

Dossier – Bioplastics as food contact materials

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1 Definition of bioplastics

The two main groups of bioplastics are biobased polymers and biodegradable plastics. Biobased polymers are derived from biomass sources, which are not necessarily biodegradable. Biodegradable plastics, on the other hand, can be either made of natural or fossil sources. In 2012, the IUPAC recommended a terminology for biorelated polymers [1, 2]. Two further, special classes that may be termed bioplastics are oxo-biodegradable plastics and bio-nanocomposites.

1.1 Biobased polymers

The term *biobased* refers to polymeric products that are composed or derived of biological products made from biomass (Figure 1) [1]. The polymers are either directly extracted from the biomass (e.g. starch, cellulose) or produced by microorganisms in fermentative processes (e.g. polyhydroxyalkanoates (PHA)) utilizing a suitable carbon source. Furthermore, plant biomass can be either chemically or biocatalytically converted into building blocks for other polymers (e.g. polylactide (PLA), polyolefins). However, biobased products do not have to consist exclusively of renewable products; they may also contain fossil fuel-based raw materials. Biobased plastics are commonly made of carbohydrate-rich food crops, e.g. corn or sugar cane (first generation feedstock). Second generation feedstock is derived from non-food crop, e.g. lignocellulosic material, which can be transformed into chemical building blocks suitable for the production of a variety of bioplastics. Currently, this technology is not economically feasible, but in future it might be a promising approach. Also biomass originating from animals (e.g. whey, chitosan) and protein- or oil-rich plant biomass (e.g. soy protein isolate, castor oil) has been used for the production of bioplastics.

1.2 Biodegradable plastics

Biodegradable plastics should be mineralizable by the action of microorganisms in their natural environment (e.g. in soil, surface waters or compost). The products of this process are energy, biomass, water and carbon dioxide or methane, depending on the presence or absence of oxygen. Polymers may be labelled compostable, if they are degraded in accordance with defined standards, e.g. the European standard EN13432 (see 6.2). Under EN13432 at least 90% of the material must be converted into carbon dioxide in industrial composting plants within 6 months. Furthermore, particles have to be disintegrated into residues with dimensions below 2 mm during this period. The composting process, the effects on plant growth and physico-chemical parameters of the compost should not change in the presence of the biodegradable plastic according to this standard. Materials complying with the EN13432 do not necessarily biodegrade in private composts, even if they are certified as compostable.

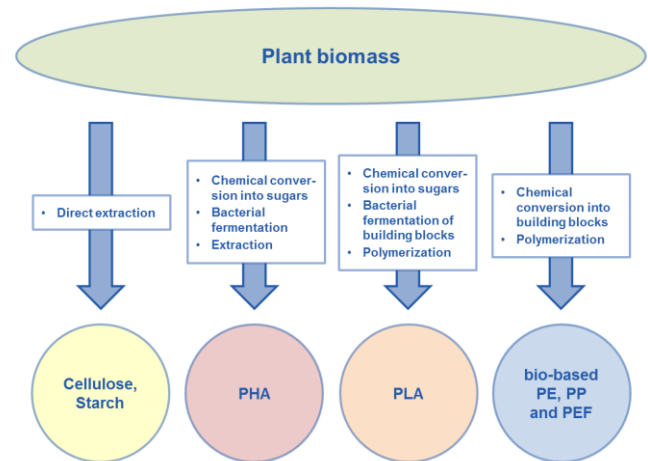


Figure 1. Production routes of bioplastics based on plant biomass.

