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IKT KUNSTSTOFF TECHNIK STUTTGART

BioSinn

Products for which biodegradation makes sense









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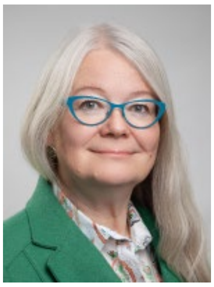
Asta Partanen



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Executive Summary

For which plastic products is biodegradation a viable end-of-life-option?

The BioSinn project found products and applications for which biodegradation at the end-of-life is a real option. 25 fact sheets answer technical and regulatory questions for each application. The market volume of these applications was also estimated: in Germany it is about 170,000 tonnes, in the European Union about 1 million tonnes per year!

In the EU, several million tonnes of plastics end up in the environment. In nature, in water, in the compost stream – every year, unhindered. Once landed there, it is often almost impossible to return them to the recycling stream: too small, untraceable, too costly. But there are plastic products that, even when used correctly, don't even make it into the recycling stream and end up in nature, in water or in the compost. And we deal with many of them every day. Think of cosmetics, tea bags, chewing gum or stickers on fruit and vegetables.

Would the use of biodegradable materials made from renewable feedstocks be a sensible option here? Critics doubt that biodegradation is of any benefit at all and rely on comprehensive reduction, collection and recycling of plastic products. They also fear that biodegradable products could induce consumers to dispose of the products in the environment.

In the project "BioSinn – Products for which biodegradation makes sense", which was funded by the Federal Ministry of Food and Agriculture (funding code 2219NR197), experts from the nova-Institute in Hürth near Cologne investigated whether there are applications and products for which biodegradation is a sensible or even the best end-of-life option. The selection criteria were that collecting the products (or their remaining parts), separating them from other organic waste or material recycling is not possible, economically not feasible or does not take place in practice. Further criteria were that the input of microplastics into the environment can be avoided through the use of biodegradable materials or that indirect positive effects, a relevant secondary benefit, can be achieved through the use of biodegradable materials.

Experts from the nova-Institute, together with the project partner Institut für Kunststofftechnik at the University of Stuttgart (IKT Stuttgart) and a project advisory board made up of representatives from industry, academia and politics, were able to identify 25 applications on this basis for which biodegradability is a good or even the best end-of-life option. These were examined from all sides: in which environments exactly do the products remain? Are there already suitable biodegradable materials made from renewable raw materials for these specific requirements? What are current market or political framework conditions?

In addition to the products used by end consumers, more unknown or inconspicuous applications have also been uncovered that cause a large plastic input into the environment. For example, the bristles of most municipal sweepers are made of plastic, which wears out and remains irretrievably in the environment. Agricultural applications such as seed coating or flocculation aids in sewage sludge are often made of non-biodegradable polymers and systematically enter the soil. Or products in fisheries that are lost in the sea. Compost streams can also be contaminated by plastics.

The result of the project is a brochure for decision-makers from industry and politics but also for the general public, with 25 fact sheets and extensive background information on biodegradation. For each product, it explains to what extent biodegradation is a sensible and feasible option and what technical substitution options are available for a more sustainable use of materials. In addition, political framework conditions and regulations were highlighted and evaluated on a product-specific basis. For the first time, the market volumes for Germany and the EU were also surveyed and estimated. The total volume of the 25 applications in Germany is about 170,000 tonnes and in the European Union even about 1 million tonnes (see chart/table), of which the largest share ends up in the environment. Here, the use of biodegradable materials would bring considerable environmental benefits.

One of the project goals was to highlight potentials for biodegradable plastics that have often been overlooked so far. Much of the public debate revolves around packaging, but this can and should generally be collected and recycled. BioSinn therefore focused precisely on those applications where collection is not or hardly possible in practice. For example, the volume in agricultural applications is particularly high due to flocculant aids in sewage sludge, seed coating, carrier polymers for pesticides and mulch films.

For 24 of the 25 applications, it was possible to find possible biodegradable substitutes to the currently used materials. This was only not successful for one application, the dirt eraser. So far, there is no sustainable alternative with the same properties. To avoid the release of microplastics in this case, the only solution would be to stop using it.

Often, the alternative products are more expensive, but above all, they are usually little known or poorly available on the market. Users and consumers often lack awareness of the problems and alternatives. For example, consumers are usually not aware that conventional chewing gum is made of plastic or that wet wipes have a high plastic content to get their strength. In both cases, plastics remain in the environment and do not biodegrade. Current legislation and existing standards are often still barriers to the greater market introduction of biodegradable products in appropriate applications, and policy guardrails are lacking. In many cases, specific policy measures could have a significant impact and open up markets for alternatives.

Michael Carus, Managing Director of the nova-Institute, summarises the results of the BioSinn project: *"At the beginning of the project there was one question: Could there be applications where biodegradation is the best end-of-life option because collection and recycling is for example not practicable? The project was able to find and analyse 25 such applications. It was surprising to find that these applications total 1 million tonnes in the European Union - and most of this still ends up in the environment in the form of non-biodegradable macro- and microplastics. This is where biodegradable products made from renewable raw materials could make a significant difference to the environment. We hope that our comprehensive report with 25 fact sheets will both significantly raise awareness of the problem and substitution possibilities, and stimulate appropriate political action."*

Due to the great international interest, the conference as well as the final report will be offered in German as well as in English.

www.renewable-carbon.eu/publications

1 Introduction

For many decades, the German government, like the European Commission, has been promoting the research and development of biodegradable plastics and other materials, alongside the corresponding standards, norms and labelling.

Biodegradable, often bio-based polymers such as Cellulose acetate (CA), Polylactid acid (PLA), Polybutylene adipate terephthalate (PBAT), Polybutylene succinate (PBS), Poly(hydroxybutyrate) (PHB) and PHB copolymers or starch blends are now commercially available for use in various environmental conditions. The total production volume worldwide in 2020 was close to 2 million tonnes, with a growth rate of about 10 % per year (compared to 3 % to 4 % per year for fossil, non-biodegradable plastics). In addition to plastics, other materials are available that are biodegradable and made from renewable raw materials. Cellulose and bast fibres or cardboard and paper, for example, are well established on the market and readily available.

Biodegradable (both bio-based and fossil-based) plastics should be able to benefit concretely from the increasing discussions about macro- and microplastics in the ocean, in fresh of water, in nature, in wastewater and even in compost production. However, this only applies to a limited extent. There are several reasons behind this:

On the one hand, biodegradable plastics are currently used mainly in packaging, for which collection and recycling (and even thermal use) are clearly better end-of-life options from an environmental point of view. This has been proven in several studies and is reflected in the European Union's waste hierarchy. Here, politicians and NGOs do not want to send the wrong signals, which could open up the environment and the sea as a disposal path for biodegradable packaging (keyword: Littering).

On the other hand, there is often uncertainty about the actual degradation properties of the alternative materials. This is mainly because biodegradation standards and norms do not yet exist for all environments and conditions or are often unknown, ignored or perceived as too weak and uncertain. There is a call for research and development in this field to make biodegradation standards and norms robust and binding in all environments and applications.

In line with these two circumstances, the papers currently available from the European Commission, DG Environment, ban certain single-use products or limit their use; no exceptions are made for biodegradable plastics ("Single-Use Plastics Directive"). As the European Parliament and the Council of Ministers have already agreed, national implementation is expected in 2021.

One of the points that is difficult to understand is why, for example, paper products should not be covered by the bans, whereas plastic made from the biodegradable polymer PHB is, although this biodegrades even faster than paper in some environments. The underlying cause of these discrepancies is the fact that DG Environment considers the current certifications to be insufficiently robust for legislation and has therefore developed the concept of "natural polymers" – one which, however, does even less justice to the actual biodegradation properties of the materials.

The debate has been raging for decades as to whether biodegradable plastics are a sensible and desirable option and whether biodegradation is a good end-of-life option for the product. In the BioSinn project, we took a different, pragmatic approach: are there applications where material biodegradation is a good or even the best end-of-life option? And if so, what are these products or applications? The project identified and detailed 25 applications of this kind.

The BioSinn project demonstrates that biodegradable plastics and other biodegradable materials made from renewable raw materials will be able to play an important role in the future. The project identified 25 products or applications where biodegradable materials are the best option for the particular use case and the optimum choice for environmentally friendly disposal. Some are products and product applications where, even in cases of proper use, collection and recycling are not possible or economically feasible, or simply do not take place in practice because no economic structures are in place to do so; others are products or applications where the separation of organic waste and plastic is too laborious and thus cannot be recommended due to ecological considerations. Beyond this, we consider cases where biodegradation has an indirect positive impact (less non-degradable plastic in the environment, higher organic waste collection rates).

