated by the fact that plastics often come in complex mixtures, are contaminated with other materials, and can be aged, making it difficult to recycle them. The second challenge is the **persistency of plastics in the environment**, including the issue of microplastics and the safety concerns that come with them.

Current methods of plastic waste collection and treatment do not completely address the problems associated with fossil feedstock use and the leakage of plastics into the environment. To improve the end of life of plastics, several steps are necessary. These include improving collection methods, sorting techniques, and recycling technologies.

Additionally, there is a need for plastics that have improved recyclability, making it easier to recycle them and reduce waste. Furthermore, plastics that are not persistent in the environment are also required, which means they should be able to break down naturally without causing harm to the environment [5].

Recyclability is considered a system property, meaning that it depends on the entire system in which the plastic is used, rather than just the material itself. To assess recyclability, it is measured at a product level, with a focus on designing products that are circular by design. For a plastic to be considered recyclable, it must fit into the existing waste management system. The goal is to recover the feedstock, or carbon, from the plastic, rather than just treating the waste.

A best practice example of this is the recycling of polyethylene terephthalate (PET) bottles, which are designed to be circular and can be used in contact with food.

The recycling of PET bottles is facilitated by a separate collection system, a refund system, and agreements on design and sufficient volume. Additionally, decontamination methods and repair methods are used to ensure that the recycled material is of high quality. In some cases, alternative chemical recycling methods, such as solvolysis, may also be used to break down the plastic into its raw materials. By adopting these best practices, it is possible to create a more circular and sustainable plastic lifecycle.

Most bio-based plastics are polyesters, that can be sorted and recycled via various routes (mechanical and chemical). This makes polyesters a more sustainable option compared to polyolefins. However, it is noted that sufficient volumes of polyesters are required to make recycling economically viable. Despite this, the fact that polyesters can be sorted and recycled makes them a promising option for reducing plastic waste and promoting a more circular economy.

Polylactic Acid (PLA) is a versatile bio-based plastic that offers several advantages at end-of-life. Currently, PLA has the largest production volume among bioplastics. Post-industrial waste, such as trimmings, is often used in-house or converted into products like plant pots. Some PLA producers have also set up closed-loop recycling systems, which use solvolysis to break down the PLA back into lactic acid, allowing to produce new (virgin grade) PLA. PLA can be sorted out from other plastics, provided that sufficient volumes are available. Potential products that can be made from PLA include flow packs for cut vegetables, trays for meat or vegetables, and flowerpots. At end-of-life, PLA can be managed in several ways. In the PMD (Plastic, Metal, Drink cartons) stream, PLA can be sorted and subsequently recycled. In residual waste, PLA is incinerated, releasing biogenic carbon. In the GFT (Garden and Food waste) stream, PLA is composted along with the content, resulting in no microplastics. If PLA is littered, it is not persistent, as shown by a meta-study conducted by Hydra [6]. Overall, PLA offers a range of benefits and can be managed in a way that minimizes its environmental impact.

As an example; a coffee capsule is a small product that is hard to recover and recycle, and it often contains organic waste. In terms of end-of-life scenarios, there are several options to consider: bio-based compostable, aluminium, and conventional plastic. Composting coffee grounds is only possible in mono-collection or when collected with Garden and Food waste (GFT). On the other hand, closed-loop recycling of aluminium is only possible in mono-collection, as to produce thin-walled aluminium products specific alloys are required. Conventional plastic, however, can contaminate GFT if it is not properly separated. The study by WUR [7] focussed on the capsule material, comparing the environmental impacts of biobased compostable, aluminium, and conventional plastic coffee capsules. It also included the circularity of the different options. The comparison can help to identify the most sustainable option and inform decisions about coffee capsule design and waste management. In a next step impact of the content of the coffee capsule, which is the coffee itself can be included and specifically whether or not coffee can be composted or needs to be incinerated in the specific waste scenario.

Environmental impacts

The environmental impacts of bio-based plastics are complex and multifaceted. While they often have lower greenhouse gas (GHG) emissions compared to conventional plastics, they can have higher impacts related to agriculture, depending on the type of biomass used and the efficiency of production. Waste streams are often preferred as a feedstock for bio-based plastics, as they can help to reduce waste, have a lower environmental impact and promote a more circular economy.

However, Life Cycle Assessments (LCAs) of bio-based plastics often do not include various aspects that are important for a comprehensive understanding of their environmental impacts. These aspects include for example plastic pollution and microplastics, the long-term effects of climate change, biodiversity impacts, and waste management. As a result, LCAs may not provide a complete picture of the environmental benefits and drawbacks of (bio)plastics.

Additionally, the impact of fossil-based plastics is increasing due to the growing relative share of impacts from oil drilling and shale gas processes. This means that the environmental footprint of conventional plastics is likely to increase over time, making bio-based plastics a more attractive alternative from an environmental perspective.

Microplastics are a significant environmental concern, and there are several important sources of microplastics. These include synthetic fibres from textiles, car tire abrasion, agricultural films, littered plastics, and compost from garden and food waste (GFT). Biodegradable plastics also play a role in microplastic formation, as microplastic formation is a part of the biodegradation process. In other words, as biodegradable plastics break down, they can fragment into smaller microplastics.

The effect of these microplastics is a topic of ongoing research and concern. Microplastics have been shown to have negative impacts on the environment and human health, including ingestion by animals, contamination of the food chain, and potential harm to human health. However, the exact effects of microplastics from biodegradable plastics are not yet fully understood and require further studies. When modelling the number of microplastics over time, due to the use of PE mulching film and biodegradable mulching film, it can be seen that biodegradable microplastic do not accumulate like microplastics originating from non-degradable sources.

In general, it is noted that bio-based plastics will be necessary in a future circular society. To achieve this, efficient production routes with low energy demand as well as a product shift with a focus on oxygen-containing plastics, will be necessary. Polyesters are highlighted as offering advantages during recycling, making them a promising option for a circular economy. Furthermore, there is a need to move towards plastics that are less persistent in the environment, reducing the risk of plastic pollution.

8. Parallel session 1. Material performance, costs and economic viability

Facilitator: Karin Molenveld, Programme Manager Renewable Plastics – WUR

Integration of bio-based plastics into existing infrastructure and supply chains, and implications for the broader plastics industry

The integration of bio-based plastics into existing infrastructure and supply chains poses significant challenges but also offers opportunities for the broader plastics industry.

With global plastic production at 400 Mt, mostly polyolefins, increasing the use of bio-based plastics requires leveraging existing infrastructures and developing new value chains to derisk investments.

Bio-based plastics offer advantages like feedstock substitution, but their competitiveness is impacted by high raw material costs, particularly for European companies, as most polylactic acid producers manufacture outside Europe, in countries like Thailand or China, due to lower production costs.

To produce bio-based plastics, bio-based monomers are needed, which are the building blocks of polymers, and the question arises whether it is feasible to produce these monomers in Europe or if it is more cost-effective to import them from other regions.

However, the price difference between conventional materials and bio-based materials is significant, making it difficult for European producers to compete, and bridging this gap requires educating consumers about the added value of bio-based materials, particularly their environmental benefits.

Furthermore, the industry faces challenges such as fake products, including those that claim to be bio-based and biodegradable but are not, and reusable products that are not actually reusable, which necessitates policy support and regulation to prevent unfair competition and ensure products meet required standards.

To develop a bio-based plastic industry, incentives and regulations, such as those for bioenergy, are needed to create a market for these products, and companies need certainty and stability to make investment decisions with confidence. Additionally, tax credits or other mechanisms could be used to incentivise companies to use European-sourced biomass.

A proposal is to focus on high-impact areas, such as replacing materials with high CO_2 emissions, toxic materials, and high production costs, and using a horizontal approach to promote sustainability across sectors, rather than targeting only packaging.

Currently, the European primary sector, including agriculture, is a crucial sector that needs support, and ensuring sufficient resources and a stable market for farmers is essential. The sector's success depends on the support of farmers, the farming community, and effective sustainability criteria, as well as consideration of geopolitical factors, such as the impact of the war in Ukraine on grain supplies and prices. Ultimately, the success of the bioeconomy strategy relies on finding ways to make it work for farmers and the farming community, ensuring they see a financial benefit from the strategy, and addressing the complex issue of balancing food, feed, and industrial uses of biomass.

Replacement of conventional plastics market with bio-based plastics and preferred markets/applications

The replacement of conventional plastics with bio-based plastics requires significant investment and innovation in developing new materials, processing technologies, and applications. While some respondents to the pre-survey workshop suggest that up to 95% of plastics could be replaced with bio-based plastics, a more realistic goal is to replace 20% of traditional plastics, which would still require a fundamental transformation of the plastics industry, including the development of new materials, processing technologies, and applications.

The production of bio-based plastics, such as PLA, is currently limited, with the largest plant, Total Energies Corbion, having a licensed capacity to produce around 300 kt per year, and scaling up production to match conventional plastic plants is a significant logistical challenge.

To produce this amount of PLA, a significant amount of feedstock, likely around 600,000 to 1.2 Mt per year, would be needed, considering a conversion rate of 3 to 4, which raises a question whether biomass is to be sourced locally or at a European scale.

The use of biomass as a feedstock for bio-based plastics also raises concerns on food security, and efforts are being made to ensure that bio-based plastic production does not compromise it. Some studies estimate that the maximum production of bio-based plastics will not threaten food production.

According to one participant., using sugar as a feedstock for bio-based plastics could potentially reduce the amount of sugar available for human consumption, which could have positive health implications.

To decarbonise the industry, it is essential to consider all available feedstock options, including first-generation feedstocks, secondary raw materials, and forest-based raw materials, and to develop more efficient biotechnological processes for converting biomass into chemicals.

However, biotechnological processes that convert biomass into chemicals are still in the early stages of development, and it's challenging to run the process efficiently when using secondary raw materials. There are some European projects, such as the Agroinlog and Biorest projects, that focus on improving the agricultural supply chain to increase the efficiency of biomass preprocessing and make it more widely available.

Companies like Avantium are making progress in introducing bio-based materials into the market, with improved properties including recyclability, but the cost of production remains a significant challenge, and addressing the price issue is crucial to make bio-based materials production more viable and competitive with respect to traditional plastics. The price of sugar, for example, needs to be brought down to make bio-based plastics more competitive and attractive to investors, and using first-generation biomass, such as sugarcane or corn, could be a viable option for scaling up biomass production.

Additionally, second-generation and forest-based raw materials are promising solutions that can help address the challenges of biomass sourcing and availability. If the price issue can be addressed, there are many more opportunities for bio-based materials to be used in a wider range of applications. However, if the price remains a barrier, it may be more challenging to compete with traditional fossil-based plastics. Therefore, it's essential to explore alternative solutions and find ways to make bio-based materials more cost-competitive.

In the long run, as bio-based materials become more widely accepted and integrated into the industry, they will likely become more cost-competitive with traditional plastics. However, in the short term, companies need to be proactive in finding ways to reduce costs and make bio-based materials more viable.

Ultimately, replacing fossil-based plastics with bio-based alternatives requires a nuanced approach, considering the type of plastic being replaced, and the industry needs to be proactive in finding ways to reduce costs and make bio-based materials more cost-competitive.

Consumers' attitudes and expectations towards performances and costs of bio-based plastic products

According to the participants, consumers prioritise affordability and functionality over sustainability. When it comes to buying a plastic bottle, for example, consumers want it to be functional and not too expensive, as it doesn't have a lot of added value to justify a higher cost. This creates a challenging equation for producers, as they need to balance the consumer's desire for affordability with the need to educate them about the benefits of bio-based plastics. Educating consumers about the advantages of bio-based plastics could help to increase demand, but it's also important to note that consumers may not see a significant difference between conventional plastics like PE and PET, and bio-based plastics. From a consumer perspective, the primary concern is that the product works well and is affordable.

The lack of high-performance engineered polymer applications for bio-based plastics, particularly in industries like automotive, is a significant challenge. One possible solution is to use existing production facilities and substitute the feedstock with bio-based materials, allowing to produce high-performance materials that can compete with traditional plastics. In high-value applications like cars, the increased cost of bio-based plastics may be more justifiable, as the overall cost of the product is higher. This could make it easier for consumers to accept the higher cost of bio-based plastics. However, for lower-value products like plastic bottles, the cost difference may be more noticeable, making it harder for consumers to accept the higher cost of bio-based plastics.

From a brand consumer perspective, consumers do not want to pay more for bio-based plastics. They expect the brands to absorb the added cost. The Lego group, for example, has invested billions of dollars in finding alternatives to fossil-based ABS (Acrylonitrile Butadiene Styrene), but it's been a challenging process. One of the major problems in the bio-based plastic sector is that engineered polymers have been developed to work with fossil-based materials, and it's difficult to change that. For instance, the Lego brick was originally made from cellulose acetate, but it was later switched to ABS, which has been the standard material since the 1980s. The Lego group has explored other alternatives, including acetate solutions and advanced polymers, but they always come back to ABS because it's what their products were designed to work with.

Producing bio-based ABS is a complex technological question, and the environmental impact of producing such a material could outweigh the benefits of using recycled ABS. The molecule is complex, consisting of butadiene and styrene, and while it's theoretically possible to produce bio-based versions of these components, it's not currently being done due to the lack of a dedicated supply chain and infrastructure. The butadiene component can be produced bio-based, but the styrene and acrylonitrile components are more difficult to produce in a bio-based way. The main obstacle is not the technology itself, but rather the fact that the investments in industry are not there yet, and the volumes are too low to make it economically viable. If the demand for bio-based ABS were high enough, it could potentially be produced at a price that is not prohibitive. However, this would require significant investment in new infrastructure and supply chains.

Instead, companies like Lego are focusing on recycling technologies, which have enabled them to produce ABS with up to 70-80% recycled content. This approach is more feasible for them than using bio-based materials, as it allows them to achieve sustainability through recycling. The production of PLA is scaling up, with many new production facilities being built, but most PLA production is not currently taking place in Europe. To address this, it's essential to consider the entire value chain, starting from the feedstock, and to provide support for innovation, industrialization, and market creation.

The CBE-JU program is working on various topics and projects, including solutions for high-performance applications and technological innovations, and has concluded that more research is needed to develop the bio-based sector.

According to some participants, the industry needs to stop comparing bio-based products to fossil-based solutions, as this is not a fair comparison. Bio-based solutions are still in the early stages of development, while fossil-based solutions have been around for many years. The dialogue is shifting towards comparing bio-based solutions to each other, rather than to fossil-based solutions. This is because, in the end, bio-based solutions will never be competitive if they are compared solely on price and availability of materials. Instead, there may be a need for more regulation, such as banning certain types of plastic, to create a level playing field for bio-based products.

Main challenges related to upscaling lab-scale facilities and entering the market

From an investor's point of view, the support for bio-based plastics is still not there, despite technical advancements. In addition, there is a need for clarity on the findings from Article 8 of the PPWR to provide a clear understanding of the market in Europe. This lack of clarity is evident in the experience of Total Energies Corbion, which had committed to producing PLA (Polylactic Acid) in Europe in 2020, but rolled back the decision in 2023 due to a lack of legislative support and a market-wide ban on the afterlife application of their materials. Small to medium-sized enterprises (SMEs) in the packaging production sector have made significant strides in incorporating bio-based materials into their processes over the past two years, but the introduction of the PPWR has shifted their focus towards recycling materials and developing related technologies.

It's crucial to recognise the urgency of integrating bio-based materials into the PPWR framework and to consider them as complementary solutions to recycled materials, rather than viewing them as competitors. By taking a holistic approach, we can create more effective and sustainable solutions. However, the scalability of these technologies is also a key consideration, with a substantial gap in terms of scaling up production to meet global demands. To bridge this gap, we need to invest in development steps such as batch-wise synthesis, which can help bring polymers closer to market readiness. This process requires significant resources, including time, money, and collaborative efforts between companies and research organizations.

The current investment landscape poses a significant challenge to companies working with first-generation feedstocks, with the European Investment Bank (EIB) excluding investments based on these feedstocks, which includes companies producing lactic acid or other products derived from sugar, starch, or similar biomass sources. This funding gap has a detrimental impact on the development potential of these companies, hindering their ability to scale up and commercialise their technologies. Furthermore, the PPWR requires bio-based plastics like PLA to demonstrate recyclability within a very short timeframe - just 3 years. This means that by 2028, we need to have a clear plan in place to show that these materials can be recycled at scale. In contrast, more traditional polymers have had over 25 years, since 1994, to develop and demonstrate their recyclability, creating an uneven playing field.

To address these challenges, there is a need to increase the availability of feedstock for the bio-based industry. A recent report from the Bio-based Industry Consortium highlights the challenges in bio-waste collection, revealing that many EU countries have not met the targets set out in Article 22 of the Waste Framework Directive. This suggests that there is an opportunity for improving the separate collection of bio-waste, which could help to increase the availability of feedstock for the bio-based industry. Currently, much of this waste ends up in landfills or is incinerated, rather than being utilised as a valuable resource. One potential solution could be to provide support for infrastructure development or other initiatives that facilitate the separate collection of bio-waste. For example, using collection bags has been shown to be an effective way to encourage people to collect more bio-waste.

In the context of the lab-to-fab pillar of the bioeconomy strategy, it's essential to understand the extent to which we can leverage existing facilities and adapt them for new purposes, rather than relying solely on the development of new installations. This could help us to accelerate the transition to a more sustainable bioeconomy and to reduce the time it takes to bring new solutions online. Integrating different value chains can also help to achieve more efficient biomass use. By processing biomass in an integrated refinery, for example, we can create multiple streams that can be used by different users. This approach can also help reduce investment costs by allowing companies to share utilities, sites, and services. Companies like BASF are committed to making the most out of their existing facilities while transitioning away from fossil fuels and towards more sustainable feedstocks like recycled materials and biomass. Their 'Verbund' site, such as the one in Ludwigshafen, Germany, are extremely complex and interlinked value chains that can be adapted for new purposes, and the company is exploring ways to offer bio-attributed or recycled products through a mass balance approach, which enables them to reduce environmental impact while still utilising their existing facilities to their full potential and minimizing the need for new infrastructure and reducing waste.

Knowledge gaps

The discussion highlighted various knowledge gaps related to the use of bio-based feedstocks in the petrochemical supply chain.

One key gap is the lack of understanding of how a decrease in fuel production would affect the balance of products and the availability of feedstocks for chemical production. This is a complex issue that depends on various factors, such as the implementation of the 2035 ban on internal combustion engines, the availability of electricity at a reasonable price, and other related aspects. While it's difficult to predict exactly how things will unfold, the general trend does suggest that the use of fuels will decrease, and that could have a positive impact on the availability of feedstocks for chemical production.

Another gap concerns how to track and measure the impact of mass balance on the supply chain, including the amount of bio-based feedstock used compared to fossil feedstocks, and progress towards higher level of bio-based feedstocks. A proper framework is missing. To ensure that mass balance is truly contributing to an increase in the overall level of bio-based feedstocks in the petrochemical supply chain, it's essential to establish a framework for accounting and tracking progress.

Additionally, the participants highlighted a lack of transparency and standardisation in lifecycle assessment methodologies for mass balance, which can lead to inconsistent and misleading claims. While certifications like ISCC Plus are important, they typically focus on the batch level or individual products, rather than the overall impact of mass balance on the supply chain. To effectively leverage mass balance as a tool for increasing bio-based feedstocks, we need to be able to track and measure progress at a higher level. This could involve setting targets for increasing the percentage of bio-based feedstocks used and regularly reporting on progress towards those targets.

The specific knowledge gaps are:

1. The impact of decreasing fuel production on the balance of products and feedstock availability.
2. How to define a framework to track and measure the impact of mass balance on the supply chain.
3. How to increase transparency and standardization in lifecycle assessment methodologies for mass balance.
4. More data and research on the effectiveness of mass balance in increasing bio-based feedstocks.

9. Parallel session 2: Feedstock sustainability – land use and resource competition

Facilitator: Sarah Mubareka, Joint Research Centre

Fossil VS bio-based: impacts on climate and land use

In a recent study, Systemiq assessed that even with the most ambitious 'reduce-reuse-recycle' measures, up to 28 Mt of virgin fossil plastic will still be needed in Europe each year to meet the market demand [8]. Without alternative, fossil-free feedstock, that demand will lock in further fossil emissions. There is an urgency to reduce our consumption of fossil-based feedstock due to its impact on climate change. Climate change will affect arable land availability by means of land degradation and desertification, meaning that fossil-based plastics have an indirect impact on land use. That's why we need to scale up the use of biomass, broadening the feedstock pool.

On the other hand, increasing bio-plastic production may also have environmental impacts, including on land use. According to European Bioplastics, the land used to grow the renewable feedstock to produce bioplastics was 0.8 million hectares in 2022, accounting for 0.013 % of the global agricultural area [9]. Along with the estimated growth of global bioplastics production in the next five years, the land use share for bioplastics will increase to still below 0.06%. The potential of it to affect land use change or to really be a driver for regenerative practices looks limited. Nevertheless, the additional demand in the bio-based plastic sector could affect the land use change. Each feedstock can have both indirect or direct impacts, depending on how it is grown, how much water is required and whether it has a regenerative capacity. The long-term effects have to be carefully investigated, also looking into marginal land use.

Available feedstocks

Bioplastic polymers are made of sugars, starch, oils, and proteins. Feedstocks in use nowadays are mainly maize and sugar cane. Their high starch and sugar content ensures high yields. Other agricultural feedstocks (both arable crops and residues) as well as cellulosic and perennial crops are also suitable for bio-based plastic production. They can be grown either on arable land, also as part of the rotation system, or on permanent grassland. Food crops are very land efficient and have multiple by-products and residues that can be used for different purposes, some of them also for the chemical and bioplastic cycle. Where possible within the ecological boundaries, increasing food crops production means increasing not only food availability but also the availability of other products in a land efficient way. Cereals crops for example can be used for different outlets, e.g. keeping the protein part for the food while using the starch for bio-plastics or for chemicals and material outputs.

Bio-based plastic production from microalgae is an opportunity to be explored and further improved. At present algae have yield issues and are not available in sufficient quantities to ensure the scale up of the production process, leading to price issues.

Bio-based plastics can be made of mixed municipal biowastes, industrial biowastes, residues and by-products like used cooking oil and animal fats. In Europe there are a lot of competing uses for bio-wastes, and significant amounts of waste materials which are suitable for plastic production are already used, mainly by the agricultural sector as animal feed. In terms of cascading, biofuels use 0.8%, including a lot of woody biomass which could be used to make chemicals. Biorefineries are very efficient, using everything which gets out of the processing plant, the residues are usually processed to avoid disposal costs for the producer.

In general, the use of bio-wastes for bioplastic production faces several issues:

1. Availability and costs: scaling up the production of plastics made of bio-waste requires high amounts of feedstock at affordable prices.
2. Definition of waste: a waste is what you intend to discard or must discard, the rest are residues or by-products but agricultural residues are not waste, they're outside of the waste regulations.
3. Quality: purity and homogeneity are critical issues.
4. Sourcing: bio-waste generated on a local/regional scale can be the lowest impact solution.
5. Undesired effects: putting a premium on the use of secondary or tertiary waste as feedstock could increase their generation.

Gas fermentation is very versatile as it can process all types of waste and convert them into biogas or into synthesis gas and then you have a pure gas which you can put into bio-based plastics or some other product, thus avoiding hydrolysis, which is complex and expensive due to enzymes.

Research shows that it is possible to produce PHB from wastewater sludge [10]. The process is not economically viable but still has high potential.

Sustainability criteria

Plastics production in Europe totaled 54 Mt in 2023. Although it is a significant amount, bioenergy requires a lot more carbon [11]. Besides, applying stricter criteria for materials in comparison to energy would not be consistent with the cascading principle.

To define a robust set of sustainability criteria for bio-based materials we must see whether there are potential environmental threats, whether there are ecological issues to consider and what is the way forward, considering also economic and social aspects.

CBE-JU has defined a set of criteria for the projects it supports. These criteria focus on cascading uses, meaning on non-food feedstocks which are residues or waste streams, as well as different sources like aquatic agriculture.

