Biopolymers – Vision and Reality

Introduction:

Biopolymers are very often mentioned as an important element for sustainable packaging solutions in the context of subjects like plastic waste and circular economy. But how precisely is a biopolymer defined; which product characteristics can be achieved with them, and what possibilities for disposal are available? The term “biopolymer” will be more precisely defined below, and possible applications, trends and visions will be discussed without, however, ignoring the reality, facts and problems.

Definition of biopolymers

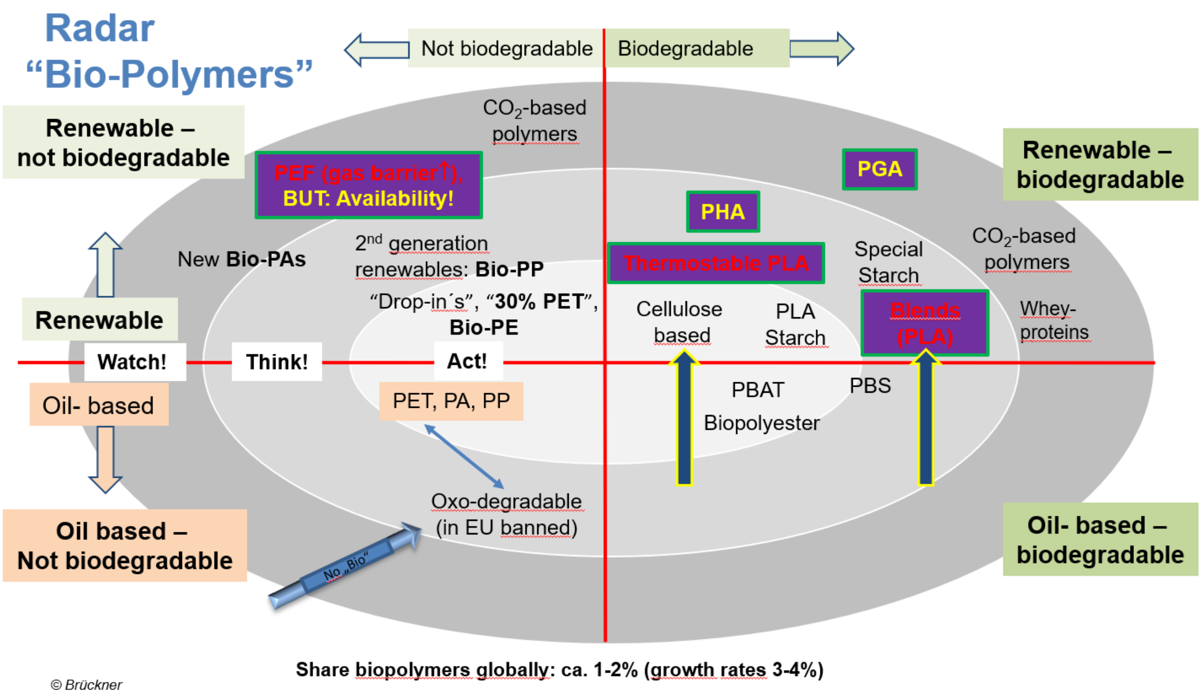


Fig. 1: Definition of biopolymers, examples of various representatives.

Diagram 1 subdivides polymers on the one hand into those “manufactured from renewable raw materials” as opposed to those that are “petroleum-based” (top-bottom), and on the other into those that are “biologically degradable” or “not biologically degradable” (right-left). Not only plastics made from renewable raw materials and biologically degradable polymers but also those that fulfil both criteria are described as “biopolymers”. Biopolymers which correspond exactly to their fossil-fuel counterparts, e.g. “green polyethylene”, can be very quickly integrated into existing processes. Plastics of this kind are described as so-called “drop-ins”. The familiar PLA (polylactic acid), on the other hand, is manufactured from maize (corn), for example. It is biologically degradable or compostable; at the beginning of its development it could only be processed initially to a certain extent in established added-value chains. While just a few years ago the renewable character of biopolymers carried considerably more weight, today their biological degradability has become increasingly important (again), for example in the latest Chinese legal requirements regarding plastic articles.

