Biodegradability explained:

What is it and how can it support minimizing environmental impact

WHITEPAPER

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The use of biodegradable polymers are one of the options in the transition to a more circular economy, as well as helping manufacturers to comply with increasingly strict regulations around plastics. But, to make full use of these benefits, manufacturers need to understand how biodegradability is defined and measured, and the relevant regulations related to it. In this whitepaper, you'll learn how biodegradation happens, the criteria that materials must meet to be considered biodegradable, the implications of emerging microplastics regulations, and how Covestro can support with tailored biodegradable solutions.

Striving for a circular economy

Polymers are all around us – including in personal care products, agricultural applications, packaging, wallpaper and paint. But, in recent years, concern about the environmental damage caused by polymers has increased and the regulations around them have tightened, particularly when it comes to microplastics and single-use plastics. Securing a sustainable future requires a greater focus on resources and circularity: specifically, ensuring the future availability of natural resources and unlocking more value from the limited resources that are available. This ambition will involve reducing our resource consumption, replacing fossil feedstock with recycled and biobased materials, extending product lifetimes using durable and protective materials, designing for circularity, and recovering internal waste streams.

Biodegradation: Another way to close the loop

When reuse, recovery, and recycling are not possible, such as for polymers in agricultural and personal care products, circularity can also be achieved through biodegradation. As such, biodegradable materials have an important role to play in reducing the accumulation of microplastics and in supporting the transition to a circular economy. Biodegradability is a tool to close the loop leaving no trace in the environment. This potential is reflected in regulations such as the European Chemical Agency (ECHA)'s restriction proposal for microplastic particles that are intentionally added to mixtures used by consumers or professionals. The proposal defines microplastics as synthetic polymer particles with a size below 5 mm that, importantly, resist biodegradation. If a material can be certified as biodegradable, it will not be classified as a microplastic, and manufacturers can continue to use it without restriction. In the US, the Environmental Protection Agency (EPA) is also piloting product labels that certify biodegradability, with similar requirements.

The importance of understanding biodegradability

But, to make full use of the advantages of biodegradable materials, manufacturers need to understand how different factors affect biodegradation in different materials. And there are still many misconceptions about biodegradability – for example, that synthetic or fossil-based polymers cannot be biodegradable, or that disposal conditions for biodegradable materials do not matter. To better understand these issues, it is necessary to explore exactly how biodegradation works.

What are biodegradable materials?

The EPA defines biodegradation as: "A process by which microbial organisms transform or alter (through metabolic or enzymatic action) the structure of chemicals introduced into the environment." This can occur under aerobic or anaerobic conditions. However, biodegradation in anaerobic environments (such as landfills) produces methane, a highly flammable greenhouse gas that has 23 times higher green house gas potential than CO_2. Because of this, biodegradable materials are typically defined as those that can be broken down by aerobic biodegradation into CO_2, water, and other organic materials. While all materials will eventually biodegrade through mechanical and physical influences after decades or centuries, the materials we call biodegradable break down within months or years. According to the Organization for Economic Co-operation and Development (OECD), to qualify as 'readily biodegradable', substances must degrade by at least 60% within 28 days under conditions designed to resemble waste water treatment plants. And since there are several ways to measure biodegradability and compostability the correct selection of testing conditions is very important to ensure that materials we use will decompose in H_2O and CO_2 once they reached their end of life.

Biodegradable, compostable, biobased, and oxo-degradable: What's the difference?

