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presents

Bioplastic Packaging Design: Safe, Sustainable and Recyclable

PROCEEDINGS

How to design bioplastic packaging to make it safe, sustainable, recyclable, and also compliant?

Funded by the European Union

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Contributing projects

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Circular Bio-based Europe Joint Undertaking
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Introduction

Biodegradable polymers for sustainable packaging materials

European Bioplastics: Chiara Bearzotti and Estela López-Hermoso

Five projects have been funded under a specific call of the Horizon Europe programme to collectively advance the next generation of biodegradable polymer materials and drive the transition toward sustainable packaging solutions across Europe: E-OILE', BioPackMan, UPCYCLE, GRECO and Be-UP. Building on the strategic priorities outlined in the funding call, these projects **will deliver innovative materials and robust evidence to support the packaging industry's shift away from conventional plastics toward environmentally responsible alternatives.**

The funded projects are designed to contribute to three key outcomes that will transform the packaging sector:

- First, the projects will provide the packaging industry with access to next-generation biodegradable polymer materials that can be recycled through novel organic processes. Through their research and development activities, they will enable materials producers to transition from PP, PE, and PET to biodegradable materials, thereby significantly reducing GHG emissions across the entire value chain.

- Second, the projects will support the packaging industry in implementing circularity-by-design business models and sustainable end-of-life approaches for plastic packaging materials. Their work will demonstrate the potential to substantially reduce landfill waste volumes and contribute to achieving the ambitious littering reduction targets outlined in the Horizon Europe Ocean and Waters mission, the plastic pollution reduction goals of the Single-use Plastics Directive, and the EU Circular Economy Action Plan (CEAP).

- Third, the projects will advance the development of testing standards and application-specific labels for biodegradability in open environments, providing the certification frameworks necessary for market adoption and regulatory compliance.

To achieve these outcomes, each funded project addresses at least four of the following integrated activities.

Development and Scale-up of Advanced Bio-degradable Polymers
The projects will develop, demonstrate, and scale up novel, advanced, biodegradable polymer materials and innovative production processes that enable large-scale production of these polymers with economies of scale comparable to those of existing production methods. The materials will demonstrate improved or comparable technical performance, production costs, and end-of-life characteristics relative to current PP, PE, PET, and conventional biodegradable polymers.

Production System Innovation
The funded projects will develop cost-effective additives and catalysts to support industrial-scale production of biodegradable polymers, ensuring that the manufacturing processes are economically viable and technically robust.

Life Cycle and Techno-Economic Assessment
The projects will provide extensive evidence through Life Cycle Assessment (LCA) and Techno-Economic Assessment (TEA) demonstrating that the costs of the novel, advanced biodegradable polymer products are not significantly higher than those of existing polymer products (PE, PP, PET) currently on the market. This analysis will provide the economic justification for industry adoption.

Pilot-Scale Production and Testing
The funded projects will scale up the production of packaging materials to pilot level, enabling practical demonstration and validation of the materials in real-world applications.

Biodegradability Pathway Characterisation
The projects will identify and rigorously test the biodegradability pathways in all environmentally relevant conditions for the application of the developed materials. This includes comprehensive assessment across various relevant forms (landfill, compost, soil, litter in marine environments, continental freshwater, and marine offshore environments), supported by extensive quantified risk analysis from both human and environmental perspectives.

Environmental Impact Assessment
The funded projects will conduct a thorough assessment of all biodegradable intermediates and end products, including quantifying their contributions to GHG emissions. They will model the complete lifetimes of the developed polymers along their biodegradation pathways under environmentally relevant conditions across human, terrestrial, and marine environments, as well as in waste processing facilities.

Biodegradability Demonstration in Real Conditions
The projects will demonstrate complete biodegradability and compostability in all relevant conditions and environmental compartments, including landfill, compost sites, litter in marine and continental freshwater environments, and offshore marine environments. This work will identify the main environmental conditions influencing biodegradation rates and pathways and assess their impact.

Through this coordinated portfolio approach, the five funded projects will deliver the scientific evidence, technical innovations, and practical demonstrations needed to accelerate the adoption of truly biodegradable packaging materials across European markets.

Last but not least, two additional projects will be present at this event: **MoeBIOS and ReBioCycle.**

Both MoeBIOS and ReBioCycle address the fundamental challenge of establishing **viable recycling pathways for biobased and biodegradable plastics within Europe's circular economy**. The projects address the critical gap between laboratory-scale recycling solutions and demonstration-scale implementation, advancing technology readiness levels from experimental phases to pilot and industrial integration within existing waste management facilities.

A central challenge both projects address is the sorting and separation infrastructure for bioplastics and the capacity to efficiently recover biobased materials such as PLA, PHA, PBS, and bio-composites from mixed waste streams. Both initiatives recognise that effective near-infrared sorting technologies and pre-treatment processes must be developed and validated at demonstration scale to enable the separation of specific bioplastic types from mixed municipal and industrial waste streams.

The projects address the technological challenge of recycling complex bioplastic materials through multiple innovative pathways, including **mechanical, chemical, enzymatic, and microbial recycling processes**. They aim to prove that biobased, biodegradable plastics can achieve the same or superior quality as virgin materials after recycling, thereby countering the widespread perception that biodegradable plastics cannot be effectively recycled and must only be composted or incinerated. This quality verification is essential to gain acceptance from biopolymer producers, brand owners, and waste management operators, who need assurance of material performance in real-world packaging applications.

Both MoeBIOS and ReBioCycle recognise the economic viability challenge: by establishing waste-processor-centric demonstration hubs across multiple European countries and integrating novel recycling processes into existing industrial facilities, the projects aim to demonstrate financial feasibility and scalability without disrupting current operations. This approach seeks to create compelling business cases that will attract investment from waste management companies and support the transition toward circular bioplastics value chains, ultimately contributing to European policy frameworks, including the Bioeconomy Strategy, Circular Economy Action Plan, and Packaging and Packaging Waste Regulation.

In this document, you will find an overview of the talks and of the projects.

Happy reading and happy matchmaking!

The Talks

Packaging Design for Bioplastic Materials: A Designer Perspective

ARAPAHA: Jorn Behage

Short summary

Bioplastic packaging design requires a holistic approach integrating materials science, production technology, aesthetic considerations, and circular economy principles from project inception. ARAPAHA's work demonstrates that, with proper design thinking, bioplastics can deliver both substantial environmental benefits and functional performance that meets market requirements. The 70% reduction in global warming potential relative to conventional products and the 73% reduction achieved through molecular recycling versus virgin production provide quantitative evidence of environmental advantages.

Success depends on understanding the capabilities of regional waste management infrastructure and on designing products compatible with available end-of-life pathways. Innovative technologies such as supercritical CO_2 dyeing and molecular recycling demonstrate that technical solutions exist to address the historical limitations of bioplastics. Designers who embrace these approaches while carefully attending to removable components, material purity, and clear end-of-life communication can create products that genuinely advance circular economy goals.

As production volumes increase, costs decline, infrastructure expands, and policies clarify, bioplastic packaging will increasingly compete on equal terms with conventional materials. The design principles and practical approaches demonstrated by pioneers such as ARAPAHA provide a roadmap for this transition, showing that environmental sustainability and product functionality need not be in conflict when design proceeds with complete lifecycle thinking from the outset.

Long abstract

ARAPAHA: Sustainable Design Innovation

ARAPAHA BV focuses on discovering lifestyles in balance with our planet through innovative design and materials science. The company demonstrates that bioplastic products can achieve significantly lower environmental impacts than conventional alternatives. According to research conducted by TNO, the Netherlands Organisation for Applied Scientific Research, ARAPAHA products exhibit a 70% reduction in Global Warming Potential (GWP) relative to products made from fossil-based plastics. Even more impressively, the molecular recycling of ARAPAHA products achieves a 73% lower GWP than virgin production processes, demonstrating the substantial environmental benefits of closed-loop material systems.