REDIII sustainability criteria are an important term of reference. As a matter of fact, PPWR Article 8 affirms that the Commission shall design a legislative proposal to promote minimum bio-based content for plastics, based on the state of technological development of bio-based plastic, taking into consideration the REDIII article 29. FSC certification for wood products is another relevant reference. To define sustainability criteria for bio-based plastics it is necessary to build up on what is already there considering the nexus between energy and material uses. About 50% of the bio-based plastics are made from biofuels which are compliant with REDIII criteria. For this reason, sustainability criteria for bio-based chemicals and materials should be consistent with REDIII sustainability criteria, even though they should be adapted. In fact, bio-based plastic production often takes place in the same biorefinery where SAF/biodiesel/bioethanol are produced, starting from similar feedstocks. Bioenergy, biomaterials or biochemicals share the same types of feedstocks. By processing such feedstocks, the industry gets either bioenergy or bio-based plastics. That's why there is a need for a reference to the REDIII criteria. Enforcing different standards for the same types of raw biomass and raw materials, which are processed into the same production site, would create issues.

Although feedstock can be grouped into first, second, third and fourth generation (linked to gas permutation and CCU principle), this hierarchy has been more and more abandoned. Ranking feedstocks based on their sustainability is not effective because sustainability is not an intrinsic property, but it depends on many different aspects, including:

1. how you cultivate a feedstock: carbon farming practices can improve the sustainability of feedstock cultivation.
2. where a feedstock is grown sustainable cultivation practices are context dependent.
3. its mode of transport and the related fossil energy use: locally sourced feedstock is preferable, good to have, but transporting feedstock by barge for 200 km might be better than by truck for 20 km.
4. how it is processed: process yield and efficiency also affect the sustainability of the final product.
5. for which final application it is used.

The most efficient option depends also on the specific context. In Scandinavia for instance forestry makes the most sense. Nevertheless, virgin crops always entail the risk of converting new land areas into agricultural areas. In overall the bio-based plastic industry promotes a feedstock agnostic approach, avoiding excluding certain feedstocks based on competition with other uses (e.g. food, for which sustainability criteria are not yet in the radar), while supporting sustainable sourcing practices for all of them. Excluding the food crops would in fact limit bio-based plastics industrial production as today the production from those agricultural crops is the most mature. Sustainability criteria are also market pool measures and demand measures which should ensure a level playing field for bio-based plastics and bioenergy products.

In REDIII, the cap on crop-based biofuels is maintained at 2020 consumption level (with a max of 7%), and the framework for crops remains stable until 2030. In the energy sector, limiting the variety and quantity of eligible biomass feedstock doesn’t prevent the defossilisation process, as there are alternative renewable energy sources. In the material sector, the alternatives to biomass are limited: only carbon capture and recycling are possible options. For this reason, a cap on biomass use for the production of bio-based plastics may be a barrier to defossilisation, putting mid-term or even long-term climate targets at risk.

Regenerative practices

It is evident that sustainable production of agricultural and wood-based feedstocks is the only possible way for the paper, textile and all the other biomass processing sectors. In fact, these industries need the land to be fertile to keep yields high enough. For plastics it will be the same.

Sustainable agriculture encompasses different techniques: intercropping is when you grow two crops at the same time on the same piece of land; sequential cropping is when you grow a crop in between two main crops; a break crop is a crop within a main crop in a rotation that breaks cereal production. Degraded land can benefit from arable rotations practices, which preserve the nutrient value of the soil by breaking up the cycle of pests. Cultivating break crops within the rotation cycle avoids that land is left unused, causing soil erosion. Currently we don't have enough break crops in Europe that farmers can grow, due to a lack of market opportunities. In the UK typically 5% of arable land is left uncropped, meaning 4,000,000 hectares of uncropped cropable land in the UK. A lot of land is just left bare because we don't actually have crops that will pay a farmer a profit to actually grow it. Break crops that fit within an agricultural rotation, providing starch, oil or sugar, are high potential sustainable feedstock for bio-based plastics. Novel break crops are a very interesting area that's often overlooked.

Leaving some agricultural residues on the ground after harvest prevents soil erosion. How much has to be left on the ground depends on soil quality[1] and it depends on what the farm is going to do with the land the year after they've grown a crop. It may purely be the amount of straw you can't actually harvest. In fact, you don't take all straw off a piece of cereal land because you can only cut so low.

Braskem produces bio-based plastics from sugar cane in Brazil. Sustainable use of land is ensured by nutrient recycling practices and biodiversity protection [12]. In Brazil the Forest Code requires landowners in the Amazon to maintain 35 to 80% of their property under native vegetation. So, rural farmers of all kinds can buy land in the Amazon, but they can only farm 20% of it. Europe could look into a similar approach as well.

The role of primary producers

Farmers can take the opportunity to be part of the bio-based plastics supply chain: they can diversify their sources of revenues by providing sustainably grown feedstock like break crops and restore degraded farmland at the same time. This approach can help develop new business models and integrated bioeconomy chains, supporting rural development.

Futerro plans to establish Europe's first fully integrated Lactic Acid, Lactide and PLA biorefinery in Normandy [13]. Whitin the context of this project, Futerro signed a partnership with a French agricultural cooperative which will provide the raw materials, acknowledging this is a sustainable choice in terms of productivity. With climate change affecting the yields of agricultural production, farmers need more than ever additional sources of revenue.

In Andalucía, Neste joined forces with local farmers and the local rice growers association to start a project that focuses on growing intermediate crops between the rice-growing seasons [14]. Farmers contributed to the creation of a new sustainable supply of raw materials, and they could benefit from additional revenues. This was possible thanks to REDIII targets for sustainable aviation fuels based on advanced feedstocks like novel vegetable oils. Such targets created a market demand for the oil from the intermediate crops, to be used for aviation fuel applications. This example shows that specific measures giving value to regenerative practices can reward the farmers who implement them. Farmers can adopt regenerative approaches like intercropping or rewetting if good market options for the outcoming products are available.

CBE-JU has just established the Working group on primary producers to further engage the farmers on the bio-based product topic and innovation aspects in general. Farmers show high interest in this initiative.

Regions like Eastern Europe can provide high amounts of suitable feedstock but they need to have some kind of incentive.

[1] On heavy clay for example you probably don't want to plough in too much straw from cereal production because it would just stay there and rot in the ground which isn't good. On a light low soil you'll want to maybe plough in a bit more carbon because it improves water retention and land use.

Knowledge gaps

Are REDIII sustainability criteria robust enough? More evidence on the REDIII functioning is needed. The REDIII criteria for wood-based feedstocks are more controversial than the ones for using food-based crops, which is capped. The cap is pretty strict, but it is fine to limit the amount of agricultural biomass available for bioenergy production: it stimulates the consumption of more advanced feedstocks like waste, residues, and novel vegetable oils, thus ensuring not only environmental sustainability but also bringing socio-economic benefits. Financial resources are needed to reward farmers undertaking sustainable production practices. The investments' size can be estimated according to the urgency to defossilise.

We need to understand how to achieve our climate targets while complying with the cascading principle. Acknowledging the benefits of bio-based materials in terms of climate mitigation can solve this conflict between cascading principle and climate targets. Renewable energy targets are complementary because biorefineries' production capacity should be scaled up effectively in order to replace fossil-based feedstocks. We need to pursue long term goals on climate neutrality by means of policy coherence, identifying what could be undermining.

Market opportunities and industrial scale-up

Neste is expanding the Rotterdam refinery to increase its renewable production capacity but there's no business case for it at the moment. The investment is based on the expected future demand for SAF. The renewable energy targets are enabling the technology scale up.

The clean industrial deal promotes the industrial scale up. This is crucial to take advantage of the EU investments in R&I of bio-based plastics. The industrial scale up should preferably take place in Europe or at least the technology should stay here.

Europe 's dependence on foreign feedstocks and products

Most fossil feedstock is currently imported. Phosphorus is largely imported from outside Europe too. Increasing the share of locally produced feedstock is a long process. That's why at present we need both imported and locally produced feedstock. It is also a fact that the global South produces much more biomass than the North because of its climate conditions. In addition, the local scale risks limiting the ambition to replace fossil fuels, which are largely sourced outside of Europe.

Imports can be a way to do so-called premarketing. Braskem for instance, has provided biopolymers to the Japanese market for over 15 years. In October 2024, Braskem Siam chose a Japanese company as contractor for bio-based ethylene plant in Thailand. It thus started producing locally.

Central, Eastern Europe and Ukraine could provide high amounts of feedstock for bio-based plastic. Europe produces around 6 billion litres of ethanol which is mostly used as fuel. Investments in dehydratation would make it possible to produce 2,5 Mt of polyethylene out of it but ethanol made in Europe is expensive. Ethanol can be blended into transport fuels up to a certain threshold, representing a limit for its market. Brazil is blending up to 30% while in the EU it's between 5 and 10%. Although there is untapped potential, the cap limits the demand and the market dimension. The cap is an issue for the local production.

Making products from our own waste is another opportunity we have. It's all a question of having the right framework. Europe can become more attractive for bio-based products producing industries, thus making European bioeconomy more competitive. The upcoming bioeconomy strategy and other related policy initiatives can make the bioeconomy in Europe a leverage for

growth and competitiveness.
To ensure a level playing field, it is important to take into account how the biomass feedstock gets to the EU. SAF and other biofuels made of imported from China UCO can benefit of subsidies. When importing from abroad, the risk of fraud is there and controlling is a complex task.

The USA could maintain a clean fuel production tax credit which they are going to make eligible only for made in USA feedstock. There are other regions of the world that are going local, mainly for economic reasons.

A new UK-US trade deal will remove the previous 19% tariff on US bioethanol imports, allowing 1.4bn litres of US tariff-free ethanol to access the UK market each year. The UK biofuels sector has warned the consequences could be devastating, with domestic plants, supplied by UK cereal farmers, being forced to shut as they struggle to compete with subsidised imports.

It is not likely that biomass feedstocks would ever be imported for chemical use to Europe, it would be rather produced at source with import of ethanol, polyethelene or lactic acid. It does not make sense to ship biomass around the world.

10. Parallel session 3. Product sustainability - Environmental performance

Facilitator: Giulia Listorti, JRC

The Joint Research Centre (JRC) has a team working on life cycle assessments, considering all stages of the value chain and mapping the use of resources and corresponding emissions throughout the life cycle. The method takes a holistic approach, looking at the entire system perspective.

The JRC has been working closely with the Directorate-General for Environment to develop and update the Environmental Footprint method, as it is important to have a transparent and common methodology to ensure a level playing field.

The method considers 16 environmental impact categories, including carbon footprint, greenhouse gas emissions, water, land resources, toxicity, and pollution. Additionally, JRC is working on the Safety and Sustainability Assessment (SSA) framework, which is a set of voluntary criteria for innovations that consider both environmental sustainability and safety to avoid regrettable solutions.

The JRC conducted an extensive desk research on conventional and bio-based solutions for chemicals, housing, textiles, and plastics. The results show that bio-based solutions perform better in some environmental impact categories, such as climate change and resource use, but worse in others, like land use.

Sustainability of bio-based plastics - and comparison with fossil-based products

The comparison between bio-based plastics and fossil-based plastics raises questions about the suitability of the benchmark used, with some arguing that using fossil-based plastics as the baseline is not fair due to the externalised costs and environmental impacts associated with their production. A more neutral approach might be to use a generic material as a baseline, rather than comparing bio-based plastics directly to fossil-based plastics. The issue of benchmarking is complex, and there is a need for standardised and coherent methods to ensure that comparisons are fair and accurate. life cycle assessments (LCAs) and footprint analyses can help to evaluate the environmental sustainability of bio-based plastics, but these methods can be complex and may not always provide a clear answer. Additionally, the terminology used when discussing environmental impact assessments can be misleading, as we are not measuring actual environmental impacts, but rather calculating potential impacts. To ensure transparency and accuracy, it's necessary to clearly disclose the underlying assumptions and methodologies used in LCAs, and to consider the limitations and restrictions of each approach. When evaluating the sustainability of bio-based plastics, it is essential to consider multiple factors, including the baseline or benchmark used, the timeframe, and potential future developments. The use of bio-based plastics in certain applications, such as aquaculture and fishing gears, could help to reduce plastic pollution in the ocean and minimise environmental impacts. Ultimately, the key is to ensure that the methodology used is transparent, consistent, and fit for purpose, and that the limitations and restrictions of each approach are clearly understood, in order to make informed decisions about the sustainability of bio-based products and to build trust and credibility with stakeholders.

The specific points mentioned are:

1. The need for a neutral benchmark to compare bio-based plastics to fossil-based plastics.

2. The complexity of LCAs and the need for standardised methods.
3. The importance of transparency and accuracy in LCAs, including the disclosure of underlying assumptions and methodologies.
4. The need to consider multiple factors when evaluating the sustainability of bio-based plastics, including the baseline, timeframe, and potential future developments.
5. The potential benefits of using bio-based and biodegradable plastics in certain applications, such as aquaculture and fishing gears.
6. The importance of educating consumers and stakeholders about the complexities of sustainability and the trade-offs involved in evaluating different products.
7. The need for a system that can normalise and weight different impact categories, allowing for a single score or number that summarizes the overall sustainability of a product.

Environmental impacts of different types of feedstocks

Different feedstocks entail different environmental impacts. When evaluating the sustainability of bio-based plastics, it's essential to consider not only the impact of using biomass for plastic production but also the opportunity costs of using it for other purposes. The use of the RED III framework as a benchmark for sustainability criteria for biomass feedstock is a step in the right direction but benchmarking different feedstocks against each other can be challenging. A more effective approach may be to evaluate them against a set of sustainability criteria, such as those outlined in the RED framework. The development of the Environmental Footprint is expected to propose a solution for a midpoint impact category, which will help address some of the methodological challenges and data gaps associated with biodiversity assessments.

Conducting a consequential life cycle assessment (LCA) can be a useful first step in evaluating the sustainability of bio-based plastics, but it's essential to consider the broader solution or system that the material is a part of. For example, according to some participants, when evaluating a bio-based bottle, we should consider the entire packaging solution, including alternatives like glass bottles or aluminum cans. However, the comparison between bio-based products and metal alternatives can be misleading and oversimplify the complexities of the issue. Instead, we should focus on the broader societal debate about the role of plastic and other materials in our economy.

The industry is evolving, and the market is shifting towards valuing sustainability and other factors beyond just cost. As a result, the way we compare and evaluate bio-based materials needs to adapt to these changing market dynamics.

From an SME perspective, the most important category is carbon, as it has a direct economic value. However, biodiversity is also a critical topic, particularly in the construction sector, and it's essential to develop methodologies that can adequately address this issue. The development of the Environmental Footprint is expected to propose a solution for a midpoint impact category, which will help address some of the methodological challenges and data gaps associated with biodiversity assessments.

In the context of the bioeconomy, it's essential to prioritize the most impactful issues, such as biodiversity, and to consider the broader context when evaluating the sustainability of different materials. Simplifying the comparison between fossil-based and bio-based materials by focusing on carbon emissions could be a useful approach for regulatory purposes. However, different impact categories should not be equally weighted, and the weighting of impact categories should be linked to policy objectives and the progress we need to make to achieve them.

Establishing sustainability criteria or standards for biomass production could potentially simplify the evaluation process, but it would require setting up robust sustainability criteria and standards for biomass production. Ultimately, the goal is to achieve net zero emissions by 2050, and bio-based plastics are just one tool among many that can help us reach this goal.

Communication to the public and consumers' attitude and expectations towards bio-based plastics

The communication of bio-based plastics' benefits and impacts to the public is a crucial challenge, as consumers may not be aware of the environmental impacts of their behavior and may not be willing or able to pay a premium for bio-based products.

Clear definitions and methodologies are essential for communicating the benefits and differences between bio-based plastics and bio-attributed plastics, and for educating consumers about the benefits of sustainable consumption patterns. The lack of clear definitions and methodologies can lead to confusion among consumers, which can ultimately erode trust in the industry.

Companies like Unilever have found that consumers are primarily driven by price and performance and may not be concerned with the environmental or social impact of the product. However, some companies have successfully promoted sustainable products and practices, and regulatory efforts such as the Empowering Consumers for the Green Transition directive and the Green Claims directive aim to promote transparency and accuracy in environmental claims.

The use of labeling and certification schemes, such as the ISCC (International Sustainability and Carbon Certification) scheme, and C14 measurement can help to ensure that companies are accurately labeling their products and making reliable environmental claims. Transparency is key, and consumers should be informed about the mass balance approach used to attribute the bio-based content of products.

It is likely that most consumers wouldn't fully understand the details of bio-based and bio-attributed products and may not even be interested in learning about them. Many consumers may not care about the specifics of these products and may not be able to understand the technical terms used to describe them.

When it comes to communicating information about these products to consumers, labelling on bottles may not be the most effective approach. The space available on labels is limited, and the information that can be included is often restricted. Adding a QR code that links to a website with more information may not be a practical solution, as few consumers are likely to take the time to scan the code and read the additional information. A more effective approach may be to use eco-labels or other simplified communication methods that convey the key benefits of bio-based and bio-attributed products in a way that is easy for consumers to understand. For example, a label that simply states that a product is "environmentally preferable" or "safe" may be more effective than one that includes detailed technical information.

While some consumers may not prioritise sustainability, others do care about the environmental and social impact of the products they buy, and clear labeling and communication can help them make informed decisions. The use of digital product passports and eco-labels may be effective ways to communicate the value of bio-based and bio-attributed products to consumers, and to provide them with the information they need to make informed decisions.

How to include innovation in the analysis of the impacts, namely when comparing conventional with bio bases alternatives

The inclusion of innovation in the analysis of impacts, particularly when comparing conventional with bio-based alternatives, requires careful consideration of the scaling up of technologies and the potential changes that can occur as a result. According to some participants, conducting life cycle assessments (LCAs) for pilot plants and low-tier technologies, it is important to work with technology experts to understand how the process would change as it is scaled up. The development of guidelines or recommendations on how to upscale LCAs would be helpful in ensuring that comparisons between different technologies are fair and accurate. However, even with such guidelines, there will always be uncertainties and limitations in the data, and it is essential to be transparent about these limitations and provide ranges or disclaimers to indicate the potential changes that can occur when scaling up.

In the context of the circular economy, particularly in packaging, the introduction of new biopolymers can create dilemmas, as they may have improved resource efficiency but worse end-of-life impacts than traditional polymers. According to some participants, the European Commission's granting of transition periods for new materials is not a long-term solution, and it is essential to consider scenario planning in LCAs to account for trade-offs and identify key drivers of environmental impacts. The use of scenario planning, such as assuming that a new bio-based material can be recycled in the same stream as a traditional material, can help model different end-of-life scenarios and understand how environmental impacts might change over time.

The creation of incentives for companies to develop and use sustainable materials, such as through the use of Environmental Product Declarations (EPDs) for construction products, is crucial. The trend of using a 100% scenario, where the manufacturer supplies the results for several 100% scenarios, and then it's up to the user to determine the end-of-life scenario for a specific market, can help move the needle and create an incentive for companies to develop sustainable solutions. However, there is a risk of creating an incentive for companies to start collecting and recycling materials without considering the producer responsibility aspect, where companies should be incentivised to design products that are recyclable and have a high recycled content. Ultimately, the goal is to minimize the number of materials that are impossible to recycle and promote sustainable consumption and production patterns.

Knowledge gaps

The discussion highlighted various knowledge gaps and challenges in promoting sustainable innovation and product sustainability. One of the main challenges is the difficulty in making direct comparisons between different technologies and materials due to deficiencies in one impact category or another, such as end-of-life. However, rather than waiting for a technology to be fully mature, we can use current data to give an incentive for performance and encourage innovation and improvement in areas where it's lacking.

The interaction between life cycle assessment (LCA) thinking and market economy thinking is also crucial, as companies need to be incentivised to invest in research and development to address deficiencies and improve the overall sustainability of their products.

It was also highlighted the importance of considering the entire value chain, from production to end-of-life management, when evaluating the sustainability of bio-based materials. The involvement of primary producers, such as farmers and foresters, is essential in providing valuable insights into the production process and the potential uses of waste materials. Additionally, the end-of-life management of bio-based materials is critical, as it can have a significant impact on the environment. The complexity of natural systems and the interconnectedness of resources are also important considerations, as removing resources from one system can create gaps and imbalances in other systems.

11. Parallel session 4: End of Life Management

Facilitator: Karin Molenveld, Programme Manager Renewable Plastics – WUR

End of life is very complex for plastics, as when plastic products were designed, reusability or recyclability were not among the design criteria.

Recycling rates of plastics are very low compared to other materials because there is a big amount of plastic that perform badly in terms of recycling: about 150-100 Mt of plastic every year cannot be recycled. Dealing with this amount is thus a priority, as incinerating non-recyclables prevents a circular use of primary materials.

Policy framework

The EU policy aims at minimising waste, while keeping materials in the system as long as possible. It addresses non-recyclable materials, whether they are fossil or bio-based.

The current understanding of circular economy focuses on mechanical recycling, and the European policy gives priority to this method. In this way, waste treatment prevails on circularity and replacing fossil-based feedstock. Broadening the **circularity concept** could help effectively reduce plastic waste in Europe.

Recycling alone is not enough: introducing other sources of carbon is also necessary because of the losses. In fact, the plastic sector will not likely become 100% circular, thus leaving space to bio-based options, which can make it possible to reduce our dependency on fossil-based products.

PPWR states that all type of packaging should be recyclable by design and recycled at scale by 2030. It sets 2030 and 2040 targets for a minimum percentage of recycled content in packaging. To achieve concrete results, meaning a true progress towards circularity, several initiatives or secondary legislation will also play an important role: design for recycling guidelines, technical standards by Cen (European Committee for Standardization), and an implementing act for recycling methodologies are crucial. By putting emphasis on design for recycling, PPWR is expected to limit the amount of laminated and full of adhesive or ink packaging on the market. On the other hand, enforcing the PPWR provisions on a national level could be very hard. Including more than 50% recycled content[1] into plastic products is very challenging, at least for the ones made of polyolefins, due to risks of degradation. Enormous investments are needed for new recycling facilities (either for mechanical and chemical recycling) but the industry does not believe going above 50% recycled content or recyclability rate is feasible, while bio-based materials struggle to be integrated into the recycling loop. Many economic operators will not comply with the PPWR targets, but control authorities will not have the resources to enforce the provisions. There are severe risks of not compliant products being dumped onto the market. In addition, PPWR is all about packaging, but many other sectors exist.

The PPWR includes a limited list of mandatory **compostable applications**, which can be possibly extended by MS. According to Article 9, paragraph 2, MS are free to make available on their territory compostable packaging of different kinds. This article makes the Regulation work as a Directive, leaving too much space to MS to sort out their own markets. As a matter of fact, Italy is coming up with a long positive list whereas Germany is probably not including any item on its own list. From a single market point of view, this is worrying. If a certain application is going to be marketable in Italy for example, it's also going to be marketable in Germany but without the same mandatory requirements for industrial composting.

According to PPWR Article 9, paragraph 5, the Commission may analyse whether to identify further mandatory compostable applications, if justified and appropriate due to technological and regulatory developments, and, where appropriate, present a legislative proposal. No deadline is mentioned, showing a low commitment level on this side. By contrary, the Commission commits to publish, no later than 3 years after the entry into force of PPWR, a review of the state of technological development and environmental performance of biobased plastic packaging, and, where appropriate, present a legislative proposal with sustainability requirements and targets.

The biodegradable applications which are not on the list, need to be designed for material recycling, thus requiring a full shift for a sector that was intended to be degradable, compostable, to material recycling.

The waste framework directive defines composting as organic recycling and part of the waste hierarchy, while the PPWR seems to follow another line, enforcing eco-design and recycling criteria that compostable material can hardly comply with. In practice, after the deadlines set by the PPWR, these products won't find any market.

In addition, the eco-design and recycling criteria leave to new materials only five years to achieve recyclability at scale. Any **innovative packaging material** has only five years to be developed at TRL 9, marketed and to find adequate sorting and recycling facilities, which need to be developed. Even PLA, which exists since 2005-2010, is not yet recyclable at scale because no recycler wants to sort it. New materials like PHA, which has been on the market only in the last five years, risk to be completely cut out. These eco-design and recycling criteria risk preventing the commercial development of any new plastic material for packaging application, losing the opportunity to take advantage of the previous investments in R&D.

The tables included in PPWR Annex II show that the proposal lacks proper recognition of bio-based materials, mentioning only biodegradables. On the other hand, PPWR leaves room to define the role of bio-based plastics specifically in those applications where really you cannot use recycled content e.g. in food applications.

Enforcing **minimum bio-based content** is easier than enforcing minimum recycled content, as the amount of bio-based carbon can be measured much more easily, proving its sustainable credentials.