When the project was launched, the nova-Institut estimated that the conditions outlined above applied to what amounted to several 100,000 tonnes per year in the EU. This assessment was confirmed and even exceeded during the project.

Political discussion, however, largely ignores precisely those products and applications where biodegradation has obvious benefits. This is often down to lack of knowledge of the product or application, its volumes and options for substitution. Regarding the use of biodegradable plastics, producers usually focus on the packaging sector in their product development and communications, simply because of its size and omnipresence. In doing so, they miss the opportunity to draw attention to actually useful applications and develop such niches. Other biodegradable materials are often unknown, at least as potential substitutes for fossil-based plastics. It is often not even considered that, for example, a cellulose fibre can easily replace a polypropylene in twine used for certain applications.

This project strives to shed light on this issue and has developed 25 fact sheets of well-known and lesser-known products and applications in order to draw public attention and raise awareness of the issues. These products call for new solutions; biodegradable plastics and other renewable raw materials are thus an interesting option that makes sense in this context. Cases where solutions are already available on the market are highlighted, as are obstacles to their use. Where there are none at present, the need for research and development is outlined.

2 Project objective

The project objective is to promote dialogue within society on biodegradable materials, to promote biodegradable materials for certain products and applications as an environmentally friendly alternative and to highlight ways to promote these products and bring them to market. The fact sheets are used to inform the public about the potential advantages and disadvantages in a targeted, scientifically grounded and objective approach. Specific materials to substitute conventional plastics are suggested; and all contributing factors and conditions are explored and evaluated for each product. The fact sheets focus not only on the overarching political conditions and market volume of the product in question, but also on certification processes that can provide important benchmarks for measuring biodegradability.

The primary target groups are decision-makers in politics and industry as well as environmental groups and non-government organisations (NGOs). However, the general public should also be able to gain insight and increase their awareness and knowledge of the biodegradability of plastics, something that could influence their personal actions.

The 25 compact fact sheets are structured identically with each covering the following:

1. Description of the product / application
2. Main material currently used
3. Problem
4. Market volume in Germany / the EU
5. Biodegradable products on the market
6. Policy and regulatory considerations
7. Other barriers
8. Technical requirements
9. Relevant standards and certificates for biodegradability
10. Possible substitutes
11. Outlook

These eleven aspects cover clearly, but with the necessary detail, the specific requirements, hurdles and opportunities. Reference to general chapters is made repeatedly in order to avoid repetition in the fact sheets.

3 Methodology

First, selection criteria were developed to identify the 25 products and applications. These criteria were then applied to evaluate the proposals from the project team, the project advisory board (see section 13) and the public. The selection criteria can be summarised as follows:

For products that are used or end up in the natural environment or the compost stream, biodegradability is a suitable option if ...

1) it is not possible / economically feasible / common practice to collect the products or their leftovers;

2) it is not possible / economically feasible / common practice to separate the products or their leftovers from organic waste

3) Recycling it is not possible / economically feasible / common practice;

4) thermal recycling is not a viable option due to the high moisture content;

5) the use of biodegradable materials prevents microplastics from entering the environment;

6) there are indirect positive effects / there is a secondary benefit (e. g. more bio-waste can be collected);

7) relevant quantities of the product are produced;

8) biodegradable substitutes are technically feasible.

On the basis of these criteria, the set of products was selected for which collection, separation, recycling or incineration were not realistic options. If these are realistic options, they are always to be considered more valuable processes and a better end-of-life option, as life cycle assessments show.

When the project was launched, some 60 proposals were submitted and compiled in response to a public call and internal project work. An expert advisory board consisting of 40 representatives from industry, environmental organisations and other interest groups then discussed and evaluated these proposals based on the criteria.

Products whose biodegradability means they are disposed of in the environment rather than entering the recycling stream were specifically excluded. Applications for which there is currently no suitable substitute that can guarantee technical feasibility were also excluded from the study.

A total of three workshops were held, two of which were online and in English. Over 100 participants attended the three freely accessible workshops.

The 25 products and applications which were ultimately selected were processed and drawn up over the subsequent months by the specialist departments at the nova-Institute, with the support of the Institut für Kunststofftechnik Stuttgart as an external partner and with the friendly assistance of experts from the advisory board and the workshops.

4 Background information on biodegradation

Plastics that end up in the environment where they remain as macro- and eventually microplastics pose a host of problems. They can disrupt the natural balance of ecosystems and threaten animals and their habitats. Ultimately, they can enter the human food chain, where they can potentially harm human health – although a great deal more research is still needed to assess the risk more accurately. However, it is not currently possible to completely avoid the ingress of plastics in their various forms into the environment. This makes it all the more urgent to intervene wherever possible to mitigate the environmental impact of plastics and microplastics. Biodegradability is therefore a clean and potentially interesting option for plastic products at risk of entering and remaining in the environment. Essentially all plastics, be they fossil-based or derived from sustainable resources, will decompose in most environments. Initially, this is primarily a physical process, sooner or later breaking down plastics into microplastics. While plastics that are biodegradable are then completely biodegraded, non-biodegradable plasics remain in the environment for centuries even tough they cannot be seen by human eyes.

Only a handful of plastics are actually biodegradable. It is a porperty that means that the product is completely broken down, leaving behind no no plastic residue. A plastic is classified as biodegradable if all its organic components are converted into carbon dioxide, water, mineral salts and biomass under aerobic conditions (with oxygen) as a result of microbial action or into carbon dioxide, methane, mineral salts and biomass under anaerobic conditions (without oxygen). During the process of biodegradation, some of the carbon in the plastic is released into the atmosphere as CO_2 (and possibly also CH_4) while the rest is involved in the growth of biomass, i. e. microorganisms and fungi. The process of biodegradation is influenced by the chemical structure of the polymers and also significantly by the surrounding environmental conditions. Temperature, water content, nutrient availability, pH-value, supply of oxygen, concentration and activity of microorganisms etc. all affect the rate of biodegradation. Under similar environmental conditions, the rate of biodegradation can vary for different products or materials.[1]

Oxo-fragmentable (also known as “oxo-degradable”) plastics are not classified as biodegradable plastics and were not included in the project. Oxo-fragmentable plastics are to be banned in the European Union under the “Single-Use Plastics Directive”, with national implementation scheduled for 2021. Oxo-fragmentable plastics have certain additives that catalyse and accelerate the breakdown process in the environment by light, heat or mechanical stress. However, oxo-fragmentable plastic does not biodegrade, but fragments into small pieces that accumulate in the environment as microplastics.[2]

Biodegradation is subject to, and even significantly dependent on, the prevailing environmental conditions at the disposal site, such as the number of micro-organisms and composition of the microbial population, temperature, oxygen and nutrient levels and pH.

This project has identified various routes by which plastics enter and end up in the environment and has determined suitable substitutes. Six main routes and destinations have been identified:

1) Industrial composting,
2) Home composting,
3) Soil,
4) Wastewater,
5) Fresh water and
6) Saltwater.

There are two different factors at play here: the products either remain in their place of use at the end of their life without being able to be disposed of properly, or they are disposed of incorrectly. In some cases, a product may potentially end up in several different environments. These are addressed and classified in the fact sheets.

