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EUBP TALK SERIES PAPERS

Alternative feedstock for biobased plastics: Bridging the gap between research and the market

A WHITE PAPER

How EU-funded research and innovation projects researched alternative feedstock for the production of biobased plastics.

About us

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The projects BioSupPack, CAFIPLA, LUCRA, MoeBIOS, PERCAL and WASTE4SOIL are funded by the European Commission under the European Union Research and Innovation Programme Horizon 2020, Horizon Europe and their European Partnerships, the Bio-based Industries Joint Undertaking (BBI JU) and the Circular Bio-Based Europe Joint Undertaking (CBE JU).

Our Goal

The following projects researched alternative feedstock for the production of biobased plastics.

BioSupPack: Demonstrative process for the production and enzymatic recycling of environmentally safe, superior and versatile PHA-based rigid packaging solutions by plasma integration in the value chain https://biosuppack.eu/

CAFIPLA: Combining carboxylic acid production and fibre recovery as an innovative, cost-effective and sustainable pre-treatment process for heterogeneous bio-waste https://cordis.europa.eu/project/id/887115

LUCRA: Sustainable succinic acid production using an integrated electrochemical bioreactor and renewable feedstock https://lucra-project.eu/

MoeBIOS: Improving waste management of biobased plastics and the upcycling in packaging, textile and agriculture sectors https://www.linkedin.com/company/moebios-eu-com

PERCAL: Chemical building blocks from versatile MSW biorefinery https://www.cbe.europa.eu/projects/percal

WASTE4SOIL: Turning food waste into sustainable soil improvers for better soil health and improved food systems https://waste4soil.eu/

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October 2024.

Executive Summary

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Millions of tonnes of biowaste, particularly urban organic food waste, inundate European waste management systems yearly. However, approximately 60% of this resource currently finds its way to incineration or landfills, resulting in significant environmental and economic losses.

At the workshop held on 16 October 2024 at European Bioplastics in Brussels, European Bioplastics discussed the concepts of alternative feedstock with representatives of outstanding research and innovation projects and how biowaste can be successfully used for bioplastics production.

In the past years, several projects funded by the Horizon Programme for Research and Innovation and the Circular Bio-based Europe Joint Undertaking have been exploring ways to give residual and biowaste a second chance. These projects have transformed organic materials into eco-friendly alternatives to conventional plastics, with benefits ranging from landfill reduction to minimising the environmental footprint. In the meantime, new projects have started investigating and scaling up recycling technologies for bioplastics.

This white paper presents how biowaste can be a suitable source of feedstock, transformed into building blocks for biobased plastics, and ultimately pave the way to a sustainable future. It provides insights into the production of biobased monomers and biopolymers from biowaste and how the sorting and waste management systems can be enhanced for bioplastics recycling.

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Introduction

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As most of you know, the European Union aims to have at least 20% of the carbon used in chemical and plastic products come from sustainable non-fossil sources by 2030. This provides an incredible opportunity for bioplastics, and the upscaling of alternative feedstock uses for bioplastics.

Since April 2024, European Bioplastics has organised a monthly EUBP Talk focusing on alternative sustainable feedstock sources for bioplastics.

In each talk, a research and innovation community member explored a case study of alternative feedstock uses, explaining its successes and bottlenecks. Our goal was to set up a platform to share the latest research and innovation results, which we hope will be scaled up in the coming years.

With the wrapping-up event on 16 October 2024, the experts gathered in Brussels to propose some highlights and recommendations for policymaking at the final live event of this series.

This is a vast task, but we hope the workshop and these proceedings will provide insights and ideas for bridging that gap more effectively.

1. Biowaste as a source of biobased plastics

The Food and Agriculture Organization estimated that one-third of the food produced for human consumption is lost or wasted, equivalent to approximately 1600 million tons per year (FAO, 2017). The numbers are even more impressive when looking at agroindustrial waste: Europe's food and beverage industry produces up to 37 million tons of agroindustrial waste. This situation becomes critical if we consider that agroindustrial waste increases with an increase in human population, estimated to grow by 9.3 billion people by 2050.

Recycled agroindustrial waste has been of great interest during the last decade as a low-cost and sustainable substrate for fermentation processes. The types of products, yields, and potential applications depend mainly on the waste composition, which varies in terms of proteins, carbohydrates, and polyphenolic compounds (Astudillo et al. 2023).

Scientific literature has shown that most waste is rich in nutrients and chemical compounds that can serve as raw materials for obtaining various products with high-added value through microbial fermentation.

There are two sorts of agroindustrial waste: Field waste and process waste. Field waste corresponds to that generated during harvesting (e.g., leaves, stalks, seed pods, and stems). In contrast, process waste is generated after processing the harvested crop (e.g., molasses, bagasse, and roots). Agroindustrial waste consists of polysaccharides, proteins, carbohydrates, and other constituents, making it an interesting source for the production of nutrients through fermentation.

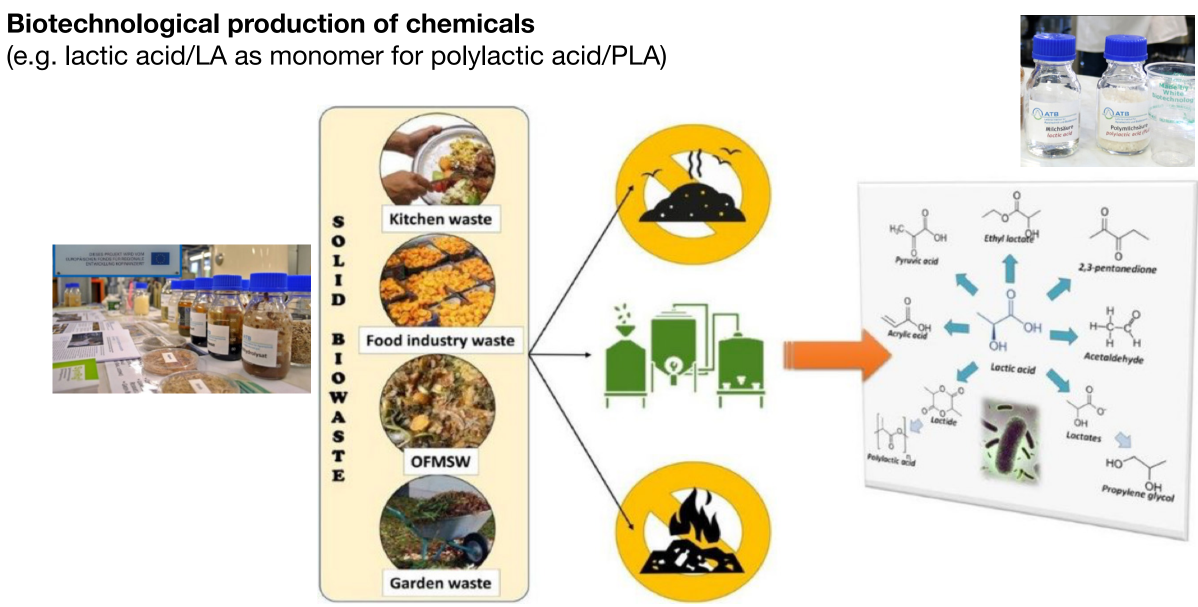

Fig.1.1: Biotechnological production of chemicals (e.g. lactic acid/LA as a monomer for polylactic acid/PLA). Source: J. Venus, ATB.

Agroindustrial waste is a source of sustainable, low-cost, and relatively easily accessible nutrients that can be reused and transformed to obtain microbial products.

There are two ways to profit from agroindustrial waste to produce biobased materials: Agroindustrial waste can be used as a substrate for fermentation processes, and high-added-value products can be obtained from agroindustrial waste through microbial conversion.

An ideal solution is to use alternative waste streams to create feedstocks, using heterogeneous biowaste - a mix of municipal/urban biowaste, sewage sludge, industrial residues, and agricultural harvest residues. The heterogeneous biowaste is difficult to treat (a pre-treatment is needed) and is a challenging source due to the fluctuating nature of its supply and availability.

The CAFIPLA project has focused on using heterogeneous biowaste to increase the supply of suitable feedstocks. It introduced a novel approach to biomass pre-treatment with a cascade process that converts biowaste streams into high-quality intermediates for the biobased industry. Lactic acid from pasta waste has been produced using a biorefinery approach (Marzo-Gago et.al 2022).