Regarding cases where closed loop is not possible, the Dutch government proposed bio-based content as a tool to limit reliance on fossil feedstock within a broader circularity approach. The bio-based content could help packaging which is not recyclable in closed loop to score better under the PPWR, either to pay a lower eco-modulated Extended Producer Responsibility (EPR) fee, thus mitigating the higher production cost of bio-based plastics. This approach would promote the introduction of higher bio-based content in packaging, allowing market access to products that are not highly recyclable or ensuring lower EPR fee.

Thanks to the **EPR** mechanism, the creation of new recycling streams is financed by private financial resources, enabling synergies within the supply chain. The issue is that today there are recycling facilities only for fossil-based materials. In fact, the conventional plastic sector has been developing proper collection, sorting and recycling systems over many decades, while the bio-based plastic sector struggles to provide a solution in a few years. In addition, waste management is a competence of national governments, and different MS have very different waste management systems, which makes it very difficult for economic operators to find their way in every MS.

Recyclers can sort PHA, PLA, PBAT and any other material through near infrared technologies but they need high volumes. Moving the recyclers away from the status quo is challenging, because they are quite conservative and they only massify currently existing waste streams. Waste management companies often say that bio-plastics may contaminate the waste stream, showing that until they are produced in low volumes, bio-based plastics are perceived as a contaminant. The public authorities should avoid providing incentives to the recyclers who don't accept novel materials in their streams, unless scientific evidence shows that there is real contamination. The sector needs both coordination among stakeholders and enabling policies to switch to bio-based or to support increasing bio-based contents in plastic materials. Otherwise, until the production volumes of bio-based plastics don't get to the 10 kilotons threshold, they won't be able to create the demand to be recycled, and recyclers won't be interested in treating them. With some exceptions[2], high EPR prices contribute in a sense to keep the volume so low: in countries like Belgium or France the EPR scheme makes bio-based or biodegradable plastics much more expensive than fossil-based ones. In Belgium, the fee to put on the market compostable materials including bio-based materials, is four times higher than the one that polystyrene packaging producers must pay, even if there are no recycling facilities for polystyrene at scale. The packaging producer transfers the extra cost to the final sale price, thus requiring consumers to pay a higher price, also due to higher EPR fee, for packaging which is bio-based, and which could be recycled.

The net zero target requires about 20% of bio-based and at least 50% of recycled materials. We risk missing both ambitious recycling targets and targets for bio-based products, since recycling is holding back bio-based.

By banning all plastic for **single use** applications, Europe missed the opportunity to create a market for biodegradable plastics not releasing persistent microplastic in the environment. By contrary, China banned fossil-based plastic but not biodegradable ones, creating huge opportunity. Currently China has almost 1,000,000 tonnes PLA production capacity, following an increasing trend. This industrial scale up taking place in China, largely takes of IP which was developed in Europe.

Bio-based plastics, both bio-attributed or bio-based in the narrow sense, are still more expensive than their fossil counterparts. Such a cost barrier should be addressed by **market pull measures**, making the bio-based plastic sector more attractive for investors. PPWR includes a legislative hook for bio-based plastics, first of its kind in the EU regulatory framework. Nevertheless, it may come too late for the European market. Within the bio-based and biodegradable plastic industry, many players are European, most of them have been supported by the European Commission, and most of them are willing to invest. Some are investing in Europe, thus increasing the EU production capacity, some others are investing elsewhere, due to lack of support and uncertain legislation. Investors need a clear, robust and long-term framework they can build their investment decisions on, which may include targets for bio-based materials. Such a framework is crucial to put on the market novel technologies like chemical recycling where the risk profile is potentially high. To bring new materials to the market, it is necessary to acknowledge that innovative materials need time to achieve full recyclability.

CBE-JU is a partnership between the Commission and the bio-based industries consortium which was established to derisk the investments and to enable the scale up of bio-based industries in Europe. It has largely supported the technological development of bio-based technologies, including bio-based plastics, by means of EU funds. CBE-JU is thus aware of both the amounts of financial resources which were invested in innovation and the **regulatory barriers** preventing the industrial scale-up of such innovation.

The Commission has just launched a new start-ups and scale-up strategy. The multi annual financial framework will also have more on startups and **competitiveness**, while one of the pillars of the new bioeconomy strategy will be from fab to lab. In the meanwhile, the clean industrial deal recognized the key role of recycled and bio-based materials to replace fossil-based ones. There is a strong political will to promote bio-based innovation by many different tools, going beyond regulatory barriers. The idea is to make Europe more competitive, taking advantage of patents by supporting investments. It is important to exploit the political momentum to come up with concrete measures, designing and enforcing a clear and viable policy framework for the sustainable development of the plastic sector.

Recycling technologies

Sorting is challenging not only for bio-based plastics but also for some kinds of traditional plastics. Consumers cannot improve their sorting skills beyond a certain level. There are many different solutions being developed, ranging from deposits schemes to near-infrared (NIR)/mid-infrared (MIR) spectroscopy combined with AI and other technologies for mixed wastes sorting. In this way you create sub streams that can go into the most suitable next process step.

Mechanical recycling has a very important part to play in the end-of-life management of plastics, but it is by no means the only end of life treatment available. It works well for PET bottles but not for all other packaging. Mechanical recycling often occurs in open loops, also called downcycling. The alternative is chemical recycling, a new promising option that still has low yield, meaning abundant carbon loss. According to the report [15], we need all available methods to treat the plastic at the end of life in order to reduce plastic waste. We need to combine different recycling techniques: mechanical recycling, organic recycling and emerging advanced recycling or chemical recycling depending on the polymer and the application.

As illustrated in [16] the plastic sector is focusing a lot on the beginning of life perspective meaning on replacing the feedstocks from fossil to bio-based, both in recyclable applications and traditional plastic applications. Europe wants to take advantage of the already existing infrastructure but also to move away from fossil feedstocks, while improving the recyclability and investing in new reusable business models. Biodegradable materials suffer a lack of know-how and dedicated infrastructure, limiting further investments.

Industrial composting facilities are needed to offer a valid end of life option to compostable plastics and in particular to food contact sensitive materials.

Most of the bio-based plastics currently available are either recyclable or biodegradable or compostable. It's relatively few that cannot be reused or recycled. PET, PP, and PE bioplastics can integrate into existing recycling systems. Novel bio-based polymers are also recyclable through NIR spectroscopy, but the low volumes prevent the scale up of the recycling processes and infrastructure. The recycling industry should be more engaged in solving these challenges.

Technical properties

Some materials and products are easier to recycle than others. Fossil-based polyester performs very well in terms of circularity. In fact, with bottle grade polyester, usually without pigments, it is much easier to close the loop. The problem is that we must move away from fossil feedstock and that the properties of polyester are not suitable for every kind of application. Polyolefins and polyesters have different uses; most of the time they don't compete that much. In terms of circularity, polyester performs better. Over the past decades, the polyolefins industry has been working to improve packaging sustainability, meaning improving resource efficiency, making more packaging with less material. This effort led to producing a mix of grades which is extremely difficult to recycle.

There are a lot of articles on the market and when putting on the market new bio-based ones which aim to substitute fossil-based plastic, an important question we need to answer is: do we need everything we have now, in terms of properties? In supermarkets you can find Bio-PP packaging, which by the way is not really recyclable, with holes to let the moisture out. The market offers a variety of products whose properties are not needed for the applications they are used for. Both plastic producers and brand owners have to engage in reducing and improving the material mix.

Design

Bioplastics is a broad category, including:

- biodegradable polymers;
- drop-ins that have the same characteristics of the fossil based and can utilise the current infrastructure for recycling or collection;
- the newer ones.

In any case, it's very important that the end-of-life scenarios are considered during the design phase of a product. Recyclability is crucial to minimize the environmental impact, but other end-of-life scenarios can be considered, including compostability or biodegradability. The lowest impact end-of-life option does not depend only on the intrinsic characteristic of a material: it's not the polymer that should define the end of life but its application and the overall waste management system. For example, for mulch films there's no proper collection taking place, and biodegradable options are indeed better. For in-soil applications, biodegradability is necessary but in other applications they should be also recyclable.

Knowledge gaps

There are knowledge gaps: we need more data and information to see whether new materials are biodegradable, if they are compatible with existing recycling streams, if they distort them, and how much they distort.

12. Conclusions and next steps

Andrea Camia, Joint Research Centre

The workshop enabled a fruitful discussion between European Commission staff and external experts. The policy framework described as well as the inputs on processes, current and future market trends, environmental impacts, trade-offs, knowledge gaps and policy needs will be elaborated in a dedicated technical report and summarised in the knowledge for policy brief on bio-based textiles.

Such information material will integrate the outcomes of this workshop, which contributed to a better understanding of a complex sector such as the bio-based plastics.

To extend the possibility to provide inputs to experts who did not attend the workshop in person, the KCB created and launched a survey, including the questions discussed during the parallel sessions.

Highlights from the parallel sessions:

Parallel session 1 on material performance durability versus cost and economic viability

- Sustainable products and feedstocks are expensive. The cost barrier is seen as the main barrier, lowering competitiveness and hindering the bio-based plastic sector uptake. Both replacing fossil feedstock with bio-based ones in the current infrastructure and producing new plastics in new facilities face viability challenges. Different strategies can be adopted: one is targeting high added value end-products, which are produced in low volume; the other is replacing products with high volumes and very low cost. The second option has a lower impact.
- The bio-based content in fossil-based plastics can get to 20-25% but it will take time to fully achieve this target.
- Once a product has been designed to accommodate the properties of a specific fossil-based polymer (e.g. LEGO bricks made of ABS), replacing it with a substitute made of bio-based plastic is very challenging. In such cases, it is easier to redesign and develop new products. The risk is a low brand owner/consumers acceptance/willingness to pay more. Again, costs determine what you can do. When offering functional advantages, bio-based plastics have a better chance to succeed.

Parallel session 2 on feedstock sustainability, land use and resource competition

- Many participants did not have specific expertise on land use, so the topic was not really the focus of the discussion, on the contrary it was almost referred to as a kind of non-issue.
- The feedstock range for bio-based plastic production is wide but should be further broadened.
- On one hand, the bio-based plastic sector needs sustainably grown feedstock. On the other hand, farmers need to diversify their sources of income while keeping their land productive. Farmers are willing to invest in such diversification if they see some kind of payback. Inter-cropping, sequential cropping and break crops represent sustainable farming practices, of

which both farmers and bio-based plastic producers can take advantage. Cooperatives could ensure a continuity of farmers feedstock in terms of diversification of farming practices.

- How and where we produce feedstock is really relevant. EU-grown feedstock would ensure our sovereignty and competitiveness, whereas yields (e.g. for sugar cane) are much higher in warmer countries. The cap for food crops used to produce biofuel in the REDIII may influence the cost of EU-grown feedstock for bio-based plastics.

- In terms of knowledge gaps, in the answers to the survey the following aspects are mentioned: market predictability, the potential of integrated production systems and supply chains allowing waste recovery for bio-based plastic production, how primary sectors can diversify, LCA approaches, how to link the agri sector and the biotech sector, impacts on water, land and human health

- For sustainability criteria, stakeholders require at least the level playing field with respect to bioenergy, so not more stringent rules pertaining to sustainability and need of recognition of environmental benefits of bio plastics, as well as policy coherence.

- The regenerative potential of specific feedstocks could be further investigated with the help of farmers. We should focus on the biophysical and societal impact of the different ways of growing sustainable feedstocks for bio-based plastics.

Parallel session 3 on product sustainability and specifically on measuring environmental impacts

- It is not possible to identify the most environmentally sustainable bio-based plastics.

- Life cycle approach is recognised as important, but it is necessary to take into account a variety of environmental impacts beyond the carbon footprint. Keeping this simple, both for the analysis and for communication, while ensuring transparency and communicating the trade-offs across the various impacts, is a true challenge.

- It was challenged whether we should consider only fossil fuels as a baseline. Participants discussed and agreed that this is the reference of what we have now, highlighting the need to also consider projections and possible future evolutions in the market, which may be pushed by legislative action.

- Bio-based plastics perform better than fossil based in terms of carbon emissions and fossil resources consumption, while mixed evidence is available for impacts on land, toxicity and other aspects. Methodology and communication should become more coherent and simpler.

- The production of feedstocks for bio-based plastic has impacts on water, land, ecosystems and human health. Impacts e.g. on land use and biodiversity are not easy to assess due to methodological challenges that this entails in the accounting: on one hand we need simple and clear communication and calculation of the impacts, on the other methods are intrinsically complex due to regional specificity. In fact, it depends where you source your feedstock, from which country, under which condition, etc. so it's highly context specific.

- There are many competing uses for biomass. Opportunity cost and optimal uses of that biomass, whether for bio-based plastic or for other uses, have to be carefully assessed.

- Bio-based plastic producers are very proactive in communicating the details of the processes behind their product, even complex processes taking place in biorefineries and multiple lines facilities. They do their best to ensure transparent communication, as they believe it can valorise their product.

- Consumers' choices are mainly price driven. It is extremely difficult to make consumers willing to pay more for a plastic bottle, by the only means of explaining and communicating what's behind. Packaging labels are not the right tool to inform consumers as they already include a lot of information, making it difficult for consumers to understand what that means. Communication campaigns can better show the general attributes and positive benefits that are associated with a bio-based product. This could at least complement and support information available on labels.
- The bio-based plastic sector is a highly innovative, rapidly growing sector. Consequently, data on environmental performances are not yet available or they are available only on pilot scale. It is very important to communicate clearly the factors affecting the robustness and quality of the environmental impact analysis, including limited data availability, thus ensuring a better comparison with fossil fuels. For example, assumptions on the end of life are particularly challenging, as possible upscale dynamics can play a big role. Sensitivity analysis or specific upscaling techniques could help improve the quality of the information, but the most important thing is to present the results in a very transparent way. Innovation is a dynamic process, to be continuously monitored to identify the emerging solutions in the market.
- While there are many knowledge gaps, it is important to valorise the already existing knowledge to feed into the policy debate. How can we make the best use of all the elements that we have to contribute to the policy debate?

Parallel session 4 on end of life

- PPWR was quite much at the centre of the discussion.
- Although it is quite sound that bio-based plastics can be recycled, being recyclable at scale as well as meeting the PPWR requirements is more challenging.
- The policy framework does not sufficiently recognise the benefits of bio-based plastics as well as the benefits of composting. The PPWR focuses only on mechanical recycling, thus penalising bio-based plastics which are designed for different end of life options.
- If innovative bio-based plastic industries will not be given enough time to scale-up and to comply with the required recyclability criteria, these industries will leave Europe, diverting investments to China or other countries where they could find better market conditions.
- We need to know more about the effects of the biodegradables or bio-based materials but the biggest knowledge gap concerns how to integrate bio-based plastics and biodegradables into the waste management system.

Next steps

The outcomes of this workshop will be used as an input to a KCB Technical report and a Science for Policy brief on bio-based plastics.

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Annex 3: Outcomes of the survey

Annex 4: Presentations

Annex 1: Agenda

9:00-9:15	**Registration**
PART 1	Chaired by Andrea Camia, EC Knowledge Centre for Bioeconomy, JRC.D.3 - Land Resources and Supply Chain Assessments
9:15-9:30	**Welcome address**
	Serenella Sala, Head of Unit JRC.D.3 - Land Resources and Supply Chain Assessments Peter Wehrheim, Head of Unit DG RTD B.2 - Bioeconomy & Food Systems
9:30-9:45	**EU-funded research on bio-based plastics + Q&A**
	Martin Policar, DG RTD B.1 – Green Transitions
9:45-9:55	**Introduction to the KCB deep dive study on bio-based plastics**
	Maria Teresa Borzacchiello, EC Knowledge Centre for Bioeconomy, JRC.D.3 - Land Resources and Supply Chain Assessments
9:55-10:20	**Overview of policy developments on bio-based plastics in EU + Q&A**
	Werner Bosmans, DG ENV B.1 - Circular Economy, Sustainable Production & Consumption
10:20-11:10	**Bio-based plastics sector and key issues at stake**
	Karin Molenveld, Programme Manager Renewable Plastics, Wageningen University Research
11:10-11:30	**Break and transition to parallel sessions**
PART 2	
11:30-13:00	**Parallel sessions**
Floor 0/Room 021	1.Working table on *material performance and durability vs. costs and economic viability*, facilitated by Karin Molenveld, Programme Manager Renewable Plastics, Wageningen University Research

Floor 1/Room A14	2.Working table on *feedstock sustainability – land use and resource competition*, facilitated by Sarah Mubareka, JRC.D.3 - Land Resources and Supply Chain Assessments
13:00-14:00	**Networking lunch**
14:00-15:30	**Parallel sessions**
Floor 1/Room A14 Floor 0/Room 021	3.Working table on *product sustainability – measuring environmental impacts*, facilitated by Giulia Listorti, JRC.D.3 - Land Resources and Supply Chain Assessments 4.Working table on *end-of-life management* - challenges and solutions, facilitated by Karin Molenveld, Programme Manager Renewable Plastics, Wageningen University Research
15:30-15:45	**Break**
15.45-16.45	**Groups reporting and plenary discussion**
	Group facilitators
16.45-17.00	**Conclusions and next steps**
	EC Knowledge Centre for Bioeconomy

Annex 2: List of participants

N	SURNAME	Name	Organisation
1	AMADEI	Andrea	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments (online)
2	BAILLARGEON	Laure	European Commission, DG GROW.I.4 - Sustainable Products (online)
3	BALKO	Jens	Fraunhofer Institute for Applied Polymer Research, Germany
4	BEIRAS	Ricardo	University of Vigo, Spain (online)
5	BORZACCHIELLO	Maria Teresa	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments
6	BOSMANS	Werner	European Commission, DG ENV.B.1 – Circular Economy, Sustainable Production & Consumption
7	BOULO-DANIEL	Eugénie	BASF, Belgium
8	CAMIA	Andrea	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments
9	CARDONA	Juan Tur	(online)
10	CARLOTTI	Monica	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments (online)
11	CIAIAN	Pavel	European Commission, JRC.D.4 - Economics of the Food System (online)
12	CLEMESHA	Martin	Braskem, The Netherlands
13	COLLEU	Romane	Citeo, France
14	DELVINQUIER	Geoffroy	Futerro, Belgium
15	DUPEYROUX	Bertrand	Lactips, France (online)
16	ELIASSON	Åse	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments

N	SURNAME	Name	Organisation
17	GURRIA	Patricia	European Commission, JRC.D.4 - Economics of the Food System (online)
18	HIGSON	Adrian	NNFCC Limited, United Kingdom
19	HIRSCH	Patrick	Fraunhofer Institute for microstructure of material and systems, Germany
20	HOLDORF	Peter	Neste, Belgium
21	KIEVETS	Aleksandra	European Commission, DG GROW.F.2 - Bioeconomy, Chemicals & Cosmetics
22	KOUGOULIS	Jiannis	European Commission, DG GROW.F.2 - Bioeconomy, Chemicals & Cosmetics (online)
23	KOYUNCU	Bahar	Circular Bio-Based Europe Joint Undertaking
24	KRAUS	Franz	Novamont, Belgium
25	LACKNER	Maximilian	Lackner Ventures & Consulting GmbH, Austria (online)
26	LASARTE LOPEZ	Jesus	European Commission, JRC.D.4 - Economics of the Food System (online)
27	LEIP	Adrian	European Commission, DG RTD.B.2 - Bioeconomy & Food Systems
28	LISTORTI	Giulia	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments
29	MAGNOLFI	Valeria	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments
30	MALMFORS	Fedrik	Lignin Industries, Sweden (online)
31	M'BAREK	Robert	European Commission, JRC.D.4 - Economics of the Food System (online)
32	MCKEIVOR	Jack	TotalEnergies Corbion, The Netherlands
33	MOLENVELD	Karin	Wageningen University Research, The Netherlands

N	SURNAME	Name	Organisation
34	MUBAREKA	Sarah	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments
35	MULLER	Dominik	UPM Biorefining, Germany
36	OGER	Enora	Futerro, Belgium (online)
37	NORIEGA FERNANDEZ	Estefania	European Food Safety Authority
38	OINONEN	Petri	Ecohelix, Sweden
39	OLABI	Valentina	Emirates Biotech, UAE (online)
40	PELLEGRINI	Marco	CEFIC, Belgium
41	PEREZ-CABERO	Monica	Circular Bio-Based Europe Joint Undertaking
42	PIETERS	Julie	European bioplastics, Belgium
43	POZLEVIC	Olga	European Commission, DG GROW.I.4 - Sustainable Products (online)
44	RÖDER	Alexander	Plastics Europe, Belgium
45	ROMANIN	Maria Silvia	Circular Bio-Based Europe Joint Undertaking (online)
46	ROSENBERGER PETERSEN	Maria	Artelia, Denmark
47	SAINZ LOPEZ	Noa	European Commission, DG RTD.B.2 - Bioeconomy & Food Systems
48	SALA	Serenella	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments
49	SCALIA	Rosalinda	European Commission, DG RTD.B.2 - Bioeconomy & Food Systems
50	SINKKO	Taija	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments (online)

N	SURNAME	Name	Organisation
51	SOUSA	Celmira	NatureWorks, (online)
52	VALENZANO	Annarita	European Commission, JRC.D.3 - Land Resources and Supply Chain Assessments
53	VOM BERG	Christopher	Nova Institute, Germany
54	WEBER	Johannes	European Commission, DG RTD.B.2 - Bioeconomy & Food Systems (online)

Annex 3: Outcomes of the survey

A survey of 19 questions was shared just before the workshop with the participants, to pave the way to the working table discussions. After the workshop, the survey was opened to further stakeholders. It collected 21 feedbacks from companies, business associations and research institutes working in the bio-based plastic sector in the EU and UK. To analyse and synthesise the outcomes of the survey, gpt@JRC was asked to find out five highlights for each group of answers.

1. **Please explain your understanding of the bio-based plastics in a few words.**

Bio-based plastics are plastics wholly or partly derived from biomass (renewable resources) such as corn, sugarcane, or cellulose, distinguishing them from fossil-based plastics.

They include both bio-based plastics (with measurable 14C-traceable bio-content) and bio-attributed plastics (using mass balance certification to account for bio-based feedstock in mixed production systems).

Not all bio-based plastics are biodegradable, but biodegradable/compostable variants are critical for reducing plastic pollution and enhancing organic waste management.

The primary goal of bio-based plastics is to defossilize the plastics industry by replacing fossil carbon with biogenic carbon, reducing reliance on non-renewable resources.

They offer a carbon-neutral potential, with a CO_2 footprint 30–40% lower than fossil plastics, and can provide novel properties through innovations in bio-sourced polymers.

2. **How can bio-based plastics be integrated into existing infrastructure and supply chains, and what are the implications for the broader plastics industry?**

Drop-in bioplastics (e.g., bio-PE, bio-PET) can seamlessly integrate into existing infrastructure without requiring modifications to processing, recycling, or supply chains. These materials are chemically identical to fossil-based counterparts, enabling direct substitution and reducing barriers to adoption.

Novel bioplastics (e.g., PLA, PHA) require targeted investments in sorting and recycling systems due to their distinct chemical structures, which complicate compatibility with conventional recycling streams. Clear labeling and standardized protocols are critical for their successful integration.

The mass-balance approach allows partial substitution of fossil feedstocks in existing facilities using bio-naphtha or biomethane, enabling gradual scaling of bio-based production while maintaining economic viability. This method prioritizes infrastructure efficiency over segregated bio-based streams.

Regulatory measures (e.g., mandatory quotas, bans on fossil plastics, and specific labeling) are essential to accelerate adoption, particularly for high-risk applications like mulching films. These policies ensure bio-based plastics meet environmental criteria (e.g., biodegradability, low toxicity) and compete fairly with conventional plastics.

The broader plastics industry must shift toward bio-based feedstocks, which will reduce fossil raw material sales for major producers. However, this transition requires addressing recycling challenges, such as chemical heterogeneity and sorting limitations, while leveraging synergies across sectors (e.g., biorefineries) to optimize biomass use.

3. **What is the percentage of conventional plastics market that can be realistically replaced with bio-based plastics by 2050, considering the barriers highlighted above? What would be preferred markets/applications?**

By 2050, bio-based plastics could replace 15–20% of conventional plastics in Europe, with some studies suggesting up to 20–30% under favorable policy and market conditions.

