Certified biodegradable and biobased materials are targeted enablers for a circular economy and a closed nutrient loop

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Abstract

Biobased and certified biodegradable polymeric materials provide superior functionality for targeted applications with improved sustainability. This includes for example mulch film applications for agriculture, organic waste bags and thin film coatings for paper. Most materials proposed join a biobased sourcing and a certified biodegradation behaviour proved by standardized and recognized methodology. The combination of such materials and applications enables to close the loop of nutrients thought the life cycle and brings organic material back to the soils where biobased raw materials were originally sourced. That is how these materials contribute to various Sustainable Developmental Goals of the United Nations.

Introduction

Demographic challenges set the stage for the future of our planet. With a steadily-increasing population, fundamental needs remain at the focus and include food and nutrition, resources towards environment as well as the quality of life.

It is key that arable land and overall resources are limited and cannot be increased at equal rate es demand increases. For example, demands in agriculture include higher efficiency of water and nutrient use, increase of yield & productivity and advanced demands towards sustainability. One important tool towards such increased demand and sustainability is the use of biodegradable and biobased mulch films in agricultural applications. Such films enable earlier planting and harvesting dates, provide higher yield, improved water management, reduction of soil compaction, etc.

To cover raising demands and limited resources for an increasing population, there is also a need to close the loop of production and to work towards a circular economy where substances and materials are kept in closed loops. But it is not only about a loop of production and substances. There is also the loop of nutrients that enables agriculture and sourcing of renewable raw materials. Organic recycling (composting) is critical to close the biological cycle and to contribute to a circular routine (Fig. 1). This will keep the soils fertile by bringing nutrients back to our agricultural fields. Compostable packaging supports easier collection of biowaste (e.g. bags, brewing aid, selected fruit/vegetable/food packaging) and smart usage of certified compostable and biobased material increases quality and quantity of organics recycling.

Paper has been the prominent packaging material some decades ago. To protects goods from outside influences helps to keep products or food lasting longer or enables certain applications. Due to missing performance characteristics and barrier properties (e.g. fat resistance) paper has been largely replaced by some non-biodegradable polymers (e.g. polyolefins). Still, paper remains a renewable and biodegradable packaging material that is globally accessible. The combination of biodegradable and biobased polymer could help to overcome some of the missing performance of paper in some particular applications. The missing performance and barrier properties of paper can be compensated by adding a thin film of biodegradable and bio-based polymers. The combination of paper with biodegradable and biobased polymers enables two end of life options: paper recycling as well as paper composting (biodegradation).

Overall, certified biodegradable and biobased polymers and materials will enable advancement in different sectors that so far seek sustainable solutions along the SDGs.

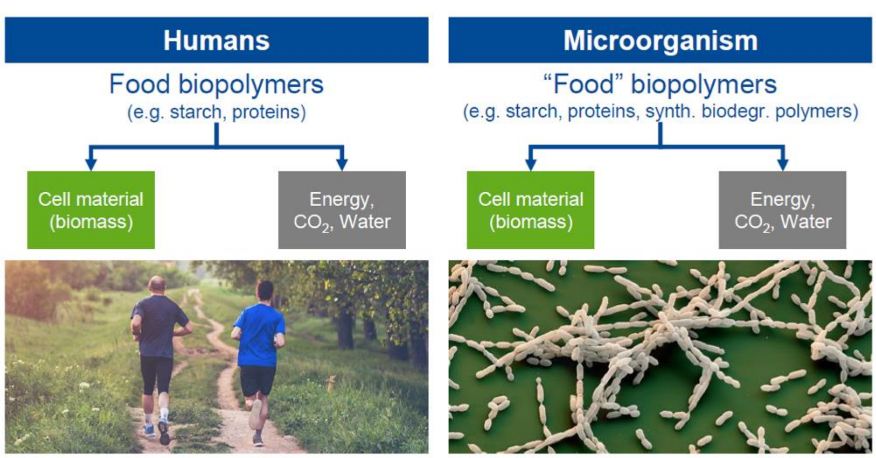
Figure 1. The circular economy has in principle two cycles, one on the technical side and another one towards the nutrient cycle that enables agriculture and sourcing of renewable raw materials. Composting is imminent to the nutrient cycle.

What are biodegradable and biobased polymers?