1.3 Oxo-biodegradable plastics

Oxo-biodegradable plastics form a special class of plastics. They mainly include polyolefins, such as polyethylene (PE) and polypropylene (PP). PE and PP are generally stabilized by the addition of antioxidants. However, oxo-biodegradable PE and PP are supplemented with further chemicals (so-called prodegradants) to accelerate the degradation after a certain period of time. Prodegradants enhance the oxidation of the polymers by oxygen from the air thereby making them more susceptible to microbial degradation. This leads ideally to complete mineralization. Typical prodegradants either contain transition metal salts, or are metal-free organic molecules with ketone groups or conjugated double bonds (e.g. benzophenones, dithiocarbamates) [3]. Only few studies report full degradation of oxo-biodegradable plastics under environmental conditions [4]. Furthermore, oxo-biodegradable plastics do not degrade under the conditions specified in the standards defining general biodegradability or compostability (see 6.2 and 6.3). Currently, associations representing the bioplastics industries (e.g. Australasian Bioplastics and European Bioplastics) and manufacturers of oxo-biodegradable plastics (e.g. EPI Environmental Products Inc.) debate the environmental impact and benefits of biobased or biodegradable plastics versus oxo-biodegradable plastics.

1.4 Bio-nanocomposites

A special case of biopolymers that might be used for food packaging are bio-nanocomposites. Bio-nanocomposites consist of a biopolymeric matrix stabilized by nanoparticles (e.g. organic clays, silver nanoparticles) [5]. Technical characteristics such as barrier properties and thermal, chemical or mechanical stability can be improved by the inclusion of nanoparticles into the polymeric matrices [6].

2 Materials

Biobased and/or biodegradable polymers relevant for food contact materials (FCMs) are detailed in the following sections (Figure 2). In most cases, only the backbone polymers are described, but many of these plastics require additives, including nanomaterials, to fulfill the technical demands of FCMs. Alternatively, polymers are combined with each other or co-polymerized to obtain materials with improved properties (e.g. starch-blends with PLA, PCL, and PBA; PBAT-PLA; PBS-PLA [7, 8]).

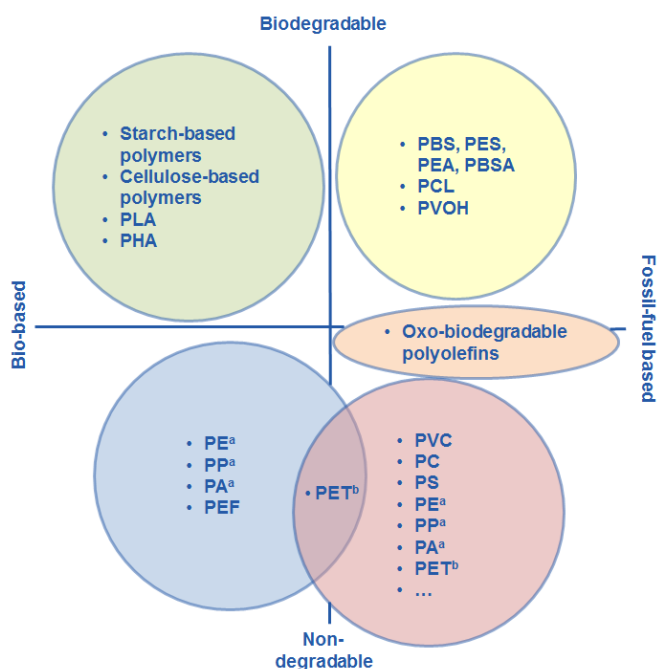


Figure 2. Overview of biobased and fossil-fuel based plastics including their degradabilities. ^aPE, PP, PA can either be produced from biobased or fossil-fuel based resources. ^bPET is usually synthesized based on fossil raw materials, but up to 30% biobased starting materials can be included during production.

2.1 Starch-based polymers

- Biodegradable polysaccharide.
- Derived from plant sources, e.g. corn or potatoes.
- Thermoplastic starch (TPS) is formed after application of thermal or mechanical energy.
- TPS is an alternative for polystyrene (PS) [9].
- Disadvantages of additive-free TPS: low water vapor barrier, poor mechanical properties, bad processability, brittleness [9].
- Applications: food packaging, disposable tableware and cutlery, coffee machine capsules, bottles [8].
- Producers of starch-blends: e.g. Novamont, DuPont, Starch Tech.