As opposed to current sugar/starch-dominated bio-economy schemes, CAFIPLA project has relied on the combination of a Carboxylic Acid Platform (CAP) and Fibre Recovery Platform (FRP) to valorise biomass into biochemicals, bioproducts, feed and biomaterials.

The Carboxylic Acid Platform (CAP) - converts the easily degradable fraction into Short Chain Carboxylic Acids (SCCAs) and nutrients. The Fibre Recovery Platform (FRP) extracts insoluble lignocellulosic fibres from the remaining fraction. The residue is converted to biogas and compost.

The combination of the CAP and FRP platforms has proven to be an economically viable and environmentally friendly treatment technology to create biowaste-based feedstock from a currently under-valorised biowaste.

Production of lactic acid from pasta waste using a biorefinery approach

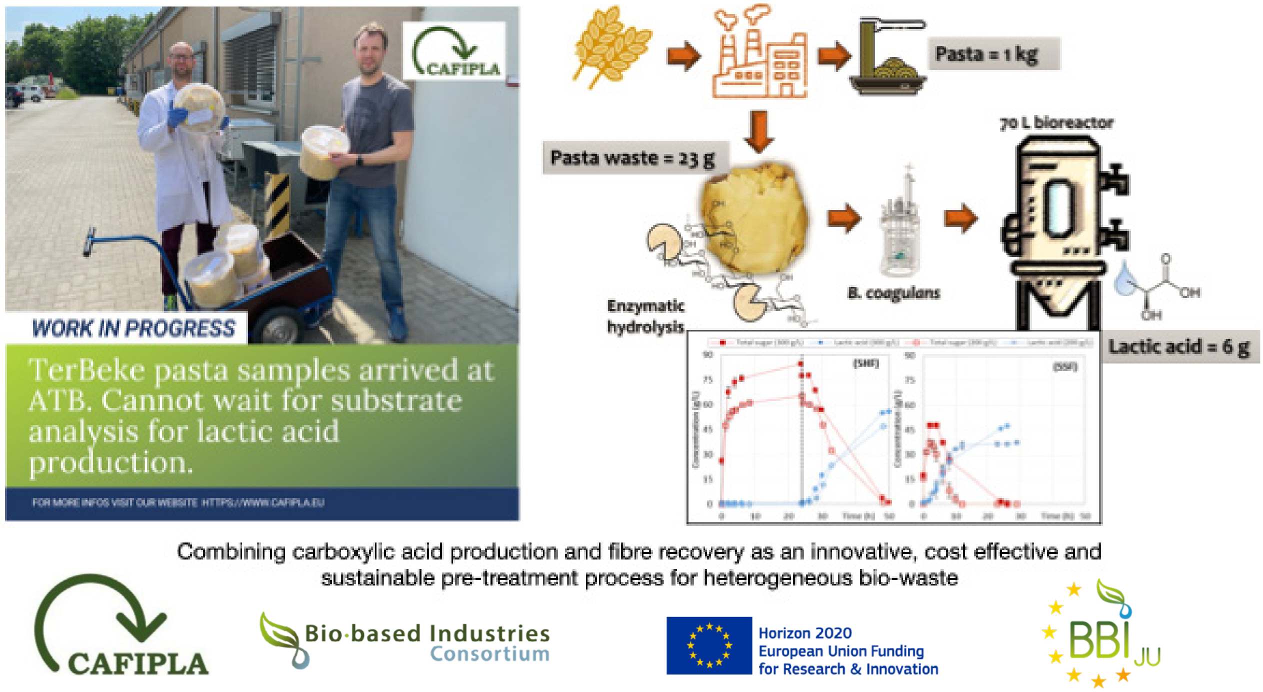

Fig.1.2: The CAFIPLA approach combines carboxylic acid production and fibre recovery as a pre-treatment process for heterogeneous biowaste. Source: J. Venus, ATB.

Municipal Solid Waste (MSW) can also be used as a feedstock to develop intermediate chemical products at high yield and low impurity levels, making it attractive for the industry. PERCAL focused on complementing its approach with the existing PERSEO Bioethanol® technology, thus creating a cascade of valorisation from the MSW components.

Chemical building blocks from versatile waste processing

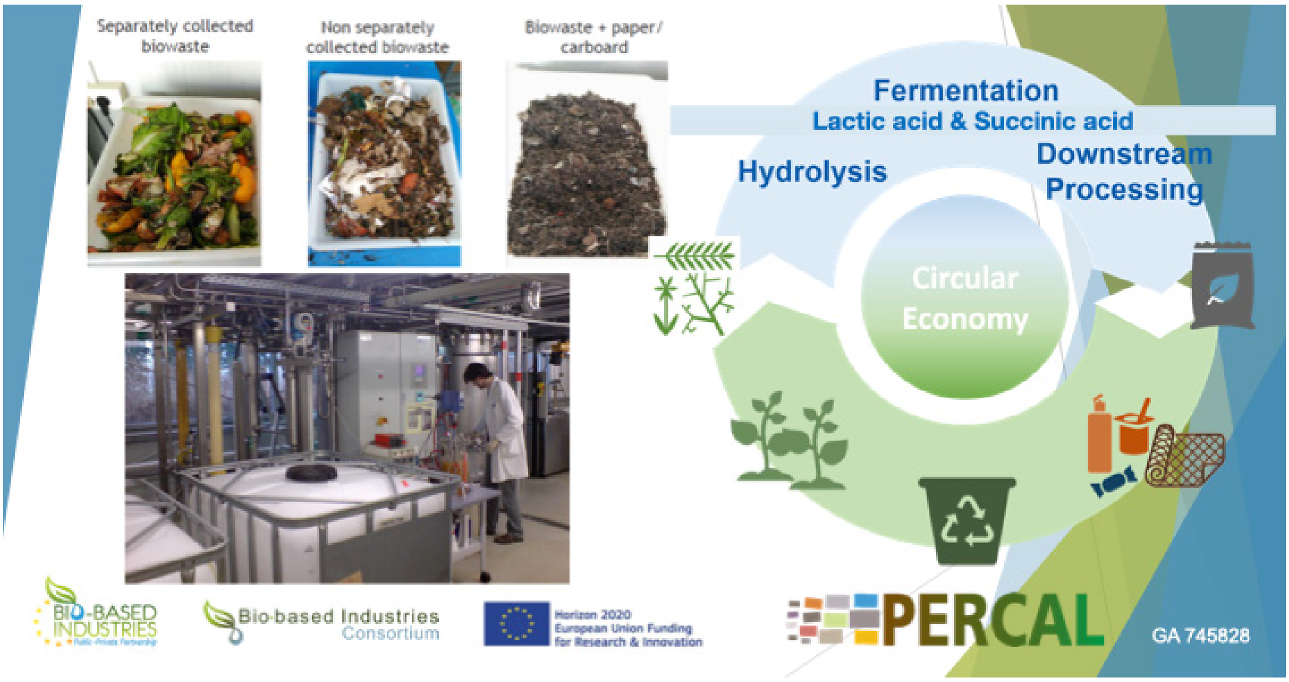

Fig. 1.3: PERCAL's Chemical building blocks from versatile waste processing. Source: J. Venus, ATB.

The intermediate chemicals bioethanol, lactic acid, and succinic acid are produced by fermentation from the hydrolysates obtained from the organic fraction of the MSW. Other intermediate chemicals, the biosurfactants, will be obtained by chemical and microbiological modification of the protein and lipid fraction from the remaining fraction of MSW after fermentation.

Significant progress has been made in the intermediate products ([1]). Lactic acid, an intermediate product in the project, can now be produced from organic municipal solid waste stream feedstocks at a laboratory scale. Also, using newly isolated strains, suitable raw materials can be applied for lactic acid production via simultaneous saccharification and fermentation approaches. The centrifuged samples achieved high lactic acid purity. Moreover, preliminary screening in the microplates for lactic acid fermentation of new strains has been successfully carried out.

The characterisation analysis done for valorising fermentation by-products provides a comprehensive overview of their principal parts. They have been focused on the protein and lipid fractions since both are the main precursors for the production of biosurfactants.

Lab tests to produce and purify lactide from lactic acid have been carried out, as well as tests on the production of PLA and PLA-copolymers by reactive extrusion in AIMPLAS, where PLA with a molecular weight of up to 250kDa was obtained.