Key sectors include food packaging (e.g., compostable food service ware, organic waste bags), agriculture (biodegradable mulch films, slow-release fertilizers), textiles (to address microplastic issues), construction, and automotive.

Long-term carbon storage: Bio-based plastics are prioritized for durable products (e.g., PE, PP, PET) to lock biogenic carbon in long-term applications, avoiding competition with food production.

Sustainable feedstock focus: Preference for forestry-based materials (e.g., pulp mill waste) over agricultural crops to avoid land-use conflicts, reduce emissions, and improve logistics.

Achieving higher replacement rates (up to 50%) depends on policy incentives, feedstock access, and closed-loop recycling of bio-based plastics. Compostable options also aid organic waste management if industrial composting infrastructure expands.

Plastics Europe's roadmap projects 11 million tons of bio-based plastics (17% of total demand) by 2050, emphasizing collaboration and circularity goals.

4. **What are best practices (materials, applications, markets) in the production and use of bio-based plastics?**

Feedstock prioritization: Focus on sustainably sourced biomass (agricultural residues, ligno-cellulosic feedstocks, biowaste) and non-food competing materials (e.g., forestry byproducts) to avoid land-use conflicts and ensure defossilization.

Material selection: Favor recyclable drop-in solutions (bio-PE, bio-PP, bio-PET) for high-end applications (automotive, construction, textiles) where technical performance and carbon sequestration are critical, and compostable bioplastics (PLA, starch blends) for low-end uses (agriculture, food packaging) where end-of-life composting is feasible.

Certification and traceability: Use verified certification schemes (e.g., TÜV, DIN CERTCO) to ensure biobased content transparency and compliance with standards (e.g., ISO, CEN), building consumer trust and market credibility.

Application alignment: Target high-value, high-sustainability-impact sectors such as:

- Agriculture: Soil-biodegradable mulch films and plant pots.
- Packaging: Compostable food service ware and bio-based beverage bottles.
- Consumer goods: Footwear and electronics components with bio-based polymers (e.g., EVA, TPU).

System integration: Ensure compatibility with existing recycling systems for bio-based plastics (e.g., bio-PE/PP in mechanical recycling) and prioritize end-to-end sustainability (feedstock traceability, recyclability, carbon footprint reduction) to maximize long-term benefits.

Collaboration across value chains, policy incentives (e.g., EPR schemes), and R&D investment to address cost, scalability, and infrastructure barriers are also emphasized.

5. **What are the main challenges related to upscaling lab-scale facilities and entering the market? Which are the most promising emerging solutions?**

High Costs and Capital Investment Barriers: Scaling biobased technologies requires significant capital due to higher production costs compared to fossil-based alternatives and the need for new infrastructure. Solutions include targeted funding programs (e.g., Horizon Europe, Innovation Fund) and financial incentives like tax breaks to attract private investment.

Feedstock Availability and Heterogeneity: Challenges include inconsistent feedstock supply, cost, and variability (e.g., first-generation vs. waste-based feedstocks). Emerging solutions focus on utilizing lignocellulosic waste, treated wastewater, and circular carbon approaches (CCU) to secure sustainable feedstocks.

Regulatory and Policy Uncertainty: Regulatory barriers (e.g., GMO authorization delays, GHG accounting methods) and lack of stable policy frameworks deter investment. Streamlining authorization processes and embedding market-pull mechanisms (e.g., quotas, targets in legislation like PPWR) are critical to create demand and reduce risks.

Low Technology Readiness (TRL) and Industrialization Gaps: Many technologies remain at low TRL, requiring de-risking and industrialization support. Scaling mature technologies and prioritizing high-TRL projects in funding programs (e.g., CBE-JU, IPCEIs) can bridge this gap.

Market Demand and Competitive Disadvantages: Bio-based products face unfair competition with fossil-based materials due to higher prices and limited infrastructure. Creating a level playing field through policy incentives, stable offtake agreements, and industry partnerships (e.g., corporates like UPM or Novamont) is essential to drive market uptake.

6. **What are consumers' attitudes and expectations towards performances and costs of bio-based plastic products? Are there specific applications where a clear preference is revealed?**

Expectations of Equivalent Performance and Cost: Consumers expect bio-based plastics to match the performance of fossil plastics (e.g., durability, recyclability) at similar costs or with minimal price premiums. However, current production costs for bio-based plastics are 1.5–2 times higher, creating a significant barrier to market adoption.

Willingness to Pay for Sustainability in Specific Sectors: While general cost sensitivity exists, consumers are more willing to accept price premiums for bio-based products in applications with clear sustainability value, such as compostable food packaging, organic waste bags, and personal care products. In these cases, perceived environmental and safety benefits drive demand.

Preference for Biodegradability in Critical Applications: Clear consumer preference emerges for bio-based plastics in sectors where biodegradability is essential, such as seed and fertilizer coatings, where traditional plastics are unsuitable. Subsidies or policy support are seen as necessary to justify the premium in these niche but high-impact areas.

Need for Education and Transparent Labeling: Misconceptions and misleading labels (e.g., "BIO-PET") hinder trust. Studies show 8 out of 10 consumers want more information about bio-based products, highlighting the need for clear labeling, certification, and education to foster informed decision-making.

Role of Brands and Policy in Driving Adoption: Consumers expect brands to absorb the added costs of sustainability and invest in bio-based solutions. Policies, such as taxing fossil plastics or incentivizing bio-based feedstocks (e.g., agricultural waste, biomethane), are critical to level the playing field and scale up production.

7. In your opinion, which are the knowledge gaps?

Transparency and Disclosure: Many formulations of bioplastics remain proprietary, and the chemical composition of plastics (including additives) is often not disclosed to consumers, hindering informed decision-making.

Technical and Production Gaps: There is a need for more efficient biotechnological processes to convert renewable raw materials into bio-based chemicals, as well as scalable methods to produce bioplastics with customizable properties and controllable lifespan.

Consumer Awareness and Education: A significant gap exists in public understanding of bio-based plastics, including their environmental benefits, differentiation from conventional plastics, and proper end-of-life disposal.

Policy and Market Predictability: Harmonized labeling, standardized LCA methodologies, and clear policy frameworks are lacking, alongside economic models to assess the viability of bio-based markets and their job creation potential.

Environmental and Recycling Research: Challenges include quantifying climate benefits of bio-based materials, assessing recycling compatibility of novel polymers, and understanding the circularity of fossil-based vs. bio-based systems.

8. What are the most sustainable feedstocks for bio-based plastics production, and how can we optimise their use to minimise land use and resource competition?

Prioritize Waste and Byproducts: Biomass wastes (e.g., agricultural residues, used cooking oil, lignin) and byproducts are preferable feedstocks as they avoid land use competition and align with circular economy principles. These materials require minimal additional resource input and reduce reliance on dedicated crops.

Leverage Lignocellulosic Feedstocks: Second-generation lignocellulosic materials (e.g., straw, wood residues) are highlighted as sustainable options if processed via gasification or hydrolysis. Their use avoids land use conflicts and competes only with low-value energy applications (e.g., burning for energy), emphasizing the cascading principle to prioritize material over energy use.

Sustainable First-Generation Feedstocks: Certified first-generation feedstocks like sugar, starch, and plant oils can be viable if sourced sustainably (e.g., via traceability and resource-efficient practices). Current bioplastic production uses less than 0.02% of global agricultural land, with minimal risk to food security due to diversified crop use (food/feed/industrial).

Adopt Robust Sustainability Criteria: Feedstock sustainability depends on risk-based frameworks (e.g., RED III's land use and biodiversity criteria) to ensure no deforestation, high GHG savings, and avoidance of high-diversity ecosystems. Certification schemes and due diligence along supply chains are critical to prevent unintended environmental impacts.

Optimize Through Policy and Innovation: Regional valorization of feedstocks, supportive policies (e.g., incentives for cascading use), and infrastructure for waste collection are essential. Scaling third-generation feedstocks (e.g., algae) requires technological breakthroughs, while diversification of feedstocks (e.g., glycerol, lignin) reduces dependency on single sources.

Significant emphasis is put on balancing feedstock availability, sustainability, and systemic optimization to minimize resource competition.

9. Can Europe-based production of bio-based plastics contribute to reduce Europe's dependence on foreign feedstocks and products?

The responders think that bio-based plastics production in Europe can reduce dependence on foreign feedstocks by leveraging sustainable biomass (e.g., lignin, agricultural/forestry residues) and regional value chains, enhancing strategic autonomy and aligning with the EU's Green Deal and Circular Economy goals.

Local production of bio-based plastics supports decarbonization, supply chain resilience, and rural development, while avoiding competition with food crops through the use of non-food biomass and multi-product biorefineries.

Scalability and feedstock availability are critical challenges, requiring policies to prioritize high-value outputs (e.g., PHA copolymers, bio-PE) and integrate recycling infrastructure to ensure circularity.

Europe's current reliance on imported fossil-based feedstocks necessitates a shift to domestic renewable resources, with biorefineries already capable of producing bio-based materials if policy frameworks prioritize non-energy outputs.

Uncertainty remains due to dependencies on agricultural policies, recycling systems, and feedstock logistics, but studies confirm Europe has the potential to source sufficient biomass for bio-based plastics without compromising sustainability.

10. What are the attitudes and expectations of primary producers towards the use of their products as bio-based plastics feedstock?

Economic Viability: Producers emphasize that bio-based plastics feedstock must be economically attractive, with fair returns on raw materials, simple processing, low costs, and scalability to ensure competitiveness with conventional materials.

Fair Compensation and Sustainability: Farmers expect equitable treatment and transparent sustainability criteria to avoid historical issues of under-compensation (e.g., for land set-aside programs). They seek policies that balance environmental, economic, and social sustainability.

Processability and Compatibility: Materials must integrate seamlessly into existing industrial processes to minimize technical and operational barriers, reducing the need for costly adaptations.

Policy and Market Stability: Clear, long-term policies, guaranteed demand, and reduced administrative burdens are critical to build trust and encourage participation in bio-based value chains.

Income Diversification and Rural Development: Producers view bio-based markets as opportunities to diversify income streams, reduce agricultural risks, and revitalize rural areas through integrated bioeconomy initiatives and synergies with industries like biorefineries.

11. In your opinion, which are the related knowledge gaps?

Standardization and Availability of Bio-Based Feedstocks: There is a critical need for uniform standards in the processing, purity, and availability of bio-based agricultural residues, alongside assessing their long-term sustainability under climate change impacts.

Underestimated Role of Biomass in Decarbonization: The document highlights the underestimation of biomass's potential to drive growth, competitiveness, and decarbonization in Europe, particularly for the plastics industry's transition to bio-based alternatives.

Comparative Analysis of Feedstock Generations: Knowledge gaps exist regarding the opportunities and limitations of 1st vs. 2nd/3rd generation feedstocks, including their environmental impacts evaluated through lifecycle assessment (CLCA).

Diversification of the Primary Sector: A lack of information hinders the primary sector from diversifying into bioeconomy activities, which could improve incomes and align with cascading biomass use principles.

Integrated Biomass Systems and LCA Harmonization: Research is needed on cascading biomass use, harmonizing lifecycle assessments (LCAs) across feedstocks, and resolving cross-sectoral competition between material production and energy uses (e.g., biofuels vs. bio-based plastics).

12. What are the most environmentally sustainable bio-based plastics and based on which criteria?

Biodegradability and Microplastic Prevention: The most sustainable bio-based plastics, such as PHA (polyhydroxyalkanoates), are fully biodegradable and avoid persistent microplastics. Their formulation (not just the polymer) must ensure safe degradation in the environment.

Sustainable Feedstocks: Prioritizing biomass wastes, byproducts, or residues (e.g., lignin, agricultural waste) over virgin biomass reduces environmental trade-offs. Feedstocks must be certified via systems like ISCC+, RedCert, or RSB to ensure sustainability.

Lifecycle Assessments (LCA) and Circular Design: Sustainability depends on rigorous LCA covering carbon footprint, resource efficiency, and end-of-life solutions (recyclable, compostable). Long-term carbon storage in durable products and separability at end-of-life are critical.

Application-Specific Benefits: Bioplastics like PLA (polylactic acid) or compostable materials excel in applications where biodegradability prevents pollution (e.g., agricultural mulch films, food packaging). Their use must align with circular economy principles to avoid unintended impacts.

Climate and Land-Use Considerations: Bio-based plastics must demonstrate significant GHG savings compared to fossil alternatives and avoid land-use changes (e.g., no deforestation). Agroecological zoning and sustainable sourcing criteria (e.g., RED-III for biofuels) are recommended to prevent biodiversity and water scarcity risks.

13. How do the different feedstocks used to produce bio-based plastics impact water and land use, ecosystems and human health?

Feedstock Source Sustainability: The environmental impact of bio-based plastics depends heavily on feedstock sources (e.g., waste/residues, agricultural, or forest materials). Sustainable options like managed forests or industrial waste minimize water, land, and ecosystem impacts, while agricultural feedstocks require careful management to avoid overuse of pesticides, fertilizers, and irrigation.

Lignin as a Low-Impact Feedstock: Lignin, a byproduct of industrial processes, requires no additional water or agricultural inputs. Its use reduces CO_2 emissions and microplastics, offering a positive impact on human health and ecosystems.

Responsible Sourcing and Scalability: Agricultural residues and organic waste have lower environmental impacts but face challenges in scalability due to collection and transportation complexities. Sustainable practices (e.g., RED III criteria) are critical to minimize land use and biodiversity risks.

Regional Context and LCA Analysis: Life Cycle Assessments (LCAs) are essential to evaluate feedstock impacts, considering regional factors like water availability. For example, bio-based PE from sugarcane in Brazil uses rainfall rather than irrigation, reducing water stress despite higher theoretical water consumption.

Current Low Land Use and Climate Benefits: Bio-based plastics currently occupy only 0.013% of global land use, with minimal direct environmental impact. Their primary benefit lies in climate mitigation through reduced CO_2 emissions, indirectly supporting biodiversity by curbing climate change.

14. How are these impacts communicated to the public and what are consumers' attitudes and expectations towards bio-based plastics?

Consumer Priorities and Preferences: The public often prioritizes cost over sustainability, and many prefer recycled fossil plastics over bio-based alternatives. However, bio-based plastics are increasingly viewed positively when framed as using waste materials or supporting local systems.

Communication Gaps and Misinformation: Public understanding of bio-based plastics is limited, often influenced by myths rather than scientific facts. There is a critical need for clear, science-based communication to address misconceptions and improve awareness.

Focus on CO_{2eq} Over Other Impacts: Current communication emphasizes carbon footprint (CO_{2eq}) but neglects other critical impact categories like water use, land use, and ecosystem effects. This narrow focus risks "burden shifting" and requires balanced data-driven approaches.

Role of Certifications and Labels: Certifications, labels, and third-party verifications (e.g., 2BS certification) are key tools to build trust and demonstrate sustainability. However, harmonized standards and labels are still lacking, leading to consumer confusion.

Need for Transparent and Verifiable Claims: Consumers expect transparency and verifiable environmental benefits. While bio-based plastics gain support when sustainability is clearly demonstrated, claims about water, land use, or health impacts are rarely marketed, limiting informed decision-making.

15. Innovation in the sector is rapidly evolving. How can this be taken into account in the analysis of the impacts?

Dynamic and adaptive methodologies: Use dynamic life cycle assessments (LCAs), periodic data updates, and flexible policy tools to reflect evolving technologies, feedstocks, and end-of-life solutions (e.g., emerging bioplastics innovations).

Biomass balance approach: Incorporate renewable feedstocks like biomethane and bionaphtha as drop-in solutions in complex production networks to reduce fossil dependency while maintaining process efficiency.

Regulatory flexibility: Implement regulatory sandboxes or temporary exemptions to allow innovative products time to reach market and gain consumer acceptance before facing full compliance requirements.

Stakeholder transparency and engagement: Ensure traceability and clear communication of mass-balance-based materials, while fostering collaboration with stakeholders (consumers, value chains) to support informed decision-making.

Periodic reevaluation of criteria: Regularly update impact assessment frameworks and standards to accommodate disruptive innovations and ensure they remain relevant to the sector's rapid technological advancements.

16. In your opinion, which are the related knowledge gaps?

Environmental Impact Assessment Limitations: Current models are overly focused on the European context, lacking regionalized data for biomass production regions. Transparent traceability and sustainability reporting for bio-based feedstocks are also insufficient compared to fossil feedstocks.

Insufficient Lifecycle and Real-World Data: Key gaps include up-to-date, comparable lifecycle assessments (LCAs) for biobased plastics, proper accounting of biogenic carbon, and real-world end-of-life performance data. Indirect environmental impacts and regional biodiversity effects remain poorly understood.

Consumer Awareness and Communication: There is a lack of effective communication to educate consumers and value chain actors about the environmental benefits of bio-based plastics, hindering informed decision-making.

Technological and Methodological Gaps: Simple, rapid, and ecologically relevant lab tools for assessing novel materials' persistence and ecotoxicity are urgently needed. Additionally, the complexity of mass-balance systems and limitations in using lignocellulosic materials (e.g., scalability, cost) remain underexplored.

Policy and Regulatory Misalignment: Existing legislation (e.g., PPWR, ELVR) prioritizes recycled materials over innovative bio-based solutions, stifling European innovation. Sustainability criteria for bio-based feedstocks require harmonization and risk-based approaches to avoid overregulation.

17. Can the bio-based plastics be recycled together with conventional plastics or should they be sorted out? What are most efficient processes for end-of-life management?

Drop-in bio-based plastics (e.g., bio-PE, bio-PET) are chemically identical to conventional plastics and can be recycled together without issues, following existing mechanical recycling pathways. No separate sorting is required for these materials.

Novel bio-based polymers (e.g., PLA, PHA) require dedicated sorting and recycling processes due to differences in chemical composition. Near-infrared (NIR) spectroscopy can aid separation, but infrastructure scalability remains a challenge due to low market volumes.

Biodegradable/compostable bio-based plastics (e.g., for food-contact applications) should be diverted to composting or organic recycling streams to avoid contaminating traditional plastic recycling and to optimize carbon recovery.

Recycling efficiency depends on homogeneity: Monomaterials and closed-loop systems improve input quality for recycling. For industrial applications, higher-quality recycled material is achievable through controlled sorting.

Labeling and policy alignment are critical. Clear labels must distinguish between recyclable non-biodegradable bio-based plastics (recycled with conventional plastics) and compostable/biodegradable variants (sorted for organic streams). Certifications like Recyclass and PPWR should promote bio-based recycling pathways.

The answers emphasize that end-of-life strategies should prioritize the application context and polymer type, combining mechanical, chemical, and organic recycling as needed.

18. How can bio-based plastics be designed and produced to be more compatible with existing waste management infrastructure, and what are the challenges and opportunities for developing new waste management technologies and systems?

Design for Compatibility: Bio-based plastics must be designed with detectability via near-infrared (NIR) sorting, clear labeling, and alignment with existing end-of-life (EoL) routes (recycling, composting) to ensure seamless integration into waste management systems. For example, compostable bio-based plastics already comply with standards like EN13432 for industrial composting.

Leverage Existing Infrastructure: Focus on improving current recycling supply chains rather than developing new materials or EoL solutions. Bio-based plastics should ideally be recycled alongside fossil-based plastics to avoid complicating waste management.

Challenges in Scale and Economics: Low recycling rates (14% globally) and the "business as usual" approach of waste operators hinder innovation. Economic viability for new recycling technologies requires sufficient input volumes (e.g., 5% mass flow), which is harder to achieve for bio-based plastics due to current low production volumes.

Opportunities in Advanced Recycling: Technologies like Futerro's Loopla (for PLA chemical recycling) demonstrate potential for monomer recovery and scalability. Policy support and investment in advanced sorting, organic recycling, and dedicated streams for bio-based plastics could create jobs and boost the EU economy.

Policy and Collaboration Needs: Harmonized standards, design-for-recycling guidelines, and cross-sector collaboration are critical. Policy measures (e.g., avoiding EPR penalties for novel materials) and infrastructure investments (e.g., composting bins) are required to enable carbon recovery and prevent contamination of traditional recycling streams.

19. What are consumers' attitudes towards disposal of bio-based plastics, are they adequately informed and supported?

Low Awareness and Education: Consumers often lack sufficient knowledge about bio-based plastics, their differences from biodegradable/compostable materials, and correct disposal methods. Misleading labels and greenwashing further confuse them.

Need for Clear Labeling and Harmonized Rules: There is a strong demand for standardized, transparent labeling and EU-wide harmonized regulations to clarify disposal options. Inconsistent national waste systems and labels lead to improper disposal.

Overwhelmed by Complexity: Consumers prefer simplified systems over multiple recycling streams. Advanced, centralized recycling infrastructure (e.g., deposit return systems) is recommended to reduce the burden of sorting materials.

Education and Local Guidance: Targeted education, public campaigns, and local authority involvement are critical to improving disposal behaviors. Successful examples, like Biorepack's 60.7% collection rate in Italy, highlight the role of clear communication.

Behavioral and Systemic Challenges: Littering and contamination remain issues due to inadequate education and inconsistent waste management. Technological innovations (e.g., gasification) and stricter enforcement of proper disposal practices are needed.

20. In your opinion, which are the related knowledge gaps?

Classification of fossil-based plastics as hazardous waste: There is a need to reclassify non-degradable fossil-based plastics as dangerous waste, akin to batteries, to address their environmental risks.

Challenges with additives and biopolymer recyclability: "Hidden" additives in plastics hinder recycling, while the recyclability of biopolymers requires further research, standardized sorting, and adapted post-sorting processes.

Consumer awareness and sorting systems: A lack of understanding about bio-based plastics' end-of-life management persists, necessitating clearer communication and a harmonized pictogram-based waste-sorting system.

Infrastructure and policy gaps: Scalable recycling infrastructure for all materials, including bio-based plastics, is lacking. Applied research, harmonized standards, and EU-level data collection are needed to support policy and infrastructure development.

Traceability and incentives: Adoption of compostable RFID tags or digital watermarks is limited, hindering supply chain traceability and effective Extended Producer Responsibility (EPR) schemes.

21. Sources of data and scientific knowledge

EU-funded projects

- Land-Based Solutions for Plastics in the Sea (LABLAS) Project results

Commercially available solutions

- BASF Biodegradable polymers
- Braskem Responsible Ethanol Sourcing Program - Sustainably sourced bio-based plastic Responsible Ethanol Sourcing Program - Sustainably sourced bio-based plastic
- UPM bio-PET

Scientific and grey literature

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Relevant policy acts

- EU Waste Framework Directive (2008/98/EC)
- Single-Use Plastics Directive (EU 2019/904)

Policy recommendations

- European Bioplastic's position paper "Industrial use of agricultural materials as feedstock for biobased plastics" (June 2025)
- Plastics Europe "The plastics transition - Our industry's roadmap for plastics in Europe to be circular and have net-zero emissions by 2050" (2021).
- RCI's Position paper "Sustainability Criteria for Biomass" (June 2025)
- RCI's scientific background report "The use of food and feed crops for bio-based materials and the related effects on food security – Promoting evidence-based debates and recognising potential benefits" (June 2023) Long Version
- Joint BIC and RCI Scientific Background report "Is there enough biomass to defossilise the Chemicals and Derived Materials sector by 2050?" (Feb 2025)

Further sources

- BioPlastic Feedstock Alliance
- Publications by Kevin O´Connor (University College Dublin)
- Studies on renewable carbon by Nova Institute
- Key Documents of the RCI

Annex 4: Presentations

Welcome address

Serenella Sala, Head of Unit JRC.D.3 - Land Resources and Supply Chain Assessments

Rosalinda Scalia, Deputy Head of Unit DG RTD B.2 - Bioeconomy & Food Systems

European Commission

EU-funded research on bio-based plastics

Martin Policar, DG RTD B.1 – Green Transitions

Scope

Bio-based

made from biomass/biological resources, i.e., animals, plants, micro-organisms and derived biomass, including bio-waste

Polymers

"A polymer is a substance consisting of molecules characterised by the sequence of one or more types of monomer unit.….natural polymers that have not been chemically modified"…" Polymers that occur in nature that have not been chemically modified (other than by hydrolysis)"

Plastics

"'a material consisting of a polymer as defined in (REACH), to which additives or other substances may have been added, and which can function as a main structural component of final products, with the exception of natural polymers that have not been chemically modified…"

R&I framework programme

Horizon Europe Pillar II
Global Challenges and European Industrial Competitiveness

Cluster 6 - Food, Bioeconomy, Natural Resources, Agriculture and Environment

..circular bio-based systems from sustainably sourced biological resources…

Circular Bio-based Europe Joint Undertaking
https://www.cbe.europa.eu/

EUR 2 billion European **partnership** between the European Union and the Bio-based Industries Consortium (BIC)

Cluster 4 - Digital, Industry and Space

breakthrough technologies… dynamic industrial innovation

Made in Europe

Process for Planet P4P

CL&CL6, CBE JU: bio-based polymers/plastic/packaging, biodegradability

bio-based polymers/plastics/packaging, biodegradability

approx (70+103.5) M€

Examples of topics, ToA, budget and number of funded projects:

HORIZON-CL4-2024-RESILIENCE-01-35: **Biodegradable polymers** for sustainable packaging materials. (IA, 31 M€, 4p).

