

# Bioplastic Explained: “How Much “Bio” Can You Expect in Plastic?”

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Most of the plastic we use in our daily life – and in the lab – is made of fossil sources. Its production and disposal lead to high CO<sub>2</sub>e (CO<sub>2</sub> equivalents) emissions and further environmental impacts. It is therefore mandatory to reduce the negative impacts over the whole life cycle from the production to the disposal. Bioplastic is seen as a solution, but one has to look into the details to make the right decisions – as a manufacturer and as a consumer. This whitepaper gives a deep dive into the different terms and concepts of biobased plastic.



## Introduction

The term bioplastic is generally connected to “good plastic” – mainly due to the “bio” in the wording. Many people associate this term with plastics which are biodegradable, having in mind a plastic item that will fully decompose in nature, and a polymer made of 100% renewable resources. But not all “bioplastics” are the same.

This term comprises at least three different categories, and even more when it comes to designations such as biodegradable and compostable. This whitepaper guides you through the different meanings and provides clarification on which type of plastic can be used in the laboratory – and why it should not be the biodegradable variant.

## Definition – what is bioplastic?

First, “bioplastic” is not a specified, protected term; rather, different types of plastic are grouped under this category. Bioplastic integrates a huge variety of different materials with different properties – comparable with the term plastic itself, which also comprises a wide array of very different polymers and materials.

European Bioplastics defines bioplastic [1,2] as a material which is either:

- a) Biobased
- b) Biodegradable, or
- c) Biobased and biodegradable.

The different materials can therefore be classified by the source of the raw materials from which they are made and/or their fate at the end of life. [Figure 1]

