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Bioplastics

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ABSTRACT. The present technical note about bioplastics will open with some generalities and market data. Next, the main classes of bioplastics will be shortly presented, to finally conclude with some perspectives.

1. Generalities

"Bioplastics" are materials that are generally defined as either (partly) biobased or degradable under defined conditions ("biodegradable"), or both. While some bioplastics break down through microbial action into water, carbon dioxide, and biomass, not all bioplastics are biodegradable. Bioplastics are considered as an essential building block in the circular economy, since they constitute a potential sustainable alternative to the widespread plastic materials mostly made from fossil resources. Most of these are characterized by their long lifetime and pronounced persistence in the open environment and therefore generate environmental concerns.[1] Several standards and test protocols have been developed to assess, certify, and advertise the properties of bioplastics, mainly related to the properties of biodegradability and biobased carbon content.[2] Bioplastics, sourced from renewable materials, are expected to decrease dependency on fossil fuels and help lower carbon footprints during production and disposal. Still, the trade-off between manufacturing cost, technical performance and environmental impact requires a case-by-case analysis.[3]

Figure 1 below illustrates how the main bioplastics and fossil-based plastics can be positioned in a bio-based/fossil-based vs biodegradable/not biodegradable space.

In 2024, the worldwide production volume of structural (partly) bio based polymers - comprising cellulose acetate, epoxy resins, polyamides, polyethylene, poly(ethylene terephthalate), poly(lactic acid) and others - was 4.2 million tons, which is 1 % of the total production volume of fossil based polymers. The compound annual growth rate (CAGR) of bio-based polymers is at 13 % significantly higher than the overall growth of polymers (2–3%) – this is expected to continue until 2029. With these growth rates, the share of bio-based polymers will increase up to 2 %. Currently, cellulose acetate and epoxy resins are the two major biobased plastics, accounting for 26% and 32% respectively of the total production of biobased plastics worldwide, as shown in Figure 2.[4]

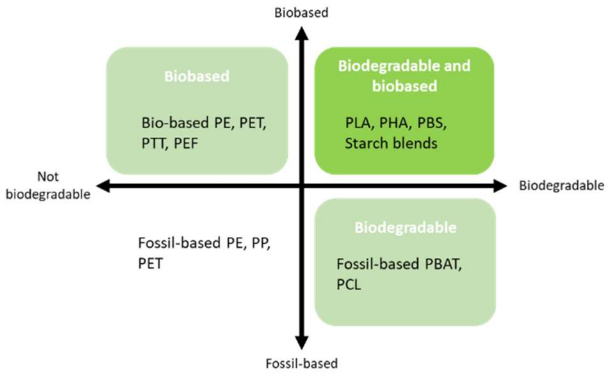

Figure 1. Positioning of main commodity thermoplastics in terms of origin (fossil- vs biobased) and biodegradability. PE = polyethylene, PET = poly(ethylene terephthalate), PTT = poly(trimethylene terephthalate), PEF = poly(ethylene furanoate), 2PLA = poly(lactic acid), PHA = poly(hydroxy alkanoate), PBS = poly(butylene succinate), PP = polypropylene, PBAT = poly(butylene adipate terephthalate), PCL = polycaprolactone. Visual based on previous work.[5]

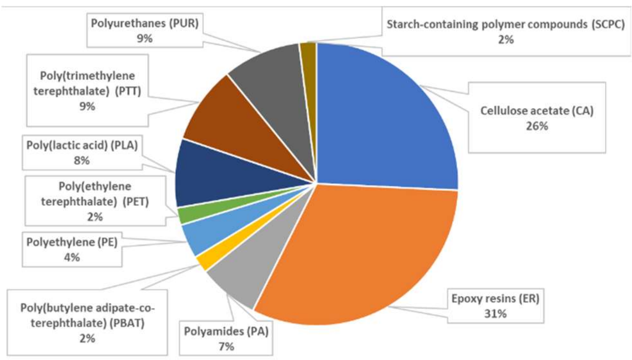

Figure 2. Bio-based polymer worldwide shares in 2024, on a total volume of 4.2 million tons. Other biobased polymers like aliphatic polycarbonates, ethylene propylene diene monomer rubber, polypropylene and some polyesters have a global volume share below 1 % and are not represented (visual based on data published elsewhere[4])