HORIZON-CL6-2022-CIRCBIO-02-03-two-stage: Sustainable **biodegradable novel bio-based plastics**: innovation for sustainability and end-of-life options of plastics. (IA, 12 M€, 2p).

………………

HORIZON-JU-CBE-2023-IA-04 Recycling **bio-based plastics** increasing sorting and recycled content (upcycling) (IA, 15 M€, 2p)

HORIZON-JU-CBE-2024-IA-01 **Bio-based** materials and products for **biodegradable** in-soil applications 15 M€

HORIZON-JU-CBE-2025-IAFlag-03 Circular-by-design **fibre-based packaging** with improved properties- 18 M€

CL&CL6, CBE JU: bio-based polymers/plastic/packaging, biodegradability

- FIBER-BASED packaging: any sector
- FOOD PACKAGING with enahnced properties
- COMPOSITEs: any sectors (packaging, construction, automotive)
- PLASTICS with advanced performances (e.g., fire-resistance, isolation, etc.): any sectors
- BIODEGRADABLE polymers for AGRICULTURE/HORTICULTURE applications
- BIODEGRADABLE plastics for HUMANITARIAN context

CL&CL6, CBE JU enabling technologies; social innovation

enabling bio-based technologies
approx 100 M€

HORIZON-CL4-2021-TWIN-TRANSITION-01-05: Manufacturing technologies for bio-based materials (Made in Europe Partnership) (RIA, 20 M€, 5p)

HORIZON-CL6-2025-01-ZEROPOLLUTION-01-two-stage: Substances of concern and emerging pollutants from bio-based industries and products: mapping and replacement (IA, 10 M€, 2p)

HORIZON-CL6-2025-01-CIRCBIO-11: Demonstration of reduced energy use and optimised flexible energy supply for industrial bio-based systems (IA, 11M€, 2p)

social innovation
approx 220 M€

HORIZON-CL6-2023-ZEROPOLLUTION-01-7: Strategies to prevent and reduce plastic packaging pollution from the food system (RIA, 8M€)

HORIZON-CL6-2023-CircBio-02-1-two-stage: Circular Cities and Regions Initiative (CCRI)’s circular systemic solutions (IA, 58M€)

HORIZON-CL6-2024-ZEROPOLLUTION-01-3: Environmental impacts of food systems (RIA, 7M€)

EUROPEAN UNION

EU MISSIONS

RESTORE OUR OCEAN & WATERS

Concrete solutions for our greatest challenges

#EUmissions #HorizonEU #MissionOcean

EUROPEAN UNION

EU MISSIONS
RESTORE OUR OCEAN & WATERS

Mission objectives and targets

Restore our Ocean and Waters by 2030

PROTECT AND RESTORE MARINE AND FRESHWATERS ECOSYSTEMS AND BIODIVERSITY

- Protect at least 30% and strictly protect 10% EU's sea areas
- Restore 25.000 km free flowing rivers
- Marine nature restoration targets (incl. degraded seabeds, coastal ecosystems)

PREVENT AND ELIMINATE POLLUTION OF OUR OCEANS, SEAS AND WATERS

- **Reduce by at least 50% plastic litter**
- **Reduce by at least 30% microplastics**
- Reduce by at least 50% nutrient losses, chemical pesticides

MAKE THE BLUE ECONOMY CARBON- NEUTRAL AND CIRCULAR

- Net zero maritime emissions
- Zero carbon aquaculture,
- Low carbon multipurpose use of marine space

ENABLERS

Digital Ocean and Waters Knowledge system

Public mobilization and engagement

Bio-based materials enabling the transition

replacement of fossil intensive resources by sustainable and renewable biomass, including bio-waste

substantially contribute to climate neutrality and biodiversity and environmental protection

enabled by the power of biotechnology combined with advances in information technology - including AI

enabling the equal distribution of benefits and revenues along the value chain, from primary producers, to the industrial operators to end users, including local governments and citizens

increasing the level and appeal of jobs in agriculture, forestry and, potentially, fishery sectors, also due to the rapid deployment of digital tools for the primary production

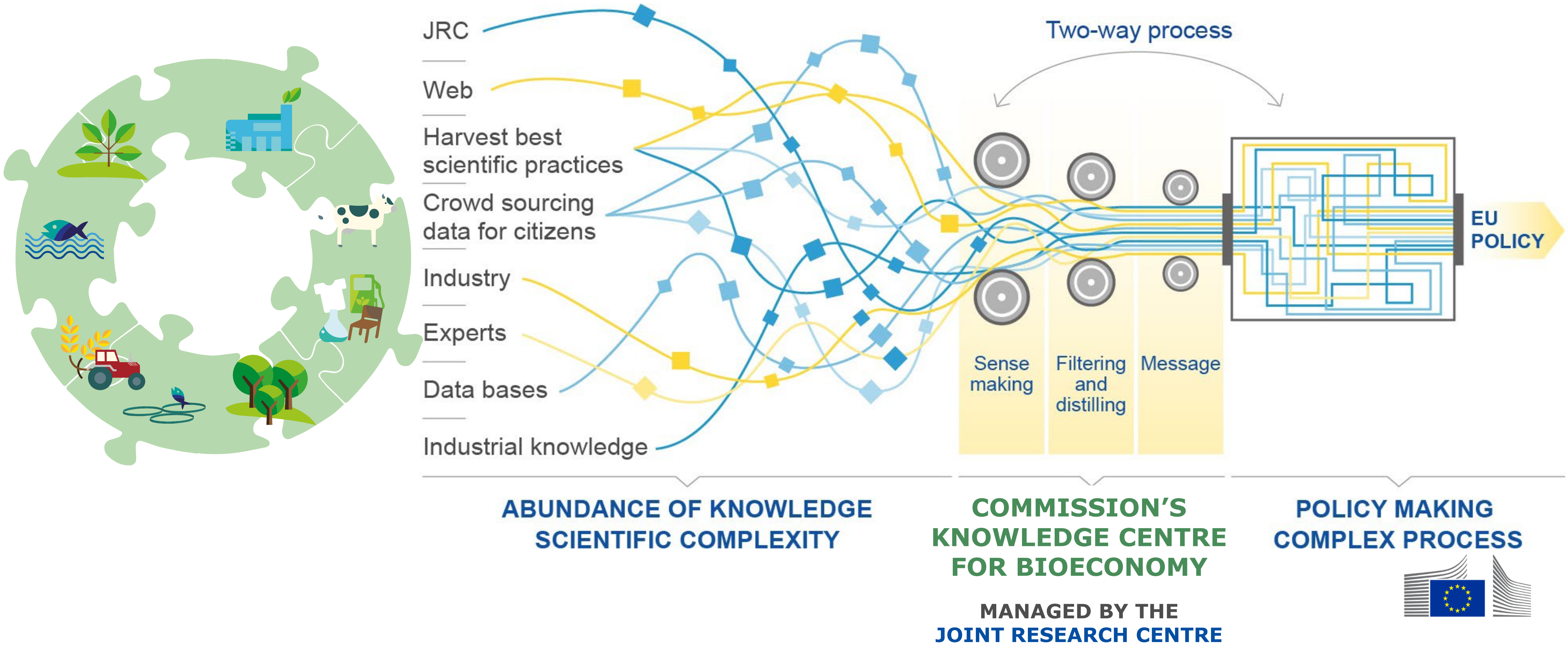
sustainability resilience inclusion

Introduction to the KCB deep dive on bio-based plastics

Maria Teresa Borzacchiello
EC Knowledge Centre for Bioeconomy

JRC.D.3 - Land Resources and Supply Chain Assessments

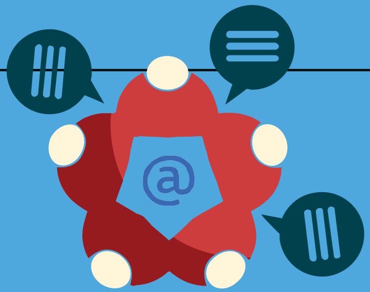
The Knowledge Centre for Bioeconomy



Knowledge Centre for Bioeconomy

Identifying and **filtering** relevant information and making it accessible.

Bringing together researchers, policymakers and **other experts** in the field.



Analysing, synthesising and **communicating** available evidence.

Enhancing the **knowledge** base for policymaking.

https://knowledge4policy.ec.europa.eu/bioeconomy_en

Knowledge Centre for Bioeconomy

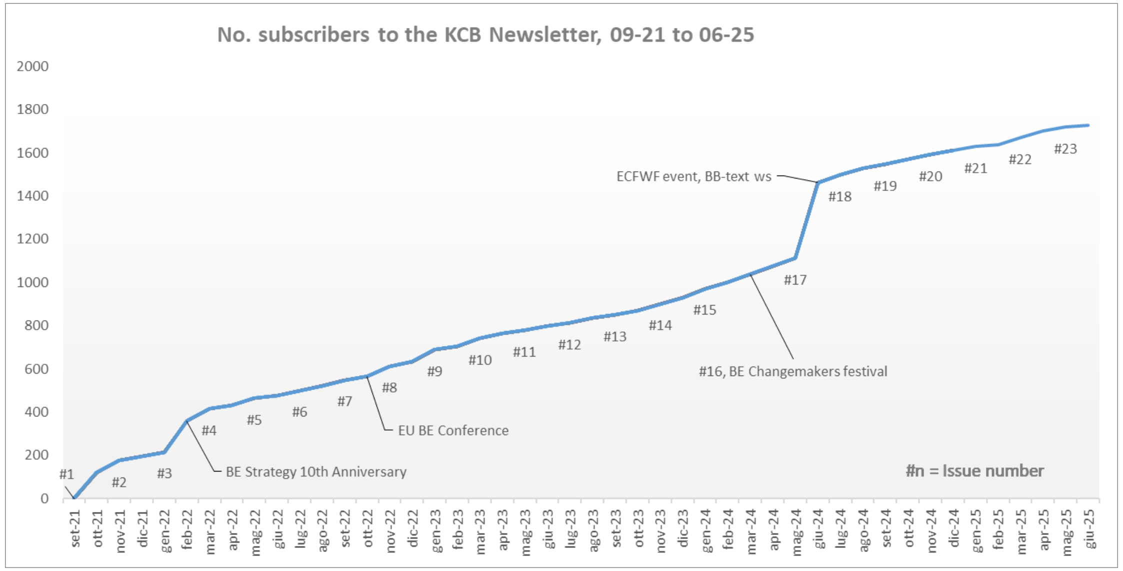
Identifying and **filtering** relevant information and making it accessible:

The online knowledge base & the newsletter

>300 sources monitored weekly

Knowledge library with

>6.5k resources (publications, datasets, data visualizations, news, events, briefs, online tools, videos, definitions …)



>1700 subscribers to the Newsletter in Q2/25

Newsletter subscription at: https://ec.europa.eu/newsroom/know4pol/user-subscriptions/2358/create

Bringing together researchers, policymakers and other experts:
Community of Practice

The Community of Practice – focus on 2024 events

Participants from various DGs and practitioners, Bio-based textile workshop, June 2024, Brussels

European Consumer Food Waste **Forum**

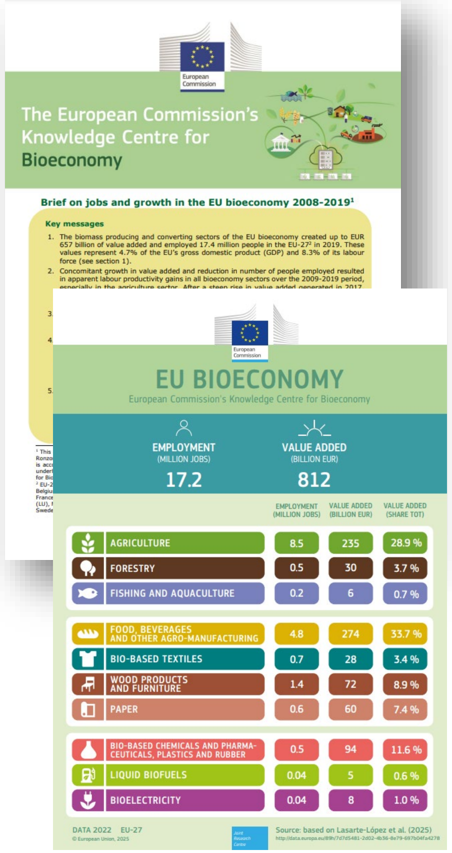
ECFWF public event, KCB tutorials stand and organising team (JRC & SANTE), June 2024, Brussels

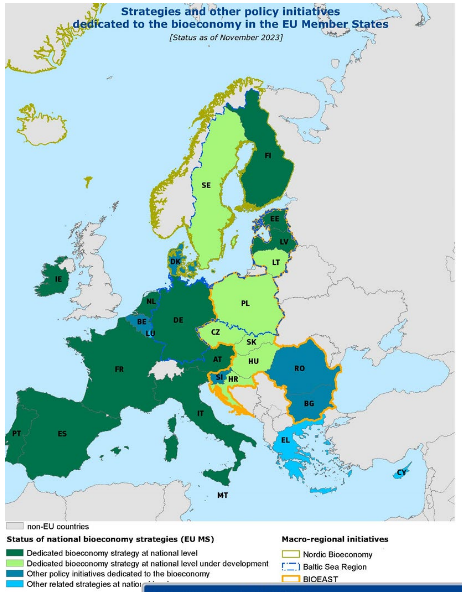
To join the CoP bioeconomy: https://ec.europa.eu/eusurvey/runner/CoP_bioeconomy

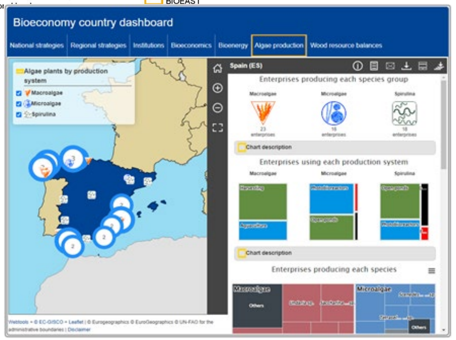
Knowledge Centre for Bioeconomy

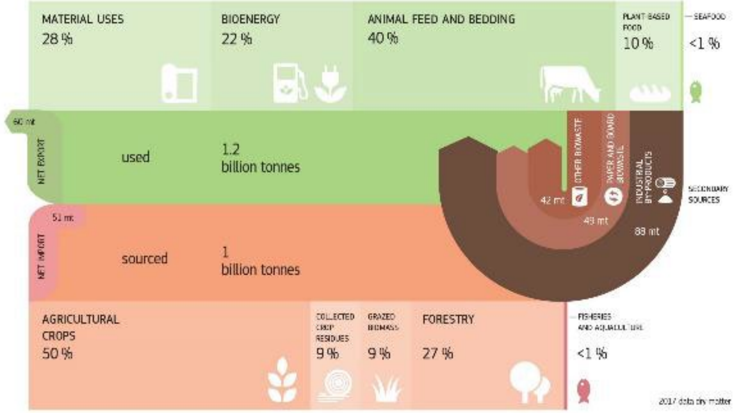
Analysing, synthesising and **communicating** available evidence.

Briefs, dashboards, videos & infographics





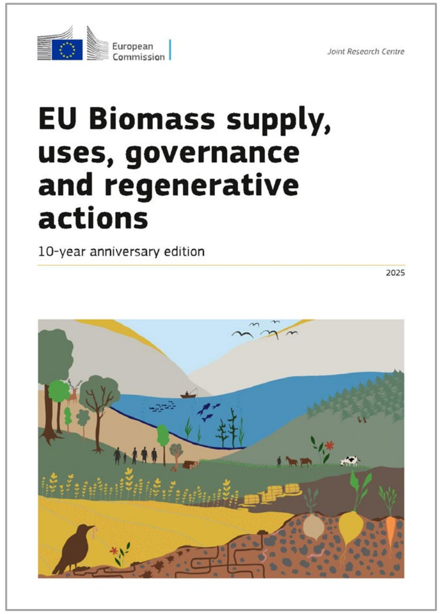




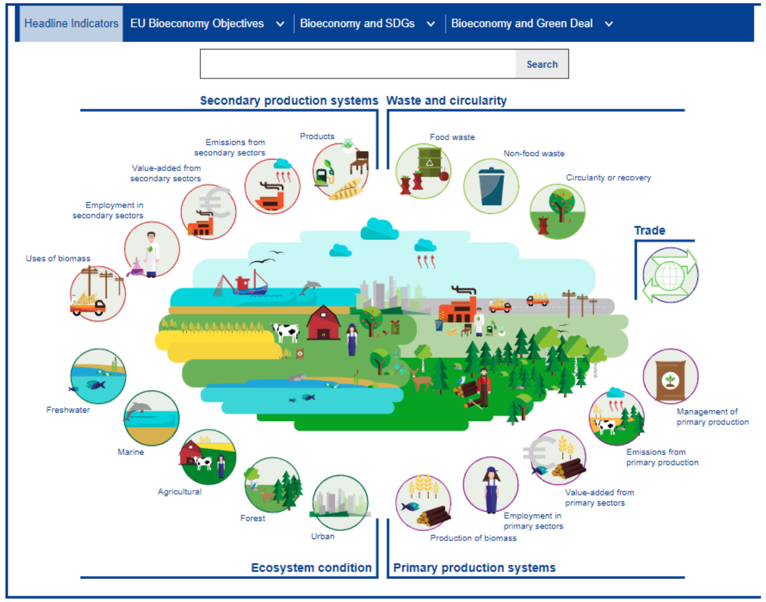
Knowledge Centre for Bioeconomy

EU Bioeconomy Monitoring System dashboard & evidence reports

Enhancing
the **knowledge** base
for policymaking.



https://publications.jrc.ec.europa.eu/repository/handle/JRC140117



https://knowledge4policy.ec.europa.eu/bioeconomy/monitoring

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KCB deep dive on bio-based plastics

Collecting, synthesising and presenting the best available evidence on the bio-based plastics topic, to:

- discuss the main issues at stake to inform policymaking
- represent the sector in a clear and multifaceted way
- assess its potential role in the European bioeconomy context
- identify the knowledge gaps and opportunities for research and innovation in this field

4 main topics for discussion today

Land use and resource competition

Material performance, costs and economic viability

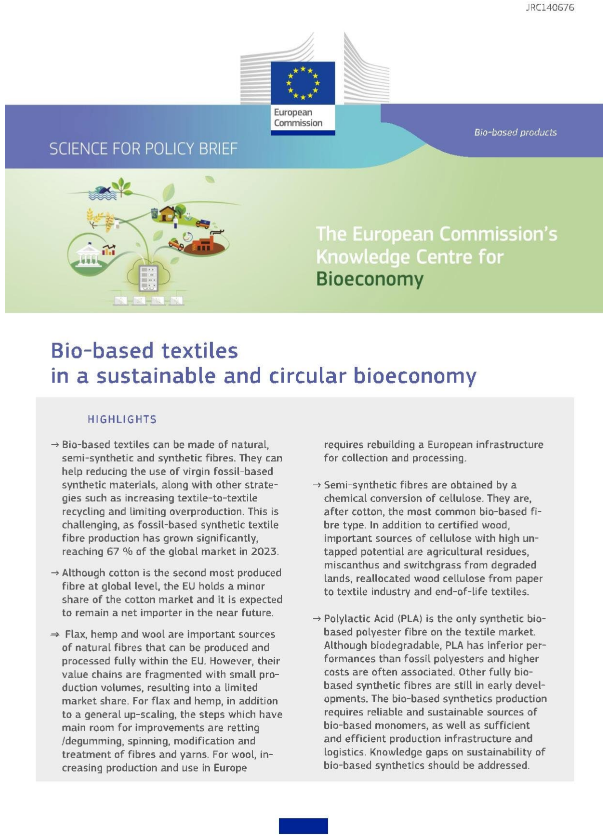
Environmental impacts

End of life management

Expected outputs

A **new topic page on bio-based plastics**, including:

- A ‘**knowledge for policy brief**’, that synthesises currently available knowledge, facts and figures **(support from external expert)**
- An ’**Explore further**’ section including latest data, visualisations, projects and additional selected resources
- A ’**Latest resources**’ section with the latest news and publications in KCB’s knowledge base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SCIENCE FOR POLICY BRIEF

European Commission

Bio-based products

The European Commission's Knowledge Centre for Bioeconomy

Bio-based textiles in a sustainable and circular bioeconomy

HIGHLIGHTS

→ Bio-based textiles can be made of natural, semi-synthetic and synthetic fibres. They can help reducing the use of virgin fossil-based synthetic materials, along with other strategies such as increasing textile-to-textile recycling and limiting overproduction. This is challenging, as fossil-based synthetic textile fibre production has grown significantly, reaching 67 % of the global market in 2023.

→ Although cotton is the second most produced fibre at global level, the EU holds a minor share of the cotton market and it is expected to remain a net importer in the near future.

→ Flax, hemp and wool are important sources of natural fibres that can be produced and processed fully within the EU. However, their value chains are fragmented with small production volumes, resulting into a limited market share. For flax and hemp, in addition to a general up-scaling, the steps which have main room for improvements are retting /degumming, spinning, modification and treatment of fibres and yarns. For wool, increasing production and use in Europe requires rebuilding a European infrastructure for collection and processing.

→ Semi-synthetic fibres are obtained by a chemical conversion of cellulose. They are, after cotton, the most common bio-based fibre type. In addition to certified wood, important sources of cellulose with high untapped potential are agricultural residues, miscanthus and switchgrass from degraded lands, reallocated wood cellulose from paper to textile industry and end-of-life textiles.

→ Polylactic Acid (PLA) is the only synthetic bio-based polyester fibre on the textile market. Although biodegradable, PLA has inferior performances than fossil polyesters and higher costs are often associated. Other fully bio-based synthetic fibres are still in early developments. The bio-based synthetics production requires reliable and sustainable sources of bio-based monomers, as well as sufficient and efficient production infrastructure and logistics. Knowledge gaps on sustainability of bio-based synthetics should be addressed.

Example – Topic page on bio-based textiles
https://knowledge4policy.ec.europa.eu/bio-based-textiles_en

Example – Science for Policy brief on bio-based textiles
https://publications.jrc.ec.europa.eu/repository/handle/JRC118214

Deep dive on bio-based plastics – next steps

May 2025

Start collaboration with bio-based plastics expert

Workshop on bio-based plastics

26/06/2025

- **Objectives**:
- to offer an overview of the policy framew ork
- to present preliminary results of the analysis performed by the expert
- to gather inputs from the participants on the current state of the art and knowledge gaps of the bio-based plastics sector

September 2025

draft **Knowledge for policy brief** for DG consultation

Bio –based plastics webpage

Autumn 2025

Thank you and enjoy the workshop!