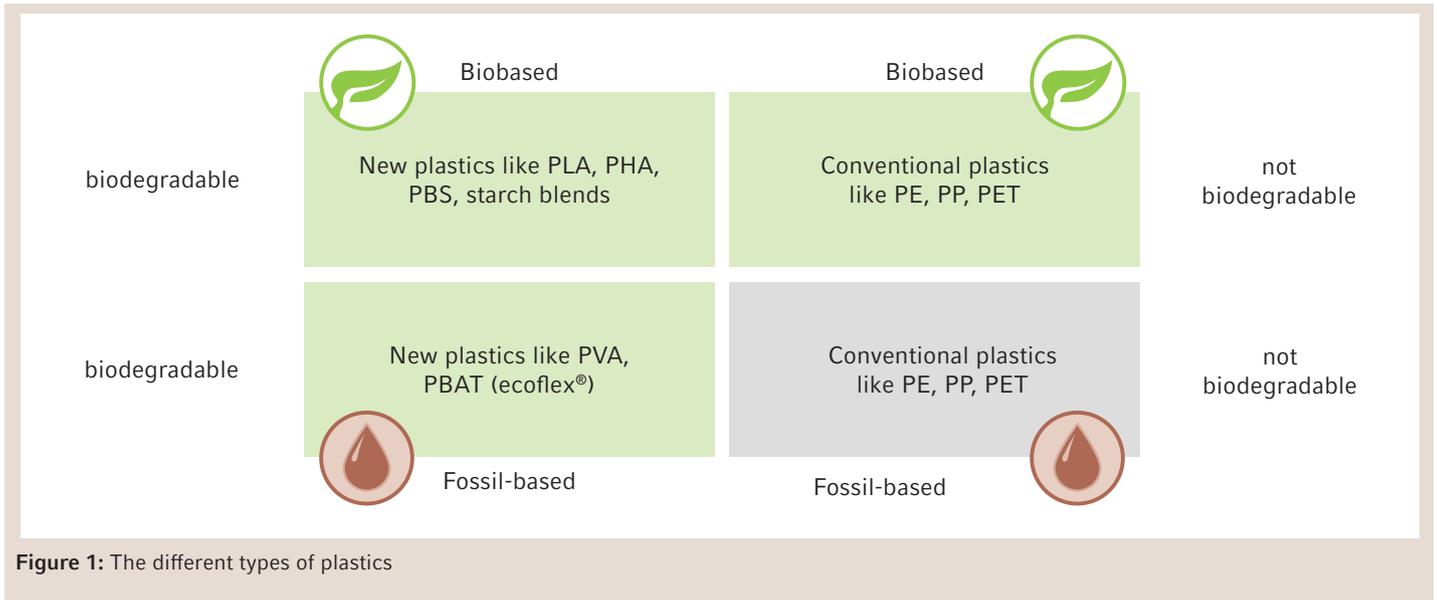


Figure 1: The different types of plastics

**Biobased plastic** is made of biomass from different sources. It is important to know that biobased does not mean that a product is made of 100% biomass. It can be made of renewable resources fully or in part. Therefore, the amount of biomass included in a specific product should be specified. Independent certifications and labels such as “DIN-Geprüft biobased”, “OK biobased”, “USDA certified biobased product” or “biobased” specify the amount of biobased carbon, or the percentage of biobased materials, respectively, in a specific product [Table 1]. These labels are based on norms like EN 16640 or EN 16785-1.

The amount of biomass is measured by the radiocarbon method where the bound carbon in the product indicates whether a product is biobased or fossil-based, determined by its percentage of <sup>14</sup>C. [2,3,4] Biobased products contain a higher percentage of <sup>14</sup>C whereas fossil-based products contain a significantly lower amount due to their longtime storage as a non-active material in the Earth. Other certification systems such as ISCC use the Mass Balance Approach (MBA)\* to specify the amount of biobased feedstock in a product. [5]

*\*The Mass Balance Approach (MBA) is a process for determining the use of chemically recycled or biobased feedstock in a final product when both recycled and virgin feedstock or biobased and fossil feedstock have been used in the process.*

| Name of the label  | Logo  | Standards behind the label                       |
|--|---|--|
| TÜV OK-Biobased [1]<br>(four labels indicating different amounts of biobased carbon content)                         |  [2] | EN 16640   |
| DIN-Geprüft Biobased [1]<br>(three labels indicating different amounts of biobased carbon content)                   |  [2] | ASTM D 6866; ISO 16620 series (1-5);<br>EN 16640 |
| NEN Biobased [1]<br>(label indicating the proportion of biobased content based on biomass, not just biobased carbon) |  [3] | EN 16785-1                                       |
| USDA Certified Biobased Product<br>(the amount of biobased carbon content in the product)                            |  [4] | ASTM D-6866 standard                             |

**ASTM D-6866 standard:**

US standard specifying standard test methods for the determination of the **biobased carbon content** of solid, liquid and gaseous samples by radiocarbon analysis [5]

**DIN EN 16640:2017-08:**

European Standard specifying a method for the determination of the **biobased carbon content** using the radiocarbon method [6]

**DIN EN 16785-1:**

European standard for the determination of the **biobased content** using radiocarbon and elemental analysis. This standard takes into account the **total biobased mass fraction**, i.e. also biobased oxygen, biobased hydrogen and biobased nitrogen, in relation to their overall contents [7]

**ISO 16620:**

International standard for measuring the **biobased content of plastics** [8]

[1] <https://biowerkstoffe.fnr.de/biokunststoffe/guetezeichen-fuer-biobasierte-kunststoffe>

[2] <https://www.european-bioplastics.org/faq-items/is-there-a-certain-percentage-threshold-value-that-marks-the-minimal-biobased-carbon-content-biobased-mass-content-in-a-productmaterial/>

[3] <https://www.tuv-at.be/de/green-marks/zertifizierungen/nen-bio-based-content/>

[4] <https://www.usda.gov/media/blog/2011/01/20/usda-biobased-product-label-launches-today>

[5] <https://www.en-standard.eu/astm-d6866-22-standard-test-methods-for-determining-the-biobased-content-of-solid-liquid-and-gaseous-samples-using-radiocarbon-analysis/>

[6] <https://www.en-standard.eu/din-en-16640-bio-based-products-bio-based-carbon-content-determination-of-the-bio-based-carbon-content-using-the-radiocarbon-method/>

[7] <https://www.en-standard.eu/din-en-16785-1-bio-based-products-bio-based-content-part-1-determination-of-the-bio-based-content-using-the-radiocarbon-analysis-and-elemental-analysis/>

