biontop

Novel packaging films and textiles with tailored end of life and performance based on bio-based copolymers and coatings.

D.7.8 Industry, stakeholders and policy guidelines regarding BIOnTop waste management

BBI JU

Bio-based Industries Consortium

Horizon 2020
European Union Funding
for Research & Innovation

This project has received funding from the Bio Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 837761

Grant Agreement No:	837761	**Project Acronym:**	BIOnTop
Project Title:	**Novel packaging films and textiles with tailored end of life and performance based on bio-based copolymers and coatings**		
Funding scheme:	BBI-JU-Horizon 2020 – Research & Innovation Action		
Project Coordinator:	AIMPLAS		
Lead Beneficiary	ENCO		
Start date of the project:	01.06.2019	**Duration of the project:**	48 months
Deliverable:	**D.7.8 Industry, stakeholders and policy guidelines regarding BIOnTop waste management**		
Contractual delivery date:	**31.05.2023**		
Actual delivery date:	**01.06.2023**		
Type of Deliverable	R (Document, Report)		
Dissemination level:	Public		
Authors:	ENCO		
Contributors:	EUBP (Bearzotti, Lopez-Hermoso) OWS (Verstichel)		
Version:	**1.2**		

History of changes

Version	Author	Date	Comments
0.1	ENCO	13.05.2023	ToC
1.0	ENCO	17.05.2023	First Draft
1.1	EUBP	29.05.2023	Integrations
1.2	OWS RF	31.05.2023	Integrations

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Acronyms

WP	Work Package
D	Deliverable
EU	European Union
EC	European Commission
BBI-JU	Bio-Based Industries Joint Undertaking
H2020	Horizon 2020
EoL	End of Life
IPR	Intellectual Property Rights
LCA	Life Cycle Analysis
s-LCA	Social life Cycle Analysis
LCC	Life Cycle Cost
PLA	Polylactic Acid
AB	Advisory Board
CA	Consortium Agreement
E&D	Exploitation and Dissemination
KER	Key Exploitable Results
EoL	End of Life
IB	Industrial Biotechnology
OA	Open Access

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Executive summary

This deliverable intends to provide an analysis of the current European waste management landscapes, an overview of the results of EoL tests and LCA carried out during the project, and policy recommendations and position papers produced on waste management.

It has been demonstrated that companies and consumers have to shift their habits into new, innovative and sustainable products that can guarantee the prevention and reduction of waste; the reuse of materials; the easy mechanical recycling; feedstock and energy recovery according to the EU legislations and the promising results carried out during BIOnTOP project. In this sense, the EU current political and policy framework for bio-based and biodegradable plastics has been surveyed, detailing any beneficial and detrimental legislation and initiatives, and the key actors on the EU level, and in some exemplary Member States that exhibit either very progressive or very inhibitive legislation for bioplastics, as well as depending on their waste management land scape. In order to positively influence the political framework for BIOnTOP exploitation, specific fact-based, scientifically backed information have been used in policy recommendations, for example in the areas of waste management and increased resource efficiency, to help utilise the potential of bioplastics in implementing circular bioeconomy principles. In this deliverable BIOnTOP reaches out to EU decision-makers contributing to progressive policy initiatives supporting the bio-based economy.

1. INTRODUCTION

The present deliverable reports the activities carried out and the main results reached in T7.3 within WP7 and in particular the analysis of the EU current Waste Management Landscape for bio-based and biodegradable packaging; the beneficial legislations and initiatives and some recommendations on the use of biodegradable and bio-composite materials. The Deliverable consists of 3 main paragraphs, starting from a detailed analysis of the current EU legislation; waste disposal practices and options; an overview of the benefits of using bioplastics is shown. On Section 3 the results of EoL tests and LCA conducting during the BIOnTOP project are reported, Section 4 is dedicated to the analysis of the EU Policy Framework for bio-based, biodegradable and compostable plastics; the new Packaging and Packaging Waste Regulation proposal is described underlying the benefits of using bio-based packaging and coating materials. Recommendations and guidelines on using BIOnTOP bio-based and compostable materials are also provided, taking into account the results of the tests developed during the project development.

2. CURRENT WASTE MANAGEMENT LANDSCAPE

Efficient waste management is key to the European Commission's flagship policy goal of a resource efficient Europe and its circular economy vision. EU waste management policies aim to reduce the environmental and health impacts of waste and improve Europe's resource efficiency by extracting high-quality resources from waste as much as possible. The European Green Deal aims to promote growth by transitioning to a modern, resource-efficient and competitive economy. The Waste Framework Directive (Directive 98/2008/EC article 4[1]) introduced a five-step waste hierarchy where prevention is the best option, followed by re-use, recycling and other forms of recovery, with disposal such as landfill as the last resort:

- Reduce the amount of waste generated;
- Maximise recycling and re-use;
- Limit incineration to non-recyclable materials;
- Phase out landfilling to non-recyclable and non-recoverable waste;
- Ensure full implementation of the waste policy targets in all EU Member States.