The possible applications and advantages of biopolymers

In principle, biopolymers can be processed exactly like petroleum-based plastics. The manufacture of films, bottles and thermoformed containers as well as permanent mouldings and even textiles is easily possible with certain modifications, and in many cases the characteristics are comparable with their fossil-fuel counterparts – and sometimes even better. Organic bin liners appear ideal for disposal together with organic waste. And there are also a number of examples for biaxial oriented films, the best-known being BOPLA. Since many biopolymers are manufactured from plants and these are capable of synthesising organic mass from CO_2 and water, the Product Carbon Footprint (PCF) of these plastics can even initially be “credited” with a certain amount of CO_2. For example, according to data from Braskem, a tonne of “green PE” will bind approximately 3 tonnes of CO_2. That is, of course, a major advantage compared with petroleum-based plastics. After all, one tonne of PE manufactured from fossil-fuel educts will emit a similar amount of CO_2, namely almost 2 tonnes CO_2. Moreover, “green PE” is just as recyclable as its fossil-fuel counterpart, so this is a clear win-win situation.

An idealised cycle similar to the one in Fig. 2 can also be created for PLA which is not only manufactured from renewable raw materials but which is also biologically degradable. Indeed PLA can also be recycled mechanically and even as feedstock. And it is claimed that the new star among the biopolymers, PHA, can even be rapidly and completely degraded in the sea and hence may possibly be excluded from the bans on plastic as a “naturally occurring polymer”!

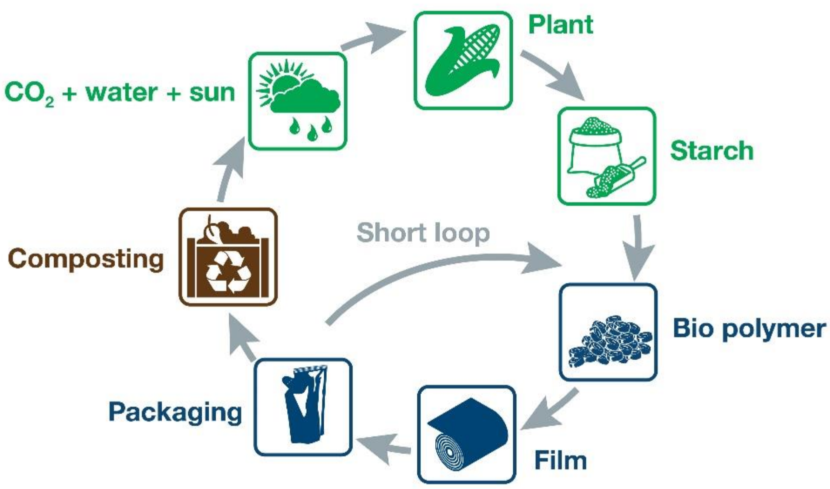


Fig. 2: Idealised recycling management using the example of a biopolymer.

The interest in biopolymers continues unabated with regard to applications in the agricultural sector. For example, the biopolyester PBAT demonstrates strong growth. It can be used for the manufacture of mulch films, for example, and after the crop has been harvested it can be ploughed in without hesitation because of its good biodegradability.

With all these advantages of biopolymers it should really be possible to solve many of the urgent current global problems such as climate warming, marine littering and a lack of recycling management very quickly! There are, however, also a number of facts which will prove disadvantageous.

Data, facts and figures regarding biopolymers

Fig. 3 indicates the quantities of biopolymers available worldwide during 2019; the data source was *European Bioplastics*. The 2.11 million tonnes represent less than 1% of the plastics manufactured worldwide. Since according to many prognoses the growth in “green” plastics is similar to that of petroleum-based polymers, this situation is not likely to change in the short term. So what does this mean for our biax market? Here is a concrete numerical example.
During 2019, approximately 75,000 tonnes p.a. of PLA were used worldwide for all kinds of flexible packaging. At approximately 260,000 tonnes p.a. the BOPP-C segment represents about 1% of the worldwide biax capacities. Hence we can see that with the PLA capacities currently available, only a small number of biax installations can be realised, even if all of the production were to be used for biax applications. And sudden increases in the quantities of PLA available are not to be expected. It took a relatively long time until operations in Thailand commenced in 2019 with 75,000 tonnes p.a. of PLA production.

