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# To what extent are Bioplastics truly harmless?

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**Abstract**

Biodegradability is a growing interest in the field of research in Bioplastics. To what extent are we fully aware of the benign impact Bioplastic has on the environment, especially in water?

Wastewater treatment plants are the primary source of microplastic release in the hydrographical environment. Almost 56% of annual plastic is discarded (19% recycled, 25% incinerated), the majority of which is discharged in the ocean.

To reduce the negative impact of plastic waste on the environment, Bioplastics are chosen as an eco-friendly solution. Although Bioplastics are produced from renewable sources, it is a misbelief to consider all bioplastic harmless for the environment. As a matter of fact, most bioplastics are biodegradable but not compostable, a necessary criterion of sustainability. The behavior of micro-bioplastics in the aquatic environment is a complex ongoing area of research.

The aim of this work is to give insight on the overlooked damaging nature of bioplastics in both production and disposal processes.

Furthermore, a focus is placed on the recovery of bioplastics from wastewater by applying circular economy criteria and technology, including WWTPs processes.

**Keywords:** bioplastics sustainability, WWTPs, microplastics, biodegradability, wastewater

## 1. Introduction

Nowadays, plastic waste represents one of the major, if not the major, cause of pollution, in particular water pollution. Approximately 269,000 tons of plastic (Eriksen, 2014) are currently floating in the marine environment. As an attempt to reduce plastic waste, bioplastics have been chosen as the main substitute to petroleum-based plastic. Bioplastics (BPL) are made from renewable sources, varying from biomass to biopolymers. In comparison to petrol-based, bio-based plastic decompose in $CO_2$ and $H_2O$ but, as we will discuss later in this article, not all bioplastics can completely decay without harming the environment. Full decomposition is strictly connected to biodegradability, making it a common denominator for the classification of Bioplastics (Fig.1).

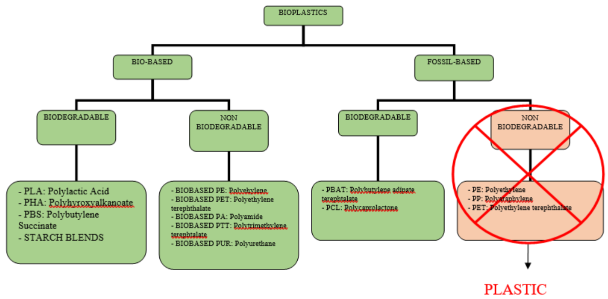



**Figure 1.** Bioplastics Classification (European Bioplastics: bioplastic materials; 2015)

Production of most bioplastics is carried out with the use of biodegradable polymers, available from natural resources. A more thorough classification of biopolymers leads to Agro-polymers, from natural origin (starch, cellulose, proteins, lipids..) and Bio-polyesters, from mineral resources (aromatic polyesters, aliphatic polyesters, modified polyolefins…).

Specifically, five branches of BPLs are identifiable: *Starch Based*, corn starch blended with bio-polyesters, *Cellulose Based*, cellulose esters combined with cellulose derivatives, *Protein Based*, from wheat, gluten casein and milk, *Aliphatic Polyesters* (PHB, PHA, PHV, PHH, PLA, $PA_{II}$) and *Organic Polyethilene*, from fermentation of raw agricultural materials such as sugar cane and corn (S. A.Ashter)

Based on the mentioned branches, the most used BLPs are:

- Polyhydroxyalkanoates (PHA): from the fermentation of carbonate through the action of bicrobes. It includes PHB and PHV.
- Polylactide (PLA): from natural lactic acid, produced from the fermentation of sugar or starch by microbes.
- Biobased Polysuccinates (PBS): from Butanediaol and succinic acid.
- Biobased Polyamides: produced from dicarboxylic diamino acid produced from renewable feedstock (Nylon and Perlon).
- Biobased Polyurethanes: produced by reaction of Polyols (from soya, castor, sunflower oil, rapeseeds) and Diisocynates.

- Biobased Polyacrylates (Plexiglass): from enzymes combined with sugars, alcohol and fatty acids.
- Biobased PVC: produced from ethylene derived by bioethanol. (Anil Pratap Singh et al.)