[1] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32008L0098

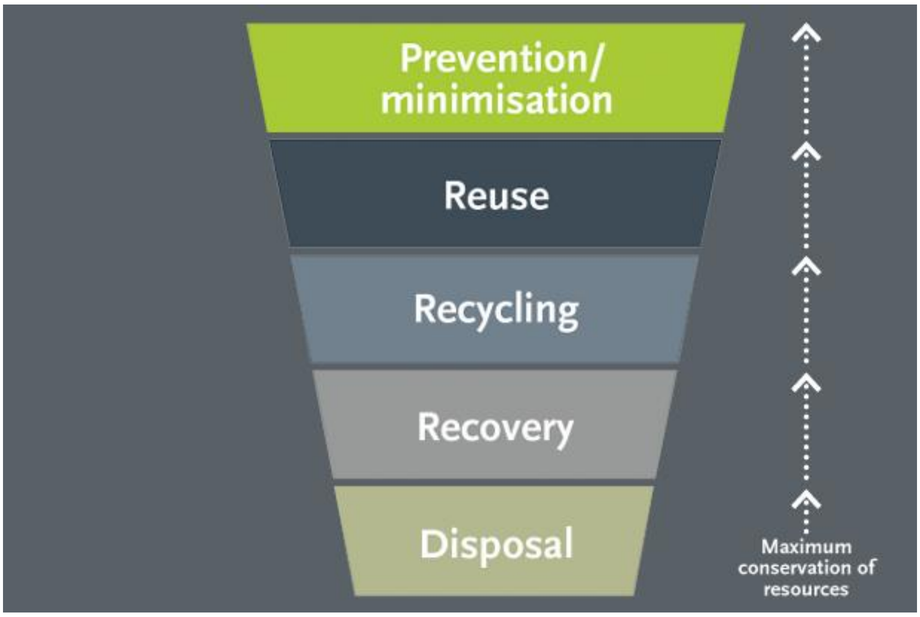

Figure 1: EU waste hierarchy

Waste, defined by Directive 2008/98/EC Article 3[2] as 'any substance or object which the holder discards or intends or is required to discard', potentially represents an enormous loss of resources in the form of both materials and energy. In addition, the management and disposal of waste can have serious environmental impacts. Landfill, for example, takes up land space and may cause air, water and soil pollution, while incineration may result in emissions of air pollutants.

EU waste management policies therefore aim to reduce the environmental and health impacts of waste and to improve the EU's resource efficiency. The long-term aim of these policies is to reduce the amount of waste generated and when waste generation is unavoidable to promote it as a resource and achieve higher levels of recycling and the safe disposal of waste. The waste management sector is responsible for all aspects of the waste cycle. It provides vital services including the collection, transportation, processing, disposal, and recycling of materials that have been discarded. These services are in place to not only protect human health and reduce environmental impacts but also recover valuable resources.

[2] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32008L0098

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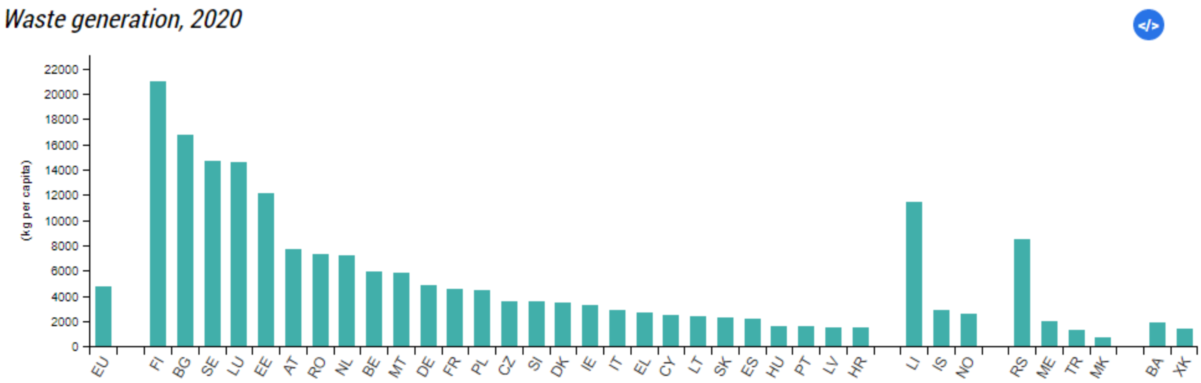

***Figure 2: EU waste generation*[3]**

The European Union is recognized as a global leader in waste management, with many of the highest recycling rates in the world reported by EU Member States such as Germany, Italy, and Austria.