[8] <https://www.en-standard.eu/search/?q=ISO+16620>

Table 1: Certifications for biobased plastic

Biobased material is mainly used to produce conventional plastics – e.g., biobased polyethylene (PE), biobased polyethylene terephthalate (PET) or biobased polypropylene (PP). The latter is the basis for the new Eppendorf biobased tubes, pipette tips, and plates. Their amount of biobased feedstock is certified using the Mass Balance Approach [6]. Although these plastics come from renewable sources, they do not differ from their traditional counterparts that are made from fossil sources. They can be processed in the same way as their fossil counterparts; they have the same mechanical and chemical stability, and they provide the same haptics

and optics. At the end of their lives, these plastics can be fed into the recycling stream to be the starting material for new products. Biobased plastic is easily integrated into the existing infrastructure of traditional plastic which is why they are also called “drop-in” plastics. It is important to keep in mind, however, that plastic consumables in the laboratory are by definition contaminated after use. This means, although technically recyclable, they require dedicated waste management depending on local conditions.

Although traditional polymers like PP or PE can be made from biobased sources, research has not stopped here. Polymer chemists continue to search for new materials; one example being polyethylene furanoate (PEF). While this more complex polymer is not biodegradable, it can be manufactured from materials which are 100% based on renewable resources already today. PEF is very similar to PET but with better barrier performance against oxygen and water as well as higher rigidity. Furthermore, it can be recycled in the same way as PET. [7]

**Biodegradable plastic** refers to polymers which are degradable under certain conditions but are made partially or entirely from fossil sources. It is important to remember that biodegradability is not dependent on the source of the building blocks but only on the chemical structure. Polymers like polybutylene adipate terephthalate (PBAT) or polyvinyl alcohol (PVA) are two examples of such polymers [8]. PBAT had been introduced by BASF under the name ecoflex® as early as 1998; it is made from adipic acid, terephthalic acid and 1,4-butanediol [9]. The latter is derived from fos-

sil sources. Of course, there are efforts to produce these plastics entirely from biobased sources, and 1,4-butanediol is nowadays also manufactured from renewable sources on an industrial scale. [10]

**Biobased and biodegradable plastic** combines the aforementioned attributes – the material is made of renewable resources, and it is biodegradable. Examples include polylactic acid (PLA), which is the most produced bioplastic and is mainly used for packaging [11]; others include polyhydroxyalkanoates (PHA) and different starch blends. But the term “biodegradable” per se does not indicate when and under what conditions a product will degrade.



**Note:** Consider the term “bioplastic” and ask to which type of plastic this term refers. In fact, the European Union (EU) recommends not using the term “bioplastic” but instead using the terms biobased, or biobased and biodegradable, respectively, compostable plastic. [12]

## Biobased plastic – which resources are used for it?

Most of the biobased plastic today is made of biomass [Figure 2], mainly from sugar cane, sugar beet, potatoes, corn or wheat, also known as **1<sup>st</sup>-generation biomass** [8,13]. Its production releases fewer CO<sub>2</sub> equivalents than the production of fossil-based plastic. A study conducted by NESTE compared the climate impact of polypropylene made of fossil feedstock with polypropylene made of renewable resources from the sourcing to the production of PP. Using renewable resources reduces the release of CO<sub>2</sub> equivalents by more than 80%. Furthermore, fossil resource depletion is minimized by more than 75%. [14]

But the production of first-generation biobased plastic also has downsides. Besides the better carbon footprint, the negative environmental impact includes land use change which leads to biodiversity loss, deforestation or water scarcity and competition for farmland normally used to grow crops for human consumption. This competing usage is still marginal with only 0.025% of the global agricultural area affected [Figure 3]. Furthermore, fertilizers and pesticides are often used to grow the aforementioned plants, leading to additional negative impact on the environment.