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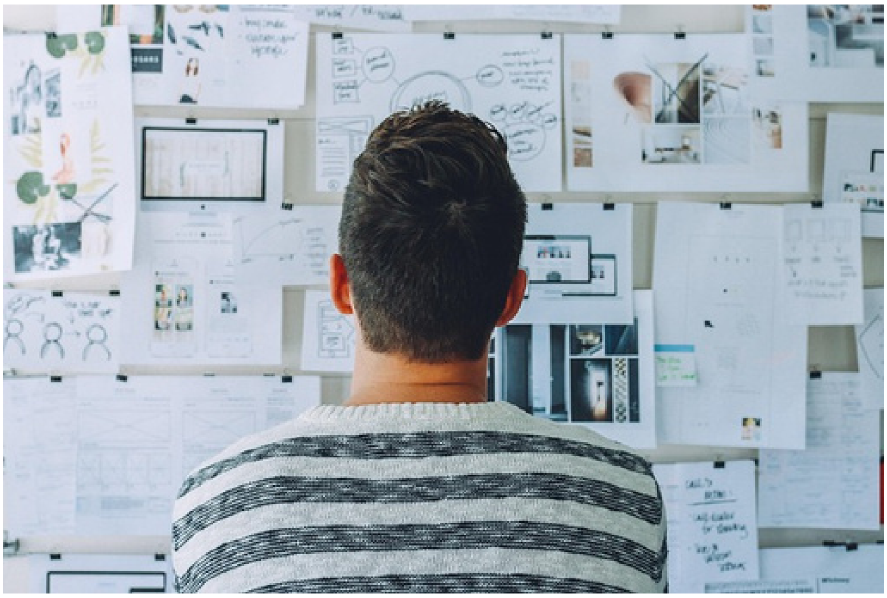
Key Design Requirements for Bioplastic Packaging

Successful bioplastic packaging design requires comprehensive technical knowledge and strategic planning across multiple domains. Designers must possess fundamental knowledge of the molecular structure of bioplastic materials, such as polylactic acid (PLA), understand how polymer chains behave under different processing conditions and how molecular architecture influences material properties. This molecular-level understanding enables informed decisions about material selection and processing parameters.

Additionally, designers need expertise in additives and dye technologies suitable for bioplastics. Many conventional additives used in fossil-based plastics prove incompatible with biopolymers, requiring specialised formulations. Knowledge of suitable production technologies and their limitations is equally critical, as bioplastics often require different processing temperatures, pressures, and cooling rates than conventional plastics. The application of digital twins in packaging development represents an emerging requirement, enabling virtual testing and optimisation before committing to physical prototypes. Designers must also recognise and work within the aesthetic limits of biomaterials, which may not achieve the same visual properties as conventional plastics without careful formulation. Finally, the full integration of end-of-life options into the design process from the beginning ensures that recyclability or compostability considerations shape material choices rather than constrain them after design completion.

Practical Tips for Designers

When implementing bioplastics in packaging design, designers should address three fundamental questions that shape successful outcomes. First, designers must clearly define what problem they solve when applying bioplastics in packaging. This involves identifying the specific environmental or functional challenge being addressed, whether reducing food waste through improved barrier properties, enabling composting of contaminated packaging such as food service items, or creating marine-biodegradable solutions for applications with high loss rates. Without a clear problem definition, bioplastic selection may default to greenwashing rather than genuine improvement.



Second, developing a digital twin for different packaging types enables testing of various scenarios, material combinations, and lifecycle impacts before physical production. Digital modelling reduces development costs, accelerates iteration cycles, and provides quantitative data for decision-making. The digital twin can simulate mechanical performance, barrier properties, degradation behaviour, and environmental impacts across different end-of-life scenarios, informing material and design choices with evidence rather than assumptions.

Third, adapting packaging concepts to the waste treatment possibilities in the target region proves essential for ensuring proper end-of-life management. A packaging design optimised for industrial composting facilities fails in regions lacking such infrastructure, while designs intended for mechanical recycling require compatible sorting and processing equipment. Understanding local waste management capabilities—including collection systems, sorting technologies, composting facilities, and recycling infrastructure—ensures that packaging can achieve its intended end-of-life pathway rather than defaulting to landfill or incineration.

ARAPAHA Case Study: Design for Circularity

ARAPAHA's shopping bag demonstrates comprehensive design-for-recycling principles through careful attention to material selection and component separability. The bag employs narrow-weave PLA straps that can be easily removed during recycling, ensuring these components do not contaminate the main material stream. Similarly, the jacquard-weave polyester and PLA label attaches in a way that allows simple removal before recycling processing. This design philosophy recognises that multi-material products require disassembly strategies to enable effective recycling.

The bag's PLA felt material showcases innovative processing through a special dye recipe using supercritical CO_2, a patented process developed by ARAPAHA. This waterless dyeing technology eliminates water consumption and wastewater treatment needs while achieving vibrant, durable colours. The product passport, implemented as a 3D-printed QR code mounted on a magnet, provides traceability and recycling information while remaining removable before recycling. The knitted PLA liner utilises water-free printing technology, further reducing environmental impact during production.

Structural components demonstrate careful material engineering, with injection-moulded PLA enhanced by impact modifiers to achieve extra strength without compromising recyclability. The polyester sewing thread, while not PLA, attaches components in a manner allowing removal during recycling preparation. This comprehensive approach to design-for-recycling ensures that the bag can enter molecular recycling streams and return as high-quality recycled material.

Innovative Dyeing Technology

ARAPAHA has developed and patented a PLA dyeing process using supercritical CO_2, representing a significant advancement in sustainable textile processing. This waterless dyeing technology eliminates the substantial water consumption and wastewater treatment burden associated with conventional aqueous dyeing processes. By using CO_2 in its supercritical state—a phase where it exhibits properties intermediate between gas and liquid—the process achieves excellent dye penetration and fixation without requiring water as a solvent or carrier. The result is vibrant, durable colours in PLA materials with dramatically reduced environmental impact. The supercritical CO_2 can be recovered and reused, creating a closed-loop dyeing system that minimises both water use and chemical releases.

Molecular Recycling of Multiple Form Factors

ARAPAHA demonstrates closed-loop circularity through molecular recycling of diverse product formats, including shopping bags, packaging, and other consumer goods. The process begins with shredding, in which whole products undergo mechanical size reduction to increase their surface area for subsequent chemical processing. The shredded material then undergoes partial hydrolysis, in which controlled chemical reactions break down polymer chains into smaller oligomer fragments. These oligomers are then subjected to distillation, where purification separates the desired chemical components from contaminants and degradation products.

Following distillation, recrystallisation forms pure lactide monomer from the purified oligomers, effectively returning the material to its original building-block state. This lactide then undergoes polymerisation to create virgin-quality recycled PLA indistinguishable from material produced from fresh feedstock. This molecular recycling approach enables true circular-economy principles, in which products can cycle repeatedly through use and recycling without degrading in quality. ARAPAHA embeds product passports in the form of QR codes that communicate the product's recyclability and provide the message **"I'll be back",** emphasising the circular nature of the material flow.

Main Challenges in Bioplastic Packaging

Despite significant progress, the performance gap between bioplastics and conventional plastics has narrowed considerably, and some challenges remain to the widespread adoption of bioplastic packaging. Material performance, both with and without additives, remains challenging as designers seek to achieve the mechanical properties, barrier characteristics, and thermal stability required for demanding packaging applications.

Production technologies and their associated embedded energy represent another challenge area. While bioplastics derive from renewable feedstocks, the energy required for polymerisation and processing can diminish environmental benefits if not carefully managed. Optimising production efficiency to minimise energy inputs while maintaining product quality requires ongoing technical development.

The packaging end-of-life options, whether through recycling, biodegradation or composting, must be coherently integrated with available infrastructure. Designing packaging for recycling relies on collection and processing systems, while compostable packaging requires access to industrial composting facilities for most materials.

Cost competitiveness compared to current materials remains a barrier to market expansion. Bioplastics typically carry higher material costs than commodity fossil-based plastics due to smaller production volumes and less mature manufacturing processes. While costs continue to decline as production scales, the price premium still limits adoption primarily to applications where consumers are willing to pay higher prices for environmental benefits.

Consumer behaviour represents a challenge that extends beyond technical solutions. Educating consumers about proper disposal practices, managing expectations regarding material performance, and fostering acceptance of diverse aesthetic properties all require sustained effort. Additionally, European and national policies on fossil-based materials versus biopolymers continue evolving, creating regulatory uncertainty that complicates long-term planning and investment decisions.

Presentation: https://www.european-bioplastics.org/events/ebc/bioplastic-packaging-design-safe-sustainable-and-recyclable/

How is the legislative framework for biodegradable plastic packaging changing, and how can R&I cope with the changes?

European Bioplastics: Julie Pieters

Policy Transition: From Green Deal to Clean Industrial Deal

The European regulatory landscape for bioplastics is undergoing a fundamental transformation as the EU transitions from the Green Deal (2019-2024) to the Clean Industrial Deal (2024-2029). While the Green Deal prioritised climate neutrality by 2050 through regulatory frameworks, carbon pricing mechanisms, and energy transitions across sectors, including energy, transport, buildings, and agriculture, the Clean Industrial Deal represents a strategic pivot to strengthen European industrial competitiveness while accelerating the clean transition. This new framework emphasizes scaling EU manufacturing of strategic clean technologies through initiatives such as the Net-Zero Industry Act (NZIA) and Critical Raw Materials Act (CRMA), expedited permitting for industrial and energy projects, mobilization of public and private investment via STEP and national schemes, reduction of energy costs coupled with renewable energy expansion, decreased dependency on external supply chains through the Economic Security Strategy and Circular Economy initiatives, and crucially, simplification of regulation including reduced reporting burdens.