Biodegradation occurs most quickly and effectively in industrial composting and is comparatively slower in home compost. The process is slowest in or on the soil and in freshwater and saltwater, where conditions are least constant and, in the case of saltwater, in the case of freshwater and saltwater, there is a low density of micro-organisms due to a large dilution (above all, hardly any funghi).[3]

1 European Bioplastics 2021: Claims on biodegradability and compostability on products and packaging. 01/2021. Last accessed: 17/03/2021. Download at https://docs.european-bioplastics.org/publications/Claims_on_biodegradability_and_compostability_on_products_and_packaging_210108.pdf

2 Burgstaller M., Potrykus A., Weißenbacher J., Kabasci, S., Merrettig-Bruns, U. and Sayder, B. 2018: Gutachten zur Behandlung biologisch abbaubarer Kunststoffe. German Federal Environmental Agency. 07/2018. Download at https://www.umweltbundesamt.de/publikationen/gutachten-zur-behandlung-biologisch-abbaubarer

3 OWS 2021: Degradation in other environments. Last accessed 3.3.2021. https://www.ows.be/tests/degradation-in-other-environments

4.1 Industrial composting

Industrial composting conditions are controllable and constant. Industrial composting takes place in special composting plants under controlled conditions. These specify, for example, a high temperature (approx. 60 °C), high humidity, a precise retention time, the composition of the compost material and the supply of atmospheric oxygen. Large numbers of fungi and bacteria can be found here. Under these conditions, biodegradation is very efficient and takes only a few weeks, depending on the plastic.[1]

4.2 Home composting / garden composting

Home composting (or garden composting) is often used by individuals or even farmers for garden or kitchen waste. Conditions here can fluctuate, as they cannot be easily controlled. In general, the temperature and humidity are much lower than in an industrial composting plant, with no opportunities for quality control. The proportion of fungi and bacteria is influenced by several factors such as weather conditions and composting practices. It is a slower process than industrial composting, which produces a comparatively small volume of waste, and does not lend itself to handling large volumes of compost throughout the year.[1]

4.3 Soil

In the environment, soil conditions vary greatly: some soils are wetter and have a higher proportion of micro-organisms than others. There may also be temperature differences; snow and frost are factors that can impede the rate of biodegradation. Depending on precipitation and climate, temperatures can fluctuate and pH values can vary from two to eleven.[4] However, soil conditions suitable for plant cultivation – e. g. with the presence of microorganisms – are also ideal for biodegradable materials.[1] Over 90 different species of micro-organism able to recycle biodegradable plastics have been identified in soil and compost.[2]

Two special cases identified in the project are inner-city tarmac and forest soil. The conditions for biodegradation are very demanding in both environments. There are hardly any micro-organisms on asphalt that could support biodegradation. Forest conditions are also classified as difficult for the biodegradation of plastic products and cannot be likened to agricultural soils. The forest floor is very heterogeneous; water conditions and thus conditions for decomposer organisms vary depending on the type of vegetation (forest ecosystem of coniferous or deciduous trees), aspect (north or south slope, depression) and grain size of the soil (sand or clay).

4 Kliem, S., Kreutzbruck, M. and Bonten, C. 2020: Review on the Biological Degradation of Polymers in Carious Environments. Materials, Vol. 13, 4586. doi: 10.3390/ma13204586

4.4 Wastewater

Wastewater is fed through the sewage system to treatment plants where it undergoes mechanical, physical and chemical processes. There is also biological clarification stage where substances in the wastewater are biodegraded. The resulting sewage sludge is finally separated from the treated water. Sewage sludge is usually used as a fertiliser on fields and thus ends up in agricultural soils. Containing organic matter and other nutrients, sewage sludge provides optimal growth conditions for micro-organisms. The microbial population density is therefore significantly higher than that of fresh or saltwater. Depending on the composition of the sewage sludge and the processing conditions, degradation may be aerobic or anaerobic. Temperatures between 37 °C and 50 °C are considered beneficial.[4] The purified water is released into the environment, usually into fresh water, and from there the water can also return to the sea.

4.5 Freshwater

Freshwater types can be divided into standing and dynamic waters (rivers, lakes). Temperatures depend on the season (0 to 35 °C), precipitation, location and depth of the water. The pH value of freshwater is between six and nine. Fungi and bacteria are primarily responsible for biodegradation in freshwater, although fungi are less prevalent. This fact, and the generally low ambient temperature, considerably hamper the biodegradability of plastics.[2 4]

4.6 Saltwater

The environmental conditions in saltwater, as found in the world's oceans, vary quite considerably – just think of coastal regions, the open sea and the deep sea. The temperature varies considerably depending on depth, location and season (between -1 °C and 30 °C).[4] The concentration of micro-organisms is even lower than in freshwater and active fungi are almost completely absent. The degradation process is even more demanding than in freshwater.[2]

The following section considers in general various situations in which plastics can end up in the environment. In reality, influences such as wind, rain, erosion and similar factors transport the plastics from one environment to the next, such as from the ground into a river and ultimately into the sea. Especially when plastics in the form of microplastics enter the soil or decompose into it, release into other environments has to be considered.

Since biodegradation becomes increasingly difficult passing from soil to freshwater to saltwater, biodegradation should, ideally, already take place in soil or freshwater, ensuring that the plastic does not reach saltwater in the first place.

The framework of this project has been restricted to the initial destination and biological degradation within it. In the certifications considered in this project, material certified for biodegradation in seawater automatically also degrades in home compost, but not the other way round. Accordingly, we have not exclusively recommended materials that degrade in both possible environments if the primary point of release and destination is clear.

The actual environmental conditions for biodegradation are rarely constant. Under laboratory conditions, the optimal environment can nevertheless be simula-

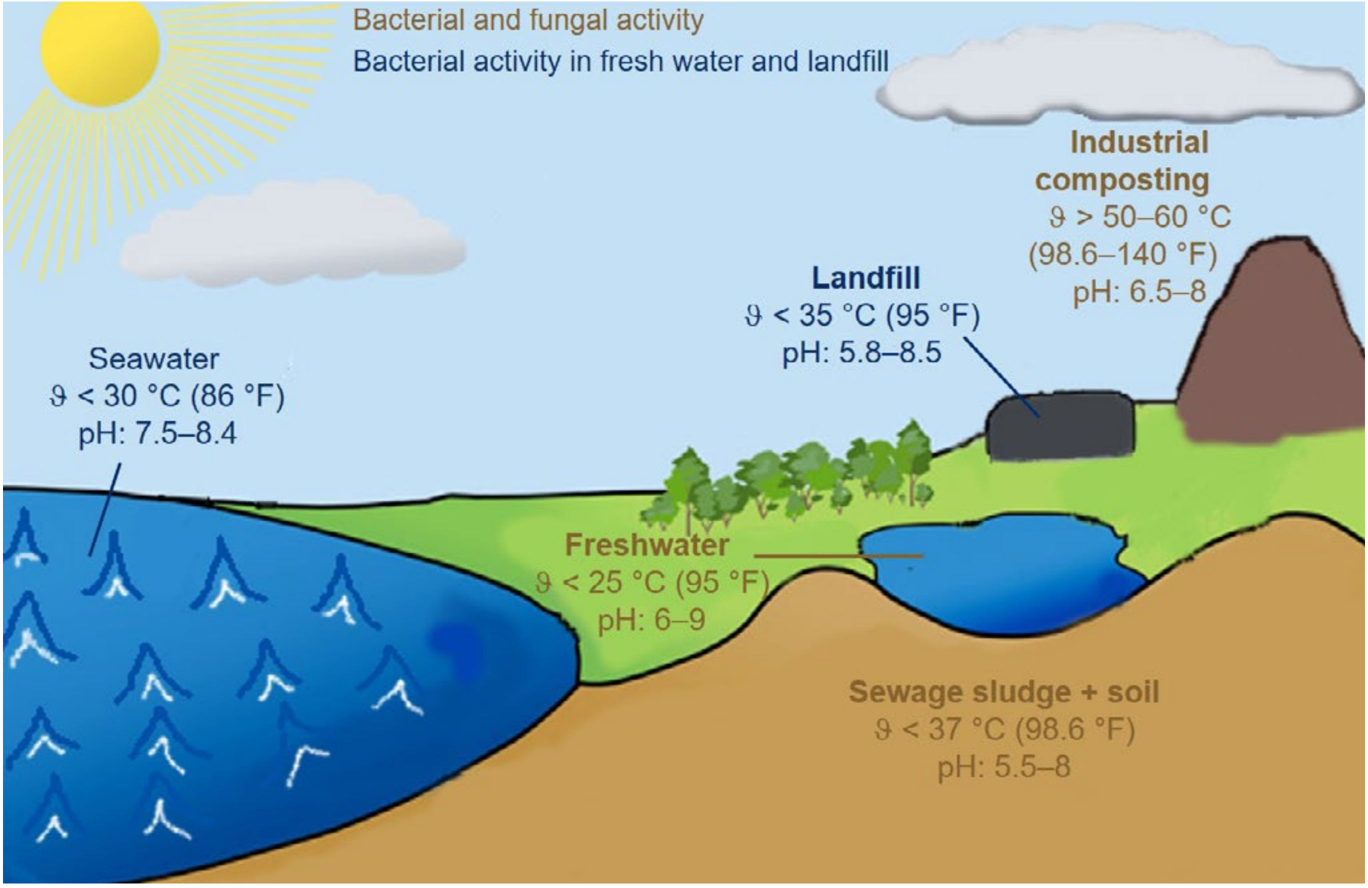


Figure 1: Schematic overview of the different environmental conditions for the biodegradation of polymers in the environment

ted and allow reliable conclusions to be drawn about biodegradation patterns under real-life conditions. To be considered biodegradable in a given environment, a plastic or plastic product must be tested accordingly. Norms, standards and certifications defining the biodegradation of plastics in various relevant environmental conditions and specific timeframes can allow this biodegradation process to be demonstrated in a standardised manner, creating a scientific framework sound framework. In the following section, standards and certificates for the respective environments are presented and explained.