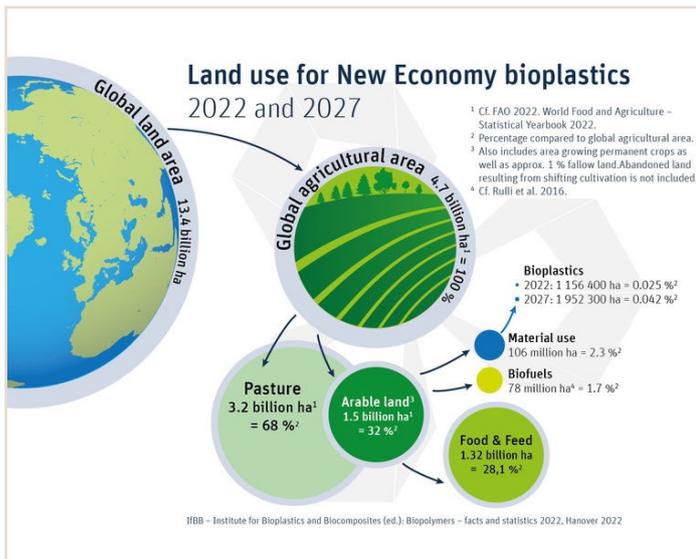
Figure 2: The different sources for biobased plastic

The use of what is known as **2<sup>nd</sup>-generation biomass** is seen as a more sustainable resource for biobased plastics. Here, biomass is extracted from waste streams like sugarcane

bagasse, wheat straw from agricultural sources or wastewater streams and converted to PLA, PHA, and other polymers. Another source is food waste including used cooking oil from canteens, restaurants and the global food industry. This waste stream is collected, cleaned, and converted to polypropene.

This material is the basis for the new biobased Eppendorf tubes, pipette tips, and plates. Therefore, this material is not competing with any land use or food streams.

The **3<sup>rd</sup>-generation of biomass** is seaweed and brown or red algae. These cells produce polysaccharides, like alginate, which can then be used in various applications, for example, as films for food packaging. [15]



Source: [https://www.ifbb-hannover.de/files/IfBB/downloads/faltblaetter\\_broschueren+s/Einzelgrafiken%202022/Land%20use%20for%20New%20Economy%20bioplastics-2022-2027.jpg](https://www.ifbb-hannover.de/files/IfBB/downloads/faltblaetter_broschueren+s/Einzelgrafiken%202022/Land%20use%20for%20New%20Economy%20bioplastics-2022-2027.jpg)

Figure 3: Land use for agriculture and biobased plastic

**Note:** What is the source of the plastic you are holding in your hand? Is it a first-generation source or is it derived from other sources like algae, agriculture waste, or other waste streams?

## Biodegradable versus compostable plastic

When talking about biodegradable plastic, you may think of plastic which is readily degraded in the environment. But

this process is far more complex. You have to distinguish between the terms “biodegradation” and “compostability”. [Figure 4]