According to the *European Bioplastics*, the statistics on production capacity of bioplastics sees PLA and Starch Blends both at 18,7% and PBAT 13,5% as the top three Bioplastics on the market (Fig.2).

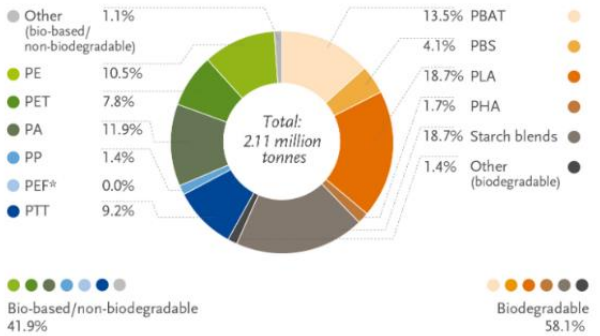



**Figure 2.** Global production capacities of Bioplastics 2020 by material type (European Bioplastics)

## 2. Sustainability and Disposal

Bioplastics are commonly considered to be harmless for the environment. Ongoing research from cradle-to-grave are highlighting the harmful aspects of Bioplastics.
The production of BPLs, such as PBS, PLA, PHA, is an expensive process that requires a copious electricity consumption as well as the use of chemicals to produce resin, a necessary component of BPLs. Within the manufacturing, bioethanol and $CO_2$ are released, contributing to the rise of Global Warming (GW) and Fossil Depletion (FD). Unless less invasive technology is developed, GW and FD will continue to be a collateral effect of BPLs (K. Chankwichan et al).
Disposal of bioplastics is another underestimated aspect. Contrary to plastic, material recycling is not the preferred end of life option for BPLs: a role held by composting. Incineration is also not suitable for this new material, due to the high production of heat caused by carbon and hydrogen released from the incineration (X. Ren).
To accomplish total decomposition, BPLs must be biodegradable and compostable. Although it is assumable that BPLs could be disposed in a homemade way, this is not the case.
For an efficient and eco-friendly disposal, BPLs not only need to be treated separately from conventional plastics but have to be handled by employing a partition based on the biopolymer used for each BPLs. This separation process is a challenging task; BPLs are generally classified as “other plastic” waste, making the disposal classification nearly impossible (X.Ren). Consequently, BPLs are currently collected in landfills, where they are added to common plastic, increasing the rise in waste.
Collecting BPLs in landfills does not improve the environmental impact; indeed, it increases gas emissions, worsening the contamination of the environment. (R. Maheshwari et al).
A safe way to dispose BPLs is only achievable by advanced composting facilities, as it requires strict conditions of temperature, PH, biodegradability level, humidity, and oxygen.
Recent studies have brought to a classification of BPLs based on biodegradability (%), period of biodegradability (days), conditions and type of environment. (**Tab.2**)

**Table 1.** Partial classification of BPLs based on biodegradability (S.M. Emadian et al./Waste Management 59(2017) 526-536)

| Bioplastic | Type of Environment | Conditions | Biodegradability (%) | Period of Biodegradability (days) |
|---|---|---|---|---|
| PA -Based | Composte Soil | Aerobic, 58°C | 100 | 120 |
| PLA | Synthetic material and compost | 58°C | 100 | 28 |
| PLA/PHB(75/25%) | Synthetic material and compost | 58°C | 100 | 35 |
| PHB | Brackish water sediment | 32°C, PH=7.06 | 100 | 56 |
| PHB | Sea water | Static Incubation, 21°C | 99 | 49 |
| PHBV | Sea water | Static Incubation, 21°C | 99 | 49 |
| PHB | Soil | Real conditions | 98 | 300 |

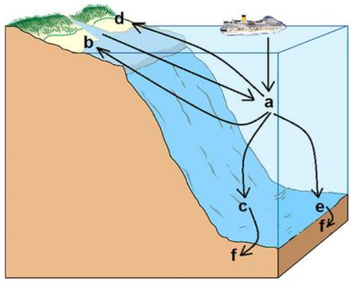
## 3. Bioplastics in the marine environment

It is widely acknowledged that mismanagement of bioplastics disposal has led to the presence of BPLs pollution in the marine environment. Although further research is needed owing to the lack of data concerning the true quantity of bioplastic material in such environment, it is possible to discuss the causes of the harmfulness of its presence.