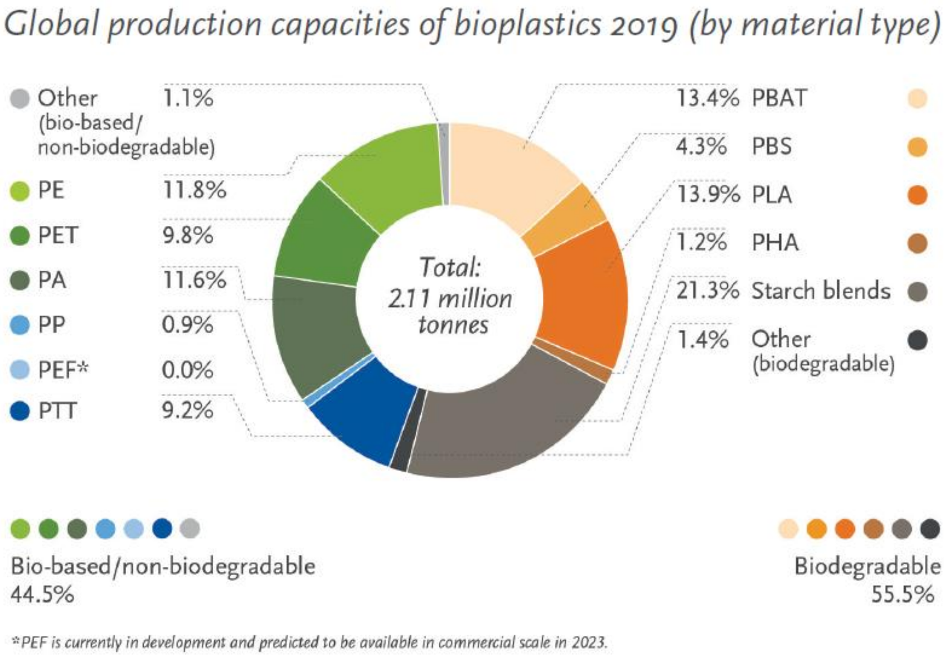


Fig. 3: Global production capacities for biopolymers (European Bioplastics).

The considerably higher prices of many biopolymers also represent a not inconsiderable problem. The least expensive is “Green PE” by Braskem; at ≥ € 2 / kg it costs roughly twice as much as the fossil-fuel types. Standard PLA types cost approximately € 3 / kg, while PLA which is more temperature-stable can cost up to € 8 / kg. PBAT costs approximately € 6 / kg, and the cellulose-based raw materials will probably lie in roughly the same price range; PHAs are listed at € 6-16 / kg.

Also essential: Since no separate collective flows exist for biopolymers, a targeted disposal and exploitation is currently almost impossible. Incorrect sorting into other material streams such as, for example, PET or PE, will adulterate these and even operators of industrial composting plants try to keep bio-based plastic bags our of their material streams. Biological degradability is clearly defined in norms, but under real environmental conditions there are many different variations. PLA needs, for example, special composting conditions: if you put the material into the domestic compost, its decomposition will take a very long time. Correspondingly, the approach whereby biologically degradable materials are promoted as the solution for littering is more than questionable. And even if it does decompose of its own accord, the energy stored within it would be lost and CO_2 would nonetheless be emitted. Different biopolymers are very often combined in multi-layered films and blends, so that the decomposition characteristics of the individual materials are no longer the decisive factor. It is thus hard to imagine it being used for material recycling or as feedstock.

The land-use requirements of biopolymers are currently very low, considerably less than 1%. However, if the quantities of biopolymers were to increase continuously they would come into direct competition with food production. More recent research therefore aims at making organic waste and possibly even CO_2 itself into base materials for biopolymers. However, this will not solve the general CO_2 climate problematic. By way of comparison: the total "Green PE" production of Braskem currently binds approximately 600,000 tonnes of CO_2; with an annual worldwide emission of 32.3 billion tonnes of CO_2 (2015 value, increasing rapidly) this represents a mere 0.0019%.

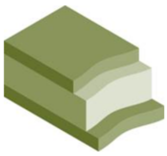
And that list of disadvantages is by no means complete. Biopolymers may offer a wide range of possibilities, but the list of limitations is equally long, and this results in many fragmented individual solutions in niche applications.

Work on biopolymers at Brückner

Within the framework of its raw materials scouting and new business development, Brückner is observing the developments in this sector attentively. Basic experiments are carried out in the technology centre, both internally and with customers. A recent project resulted from the enquiry of a customer regarding biaxial-oriented biopolyester film. Single-layer and triple-layer films were produced and evaluation on a laboratory scale carried out; Fig. 4 shows the data sheet for a triple-layer film with the addition of PLA only in the outer layers:

30µm 3-layer sim. BO-Blend Biopolyester/ PLA
Biaxial Oriented Compostable Film

- Structure:
  - A: 20% Biopolyester/ PLA + AB
  - B: 60% Biopolyester
  - A: 20% Biopolyester/ PLA + AB