Not only humans do metabolize energy rich molecules like starch or proteins into energy for growth and everyday life, but there are also microorganisms that make use of starch, proteins and also synthetic biodegradable polymers to gain energy and biomass. Basically, these are very similar biochemical processes underlying these catabolic processes, independent of species or source: biodegradation describes the metabolism of higher energy (polymeric) molecules into C02, energy, water and biomass (aerobic conditions) (Fig. 2). Synthetic polymers that are able undergoing such processes in reasonable timeframes are called biodegradable (Künkel et al., 2016). Usually, this work is done by microorganisms that possess a wide variety of metabolic capabilities.

Synthetic polymers that are deemed biodegradable are not necessarily biobased. Biobased includes sourcing of raw materials based on a renewable feedstock and carbon source. Therefore, the carbon content of annually renewable raw materials needs to be given as the share of the total carbon content to finally account renewable sourcing. Biobased building blocks to the polymer may include, for example, 1,4-butanediol, azelaic acid, lactic acid, or succinic acid. These monomers will make the synthetic polymers polybutylene adipate-co-butylene terephthalate (PBAT), polylactic acid (PLA), or polybutylene succinate (PBS). Polyhydroxy alkanoates (PHA), produced in a biotechnological process, and starch are other classes of biobased and biodegradable polymers. Such polymers, either as homopolymers or heteropolymers and corresponding blends (combination of the above-mentioned polymers) can then be applied in various forms for market demands as described above (Künkel et al., 2016).

Figure 2. Schematic illustration of common processes for aerobic biodegradation leading to biomass, energy, CO_2 and water

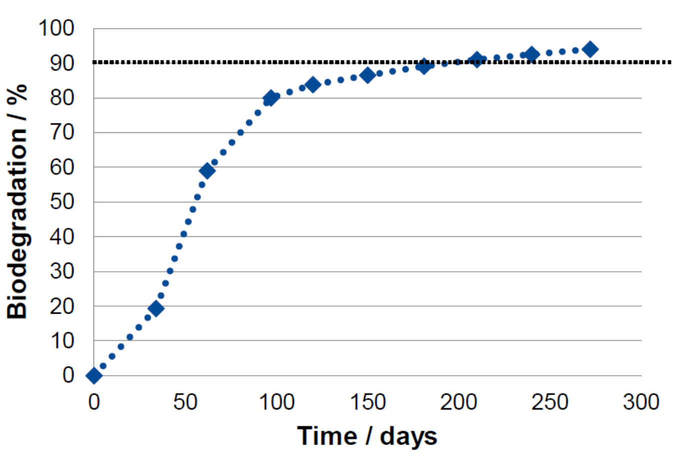


How is biodegradability assessed?

All polymers undergo some degradation, either physico-chemical and /or biological. Also, natural polymers undergo (bio-)degradation. The process itself is rate limited and determined by several factors. The degradation of biodegradable plastics is caused by microorganisms, covers bacteria and fungi and enables the conversion into CO_2 and microbial biomass (Zumstein et al., 2018). Biodegradability is primarily a material property, but its actual rate is influenced by environmental conditions including humidity, diversity and availability of microorganisms, temperature, etc.

As biodegradation can be influenced by confounding factors, biodegradation needs to be assessed on a standardized environment (Zumstein et al. 2019). Standards have been developed to verify biodegradation in various settings, including industrial composting or home composting. There are also standards by ISO and ASTM to prove for biodegradability in a soil or aquatic environment. Endpoints to prove biodegradability are usually the conversion into CO_2 at a very high rate and limited time compared to a naturally occurring structural polymer (Fig. 3). Such assessment is widely accepted to proof on biodegradability of a synthetic polymeric material. However, simply because a material is proven biodegradable does not relive a consumer to responsible dispose its item after use and to take it to organic waste collection.

Figure 3. Biodegradation of a structural polymer in a standardized test setting for assessment of biodegradation. The curve describes the percentage of biodegradation of the synthetic structural polymer over time compared to naturally occurring polymer of the control. The dotted line describes the threshold to be reached to prove biodegradability.



How are certified biodegradable and biobased polymers applied?