2. Transforming biowaste into bio-succinic acid on a pre-industrial scale

Several projects are paving the way for a more resource-efficient and sustainable bioeconomy, demonstrating the viability of converting waste into valuable chemical products and setting a precedent for future initiatives. One of these, LUCRA, is working on demonstrating the technical and economic feasibility of producing bio-succinic acid from organic waste on a pre-industrial scale. Biobased succinic acid is a platform chemical in significant demand in the industry.

LUCRA was set up based on the results of the PERCAL project to address the complexity of optimising organic waste streams. LUCRA has introduced a novel waste valorisation approach involving the synergistic treatment of relevant waste streams, specifically biowaste and sawdust. LUCRA leverages cutting-edge technologies, including thermal and enzymatic hydrolysis, to extract valuable components such as sugars and nutrients from these waste and side stream materials. These recovered resources will serve a dual purpose: feedstock for succinic acid production and as inputs for innovative applications.

[1] AIMPLAS: https://www.aimplas.net/blog/percal-chemical-building-blocks-from-versatile-msw-biorefinery/

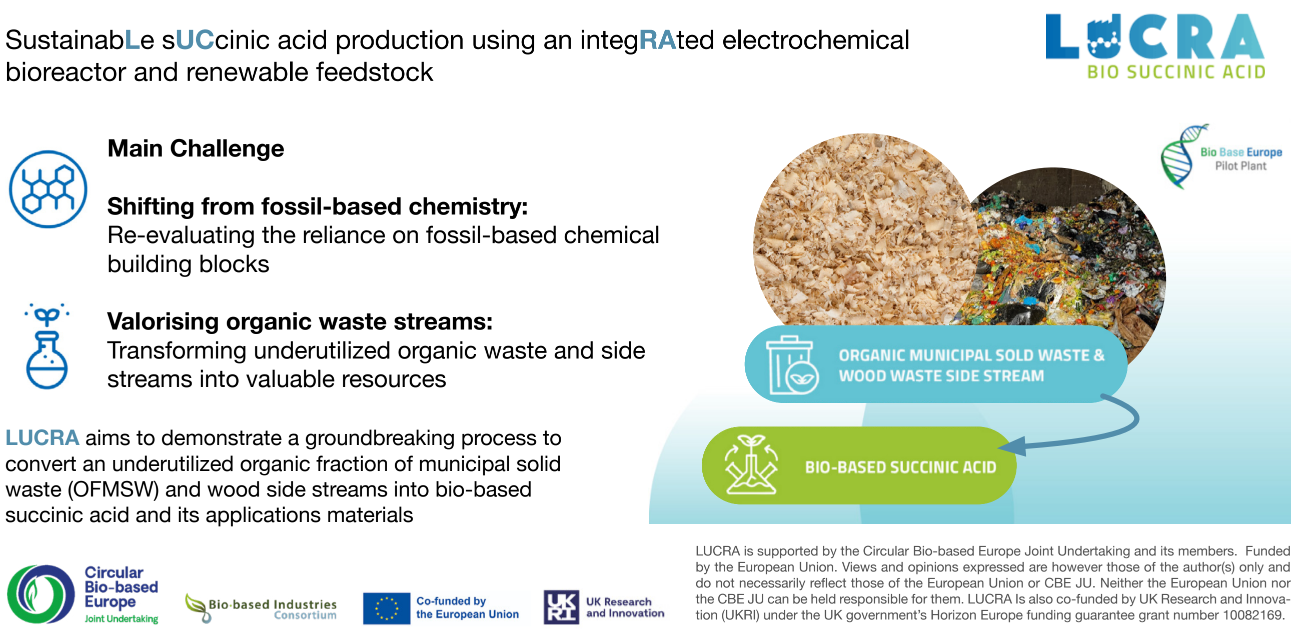

Fig 2.1: LUCRA main challenge. Source: LUCRA project.

Methodology of the LUCRA Project

1. Feedstock Selection and Pre-treatment: First, the project utilises abundant and underutilised organic municipal solid waste and wood waste as feedstocks, employing innovative hydrolysis methods to release carbohydrates from these materials.

2. Hydrolysis and Fermentation: Next, the extracted carbohydrates undergo hydrolysis, breaking them down into simpler sugars, which are then fermented using advanced fermentation processes to produce bio-succinic acid.

3. Electrochemical Bioreactor Integration: An integrated electrochemical bioreactor enhances the fermentation process's efficiency, optimising the bio-succinic acid production yield.

4. Scale-Up and Demonstration: The project then aims to scale up production from pilot to pre-industrial levels. It uses bio-succinic acid to create polyester-based polyurethane dispersions and resins, demonstrating its practical applications.

5. Environmental and Economic Assessment: The project also includes a thorough assessment of environmental benefits, such as reduced greenhouse gas emissions, and evaluates economic feasibility to ensure cost-effectiveness and competitiveness.

The transformation of organic waste into valuable bio-succinic acid reduces the reliance on fossil-based resources and promotes sustainable industrial practices.

The main challenge is demonstrating the technical and economic feasibility of producing bio-succinic acid from underutilised organic municipal solid waste and wood waste and demonstrating its processes' scalability, moving from pilot to pre-industrial scale production.

Bio-succinic acid can create polyester-based polyurethane dispersions and resins, showcasing practical applications and market potential. LUCRA deploys innovative hydrolysis methods to release carbohydrates from the waste and ferment them to extract bio-succinic acid. These innovative hydrolysis and fermentation methods have optimised production yields, making the process more efficient and cost-effective.

Fig 2.2: LUCRA hydrolysis process. Source: LUCRA project.

Additionally, environmental benefits are another critical outcome, with the LUCRA effectively showing a reduction in greenhouse gas emissions compared to conventional production methods.

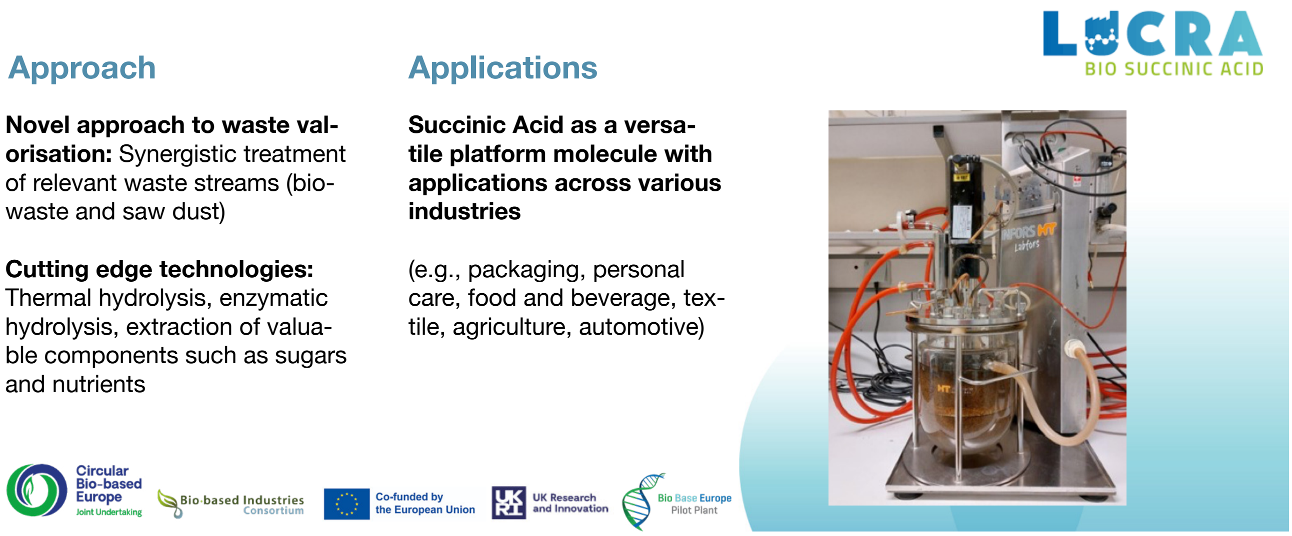

Fig 2.3: LUCRA approach and applications. Source: LUCRA project.

3. How can waste from beer production be valorised to produce bioplastics?

Waste of beer production can also serve as a source for bioplastics production, offering promising applications for food contact, cosmetics and homecare. Several projects explicitly aim to deliver versatile and competitive biobased packaging solutions based on Polyhydroxyalkanoates (PHA) and Polyhydroxybutyrate (PHB) for these applications. BioSupPack is one of these and is achieving excellent results.