2.2 Cellulose-based polymers

- Biodegradable polysaccharide.
- Derived from de-lignified wood pulp or cotton linters.
- Cellulose derivatives are cellophane, cellulose acetates, cellulose ethers.
- Expensive polymers.
- Disadvantages of cellulosic polymers without additives: low water vapor barrier, poor mechanical properties, bad processability, brittleness.

- In Europe, coated and uncoated regenerated cellulose films are regulated under Commission Directive 2007/42/EC [10]. The directive includes a positive list of substances authorized for food contact. Cellulose-based polymers are not considered as plastics by the legislator.
- Applications: Coated, compostable cellulose films are used for the packaging of all kinds of food (e.g. bread, fruits, meat, and dried products).
- Producers: e.g. NatureFlex, Clarifoil.

2.3 Polylactide (PLA)

- Biodegradable, thermoplastic polyester.
- Produced by chemical conversion of corn or other carbohydrate sources into dextrose. Dextrose is fermented to lactic acid followed by polycondensation of lactic acid monomers or lactide.
- Three different stereochemical compositions exist: L-, D- and L,D-lactide with melting temperatures of 170-180°C and 55°C for the optical pure L- and D-lactide and the amorphous L,D-lactide, respectively.
- High tensile strength.
- Possible substitution for low-density and high-density polyethylene (LDPE and HDPE), polystyrene (PS) and polyethylene terephthalate (PET).
- Applications: Transparent, rigid containers (e.g. cups, bowls, bottles), bags, jars, films.
- Producers: e.g. NatureWorks LLC, Purac, Far Eastern Textiles, Toray Industries.

2.4 Polyhydroxyalkanoates (PHA)

- Easily biodegradable polyester.
- Bacterial storage material.
- PHA production induced by excess of carbohydrates during bacterial growth.
- Genetically modified bacteria as well as plants may be used in alternative production processes.
- More than 100 PHA composites enabling different applications of the materials are known.
- Melting and glass transition temperatures vary from 60 to 177°C and from -50 to 4°C, respectively.
- Polyhydroxybutyrate (PHB) is the most common, industrially used polymer produced by bacteria; polyhydroxyvalerate and polyhydroxyhexanoate are two further examples.
- Disadvantages: Brittleness, stiffness, thermal instability.
- Producers: PHB Industrial Brasil, Telles, Kaneka Co., Metabolix, DSM.

2.5 Biobased polypropylene (PP) and polyethylene (PE)

- Non-biodegradable vinyl polymers.
- Production of the monomer ethylene from ethanol, which is derived by fermenting corn or sugar cane. Propylene is chemically synthesized from ethylene (by metathesis).
- The chemical and physical properties of PE and PP are not related to the origin of the monomers.
- Producer: Braskem, Brazil. Biobased PE was first produced in a commercial scale in 2010; the same company plans a plant for the production of biobased PP.

2.6 Partially biobased PET

- Non-biodegradable aromatic polyester.
- Composed of monoethylene glycol (MEG) and terephthalic acid.

- In biobased PET, MEG is retrieved from renewable resources (accounting for up to 30% of the carbon).
- To our knowledge, the second monomer, terephthalic acid, is still synthesized from fossil-fuel based materials, but several companies are working on biobased solutions (e.g. Virent and Gevo).
- Applications: PlantBottle™ introduced by The Coca Cola Company (TCCC) in 2009 and also used for Heinz ketchup since 2011. Greener Bottle or Bouteille Végétale introduced by Danone in 2010.

2.7 Biobased polyethylene furanoate (PEF)

- Non-biodegradable aromatic polyester.
- Recently reported on by the FPF [11].
- Consists of 100% biobased furandicarboxylic acid (FDCA) and MEG.
- MEG is synthesized from biomass (as in the production of biobased PET).
- FDCA is chemically produced from biomass by dehydration and oxidation, and then it is polymerized in the presence of MEG forming PEF.
- Better barrier functions than PET.
- Small amounts of PEF could be recycled together with PET.
- (Future) applications: Bottles, fibers, films.
- Producers: Avantium, Netherlands, in collaboration with ALPLA, TCCC and Danone.