2. Main bioplastics families

2.1. Epoxy resins

Epoxy resins are the major biobased polymers in terms of volume. These resins can either use drop-in substitutes for oil-based raw materials (e.g., using bio-based epichlorohydrin, obtained from glycerol, a by-product of food waste) or by new epoxies synthesized from new renewable precursors. Chemical routes for obtaining the latters include epoxidation of vegetable oils, lignin-based resins, tannin or cardanol-based resins and others.[6] Typical applications comprise adhesives, composites, paints and coatings, electronics, construction.

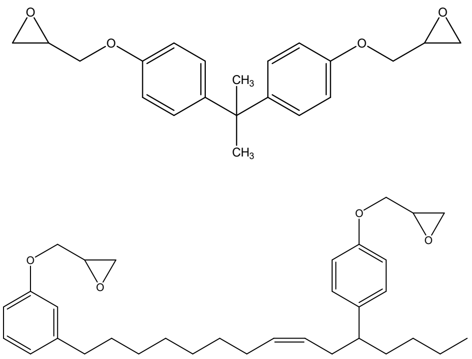

Figure 3. Structure of bisphenol A epoxy resin (top) and a di-functional cardanol-based epoxy resin (bottom).

2.2. Cellulose derivatives

Cellulose derivatives are the second major class of biobased polymers volume-wise. They are obtained by chemical modification of cellulose, a polysaccharide of vegetal origin, to allow processing like injection molding or extrusion. Common modifications include etherification, esterification, or the use of plasticizers like fatty acids. For instance, cellulose acetate (CA) is used in films, coatings and fibers for textiles and clothing, while ethyl cellulose is commonly used in pharmaceutical coatings, adhesives, and as a binder in tablet formulations, as well as a thickening agent in the food industry.[7]

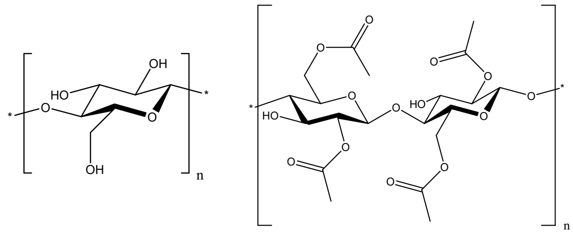

Figure 4. Repeat units of cellulose (left) and cellulose diacetate (right).

2.3. Polyesters

While currently still small in volume on a global scale, biobased polyesters like poly(lactic acid) (PLA), polyhydroxyalkanoates (PHAs) and polycaprolactone (PCL) have gained popularity this last decade thanks to their interesting balance of properties. Comparatively, standard poly(ethylene terephthalate) (PET) is made from fossil-based raw materials while biobased PET (bio-PET) can be obtained by starting from ethylene glycol (EG) and terephthalic acid (PTA) and/or di-methyl terephthalate (DMT) monomers from biological sources.[8] PET being notoriously hard to hydrolyze, none of these oil- or biobased grades are naturally biodegradable but recent research has shown it is nevertheless possible to break PET down with high productivity using an engineered enzyme.[9]

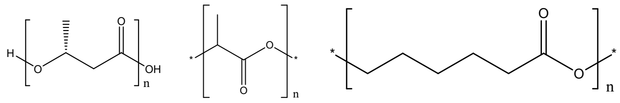

Figure 5. Repeat units of PLA (left); P3HB (=poly-(3-hydroxy-butyrate, a specific PHA) (middle) and PCL (right).

