Confusion about terminology and definitions for bio-based and biodegradable plastics

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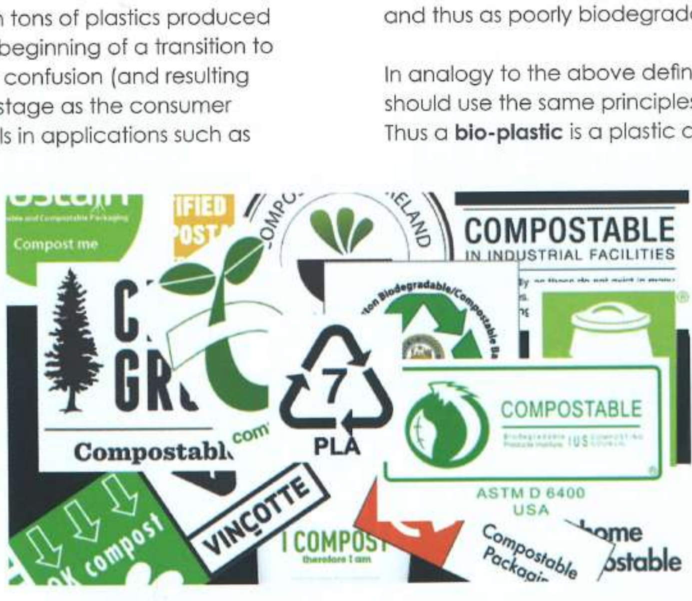
Citizens (consumers) are confused. The general public assumes that bio-based polymers are biodegradable and because biodegradability is considered a positive attribute, this confusion is often cherished, rather than clarified. Is a compostable plastic biodegradable? Why does the answer to this question depend on which definition we use? We can explain why there are different standards in different countries and why are there often even regional or local differences for disposal of degradable packaging waste but why are there different definitions? Why do international organizations come up with definitions that are scientifically nonsense such as calling fossil-based biodegradable polymers biopolymers? At a recent conference I heard someone suggest in his plenary lecture to use the terms "plastics" and "polymers" to differentiate between fossil-based and bio-based plastics, respectively. While I do have sympathy for using a different term than plastics for bio-based families, we cannot redefine a term such as polymer which has a clear (scientific) definition already.

In humanity's quest to a more sustainable circular economy, we need to use towards 2050 more and more carbon that is already above the ground, not only for our energy but also for our (plastic) materials. While for energy many alternatives are available, for plastic materials today the only alternative carbon sources for (virgin) materials is biomass. As today less than 1% of the annual 350 million tons of plastics produced is bio-based, we are only at the beginning of a transition to circularity for plastics. Consumer confusion (and resulting frustration) does not help at this stage as the consumer demand for sustainable materials in applications such as packaging can become an important force to accelerate this transition. On the other hand it is clear that certain established industries may benefit from this confusion as it helps to maintain the status quo.

In order to take away confusion, we first need to get our definitions right. Let's look at the definition for **biopolymer**. According to the Merriam-Webster dictionary, a biopolymer is "*a polymeric substance (such as a protein or polysaccharide) formed in a biological system*" and according to Wikipedia biopolymers are "*polymers produced by living organisms*". Examples of biopolymers are DNA, insulin, starch and cellulose. In specific cases, organisms can be "tuned" to produce specific biopolymers such as polyhydroxyalkanoates (PHA's). The biopolymers are under most general conditions also biodegradable (see definition below).

On the other hand we have synthetic (man-made) polymers that can be made from building blocks that originate from biological (once living) systems. Most of these building blocks (monomers) are derived from sugars. Some examples are lactic acid, succinic acid, ethylene glycol, furan dicarboxylic acid and isosorbide. We call the polymers obtained from these bio-based monomers (partly) **bio-based** polymers. Examples for this category are polylactic acid (PLA), polybutylene succinate (PBS), polyethylene terephthalate (PET; only MEG bio-based), polyethylenefuranoate (PEF), bio polyethylene (bio-PE) and many others. Although these definitions are unarguably very clear, here the confusion already starts. Although of course all biopolymers are also bio-based, none of the man-made bio-based polymers are actually biopolymers. By calling bio-PE a biopolymer (it is not!), the general biodegradability of biopolymers is falsely associated with bio-PE. Of course bio-PE is identical to fossil-PE and thus as poorly biodegradable.

In analogy to the above definitions, the definitions for plastics should use the same principles as those for polymers. Thus a **bio-plastic** is a plastic derived from a biopolymer. PHA's and (modified) starches are examples. In analogy, **bio-based plastics** are plastics derived from man-made polymers obtained (partly) from bio-based monomers. Bio-PE, PLA, PEF and PBS are examples of this class. **To end this confusion, I sincerely hope that we will STOP using the terms biopolymers and bioplastics for man-made bio-based polymers and bio-based plastics such as bio-PE, PLA, PBS and PEF.**



Now let's look at the confusion about the terms "biodegradable polymer" and "biodegradable plastic" by first looking at the definition for biodegradability. **Biodegradation** (aerobic) is the breakdown of organic matter by microorganisms, such as bacteria and fungi in the presence of oxygen to produce mostly carbon dioxide, water, and some type of new biomass (e.g. uptake by the fungi to grow); standard CEN/TR 15351:2006, page 23. In practice, almost all chemical compounds and materials are subject to biodegradation processes. The significance, however, is in the relative rates of such processes, such as days, weeks, years or centuries. A number of factors determine the rate at which this degradation of organic compounds occurs. Next to factors related to the polymeric structure such as composition, monomer distribution, crystallinity and molecular weight, environmental factors include light, water, oxygen and temperature.