This policy evolution creates both opportunities and challenges for the bioplastics sector. The comprehensive legislative framework now encompasses multiple interconnected regulations including the EU Plastics Strategy (2018), Single-Use Plastics Directive (2019), EU Bioeconomy Strategy with its 2025 review, various remaining Green Deal components (EU Taxonomy, Farm to Fork, Biodiversity Strategy, RED III), waste management directives, and critically, the Packaging and Packaging Waste Regulation (PPWR) alongside emerging legislation on microplastics, green claims, and the Ecodesign for Sustainable Products Regulation (ESPR). The implementation of the new EU Bioeconomy Strategy and upcoming Biotech Acts I and II, alongside the proposed Circular Economy Act, will further shape market conditions for biobased, biodegradable, compostable plastics.

Bioeconomy Strategy Review: Opportunities And Challenges

The Bioeconomy Strategy Review aims to build a sustainable and nature-positive EU bioeconomy through innovation, competitiveness, and coherent policy frameworks. Structured around four strategic pillars—scaling innovation and investments, creating new lead markets for biobased materials and technologies, ensuring sustainable biomass supply across value chains, and harnessing global opportunities—this non-legislative strategy includes an Action Plan with concrete measures. Notably, it mandates the adoption of (sustainability) criteria and targets for biobased plastics under the PPWR by 2027, thereby providing the biobased plastics sector with reafirmed political recognition and a future license to grow.

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For the bioplastics sector, this strategy presents significant opportunities, including formal political recognition with lead-market status, demand creation through market-pull mechanisms, enhanced investment to support industrial scale-up, and improved policy coherence through regulatory simplification. However, substantial challenges persist: the need for rapid operationalisation of strategic objectives, the current absence of clear sustainability criteria and harmonised standards, persistent gaps in market uptake and consumer awareness, and, critically, insufficient uptake infrastructure for compostable solutions despite their technical viability

PPWR: Comprehensive Packaging Requirements

The PPWR, which entered into force on 11 February 2025, establishes the most comprehensive framework for packaging sustainability to date. The regulation pursues four primary objectives: reduction of packaging waste (15% reduction per capita by 2040 compared to 2018 baseline, minimizing unnecessary packaging and overpackaging); enhancement of recyclability (all packaging fully recyclable by 2030 with establishment of specific Design for Recycling criteria); promotion of reuse and refill systems (mandating companies offer products in reusable or refillable packaging with Member State support for collection infrastructure); and standardization with clear labeling to facilitate consumer decision-making regarding recyclability and proper disposal methods.

Critical implementation milestones include:

- application of the Regulation on 12 August 2026;
- by 1 January 2028, delegated acts establishing design for recycling criteria, recyclability performance grades, and Extended Producer Responsibility (EPR) modulation frameworks;
- by 12 August 2028, implementing acts for EU harmonised waste labelling systems;
- by 1 January 2030, implementing acts for recyclable-at-scale assessment methodologies; and
- by 2030, bans on packaging below grade C (70% recyclability threshold), alongside reuse targets, minimum recycled content requirements, material composition labelling, and restrictions on certain packaging formats.

Biobased Feedstock Requirements

Article 8 of the PPWR establishes a framework for future mandatory targets for biobased content in plastic packaging. By 12 February 2028, the Commission must review the technological development and environmental performance of biobased plastic packaging, taking into account the existing sustainability criteria of the Renewable Energy Directive. Based on this review, the Commission shall, where appropriate, present a legislative proposal to: (a) establish sustainability requirements for biobased feedstock in plastic packaging; (b) set targets increasing biobased feedstock use; and (c) introduce the possibility of achieving recycled content targets through biobased plastic feedstockparticularly when suitable recycling technologies for food-contact packaging complying with Regulation (EU) 2022/1616 are unavailable. This provision, as confirmed in the Bioeconomy Strategy Review, creates pathways to scale advanced biobased polymers while maintaining sustainability safeguards.

Compostability Requirements and Market Access

Article 9 of the PPWR transforms compostability from an end-of-life routeinto a mandatory market access condition for some specific packaging formats. By 12 February 2028, certain products will become mandatorily compostable across the EU: permeable tea, coffee, or beverage bags and soft single-serve units intended for disposal with the product content, and sticky labels attached to fruits and vegetables. These products must comply with EN 13432, the harmonised standard for industrial composting and, where required by Member States, meet forthcoming harmonised home compostability standards (mandate to CEN by 12 February 2026).

Additionally, Member States may require compostability for specific formats on their national markets, provided they implement separate bio-waste collection systems and possess adequate treatment infrastructure. Eligible formats without limitation in time include very lightweight plastic carrier bags (VLPCB, otherwise banned); lightweight plastic carrier bags (LPCB); non-permeable beverage system single-serve units (non-metal) intended for machine use and disposal with product content; and additional formats for which Member States required compostability before 12 August 2026. For the compostable market, it will be crucial that Member States develop apositive list of additional compostable packaging formats. Critically, all other biodegradable plastic packaging must be designed for material recycling in accordance with Article 6 and future performance grades and recyclable-at-scale criteria, without negatively affecting the recyclability of different waste streams. This dual pathway—organic recycling for specified applications and material recycling for the remaining biodegradable packaging—requires strategic material selection and design to scale biodegradable polymers.

Strategic Implications for Scaling Biodegradable Polymers

The evolving legislative framework creates a complex but navigable pathway in R&I for the development and scaling of advanced biodegradable and recyclable polymers. These challenges are addressed by projects such as **Be-UP, GRECO, MoeBIOS, and ReBioCycle.** Success requires simultaneous attention to multiple regulatory streams: development and validation of polymers meeting both compostability standards (EN 13432 and forthcoming home compostability requirements) and Design for Recycling criteria; demonstration of sustainability credentials aligned with RED criteria for biobased feedstock; investment in both organic recycling infrastructure and material recycling pathways (also through the innovation in developed in MoeBIOS and ReBioCycle); and clear communication strategies addressing consumer awareness gaps. The regulatory certainty provided by mandatory compostable applications, combined with potential future biobased content targets and the Clean Industrial Deal's emphasis on strategic clean technologies, positions biodegradable polymers as essential components of Europe's circular packaging economy. However, rapid operationalisation of standards, clear sustainability criteria, and coordinated infrastructure development across Member States remain critical enablers for achieving commercial scale and realising the sector's environmental and economic potential within the European bioeconomy framework.

Presentation: https://www.european-bioplastics.org/events/ebc/bioplastic-packaging-design-safe-sustainable-and-recyclable/

Safe and Sustainable by Design (SSbD) & SATISPHACTION for Sustainable Packaging

Biobased, Biodegradable and Compostable Packaging

Normec OWS: Gaëlle Cavalié and Pieter Deckers

Summary

Safe and Sustainable by Design offers a comprehensive roadmap for developing packaging materials that minimise environmental and health risks while supporting circular-economy objectives. The SATISPHACTION project exemplifies practical SSbD implementation, demonstrating how the framework guides development of innovative biobased packaging from concept through laboratory validation. By systematically addressing hazard assessment, production and use phase safety, environmental sustainability, and socio-economic factors, SSbD enables informed decision-making that considers multiple dimensions of sustainability rather than optimising single attributes in isolation.

Despite existing limitations around data complexity, trade-off management, and criteria weighting, SSbD represents a significant advance in systematic sustainability assessment. The framework provides the industry with structured tools for developing more sustainable packaging solutions, and a more comprehensive evaluation based on functional performance, safety and sustainability. As the framework evolves through its 2025 revision and as practitioners gain experience with its application, these limitations will likely be addressed through clearer guidance, standardised methods, and accumulated case studies demonstrating best practices. For packaging developers, waste managers, and policymakers, SSbD offers a common language and methodology for discussing and achieving sustainability goals, facilitating collaboration across the value chain toward genuinely circular bioplastics systems.

Long abstract

Why Sustainable Packaging Matters

The urgency for sustainable packaging solutions stems from multiple converging factors that are reshaping the packaging industry. Growing environmental awareness among consumers and businesses increasingly drives recognition of the environmental impact of conventional packaging materials, creating sustained demand for sustainable alternatives. This heightened awareness runs alongside increasing regulatory pressure as European and national laws tighten requirements for packaging sustainability, waste reduction, and the circular economy. To navigate these challenges systematically, industry stakeholders require robust sustainability frameworks. The Safe and Sustainable by Design approach provides a framework with structured methods for developing sustainable packaging that balances human health, environmental protection, economic viability, and social responsibility.

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Safe and Sustainable by Design Framework

Safe and Sustainable by Design is a voluntary framework introduced in 2022 and revised in 2025. SSbD serves as a guiding tool for developing safe and sustainable product innovations that balance human health, environmental protection, and socio-economic considerations. The framework begins with critical scoping activities, including defining system boundaries and identifying relevant stakeholders affected by or involved in the innovation process.