Poly(lactic acid) (PLA) is obtained either by condensation of lactic acid (with concomitant release of water) or ring-opening polymerization of lactide, the cyclic dimer of the basic repeating unit. Lactic acid or lactide originate from fermented plant starch such as from corn, sugarcane, or sugar beet.[10] PLA key applications include food packaging and disposable products like cutlery and containers, medical devices such as sutures and implants, drug delivery systems, tissue engineering, 3D printing filaments, and textiles for upholstery and clothing.[11] The use of PLA as engineering material, in combination with various types of fillers and fibers, is also growing.[12, 13]
Depending on its stereochemistry (L vs D monomer) and thermal history, PLA can exhibit amorphous or semicrystalline state. PLA as such is a brittle material and exhibits less than 10% elongation at break,[14] but numerous additives can broaden the practical applications of PLA. For instance, common plasticizers for this bioplastic include citrate esters such as acetyl tributyl citrate (ATBC) and triethyl citrate (TEC), polyethylene glycols (PEGs), and oligomeric lactic acids. Other bio-based options include glycerol-derived organic carbonates, tartrates, α-tocopherol derivatives, and natural oils. These plasticizers increase PLA's ductility and flexibility, though often at the cost of tensile strength.[15] PLA mechanical properties can also be adjusted by blending with amorphous PHA, resulting in higher toughness.[16] PLA can degrade under industrial composting conditions but shows very slow break down under home-compost and in soil conditions. It has been shown that melt-extrusion with an optimized enzyme can make PLA fully break down under home-compost conditions within 20–24 weeks, thereby meeting home-composting standards.[17]

Polyhydroxyalkanoates (PHAs) are polyesters produced in nature by numerous microorganisms, including through bacterial fermentation of sugars or lipids. They can be either thermoplastic or elastomeric materials, and generally have a semicrystalline structure, with melting points ranging from +40°C to +180°C. PHA polymers are thermoplastic and can be processed on conventional processing equipment and their properties will depend on their chemical composition (i.e. the repeat units in the polymer chain, leading to a homo-or copolyester, possibly containing hydroxy fatty acids …). For instance, pure poly-(3-hydroxybutyrate) 3PHB is a relatively brittle and stiff material, close to polypropylene homopolymer. Comparatively PHBV copolymer (poly(3-hydroxybutyrate-co-3-hydroxyvalerate)) is less stiff and tougher, and it may be used as packaging material. The biodegradability of PHAs has opened a lot of potential applications in agricultural, medical, and pharmaceutical industries like fixation and orthopedic applications (sutures …).[18, 19]

Polycaprolactone (PCL) is a synthetic, semi-crystalline, biodegradable polyester. It is produced by catalyzed ring opening polymerization of ε-caprolactone. Thanks to its biodegradability in physiological conditions, PCL has been widely used in long-term implants and controlled drug release applications. Volume-wise, PCL main use is that of a hydroxyl functional polyester block in the production of specialty polyurethanes. Polycaprolactones impart good resistance to water, oil, solvent, and chlorine to the polyurethane produced.[20]
Other polyester bioplastics mainly comprise poly(butylene adipate-co-terephthalate) (PBAT), poly(trimethylene terephthalate) (PTT), poly(ethylene furanoate) (PEF).

2.4. Other bioplastics

Polyethylene, polyamides, polyurethanes, and starch-based materials make up for most of the other bioplastics.

Biobased polyethylene production process involves ethanol extraction from renewable materials like sugarcane (after anaerobic fermentation), dehydration to ethylene and polymerization leading to polyethylene. Biobased polyethylene is chemically identical to conventional polyethylene, making it a "drop-in" replacement that can be used in existing manufacturing processes for products like packaging, car parts, and others. While biobased, it is not biodegradable, though recyclable.[8]