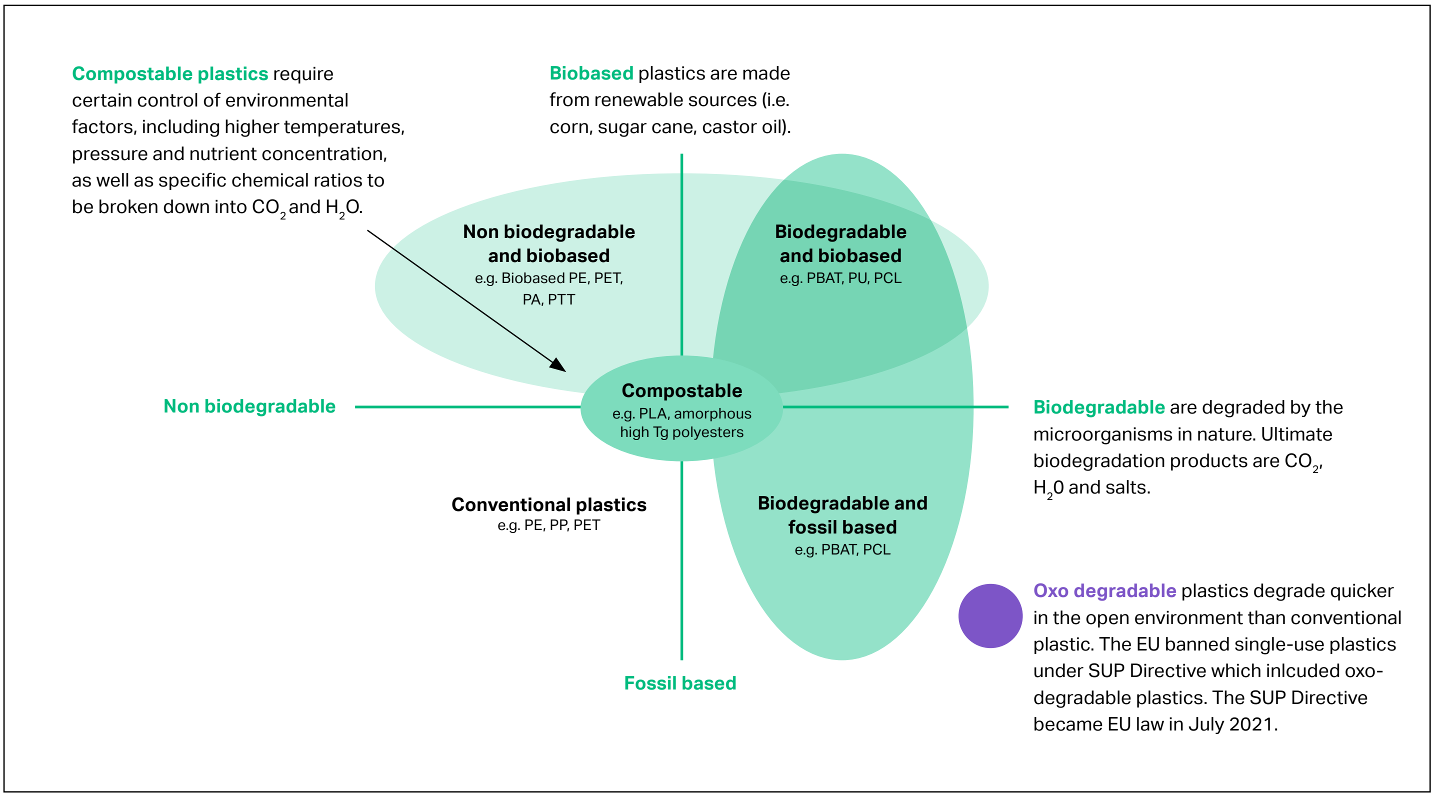

Figure 1: Diagram showing the relationship between biodegradable, biobased, compostable, and oxo-degradable materials

Compostable materials are a subset of biodegradable materials including PLA and amorphous polyesters with high glass transition temperatures. Composting is an industrial process requiring high temperatures, pressure and nutrient concentration, and specific chemical ratios. To be certified compostable, materials must meet ASTM D6400 requirements, or degrade by 90% in 180 days under the humidity, temperature, and aeration conditions of an industrial composting facility.

Biobased plastics are made from renewable sources for example corn, sugar cane, or castor oil. Some materials are both biodegradable and biobased, such as PHA, PBS, and starch blends. And many conventional plastics, like PE, PP, and PET, are neither biobased nor biodegradable.

However, it's also possible for a material to be biobased but not biodegradable – biobased forms of PE, PET, PA, and PTT – or to be synthetic or fossil-based but still biodegradable, like PBAT, PU and PCL. Some synthetic substances can even biodegrade better or faster than some natural substances.

Oxo-degradable plastics are not biodegradable: they are conventional plastics mixed with an additive to imitate biodegradation. Oxo-degradable plastics may break down into microplastics in the open environment more quickly than conventional plastic. However, unlike biodegradable plastics, they don't break down at the molecular level; the microplastics remain in the environment.