2.8 Aliphatic (co)polyesters

- Biodegradable polymers.
- Monomers are one or more kinds of aliphatic dicarboxylic acids and diols, respectively. Polymerization leads to the formation of e.g. polybutylene succinate (PBS), polyethylene succinate (PES), polyethylene adipate (PEA), and polybutylene succinate adipate (PBSA).
- Synthesis is generally based on fossil fuel-based materials, but also synthesis routes using biobased materials were published [12].
- Applications: e.g. disposable cutlery (PBS).
- Producers: e.g. IRE Chemical Ltd., SK Chemicals.

2.9 Aliphatic-aromatic (co)polyesters

- Biodegradable polymers [7].
- Produced by condensation of aliphatic diols, aliphatic dicarboxylic acids and aromatic dicarboxylic esters/acids, e.g.

polybutylene adipate terephthalate (PBAT), polybutylene succinate terephthalate (PBST).

- PBST is used as fast food disposable packaging, PBAT for plastic films.
- Producers: e.g. DuPont, IRE Chemical Ltd.

2.10 Polycaprolactone (PCL)

- Biodegradable polyester.
- Produced by ring-opening polymerization of ϵ -caprolactone. The resource is not renewable.
- Low melting point (62°C), usually applied as blend with other biopolymers (e.g. starch).
- Applications: Pure PCL is mainly used in medical applications due to the low melting temperature and good biodegradability. PCL blends are used as FCMs [13].
- Producers: e.g. Daicel Corporation, Dow Chemicals.

2.11 Polyvinyl alcohol (PVOH)

- Biodegradable vinyl polymer (although PVOH-degrading microorganisms need selective enrichment to efficiently mineralize PVOH or PVOH-blends [14]).
- Water-solubility is dependent on the hydrolysis ratio of the polymer.
- Raw materials are fossil-fuel based.
- Applications: Coatings (e.g. carbon dioxide barrier of PET), component of adhesives, additive in the production of paper and board.
- Producers: e.g. Kuraray, DuPont.

2.12 Polyamides (PA)

- Non-biodegradable polymer.
- Different PAs can be synthesized using up to 100% of vegetable oils and other plant derived substances as raw materials [15].
- Applications: high-performance polymers, not commonly used as FCM.
- Producers: e.g. DSM, Evonik.

2.13 Further biobased polymers

- Also animal sources are used to produce bioplastics (e.g. chitosan, a derivative of chitin technically derived from shell fish; whey protein isolate; gelatin).
- Plant raw materials based on proteins are a further biomass source for biodegradable plastics (e.g. soy protein isolate; gluten and zein (mixtures of wheat and corn proteins, respectively)).
- Niche products that do not find broad applications as FCM.

Table 1. Production capacities of bioplastics and fossil fuel based plastics

Year	Bioplastics		Fossil fuel based plastics	
	European capacity (1,000 tons/year)	Global capacity (1,000 tons/year)	European capacity (1,000 tons/year)	Global capacity (1,000 tons/year)
2005	50 [2, 16]		53,000 [2]	>200,000 [2]
2006	100 [2, 16]	350 [2, 16]	>50,000 [17]	>200,000 [17]
2007		65 ^a [7]		250,000 [7]
2010		327 [18]; 1,016 [16]	57,000 [17]	270,000 [17]
2011	215 [16]	1,161 [16]	58,000 [17]	280,000 [17]
2012	318 [8, 16]	1,395 [16]	57,000 [17]	288,000 [17]

^aOnly biodegradable and biobased plastics.