Beyond their environmental benefits, **biobased polyamides** offer structural diversity and functional versatility thanks to the chemical variety of natural feedstocks on which they are based. Biobased polyamides are produced using monomers from renewable feedstocks, such as castor oil, which can be converted into key components like sebacic acid or amino-undecanoic acid. Monomers can also be produced via fermentation using metabolically engineered microorganisms, such as lysine-derived 1,5-pentanediamine used for biobased PA56. Commercially available biobased polyamides with high bio-content can be found on the market, such as PA11, PA410, PA610, and PA1010. Typical applications include automotive, packaging, textiles and fibers, adhesives.[21]

While polyurethanes (PUs) are traditionally produced from fossil-based polyols and isocyanates, **bio-based PUs** are mostly made from renewable polyols originating from plant oils, sugars, and lignocellulosic biomass. Some bio-based isocyanates are also being developed, but in the meantime the development of non-isocyanate polyurethanes (NIPUs) has further advanced the sustainability of PU materials by eliminating the use of hazardous oil-based isocyanates. Bio-based PUs can be used in various applications, including foams, coatings, and adhesives, while delivering comparable mechanical and thermal properties to their fossil-based counterparts.[22, 23]

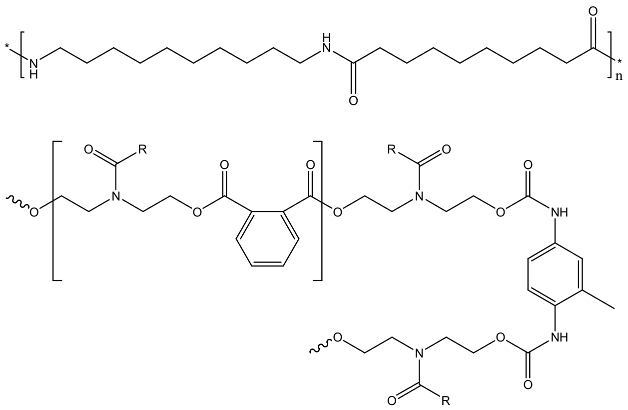

Figure 6. Repeat units of biobased PA 1010 (top) and of sea buckthorn biobased polyurethane[23] (bottom).

Starch is a polysaccharide material produced by plants for energy storage. It comprises two types of molecules: linear amylose and branched amylopectin. Starch can benefit from modifications in order to yield sustainable alternatives to conventional plastics thanks to its structural and functional diversity. Starch feedstocks can be chemically modified by esterification, oxidation, cross-linking and grafting while physical modifications comprise thermal treatment, addition of plasticizers, ball milling, cold plasma, high pressure processing, irradiation, among others. Starch can also be biologically modified, mainly via enzymatic and genetic means to produce starches with tailored properties for various industrial applications. Industrial applications of starch-based films include packaging, adhesives, agricultural practice as well as medicine and pharmaceuticals (drug delivery). Due to the potential competition with food uses, various alternative sources of starch currently underutilized such as agricultural residues and algae, are gaining attention as feedstocks for producing materials.[24]

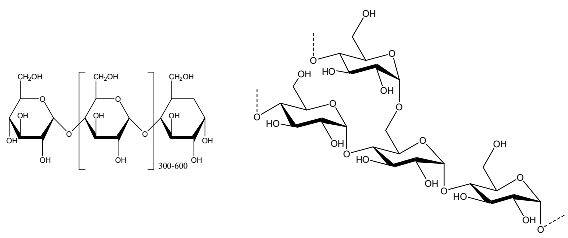

Figure 7. Starch polysaccharide constituents: linear amylose (left) and branched amylopectin (right).

