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Editorial corner – a personal view

What is the next step for bioplastics?

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Bio-based (like PLA, PHA, PBS, bio-PE, bio-PET) and biodegradable (like PLA, PHA, PBS, PBAT and PCL) plastic (bioplastic in short) products are successfully used in applications where they have a clearly demonstrable advantage compared to traditional plastics. In the case of bioplastics that have both beneficial properties, such an advantage includes, among others, the significantly lower **CO_2 requirement** of the production or (re)processing of bioplastics, their **suitability for chemical recycling** (thanks to the presence of an ester bond) or their **biological degradability (compostability)** (https://doi.org/10.1038/s41578-021-00407-8).

For a reduced CO_2 footprint, a polylactic acid (PLA) bioplastic bottle can be mentioned as an example—the CO_2 footprint of its production is ~1/4–1/5 compared to PET (PET: ~2.2 kg CO_2 equiv./kg polymer; PLA: ~0.5 CO_2 kg equiv./kg polymer). Conversely, 4–5 times as many bottles can be produced from PLA as from PET with the same amount of energy (https://doi.org/10.1007/s10924-019-01525-9). If the PLA also contains chemically recycled PLA, the CO_2 footprint is even smaller (only ~0.2 kg CO_2 equiv./kg polymer in the case of 30% chemically recycled PLA content), as no energy needs to be reinvested to create the polymer. In the case of bioplastics, they are fully suitable for chemical recycling, moreover, the chemical recyclability is already available and applied on an industrial scale (as well as for some ordinary plastics like PET by applying the enzymatic recycling process of Carbios). Chemical recycling meets the requirements of the circular economic model, since during this process, the bioplastic is broken down into its monomers and then the polymer chain is rebuilt (https://doi.org/10.1016/j.resconrec.2021.105670). That is, during the process, the polymer chain is fully restored, while in the case of mechanical recycling, the chain is damaged, and over time, the material becomes unusable, which will cause it to fall out of the recycling cycle. It is worth mentioning, that in some cases, other upcycling methods could also be applied like chain lengthening or solid phase polymerisation to restore the molecular chain length. The third great advantage of biodegradable bioplastic products is compostability; a good example of which is any packaging that comes into contact with food, because it is not always possible to clean and recycle the material, so in this case, the bioplastic product contaminated with food residue can be composted together with the remaining food (https://doi.org/10.1016/j.spc.2022.08.006). In spite of these advantageous properties, bioplastics still only have a share of 1–2% of all plastics used.

The question arises: where to go next, what is the next step in the development of bioplastics? I believe that bioplastics could be used in many more fields of application, but at the same time, without development, they are often not able to meet the requirements of a given product, or only to a limited extent. There is no single bioplastic, a kind of Holy Grail that is 'good for everything'; each bioplastic has its own specific physical, mechanical, thermal and processability properties (https://doi.org/10.1016/j.tplants.2018.11.010), and in most cases, these properties must be modified and fine-tuned for the

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specific application. Therefore, I see the development of purposefully **modified bioplastic compounds** (tailor-made compounds) as one of the main development directions. On one hand, compounding facilitates the modification of specific properties, if, for example, the strength, toughness, or heat resistance of a bioplastic (https://doi.org/10.1016/j.polymertesting.2021.107282) or its processability with the given technology is to be improved. In addition to the modification of specific properties, there are also general expectations from biopolymers, so it is recommended that they are provided with additional advantages so that they are even more attractive. One general expectation is the **reasonable price**. Price has decreased over time due to increasing production; for example, the price of PLA decreased from around 3.5–3.7 Euro/kg to around 2.8–3.3 Euro in the last five years (~10–20% decrease) and hopefully will continue to decrease. Properties-wise, it is also a general expectation that bioplastic products are at least as **durable, reusable and recyclable** as a traditional plastic product (https://doi.org/10.1016/j.rser.2021.111237). In the case of the previously mentioned bottle (say a bottle containing a chemical or a detergent), the main directions of development are increased toughness, gas barrier properties (https:// doi.org/10.1016/j.foodres.2020.109625) and improved (re)processability so that the same durable product can be (re)used as many times as possible and thus remain in the circular economy. Due to a possible deposit fee system, customers are encouraged to bring back the product either for refilling or recycling (mechanical or chemical). It is important that, in addition to increased durability, the chemical recyclability of the bioplastic remains. Also, if somehow the to-be-recyclable bioplastic products enter a mix plastic waste stream, it is proved that infrared sensors could be effectively applied to detect and separate the bioplastic parts and thus its waste stream. Finally, another important expectation on bioplastics can be the **easy biological degradability**, in home compost available to many people (https://doi.org/10.1021/acs.biomac.0c00759), or seawater (https://doi.org/10.1016/j.scitotenv.2024.172771). By achieving general home compostability of bioplastics, as well as the popularization and spread of composting, packaging (bio)polymer waste management could be decentralized (https://doi.org/10.1016/j.jenvman.2023.118824), that is, the user could participate in it at home. I believe that the two main development directions, that is, increasing durability, reusability and recyclability, and easy biological degradation, are not necessarily contradictory. If we achieve our development goal, bioplastics will no longer only be called "bio-based and biodegradable (industrially compostable)" polymers, but they can also have many other names, such as bio-based, biodegradable, compostable (home), reusable (durable), and recyclable (chemically and mechanically, etc.) polymers. Although this name would be too long, by then we will surely come up with a short, catchy name, like 'circular' bioplastics.

Dr. Tamás Tábi
Topic editor