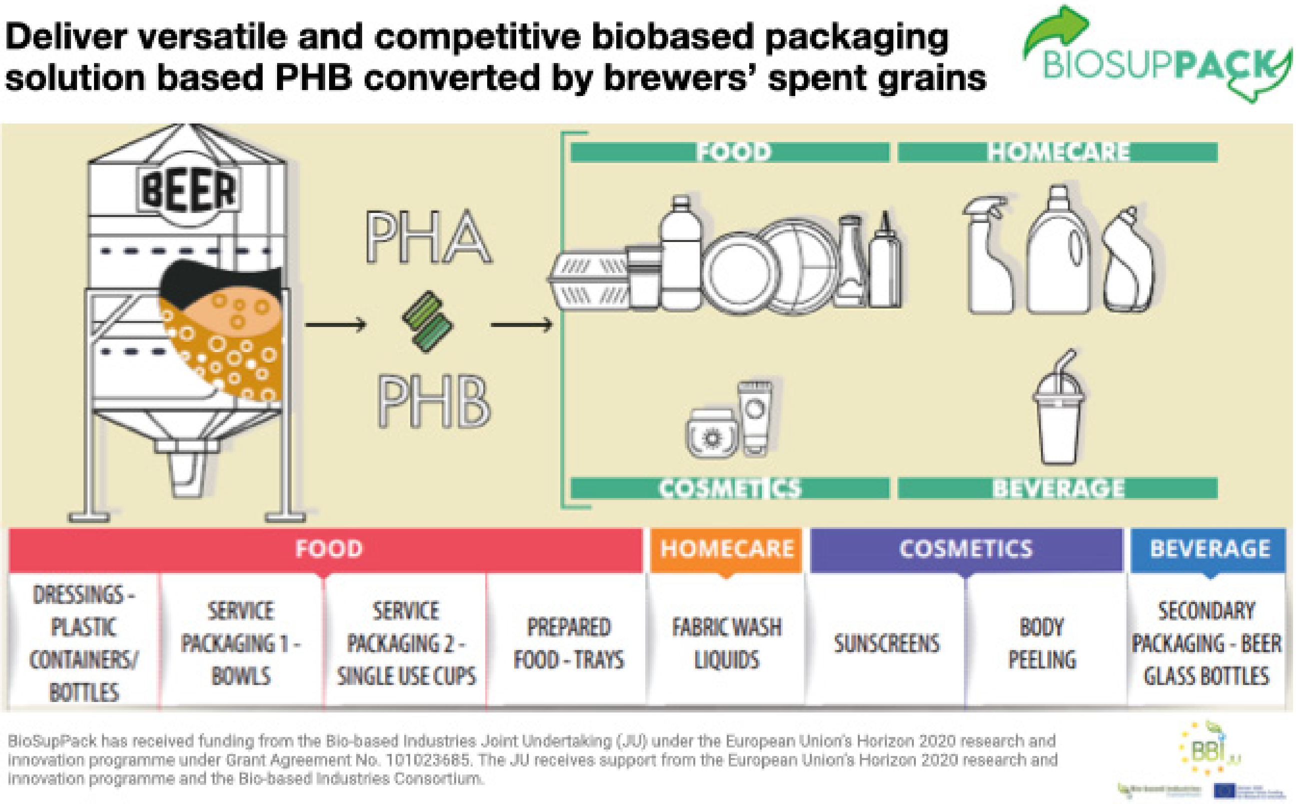

Fig 3.1: The value chain of BioSupPack. Source: AIMPLAS, ENCO.

In the BioSupPack project, teams have developed demonstrators for the packaging sector, including packaging solutions for beverages, cosmetics, and homecare applications. Homecare applications are an excellent case for substituting non-biodegradable polymers such as Polypropylene (PP) or Polyethylenterephtalat (PET) with biodegradable materials made of PHB. PHB is a wonderful alternative to traditional polymers for rigid packaging applications due to its properties, similar to polymers such as polypropylene. For example, fusion temperature and tensile strength are identical to PP's. At the same time, PHB has even better gas and liquid barrier properties than other bioplastics like polylactic acid (PLA).

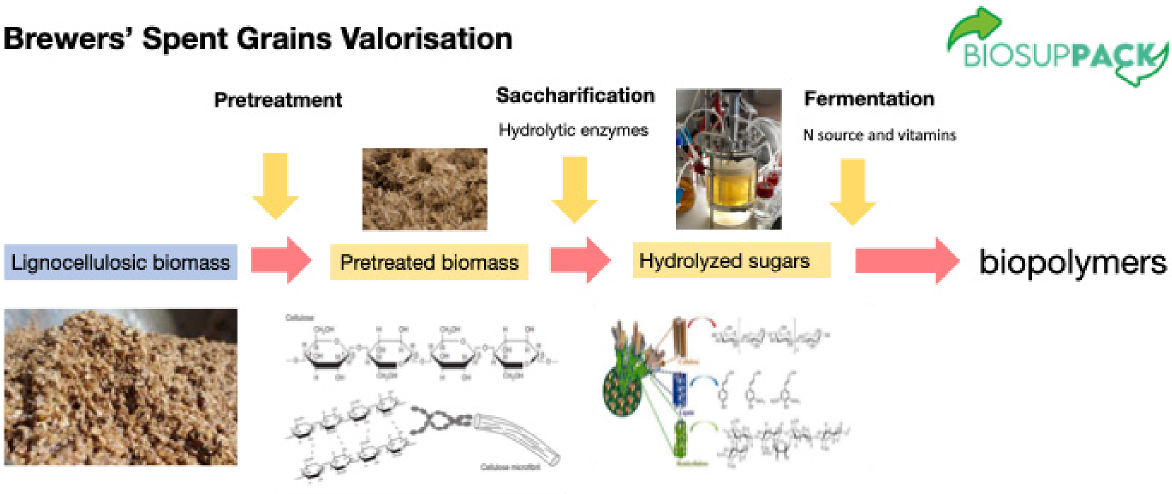

Fig 3.2 Brewers' Spent Grains Valorisation. Source: R.Jiménez Lorenzo, AIMPLAS.

However, the elongation break and melt strength are lower than other non-biodegradable synthetic polymers used in packaging, and their brittleness is very high. So, to include PHAs in different sectors as flexible packaging, we must opt for other PHAs. For example, PHBV is a copolymer composed of PHB and hydroxy valerate units, and the inclusion of valerate makes it less brittle, more ductile, and more accessible to process without comprising biodegradability. This way, we can incorporate PHAs in widely used plastic processing technologies, such as blow moulding.

An exciting sector to include PHAs in is agriculture, such as mulching films. Mulching films are disposed of into the crops, improving growing conditions and helping retain moisture. Once disposed of into the soil, these films are difficult to collect, so the excellent biodegradability of PHBV makes it an ideal material for mulching film applications.

Controlled-release fertilisers are another type of agricultural application ideal for incorporating PHAs. These fertilisers are designed to release nutrients gradually over an extended time. The polymeric matrix protects the fertiliser from run-off and lets the plant absorb nutrients gradually. After the nutrients have been released, the remaining empty matrix remains in the soil. Usually, these matrices are made of synthetic polymers such as PET that bioaccumulate into the soil and generate microplastics. Then, replacing PET with PHA reduces the generation of microplastics while meeting biodegradability requirements needed for EU fertiliser product regulations.

Most of the polymers produced by fermentation are made of monomers such as lactic acid or succinic acid, which are produced for the microorganism during the fermentation and excreted into the fermentation broth. After the purification, the monomers are polymerised to make the bioplastic (e.g., PLA or PBS). In this case, fermentation production is integrated into the industry.

In the case of polymers like PHAs, the polymer is not excreted into the fermentation broth and is then purified. Still, it accumulates inside the cell under stress conditions, such as a deficit of nitrogen or phosphorus in the fermentation media. In producing these polymers, the industry is limited by the amount of biomass produced in fermentation and the efficiency of conversion of organic matter into these reserve polymers. Hence, the yield is usually lower than that of PLA or PBS production.

One possible solution involves genetic engineering, which consists of the overexpression of related genes, which can further increase the conversion efficiency of substrates to PHAs. There are two different strategies: on the one hand, the overexpression of PHA genes increases the accumulation ratio of PHA even in conditions without stress. On the other hand, strains produced by PHAs can consume PHA for cellular respiration. Therefore, suppressing the PHA depolymerase genes can be a straightforward strategy to increase PHA accumulation.