2.14 Additives

Pure biodegradable materials generally do not perform as well as conventional plastics. The addition of chemicals enhancing a material's technical properties is very common. These compounds are either added to optimize the processability of a material and/or to improve its properties during use. Additives include plasticizers, antioxidants, light and UV stabilizers, releasing agents, cross-linking agents and many more. In Europe, additives for bioplastics are also regulated under Commission Regulation (EU) 10/2011 [19]. According to Niaounakis, none of these compounds should have adverse environmental or health effects. Furthermore, the additives should not compromise the biodegradability of the material [8].

3 Market data

In 2012, 0.5% of the global plastics demand was covered by bioplastics according to production capacity data published by the two associations European Bioplastics and Plastics Europe (Table 1). The numbers published by European Bioplastics also included only partially biobased plastics (e.g. partially biobased PET used for bottles). In 2007, starch derived bioplastics were reported to have the biggest market share (50%), followed by PLAs (40%), and PHA and further polyesters (10%) [8].

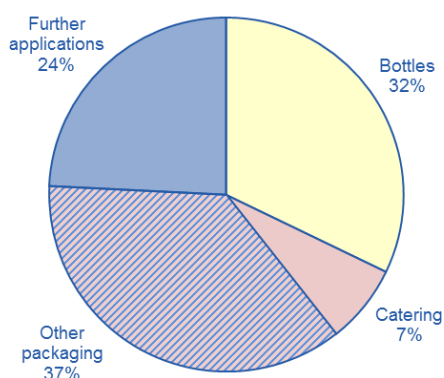


Figure 3. Global market segments of bioplastics in 2012. Total global capacity was 1,4 million tons (data were derived from [16]).

At the time of writing, the European Bioplastics association reports 70 companies being members of their organization [16]. Figure 3 shows the relative market shares and applications of bioplastics. Bottles accounted for 32% of the global market. More than 90% of the bottles were made of biobased, but non-biodegradable PET, which contains up to 30% carbon derived from renewable sources [16]. Bioplastics used for catering were reported to be made of PLA, PLA-blends, starch blends or other biodegradables. It was not clear from the available data as to what extent the 37% other packaging included food contact applications [16]. According to another source, 65% of biobased polymers were used in food-related applications in 2007 [8].

4 Migration and human health effects

4.1 General aspects

The synthesis of current knowledge about migration from bioplastics is difficult to perform, because no comprehensive studies comparing the migration behavior of chemicals from biobased and fossil-fuel based plastics exist. In our search for original research articles we mainly found studies describing migration from PLA and starch-based polymers [6, 20, 21]. Migration of lactic acid, its dimer, and lactide

from PLA were reported to be low, and under consideration of the toxicological data the authors concluded that PLA is a substance Generally Recognized As Safe (GRAS) [20]. In 2013 the intended migration of natural antimicrobial additives from TPS and a thermoplastic starch blend into the food was described by an Australian research group [22]. Although the migration of chemicals is traditionally kept as low as possible, the intentional release of antimicrobials from the packaging into the food is one attempt to increase the storage time. In a very recent paper, Zhu et al. described experimental results and a suitable model for the migration of the plasticizer triacetin from starch acetate into food simulants [21]. More research of this kind is needed to be able to understand migration on a molecular level.

In addition to these examples, further general aspects of migration should be addressed in the future to better understand and evaluate the differences between conventional and biobased plastics. (i) The different physico-chemical properties of biobased FCMs might result in higher or lower migration rates of additives compared to fossil-fuel based materials. Theoretical models covering these aspects would be desirable. (ii) Furthermore, pure bioplastics are usually less stable and have a lower diffusion barrier than conventional plastics. To overcome these problems, stabilizers and other additives are necessary. However, these may migrate from the packaging into the food. Comparative studies describing the relative or absolute migration rates of these additives are of interest, although they are currently difficult to find. (iii) The monomer of cellulose- and starch-based polymers is glucose, whose migration into the food is of no concern. Also the monomers of PHB and PLA are judged to be of no health concern [20, 23]. This stands in contrast to the toxicological profile of many other monomers used in the production of packaging materials, e.g. bisphenol A (BPA), bisphenol S (BPS), vinyl chloride and acrylamide. Possible health effects caused by these monomers during production and after migration into the food could be compared.