5 Overview of standards, norms and certification concepts

The 25 selected products and applications end up at the end of their life cycle in various different environments where biodegradation would be beneficial. However, as already mentioned, degradation is not equally efficient in every environment, as the specific conditions affect the sequence of processes and their speed. The identified environments that plastic products and their particles pass through and subsequently end up in are, as already discussed in section 4, industrial and domestic compost, soils (often agricultural) as well as wastewater, freshwater and saltwater. The extent to which each of these environments influences the processes of biodegradation varies, with each presenting its own challenges and opportunities for successful biodegradation.

These environmental scenarios must therefore be considered individually and each tested and certified in its own right. For this purpose, various standards and certificates exist to provide a set of limits within which biodegradation must take place, according to criteria that are adapted to the respective environmental influences. Otherwise, a product may not call itself "biodegradable" in accordance with these certificates.

Standards, norms and certifications are, in part, enshrined in regulations, provisions and law, allowing a legally binding foundation to be established for products, applications and their life cycles. This only applies to a limited extent in the case of biodegradable plastics. However, there are other standards and certificates that are yet to be reflected in regulation. The basic standards and certificates relevant to the project are set out and detailed below. Specific standards and peculiar characteristics of individual applications are addressed in the corresponding fact sheets.

In the BioSinn project, we mainly address the standards that are considered and used in the listed certification schemes. The standards mentioned here are not a complete overview. There are other notable standards on biodegradability, such as DIN EN ISO 18830, DIN EN ISO 19679, DIN EN 17417 and DIN EN 17427.

As is to some extent evident from the individual certification requirements, temperature plays a decisive role in degradation. In many of the tests, degradation is analysed in the range of 20 °C to 30 °C. To a great extent it is assumed that the results obtained in this range can be transferred linearly to other temperature ranges and extrapolated upwards or downwards. At an average temperature of 60 °C, decomposition in industrial composting plants takes place much faster than in home composting. Degradation in soils and water takes even longer.

The surface area of the material to be biodegraded also plays a decisive role in the overall duration of biodegradation. The larger the surface area, the more surface the microorganisms can attack to degrade the material. Consequently, degradation times often vary between laboratory environments and reality, as the material to be degraded is previously grinded in the laboratory, which shortens the degradation time. In nature, this process of fragmentation happens simultaneously to the biodegradation when the material is mechanically stressed and exposed to UV radiation.

Standards and certifications usually cover a relatively short time frame for biodegradability. They have been developed for applications with a short functional life where biodegradation must occur relatively quickly.

Some biodegradable plastics degrade more slowly in certain environments than current certifications allow. However, it is important to note that some eventually biodegrade completely and do not leave behind microplastics. Slower biodegradability is also required for applications with a longer functional life. So far, there are no standards or certification systems to account for this slower biodegradability. In the BioSinn project, both types of biodegradation are considered; one within the time frame defined by standards and the one in a longer time frame not yet defined by standards (Figure 3).

5.1 Standards

A standard specifies requirements for a product, service or process.[5] In the case of the BioSinn project, these are requirements for biological degradation. This section explains the most important standards in this respect. Where applicable, further specific standards are mentioned in the fact sheets.

5.1.1 DIN EN 13432

The standard DIN EN 13432 deals with the valorisation of packaging by composting and biodegradation. It defines criteria and test schemes according to which the biodegradation of a packaging product can be evaluated in a standardised manner. The standard sets out a scheme for testing packaging with regard to biodegradability, disintegration during biological treatment, effect on the biological treatment process and effect on the quality of the resulting compost. Both the extent and maximum duration of biodegradation are determined according to the type of biodegradation. Under aerobic conditions in industrial compost, the degradation period may not exceed six months. After this time, degradation of at least 90 % must be achieved. Under anaerobic conditions, e. g. in a biogas plant, the maximum duration should not exceed two months, during which time at least 50 % must have decomposed.

5.1.2 DIN EN 14995

The standard DIN EN 14995 specifies the requirements and methods used to determine the compostability or anaerobic treatment of plastics. Alongside general biodegradability, it also defines the limiting framework for disintegration, quality of the resulting compost and the identification of the material as biodegradable.

Essential components of the standard are a maximum test period of six months for aerobic degradation (e. g. in compost), in which 90 % of the product must have degraded. For anaerobic degradation (i. e. mainly in a biogas plant), where the testing procedure is optional, the maximum testing period is two months, during which at least 50 % must be converted into biogas.

5.1.3 DIN EN 17033

The DIN EN 17033 standard explicitly deals with biodegradable mulch films intended for use in agriculture and horticulture. Like DIN EN 13432, it defines specifications and a test method, which provide the framework for biodegradable mulch films. The framework for testing satisfactory biodegradation stipulates a maximum period of 24 months, during which at least 90 % of the material in the mulch film is converted to CO_2 (the remaining 10 % is found in the biomass of the micro-organisms) and the temperature is a constant 20 °C to 28 °C.

5 https://www.din.de/de/ueber-normen-und-standards/basiswissen

5.1.4 ASTM D6691 – 17

ASTM Standard D6691 – 17 establishes a standard test method for determining aerobic biodegradation of plastics in the marine environment by a defined microbial consortium or natural seawater inoculum. The test procedure is designed to measure the development of CO_2 over a period of 10 to 90 days and at a temperature of 30 °C ± 1 °C, on the basis of which the degree of biodegradation can be calculated.

5.1.5 AS 5810 – 2010

Australian Standard AS 5810 – 2010 covers biodegradable plastics suitable for home composting. The maximum test period is set at twelve months, during which degradation of at least 90 % must be achieved. The ambient temperature in the test procedure must be 25 ± 5 °C and may never exceed 30 °C.

5.1.6 NF T51-800

The French standard NF T 51 – 800 defines the necessary specifications for plastics suitable for home composting. According to this standard, the ambient temperature should be 25 ± 5 °C in the degradation test and should not exceed 30 °C throughout the test. For all polymers, at least 90 % of the organic carbon must have been converted to carbon dioxide by the end of the test. The maximum test duration is 365 days. Satisfactory degradation is achieved if after 180 days, no more than 10 % of the original dry mass remains after sieving with a 2 mm sieve. The plastic residues may not be distinguishable from the other compost material with the naked eye and at a distance of 500 millimetres.

5.2 Certification by TÜV Austria

TÜV Austria issues certificates based on the applicable standards. TÜV Austria limits the use of certification to products intended for use in the environment for which they are to be certified. According to this, for example, only products intended for use in the sea may bear the logo of the “OK biodegradable MARINE” certificate – i. e. no shopping bags, for example, even if they are biodegradable in the sea. The same applies to the certifications “OK biodegradable SOIL” (horticulture and agricultural products) and “OK biodegradable WATER” (freshwater).

Both TÜV Austria and DIN CERTCO certify individual polymer types, materials conditioned with additives or finished products, depending on the certification system and the customer's request. The criteria of degradation apply accordingly to the respective test item.

5.2.1 OK compost INDUSTRIAL

The requirements for the certification "OK compost INDUSTRIAL" issued by TÜV Austria are equivalent to those of DIN EN 13432. This certification thus implements and guarantees DIN EN 13432. A product that has been awarded the "OK compost INDUSTRIAL" certificate in accordance with DIN EN 13432 could in principle be sent for industrial composting via the brown bin bio-waste stream without qualms. Any product awarded this label also complies with the requirements of the EU Packaging Directive.

5.2.2 OK compost HOME

Another environment that TÜV Austria takes into account is home composting. The "OK compost HOME" certificate certifies that a product is at least 90 % biodegradable (according to DIN EN 13432) in a temperature range of 20 °C to 30 °C and within a maximum period of twelve months. Products that have the appropriate TÜV Austria certificates for biodegradation in soil and sea are automatically also considered compostable in home compost according to "OK compost HOME".