When using lignocellulosic feedstock to produce bioplastics, enzymatic steps are generally necessary when second-generation sugars are liberated from the cellulose and hemicellulose fraction. The use of commercial hydrolytic enzymes in this stage is usually another step that makes the process more expensive, as they represent between 10 and 30% of the total cost. One solution to reduce the use of commercial enzymes would be to produce the enzymes in the same biorefineries and use the same wastes used for bioplastic production. By fermentation, we can produce cellulases that we will use for enzymatic hydrolysis to recover the sugars present in the waste after a second stage. Therefore, by incorporating the two production systems (both hydrolytic enzymes and bioplastics) in the same biorefinery, since the same equipment is needed, lignocellulosic biomass recovery costs can be reduced.

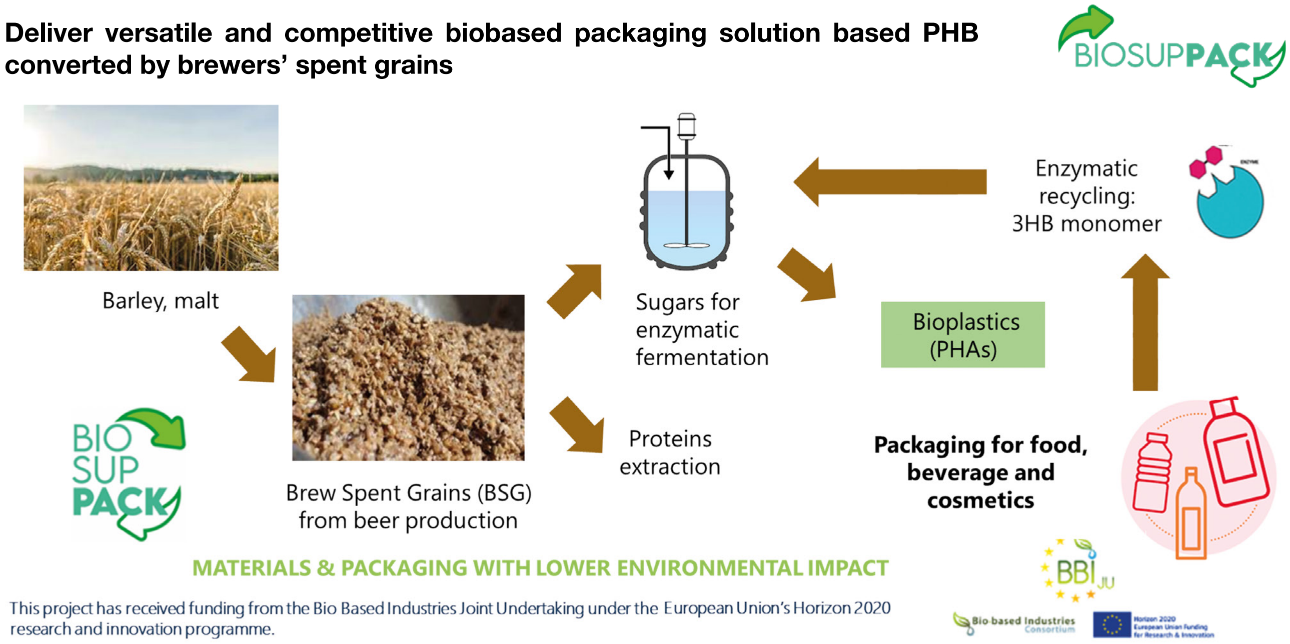

Fig 3.1: The value chain of BioSupPack. Source: AIMPLAS, ENCO.

4. Matching offer and demand: Marketplaces for industrial uptake

There are also other strategies to reduce the economic costs of bioplastic production. One of the most exciting aspects is the use of waste produced by the industry. Waste represents a feedstock with no cost, so its use dramatically reduces the final price of the polymer. In the sectors where waste is generated, there still needs to be awareness of how these wastes can be used. It's necessary to create logistics platforms for all this waste to be collected and efficiently treated so that it can be sent to biorefineries, where it can be converted into bioplastics.

Marketplaces are emerging to support the creation of new value chains. In these chains, the by-product of waste from one process can enter the production process of a second organisation ready to take this waste up, stimulating market demand and offering feedstock for bioplastics. For instance, BioSupPack is currently developing the value chain linked to the use of brewery waste (BSG) to produce PHB for biobased plastics. It will set up a B2B marketplace for industrial beer spent grains, offering a fair return for primary producers. A beta version is available online: https://biosuppack-market.eu/

Digital marketplace for brewer spent grains

Brewing-Bioprocessing Industries for valorization on available bagasse: https://biosuppack-market.eu/

Fig.4.1: The BioSupPack B2B marketplace for industrial beer spent grains. Source: BioSupPack.

In BioSupPack, the teams have created a platform that aims to introduce SMEs and large entities to participate in a new supply chain that improves the circular economy in the brewing industry. In this case, BSG generators and valorisation companies can join a network by sign ing up on the platform. In this way, the platform makes them visible to buyers and providers to foster communication. The marketplace is a splendid example of a marketplace (digital) for putting the demand and offer in contact and creating a more robust value chain for the supply of biowaste to uptakers. In the beta version of this platform, brewery producers can offer their available bagasse, including product/quality specifications and price. Once the bagasse is available, the data is public to other users in the "buy" section, showing the locations on a map. This way, valuation companies can contact brewery companies near their location to purchase the bagasse.

An additional example is provided by the WASTE4SOIL project, with a slightly different focus and target: the farmers. WASTE4SOIL has set up a farmers-to-farmers platform for industrial agrowaste to turn food waste into sustainable soil improvers for better soil health and improved food systems. The focus is on studying the valorisation of eight food processing residues (FPR), e.g., meat, fish, dairy, cereals, olive oil, beverages (wine), fruits and vegetables, and processed food. Seven living labs are deployed in Europe: Each living lab installs and checks the project platform and app to put in contact with the food processing residues with the final end-users of soil improvers (SI). This approach is circular, systemic and multi-actor, and it is implemented at the regional level and involves all food chain actors, thereby closing specific loops (nutrients, organic matter, water). The app introduces data manually or uses sensors specifically developed for the project. This way, the residues are tracked and transformed into soil improvers within each living lab.

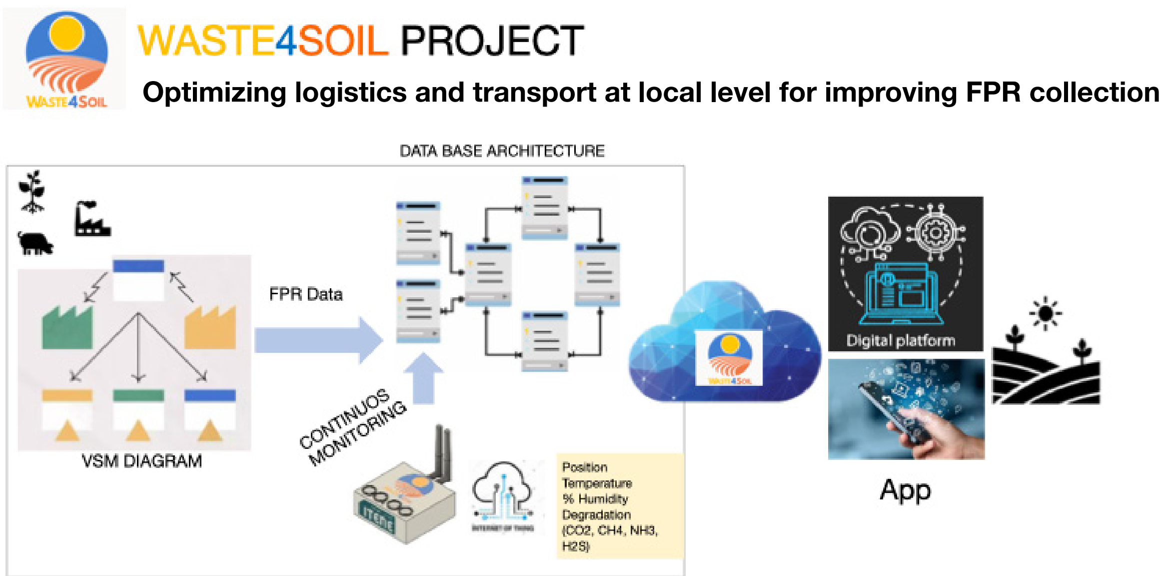

Fig.4.1: The BioSupPack B2B marketplace for industrial beer spent grains. Source: BioSupPack.