The European Union generated more than 2.1 billion metric tons of waste in 2020, or roughly 4.8 metric tons of waste per capita. Households accounted for roughly 10 % of total EU waste generation that year. The average amount of municipal waste produced per inhabitant in the EU has been increasing in recent years and reached 517 kilograms per capita in 2020. Municipal waste per person was the highest in Denmark in 2020, at almost 850 kilograms. This was followed by Luxembourg, Malta, and Germany. In comparison, Poland and Romania had the lowest per capita waste generation that year at less than 350 kilograms.

In 2020, 31% of total EU waste was disposed of at landfill sites, while almost 9% was incinerated without energy recovery or disposed of otherwise. The remaining 60% of waste was treated in recovery operations, with recycling accounting for 39%. How waste is treated in the EU varies greatly among the Member States. For example, more than 80% of waste in Italy is recycled, whereas other Member States predominantly dispose of their waste at landfills.

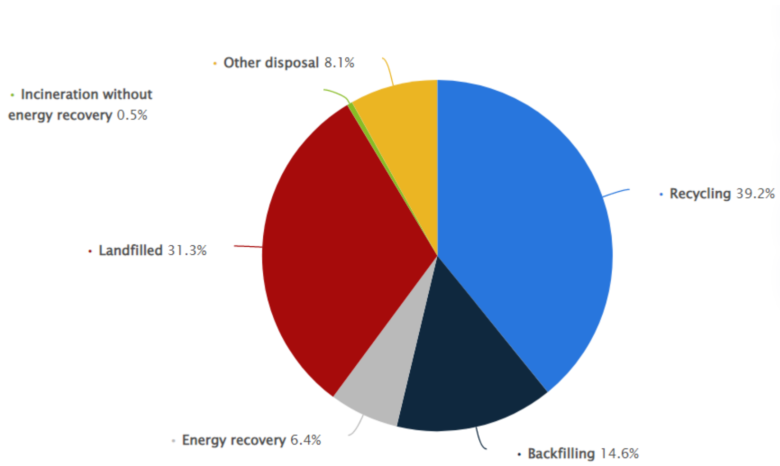

***Figure 3: Distribution of total waste treatment in the European Union (EU-27) in 2020, by type of recovery and disposal*[4]**

[3] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics

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The recycling rate of municipal waste has increased steadily in the EU over the decades and reached 48.1% in 2019. This figure dropped slightly in 2020 to 47.8% as a result of disruptions to waste services during the COVID-19 pandemic. Overall, eight EU Members have a municipal waste recycling rate of more than 50 percent, with the highest recorded in Germany.

A series of ambitious recycling targets have been set for the coming decades to promote a more circular economy within the European Union. EU Member States are now legally bound to recycle (or prepare for reuse) 60% of municipal waste generated by 2030.

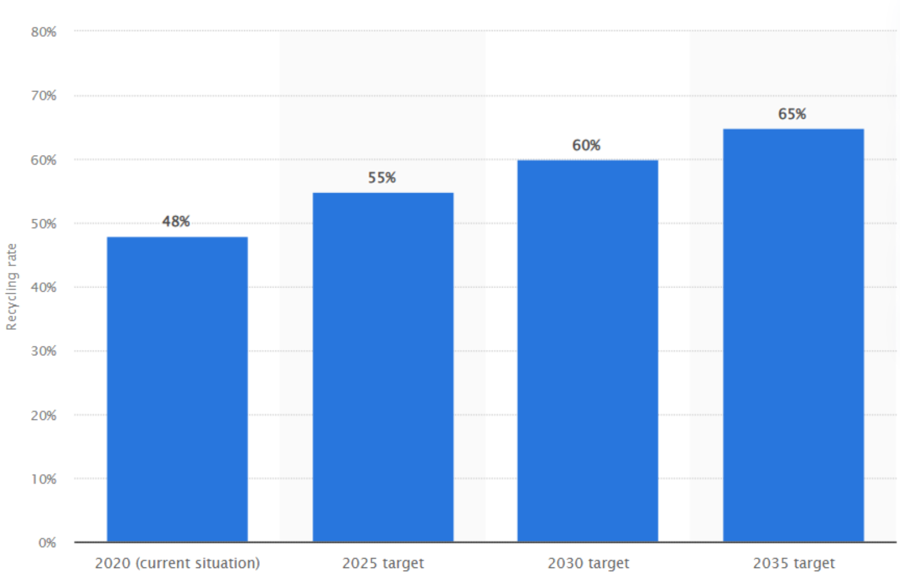

Figure 4: Municipal waste recycling targets in the European Union (EU-27) from 2020 to 2035

Under the European Commission's Waste Framework Directive, residual municipal waste needs to be reduced by 50% by 2030 to roughly 56.5 million metric tons. However, the EU is currently not on track to reach this target without reducing waste generation. This means that recycling alone is not enough to solve the waste problem, and that waste prevention is urgently required[5].