5.2.3 OK biodegradable SOIL

The DIN EN 13432 standard is also consulted and used as a basis of the successful "OK biodegradable SOIL" certification for biodegradation in the soil. However, compared to the other certificates, there are adaptations affecting individual components of the test procedure. The maximum degradation period is not six months, as stipulated in DIN EN 13432, but has been extended to two years to reflect the changed environmental conditions in the soil. However, during this time, a minimum of 90 % of the carbon must be biodegraded and converted to CO_2. Forest soil has to be considered separately; section 4.3 describes the challenging conditions of forest soil, for which there is currently no separate certification system.

5.2.4 OK biodegradable WATER

DIN EN 13432 also underpins degradation in a freshwater environment, although it has to be adapted to the factors typical of the environment. The temperature range in which testing is carried out for freshwater is 20 °C to 25 °C. Within this range, a product must achieve the usual degradation of 90 %, but after a test period of only 56 days. This illustrates the stringent demands made of materials and products put forward to be certified for freshwater degradation.

5.2.5 OK biodegradable MARINE

The environmental conditions in the sea pose the greatest challenge to the biodegradation of any substance. Low rates of micro-organisms, low temperatures and low oxygen supply have a significant negative impact, as explained in section 4.6. Therefore, this certification uses another underlying standard, ASTM D 6691, which defines a standard method for the aerobic degradation of plastics in marine environments. According to this method, 90 % of the material must be biodegraded within six months.

However, this certificate is sometimes considered to lack detail and development. A revision is expected in the next few years.

5.3 DIN CERTCO

Like TÜV Austria, DIN CERTCO (TÜV Rheinland) issues biodegradability certificates based on the relevant standards.

5.3.1 „DIN-geprüft biodegradable in soil“

“DIN-geprüft biodegradable in soil” is a certification process for biodegradation in soil. It is based on the requirements of the standard DIN EN 17033, detailed in section 5.4 . However, the certification is only awarded to materials and finished mulch films defined in DIN EN 17033. This certification explicitly does not apply to packaging, bags and other applications. The test criteria are applied here exactly as set out in DIN EN 17033. A level of 90 % degradation must have been achieved after 24 months in a temperature range between 20 °C and 28 °C.

5.3.2 “DIN-geprüft industrial compostable” & “Seedling”

Based on the standards DIN EN 13432 and DIN EN 14995, two certification procedures certify the industrial compostability of materials and products. The first is the “DIN-geprüft Industrial compostable” certificate awarded by TÜV Rheinland, and the second the “Seedling” certificate, which can be awarded by both TÜV Rheinland and TÜV Austria. The general requirements for decomposition are the same and are based on identical underlying standards: At least 90 % of the material must be fully biodegraded within six months. Furthermore, after 12 weeks, a maximum of 10 % of the original material may be found in a particle sieve for particles > 2 millimetres.

5.3.3 “DIN-geprüft home compostable”

The certificate “DIN-geprüft Home compostable” certifies the compostability of a product in home compost. It is based on Australian standard AS 5810 and French standard NF T 51-800 and is awarded by TÜV Rheinland. At least 90 % of the substance must be completely degraded within twelve months. The temperature should not exceed 30 °C. After a retention time in the home compost of 180 days, no more than 10 % of the original material may be found in a > 2 millimetre particle sieve.

6 Selection of possible substitutes

Once potential destinations and the conditions prevailing there for the selected products and applications have been identified, the task is to find technically suitable substitutes whose biodegradability can be confirmed by the independent certifying bodies. The project aims not only to identify possible applications for biodegradable plastics, but also to make specific suggestions as to which polymers or polymer groups could be used as the basis for a biodegradable alternative. Various considerations and requirements come into play here.

These can be summarised according to the three major subject areas of plastics technology: materials technology, processing technology and product development.

In terms of materials technology, the first point of interest is the factors to which the product is exposed during its service life. These can be chemicals such as acids, alkalis, fats and oils. Saliva also requires a specific material resistance. Conversely, requirements are made regarding exposure to the plastic used, for example approval for food contact or proof of biocompatibility with human tissue. Certain products require certain permeabilities, which can be either high (to hydrate fresh fruit and vegetables) or low (oxygen barrier for long-life packaging).

The requirements made of biodegradation are particularly important when selecting the material to be used. The previous section explained that different environmental conditions provide different conditions for biodegradation. Possible environmental conditions could be summarised as in Figure 1.

Rapid biodegradation is certainly not always required. Numerous applications are designed to fulfil their intended purpose outdoors for a set period of time, meaning that weather resistance can also be important for the products under consideration.

For an initial assessment of possible alternatives to polymers currently in use, it is important first and foremost to know in which environment the product is expected to end up once it has finished active deployment. This has been explained in the previous section.

Figure 2 gives an overview of which polymers biodegrade in which environments within a defined time. This predictable, relatively short time frame is usually covered by the standards and certifications. It covers applications with a short functional life where biodegradation must occur relatively quickly.

On the other hand, applications with a longer functional life also need to be biodegradable, but biodegradation must occur much more slowly. As biodegradability is a fundamental material property, it can be assumed that biodegradation will also occur in less favourable environments, but over a longer period of time. A good example of this is wood, which is generally recognised as biodegradable, but in which this only happens over a period of several decades.

Another example is PLA, which is known to be biodegradable under certified industrial composting conditions. PLA can actually also biodegrade over a longer timeframe in other conditions, such as in soil or home compost. However, slower biodegradability is not currently covered by the current standards and certification scheme outlined above.

In addition to the material requirements, its processing must be taken into account. Each processing step poses specific challenges to the material used. In injection moulding, for example, a low-viscosity melt is advantageous, helping to fill even the smallest corner of the cavity. Extrusion, on the other hand, requires highly viscous materials; blown film extrusion or foaming of plastics in particular require not only high viscosity but also high melt strength.

Finally, product development focuses on the stresses to which the product will be subjected during its service life. This includes forces and loads acting on the product. Furthermore, the product may be stretched or deformed, and should not fail under these circumstances. If it is a durable product, ageing processes will occur during its service life.

All these points taken together draw a clear profile of properties the plastic must fulfil when used as a substitute.

Figure 3 shows another overview of biodegradable polymers in different environments according to established standards and certification schemes.

In most cases, biopolymers cannot be processed in their pure form and must first be modified with suit-

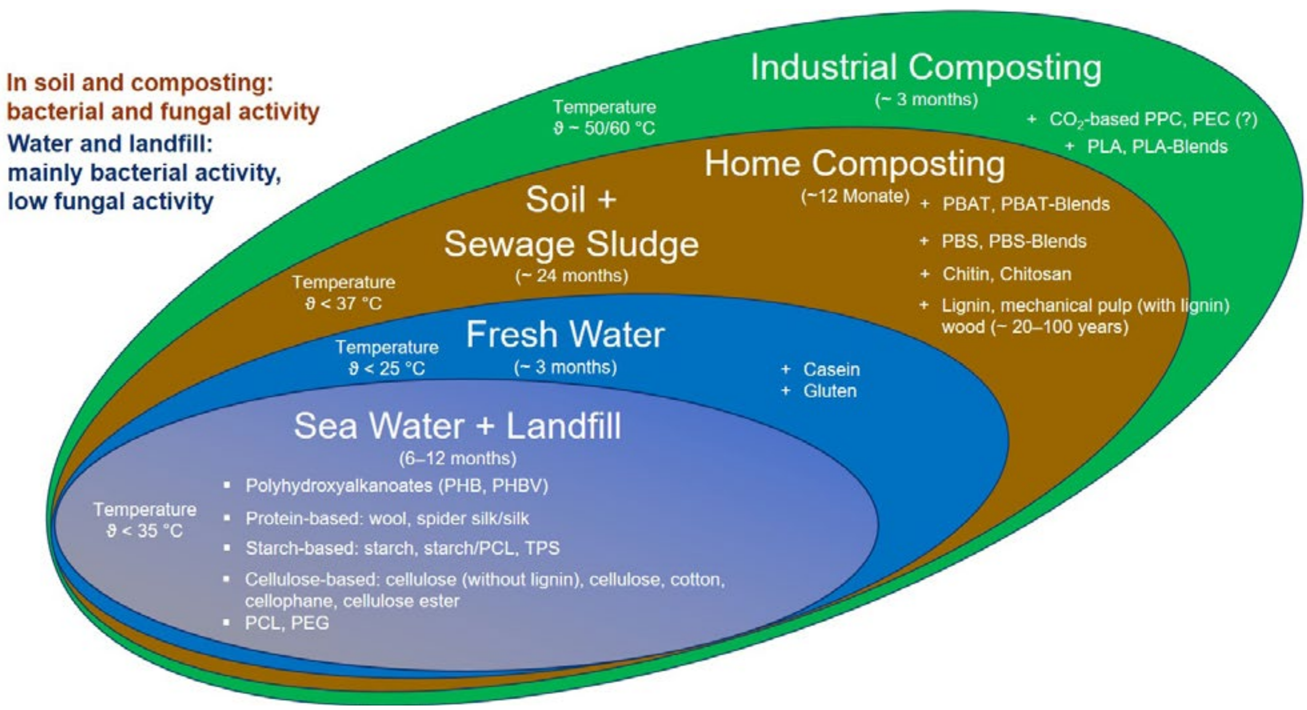


Figure 2: Biodegradation of polymers within a defined period classified according to environmental conditions