PLA: Poly(lactic acid)
PHA: Polyhydroxyalkanoate
PBS: Poly(butylenesuccinate)
PE: Polyethylene
PP: Polypropylene
PET: Poly(ethylene terephthalate)
PA: polyamide
PTT: poly(trimethylene terephthalate)
PBAT: poly(butylene adipate-co-terephthalate)
PU: polyurethane
PCL: polycaprolactone

How does biodegradation work?

Biodegradation is an active, multi-step biochemical process. Besides being degraded by abiotic factors such as UV radiation and heat, biodeterioration and biofragmentation of the polymer take place. Microorganisms like bacteria and fungi secrete enzymes, which may degrade the polymeric chains and convert them in shorter fragments. Afterwards, the bacterial and fungal degradation of such short fragments can take place. In our internal testing we include a toxicity control to prove that degradation products are not toxic. The bacteria then consume oxygen and convert the polymer's carbon and hydrogen into CO_2 and water *(Figure 2)*.

As well as the type of material, environmental conditions also affect the biodegradation mechanism and rate. Most materials degrade faster in elevated temperatures, wet environments. Industrial composting, home composting, and soil are more favorable conditions for biodegradation; the process is less efficient in freshwater, marine water, and landfill. Industrial composting at 58°C with fungi, bacteria, and actinomycetes is typically considered the quickest environment for biodegradation.

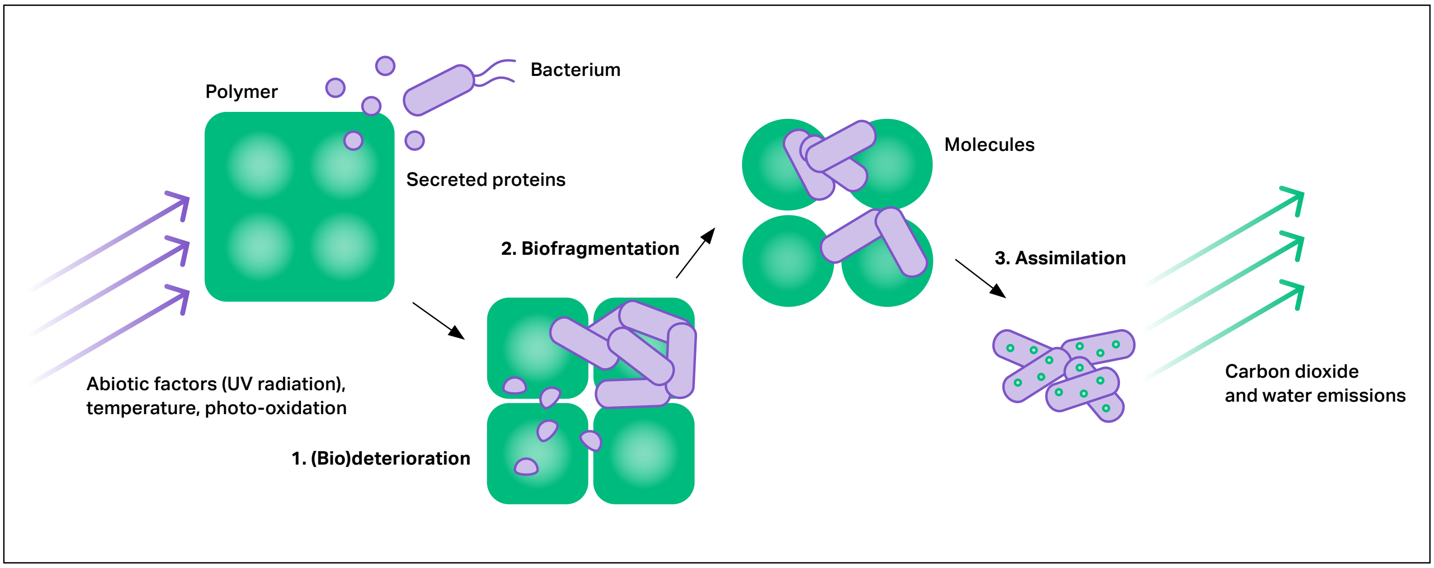

Figure 2: Simplified diagram of bacterial biodegradation

How is biodegradation measured and tested?