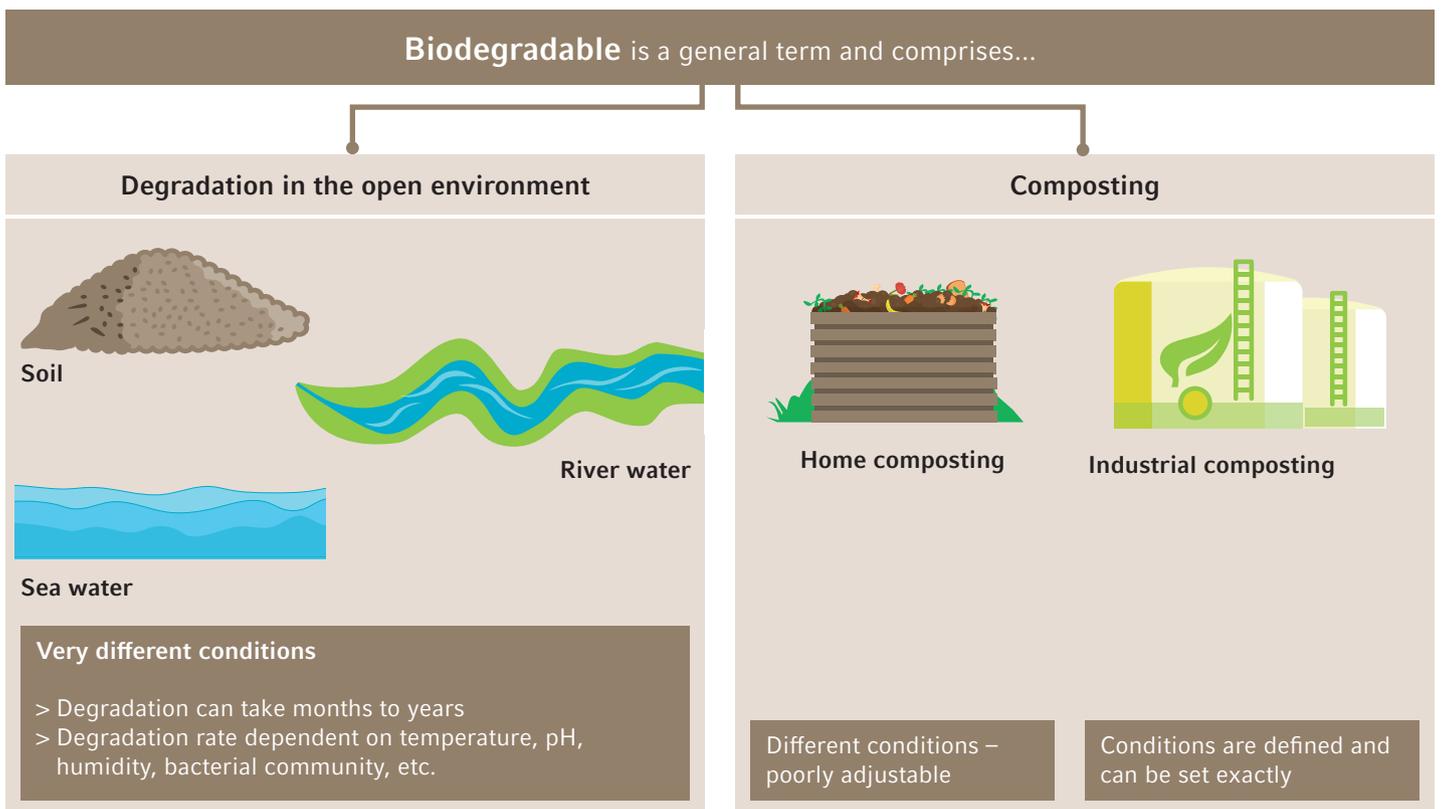


Figure 4: Differences between biodegradation and composting

**Biodegradation** is defined by the International Union of Pure and Applied Chemistry (IUPAC) as “degradation caused by enzymatic processes resulting from the action of cells”. [16] The whole process depends on environmental conditions, the appropriate bacteria or fungi, and the chemical structure of the material [Figure 5]. Furthermore, the term biodegradable does not imply a specific time frame. A tree is

also biodegradable – but it takes many years until the massive log is defragmented into its basic components and molecules. The same is true for biodegradable plastic: it can take months to years in the open environment until biodegradable plastic is finally fractionized into its basic components CO<sub>2</sub> and H<sub>2</sub>O under oxygenic conditions. Under anoxic conditions, the remaining chemical compounds are CO<sub>2</sub> and CH<sub>4</sub>.

In the latter case, the greenhouse gas methane is released – which is undesired in the open environment. The efficiency of biodegradation is also dependent on whether it takes place in the soil, in river water, or in seawater. Temperature, pH conditions or soil moisture also influence the biodegradation process. Higher temperatures and humidity can enhance biodegradability, but is it possible to predict environmental conditions once the plastic is released into nature? Even for the same type of polymer, different environmental condi-

tions lead to different results. PHA can be degraded in the soil by 75% in 80 days (39% humidity, pH 6.8, temperature unknown) whereas other studies found only 48.5% of PHA are degraded after 280 days (20°C, 60% humidity, pH unknown). [17] In addition, the chemical structure, functional groups, crystallinities, and molecular weight of plastic define its biodegradability: thick plastic is much more difficult to degrade than thin foil.