able additives or by being blended (i. e. mixed) with one or more other biopolymers. The polymers proposed in this project as substitutes for conventional plastics are thus done so on the basis of assumptions and their technical feasibility has yet to be confirmed in most cases. Often multi-component solutions deliver successful outcomes. In this case, the biodegradability of the new bioplastics must be demonstrated anew for each case, since additives and other components can influence biodegradation.

In the course of the project, however, it also became clear that some applications are customised to a conventional polymer to such an extent that a biodegradable substitute is not (yet) conceivable. A great deal of research is still required to catch up with the decades-long development lead enjoyed by conventional polymers and plastics.

The Institut für Kunststofftechnik Stuttgart (IKT Stuttgart) was available to the nova experts as a friendly partner for this part of the project.

Biodegradable Polymers in Various Environments

According to Established Standards & Certification Schemes

Update 2021

NOTES

proven biodegradability

proven biodegradability for certain grades

biodegradability not proven

The biodegradability of plastics derived from these biodegradable polymers can only be guaranteed if all additives and (organic) fillers are biodegradable, too. Dying and finishing of cellulosic fibres, for example, may prevent their biodegradation in the environment.

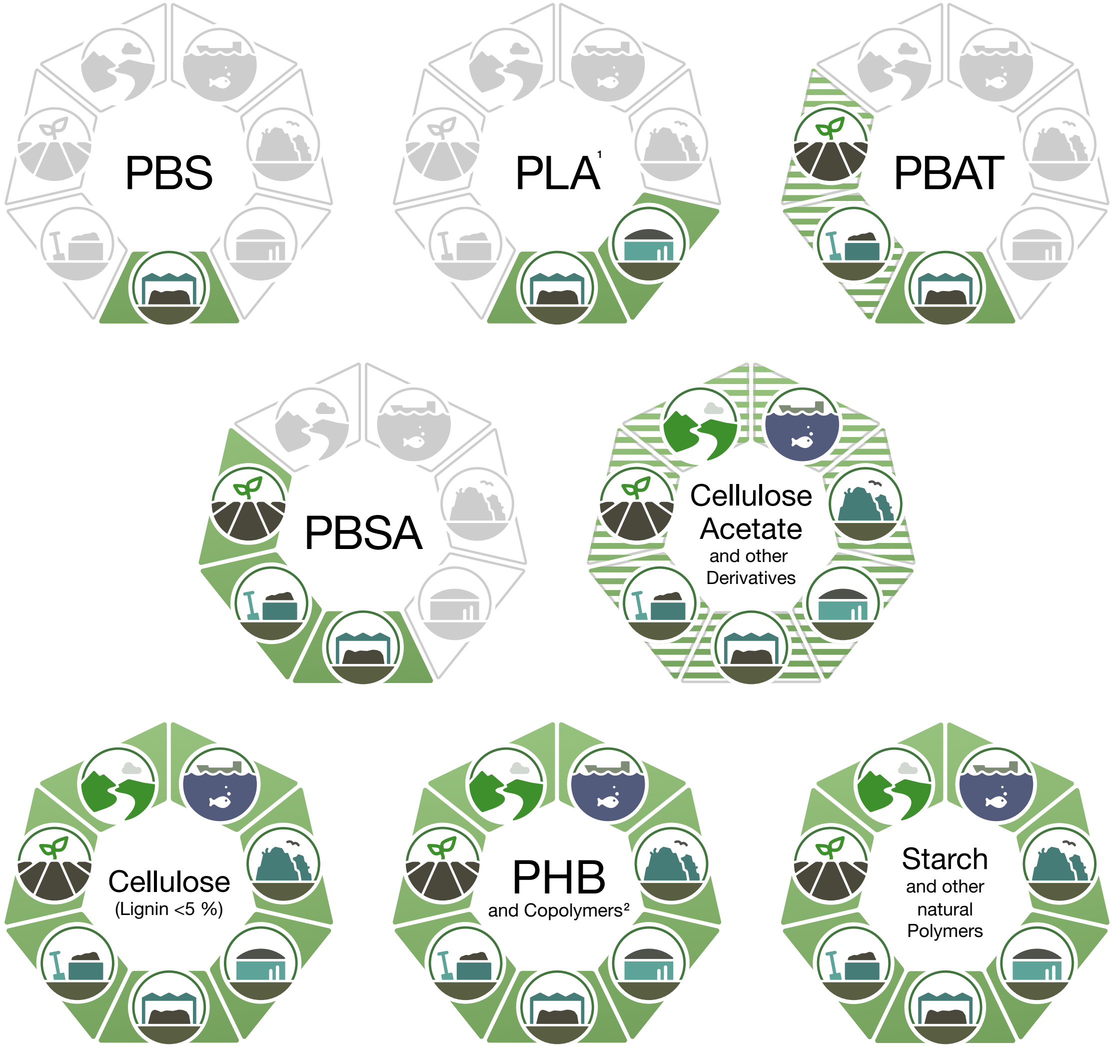
Biodegradability depends on the complex biogeochemical conditions at each testing site (e.g. temperature, available nutrients and oxygen, microbial activity, etc.). Therefore, these generalised claims about biodegradation can only serve as approximations and need to be confirmed by standardised testing under lab conditions. In-situ behaviour can vary, depending on the mentioned conditions, size of the plastic, grade of the polymer and other factors. For instance, biodegradation testing is often performed after milling, showing the inherent nature of the material to biodegrade. In reality, the same level of biodegradation will be obtained, be it possibly within a different timeframe.

SLOWER BIODEGRADING POLYMERS

The polymers shown in the poster are rapidly biodegraded in the labelled environments, within the time frame of the corresponding standards or certificates. Some biopolymers, such as PBS or PLA in soil and also lignin/wood for virtually all environments, also biodegrade, but (much) more slowly. Full biodegradation can take several years to decades to be achieved. In addition, for some applications with a use phase in a certain environment (e.g. geotextiles), too rapid biodegradation is not desired, as their function should first be given for a few years. However, for these cases no standards exist so far.

[1] PLA is likely to be biodegradable in thermophilic anaerobic digestion at temperatures of 52°C within the time frame mentioned in standards.

[2] incl. P3HB, P4HB, P3HB4HB, P3HB3HV, P3HB3HV4HV, P3HB3Hx, P3HB3HO, P3HB3HD



ENVIRONMENTS

IMPORTANT TEST CONDITIONS, CERTIFICATION SCHEMES AND STANDARDS

For more details, refer to the original documents.

MARINE ENVIRONMENT

Temperature 30°C, 90 % biodegradation within a maximum of 6 months. Certification: TÜV Austria OK biodegradable MARINE. Research on standards (both on test methods and requirements) is on-going.

FRESH WATER

Temperature 21°C, 90 % biodegradation within a maximum of 56 days. Certification: TÜV Austria OK biodegradable WATER. Research on standards (especially on requirements) is on-going.

SOIL

Temperature 25°C, 90 % biodegradation within a maximum of 2 years. Certification: TÜV Austria OK biodegradable SOIL and DIN CERTCO DIN-Geprüft Biodegradable in Soil. DIN-Geprüft Biodegradable in Soil refers to the European standard EN 17033 for biodegradation in soil and applies to mulch films only.

HOME COMPOSTING

Temperature 28°C, 90 % biodegradation within a maximum of 12 months. Certification: TÜV Austria OK compost HOME and DIN CERTCO DIN-Geprüft Home Compostable.