Core Components

The SSbD framework comprises two interconnected components that operate iteratively throughout product development. The Design Component focuses on the creation and modification of chemicals, materials, products, or services, carefully considering the results obtained in the Assessment Component. The Assessment Component evaluates product safety and sustainability throughout the entire lifecycle using pre-defined criteria, considering an initial hazard assessment, followed by safety risk assessments on human and environmental health during processing and use phase, followed by LCA and, optionally, socio-economic assessments. These design and assessment activities are intended to cycle repeatedly, with each assessment informing subsequent design refinements and each design iteration requiring fresh evaluation. The framework also represents a tiered approach, in which early “quick and dirty” assessments are recommended to identify potential red flags as early as possible, and in which increased data availability during the project is followed by more comprehensive assessments. This interplay between the Design and Assessment Components enables designers to make informed choices from the earliest stages of development, embedding sustainability into the product's fundamental architecture rather than attempting to retrofit it later. This continuous loop ensures progressive improvement toward safety and sustainability goals.

Key Principles

Apart from being a proactive approach, SSbD is built on several fundamental principles that guide its application across diverse contexts. Life cycle thinking requires considering environmental, health, and safety impacts across all stages from raw material extraction through production, use, and end-of-life, preventing the shifting of problems from one lifecycle stage to another. A multidisciplinary approach integrates expertise from chemistry, engineering, toxicology, environmental science, and socio-economics, recognising that sustainability challenges cannot be solved within single disciplinary silos. The iterative process nature of SSbD acknowledges that achieving safety and sustainability goals requires continuous refinement through repeated design and assessment cycles rather than expecting perfection in initial attempts. Finally, transparency and traceability ensure clear documentation and communication of decisions and data throughout the process, enabling verification, learning, and accountability.

SSbD Assessment Structure

The SSbD framework includes four mandatory assessment steps plus one optional socio-economic assessment, each examining different dimensions of safety and sustainability.

1 The first step, hazard assessment of the chemical or material, evaluates inherent hazardous properties of chemicals and materials used in the innovation. This is the only assessment step with a fixed cut-off criterion—substances exceeding certain hazard thresholds cannot proceed without redesign, providing a hard constraint that ensures minimum safety standards.

2 The second step assesses human health and safety aspects during production and processing phases. This evaluation considers risks to workers and the environment during manufacturing and end-of-life processing, examining potential exposures and releases throughout material handling, machine operation, waste management, and any other relevant activity. Understanding and mitigating occupational hazards and industrial environmental impacts remains crucial even when the final product poses minimal risks to consumers.

3 Step three evaluates human health and environmental aspects during the final application phase, assessing exposure risks during actual product use. For food contact materials, this includes careful analysis of substance migration from packaging into food products. For consumer products, it examines direct and indirect human exposure pathways. Environmental aspects consider potential releases during normal use and accidental scenarios.

4 The fourth mandatory step, environmental sustainability assessment, involves conducting a comprehensive lifecycle assessment across multiple environmental impacts. The framework suggests grouping the various environmental impacts into four categories: climate change, pollution, resource use, and toxicity. By quantifying the potential environmental impact throughout the product lifecycle, LCA allows for accounting of emissions and effects that are beyond the direct control of the product developer or occur over longer timeframes. Additional benefits of LCA include the ability to calculate different scenarios and identify the processes that contribute most to a specific impact.

5 The optional fifth step, socio-economic assessment, examines broader impacts including production costs, economic viability, social implications, labour conditions, and market factors, recognising that sustainability encompasses more than environmental and health dimensions.

Design Principles for Sustainable Packaging

SSbD promotes integration of sustainability considerations throughout the design process through four interconnected principles. Green chemistry focuses on minimising hazardous substances and optimising chemical processes to reduce waste, energy consumption, and toxic byproducts. Green engineering complements this by designing efficient, low-impact production systems that minimise resource inputs and environmental releases during manufacturing. Sustainable chemistry takes a broader view, selecting materials and processes that reduce environmental burden across the full lifecycle, not just during production. Finally, circularity by design involves planning for material recovery, recycling, or biological degradation from the outset rather than treating end-of-life management as an afterthought. Together, these principles create a comprehensive framework for developing packaging that minimises harm and maximises resource efficiency throughout its existence.

The SATISPHACTION Project: SSbD in Practice

SATISPHACTION demonstrates practical application of the SSbD framework for developing innovative biobased packaging materials. The EU-funded project focuses on upcycling polyhydroxyalkanoates (PHAs) into fully sustainable food packaging materials. Running from 2025 to 2029 over 48 months, the project aims to advance these materials from Technology Readiness Level 2 (concept) to TRL 4 (validated in laboratory). The project targets three specific food packaging use cases, all incorporating a PHA content greater than 80%, avoiding additives of concern, and demonstrating accelerated degradation properties.

Within the project structure, Normec OWS leads Work Package 1, which focuses on scoping SSbD methodologies, and Work Package 8, which conducts final assessments on biodegradability, LCA and socio-economic assessments. This integrated approach ensures that sustainability considerations inform the project from conception through validation. The strategic goals centre on reducing the carbon footprint by utilising renewable feedstocks and optimising production efficiency while designing packaging for both chemical and biotic recycling pathways. Simultaneously, the project prioritises avoiding hazardous substances in inks, coatings, and additives to prevent contamination and health risks throughout the product lifecycle.

SSbD Application in SATISPHACTION

The project applies each SSbD assessment step systematically to PHA-based packaging development. For hazard assessment, PHAs are generally recognised as safe materials because certain types have been extensively tested for their safety. Additionally, ancillary materials will be screened and selected based on their safety.

To minimise the exposure risks to workers, users and the environment, the project carefully assesses residuals, breakdown products and novel types of PHA that might pose concerns, using computational tools to screen as many materials as relevant, enabling proactive avoidance of problematic substances. These estimates guide material selection and formulation decisions to ensure compliance with food safety regulations.

Environmental sustainability assessment is performed both in a prospective and reactive way, where LCA is used to compare the novel PHA-based packaging against fossil-based alternatives and virgin PHA production at the product level. The analysis evaluates potential end-of-life routes, including recycling and composting scenarios, quantifying environmental impacts under different waste management conditions. This comprehensive environmental accounting identifies which design choices and waste management pathways deliver optimal environmental performance.

Socio-economic considerations examine which production techniques will prove more cost-effective than others, informing decisions about technology pathways to pursue. Understanding cost structures helps identify where innovation investments will generate viable commercial outcomes rather than technically interesting but economically unviable solutions.

Practical Example: Selecting Softeners for Food Contact Packaging

A practical example for the application of the SSbD methodology is freely available in the official SSbD documentation. In the JRC (2023) report "Application of the SSbD framework to case studies," several softener alternatives for food-contact packaging are evaluated. Multiple candidate substances undergo systematic evaluation across all four mandatory assessment criteria. Each substance receives individual scores for hazard level, processing safety, use phase safety, and lifecycle environmental impacts. The environmental impacts include detailed scoring across multiple categories: toxicity effects on human health and ecosystems, climate change contributions, pollution generation, including air and water contamination, and resource depletion. These individual scores are combined into aggregated safety and environmental ratings using defined weighting methodologies. The safety rating considers the balance between inherent hazards and exposure controls, while the environmental rating reflects the overall lifecycle burden. These separate ratings then produce an overall SSbD rating that guides material selection toward the safest and most sustainable option. This scoring approach makes trade-offs explicit, revealing whether a candidate material offers excellent performance in some dimensions while creating unacceptable risks in others, or provides balanced performance across all criteria.

Limitations of the SSbD Framework

While SSbD provides valuable guidance, several implementation challenges are worth understanding. The framework requires extensive data on chemical properties, environmental impacts, and socio-economic factors, creating complex data challenges. Gathering this information demands specialised expertise spanning multiple disciplines, and some assessments necessarily rely on computational predictions rather than experimental data when empirical information proves unavailable or prohibitively expensive to generate. This dependence on modelling introduces uncertainty that must be acknowledged and managed appropriately.

Balancing sustainability goals presents another significant challenge. Managing trade-offs among competing objectives often necessitates difficult decisions. For example, maximising biodegradability may conflict with the need for sufficient durability to protect the product during distribution and use.

A packaging material might degrade quickly in composting but fail before reaching consumers, creating food waste that generates greater environmental harm than the packaging it replaced. These trade-offs require careful evaluation through lifecycle assessment to understand net environmental outcomes rather than optimising single attributes in isolation.

The framework includes only one fixed criterion with a mandatory cut-off—the hazard assessment in Step 1. Other assessment steps lack standardised decision thresholds, leaving it up to practitioners to formulate SSbD criteria to decide whether achieved performance levels suffice or require further improvement. This absence of clear benchmarks across most assessment dimensions complicates decision-making and reduces consistency across different applications of the framework. Additionally, unclear weighing of criteria creates challenges when assessment results conflict. The framework promotes a holistic approach that examines environmental, safety, and socio-economic aspects, but provides no standardised method for prioritising these dimensions when they point to different material choices. This can lead to subjective decision-making, in which personal values or organisational priorities override systematic evaluation, potentially undermining the framework's objectivity.