In this frame, bioplastics are suitable for a broad range of end-of life options. With the overwhelming part of the volumes of bioplastics produced today already being recycled alongside their conventional counterparts where separate recycling streams for certain material types exist (e.g. bio-based PE in the PE-stream or bio-based PET in the PET stream). This way, bioplastics can contribute to higher recycling quotas in the EU and more efficient waste management.

As with conventional plastics, the manner in which bioplastics waste is recovered depends on the type of the product, the bioplastics material used, as well as the volumes and recovery systems available.

[4] https://www.statista.com/statistics/1341013/european-union-total-waste-treatment-shares-by-method/

[5] https://www.statista.com/topics/7561/waste-management-in-europe/#topicOverview

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Thanks to the factsheet "*Bioplastics - furthering efficient waste management - Recycling and recovery options for bioplastics*[6]" we can see the waste management options and benefits of bioplastics:

- Prevention and reduction: This step of the waste hierarchy requires the use of manufacturing processes and materials that minimise resource use and maximise the functional performance of the product. Plastics have consistently proved their suitability, with products becoming increasingly thinner, lighter, and stronger. The rules of competition as well as the economic and ecological demands of the market also lead to bioplastics increasing their performance and resource efficiency. The amount of products already available on the market and the high growth rates testify to what bioplastics have achieved.

- Reuse: There is already a large number of plastic products that can be reused multiple times. PET bottles can be recirculated in recycling systems after cleaning, and the same is true for bio-based PET. Carrier bags made from bio-based PE, PLA, or starch materials can be reused many times before the material wears out. Bioplastics offer numerous opportunities for creating reusable products.

- Mechanical recycling: Examples of easily recyclable plastic products are large surface films (e.g. carrier bags), large hollow containers (e.g. bottles), or construction materials (e.g. window frames). The recyclability of plastic products depends on the product design, material composition, and the cost effectiveness of the process. The task is simpler for products, which are not made from complex material blends and which can easily be separated into recyclable materials. The new bio-based versions of PE, PET or (upcoming) PP are chemically and physically identical to their widely used fossil-based counterparts and, thus, can easily be disposed of in established recycling streams. The post-consumer recycling of other bioplastics for which no separate stream yet exists will be feasible as soon as the commercial volumes and sales increase sufficiently enough to cover the investments required. New separate streams (e.g. for PLA) will be introduced in the short to medium term. Numerous research projects and tests, e.g. for PLA, are currently underway in Germany, Belgium, and the USA.

- Organic recycling/composting: Using biodegradable and compostable plastic products such as (biowaste) bags, packaging, or cutlery can increase the options for the end-of-life treatment of those products. In addition to recovering energy and mechanical recycling, industrial composting (organic recovery/organic recycling) becomes a waste management option. This is a clear benefit when plastic items are mixed with biowaste. Under these conditions, mechanical recycling is not feasible for neither the plastics nor the biowaste. The use of compostable plastics makes the mixed waste suitable for organic recycling, enabling the shift from recovery to recycling (a treatment option which ranks higher on the waste hierarchy). This way, biowaste is diverted from other recycling streams or from landfill and separate collection facilitated – resulting in the creation of more valuable compost. In order to be suitable for organic recycling, products and materials need to meet the strict criteria of the European norm EN 13432 on industrial compostability. Following successful certification, these products and materials are permitted to be advertised and labelled as 'industrially compostable'. The Seedling label is a well-known mark for products conforming to EN 13432.

[6] https://docs.european-bioplastics.org/2016/publications/fs/EUBP_fs_end-of-life.pdf

- Feedstock recovery: Whenever mechanical recycling experiences technical difficulties or is not economically viable, feedstock recovery is the recommended alternative. These processes are considerably less sensitive to contaminants and can easily be operated with mixed materials. This includes the recovery of plastic waste as a secondary raw material in concrete or steel production, for instance. Bioplastics perform just like their fossil counterparts in this process and are therefore easily recovered in the same way. Furthermore, bio-based and non-bio-based plastics together with municipal waste can be transformed into syngas through the process of gasification. The resulting syngas features a significant bio-based content that is determined by the input amount of bio-based plastics and organic waste. Syngas can be used for either electricity generation, the production of fuel (synthetic petroleum), or the production of methanol and ethanol. In the latter case, it can subsequently be transformed into chemical feedstock such as olefins and acrylates with a high bio-based content for the polymerization of polyethylene, polypropylene, polyester and other polymers.

- Energy recovery: Incineration of plastic waste to create heat and energy (electricity) is one of the most frequent recovery options for plastic waste in Europe (39.5 percent of plastic waste in 2014 was recovered through energy recovery processes).3 The high calorific value of plastics makes them an ideal replacement for coal and heating fuel. Whether they are bio-based or fossil-based makes no technical difference to the recovery process. However, in the case of bio-based plastics, renewable energy can be obtained from the biogenic carbon – a significant advantage.