EC Knowledge Centre for Bioeconomy website: https://knowledge4policy.ec.europa.eu/bioeconomy_en

Subscribe to the KCB Newsletter: https://ec.europa.eu/newsroom/know4pol/user-subscriptions/2358/create

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Contact us at: EC-Bioeconomy-KC@ec.europa.eu

EU Science Hub
joint-research-centre.ec.europa.eu

Overview of policy developments on bio-based plastics in EU

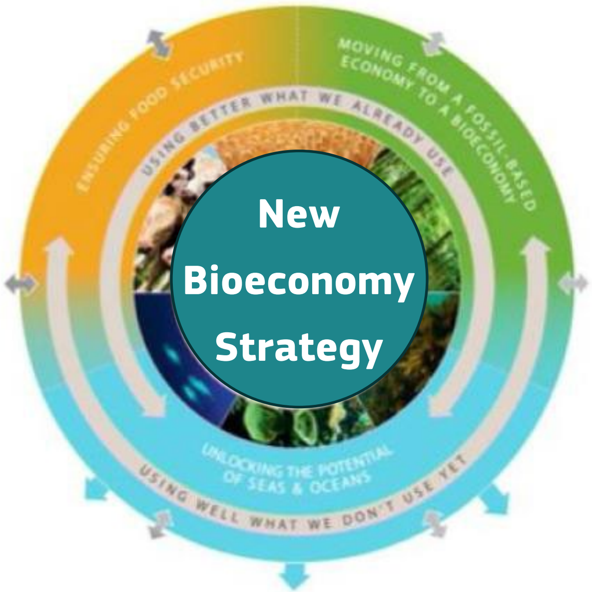
Werner Bosmans, DG ENV B.1 - Circular Economy, Sustainable Production & Consumption

European Commission

EU policies and the future of Biobased plastics

Werner Bosmans
Teamleader ‘Plastics’
DG Environment

With the help of Jiannis Kougoulis
Bioeconomy team
DG Grow



A climate-neutral, resource-efficient and competitive economy

Maintaining the value of products, materials and resources in the economy for as long as possible

Scaling up biobased sectors, within ecological boundaries

Improving the economics and quality of recycling & curbing plastic waste & littering

New Bioeconomy Strategy – a driver for green growth

- Position the EU in the **rapidly expanding bioeconomy market**
- Significant **growth** potential
- **Reduce our reliance on fossil fuels** & foster **our rural areas**

Competitiveness Compass, January 2025

- **Improve resource efficiency**
- **Reduce dependencies** on imported raw materials.
- **Prioritise manufacturing and using biomaterials**
- **Retain** them as long as possible in the economy

Clean Industrial Deal, February 2025

- **Diversification** of value streams
- Valorisation of farm **residues**
- Strengthening the role of **primary producers** and generating new jobs

Vision for Agriculture and Food, February 2025

European Commission

Interplay with policy areas in the *new* Commission

Biotech Act

Circular Economy Act

Start up and Scale up Strategy

Bioeconomy Strategy

Ocean Pact

Life Science Strategy

European Commission

Sustainability criteria vs cascading use of biomass

Sustainability **supply** for the bioeconomy

- Ensure resilience of supply
- Assure that biomass is sourced sustainably
- Sustainable land management practices

Cascading principle - Prioritizing material **demand**

- Maximise resource efficiency & circularity
- Prioritise use of residues & byproducts to extend biomass availability
- Orient biomass from bioenergy towards higher value applications (i.e. material)

European Commission

EU Bioeconomy strategy 2025: objective

- Enhance **long-term competitiveness** of the EU economy & strategic resilience
- Ensure **industrial leadership** in addressing climate change, biodiversity loss & pollution
- Lead in the emerging **biobased economy (*investments*)** & drive biotechnology innovation
- Secure **sustainably supplied biomass** & sustainable production of biological resources for food, materials, energy & services
- Create **green jobs**

EU Bioeconomy strategy 2025: scope

Pillar I - Increasing resource-efficient & circular use of biological resources

Pillar II - From Lab to Fab, priorities for scaling up

Pillar III - Securing the competitive & sustainable supply of biomass, both domestically & from outside the EU

Pillar IV - Positioning the EU in the rapidly expanding international market

European Commission

Biobased plastics

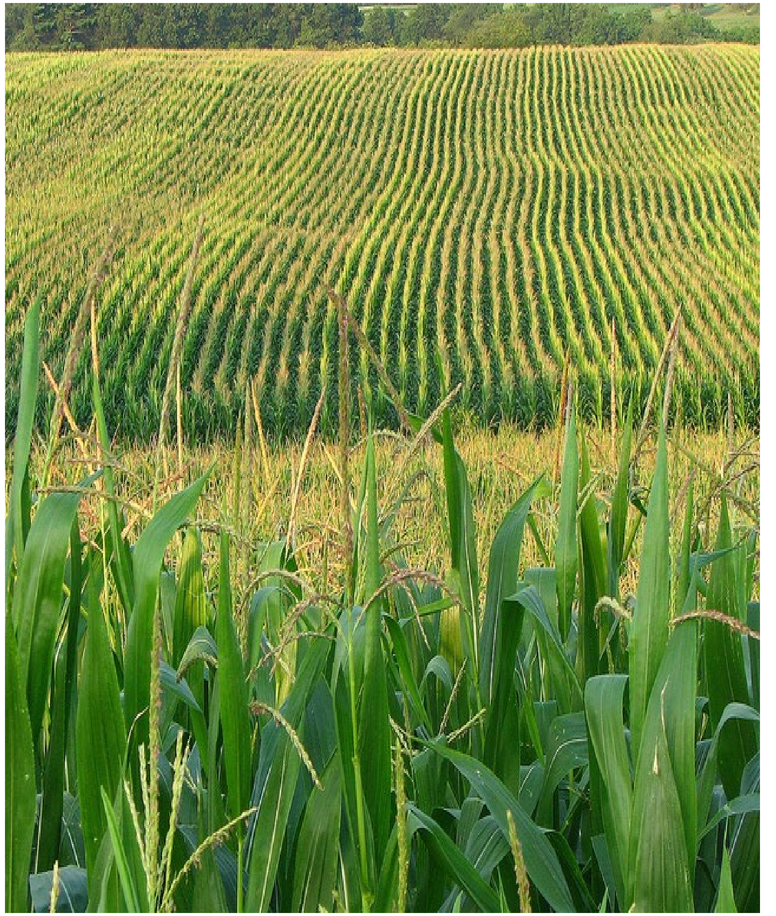
Communication 2022

- To **defossilise** industry, **reducing our dependency** on fossil resources & meeting our **climate neutrality targets**
- To **create jobs**

Challenges:

- No perpetuating single use models
- Secondary vs primary biomass
- Integrate the cascading principle
- Sustainability criteria to comply with:
    - RED III – for land use and biodiversity
    - For GHG – more research needed

- ***Biodegradable*** plastics only for **specific applications** where full removal is not possible – No licence to litter



European Commission

Biobased plastics in **Taxonomy**

- **Climate Delegated Act (2021)**
  - Focus on plastic in its primary form
  - IF substantial contribution to climate change mitigation
  - A valid option **if biomass is compliant with bioenergy sustainability criteria** and **life-cycle GHG emissions are lower than fossil-based equivalent**

- **Environmental Delegated Act (2023)**
  - Focus on plastic packaging
  - IF substantial contribution to transition to a CE
  - A valid option **when biowaste feedstock is used**

PPWR: Biobased feedstock (art 8)

Entered into force in Feb 25

By 12 Feb 2028, EC to review state of play (and possible proposal) of biobased plastic packaging:

- Sustainability requirements
- Feedstock targets
- Interplay of recycled content and biobased targets
- Definition of biobased plastic

European Commission

Upcoming EC studies on biobased content targets in products

Study	Timeplan	Lead DGs	Feedback and consultation
Study on feasibility & impacts of bio-based & other non-fossil content requirements for products	Q3 2025 to Q4 2026	GROW	Targeted consultation activities from Q4/2025 to Q1/2026
Circular economy act impact assessment study (part on biobased content targets on 1-3 product groups)	Q3 2025 to Q4 2025	ENV/ GROW	Public consultation of CEA + targeted consultation Q4/2025
Packaging and packaging waste regulation art 8 implementation	Q3 2026 (tbc)	ENV / JRC	Sector consultation in Q1/2026

Upcoming EC studies on biobased content targets in products

Communication: Building the future with nature: Boosting Biotechnology and Biomanufacturing in the EU

→

Study on feasibility and impacts on setting bio-based and other non-fossil content requirements for products

'Look on policy options to stimulate the market uptake of biobased products'

IA of Circular Economy Act

→

'To move away from fossil materials, it is vital to mandate the use of new raw material sources like recycled and bio-based materials to substitute, for example, virgin fossil materials in plastics (Clean Industrial Deal)'

Implement art 8 of PPWR

→

'Review state of play (and possible proposal) of biobased plastic packaging'

refuse

share

reuse

return
&
collect

sort

recycle

Learn more about:

[Bioeconomy Strategy - European Commission](#) & [Plastics (europa.eu)](#)

Werner.Bosmans@ec.europa.eu

European Commission

Bio-based plastics sector and key issues at stake

Karin Molenveld, Programme Manager Renewable Plastics, Wageningen University Research

European Commission

Outline

General introduction

Why biobased plastics?

Possible production routes

Feedstocks for biobased plastics

Markets, performance, applications

End of life

Environmental impacts

Introduction plastics

Plastics are organic polymers that can be moulded into shape during manufacture

- Lightweight, versatile (in shapes and properties), durable, cost-effective, chemical resistance, hygiene, flexibility, transparency, strength, abundancy

First plastics were of renewable origin (eg, cellulose derivatives)

- Replacing scares natural materials like ivory

During and after WW II production of fossil-based plastics boosted

- Nylon (polyamides) for parachutes, ropes, body armor
- Plexiglas (polymethylmethacrylate) for aircraft windows

Raw material choice predominantly based on costs

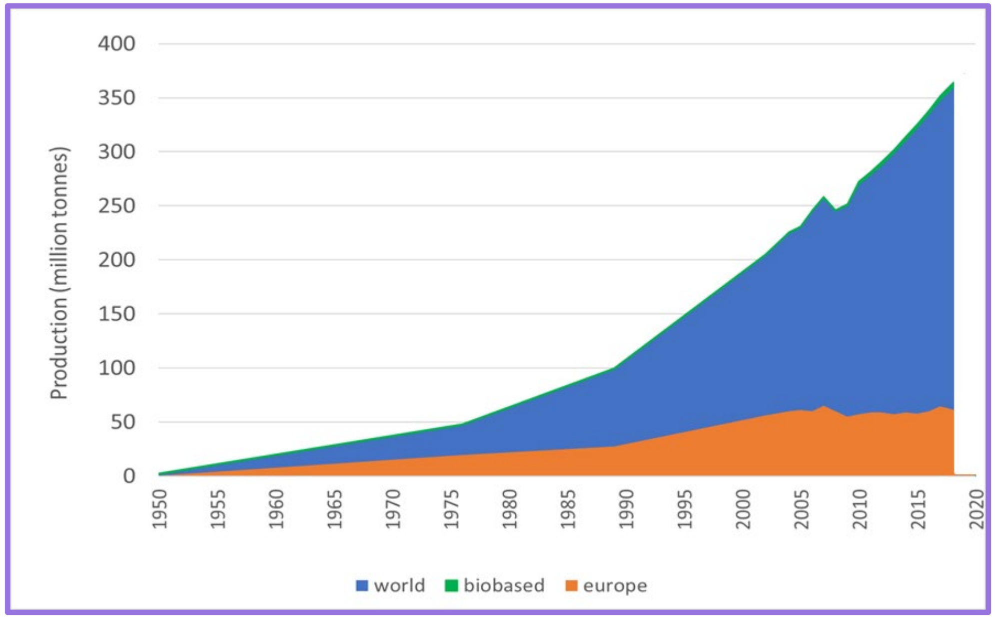
- **Nylon 11 is biobased (castor oil derived)**
- **Nylon 12 is fossil-based**

Cellulose Acetate bricks

Introduction plastics

Plastics Production Development

- Global market has grown > 400 million tonnes/annum
- Further extensive growth expected
- Strongest growth outside Europe
- Minor share of biobased plastics



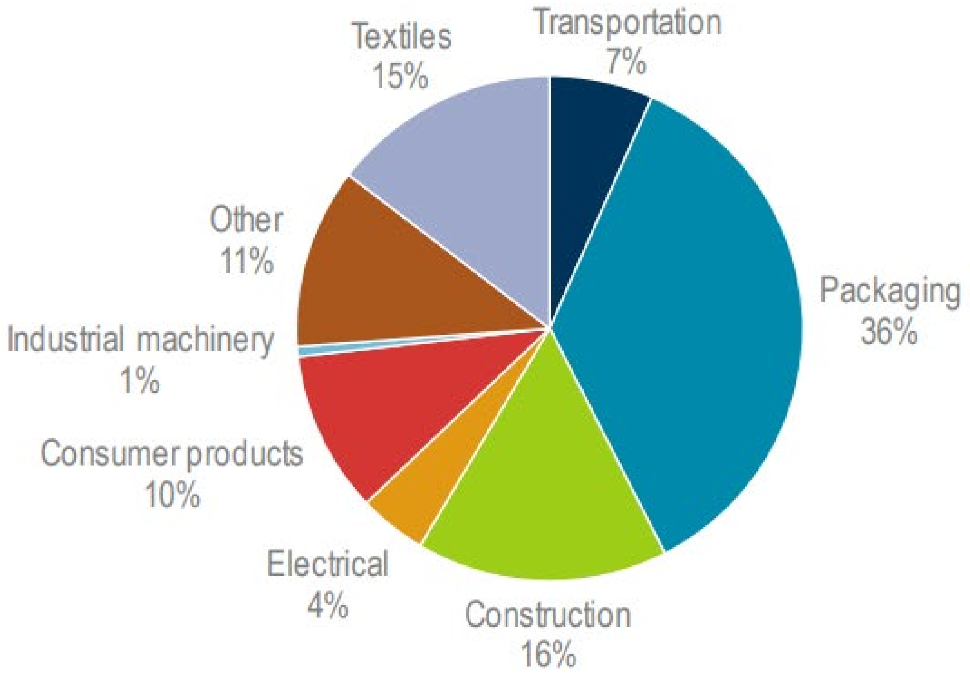
Development of global plastic production

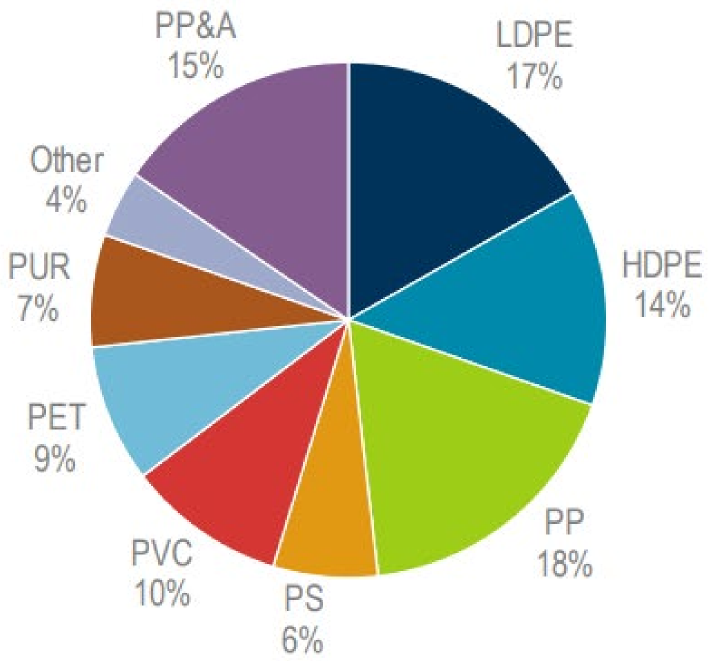
Introduction plastics

Plastic usage by end-use sector and resin type (source IEA, 2018),

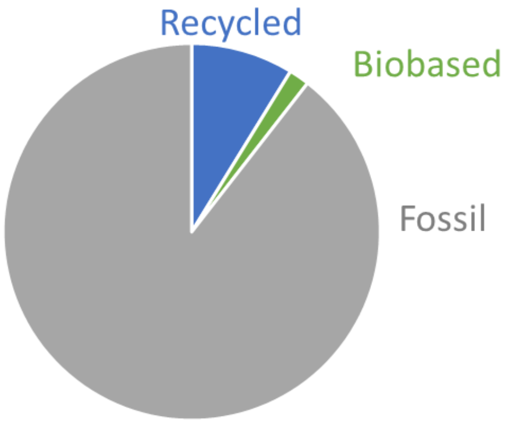
Main market is packaging

Polyethylene (PE) and polypropylene (PP) together have a market share of ~50%.





Introduction plastics



Since ~ 1980 concerns

Waste & pollution issues

Climate change related to fossil feedstock usage

Microplastics & safety concerns

Mitigation actions

Development of biodegradable plastics

Development of biobased plastics

Plastic recycling

Circularity models

Waste hierarchy

Plastic bans

Current status

Most plastics are still virgin fossil based

Biobased and recycled plastics are more expensive

Cheap imports slow down plastic transition

Special report 17/2023: Circular economy – Slow transition by member states despite EU action

Why biobased plastics?

Fossil fuel consumption for plastics and chemicals

~ 10% of fossil carbon is used as feedstock for chemicals and plastics

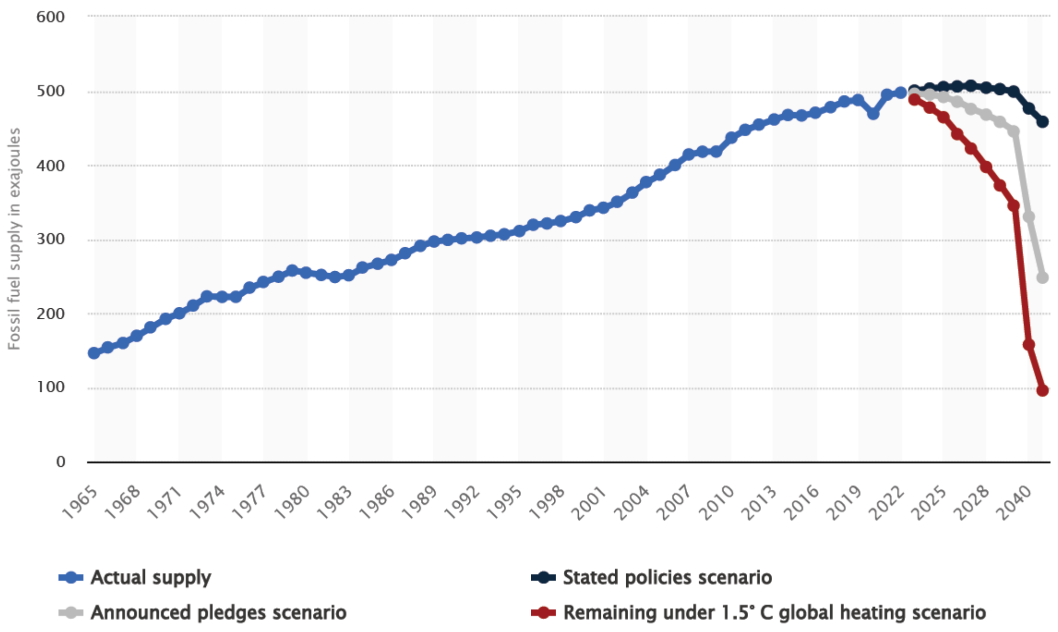
~ 7% is used as energy during production

Main use in bulk polymers like polyolefins and polystyrene and smaller part for engineering plastics adding up to a 90% share.

Due to the energy transition the relative share of petrochemicals will increase, the cost will increase and the relative contribution to (GHG) emissions will increase.

Global fossil fuel demand

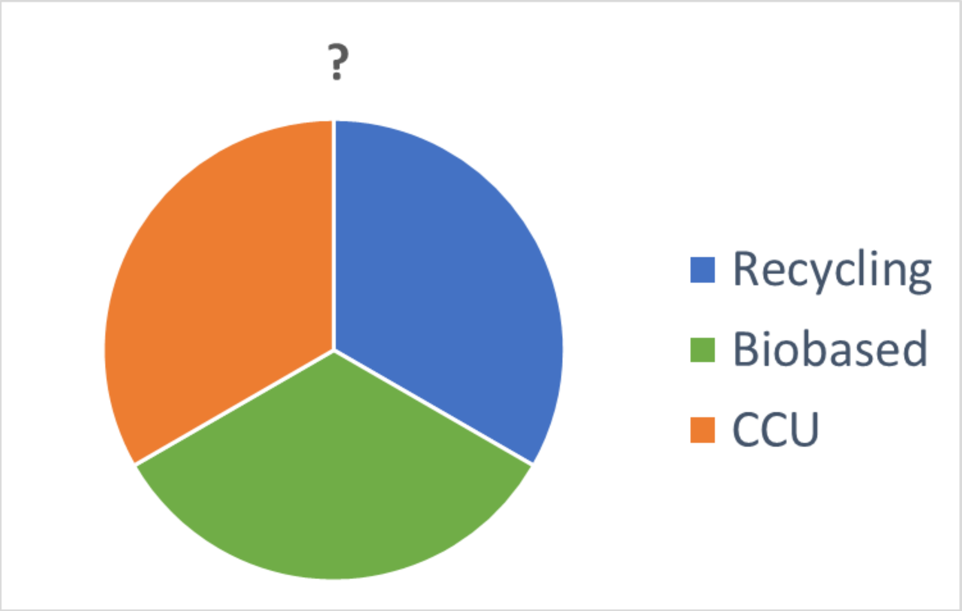
(Source:Statistica)



Why biobased plastics?

Alternative Carbon Sources
Three main options

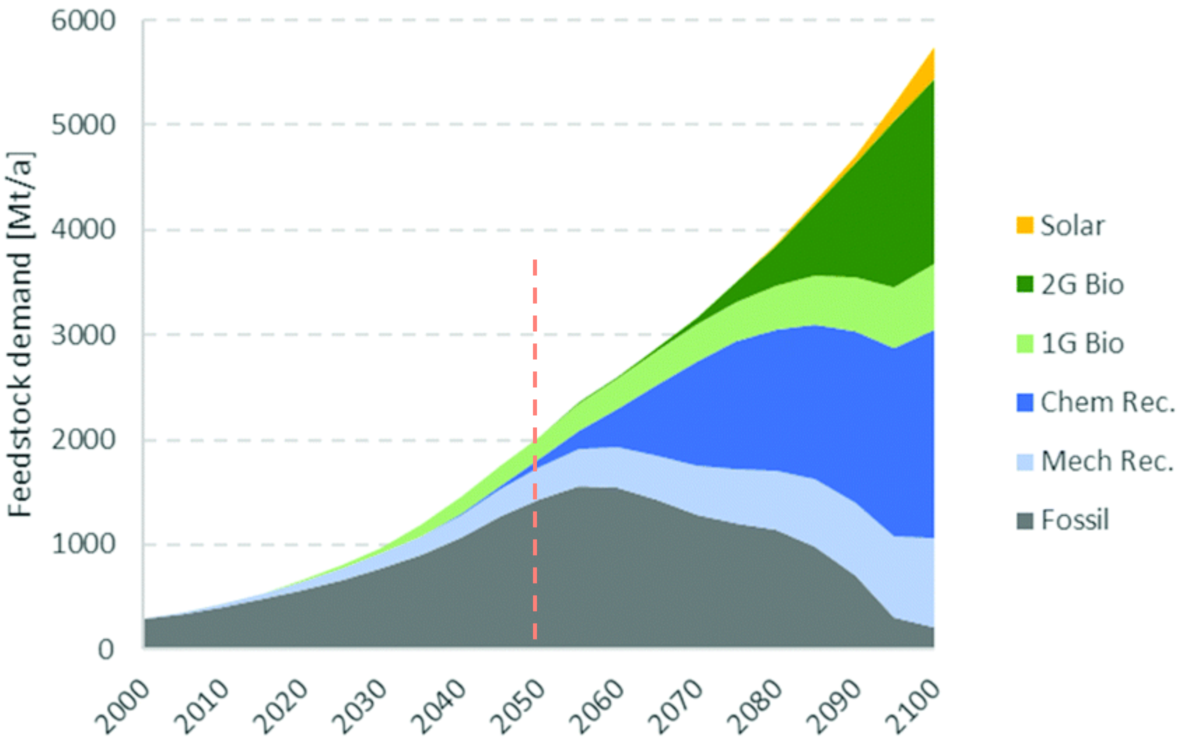
1. **Plastic recycling**
   - Mechanical
   - (Thermo) chemical
2. **Biobased feedstocks**
   - First generation
   - Second generation
3. **CCU**
   - Using Renewable energy

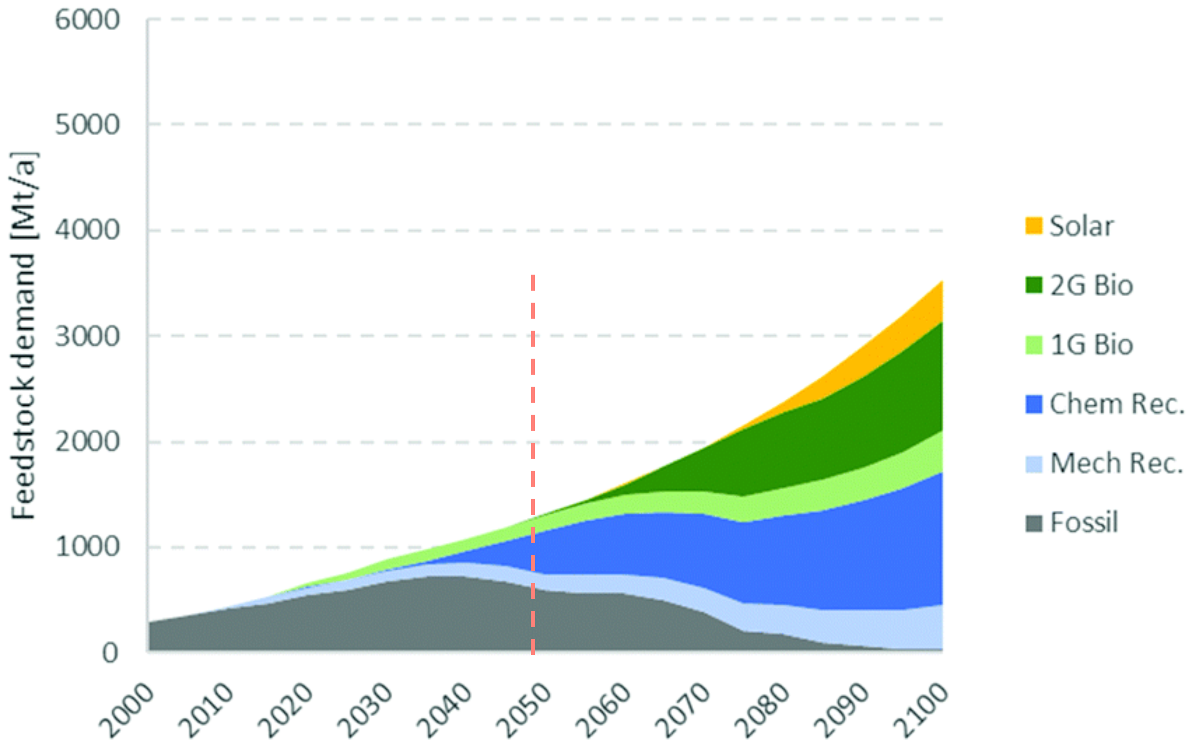


Alternative carbon sources (Biobased, CCU) are needed to allow growth of the chemical industry and to compensate for inevitable losses during recycling.