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Presentation: https://www.european-bioplastics.org/events/ebc/bioplastic-packaging-design-safe-sustainable-and-recyclable/

Improving waste management of biobased plastics and the upcycling in packaging, textile and agriculture sectors (MoeBIOS)

ITENE: Miriam Lorenzo Navarro, Coordinator

The EU-funded MoeBIOS project aims to develop three bioplastics recycling value chains to enhance waste management efficiency across Europe. These chains will establish connections that address key stages, including sorting, conditioning, and valorising waste streams from packaging, agriculture, and textile industries.

The project aims to maintain the same quality and functionality as the original bioplastic grades. Additionally, the MoeBIOS project will scale up recycling processes and seamlessly integrate them into pilot plants, ensuring they complement existing industrial recycling lines. The focus is on bioplastics that lack established recycling methods.

Objective:

MoeBIOS is an application of the circular (bio)economy concept: the development of three value chains incorporating separate recycling streams for bioplastics (BP's) to improve waste management efficiency throughout Europe. It is a systemic innovation: it will create linkages at the different key stages of the whole chain to solve a hierarchical challenge, from the collection of bioplastic waste (simulated streams) to the upcycling and validation of the final recycled end-products (holistic and coordinated solution).

The new value chain will involve sorting, conditioning and valorising three types of waste streams from the packaging, agriculture and textile industries into three end-products, aiming to achieve at least the same quality and functionality as the original grades. At the same time, end-user acceptance will also be assessed. As cornerstone targets for maximising the project's impact, the upscaling of the recycling processes will:

- Be integrated in pilot plants on the premises of actual industrial recycling lines currently operating in waste management companies, not disrupting them, and reaching a final TRL = 6/7 or even beyond.
- Focus on bioplastics for which recycling processes are still not in place, excluding bio-based analogues ("drop-ins"): PLA and PLA blends, PHA and its blends, PBS and PEF, accordingly to the market. The use of PBAT will also be assessed.

A Multi-Actor Approach (MAA) and a transdisciplinary methodology will engage waste producers, waste managers, the bio-based and (bio)plastics industry, public authorities, standardisation agencies, citizens, and media multipliers, creating a co-creation and co-ownership innovation environment with more than 50 participants.

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moeBIOS

Long abstract

Key messages: The MoeBIOS project demonstrates that technically viable recycling solutions exist for bioplastic packaging across multiple pathways. Through systematic development of collection protocols, advanced sorting technologies achieving over 85% accuracy, and recycling processes delivering high monomer recovery rates, the project proves that bioplastics can participate fully in circular economy systems. The transition from composting-focused end-of-life management to recycling-first approaches represents a fundamental shift that aligns bioplastics with broader circular economy ambitions. Success requires coordinated action across the value chain. Waste operators must invest in specialised infrastructure and training. Packaging producers must embrace design-for-circularity principles and verify recycling pathways. Policymakers must provide clear regulations and support infrastructure development. Consumers must engage with proper sorting and disposal practices. The MoeBIOS project provides the technical foundation, decision-support tools, and best practice guidelines to enable this coordinated transition. As the industry implements these advances over the coming years, bioplastic packaging will increasingly demonstrate its potential to combine functionality with genuine environmental sustainability through effective material circularity.

Scope and focus

MoeBIOS specifically addresses biobased plastics that are non-drop-ins, meaning materials like PLA, PHA, PBS, and starch-based polymers, rather than bio-versions of conventional plastics like bioPET or bioPP. This focus reflects the unique recycling challenges these materials present. Importantly, the project prioritises recycling as the end-of-life solution rather than composting, aligning with circular economy principles that emphasise material recovery and upcycling over disposal or degradation pathways. The scope encompasses diverse product applications, including food packaging containers, agricultural products like plant pots and mulch films, and textile applications. Global production capacity projections for 2029 show biobased biodegradable materials representing 66% of total bioplastics production at 5.73 million tonnes, with PLA leading at 42.3%, followed by PHA at 17%, demonstrating the significant market relevance of the materials addressed by MoeBIOS.

New Findings and Technical Achievements

MoeBIOS has made substantial progress across the entire packaging value chain.

In waste management facilities, the current bioplastic presence remains minimal, with less than 1% in dedicated packaging containers and less than 1.98% in mixed waste streams. To address this growing stream, the project has developed detailed stream-simulation protocols that define specific polymer compositions and contamination levels, establishing baseline conditions for future recycling infrastructure.

Significant advances have been achieved in sorting technology. The project developed hyperspectral and infrared techniques specifically calibrated for bioplastics, creating comprehensive material databases to enable accurate identification. Laboratory-scale tests on contaminated samples have proven satisfactory, and pilot trials have achieved separation rates exceeding 85% correct identification —a critical threshold for viable recycling operations.

In treatment processes, MoeBIOS addresses both conditioning and cascaded recycling approaches. Conditioning includes decontamination protocols and pretreatment steps for impurity elimination and material preparation.

The cascade treatment strategy combines multiple recycling pathways, including mechanical, chemical, enzymatic, and thermochemical routes. Laboratory-scale results have been promising across all pathways, and demonstrator requirements have been established to guide scale-up activities. Notably, chemical recycling routes demonstrate high recovery efficiency with monomer yields exceeding 90% for PLA, over 80% for PBS and other polyesters, and above 70% for blended material streams.

Paradigm Shifts in Bioplastic Recycling

The MoeBIOS project embodies several fundamental shifts in how the industry approaches biodegradable packaging end-of-life management. The most significant change involves moving from composting as the primary end-of-life option to prioritising recycling and upcycling for durable applications (non-designed for composting). Bioplastics are now considered valuable feedstock for material recovery rather than materials destined for biological degradation or disposal. This transition aligns bioplastics with circular economy principles, keeping materials in productive use for as long as possible. Another critical development involves establishing dedicated collection and sorting systems designed specifically for bioplastics. These specialised streams are necessary to ensure recyclability and maintain the quality of recycled outputs. Without effective separation of non-drop-in biopolymers from conventional plastics and from one another, recycling efforts cannot meet the purity and performance standards required for secondary raw materials. The concept of hybrid and flexible end-of-life routes represents another innovation. Rather than prescribing a single pathway for all bioplastic packaging, MoeBIOS recognises that optimal solutions may combine mechanical, chemical, enzymatic, or thermochemical recycling with composting or energy recovery, depending on material composition, contamination levels, and local infrastructure capabilities. This flexibility acknowledges the diverse realities across European regions while maintaining high environmental standards.

Finally, design-for-circularity principles are being integrated from the earliest product development stages. Packaging designers now consider recyclability requirements from the start, choosing mono-materials where possible, limiting additives that complicate recycling, and providing clear disposal instructions. This proactive approach responds to regulatory pressure under the Packaging and Packaging Waste Regulation, which will mandate recyclability for market access.

Practical Implications for Waste Operators

Municipal and industrial waste management operators face several concrete requirements as bioplastic recycling systems develop. Establishing separate collection and sorting streams for bioplastics, particularly non-drop-in polymers, becomes essential. This infrastructure development must be accompanied by comprehensive citizen information campaigns and training programs to ensure proper source separation. Clear packaging labelling will help consumers understand which materials belong in which collection streams.

Significant capital investment will be required in sorting technologies and protocols specifically tuned to bioplastic identification and separation. Conditioning and recycling infrastructure must be established or adapted to handle these materials effectively. Staff training programs will ensure that operators can competently manage new material streams and technologies. The MoeBIOS decision support tools will help operators select appropriate hybrid end-of-life strategies, potentially combining mechanical recycling with composting or thermochemical recovery based on local waste flows and specific bioplastic compositions.

Looking ahead, waste operators must anticipate regulatory compliance under the Packaging and Packaging Waste Regulation. From 2030, only truly recyclable or reusable packaging will be acceptable in the European market. Operators who invest now in appropriate infrastructure and expertise will be positioned to handle these materials effectively when volumes increase.

Practical Implications for Packaging Producers

Packaging producers and brand owners must fundamentally adopt design-for-circularity principles in their product development processes. This means choosing materials and formulations that are compatible with existing or emerging recycling schemes and providing clear labelling that indicates both the material type and the appropriate end-of-life routes. The days of selecting packaging materials based solely on performance and cost are ending; recyclability is becoming a mandatory criterion.

Critically, producers must verify that viable, scaled recycling or upcycling routes exist for their chosen materials to ensure compliance with the Packaging and Packaging Waste Regulation. This verification can be conducted experimentally through participation in pilot programs such as MoeBIOS or through certified third-party assessment systems. Without demonstrated recyclability, producers risk non-compliance with PPWR requirements.

Preparation for upcoming regulations extends beyond basic recyclability. The PPWR will impose minimum recycled content requirements for plastic packaging, creating demand for secondary raw materials from bioplastic recycling streams. Producers should monitor PPWR delegated acts covering labelling requirements, design-for-recycling criteria, and compostability standards. Active participation in CEN technical committees and working groups allows producers to influence standard development and stay ahead of regulatory changes.