- Landfill: Landfilling is a hurdle to resource efficiency. Even though it is still one of the main disposal options in many countries in Europe, continual progress towards a phase-out can be observed. In 2014, around 31% of plastic waste went to landfills, 4 7% less compared to 2012. European Bioplastics supports a European-wide ban on landfilling for plastic products and supports any measures in order to increase recycling and recovery of plastics waste.

New materials, such as PEF and PLA can also be mechanically recycled but still face the hurdles of low market shares. Compostability is a feature of certain biodegradable bioplastics that offers additional waste treatment options at the end of a product's life. Products, such as compostable biowaste bags or food packaging can be treated together with organic waste in industrial composting plants or AD plants and are thus diverted from landfills and turned into biogas or valuable compost. If bioplastics can no longer be reused or recycled, they can be used for the production of renewable energy.

Bioplastics can be mechanically or organically recycled and at the end of a product's life energy can be recovered. Being partially or fully bio-based and offering more waste options than conventional plastics, bioplastics drive resource efficiency in Europe and help the EU in creating a true circular bioeconomy.

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3. RESULTS OF EOL TESTS AND LCA

The LCA results of the BIONTOP materials are given in the confidential deliverable D4.2 and cannot be communicated directly to the public. Nevertheless, potential and expected benefits of the BIONTOP-materials through their tailored end-of-life possibilities can be highlighted.

The interpretation of the end-of-life impacts and whether one is more environmental friendly than the other is often obscured by the large variety of scope and depth between different studies. However, mechanical recycling often comes out as the option with the lowest impact on the environment, especially when recycling in a closed loop is possible. Unfortunately, in the field of food packaging, and even for well-established recycling routes, such as exist for PET, closed loop recycling is only possible for a part of the incoming waste and for a limited number of times. It is more probable that the waste is recycled in an open recycling route which means that the recycled material has lower processability than virgin plastic material and is subsequently used for other applications. Regardless of whether an open or closed loop is considered, the main impact benefit of mechanical recycling lies in the fact that two functions are fulfilled at the same time: waste is removed, and new raw material is produced. Evidently, the impact benefit depends for a part on the application of the recycled material and the material it replaces on the market. Does recycled material replace virgin grade plastic granulate or does it replace other materials? If recycled granulate can replace virgin produced plastic (possibly in a closed loop system) relatively large impact benefits can be expected, provided that transportation and electricity use related to the recycling process (and subsequent distribution) are not excessive. If the recycled material replaces other materials, then it really depends on the type of replaced material and intended application. Note that recycled plastics are often used in items that don't require virgin plastic quality in the first place. Recycled plastics may also be used in items with relatively long lifetimes (gardening or decorative items), although these lifetimes are mostly not long enough to be interpreted as true carbon sinks. Just as with fossil-based plastics, the processability or usability of the recycled bioplastics should be maximized as otherwise, high-end applications will still require virgin grade materials and the potential environmental benefits of mechanical recycling will not be used to the full extent. Experiments done in BIONTOP have shown that granulates from recycling of BIONTOP lidding films retain very good processability characteristics and may even be suited for closed loop recycling. Granulates from recycled BIONTOP trays had decreased properties but could still be used for downgraded applications. On the other hand, these trays showed advanced biodegradability under home composting conditions (see further).

As indicated higher, composting of plastic packaging is interesting when this packaging is spoiled with biowaste such as food waste. Food waste is not suited for incineration because of the relatively high moisture content and subsequently only limited energy can be recovered in this route. Also, landfilling of food waste is not desirable because the anaerobic conditions will lead to methane production. While this methane can be recovered with specialized techniques at some locations, any leakage of this powerful greenhouse gas cannot be prevented. Composting allows to recover a part of the carbon in the waste as compost, of which subsequently a part will enter the soil system as humus while the other part will be converted to CO_2 upon application to the soil. Compost as soil conditioner has the benefit that it can be used to replace peat, which is considered a fossil fuel, and which also is less effective for humus formation. Apart from this, compost improves the structure and health of the soil by adding organic matter, helps the soil retain moisture and nutrients, attracts beneficial organisms to the soil and reduces the need for pesticides and fertilizers, reduces the potential for soil erosion and builds resiliency to the impacts of climate change. Characteristics that are not yet recognized in life cycle analyses. Furthermore, if the composting process is performed under good conditions (oxygen-rich, suitable humidity), the emission of environmental harmful gasses such as methane, dinitrogen oxide and ammonia should be limited. Note than methane and dinitrogen oxide are much more powerful greenhouse gasses than CO_2 and that ammonia is a major impact contributor directly or indirectly on all N-related environmental impacts such as acidification, eutrophication, and fine particulate matter formation. The big benefit of industrial composting lies in the fact that the composting process is optimized (to the extent possible) in industrial composting facilities, thereby lowering the residence time while at the same time maintaining compost quality.