4.2 Additives in oxo-biodegradable plastics

The additives in oxo-biodegradable plastics, the prodegradants, form a further source of possible migrants. A review article by Ammala and colleagues gives a good overview of commercial and further potential prodegradants [3]. Although the manufacturers state that currently used additives are safe, the list includes chemicals that are suspected to be of concern for human health, e.g. benzophenones and dithiocarbamates [24].

4.3 Migration from bio-nanocomposites

In 2005, migration of nanoclay from starch-nanocomposites was reported to be of no concern and to conform to the European FCM regulation of that time [6]. A very recent study by Houtman and colleagues focused on the *in vitro* toxicity of nanoclay and reported that one of three nanoclays had cytotoxic effects on two different cell lines [25]. Two further independent studies showed cytotoxic and genotoxic effects of one organic nanoclay in cell culture [26, 27]. Lordan et al. pointed out the methodological difficulties in testing the toxicity of nanoclays in cell culture [28]. However, Li et al. performed rat and *in vitro* studies with nanoclay platelets indicating the safety of this material [29]. Most authors of these studies point out the need for further testing under more standardized conditions to perform adequate risk assessment of nanomaterials used in bio-nanocomposites.

5 Environmental aspects

5.1 Renewable sources and land use

The production of biobased plastics depends on agricultural raw materials. European Bioplastics estimated that less than 0.01% (corresponding to 400,000 hectares) of the global arable area was used for the cultivation of raw materials for biobased plastics in 2012 [16]. The same association anticipates annual production growth rates of these materials of almost 90% until 2017 [16]. In the opinion of the trade group, bioplastics do not compete with food production, because its share in land use is too small. Nevertheless, the substitution of all plastics with bioplastics would demand the use of 7% of the arable land worldwide [30].

According to Plastics Europe and European Bioplastics, sustainable sourcing of biomass could be reached by sustainability certification schemes such as the ISCC (International Sustainability and Carbon Certification) and the RSPO (Round Table on Sustainable Palm Oil). Alternatively, further developments in renewable feedstock of the second generation making lignocellulosic biomass available for further chemical syntheses may be employed. More critical voices claim that the cultivation of crops for bioplastics requires very intense farming including fertilizers, pesticides, high water usage and possibly genetically modified plants and would therefore be less in line with sustainable development criteria.

5.2 Biodegradability

Labels certifying the biodegradability or compostability of a product describe the material's potential, not its inherent value. A compostable or biodegradable material does not necessarily decompose under all conditions. Landfills, which are still common in many countries, usually provide anaerobic conditions that prevent many biological processes necessary for mineralization.

Like conventional, fossil-fuel based plastics, biodegradable plastics contain additives optimizing their technical properties. Little is known about the fate of these compounds after biodegradation or composting. When large amounts of compostable bioplastics are degraded in industrial composting facilities, these substances or their metabolites could accumulate. Testing of regulated heavy metals and any toxic chemicals in the final compost is required according to the current standards (see 6.2). Nevertheless, a comprehensive chemical analysis of such a complex matrix is difficult and expensive to achieve. Thus, the final compost might contain a mixture of plastic-derived chemicals that are formed during or remain after the degradation process.

Labelling a packaging as biodegradable may encourage people to litter the environment. To stop such behavior, Belgium introduced a law preventing packaging from being declared biodegradable (for more information see Vincotte's webpage <http://www.okcompost.be/en/recognising-ok-environment-logos/ok-biodegradable-soil-amp-ok-biodegradable-water/>).

5.3 Genetically modified organisms

Biobased plastics can be produced by using genetically modified crops as raw material [31-33]. Furthermore, genetically modified bacteria may be used to optimize PHA production [34]. Transgenic sugarcane and tobacco plants were reported to produce up to 4.8% and 17.3% weight per dry weight PHB in leaf tissues, respectively, after bacterial genes were inserted into these plants [35, 36].