Industry Outlook for the Next 2-5 Years

The bioplastic packaging industry can expect several transformative developments over the next two to five years. Commercial-scale bioplastic sorting and recycling lines will emerge from pilot and demonstration phases into operational facilities. These installations will process significant volumes of material, proving economic viability and establishing best practices for broader replication. The scaling-up phase will reveal practical challenges and optimisation opportunities that laboratory and pilot work cannot fully anticipate.

Packaging producers will increasingly adopt recycled bioplastics in their formulations, driven both by regulatory requirements and by the growing availability of high-quality secondary raw materials. This adoption creates market pull for recycling operations, encouraging further infrastructure investment in a virtuous cycle. As recycled content becomes standard, the price differential between virgin and recycled bioplastics should narrow, improving the economics of circular systems.

Design-for-circularity will shift from a voluntary best practice to an industry standard embedded in product development workflows. Designers will routinely consider end-of-life implications alongside traditional criteria like functionality, aesthetics, and cost. Standards bodies will codify these practices, creating clear guidelines that simplify compliance and level the competitive playing field.

Infrastructure upgrades will accelerate as municipalities recognise the need to adapt waste management systems to accommodate bioplastics. These investments will include collection vehicles, sorting facilities, and processing equipment specifically configured for bioplastic materials. The pace of deployment will vary across regions based on existing infrastructure, political commitment, and local waste composition, but the overall trajectory is clear.

Regulatory clarity will emerge as the European Union finalises implementation measures for the Packaging and Packaging Waste Regulation. Clear definitions of recyclability, standardised testing protocols, and unambiguous compliance pathways will reduce uncertainty for all stakeholders. This clarity, while imposing obligations, will also enable confident investment decisions by establishing stable regulatory frameworks.

A new European blueprint for circular bioplastics upcycling solutions (ReBioCycle)

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University College Dublin/BiOrbic: Kevin O'Connor, Coordinator

Once biodegradable packaging products reach the end of their useful life, they are properly collected through waste management systems. **Biodegradable and compostable** packaging must be collected with the organic fraction and processed through biological pathways, such as composting. The resulting nutrient-rich compost supports new biomass growth in agricultural systems, completing the carbon cycle and supporting the bioeconomy value chain.
If organic waste collection is still not in place or biodegradable plastic packaging **is not labelled as compostable**, citizens can place them in the plastic waste collection system.

Biobased and biodegradable plastics are not recycled in part due to limitations in the sorting system, but also because recycling technologies for biobased biodegradable plastics have not been scaled. Thus, there is insufficient domain knowledge on recycling (at an industrial scale) of biobased biodegradable plastics. Even if the sorting systems were in place, there is no evidence that the recycling of biobased biodegradable plastics could be guaranteed. This is in part due to the immaturity of recycling technologies and the low level of biobased biodegradable plastics in the plastics waste stream. Thus, ReBioCycle exists to demonstrate sorting and recycling technologies at an appropriate scale/technology readiness level that provides sufficient and robust data and evidence to build domain knowledge and deliver near-future technologies that will give society the "**readiness**" for these materials as their presence in the market grows.

Project Objectives

In this context, ReBioCycle represents a comprehensive circular-economy approach to novel **material recycling**, particularly for bioplastic packaging that is collected separately. The ReBioCycle project, with a portfolio of bioplastic sorting and recycling technologies, will operate three waste-processor-centric hubs at demonstrative scale and in real operational environments to demonstrate effective and efficient material sorting and recycling of three types of bioplastics (e.g., PLA, PHA, and starch-based materials). Furthermore, ReBioCycle aims to obtain the same or higher-grade recycled polymers and to pursue other higher-value applications. ReBioCycle addresses critical gaps in the circularity of **biobased biodegradable plastics** through four interconnected objectives. The primary goal is to propose a comprehensive portfolio of bioplastic material **recycling technologies** (e.g., mechanical, chemical, microbial, and enzymatic) and demonstrate their effectiveness, economic viability, and potential for integration at industrially relevant scales. This involves not only developing innovative technologies but also validating their performance under realistic operating conditions. Since effective sorting systems are necessary to separate different bioplastic types, project efforts will also focus on increasing the sensitivity of industrial NIR sorters to potentially enable compliance with biobased biodegradable polymer types, primarily for biodegradable packaging materials.

Beyond technology development, the project aims to generate critical data and evidence that can support decision-making across the bioplastics value chain. This evidence base will inform policy development at both European and national levels, helping to shape legislation on bioplastics, circular economy frameworks, and waste management regulations. At the same time, ReBioCycle shares knowledge and best practices with recycling operators, packaging designers, brand owners, and consumers to help more people use circular bioplastic solutions.

Portfolio of Bioplastic Recycling Technologies

The primary destination of bioplastic packaging (primary and/or secondary, or both) contaminated with organic waste is typically composting facilities, where it is converted into compost. However, in specific cases, bioplastic products can be collected within the plastic waste stream.

It is therefore in the project's interest to focus on this specific stream (plastic waste) to recover bioplastics **with added value** and reintroduce them into the production cycle. In this context, ReBioCycle explores four distinct material recycling processes (e.g., mechanical, chemical, microbial, and enzymatic), each with unique characteristics, advantages, and challenges. These innovative recycling routes represent complementary approaches to closing the loop for bioplastic materials in the source-separated plastic waste stream, offering solutions suited to different waste streams, infrastructure contexts, and Design for Recycling product requirements.

Mechanical Recycling: Mechanical recycling represents the most mature technology pathway, following established processes previously developed for conventional fossil-based plastic polymers, such as PE, PP, PET… including collection, sorting, cleaning, shredding, and reprocessing via extrusion or injection moulding. This approach offers significant advantages, including established industrial infrastructure, lower energy demand compared to chemical recycling alternatives, and an enhanced safety profile by avoiding solvents and harsh chemicals[1].

However, mechanical recycling faces several challenges that limit its application. Material degradation can easily occur during reprocessing due to heat and shear forces involved in melting and reforming the plastic, and consequently, the properties of mechanically recycled materials typically remain inferior to those of virgin materials, limiting their use in demanding applications.[2]

Within the ReBioCycle project, these challenges will be addressed by implementing upcycling strategies to minimise degradation. This will include the use of mild processing conditions during pretreatment stages and the incorporation of tailored additives during reprocessing, in order to obtain materials that meet the required final performance specifications [2].

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Chemical Recycling

Chemical recycling involves depolymerisation processes to break down bioplastics into their constituent monomers or oligomers before rebuilding them into new polymers. Alternative is a physical-chemical treatment using innovative and safe solvents that will dissolve the polyesters fraction selectively, enabling its recovery and purification, and subsequent recycling in new materials with or without the necessity to obtain their monomeric constituents. The primary advantage of chemical recycling lies in its ability to produce virgin-like polymer properties from recycled feedstock. Additionally, this approach might handle biobased biodegradable plastic streams that would be unsuitable for mechanical recycling. Chemical recycling processes designed to treat classical polyolefins typically face substantial hurdles, as they require significant energy inputs despite achieving very low yields and selectivities [Eunomia, Chemical Recycling: State of Play 2020; Petrochemicals Europe Market Overview 2021]. Chemical recycling technologies for bio-based polyesters, however, benefit from the inherent ease of molecular recycling and have therefore been scaled to high TRL levels. This approach is limited to post-industrial waste and closed-loop collection, which are currently the only options to have sufficient input quality items [https://totalenergies-corbion.com/resource/luminy-recycled-pla-lca-peer-reviewed-life-cycle-assessment/]. Within ReBioCycle, the performance of these technologies is now examined in the context of reclaiming bioplastics from urban mixed plastic waste, which introduces several challenges regarding sorting efficiency and final contamination.

Enzymatic Recycling

Enzymatic recycling uses engineered enzymes to catalyse the depolymerisation of biobased biodegradable plastics such as PHA, breaking polymer chains into monomers and/or oligomers that can be repolymerised into new materials. ReBioCycle is working on the demonstration of PHA enzymatic depolymerisation in laboratory settings (before scale-up), showing dramatic material breakdown within hours. This enzymatic approach offers significant advantages over chemical methods, including substantially lower energy demand under mild reaction conditions, the ability to produce virgin-like properties in recycled polymers, and the potential for reduced environmental impact by avoiding harsh chemicals and high temperatures[3].

However, enzymatic recycling faces considerable challenges before reaching commercial viability. Sorting requirements remain necessary to separate bioplastic types and remove contaminants that might interfere with enzyme activity. The high cost of enzyme production currently limits economic viability[4],[5], though ongoing research aims to reduce these costs through improved enzyme production methods and recovery systems. Material pretreatment is often required to optimise enzyme access to chemical bonds within the polymer, and ReBioCycle aims to increase the Technology Readiness Level through its piloting activities in the Spanish/Irish hub.