2.5. Perspectives for bioplastics

The perspectives for bioplastics are promising due to their potential to reduce reliance on fossil fuels and deliver lower carbon footprints, especially in achieving sustainability goals. However, significant challenges remain, like in some cases their limited durability and performance compared to conventional plastics, and environmental concerns related to production, such as land use and fertilizer impact. Also, public confusion over proper disposal can constitute a problem for managing the end-of-life of these materials. Overcoming these challenges requires continued innovation in materials and manufacturing, improved waste management infrastructure, and thorough public education.[25, 26]

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References

1. M. Lackner et al., *Polymers,* 2023, 15, 4695 https://doi.org/10.3390/polym15244695
2. A. Jayakumar et al., *Sci. Total Environ.*, 878 (2023) 163156 http://dx.doi.org/10.1016/j.scitotenv.2023.163156
3. S. Huang et al., *Sci. Total Environ.*, 969 (2025) 178911 https://doi.org/10.1016/j.scitotenv.2025.178911
4. P. Skoczinski et al.; Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2024–2029. nova-Institut GmbH (Ed.), Hürth, Germany, 2025-03. nova-Institut GmbH (Ed.), Hürth, Germany, 2025. https://doi.org/10.52548/UMTR4695
5. https://docs.european-bioplastics.org/2016/publications/fs/EUBP_fs_what_are_bioplastics.pdf
6. C. Chen, *Processes,* 2025, 13, 1256 https://doi.org/10.3390/pr13041256
7. E. Marhino, *Sust. Chem. Environ.,* 11 (2025) 100283 https://doi.org/10.1016/j.scenv.2025.100283
8. V. Siracusa and I. Blanco, *Polymers,* 2020, *12*, 1641 https://doi.org/10.3390/polym12081641
9. V. Tournier et al., *Nature,* 580, 216–219 (2020). https://doi.org/10.1038/s41586-020-2149-4
10. L. Mou et al., *J. Hazard. Mater. Adv.,* 18 (2025) https://doi.org/10.1016/j.hazadv.2025.100757
11. H. R. Dana and F. Ebrahimi, *Polym Eng Sci*., 2023;63:22–43 https://doi.org/10.1002/pen.26193
12. A. K. Trivedi et al., *Adv. Ind. Eng. Polym. Res.*, 6 (2023) 382-395 https://doi.org/10.1016/j.aiepr.2023.02.002
13. V. Giammaria et al., *Polymers* 2024, 16, 3059. https://doi.org/10.3390/polym16213059
14. *S.* Farah et al., *Adv. Drug Deliv. Rev., 107 (2016), 367-392* https://doi.org/10.1016/j.addr.2016.06.012
15. S. Sun et al., *Polymer Testing*, 140 (2024) 108603 https://doi.org/10.1016/j.polymertesting.2024.108603
16. I. Burzic et al., *Eur. Polym. J.*, 114 (2019) 32-38 https://doi.org/10.1016/j.eurpolymj.2019.01.060
17. M. Guicherd et al., *Nature,* 631, 884–890 (2024) https://doi.org/10.1038/s41586-024-07709-1
18. X. Liang et al., *Resour. Conserv. Recycl., Adv.*, 21 (2024) 200206 https://doi.org/10.1016/j.rcradv.2024.200206
19. J. N. Lalonde et al., *Polym. Chem.*, 2025, 16, 235 https://doi.org/10.1039/D4PY00623B
20. M. A. Ntrivala et al., *Eur. Polym. J.*, 234 (2025) 114033 https://doi.org/10.1016/j.eurpolymj.2025.114033
21. M. Diaz-Galbarriatu et al., *Polymers,* 2025, 17, 2599 https://doi.org/10.3390/polym17192599
22. P. Jayalath et al., *Processes*, 2025, 13, 1591 https://doi.org/10.3390/pr13051591
23. F. Campana et al., *Green Synth. Catal.*, 6 (2025) 217-238 https://doi.org/10.1016/j.gresc.2024.08.001
24. A. Amobonye et al., *Int. J. Biol. Macromol.*, 315 (2025) 144354 https://doi.org/10.1016/j.ijbiomac.2025.144354
25. K. Molina-Besch and H. Keszleri, *Sustain. Prod. Consum.*, 35 (2023) 72-84 https://doi.org/10.1016/j.spc.2022.10.018
26. T. Tábi, *Express Polym. Lett.*, 18 (2024) 1063–1064 https://doi.org/10.3144/expresspolymlett.2024.81

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