So far, the living labs have been set up in Greece, Finland, Spain, Poland, Hungary, Italy, and Slovenia. Still, the developed methodology is meant to be spread to improve FPR knowledge across Europe and transferred to other European regions.

5. Is the waste management system ready to collect biobased plastics, and how long can we keep them in the loop?

In plastic packaging, inadequate sorting and recycling technologies allow for only 6.3% of recycled content in the European packaging market. Synthetic textiles contribute significantly to plastic waste on a global scale, with only 0.06% of all textile waste typically recycled into new textile products ([2]). In agriculture, poor management practices result in the disposal of bioplastic waste in landfills, contributing to environmental damage. Additionally, recycled plastic content in agricultural applications is less than 22% ([3]).

Biodegradable bioplastics, especially those used for packaging, are entering both the plastics recycling and green-waste composting streams, and this could result in increased sorting cost, environmental impact, yield loss, and decreased processability and quality of the recycled or composted output.

The growing bioplastic production must be paralleled with effective end-of-life strategies for bioplastic waste, which is essential for all bioplastics, regardless of their biodegradability ([4]). Biodegradation is not always the best end-of-life option for biodegradable plastic waste, and available recycling strategies should be further enhanced to maximise the environmental benefits of bioplastic materials.

The waste management system must be optimised to support sustainable and circular strategies for bioplastics. A more efficient waste management system must integrate sorting, conditioning, and valorising bioplastic waste streams into end-products of equivalent quality and functionality to mitigate plastic pollution and foster upcycling, recovery, and reuse. There is an urgent need to scale up technologies for waste collection, sorting and recycling. Sound and cost-effective technologies for bioplastics need further demonstration and scaling up to separate bioplastic waste, guarantee high quality and purity, and ultimately produce market-competitive secondary materials.

[2] Textile Exchange, 2020, Textile Exchange, 2020,Material change insights report 2019 — the state of fiber and materials sourcing. https://www.eea.europa.eu/themes/waste/resource-efficiency/plastic-in-textiles-towards-a#:~:text=Textiles%20that%20are%20not%20separately,(Textile%20Exchange%2C%202020)
[3] OECD, Global Plastics Outlook, Economic Drivers, Environmental Impacts and Policy Options (2022), https://doi.org/10.1787/de747aef-en
[4] Fredi G. at al., Recycling of bioplastic waste: A review, Advanced Industrial and Engineering Polymer Research, 2021, https://doi.org/10.1016/j.aiepr.2021.06.006

The project MoeBIOS was launched in June 2024 to address this technological challenge. It will cover sorting waste streams for optimal treatment and scaling up several recycling technologies. The goal is to demonstrate that novel bioplastics can be sorted in existing sorting and recycling schemes without line disruption.

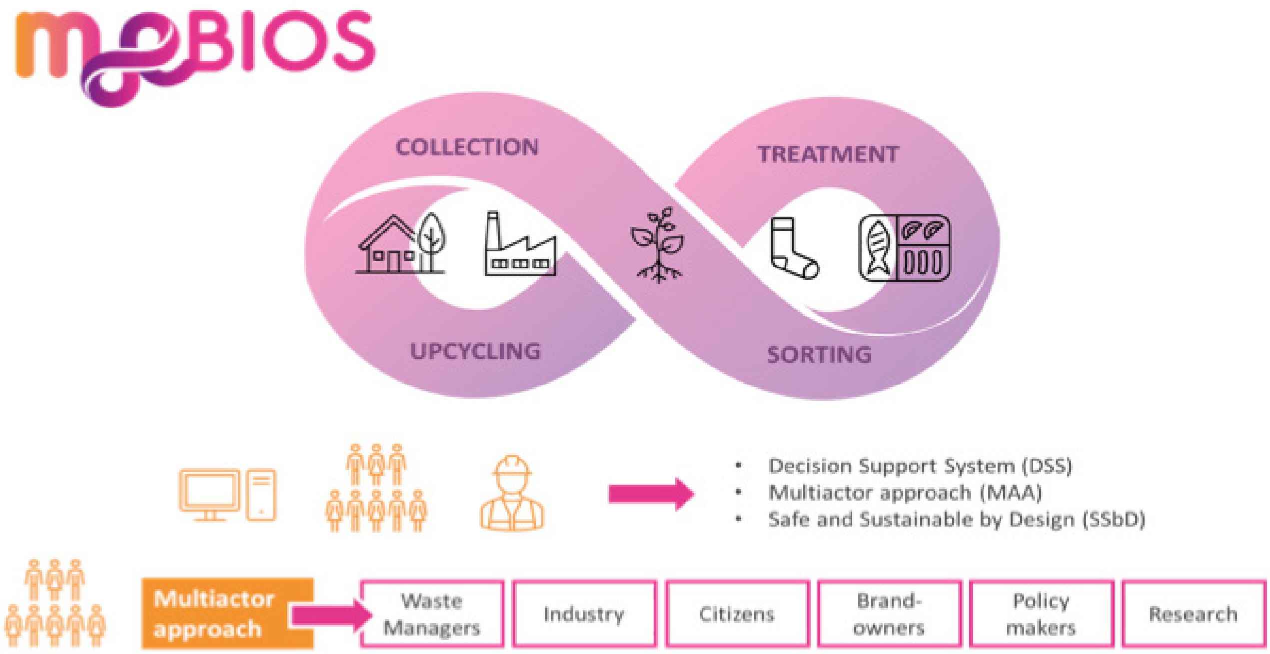

Fig.5.1 Closing the loop of bioplastics end of life. Source: ITENE.

MoeBIOS will work on mechanical, enzymatic, chemical, and thermo-chemical recycling for biobased and biodegradable plastics (BIOS) in three value chains: textiles, packaging, and agricultural waste. The goal is to find integral treatments to keep the materials in the loop as long as possible versus landfilling and incineration. Digital libraries will be built for bioplastics to increase the efficiency of compositional sorting.

- For the packaging, the waste managers will bring MSW with a separate collection.
- For the agricultural waste streams, the waste managers will focus on the post-use and post-industrial waste.
- For the textile waste streams, the waste managers will use post-use and post-industrial waste.

The sorting will be based on innovative infrared and ultraviolet technologies, using hyperspectral and chemometrics. The treatment will then be based on mechanical recycling, enzymatic recycling, chemical recycling, and thermo-chemical recycling in a hierarchical approach aimed at giving each waste stream its optimal treatment from a technical, economic and environmental point of view. The upcycling will be based on the validation of recycled products from packaging, agriculture, and textile products, counting on the expertise of brand owners in the sectors mentioned above.

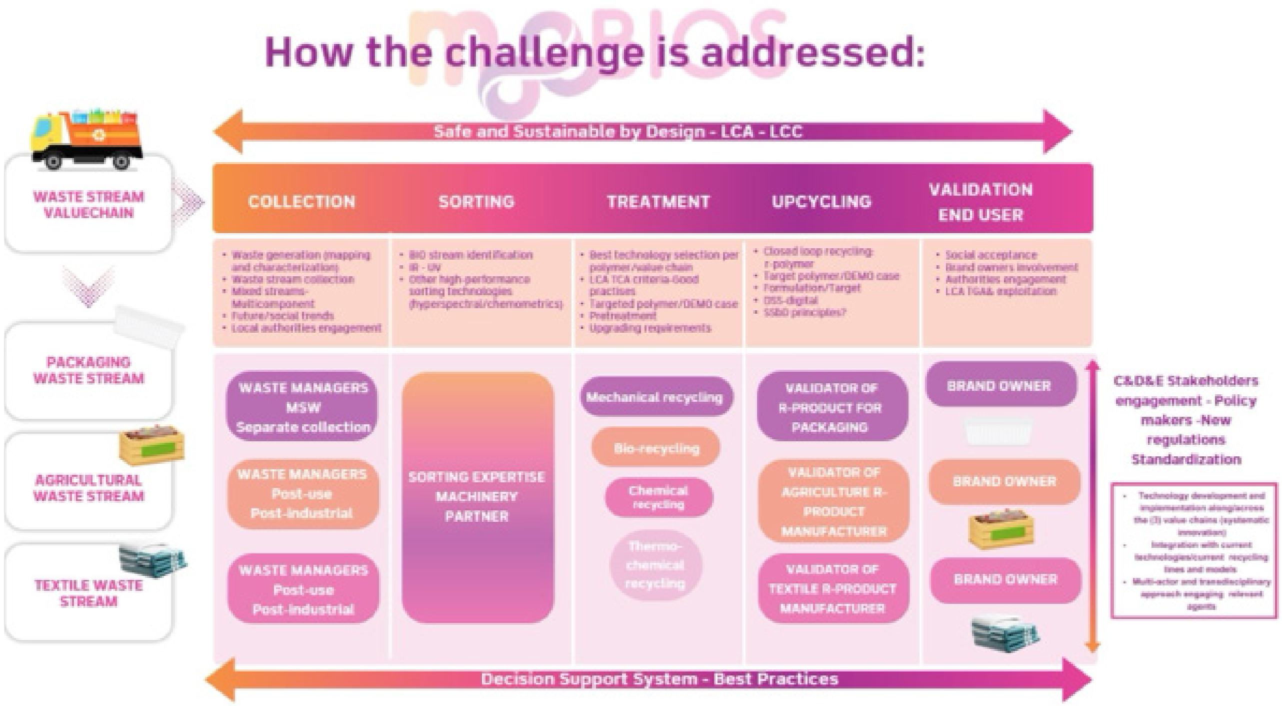

Fig.5.2: How MoeBIOS addresses the challenge of recycling biobased plastics. Source: ITENE.