Biodegradation can be measured either as a ratio of the O_2 consumed by the microorganisms with respect to the maximum amount of O_2 needed for full oxidation (e.g., OECD301F), or as a ratio of the CO_2 produced by the microorganisms with respect to the maximum amount of CO_2 produced when full oxidation will take place (e.g., OECD301B). Let's explain OECD301F as an example.
The percentage of biodegradation is calculated based on biochemical oxygen demand (BOD) and theoretical oxygen demand (ThOD). Specifically, it is the amount of oxygen that is actually consumed by the microorganisms during the process (BOD) as a percentage of ThOD (the maximum amount of oxygen that would be consumed for full oxidation):

Biodegradation = (BOD measured/ThOD) * 100

100% biodegradability cannot be shown: instead, 60% ThOD or 60% $ThCO_2$ is considered the 'pass level' for ready biodegradation. During biodegradation, some of the substance's carbon is incorporated into new biomass, so the percentage of CO_2 produced is always lower than the percentage of carbon used.

There are several test methods and criteria for demonstrating biodegradability. These range from 'ready biodegradation' to 'biodegradation relative to a reference material', as shown in the diagram below *(Figure 3)*. Tests must be conducted in laboratories accredited to ISO 17025 or certified as Good Laboratory Practices (GLP).

The OECD 301F test determines biodegradability by measuring oxygen consumption when the material is in contact with a mixture of water and activated sludge. The microorganisms consume the O_2 and form CO_2, which is absorbed by sodium hydroxide (NaOH) or potassium hydroxide (KOH). This results in a pressure drop in the system, which is directly proportional to the BOD and can therefore determine the level of biodegradation.