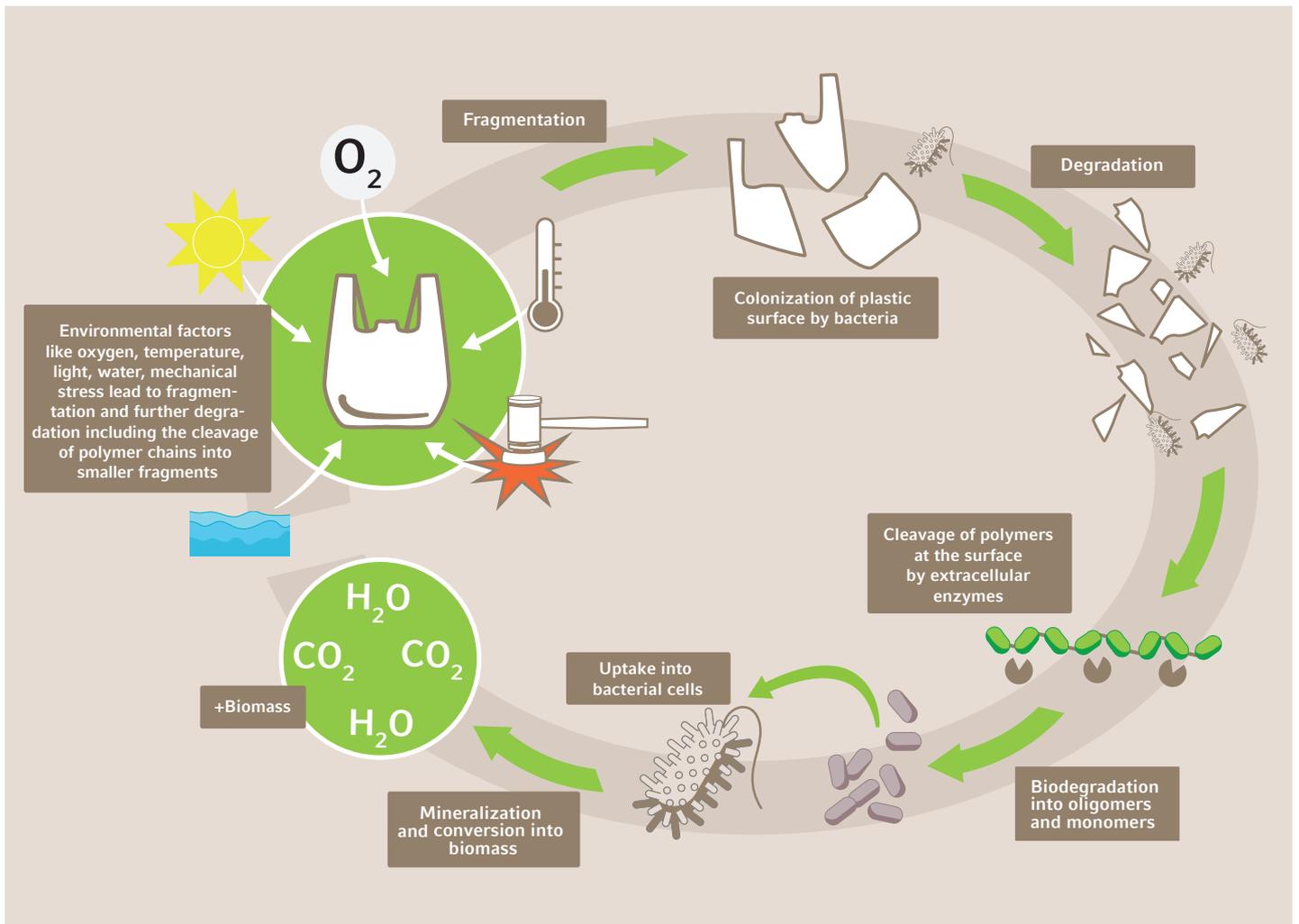


Figure 5: Biodegradation process

Another problem with biodegradable plastic in the environment is that this material is first defragmented and broken down into smaller particles before it is further degraded and mineralized. [18,19] Once in the environment, it is weakened mechanically, physically, or chemically. This includes abiotic factors like sunlight, temperature, or even chemicals in the environment. Finally, the material is broken down into smaller pieces. These small plastic fragments and microplastics can harm the environment, for example, if swallowed by animals, no matter if they are biodegradable or not. Last but not least, plastic items normally contain further substances like additives, fillers, or dyes. All of these have to be biodegradable too.