5.4 Sustainability and life cycle assessment (LCA)

LCAs are used to evaluate the sustainability and the environmental impact of products. Many studies were published comparing petroleum-based to biobased plastics; here we show a few examples. In 2009, Roes and Patel compared the conventional risks of biobased plastics (PTT, PHA) with conventionally produced materials (PE, PET, PTT) [37]. The result of this study on life cycle risks for human health showed that the risks measured as years of life lost (YOLL) are lower for biobased than for fossil-fuel based polymers, but the differences lie within the uncertainty range of the study, hence a final conclusion could be drawn.

In 2007, Harding et al. performed a cradle-to-gate LCA analysis of PHB and compared it to published LCA studies on PE and PP [38]. In the full assessment PHB was judged to perform better than the polyolefins, although the eutrophication potential and the energy and water requirements were higher for PHB. In 2010, Tabone and colleagues evaluated a total of 12 polymers (seven fossil-fuel based plastics, two PLAs, two PHAs and biobased PET) [39]. LCA analysis of these materials showed that biobased plastics ranked 4, 6, 8, and 9. PET and biobased PET were placed on the 9th and 12th rank, respectively. The authors further performed a green design assessment, in which the biobased plastics performed best ranking on places 1 to 4. Yates and Barlow recently compared LCAs of PLA, PHB and starch-based polymers with studies about polymers that they could replace [40]. They concluded that the use of bioplastics may result in a reduction of the nonrenewable energy use (NREU) and global warming potential, but further factors such as the acidification and eutrophication potentials might have a negative effect on the overall assessment. One further review investigated 44 LCAs and concluded that 55 ± 34 gigajoules of primary energy and 3 ± 1 t carbon dioxide equivalents of greenhouse gases could be saved during the production of one metric ton of biobased plastic compared to the production of fossil-fuel based materials [41]. Yet again, the eutrophication potential of biobased polymers was higher. The acidification potential and photochemical ozone formation gave inconclusive findings in this case. Niaounakis reviewed even more LCA analyses for starch, PLA, PLA and biobased PE in his recent book [8]. Chen and Patel concluded in a review on bioplastics that there has to be a trade-off between the NREU and greenhouse gas emissions on the one side and the higher land requirements caused by the biomass demands on the other side [12]. Another comprehensive review was published by Álvarez-Chávez et al. comparing bioplastics with respect to different sustainability criteria and ranking schemes (including occupational health and safety impacts and environmental effects) [42].

These few exemplary studies show that it is important to consider as many environmental impact categories as possible when developing or choosing an alternative material. Furthermore, they demonstrate the difficulty in drawing general conclusions from LCA studies, because they are highly dependent on the data quality, the specific conditions (e.g. the energy source, the stage of process development and transport distances), scope of the analysis and assumptions used.

6 Regulations, standards and certifications

6.1 Regulations

In Europe, biobased plastics are regulated under Commission Regulation (EU) 10/2011 [19]. All monomers and additives used in the production of bioplastics have to be listed on Annex I of this regulation, commonly referred to as Union list. Compounds on the Union list were assessed and restrictions for use and specific migration limits (SMLs) were set. As described in 2.2, regenerated cellulose films are specifically regulated under Commission Directive 2007/42/EC [10], because they are not regarded as “plastics”. All substances in nanoform require an explicit authorization according to article 9 of the Commission Regulation (EU) 10/2011, because authorizations of substances with conventional particle sizes do not cover the respective nanoform. To our knowledge, only three nanomaterials are authorized for the use in plastics in Europe, namely carbon black, titanium nitride and silicon dioxide. Thus, the bio-nanocomposites based on nanoclay are not authorized in the European Union. In contrast, nanoclay is generally recognized as safe (GRAS) by the U.S. Food and Drug Administration (FDA).