There are several technical applications where certified biodegradable and biobased polymers and corresponding materials can be meaningful and sustainably applied (Künkel et a., 2016; Bauchmüller et al. 2021):

Mulch Films

Beside various others, seedling emergence or horticulture applications are challenging agricultural applications to produce food. Such agricultural practice demands for many resources that can be optimized and even reduced with the application of biobased and certified biodegradable mulch film applications. Such thin films are applied during seeding or planting and provide their function until harvesting or as long as the vegetation period lasts (Fig. 4). During application, such mulch films allow for improved water management, leaching of fertilizer, improved weed control (less herbizide use), earlier planting and harvesting dates and finally higher yields. Biobased and certified bio-degradable materials are superior to conventional mulch-films applications as they do not have to be collected, do not accumulate in the soil matrix (usually significantly less than 100% of conventional mulch films are collected) but entirely biodegrade after application.

Figure 4. Biobased and certified biodegradable mulch films applied to various agricultural applications support various demands towards e.g. higher yield, improved water management, reduction of soil compaction. The foils last for the application period and entirely degrade in the soil afterwards.

Composting

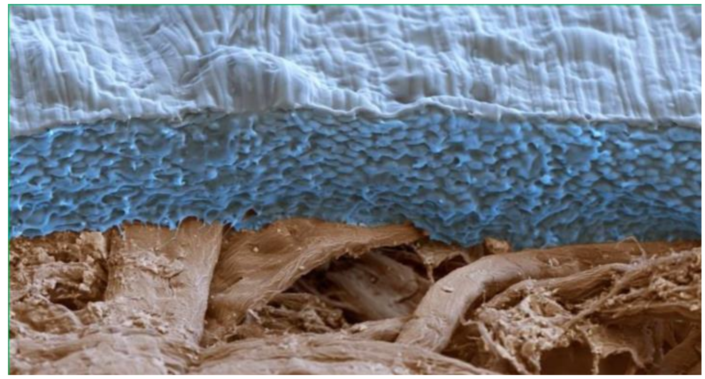
Collecting organic waste ("organic value matter") from household applications is challenging. Use interaction is key to obtain high quality and significant amounts of organic waste. Waste is usually incinerated or landfilled, but the more organic content can be collected separately, the more nutrients can be brought back into the cycle. Also, greenhouse gas emissions by organic recycling are least with organic recycling when compared to landfill or incineration. Studies have demonstrated superior quality and quantity of organic waste (Kanthak et al. 2012; Kern et al., 2020) if organic waste bags (made of certified compostable and biobased polymeric materials) are used because user perceive this as cleaner, safer and easier than other collection systems. The joint application of such organic waste bags and a professional composting facility finally brings the nutrients back to the agricultural fields and closes the nutrient loop (Fig. 5).

Figure 5. Biobased and certified biodegradable organic waste bags are applied to collect organic waste from e.g. households and are finally composted in a professional composting facility all together with the organic content.

Paper coating

Paper has decent packaging properties and is a renewable and biodegradable material. However, at the same time, there is some performance lacking. Fat and water resistance is far from being acceptable for many applications. The combination of biodegradable and biobased polymer could help to circumvent this performance deficit by adding a thin coating on the top layer (Fig. 6). For example, certain food packaging applications will be enabled with such technology while keeping two end of life options for paper: recycling as well as composting (biodegradation).

Figure 6. Microscopic imagery of a thin coating applied to a matrix. Colours added for illustration.



Implications for the Sustainable Development Goals (SDGs)

Biobased and certified biodegradable polymeric materials contribute to sustainable developments goals at various instances (Table 1). For example, the application of certified biodegradable mulch film contributes to the SDGs 2 "zero hunger", 14 "life below water", and 15 "life on land". The application of thin film coatings of biobased- and certified biodegradable polymers also contributes to SGD 2 "zero hunger", 9 "industry innovation and infrastructure", 12 "responsible consumption and production" and 15 "life on land".

Table 1. Certified biodegradable and biobased polymers and organic recycling align with the United Nations Sustainable Developmental Goals

PROPERTY	TOPIC	SUSTAINABLE DEVELOPMENT GOAL #
Certified biodegradable mulch film	Environment	2, 14 & 15
Material circularity	Waste prevention	2 & 12
Renewable content	Renewable raw materials	9 & 12
Economic prosperity	Improve farmers income	8
Agronomic benefits	Product functionality	2 & 12
Thin film coating	Product functionality	2, 9, 12 & 15

Policy recommendations

Materials based on biobased and certified biodegradable polymers are advantageous for certain applications as indicated above. There is growing evidence of its sustainable use that finally contribute to the SDGs 2, 8, 9, 12, 13, 14, and 15. We recommend fostering the application of such materials by preferring in national rule setting and legislative procedures.

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