Why biobased plastics

Feedstock scenario's; left market driven, right regulated (J.-P. Lange Energy Environ. Sci., 14, 2021)





Why biobased plastics

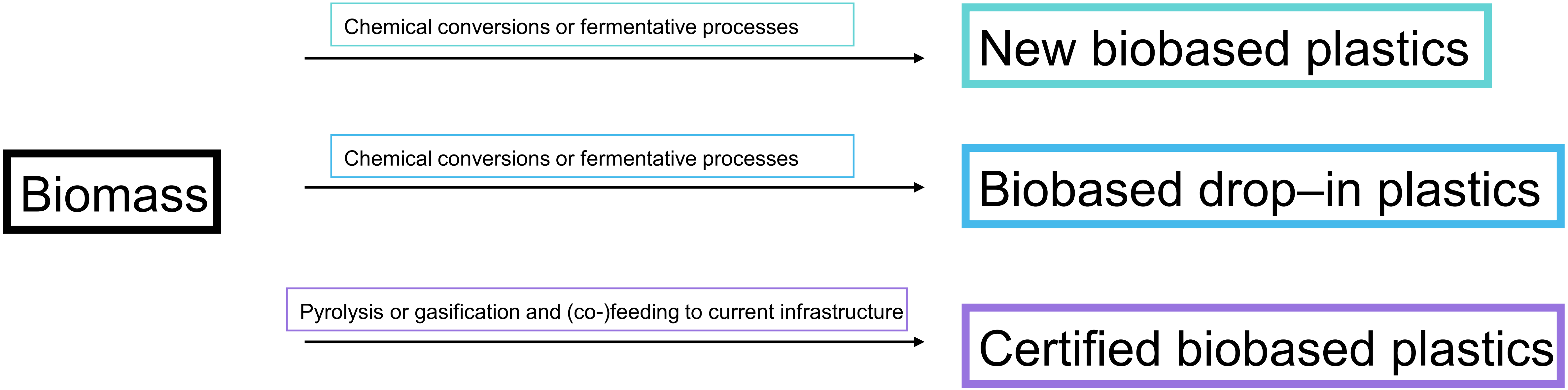
General conclusions regarding the feedstock transition

- Reducing the growth of feedstock consumption is essential
- Regulation is required
- CCS required to reach climate goals
- Efficient feedstock use, and processes with low energy demand are essential
- Products will become more expensive

- Losses during recycling are estimated to add up to 50%.
- Use of biomass as feedstock is essential, initially 1G and move to lignocelluloses
- To allow efficient feedstock use, shift in type of products required (from polyolefins to polyesters)
- CCU very expensive (high energy consumption), would also require product shift.
- New polymers require 20 years to break through and another 20 years to mature

Production routes for biobased plastics

Wide range of options



All routes require investment in additional installations and require a managed supply chain of biomass
Requirements for biomass pretreatment add to the cost.

Production routes for biobased plastics

New Biobased Plastic

Potential advantages

Efficient use of biomass

- More cost effective
- Lower environmental footprint

Processes with lower energy demand

- Low temperature processes

Decoupling from fuel and energy production

New functionalities

- Specific performance
- Improved recyclability
- Biodegradable or not persistent

Potential disadvantages

New production facilities

Long process of development and market introduction

New product design and development

Functional differences or disadvantages

Volumes initially too low for economic recycling

Production routes for biobased plastics

Drop-in Biobased Plastic

Potential advantages

Faster market introduction due to known properties

Can be recycled with fossil based plastics

Lower environmental footprint (GHG emission) as compared to fossil equivalent

Processes with lower energy demand

- Low temperature processes

Decoupling from fuel en energy production

Potential disadvantages

More expensive than fossil based equivalent

New production facilities required

No functional advantages

Inefficient use of biomass

Production routes for biobased plastics

Certified Bio-based Plastics

Potential advantages

Feedstock replacement allows versatile production of different plastic types and grades

Faster market introduction due to known properties

Can be recycled with fossil-based plastics

Lower environmental footprint (GHG emission) as compared to fossil equivalent, but depending on biobased content (% biomass added)

In operation for example using biodiesel produced from vegetable oils

Potential disadvantages

More expensive than fossil based equivalent

No functional advantages

Inefficient use of biomass

Pretreatment of biomass required (new facilities need to be developed)

Post treatment of pyrolysis oil may be required (new facilities)

Risk of only limited fossil feedstock replacement

Required scales can contribute to logistic challenges

Changes in current installation required on the long term (electrification)

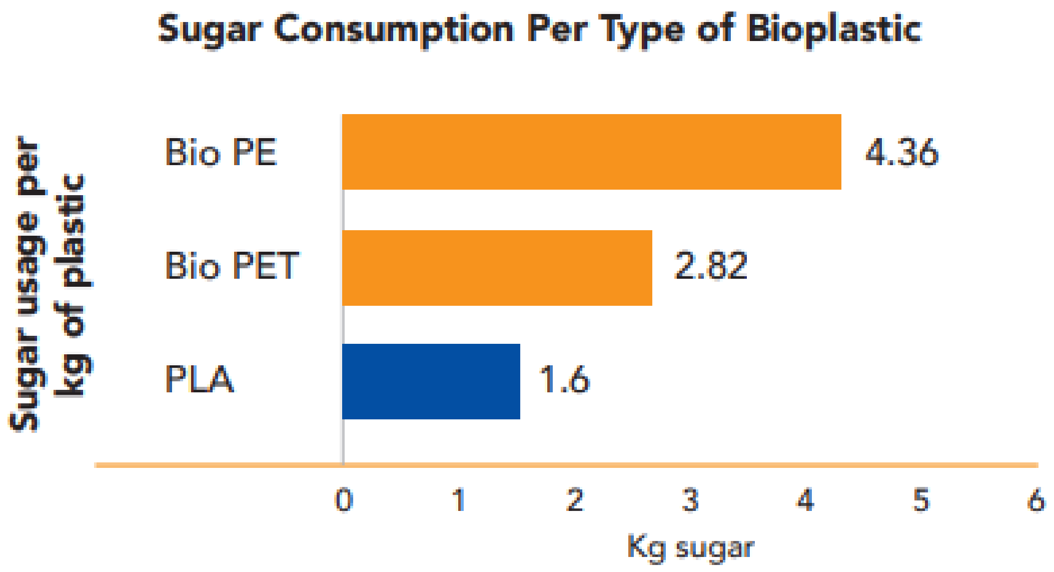
Production routes for biobased plastics

Important considerations

- Biobased resources are not abundantly available
- We need efficient conversion processes
- Biomass is oxygen rich, more logic to produce oxygen containing molecules
- Use of biomass leads to price increases

Efficient biomass use

(source Total Energies Corbion)



Feedstocks for biobased plastics

Biomass production and use

Most biomass is used for feed

- Additionally, EU imports ~ 70 Mt/y biomass for feed

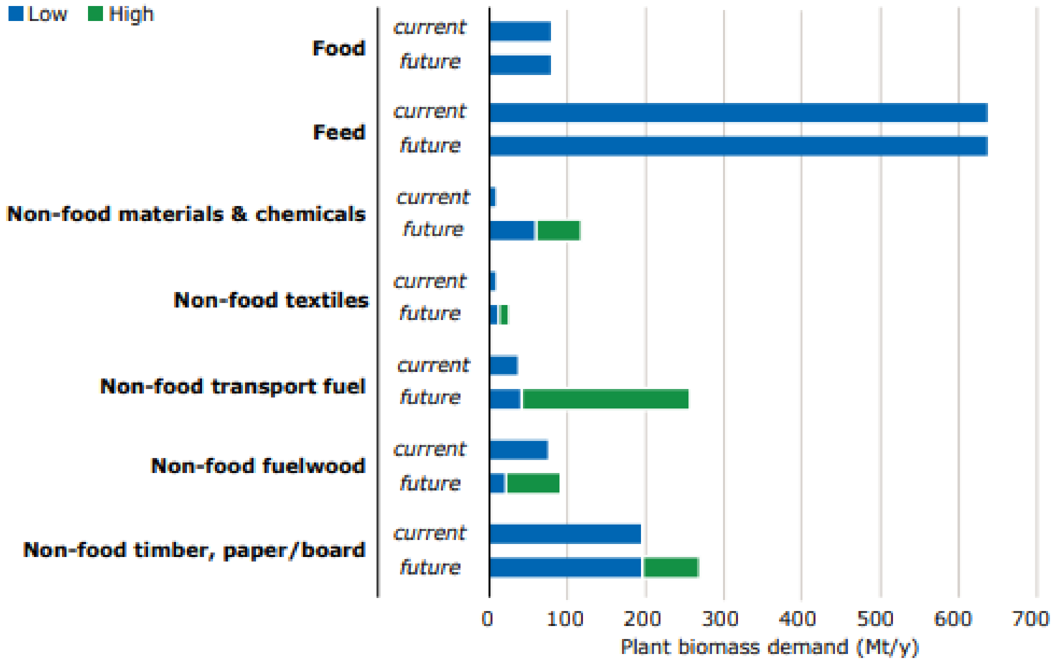
Biomass use for timber, paper/board is considerable and could grow

Current use for plastics and chemicals is low but expected to grow

Biomass use for electricity, heat and transport applications not desired/realistic

EU Plant Biomass demand

(Souce: Berkhout et al. Wageningen University, 2024)



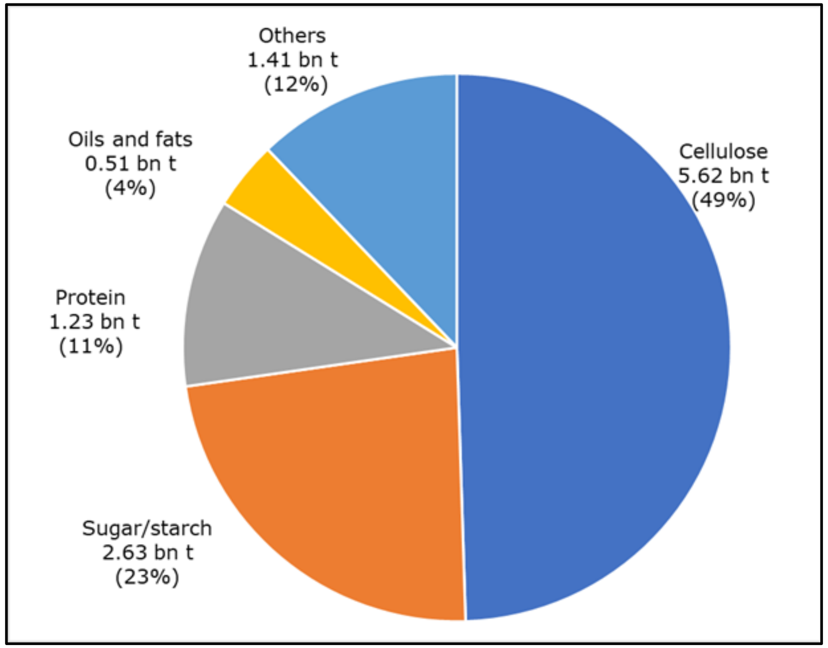
Feedstocks for biobased plastics

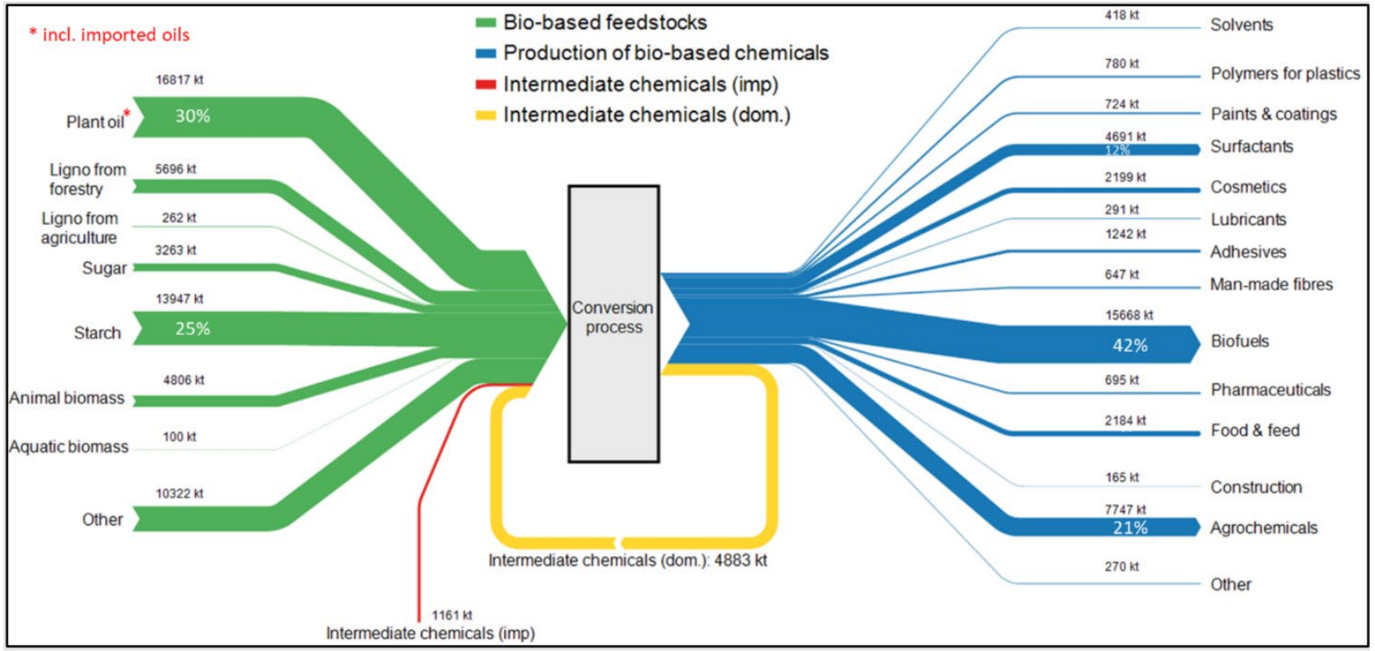
Type of biomass use should be considered

Abundant sources are (ligno)cellulose, sugar and starch; (sugar yield (beet and cane) ~ 10-15 ton/ha)

Oils and fats are scarcer; (yield palmoil ~3.3 ton/ha, rapeseed oil ~ 0.7 ton/ha)

This is not reflected in the uses in 2023





Source: Piotrowski, S. et al. 2015, Sturm et al. 2023

Feedstocks for biobased plastics

Current status

- Most used are sugars and starches in fermentation processes (50%)
- PHAs can be produced from sugars, vegetable oils or waste.
- Waste vegetable oils mainly used for biodiesel production

Main feedstocks for the production of biobased plastics.

Raw material	Feedstock	Biobased plastic
Starch	Corn, wheat, potato, tapioca	PLA, PTT, starch blends
Sugar	Sugar cane	PE, PLA, PHA
Castor oil	Ricinus	PA
Cellulose	Wood, cotton	CA
Edible oil	Palm, soy, rapeseed, sunflower	PHA
Waste vegetable oils	Used cooking oil, tall oil	Bioattributed plastics

Feedstocks for biobased plastics

General remarks

- Lignocellulosic agricultural side streams as such not well suited for chemicals and plastics production
- Need for technologies to make lignocellulosic side streams available for the production of chemicals at scale
- Non-food crops for fiber and wood are stand alone crops (not side streams), avoid energy usage

- Food and non-food products require the same crops and are interrelated
- Protein rich fibrous co-products are used as feed for livestock

Example Cereal:

- Plant based proteins for food
- Carbohydrates for chemicals and plastics
- Fibrous co-products for feed

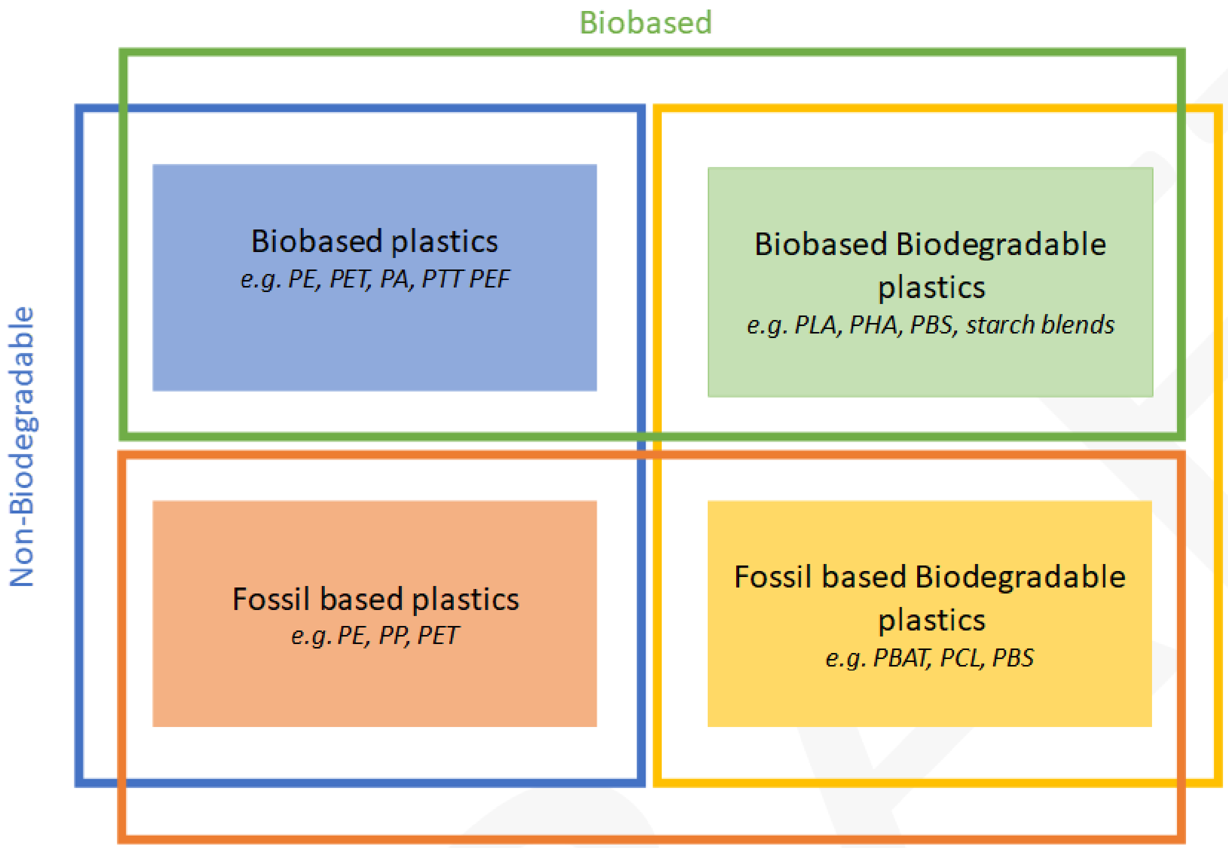
Bioplastics market

Classification

Biobased ≠ Biodegradable

Biobased plastics

- “New” biobased plastics
- Drop-in biobased plastics
- Bioattributed or certified biobased plastics



Bioplastics market

Current market shares

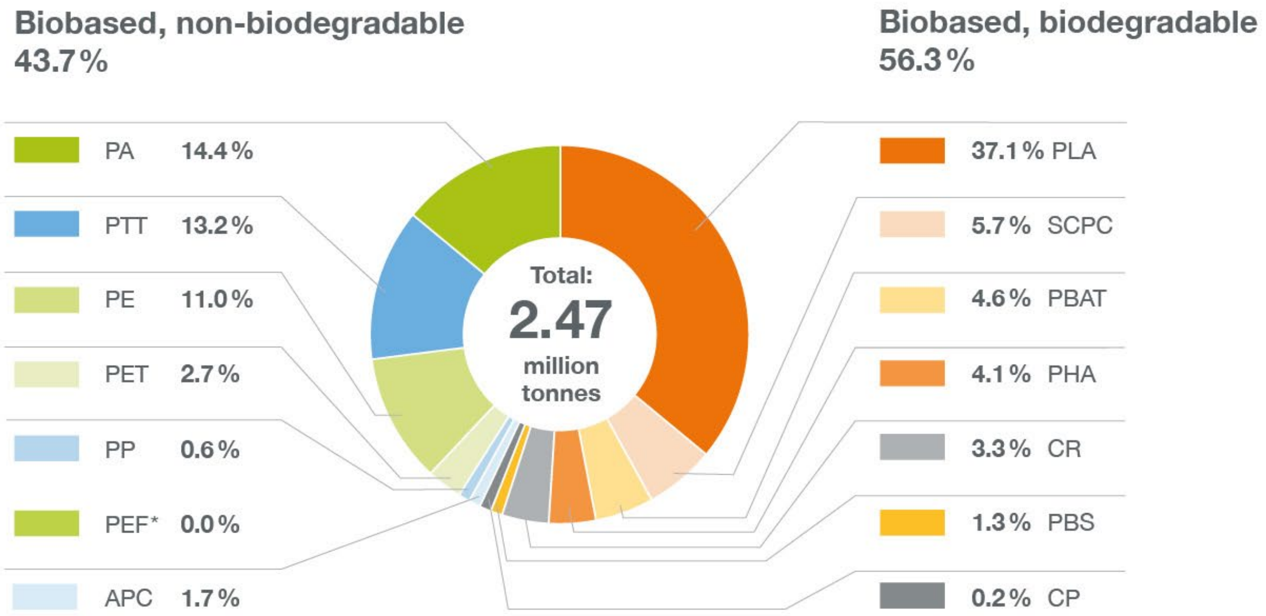
Production expected to double in the next 5 years

Main growth expected for:

- PLA
- PHA
- PE
- PP

Note: global bioethanol production for biofuel is about 135 million metric ton/a

Global production capacities of bioplastics 2024



Source: European Bioplastics, Nova institute (2024)

Bioplastics market

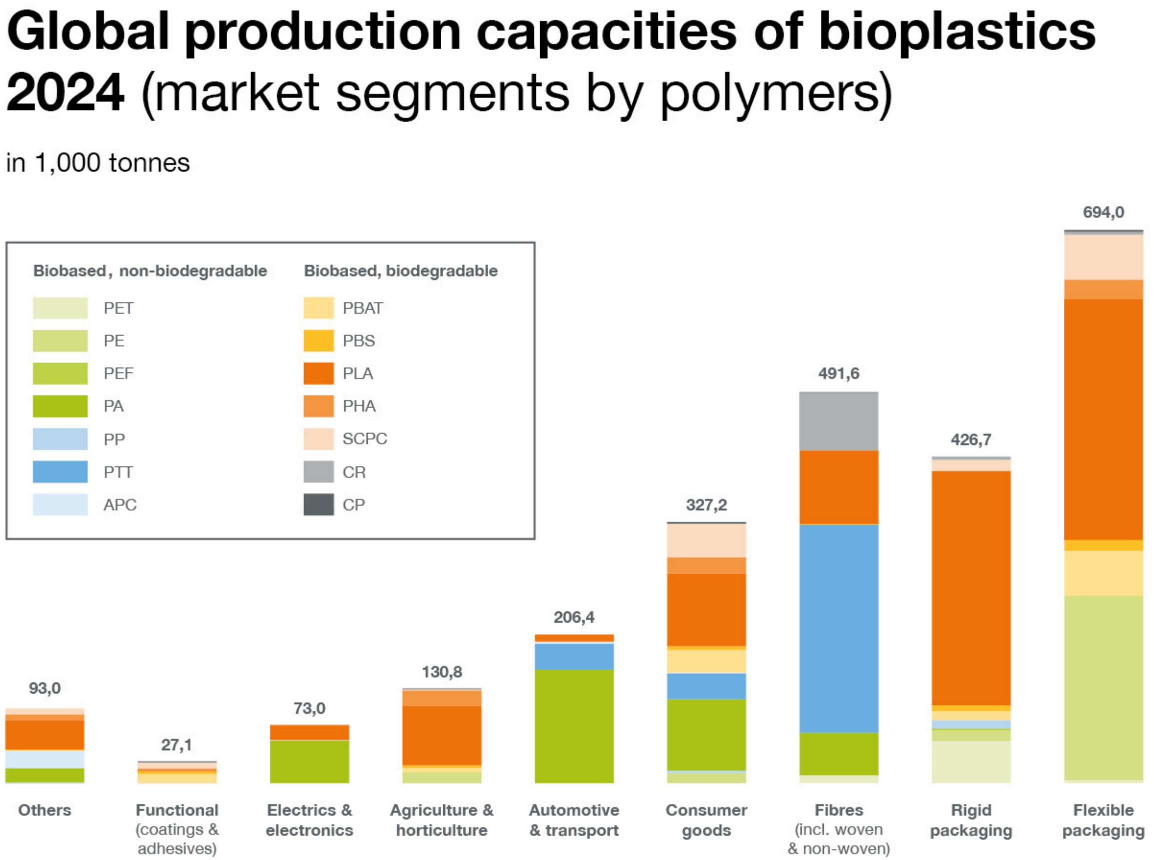
Current applications

Main application in packaging

Substantial application in fibres (functionality driven)

In agriculture typically biodegradable plastics

Large share of PA in automotive



Source: European Bioplastics, Nova institute (2024)

Bioplastics market

Growth limited by

- Economics; competitive disadvantage and lack of incentives
- This explains the relative success of biodegradable biobased plastics as there is no cheap fossil- based alternative

- Development time; 20 years to break through and additionally 20 years to mature

- Use biobased plastics because of specific advantages
- Not one to one replacement but specifically designed products uses the functionality

- Properties?