These optimal conditions are much harder to achieve when composting at home. Consequently, harmful emissions of methane, dinitrogen oxide and ammonia are much more likely to occur at home composting. The benefit of home composting, namely the lack of waste transportation, thus is counteracted by the emissions caused by the suboptimal conditions that are much more likely to occur at home composters than in industrial composting facilities. However, it is exactly here at home composting, where a potential exists for compostable bioplastics. Effective composting not only depends on factors such as oxygen availability and humidity but also on the C:N ratio of the waste. A good composting condition would require a C:N ratio of 20 to 40. Kitchen waste and food waste generally are high in N and low in C. Plastics, in contrast, consist for the largest part of C and, if they are (home) compostable, may be very effective in increasing the C:N to a more favourable ratio, especially at home composting where composting parameters are not monitored. Compostable plastics may also be used to tune the C:N ratio in industrial composting facilities, although suitable C:N ratios are usually already achieved by other C-rich materials such as straw and wood pellets. It is not straightforward to assess how the environmental impact of the (industrial) compost will change when straw or wood is replaced by theses compostable plastics. Furthermore, compostable plastics are sometimes criticized that they do not contribute to the formation of compost (and humus) and thus carbon storage. It is true that the C stored in the compostable plastics is much more likely to be used as an energy source by the composting bacteria, and therefore this plastic-C would rather be converted to CO_2 than as C stored in humus. However, without energy source, bacteria won't be able to grow in biomass and as such it influences positively the composting process. Furthermore, when these plastics are used for packaging organic matter (food, feed,…) it will allow a more easily disposal to the green fraction and bring more organic waste to the composting facilities, diverting it from incineration or landfilling, and as such inducing environmental benefits. Furthermore, for biobased materials, as developed within the BIONTOP project, composting is a circular process and as such part of a more sustainable economy.

The environmental impact of the composting process will also depend on the type of product that is considered. Tea bags, for example, are usually disposed together with their wet organic contents and generally are incinerated. Because of the high moisture content, transportation of waste tea bags is relatively inefficient, and only little energy can be recovered when this wet waste is incinerated. In BIONTOP, tea bag textiles are developed which are compostable at industrial level or at home. Given the relative inefficiency of transportation of the relatively heavy wet waste, home composting of tea bags may be a sustainable option provided that good composting conditions are maintained in the home composter. The high C content of the bioplastic may play a role in obtaining good composting conditions. Apart from these tea bag textiles, also biobased home compostable trays were developed, unlocking the potential for composting plastics at home, and at the same time improving the composting of the other biowaste.

Furthermore, these tea bags and trays are also industrially compostable, as also the developed biobased films and oriented net for food packaging. This will result in a higher biowaste capture for spoiled food, as the packaging can be treated together with its content. This is an indirect effect of these compostable packaging but will divert organic waste going to incineration and instead be recycled into valuable compost. Together with the high biobased content of the develop materials and the additional option to also mechanically these products, it will result in a more sustainable world.

4. POLICY

During the entire project lifetime, the BIOnTop partner European Bioplastics (EUBP) has fed into the consortium the challenges of a changing policy and regulatory framework at European level, to enable the researchers to be a step ahead on the upcoming changes influencing their work. EUBP represents the interests of the entire value-chain of bio-based, recyclable, and biodegradable/compostable materials and products, and in BIOnTop it has proactively contribute to feed the consortium with inputs on the ongoing discussions at European level on the changes in the policy and regulatory framework and feedback inputs from the consortium into the policy discussion at EU level.

Today, there is no European law in place applying specifically to bio-based, biodegradable and compostable plastics. Yet, the European Union has made increasing efforts to introduce or adapt policies, regulatory frameworks, and standards to strengthen and implement the bioeconomy and circular economy in Europe in recent years, all of which affect the bioplastics sector in one way or another. In particular, the policy framework for bio-based, biodegradable and compostable plastics, as part of the Commission's Circular Economy Action Plan and Green Deal, is a crucial piece of legislation. Several policy processes have the potential to boost the role of bioplastics in developing a truly circular bioeconomy, enabling innovation, and attracting new investments. In order to be able to contribute to the ambitious climate goals of the European Union, it is important that the relevant legislation acknowledges the important role of bioplastics within a circular economy.