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Microbial Recycling

Microbial recycling combines biobased biodegradable plastics with organic waste in an innovative two-stage process. In the first stage, anaerobic digestion breaks down mixed organic materials and biobased biodegradable plastics to produce volatile fatty acids (VFAs). These VFAs are then separated and concentrated before serving as feedstock for the second stage, where fermentation processes convert them into new biopolymers. This approach uniquely integrates organic waste valorisation with bioplastic recycling, creating synergies between the two waste streams[6]. A variation of this microbial recycling described above is where mixed microbial cultures are also employed to break down organic waste materials and biobased biodegradable plastics to produce VFAs, as intermediates, which are subsequently used by the same mixed microbial culture to directly make bioplastic through fermentation.

The advantages of microbial recycling include the production of virgin-like material properties from recycled feedstock and the benefit of building on mature individual technologies since both anaerobic digestion and fermentation are well-established processes in their own right. The challenges lie in effectively coupling these processes together. VFA separation and purification require sophisticated techniques to isolate specific compounds from complex digestion outputs. There is currently a lack of demonstration in relevant industrial environments [4] where the full integrated system operates continuously, and optimising the interfaces between the digestion and fermentation stages remains an active area of research.[7]

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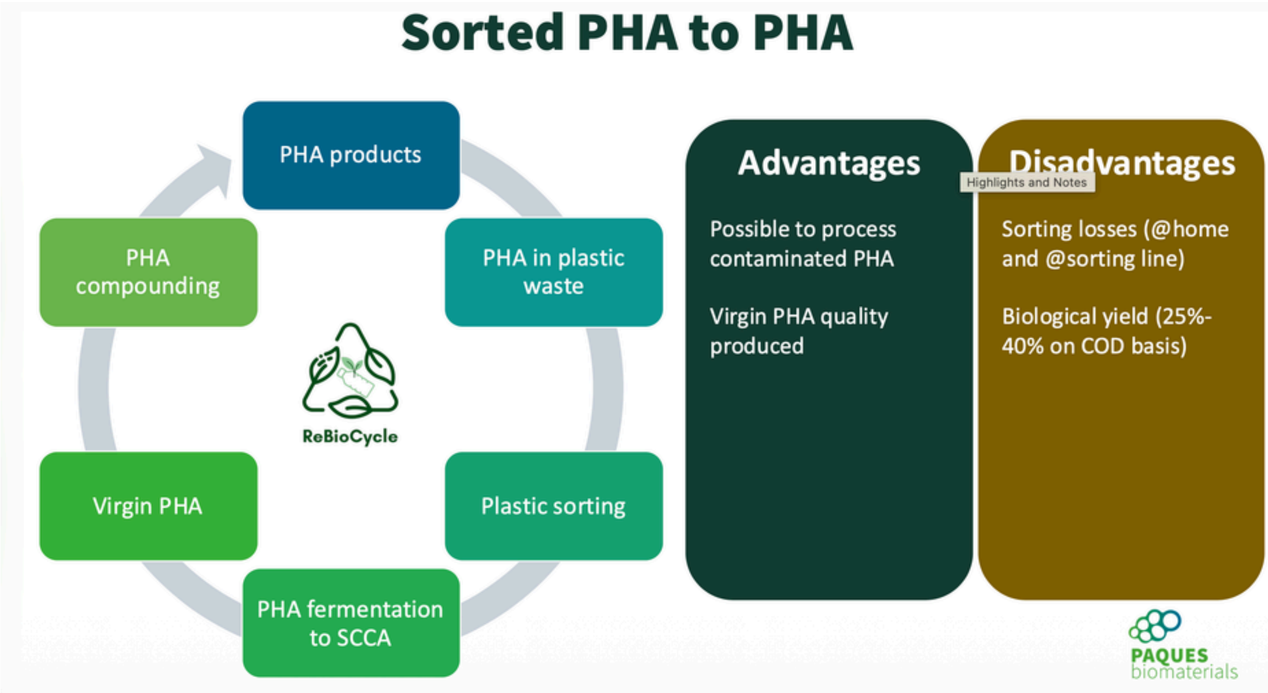

Credits: Joao Sousa, Paques Biomaterials, Zenodo https://zenodo.org/records/18468664

Current Progress in ReBioCycle

ReBioCycle has made substantial progress across all technology pathways, advancing the state of the art in multiple areas simultaneously.

- Advanced NIR sorting systems are being tested and optimised to efficiently separate different bioplastic types from source-separated plastic waste streams, addressing a fundamental challenge common to all recycling routes.
- In the mechanical recycling pathway, formulation development and processing optimisation work is improving the properties of mechanically recycled bioplastics through careful selection of additives and processing aids.
- For physical/chemical treatment and chemical recycling, an innovative, safe solvent mixture has been identified and evaluated to dissolve, recover, and recycle biopolyester mixtures from the bioplastic fraction. Furthermore, side streams (such as mineral fillers and starches, among others) derived from the solvent extraction process have been considered, processed, and purified for subsequent recycling into new bioplastic formulations, thereby increasing the overall efficiency and sustainability of the chemical recycling process. For chemical recycling, thermochemical depolymerisation of biobased biodegradable plastics (PLA and PHA) via hydrolysis has also been undertaken to produce monomers, enabling selective removal of monomers from specific polymers while leaving other constituents undissolved.
- The enzymatic recycling efforts have focused on maximising enzyme expression and scaling up enzyme production for PHA depolymerisation while reducing costs and maintaining enzymatic activity at larger scales. Complementing this work, researchers have developed pretreatment protocols to prepare biobased biodegradable plastic waste for enzymatic and microbial recycling, thereby maximising the accessibility and efficiency of biological degradation pathways.
- Microbial recycling has focused on the production of VFAs via anaerobic digestion and their subsequent conversion to the biobased, biodegradable polymer PHA by microbial monocultures, as well as by mixed microbial cultures that produce VFAs and use them directly to make PHA.

Conclusion

ReBioCycle provides a comprehensive blueprint for establishing circular (bio)economy systems for biobased biodegradable plastics in Europe by developing and demonstrating four complementary recycling technologies—mechanical, chemical, enzymatic, and microbial. Each technology offers distinct advantages for different applications and contexts, from the efficiency of mechanical recycling to the virgin-quality outputs of chemical and biological processes. By generating critical data, informing policy, and engaging industry stakeholders, ReBioCycle is well positioned to accelerate the transition of plastics from fossil-based, linear systems to truly circular, biobased systems. As technologies mature and scale up, the integration of these approaches should enable Europe to maximise resource efficiency, reduce environmental impacts, and establish global leadership in sustainable bioplastics management.

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ReBioCycle

The Pitches

Sustainable end-of-life routes for single-use monodose packaging for oily products (E-OILE’)

Near-market biodegradable packaging solutions for oily products

Fundacion Gaiker: Mª José Suárez, Coordinator

The packaging industry accounts for approximately 60% of post-consumer single-use plastic (SUP) waste, much of which ends up as litter in natural environments. Rapid consumption patterns and safety concerns complicate effective recycling. The EU-funded E-OILÉ project will develop near-market biodegradable packaging solutions using novel biopolyesters and polysaccharides. These materials are designed to improve barrier and mechanical performance, replacing polyolefins and polyethylene terephthalate (PET) in single-use packaging. The project will focus on ecodesigned biodegradable monomaterials and coatings, following the SSbD (Safeguarding Sustainability by Design) framework. E-OILÉ’s circular business model addresses food and cosmetic products through four use cases: olive oil, oily sauces, body oil, and oil serum, demonstrating complete biodegradability according to relevant standards.

Objective:
The packaging industry is responsible for around 60% of post-consumer SUP waste, which is most likely to end up as litter in natural environments. While factors such as rapid consumption patterns, safety concerns, or compact size hinder the effective recycling of packaging waste, the need for safe, biodegradable alternatives is imperative. E-OILÉ will address safe and sustainable biodegradable packaging solutions close to the market by:
a) demonstrating at TRL 7 cost-effective production of biodegradable materials based on novel biopolyesters and polysaccharides, engineered to enhance barrier and mechanical performance, to replace Polyolefin materials (PP and PE) and PET in monodose packaging solutions ecodesigned as biodegradable monomaterial structures or in combination with coating technologies and following the SSbD framework;
b) implementing a circular business model, food and cosmetic products, through 4 Use Cases (UC): Olive oil- UC1; oily sauces- UC2; Body oil- UC3 and Oil serum- UC4);
c) validating the packaging performance, shelf life, safety and sustainability along the whole supply chain (from material producers to end users) and demonstrating complete biodegradability following relevant standards and in environmentally relevant conditions and, therefore, sustainable End-of-Life (EoL) pathways for the new packaging solutions in combination with the use of Artificial Intelligence (AI) and advanced modelling mechanisms for digitally-assisted accurate prediction of degradation processes.