- Applications:
  - Fruit and vegetable packaging films
  - Bio-garbage bags
  - Agricultural films
- Stretching Ratio: 5.0 x 5.0
- Highlights:
  - Very good extrudability & stretchability
  - Wide processing window
  - Film properties similar to BOPE (good tear propagation)
  - Optical properties acceptable
  - Partly based on renewable resources
- Benefits:
  - Good sealing properties
  - Good thermostability up to 230°C
  - Compostable compound
  - Food contact approved

Film Test Results

Film Type:	sim. BO-Blend PBAT/ PLA
Sample No.:	3-Layers ABA - KARO - Block 1
Date of Production:	2020
Date of Test:	2020
Order No.:	IT

Description		Unit	Average	Comment	Method
Thickness	MD	µm	29.9		DIN 53370
Tensile Strength	MD	N/mm²	95		ASTM D 882
	TD	N/mm²	99		
Elongation at Break	MD	%	133		ASTM D 882
	TD	%	140		
Modulus of Elasticity	MD	N/mm²	251		ASTM D 882
	TD	N/mm²	244		
F-5 Value	MD	N/mm²	8.8		ASTM D 882
	TD	N/mm²	9.0		
Haze		%	30		ASTM D 1003
Thermal Shrinkage	MD	%	20.4	80°C/5min	BMS TT 0.9
	TD	%	20.3		
Tear Propagation Resistance	MD	N	0.9	Trouser Tear large	DIN EN ISO 6383-1
		N/mm	30.6		
	TD	N	1.13	Trouser Tear large	DIN EN ISO 6383-1
		N/mm	39		

Fig. 4: Data sheet for a triple-layer, biaxially oriented biopolyester film.

If amounts of PLA are added to the core layer, the E-modulus of the biopolyester films can be considerably increased, as can be seen in Fig. 5:

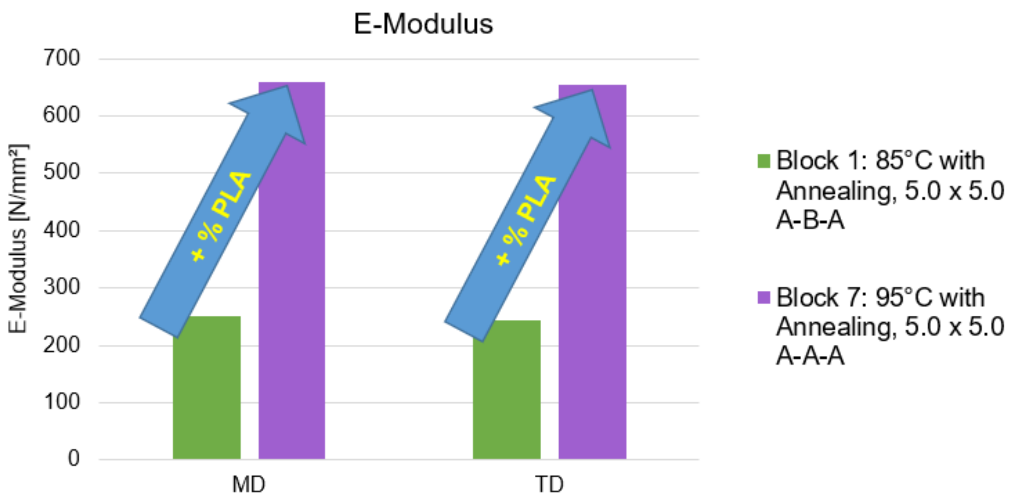


Fig. 5: Change in the E-Modulus through the addition of PLA in the core layer.

For many applications the visual appearance and shrink properties of these new biax films are not adequate and must therefore be improved. In both cases a different bioplastic on the basis of polyester could help as this can also be composted on a domestic compost heap and can also be manufactured from renewable raw materials. To this end experiments are already under way in the Brückner laboratories and trials in the semi-industrial pilot installation are planned. As for the pure BOPLA films: here we can already offer interested customers a finished concept. For this Brückner has developed first elements of a biofilm “construction set”; as a result of the wide-ranging possibilities for blends and film structure, a cooperation with an end-user seems essential here, in order to create a coherent film concept.

Prospects

Biopolymers are only at the beginning of their development; this is likely to be very time-consuming, both as regards quantities and also with regard to disposal methods. Although biopolymers offer advantages with respect to certain applications, at present they only serve a niche market and an integral disposal system does not yet exist. Nonetheless states in Africa and Asia and several brand owners offer bio-based, biologically degradable packaging solutions. Brückner is observing the developments in this field very closely and is well equipped to respond to customer enquiries regarding biaxially oriented “biofilms”.

Author: Dr. Martin Wolf, Manager Laboratory (martin.wolf@brueckner.com)