The best end-of-life option for waste product depends on the material, its volume on the market, and available collection and processing infrastructure. According to the European Commission Waste Framework Directive, waste should be managed according to a precise hierarchy indicating a priority order in the legislation and policy for waste prevention and management: prevention; preparing for re-use; recycling; other recovery, e.g. energy recovery; and disposal.

Further references to the European Commission. Waste Framework Directive **https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en#ref-2023-amendment-to-the-waste-framework-directive**

MoeBIOS has been funded under the call HORIZON-JU-CBE-2023-IA-04: Recycling biobased plastics increasing sorting and recycled content (upcycling), together with two additional projects, ReBioCycle and PROSPER, which have similar, but complementary approaches to the MoeBIOS.

ReBioCycle aims to demonstrate that bio-based biodegradable plastics can be kept in the cycle for as long as possible through innovative recycling technologies and that end-of-life bio-based biodegradable plastics can be used in the circular (bio)economy. ReBioCycle proves a portfolio of bioplastic sorting and recycling technologies within three complementary waste-processor-centric hubs at a demonstration scale and in the real operational environment the effective and efficient recycling of three types of bioplastics (e.g., PLA, PHA, composites) to demonstrate a higher impact of obtaining the same or superior grade recycled polymers and other higher-value applications. LinkedIn: https://www.linkedin.com/company/rebiocycle

ReBioCycle has received funding from the Circular Bio-based Joint Undertaking (JU) and its members under the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101156032. The JU receives support from the European Union's Horizon Europe Research and Innovation Programme and the Bio-based Industries Consortium.

The PROSPER project addresses this challenge by demonstrating the technically and financially viable sorting and recycling of bio-based plastics in packaging. The project integrates these plastics into current waste management practices and implements policy tools like Extended Producer Responsibility (EPR) systems. PROSPER seeks to boost demand for bio-based plastics by highlighting their recyclability and sustainable origins. LinkedIn: https://www.linkedin.com/company/prosperbioplastics

PROSPER has received funding from the Circular Bio-based Joint Undertaking (JU) and its members under the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101157907. The JU receives support from the European Union's Horizon Europe Research and Innovation Programme and the Bio-based Industries Consortium.

6. Closing Remarks and Recommendations

Use biowaste to lower the production costs of biobased plastics.
The market still needs to prepare to pay more for biobased plastics, so lowering their costs is vital.

- Agroindustrial waste can be a source of biobased and biodegradable plastics.
- Currently, agroindustrial waste represents a relatively free feedstock, so its use dramatically reduces the economic costs of bioplastic production and the final price of biobased polymers.
- Exploitation pathways through the creation of platforms such as the BioSupPack and the WASTE4SOIL should be further enhanced by connecting offer and demand. These portals should cater to both the needs for the valorisation of waste for biopolymer production and the use of food processing residues for in-soil applications.
- It's necessary to set up and reinforce logistics platforms for collecting and efficiently treating waste so biorefineries can convert it into bioplastics.

Look at more side streams.
There are alternative feedstocks, and biowaste plays a part in this.

- Potential side streams containing sugar-based or starch-based feedstocks could be explored to produce biopolymers. These include agricultural residues, food processing waste, industrial byproducts, and forestry residues.
- Exploring these side streams helps manage waste and contributes to the sustainability and economic viability of biopolymer production.

Valorise waste to produce bioplastics.
Our research and innovation projects have demonstrated that valorising waste to produce bioplastics is possible.

- Waste valorisation involves converting organic waste materials into valuable products, such as bioplastics, through sustainable and efficient processes. This approach helps manage waste and supports the circular economy by reducing reliance on fossil-based resources.

- The transformation of organic waste materials into eco-friendly alternatives to conventional plastics is linked to the creation of several benefits ranging from landfill reduction, raw materials reuse and minimisation of the environmental footprint.
- Several advancements have been made in the technologies and methodologies used to convert various types of waste into bioplastics. For instance, agricultural residues, food processing waste, and industrial byproducts are effectively utilised as feedstocks. Rich in sugars and starches, these materials can be processed through hydrolysis and fermentation to produce bioplastic monomers such as bio-succinic acid or polylactic acid (PLA) and polyhydroxyalkanoates (PHA).

Give bioplastics a second life.

Research and innovation projects are making strides towards giving bioplastics a second life. Strong emphasis is placed on the importance of sustainable end-of-life management routes for bioplastics, which include recycling and composting initiatives. Solid recycling routes for biobased plastics are urgently needed. The use of biobased plastics is going much faster in other regions of the world, and there is a risk that Europe will need to catch up.

- The waste management system must be optimised to support sustainable and circular strategies for bioplastics. A more efficient waste management system must integrate sorting, conditioning, and valorising bioplastic waste streams into end-products of equivalent quality and functionality to mitigate plastic pollution and foster upcycling, recovery, and reuse.
- Developing AI-driven decision support systems for waste managers is vital to improving the recycling process.
- AI technologies should be combined with further capacity-building measures targeting waste management operations.
- By integrating advanced waste management strategies and promoting circular economy practices, it is possible to ensure that bioplastics do not end up in landfills but are reused efficiently.
- Improving mechanical, chemical, and biological recycling systems for bioplastics is strategic for ensuring that the materials stay in the circular loop as long as possible.
- A holistic and integrated approach reduces environmental impact and supports bioplastic's economic viability by creating a closed-loop system in which materials are continuously repurposed.

Raise awareness and share information on technical and economic feasibility.

Long-term engagement strategies are needed.

- Engagement with industrial stakeholders and policymakers can maximise the uptake of results, ensure comprehensive visibility of its outcomes, and foster a supportive environment for adopting sustainable technologies.
- Engagement with citizens, end-consumers, and the general public is vital to increasing knowledge and changing behaviours to promote acceptance of biobased solutions.
- The continuous assessment of the social acceptance of bioplastics is also crucial to successfully deploying the end products in the market and driving the industry's positive response to resource recycling.
- Investing in increasing awareness is a continuous effort to ensure that waste can be valorised and used to enter a new production cycle.
- In the long term, increased knowledge and understanding can significantly contribute to the circular bioeconomy, reduce reliance on fossil-based resources, and promote sustainable industrial and consumer practices.

Glossary

BSG brewers spent grains: A by-product of brewing, spent grains are rich in fibre and protein but low in sugar.

MSW Municipal Solid Waste: A waste type consisting of everyday items that are discarded by the public.

PBS Poly Butylene Succinate, sometimes written as polytetramethylene succinate, is a thermoplastic polymer resin of the polyester family.

PET Polyethylenterephtalate: The most common thermoplastic polymer resin of the polyester family. It is used in clothing fibres, containers for liquids and foods, thermoforming for manufacturing, and engineering resins in combination with glass fibre.

PHA polyhydroxyalkanoates: Polyesters produced in nature by numerous microorganisms, including through bacterial fermentation of sugars or lipids.

PHB Polyhydroxybutyrate: A biodegradable polymer produced by bacteria and archaea as carbon and energy reserves. Due to its rapid degradation in natural environments, it can be considered a biodegradable plastic alternative.