6.2 Standards on compostability

Several standards exist that help to specify whether a material is compostable [8]. Three international standards (EN 13432:2000, ISO 17088:2012 and ASTM D6400-12) outline the same test schemes and specify four main criteria to be considered during testing: (i) characterization of the material, (ii) disintegration ability of the material, (iii) biodegradation of the material into carbon dioxide, biomass and water within 6 months and (iv) ecotoxicity tests of the finished compost.

6.3 Standards on biodegradability

There are a multitude of standards that define the biodegradability of plastic materials in different environments (aquatic, marine, compost, soil, in landfilling) and under different conditions (e.g. aerobic/anaerobic) [8]. All compostable polymers are biodegradable, but not vice versa.

6.4 Determination of the biobased carbon content

Standards and technical specifications exist for the quantification of the biobased carbon content of a product (ASTM D6866-12, ASTM D7026-04, CEN/TS 16137:2011). The relative carbon-14 (¹⁴C) levels, which are proportional to the biomass content of the material, are measured in the product. ¹⁴C is only found in biobased materials, but not in fossil fuels, because it has a half-life of about 5700 years.

6.5 Certifications

Certification organizations (e.g. DIN CERTCO, Vinçotte (both EU), Biodegradable Products Institute (US), Japan BioPlastics Association) verify claims made regarding the biodegradability or compostability of a polymer as well as its content of renewable resources. These processes are voluntarily, follow defined standards and allow the producers of a material the labeling with the respective logo.

6.6 Labelling

Materials successfully certified as compostable according to EN 13432 by DIN CERTCO and Vinçotte can obtain the “seedling” logo in many EU countries (Figure 4). An alternative European logo is the “OK compost” logo issued by Vinçotte only. Further variations of this logo exist certifying the potential of a material to degrade in the

garden compost heap (“OK compost home”) and biodegrade in certain environments (“OK biodegradable soil” and “OK biodegradable water”). In the U.S., the Biodegradable Products Institute licenses the “compostable” logo to companies producing materials complying with the standards ASTM D6400 and/or ASTM 6868.

Manufacturers of biobased plastics do not need to disclose the biobased carbon content of their products, but they can provide this information to better inform the customers. Different labels have been developed and can be authorized to products by certification organizations, e.g. the Japan BioPlastics Association, DIN CERTCO and Vinçotte (Figure 5). The Japanese BiomassPla logo can only be issued if the material includes more than 25% of biobased resources.



Figure 4. Logos certifying a material's compostability. In the EU, the “seedling” (1) and “OK compost” (2) logos are issued by DIN CERTCO and Vinçotte, the “compostable” logo (3) is issued by the Biodegradable Plastics Institute in the U.S.

Figure 5. The two logos 4 and 5 describing the content of biobased resources are issued by DIN CERTCO and Vinçotte, respectively. The BiomassPla logo (6) is issued by the Japan BioPlastics Association and can only be authorized if more than 25% of biobased resources are included in the material.

Abbreviations

ASTM	American Society for Testing and Materials
EN	European Standard
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
FCM	Food Contact Material
FDA	Food and Drug Administration
FDCA	Furandicarboxylic acid
GRAS	Generally Recognized as Safe
LCA	Life Cycle Analysis
NREU	Nonrenewable Energy Use
MEG	Monoethylene glycol
PA	Polyacrylamide
PBAT	Polybutylene adipate terephthalate
PBS	Polybutylene succinate
PBSA	Polybutylene succinate adipate
PBST	Polybutylene succinate terephthalate
PC	Polycarbonate
PCL	Polycaprolactone
PE	Polyethylene
PEA	Polyethylene adipate
PEF	Polyethylene furanoate
PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PLA	Poly lactide
PP	Polypropylene
PS	Polystyrene
PTT	Polytrimethylene terephthalate
PVC	Polyvinylchloride
PVOH	Polyvinylalcohol
TPS	Thermoplastic starch
YOLL	Years of Life Lost

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