Scientific evidence of total biodegradation of Bioplastics in seawater is not recorded up to date; however, a disintegration of BPLs in biobased Microplastics (BMPs) has been observed (G. Anderson et al.).

To examine the nature of BMPs effects, studies have been carried out by analyzing the behavior of BMPs in six aquatic zones (a. pelagic, b. eulittoral, c. sublittoral, d. supralittoral, e. deep sea, f. sea floor) estimating the degradation of particles (M. Tosin et al).

**Figure 3**. Marine habitats where plastics have been recorded (M.Tosin et al).




The results have shown that BPLs in the Sublittoral Zone have a higher rate of biodegradation thanks to the partial burial of bioplastic particles by sediments as well as the exposition to sunlight that reaches the seafloor. Additional studies are required to evaluate the disintegration/biodegradation rate in Deep Sea as BMPs are subjected to different temperatures, pressure, low flow, and light conditions, in addition to a partial or total burial by sediments. (M. Tosin et al.).

Biodegradation occurs in three steps:

1. Biodeterioration: the growth of microorganisms inside or on the polymer surface convoy to a modification of mechanical, chemical and physical properties of polymer;
2. Bio-fragmentation: microorganisms convert polymers to oligomers and monomers;
3. Assimilation: fragmentation causes a conversion of carbon into $CO_2$, water and biomass (S. Emadin et al).

Unless a complete biodegradation is reached, in the aquatic environment, the remaining disintegrated BMPs infiltrate into the life cycle of marine invertebrates (G. Anderson et al.).

## 4. Role of Wastewater Treatment Plants

The lack of BPLs on the market can find its cause in the high manufacturing costs of both renewable resources and energy consumption. At present, attention is being paid to the use of WWTPs to produce Bioplastics in a more sustainable and less expensive way; especially for polyhydroxyalkanoates (PHA): a bioplastic produced by fermentation of carbonate through action of microbes (A. Singh et al.). Currently, WWTPs recover energy through the production of biogas, leaving a consistent amount of carbon to waste. To avoid the increasing rate of organic waste from wastewater plants, this residual carbon can be used as the primary resources to produce PHA, even more so by choosing wastewater streams with high Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) (B. Yadav et al). By combining biogas and bioplastic production from WWTPs, it has been estimated an annual decrease of approximately 21% of $CO_2$ footprint derived from the plant itself. However, there is a side effect in the low quality of the final product, hence its use is restricted to agricultural and structural industry rather than in the food packaging industry (B. Ajao et al.).

WWTPs can solve another problem linked to the production of Bioplastics. The high demand of plant based raw materials are causing land distress and ecological pressure. WWTPs can help overcome this problematic by becoming a cultivation site for microalgae which can substitute crops as component of BPLs. Indeed, cultivating microalgae in wastewater does not require the use of soil and non-potable water can be used as medium. Moreover, they seem to double their size in a matter of hours, making the production process faster than using conventional seed farming. Additionally, the small size of microalgae allows their transformation in Bioplastics without pretreatments (contributing factor to GW and FD). The beneficial aspect derived from microalgae is to be seen in the consumption $CO_2$ and production $O_2$ as part of their life cycle (C. Rocha et al.).

## 5. Conclusion

The prospective shown from this article gives an overview on the crucial problematics linked to how Bioplastics are currently used. The twofold aspect of BPLs (harmful/harmless) lies in the mismanagement of this new material, from production to disposal.

To take advantage of the full sustainable potential of BPLs, further research, analysis, and evaluation are essential in systems of production, where a circular bioeconomy of PHA production needs to be proposed. As regards to disposal, despite advanced compost technology is required, correct labelling and selection based on the biopolymer of origin could suggest a minor solution for the time being.

Last but not least, public awareness campaigns are crucial to change the mistaken concept that the vast majority of people hold on the sustainability of BPLs. It just cannot be thrown out and left to disintegrate on its own!

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