Considering all these facts, it is obvious to question the sense of producing biodegradable plastic. In general, plastic should not end up in the environment – regardless of whether it is in principle biodegradable or not. There are certification schemes for biodegradable plastic in soil or water, such as the OK biodegradable label by TÜV Austria, but they are not based on a European or international standard. Also, these schemes define very specific conditions under which plastic is degradable. [20]

But there are some examples where the use of biodegradable plastic products is recommended as an alternative to the use of conventional plastic: For example, the use of mulch films in agriculture. [12, 21] On the basis of the European standard EN 17033, these can even be certified and labelled accordingly. [20]

**Composting** is defined as “a controlled biodegradation process where organic matter is converted into a nutrient-rich soil supplement or mulch.” [22]

**Compostable plastic** is defined as plastic that is “biodegradable under certain conditions and within the time frame of a composting cycle”. [23] The term “compostable plastic” normally refers to plastic which degrades in industrial composting facilities. Only these facilities guarantee defined conditions including temperatures above 50°C, controlled humidity, aeration, pH and carbon/nitrogen ratio, as well as defined compost cycles, which normally take 6 – 12 weeks. [24] Norms such as EN 13432, ASTM D6400 or ISO 17088 define exactly which properties a compostable plastic has to fulfill before it can be claimed as compostable. For example, it must degrade to CO<sub>2</sub>, water, and biomass to 90% in less than six months according to EN 13432 and disintegrate to a specific extent after 3 months [25]. Labels like the Seedling show consumers if plastic items like bags or food trays are compostable. [Table 2] Again, even if a plastic item is defined as compostable, it is not certain that it will end up in a composting facility. Not all industrial facilities guarantee the required conditions, for example, composting time. Therefore, German facilities often sort out bioplastic. In other countries, like Italy or Spain, biodegradable plastic, mainly bags to collect biowaste, can be processed if they are certified through respective labels. In both countries, biodegradable plastic bags have been introduced to increase the amount of biowaste in composting facilities.

| Name of the label              |                                    | Logo  | Standards behind the label [6]  |
|--------------------------------|------------------------------------|---|---|
| Industrial composting          | Seedling                           |  [1]   | EN 13432  |
| Industrial composting          | OK compost INDUSTRIAL              |  [2]   | EN 13432  |
| Industrial composting          | Industrial Compostable DIN geprüft |  [3]   | EN 13432  |
| Home composting                | OK compost HOME                    |  [2]   | No official standard, but the label builds on a certification scheme developed by TÜV Austria Belgium NV that describes technical requirements which have to be fulfilled |
| Home composting                | Home Compostable DIN geprüft       |  [4]   | NF T51-800 (French standard) and / or AS 5810 (Australian standard)   |
| Biodegradation in soil         | OK biodegradable SOIL              |  [2] | No official standard, but the label builds on a certification scheme developed by TÜV Austria Belgium NV; can be compliant with EN 17033 by adding 2 ecotoxicity tests    |
| Biodegradation in soil         | Biodegradable in soil DIN geprüft  |  [5] | EN 17033 (for mulch films only)   |
| Biodegradation in fresh water  | OK biodegradable WATER             |  [2] | No official standard, but the label builds on a certification scheme developed by TÜV Austria Belgium NV  |
| Biodegradation in marine water | OK biodegradable Marine            |  [2] | No official standard, but the label builds on a certification scheme developed by TÜV Austria Belgium NV  |

[1] <https://www.european-bioplastics.org/improved-seedling-logo-for-industrially-compostable-products/>

[2] <https://biowerkstoffe.fnr.de/biokunststoffe/guetezeichen-fuer-biobasierte-kunststoffe>

[3] <https://www.dincertco.de/din-certco/en/main-navigation/products-and-services/certification-of-products/environmental-field/industrial-compostable-products/>

[4] <https://www.dincertco.de/din-certco/en/main-navigation/products-and-services/certification-of-products/environmental-field/products-made-of-compostable-materials-for-home-and-garden-composting/>

[5] <https://www.dincertco.de/din-certco/en/main-navigation/products-and-services/certification-of-products/environmental-field/biodegradable-in-soil/>

[6] <https://www.eea.europa.eu/publications/biodegradable-and-compostable-plastics>

**Table 2:** Composting labels

What about **home composting**: can you compost plastic in your garden at home? There are some national labels including the “OK compost label” which certify that plastic is biodegradable in residential compost. [24, 25] Again, these plastics are tested under specific conditions, and if they fulfill certain conditions, they will be certified as “home compostable”. But does every compost have the same environment in terms of temperature, humidity, or pH as described in the tests?