Plastics that are biodegradable can be classified by being home compostable or industrially compostable. What does this mean?

Industrial composting conditions require elevated temperature (55-60°C) combined with a high relative humidity and the presence of oxygen. These conditions are more optimal compared to other everyday biodegradation conditions in soil, surface water or marine water. Compliance with EN13432 is considered a good measure for industrial compostability of packaging materials and requires that the plastic material are naturally biodegradable within a certain time with no negative effects on the composting process and the quality of the resulting compost.

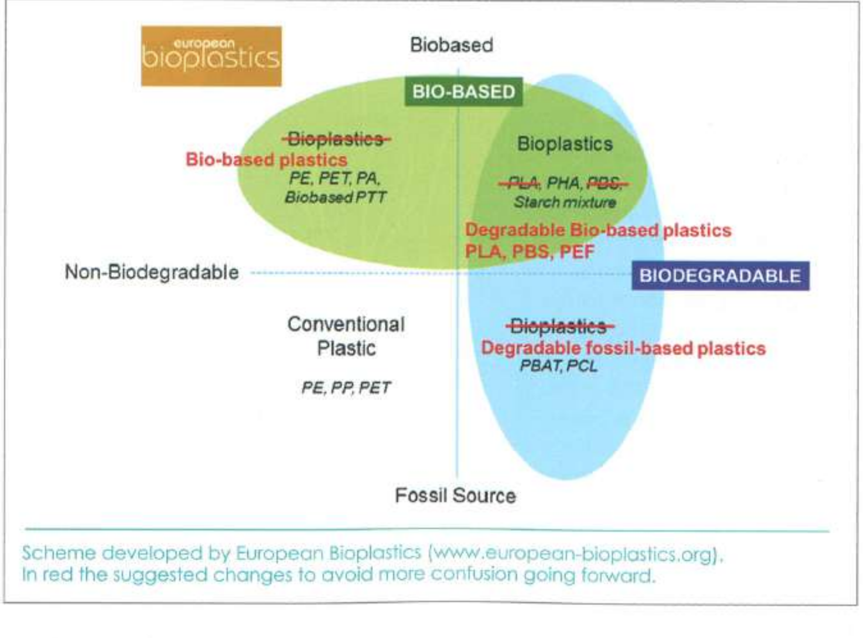
At **home composting** conditions, the temperature is lower and less constant compared to industrial composting. As a result, the degradation rate of a material is (much) slower compared to industrial composting. However, neither the Waste Framework Directive (WFD), nor the Packaging and Packaging Waste Directive (PPWD) accept home composting as a form of recycling or a legal waste treatment option.

These terms are particularly relevant when we talk about end-of-life for plastics. Before talking about biodegradation of plastics, it is clear that the most preferred end-of-life is re-use and due to future bans on single-use plastics, re-use will be much more important in the future. Re-use involves cleaning and using again without recycling. When re-use is not possible, recycling is preferred and especially closed-loop recycling (keeping the quality of the recycled material at the same level as the original material). Composting is not an attractive end-of-life solution (only for practical reasons when e.g. food waste is collected in plastic bags that can be composed together with the content). Composting waste plastics to CO_2 and H_2O in an industrial composting facility at 58°C requires energy and at the same time we do not get much "compost value" from these plastics. Instead, waste plastic incineration with energy generation (generating the same amount of CO_2 and H_2O) seems a better choice if re-use and recycling are no option.

Even if we would design all future plastic materials for re-use and recycle (which is the EU plan for 2050), human behavior results in unplanned and undesired leakage of plastic into our environment, typically into our oceans. It is estimated that yearly we lose about 8 million tons of plastics (or 8 large football stadiums filled to the roof) to the environment. For me the main reason for developing biodegradable/compostable plastics is to make sure that the materials that end up in nature do not endlessly accumulate as conventional materials often take centuries to break down. As according to the above paragraph almost all materials degrade when given enough time, we need to come up with certain rules on how to classify and label a specific plastic material for "claiming" a certain biodegradability.

It is interesting to see that certain organizations have highjacked the term "biodegradable plastic" for materials that degrade as fast or faster than cellulose and consequently emotionally fight any reference to a "biodegradable plastic" when it degrades slower than cellulose. We cannot redefine general widely accepted scientific terms but at the same time a classification e.g. on the basis of time to degradation is important and needed! According to the recently published plastics strategy, the European Union is close to proposing standardized rules for defining and labeling biodegradable and compostable plastics to allow for accurate sorting and avoid false environmental claims (A European Strategy for Plastics in a Circular Economy, EU, 2018).

In the next issue of chemistry today I will discuss the confusion around open and closed loop mechanical and chemical recycling.



Scheme developed by European Bioplastics (www.european-bioplastics.org).
In red the suggested changes to avoid more confusion going forward.