Here a list of the European top-level strategies supporting bioplastics:

- EU Bioeconomy Strategy (2018)
- EU Plastics Strategy (2018)
- EU Green Deal (2019)
- New EU Circular Economy Action Plan (2020)
- EU Climate Law (2021) & EU Taxonomy (2020)
- Packaging & Packaging Waste Regulation (review 2023)
- Waste Framework Directive (review 2023)

Other relevant policy initiatives include:

- Single-Use Plastics Directive (2019) incl. restrictions on oxo-degradable plastics
- EU rules on recycled plastics for food-contact materials (2022)
- Substantiating claims on environmental performance (2022)
- Sustainable Products Initiative (2022) / Proposal on eco-design for sustainable products Regulation
- Policy Framework for bio-based, biodegradable and compostable plastics (2022)
- Sustainable Carbon Cycles (2021)

The diagram below shows the various relevant legislative proposals, revisions, and initiatives and their connection to the wider EU strategies and related Action Plans, such as the European Green Deal and the EU Plastics Strategy (2018). The European Green Deal sets out the aim for Europe to become climate neutral by 2050. As part of this policy framework, the New Circular Economy Action Plan (2020) focuses on sustainable use of resources.

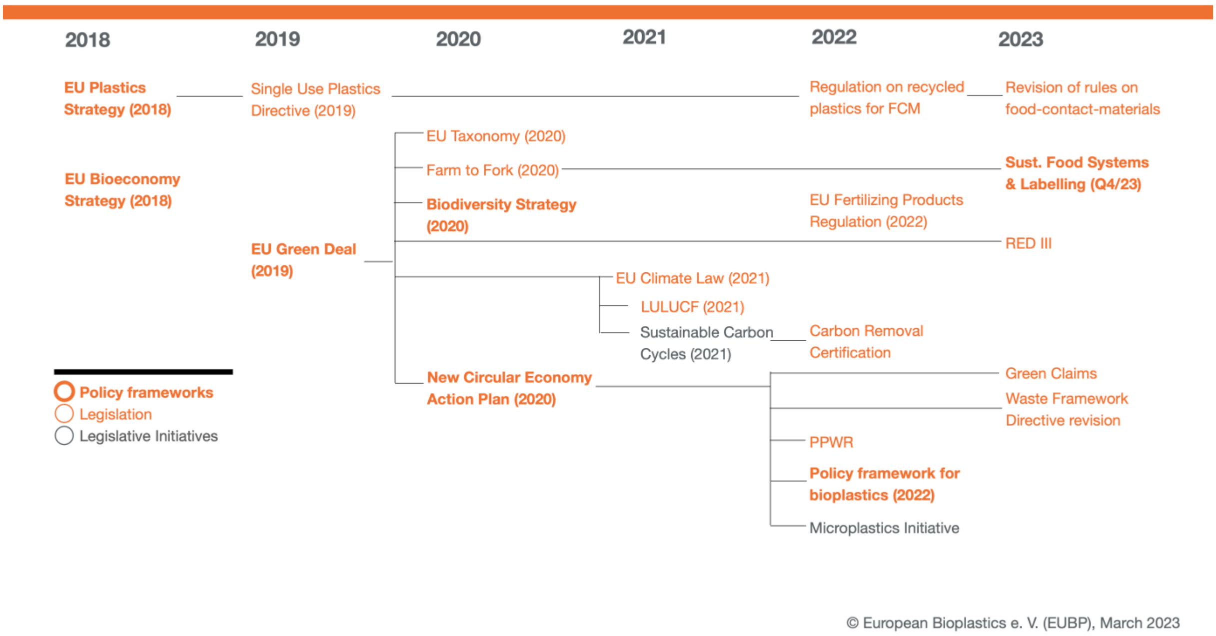

Figure 5: Overview of relevant EU legislation for bioplastics, European Bioplastics © March 2023.

In the following subsections the current status of the most relevant regulations for BIOnTop.

4.1. Policy framework for bio-based, biodegradable and compostable plastics

The European Commission (EC) published on 30 November 2022 a **Communication** on the **"EU policy framework on bio-based, biodegradable and compostable plastics".** The policy framework was announced in the European Green Deal, the Circular Economy Action Plan, and the Plastics Strategy with the aim to contribute to a sustainable plastics economy. The Communication aims to improve the understanding around bioplastics. The framework in the Communication clarifies where these innovative materials can provide environmental benefits, under which conditions, and for which applications, while holding them to the same strict standards as any other material.

While the Commission's Communication for the EU policy framework is non-legislative, e.g., is not legally binding, it reflects the Commission's views and intentions on these materials and will guide future EU policy making, such as the initiatives on green claims, eco-design for sustainable products, carbon removal, or microplastics. The Communication was simultaneously published with the European Commission proposal for a Packaging and Packaging Waste Regulation (in short PPWR), to which it is very much linked particularly regarding the use of compostable plastics in packaging applications to reduce food waste and contribute to the separate collection of biowaste.

The policy framework provides **definitions for bio-based, biodegradable, and compostable plastics** and recognises their potential benefits and underlines their challenges. According to the Commission, the priority should be to **reduce resource consumption, to keep raw materials in the loop for as long as possible, and to use secondary raw materials instead of primary raw materials**. In the Communication, emphasis is also given to the need for a more systemic approach to decisions involving bio-based, biodegradable, and compostable plastics, since EU policies and legislation on aspects and applications of these materials are not yet harmonised across the EU.