PHBV, a polyhydroxyalkanoate-type polymer: A copolymer composed of PHB and hydroxy valerate units. It is a biodegradable, non-toxic, biocompatible plastic produced naturally by bacteria and an alternative to many non-biodegradable synthetic polymers.

PLA polylactic acid: A thermoplastic monomer derived from renewable, organic sources such as corn starch or sugar cane.

PP Polypropylene: A common thermoplastic polymer with excellent properties, including high gas and water permeability resistance, mechanical properties, flame resistance, high heat distortion temperature and others.

SCCAs Short-Chain Carboxylic Acids: Metabolic intermediates with a broad range of apparently paradoxical biological effects.

SME Small and Medium Enterprises: These are defined in the EU recommendation 2003/361. https://single-market-economy.ec.europa.eu/smes/sme-fundamentals/sme-definition_en

References

Alexandri, M.; Schneider, R.; Mehlmann, K.; Venus, J.: Recent Advances on D-Lactic Acid Production from Renewable Resources: Case Studies on Agro-industrial Waste Streams – Minireview. Food Technology and Biotechnology 57 (2019) 3, 293-304, https://doi.org/10.17113/ftb.57.03.19.6023

Alexandri, M.; López Gómez, J.P.; Olszewska-Widdrat, A.; Venus, J.: Valorising Agro-industrial Wastes within the Circular Bioeconomy Concept: the Case of Defatted Rice Bran with Emphasis on Bioconversion Strategies. Fermentation 6 (2020) 2, 42,

Astudillo, Á.; Rubilar, O.; Briceño, G.; Diez, M.C.; Schalchli, H. Advances in Agroindustrial Waste as a Substrate for Obtaining Eco-Friendly Microbial Products. Sustainability 2023, 15, 3467. https://doi.org/10.3390/su15043467

Demichelis, F.; Fiore, S.; Pleissner, D.; Venus, J.: Technical and economic assessment of food waste valorisation through a biorefinery chain. Renewable and Sustainable Energy Reviews 94 (2018) 38-48, https://doi.org/10.1016/j.rser.2018.05.064

European Bioplastics, RECYCLING AND RECOVERY: END-OF-LIFE OPTIONS FOR BIOPLASTICS, Position Paper, January 2017, https://docs.european-bioplastics.org/publications/pp/EUBP_PP_End-of-life.pdf accessed online on 16 November 2024

Faria, D.J.; Carvalho, A.P.A.d.; Conte-Junior, C.A. Valorization of Fermented Food Wastes and Byproducts: Bioactive and Valuable Compounds, Bioproduct Synthesis, and Applications. Fermentation 2023, 9, 920. https://doi.org/10.3390/fermentation9100920

FAO. The Future of Food and Agriculture: Trends and Challenges; FAO: Rome, Italy, 2017; Available online: http://www.fao.org/3/i6583e/i6583e.pdf

Favoino E. and M. Giavini Bio-waste generation in the EU: Current capture levels and future potential, 2nd Edition - 2024, a report commissioned by the Bio-based Industries Consortium (BIC), published by BIC and Zero Waste Europe, https://www.biconsortium.eu/publication/bio-waste-generation-eu-current-capture-levels-and-future-potential-0#:~:text=05%20November%202024-,Bio%2Dwaste%20generation%20in%20the%20EU%3A%20Current%20capture%20levels%20and,%2C%20and%20valorising%20bio%2Dwaste.&text=Since%20January%201st%202024%2C%20it,to%20separately%20collect%20bio%2Dwaste

Fredi G. at al., Recycling of bioplastic waste: A review, Advanced Industrial and Engineering Polymer Research, 2021, https://doi.org/10.1016/j.aiepr.2021.06.006

Fredi and Dobrigato, End-of-life routes for bioplastics: not only biodegradation, article online on https://www.milanpolymerdays.org/blog/end-of-life-routes-for-bioplastics-not-only-biodegradation accessed on 16 November 2024

Jagannath, A. and Rao, P.J. (2022). Agri and Food Waste Valorization Through the Production of Biochemicals and Packaging Materials. In Biotechnology for Zero Waste (eds C.M. Hussain and R.K. Kadeppagari). https://doi.org/10.1002/9783527832064.ch34

Kwan, T.H.; Pleissner, D.; Lau, K.Y.; Venus, J.; Pommeret, A.; Lin, C.S.K.: Techno-economic analysis of a food waste valorisation process via microalgae cultivation and co-production of plasticiser, lactic acid and animal feed from algal biomass and food waste. Bioresource Technology 198 (2015) 292-299. http://dx.doi.org/10.1016/j.biortech.2015.09.003

López Gómez, J.P.; Latorre-Sánchez, M.; Unger, P.; Schneider, R.; Lozano, C.C.; Venus, J.: Assessing the organic fraction of municipal solid wastes for the production of lactic acid. Biochemical Engineering Journal 150 (2019), 107251, https://doi.org/10.1016/j.bej.2019.107251

López Gómez, J.P.; Unger, P.; Schneider, R.; Venus, J.: From Upstream to Purification: Production of Lactic Acid from the Organic Fraction of Municipal Solid Waste. Waste Biomass Valor 11 (2020) 10, 5247-5254, https://doi.org/10.1007/s12649-020-00992-9

López-Gómez, J.P.; Pérez-Rivero, C.; Venus, J.: Valorisation of solid biowastes: The lactic acid alternative. Process Biochemistry 99 (2020) 222-235, https://doi.org/10.1016/j.procbio.2020.08.029

Marzo-Gago, Cristina & Venus, Joachim & López-Gómez, José. (2022). Production of lactic acid from pasta wastes using a biorefinery approach. Biotechnology for Biofuels and Bioproducts. 15. https://doi.org/10.1186/s13068-022-02222-x

OECD, Global Plastics Outlook, Economic Drivers, Environmental Impacts and Policy Options (2022), https://doi.org/10.1787/de747aef-en

Pleissner, D.; Qi, Q.; Gao, C.; Perez Rivero, C.; Webb, C.; Lin, C.S.K.; Venus, J.: Valorization of organic residues for the production of added value chemicals: A contribution to the bio-based economy. Biochemical Engineering Journal 116 (2016) 3-16, http://dx.doi.org/10.1016/j.bej.2015.12.016

Pleissner, D.; Demichelis, F.; Mariano, S.; Fiore, S.; Navarro Gutiérrez, I.M.; Schneider, R.; Venus, J.: Direct production of lactic acid based on simultaneous saccharification and fermentation of mixed restaurant food waste. Journal of Cleaner Production 143 (2017) 615-623, http://dx.doi.org/10.1016/j.jclepro.2016.12.065

Venus, J.; Fiore, S.; Demichelis, F.; Pleissner, D.: Centralized and decentralised utilization of organic residues for lactic acid production. Journal of Cleaner Production 172 (2018) 778-785, https://doi.org/10.1016/j.jclepro.2017.10.259

Contributing projects

BioSupPack: Demonstrative process for the production and enzymatic recycling of environmentally safe, superior and versatile PHA-based rigid packaging solutions by plasma integration in the value chain. Website: https://biosuppack.eu/ LinkedIn: https://www.linkedin.com/company/biosuppack-project/

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CAFIPLA: Combining carboxylic acid production and fibre recovery as an innovative, cost-effective and sustainable pre-treatment process for heterogeneous bio-waste. Website: https://cordis.europa.eu/project/id/887115 LinkedIn: https://www.linkedin.com/showcase/cafipla---combining-carboxylic-acid-production-and-fibre-recovery/about/

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LUCRA: Sustainable succinic acid production using an integrated electrochemical bioreactor and renewable feedstock. Website: https://lucra-project.eu/ LinkedIn: https://www.linkedin.com/company/eu-project-lucra

LUCRA The project is supported by the Circular Bio-based Europe Joint Undertaking and its members. This work was also co-funded by UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee grant number 10082169.

MoeBIOS: Improving waste management of biobased plastics and the upcycling in packaging, textile and agriculture sectors. Website: https://www.cbe.europa.eu/projects/moebios LinkedIn: https://www.linkedin.com/company/moebios-eu-com

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PERCAL: Chemical building blocks from versatile MSW biorefinery. Website: https://www.cbe.europa.eu/projects/percal LinkedIn: https://www.linkedin.com/in/percal-project-017605148/

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WASTE4SOIL: Turning food waste into sustainable soil improvers for better soil health and improved food systems. Website: https://waste4soil.eu/ LinkedIn: https://www.linkedin.com/company/waste4soil/

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