LANDFILL

No European standard specifications or certification scheme available since this is not a preferred end-of-life option for biodegradable waste.

ANAEROBIC DIGESTION

Thermophilic 52°C / Mesophilic 37°C
A specific European standard or certification scheme for anaerobic digestion is not yet available. Anaerobic digestion in a biogas plant is mentioned in EN 13432 and EN 14995: 50 % biodegradation within two months, usually followed by aerobic digestion.

INDUSTRIAL COMPOSTING

Temperature 58°C, 90 % biodegradation within a maximum of 6 months. Certification: TÜV Austria OK compost INDUSTRIAL, DIN CERTCO DIN-Geprüft Industrial Compostable and both „Seedling". EN 13432 and EN 14995 are the European reference standards and the basis of these certification schemes.

RENEWABLE CARBON — More figures available at www.renewable-carbon.eu/graphics

Partners: IKT Kunststofftechnik Stuttgart; OWS; Hydra Marine Sciences

Sponsors: TÜV Rheinland; DIN CERTCO; OK compost; TÜV Austria

Your feedback is welcome: michael.carus@nova-institut.de

7 Political framework conditions

When considering the various pathways through which plastic debris and microplastics enter the environment, there are many opportunities for intervention through policy measures and other regulatory instruments. For the majority of routes by which plastic enters the environment, there are clearly attributable legal frameworks, although some of these are poorly enforced or difficult to implement. An overview of this policy framework is essential if we are to identify where action is needed and where more leeway for manoeuvre could be created.

The most important laws and regulations are outlined here.

7.1 Circular Economy Act (KrWG)

Essentially, the European Union is striving to switch to a functioning circular economy, which is laid down at a German level in the Circular Economy Act. This stipulates that, in principle, a producer or owner of waste is obliged to recycle it. However, this form of recovery is only obligatory where it is technically possible and economically reasonable. Biodegradation should only be chosen as the last resort. This means, in terms of the waste hierarchy, that the first priority is to reduce potential waste, then to recycle it, and the preferred end-of-life option for products at the end of their life cycle is reuse rather than other forms of recovery or disposal.[6]

This inevitably leads to the conclusion that preference should be given to materials that can be reused and recycled over those classified as "compostable" and/or "biodegradable". When plastics are biologically degraded in industrial composting plants, for example, only very little added value is achieved in terms of material. Most of the carbon is emitted in the form of CO_2. Only a small part remains in the compost in the form of additional biomass. However, a few exceptions are made to this requirement. In cases where biodegradable plastics generate additional benefits and thus promote the functioning of the circular economy, it is a preferable characteristic. For example, bio-waste bags are mentioned here (see section "Biowaste bags" on page 76). These encourage the collection of valuable organic waste and also reduce plastic contamination in composting facilities from conventional plastic bags that are often mistakenly used to collect organic waste.[7]

In principle, the composting of biowaste is not considered recycling in Germany, but rather "recovery" according to the waste hierarchy. More details on the legal framework regarding recycling at EU level are shown in chapter 7.2 and 7.5.

6 Federal Ministry of Justice and Consumer Protection 2012: Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen (Circular Economy Act – Kreislaufwirtschaftsgesetz – KrWG). 23/10/2020. Download at https://www.gesetze-im-internet.de/krwg/KrWG.pdf

7 Hilton, M., Geest Jakobsen, L., Hann, S., Favoino, E., Molteno, and Scholes, R. 2020: Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy. Directorate-General for Environment (European Commission), Eunomia (Ed.), 03/04/2020. doi: 10.2779/497376

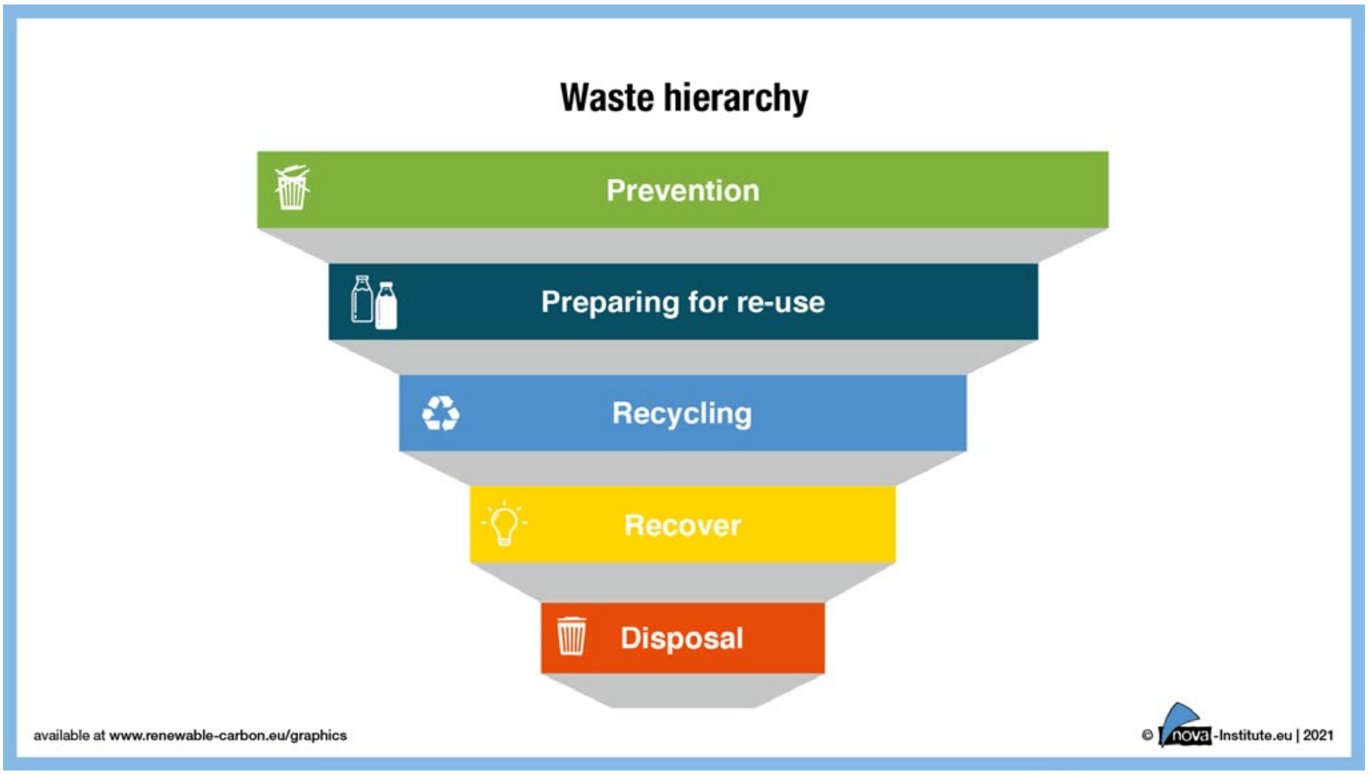


Figure 4: Waste hierarchy

7.2 Regulation on Bio-Wastes (BioAbfV)

These exceptions, mentioned in the previous section, are enshrined in Germany in the Regulation on Bio-Wastes[8] to create a binding framework that specifies and permits such cases, without overriding the principles of the circular economy. The Regulation on Bio-Wastes fundamentally defines which waste products may be added to the bio-waste stream if subsequently intended for soil-related use. In the Regulation as enforced at the time of the project, only biodegradable mulch films from gardening and agriculture that are certified according to DIN EN 13432 or DIN EN 14995 are expressly permitted to enter into the bio-waste stream. However, an amendment to this Regulation has been initiated to recognise bio-waste bags as acceptable for the bio-waste stream in addition to mulch films. The drafted amendment follows the above logic. However, the amendment has not yet been implemented in law.[9]

A major problem arises from the fact that the processing of bio-waste in industrial composting plants in Germany is not homogeneous. The individual plants operate with different compositing times and other factors influencing biodegradation and therefore do not generally meet the requirements for a complete biodegradation of plastics, despite being legally certified. Residues of biodegradable plastics are thus found in what is supposed to be readily-composted substrate. These residues are considered problematic, and then either have to be filtered out at great ex-

8 Federal Ministry of Justice and Consumer Protection and Federal Office of Justice 2017: Verordnung über die Verwertung von Bioabfällen auf landwirtschaftlich, forstwirtschaftlich und gärtnerisch genutzten Böden (Regulation on Bio-Wastes – BioAbfV) §2 Annex 1. 27/09/2017. Download at https://www.gesetze-im-internet.de/bioabfv/BioAbfV.pdf