The European Commission commits itself to continue promoting research and innovation in this field with the aim of designing circular bio-based plastics that are safe and sustainable by design and that allow for reusability, recyclability, or biodegradability. During its implementation, the BIOnTop consortium has fully aligned to these principles.

4.2. Packaging and Packaging Waste Regulation proposal

The European Commission proposal for a Packaging and Packaging Waste Regulation (PPWR) was published on 30 November 2022. Originally it was intended as a proposal for a revised Directive, but the European Commission decided to transform it into a proposal for a Regulation, to ensure uniformity in its application across member states. It was published simultaneously with the above-mentioned Communication on a policy framework for bio-based, biodegradable and compostable plastics.

The PPWR aims to make all packaging reusable or recyclable by 2030. It establishes requirements for the entire life cycle of packaging with regards to environmental sustainability and labelling, to allow its placing on the market, as well as for the extended producer responsibility, collection, treatment, and recycling of packaging waste. The proposal provides a list of the items covered in this proposal (Annex I of the proposal).

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The main relevant elements of the PPWR for BIOnTop are summarised below:

- **Sustainability requirements for packaging:** The Commission laid down requirements for substances in packaging (lead, cadmium, mercury and hexavalent chromium), without prejudice of the already existing restrictions. The proposed Regulation may be amended by EC delegated acts to reflect scientific and technical progress in order to:
  - Lower the sum of concentration levels resulting from substances present in packaging or packaging components;
  - To determine which materials and product loops are exempt from the concentration level, as well as which types of packaging are exempt from the requirements, and
  - To determine under which conditions the concentration level does not apply.

- **Recyclability requirements:** The European Commission states that all packaging should be recyclable. Packaging shall be considered recyclable when:
  - It is designed for recycling;
  - It is effectively and efficiently separately collected;
  - It is sorted into defined waste streams without affecting the recyclability of other waste streams;
  - It can be recycled so that the resulting secondary raw materials are of sufficient quality to substitute the primary raw materials;
  - It can be recycled at scale.

4.3. Recommendations and guidelines

The transition to a climate neutral plastics economy requires a shift towards non-fossil bio-based plastics in addition to efforts to rethink, reduce, reuse and recycle.[7] The BIOnTop results are outstanding examples of how this transition can be achieved and how the technical specifications of the applications can make it possible to shift to bio-based plastics.

The packaging applications developed in BIOnTop have demonstrated to be:

- Close to 100% bio-sourced.
- Providing superior product preservation in case of barrier packaging and advanced functionalities.
- Meeting converters' processability (standard techniques used).
- Meet the requirements of a wide range of products demonstrators and the perceived needs of the consumers.
- Recyclable-by-design/ EoL options adjustable to the respective applications (e.g. mechanically recycled, industrially/ domestically composted, suitable for anaerobic digestion).
- Cost competitive.

[7] SYSTEMIQ (2022). ReShaping Plastics: Pathways to a Circular, Climate Neutral Plastics System in Europe. https://www.systemiq.earth/raw-materials-europe/

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- Enable a reduction of EoL handling fees.
- Have a reduced environmental impact.

BIOnTop applications are a demonstration of how eco design for packaging products is not only technologically feasible, but also economically viable. The project has designed novel functional bio-based packaging products that are reusable, recyclable, and/or compostable and biodegradable, as an alternative to the currently identified benchmark products. The novel packaging products are recyclable or compostable/ biodegradable in various environments and able to reduce their overall environmental footprint. A more circular packaging production is possible. The benefits of circular packaging production are tangible, and this has been demonstrated by the development of novel processing solutions and products.

At its final conference, held together with other 11 EU-funded projects, the BIOnTop consortium has also highlighted the following areas of improvement for the future:

- More work is needed to assess and reduce the net greenhouse gas emissions of bio-based plastics compared to their fossil-based equivalents, taking into account the lifetime of application and the possibility of multiple recycling.
- The biodegradation processes need to be further explored to ensure that bioplastics can biodegrade safely, taking in account the possible transfer to other environments, biodegradation timeframes and long-term effects, and to minimise any negative effects, including long-term effects, of additives used in biodegradable and plastic products.
- More research is also needed into consumer behaviour and the claims of biodegradability as a factor that may have an influence on littering behaviour.

CONCLUSIONS

Considering the final goal of BIOnTOP project and the materials developed and tested together with the very promising results reached with this deliverable the consortium gave to stakeholders and policy makers some guidelines on the benefits of using BIOnTOP solutions, considering their useful waste management and disposal.

This document includes relevant information gathered from the analysis of the EU current and future waste management regulations but also taking into account the positive results from BIOnTOP EoL tests and LCA. Thus, this document is intended as a Report with recommendations and suggestions on how to optimally manage BIOnTOP waste.

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