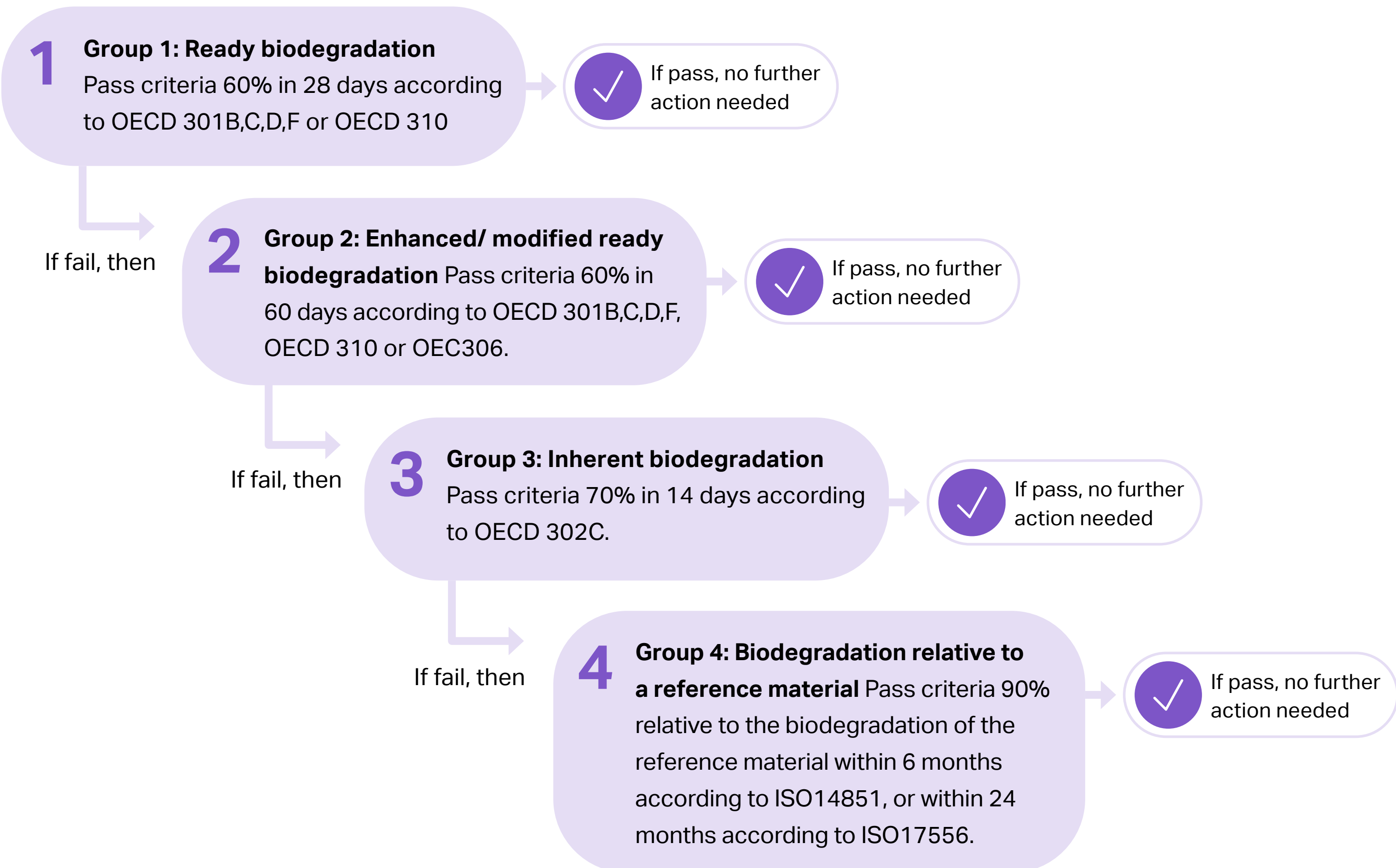

Figure 3: Criteria for demonstrating biodegradation

Covestro:
Helping drive the use of biodegradable materials

At Covestro, we are well-positioned to drive the transition to a circular economy, thanks to our position near the start of the materials value chain. We offer several liquid polymers that are compatible with upcoming regulations. These products can be used in hair styling products, cosmetics, sun protection products, or agricultural applications such as seed and fertilizer coatings.

Because different applications require different rates of biodegradation, we use different polycondensates, such as starch, polyesters, or polyesteramides, and polyurethanes with controlled monomer selection, molecular weight, crystallinity, and polarity. In this way, we can achieve biodegradation ranging from 0 – 90% in 28 days.

Amulix® seed coatings

Our Amulix® seed coatings are just one example of how biodegradable products can support the transition to a circular economy. Polymer seed coatings enable crop protection products, such as fungicides and insecticides, to be applied without becoming airborne and affecting people and pollinators. Without these crop protection products, 10-15% of harvests would be lost annually.

To enable farmers to continue protecting their crops without generating microplastics, we developed Amulix®: a biobased, biodegradable seed coating formulation.

Amulix® polymers reach biodegradation rates above 55% within 28 days according to OECD 301F test. Not only does Amulix® enable a 50% carbon footprint reduction when compared to conventional coatings, it also meets the expected performance requirements: dust control, uniform color distribution, and non phytotoxicity. In this way, these coatings enable farmers to meet global food demands, while minimizing microplastics pollution.

Baycusan® polymers for cosmetics

Today's cosmetics are not only expected to be safe to use, but also to not pose any environmental risks afterwards. For formulators, the choice of suitable ingredients therefore becomes critical and the ability of ingredients to biodegrade in water has become a must-have property to better control and to minimize the environmental impact of cosmetic formulations. Polymers are critical ingredients in cosmetic formula as they provide many of the required properties for highly performing products.

While solid polymer ingredients like e.g. microplastics contribute to marine litter and may represent a risk for the environment, only a few polymers, such as some polyurethanes have the ability to biodegrade in water. These ingredients are a wise alternative for producers of more environmental-friendly cosmetics. Baycusan® polyurethanes reach mean biodegradation rates up to 82% within 28 days according to OECD 301F ready biodegradability test.

With their outstanding long-lasting properties and improved environmental profile, Baycusan® film forming polymers can thus solve the efficacy & environmental impact dilemma opening a way towards the next generation of cosmetics.

Impranil® textile coatings
This range of high-performance, polyurethanes are water-based, making it ideal for more sustainable production processes.

It is especially well-suited to the production of low VOC synthetic materials for auto interiors, garments, shoes, bags and upholstery. Impranil® dispersions are also adaptable to majority of application methods and processes that require direct coating, transfer coating, dipping, printing and spraying. Covestro's Impranil® DLN-SD is a polyurethane dispersion showing promising degradability rates in water. It was tested for biodegradability according to the CO_2-evolution test (OECD test standard 301F) and shows a degradation of above 50% in 28 days. In general, biodegradability rates of Impranil® DLN-SD polymers are significantly higher than other film formers such as acrylic dispersions and therefore contribute to a reduced end-of-life impact.

In today's fast-changing regulatory landscape, biodegradable solutions will play a key role in helping manufacturers to keep ahead of regulatory requirements and supporting the transition to a circular economy. Together with our partners, Covestro can offer materials expertise, tailored biodegradability, and in-house testing to help facilitate these solutions.

To find out more about our biodegradable solutions, please contact:

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Edition: March 2022