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e-oilé

Biodegradable packaging materials advancing circularity, sustainability and ecoinnovation (BioPackMan)

Adaptable and recyclable biodegradable packaging materials

National Technical University of Athens,
Costas Charitidis (Coordinator). Represented by: Tatjana Kosanovic Milickovic, Coordination Team Member

Food and material packaging is dominated mainly by unsustainable solutions that often use materials like plastic, leading to large quantities of waste and requiring unsustainable manufacturing processes. This creates a strong need for green and sustainable packaging solutions. The EU-funded BioPackMan project will design and develop biodegradable compounds based on biodegradable polymer materials, enabling recyclable packaging with chemical resistance, thermal stability, gas permeability, and application-specific mechanical strength. Furthermore, to meet diverse packaging requirements, the project will develop compounds with tailored morphology, allowing them to meet specific needs. Finally, it will establish a complete value chain to maximise sustainability and innovation.

Objective:
The design of biodegradable polymer materials (BDPM) is at the core of BioPackMan, aiming to explore an extended material design space of Polyhydroxyalkanoates (PHAs), Poly(butylensuccinate) and its copolymers (PBS, PBSA) and Polylactic Acid (PLA) to develop tailored compounds that harness synergistic effects, leading to biodegradable, recyclable packaging with application-specific mechanical strength, thermal stability, chemical resistance and gas permeability. Biodegradable compounds will be developed with tailored morphology to meet diverse flexible & rigid packaging requirements and also embrace a 'biodegradation as a system property' approach from initial material and packaging design, considering specific environmental conditions for intended and unintended disposal pathways. By establishing a complete value chain (material producers, compounders, packaging converters, and end users), BioPackMan aims to provide a complete set of compounds, sustainable additives, and innovative processing technologies for the production of sustainable packaging demonstrators for the food, home care, and personal care sectors. The target is to achieve benchmark fossil-based product quality, ensuring compliance and safe use in packaging, and showcasing that BDPMs can be recycled. Circularity, safety, and sustainability are considered at all stages of development through the SSbD framework, and liaise with society and industry to assure interaction, knowledge exchange, and the adaptation of circular business models. To secure societal impact, stakeholders will be involved early in the project to identify barriers and facilitate the adoption of sustainable practices.

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BioPackMan

Sustainable plastic biorefinery for recyclable and biodegradable packaging (UPCYCLE)

A new biodegradable life for non-recyclable mixed plastic waste

Aalborg University: Cristiano Varrone, Coordinator

Green and sustainable technologies must be harnessed to combat climate change and reduce the impact of several environmental crises. Recycling has been leading this effort, yet some materials, such as mixed plastic waste, cannot be recycled and lack sustainable end-of-life solutions. The EU-funded UPCYCLE project aims to create circular value chains that transform non-recyclable mixed plastic waste into biodegradable and recyclable packaging materials for packaging applications. The project will address key scalability hotspots to achieve economic feasibility. It will also follow a safe-and-sustainable-by-design framework to reduce GHG emissions as it scales up its plastic biorefinery and ecopolymers.

Objective:

UPCYCLE aims to demonstrate novel circular value chains that transform non-recyclable mixed plastic waste into biodegradable, recyclable materials for packaging applications. Building on the promising results of the H2020 UPLIFT project, UPCYCLE addresses specific scalability hotspots to reach economic viability. The project scales up its novel plastic biorefinery and ecopolymers with a strategy that leverages: (1) A Safe-and-Sustainable-by-Design framework to ensure safety (i.e., non-toxic materials), a reduction in GHG emissions (-30%), and economic viability (<40% selling price); (2) AI-powered fast-track innovation for process intensification; (3) A versatile biorefinery process to valorise mixed plastic waste (both fossil- and bio-based) and secondary biomass residues; (4) A smart polymerisation and formulation strategy using bio-based, degradable additives to tune biodegradability and enhance technical performance for four selected packaging use cases. Leveraging a multidisciplinary consortium of top-tier academic institutions and industry leaders, UPCYCLE is poised to create a significant impact in the packaging industry. UPCYCLE's ecopolymers, derived from plastic and biomass waste streams, promote a viable circular business model for European recyclers, polymer processors, compounders, and packaging producers. Moreover, our strategy demonstrates how renewable and upcycled building blocks and additives can be blended into commercially available polymers to deliver novel PHA-, PLA-, and Furan-based packaging formulations that successfully modulate degradability and technical performance, depending on the application. By providing tools to improve the properties and economic viability of polymer systems already on the market, we offer a fast-track pathway to impact.

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Innovative bio-based, biodegradable, recyclable,safe and circular food packaging (GRECO)

Recyclable bioplastic food packaging

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Represented by: Samira El Bir, IPC Centre Technique Industriel de la Plasturgie (partner)

The food packaging industry requires innovative, circular, bio-based solutions to replace complex, multi-material structures that rely on fossil fuels. The EU-funded GRECO project will demonstrate the life-cycle and economic feasibility of safer bioplastic value chains for food packaging through a safe and sustainable by design (SSbD) strategy. It will develop new biodegradable and recyclable packaging with PLA copolymers, coatings, additives, and surface treatments. The project will also ensure regulatory compliance, propose new standards and labelling guidelines, and use digital tools for simulation and modelling. Overall, the project aims to facilitate the introduction of sustainable products and to contribute to the Plastics Strategy, the Single-Use Plastics Directive (SUP), and the EU Circular Economy Action Plan (CEAP).

Objective:
GRECO aims to demonstrate the life cycle and techno-economic feasibility of greener & safer bioplastics value chains for the food packaging sector, based on a safe and sustainable by design (SSbD) strategy. To this end, innovative bio-based, biodegradable, and recyclable packaging will be developed using new PLA copolymers, coatings, additives, and catalysts, along with surface treatments. Regulatory compliance will be demonstrated while contributions to new or modified standards and proper labelling will be proposed. Digital tools will drive developments in simulation and modelling, while the social sciences and humanities (SSH) will provide relevant information on social perceptions and acceptance. All of them will pave the way for the introduction of new products into the packaging market and into our society. Contribution to the Plastics Strategy, the Single-use Plastics Directive (SUP) and the EU Circular Economy Action plan (CEAP) will be ensured. GRECO will introduce the food packaging industry to groundbreaking bio-based, SSbD, and fully circular PLA-based materials that meet diverse application needs. These alternatives aim to replace fossil-based, complex, and multimaterial structures prevalent in the industry, improving packaging end-of-life through biodegradation in various environments, including industrial and home composting, anaerobic digestion, marine environments, and soil. The design will ensure recyclability and prevent chemical interactions that hinder overall biodegradation.

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GRECO

Boosting the Industrial Uptake of Biodegradable polymers for packaging applications by implementing digital tools and advanced techniques (Be-UP)

Biodegradable polymers for a sustainable packaging sector

ITENE: Miriam Gallur and Amparo Verdu', Coordinator
Represented by: Cecilia Giardi, Novamont (partner)

The packaging industry is focusing on circular innovations to tackle economic losses from non-biodegradable plastics. The EU-funded Be-UP project will develop novel aliphatic-aromatic biopolyesters with increased renewable content, using bio-based building blocks such as 1,4-bis(2-hydroxyethyl) terephthalate (1,4-bio-BDO), along with innovative catalysts and additives. These biopolymers will be blended with commercial biopolymers (PLA, PBAT, PHA) and chain extenders to create bioplastic packaging materials. Advanced modelling tools will optimise blend design to achieve the desired performance and sustainability targets. Key production techniques, including blown film extrusion, injection moulding, and thermoforming, will be employed. The findings will guide the development of circular design tools, enhancing the standardisation of testing and labelling for materials and packaging.

Objective:
Within the Be-UP project, new synthesis and processing routes will be developed for novel aliphatic-aromatic biopolyesters with increased renewable content using biobased building blocks (e.g 1,4 bio-BDO), alongside innovative catalysts and additives. These components will be optimised through advanced digital modelling tools, based on Kinetic Monte Carlo (kMC) models, for synthesis and polymerisation. These biopolyesters will be blended with commercial biopolymers (e.g., PLA, PBAT, and PHA), biobased chain extenders, and mineral fillers to create bioplastic packaging materials. The design of these blends will employ advanced compounding modelling tools, supported by techniques such as screw design and inline rheology measurements, to achieve the target technical performance, sustainability, and biodegradation goals through multi-objective function evaluation. Processability will also be a key factor, with a focus on the primary production techniques used in the packaging industry, namely, blown film extrusion, injection moulding and thermoforming. A set of packaging product prototypes (TRL 7) will be manufactured to validate the developed materials. The biodegradability of these novel products will be assessed across different End-of-life (EoL) scenarios, including open environments and controlled conditions, thereby filling the gap between laboratory conditions and the real end-of-life behaviour of these materials. Additionally, the recyclability of the new products will be evaluated.

The data and conclusions of these assessments will help develop guidelines and tools for circular design, supporting the adoption of the Safe and Sustainable by Design (SSbD) Framework, and improving the standardisation framework for testing and labelling of materials and packaging products. Be-UP is expected to replace more than 50,000 tonnes of non-biodegradable plastics in 2032.

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