Bioplastics market

Remarks on properties

There is a wide range of fossil plastics with very different properties; does good or bad exist?

But:

- Mainly polyesters that are more susceptible for hydrolytic degradation
- As compared to polyolefins density of biobased polyesters is higher (can add to costs)
- Different processing characteristics of polyesters (low melt strength, high melt viscosity (IM), low crystalisation rate)

Examples of replacement options

Product type	Traditional	Biobased (not drop-in)
Blown flexible film	LDPE	PBAT, starch blends
Thermoformed rigids	PS, PET	PLA
Injection moulded articles	HDPE, PP	PLA, bioPBS
ISBM bottles	PET	PEF
Fibres for non-wovens (teabags)	PP	PLA

End-of-life options

End of life of plastics

Two main challenges:

- Recyclability (complex mixtures, contaminated products and aged plastics)
- Persistency in the environment, including microplastics and safety issues

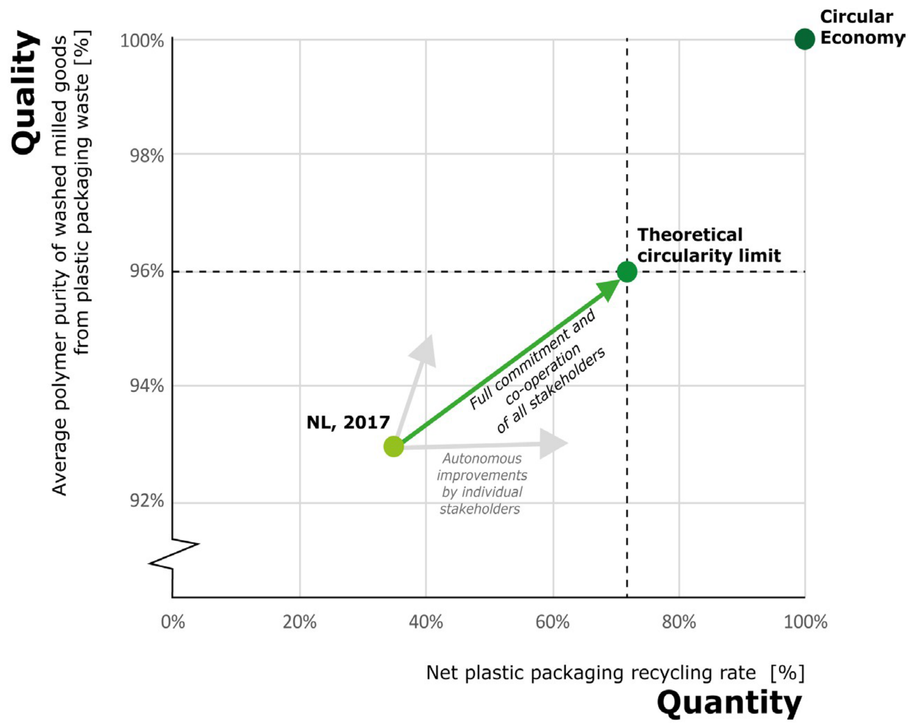
Plastic waste collection and treatment does not completely solve issues regarding fossil feedstock use and leakage to the environment

We need:

- Improved collection
- Improved sorting
- Improved recycling techniques

- Plastics with improved recyclability
- Plastics that not persistent

Recycling of plastic packaging in NL in 2017



Source: Brouwer et al. 2020, doi:10.3390/su122310021

End-of-life options

End of life of plastics

Recyclability is a system property

- Measured at a product level (circular by design)
- Fit in the waste management system
- Focus on feedstock (carbon) recovery and not on waste treatment

Best practice is rPET bottles (circular, food contact)

- Separate collection, refund system
- Agreements on design, sufficient volume
- Decontamination methods
- Repair methods
- (alternative chemical recycling via solvolysis)

	Recycled to product *		Consumption *	Implied usage amount (%)
HDPE	749		7085	10%
PP	488		10464	5%
PET	1348		4300	31%

* Estimates in kt, figures of 2018. Data retrieved from reports of Plastic Recyclers Europe

End-of-life options

End of life of plastics

Polyesters have benefits over commonly used polyolefins

Most biobased plastics are polyesters

Can be sorted and can be recycled

Sufficient volumes are required

Recycling Route	Collection efficiency (%)	Sorting efficiency (%)	Recycling efficiency (%)	Total efficiency (%)
Mechanical	70	80	90	~50
Chemical (solvolysis PET)	70	80	95	~55
Pyrolysis (mixed PE, PP)	70	80	50	~30
Gasification (mixed plastic)	70	90	50	~32

End-of-life options

Example PLA; very versatile at end-of-life and at present largest production volume

Post-industrial waste is used in house (trimmings) and for example in plant pots

PLA producers have set-up closed loop recycling (solvolysis, back to lactic acid)

Can be sorted out provided volumes are sufficient

Potential products, flow packs for cut vegetables (replacing BOPP), trays for meat or vegetables, flower pots

• In PMD,	sorted and subsequently recycled
• In residual waste	incinerated, release of biogenic carbon
• In GFT	composted with the content, no microplastics
• Littered	not persistent (meta study Hydra)

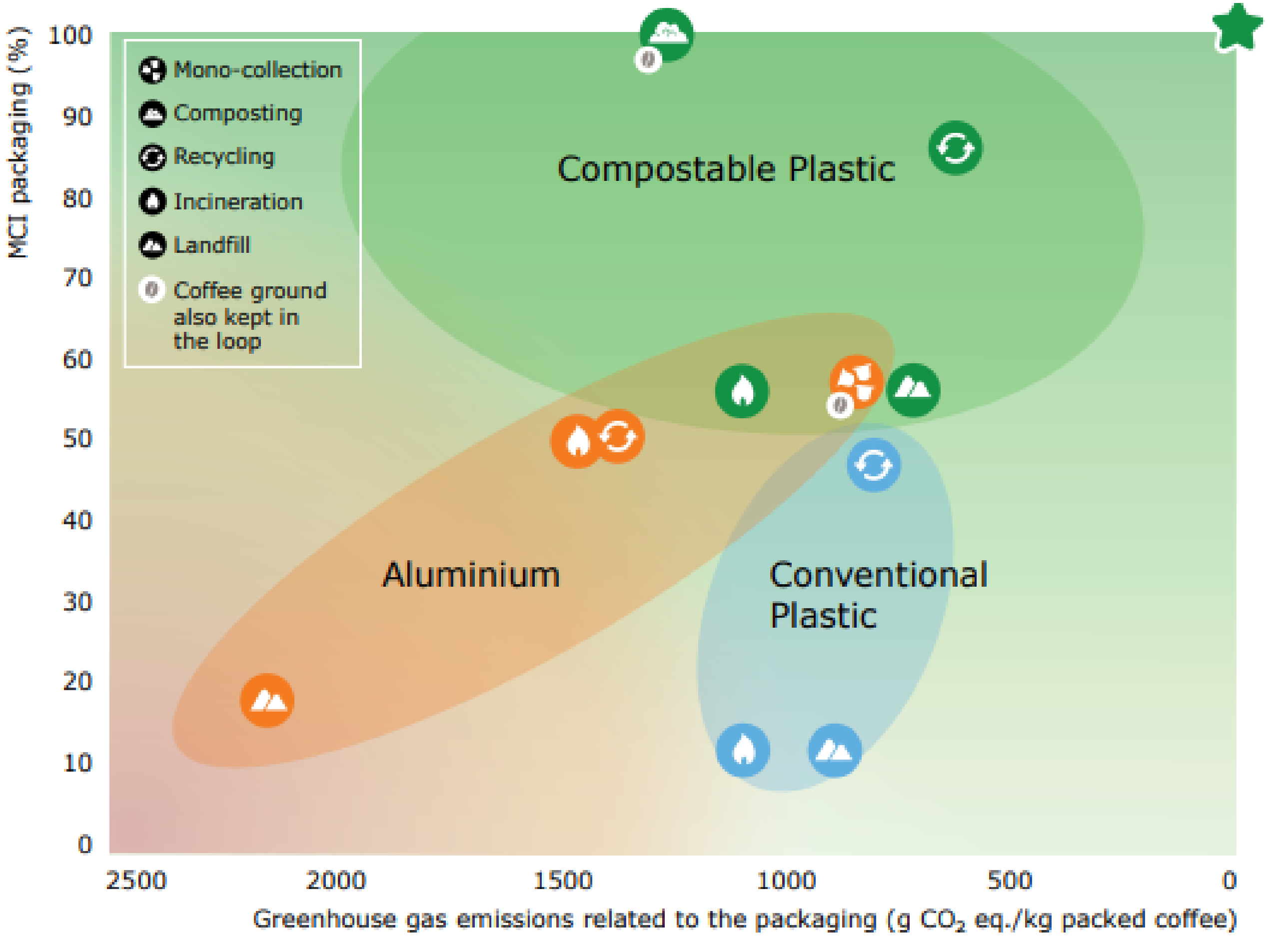
End-of-life options

Circularity example coffee capsule

Small product, hard to recover and recycle
Contains organic waste
Biobased compostable, vs aluminium, vs conventional plastic
Different end of life scenarios

Composting coffee grounds only in mono-collection or when collected with GFT
Closed loop recycling of aluminium (thin walled) only possible in mono-collection
Conventional plastic can contaminate GFT

Impacts excluding content (coffee)



Environmental impacts

General remarks biobased vs fossil

Commonly lower GHG emission

Commonly higher impacts related to agriculture

- Depending on biomass type
- Depending on efficiency of production
- Waste streams often preferred

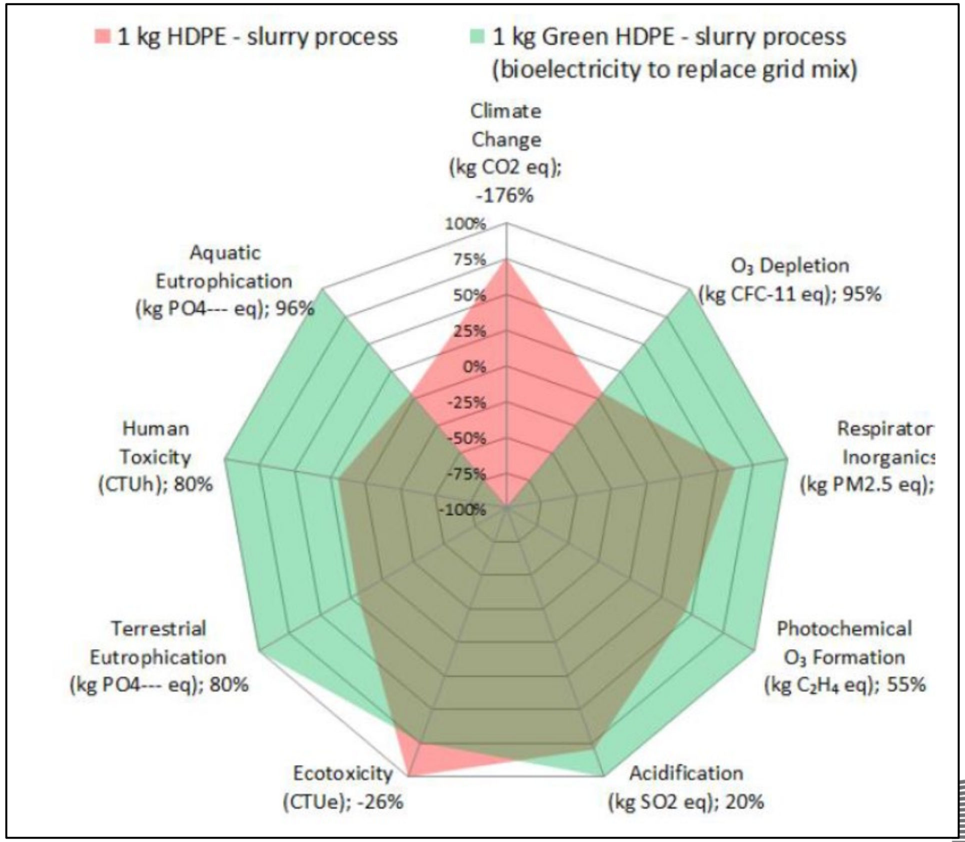
In LCA various aspects are not included

- Plastic pollution /microplastics
- Long term effects of climate change
- Biodiversity impacts
- Waste management

Impact of fossil plastic increases (relative share of impacts of oil drilling, shale gas processes)

LCA summary bioPE from sugar cane

Source: Braskem



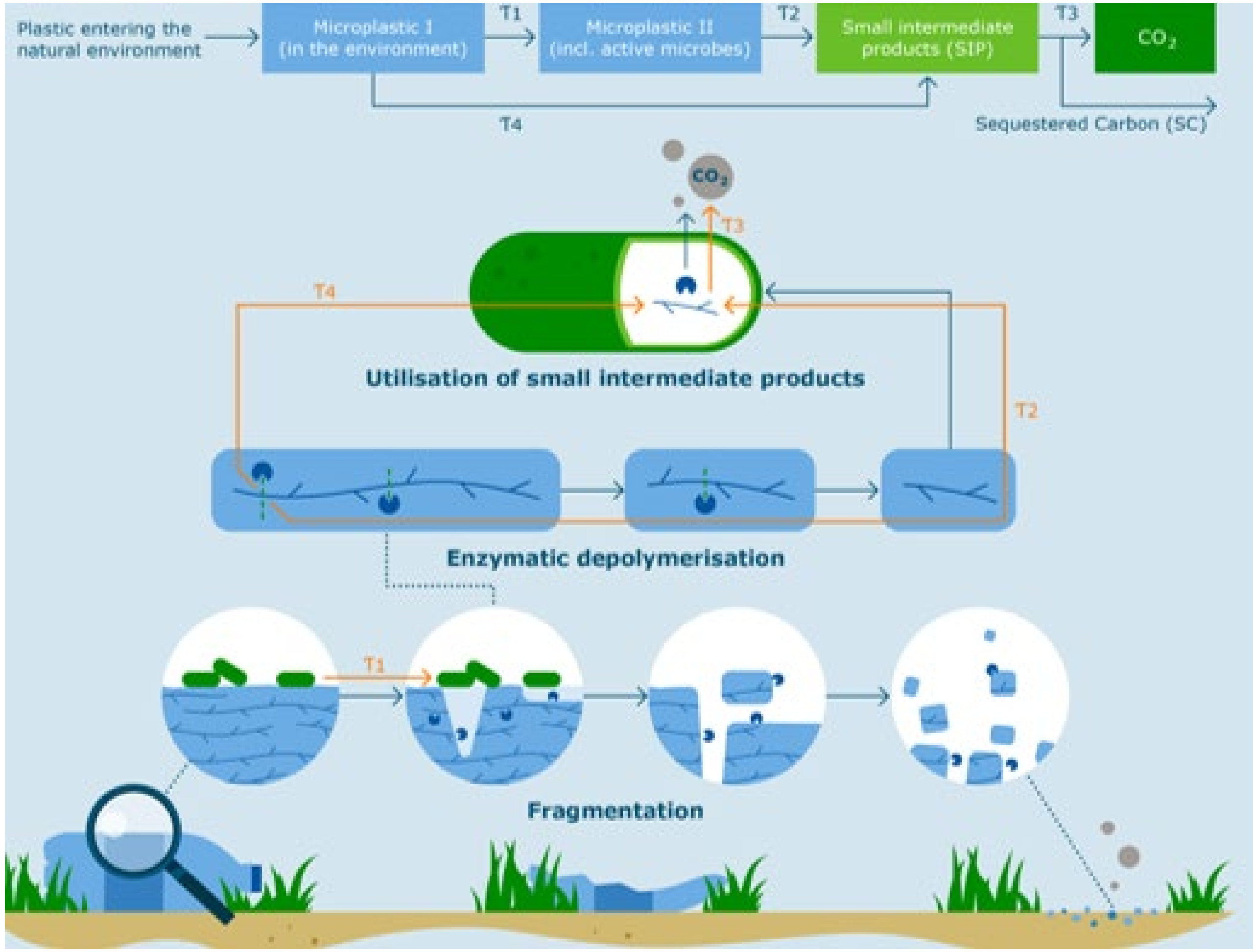
Environmental impacts

Comparing with bioenergy production

Topic	Advantages for biomass use in biobased plastics as compared to bioenergy
GHG reduction	Biobased plastics often show higher reductions and additionally can offer carbon storage
Circular economy	Biobased plastics offer various recycling options and can -at end of life- be used for energy
Employment	Up to 10 times more employment due to longer and more complex value chains
Resource efficiency	Often higher land-use efficiency and resource efficiency
Added functionality	Various opportunities including biodegradability and reduced toxicity
Renewable alternatives	For plastics (carbon-based materials) the only alternative is direct use of CO_2

Source: Vural Gursel et al. Variable demand as a means to more sustainable biofuels and biobased materials, 2021

Environmental impacts



Microplastics

Important souces are:

- Synthetic fibres (textile)
- Car tyre abrasion
- Agricultural films
- Littered plastics
- Compost from GFT

Biodegradable plastics

- Microplastic formation is a part of the biodegradation process
- What is the effect of these microplastics?

Environmental impacts

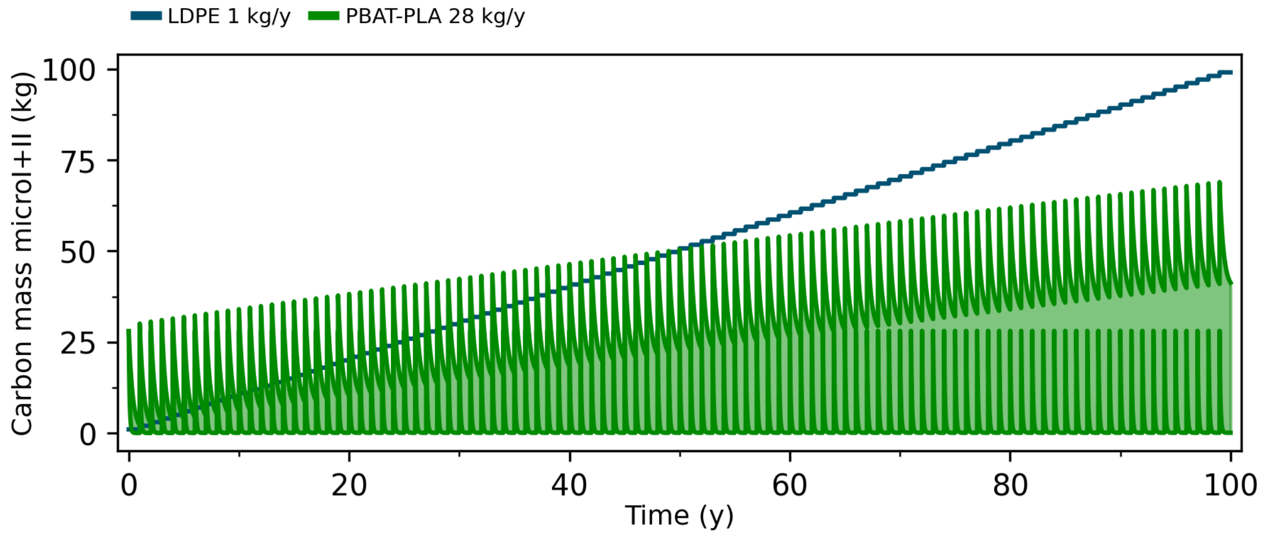
Persistency and microplastic accumulation; case study Mulch film

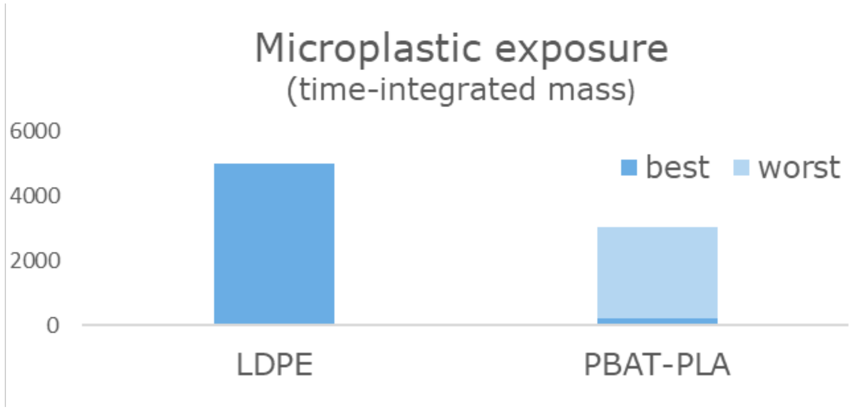
Recovery rates:

LDPE: 95%

PBAT-PLA: 0%

Even if biodegradable mulch films are left on the land microplastic accumulation is lower





Source: https://doi.org/10.1016/j.scitotenv.2024.177503

General remarks

Biobased plastics are needed in a future circular society

Efficient production routes with low energy demand required

Product shift required, oxygen containing plastics

Polyesters offer advantages during recycling

Move to plastics that are less persistent

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