There is one last aspect in this review that links to the idea of a circular economy. A circular economy aims to not waste

resources but to hold them in the loop. The waste hierarchy therefore clearly opts for recycling before energy recovery or disposal. But plastic which is biodegraded or composted is lost as resource. Wouldn't it be better to recycle plastic so that it can become a valuable product once again?



Think twice before opting for biodegradable or compostable plastic: both terms link to very specific conditions and do not necessarily contribute to the aim of a circular economy but can be reasonable only for specific use in specific cases. And always be aware that compostable plastic is biodegradable whereas biodegradable plastic is not necessarily compostable.

## Biodegradable plastic – a solution for the laboratory?

Does it make sense to utilize biodegradable, or compostable plastic, respectively, in the laboratory? The answer is a clear “no”, and here are the reasons why biodegradable plastic is not feasible for the laboratory:

- 1) Biodegradable and compostable plastics have different properties from classical polymers like polypropylene (PP) or polyethylene (PE) regarding their chemical and enzymatic stability. They are degraded by enzymes such as esterases, acid phosphatases, or beta-glucosidases, to name only a few. [17] Also, biodegradable or compostable plastics are more sensitive to acidic, basic or harsh conditions in general. PLA, for example, is sensitive to humid or acidic conditions. [26] Would you like to – or better – could you work with a plastic item at the bench which is not 100% inert to your reaction conditions?
- 2) The second argument concerns transportation. Before entering the laboratory, consumables can have long transportation routes all over the globe under very different conditions regarding temperature and humidity. The integrity of the material has to be guaranteed under those conditions as well – can this be the case when biodegradable plastic is sensitive to temperature and humidity? Even if it won't be degraded 100%, there is no guarantee that it won't be attacked at least partially. This can result in reduced stability, for example, during centrifugation.

- 3) During laboratory work, consumables are contaminated or come into contact with harmful biological or chemical substances. These consumables have to be disposed of as hazardous waste – and cannot enter a composting facility or even a landfill to decompose.

These arguments clearly show that biodegradable or compostable plastic is no solution for the laboratory, yet. There is – at the moment – no way around classic plastic materials like PP or PE. But as a first step towards consumables with a better footprint, production of conventional plastic like PP made of second-generation biomass is a good starting point. This guarantees that the laboratory consumables have the same properties and quality as their fossil-based alternatives but with a better environmental footprint as the sourcing of the raw material is improved. In the future, solutions shall focus on potential recycling systems that use new methods. Besides chemical recycling, which is currently under development, there will be further new technologies to close the resource loop for a circular economy.

## Outlook: Biobased plastic as part of the circular economy

The vision of industry and governments is to build a circular economy based on renewable resources. Biobased plastic plays an essential role in contributing to this vision. By using waste streams as a resource to build new products, one part of the circular economy approach has been addressed whereas end-of-life solutions are still hard to achieve.

To close the loop, plastic waste has to re-enter the cycle through intelligent recycling schemes. Solutions including improved mechanical recycling or chemical recycling are on their way and already today, there are examples where hard-to-recycle waste plastic has been turned into high-quality polymer feedstock through chemical recycling.

The recycling of normally hard-to-recycle pipes into new pipes for different applications, even pipes used for sensitive applications like drinking water systems, can be used as a blueprint for other hard-to-recycle plastics. [27] A recent study also found that the production of polypropylene from chemically recycled plastic waste reduces GHG emissions by at least 60% compared to fossil-based PP and also reduces the depletion of fossil resources. [28] But it is also true that it will still take some years until these solutions will be realized for consumables in the laboratory.

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## About Eppendorf

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