9 Bio-based News 2021: Less plastic in organic waste, less microplastic in the environment. 03/02/2021. Last accessed 12/03/2021. https://news.bio-based.eu/weniger-kunststoff-im-biomuell-weniger-mikroplastik-in-der-umwelt/

pense, or further biodegraded in the soil, i. e. where they are employed – a process that can take a long time. The risk of plastic residues in compost cannot at this point be adequately recorded and assessed. In addition, fertiliser regulations at both the EU and federal level currently do not consider the absence of microplastics of all kinds (< 1 millimeters) as binding.[10]

This heterogeneous industrial composting landscape is a major problem, especially in Germany, where waste streams and processing are regulated at the municipal level. Accordingly, in some municipalities and areas the introduction of products explicitly approved at BioAbfV level into these processes is not permitted. The Regulation on Bio-Wastes can thus only only fundamentally define the basics of what may in principle enter the bio-waste stream, but cannot guarantee on a national level that all permitted materials will subsequently be accepted at a municipal level. A counter-example is Italy, where the use of biodegradable (DIN EN 13432) bio-waste bags is approved at a national level and can therefore be successfully implemented throughout the country.[2] This scheme runs hand-in-hand with information campaigns and organic waste bin inspections, and is rewarded by achieving the lowest proportion of non-biodegradable plastics in compost in the whole of Europe. In principle, the EU Waste Framework Directive[11] stipulates that bio-waste must be collected separately from all other waste. This applies to all Member States. Bio-waste bags which may enter the bio-waste stream are clearly considered a driver of this legal requirement; against this background, nationwide approval, as provided in Italy, therefore makes sense.

Both the Eunomia study[7] and personal correspondence with the Federal Ministry for the Environment[12] have shown that the available standards and certification systems for successful application in the industrial composting system in Germany need to be adjusted. As, for efficiency reasons, German processing plants often opt for a significantly shorter composting time than the certificates and standards provide for, revision would have to take place at this point.

With regard to the concept of a circular economy and the regulations in the Regulation on Bio-Wastes, the BioSinn project follows a very similar logic. However, given the explicitly selected criteria for the products and applications, BioSinn always considers biodegradation directly at the primary point of use.

10 Federal Ministry of Justice and Consumer Protection 2017: Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis bei Düngen (Fertiliser Regulation – DüV). 26/05/2017. Download at https://www.gesetze-im-internet.de/d_v_2017/DüV.pdf

11 The European Parliament and the Council of the European Union 2008: Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. 19/11/2008. Download at https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32008L0098&from=EN

12 Ewens, H. (Federal Ministry for the Environment) 2021: Personal communication. 19/02/2021

7.3 REACH

For plastics and chemicals of all kinds, the Regulation concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals, abbreviated as "REACH", applies at an EU level.[13] This also applies in principle to biodegradable plastics. A novel plastic not yet registered with ECHA (European Chemicals Agency) would therefore first have to go through the processes laid out in the REACH Regulation before it may be considered as a possible substitute. However, the REACH Regulation stipulates that polymers do not need to go through the registration and evaluation processes. Only the REACH and ECHA authorisation and restriction measures are therefore relevant for plastics. Overall, the common biodegradable plastics mentioned by us in this report as possible substitutes have already been successfully approved. At the end of 2020, ECHA laid the groundwork for a possible restriction in this category by making an official amendment proposal to the REACH Regulation.[14] This proposal provides for a total ban on intentionally added microplastics to prevent them from entering the environment. In this context, biodegradable plastics are explicitly excluded from the ban and should thus be used as an alternative if they meet the proposed biodegradation criteria. These insist on decomposition in water within six months and in soil and sediment within 24 months.

This proposal, devised by ECHA, names various products and applications that were also considered within BioSinn: all kinds of seed coating, polymers for the controlled release of substances and fertilisers in agriculture, as well as microplastic particles in cosmetics and in laundry detergents and cleaning products. BioSinn suggests alternative biodegradable materials for all these applications, which could be used after a ban on plastics that are not biodegradable. This concept for changes, subject to final implementation, is a significant step towards curbing the avoidable release of plastics into the environment.

7.4 Fertiliser Regulation

A common route by which microplastics enter the environment is agriculture. As described in section 7.2, the current legislation on fertilisers does not consider microplastics (< 2 millimetres) to be a regulatory problem and there are no laws mandating their absence. While this will remain the case for industrially manufactured compost until the legislation is potentially adjusted, action is already being taken elsewhere: both the planned adjustment of the REACH Regulation, which aims to prohibit non-biodegradable microplastics in uses related to fertilisers and an amendment to the EU Fertilisers Regulation tackle this problem. From 2026, according to the EU Fertilisers Regulation, polymers will have to be biodegradable for what are classified as "long-term release" products; the exact criteria are to be defined from 2024.

13 European Commission 2006: REGULATION (EC) No 1907/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93, Commission Regulation (EC) No 1488/94, Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (EC 1907/2006). 18/12/2006. Download at https://ec.europa.eu/environment/chemicals/reach/reach_en.htm

14 European Chemicals Agency 2019: ANNEX XV RESTRICTION REPORT PROPOSAL for a restriction of intentionally added microplastics, version 1.2. European Chemicals Agency (ECHA) (Ed.), 22/08/2019. Download at https://echa.europa.eu/documents/10162/05bd96e3-b969-0a7c-c6d0-441182893720

7.5 Packaging and Packaging Waste Directive

The packaging and packaging waste regulation in force at an EU level also fundamentally paves the way for biodegradable plastics in packaging applications. Under certain conditions, (aerobic) composting or (anaerobic) recovery in a biogas plant of biodegradable plastics can be classified as recycling under this regulation. Thus, these processes could also meet the EU recycling quotas. However, this option often comes up against the absence of national implementation, as composting or recycling in biogas plants is often prohibited, as is the case in Germany, for example.

8 Market volume

Another key point of the fact sheets is the estimated market volume of each product and its application, meaning that the plastic contributed by it and thus the substitution potential can be estimated. Calculations and estimates were made for Germany as well as for the EU28 countries. These are based on the analysis of databases (the Eurostat PRODCOM database provided values for many products), publications and interviews with external experts.

The following data were used for the conversion between Germany and Europe:

Population

- Europe: approx. 741 million inhabitants
- EU28: approx. 512 million inhabitants
- Germany: approx. 83 million inhabitants
- Population share Germany in percent / conversion factor
- Germany's share of EU28: 16.2 % / factor 6.16
- Germany's share of Europe: 11.2 % / factor 8.93
- EU28 share of Europe: 67 %

Whenever only one figure was available or could be determined for Germany or for the EU28, the other figure was converted on the basis of the population shares, as the per capita figures within the EU28 were assumed to be similar. Products and applications used in fisheries are an exception. Since Germany has a comparatively small coastal area with commercial fisheries, the share was assessed as smaller (share of Germany in EU28: 10 %).

The following figures show, for the first time ever, the market volumes in Germany (Fig. 4) and Europe (Fig. 5) for 25 applications that have a particularly high potential for reducing macro- and microplastic entry into the environment. In addition, Table 1 shows estimated losses, clarifying what proportion of the total volumes remains in the environment. An important part of the project was the collection, calculation or estimation of these market volumes for 25 applications, for which there are often no reliable statistics, as well as an estimation of the respective losses. Details can be found under the specific keyword.

In summary, the following can be deduced:

- In Europe (EU28), the sum of the market volumes of the 25 applications is around 1 million tonnes, most of which remains in the environment or biowaste streams (see Table 1).
- Market volumes vary considerably for the different applications, from less than 1,000 tonnes per year to 210,000 tonnes per year.

- Twelve applications range from 20,000 to 210,000 tonnes per year.
- Agricultural and forestry applications are in the top group (mulch films, binding yarn, flocculant aids in sewage sludge and tree shelters). Landscaping, contributes geotextiles to the mix.
- The other major area is household waste, with products such as wet wipes, chewing gum, tea bags, coffee capsules, biowaste bags and packaging films for dishwasher tabs.
- In addition to the above, the bristles of street sweeping machines also fall into the top group.

Some of these applications have not yet been a matter of public concern, even though some of them, such as flocculants for sewage sludge and the bristles of road sweepers, introduce large quantities of plastics into the natural environment. Conversely, the smaller market volumes include applications that are heavily concentrated on, such as microplastics in cosmetics or even lawn trimmer threads. Policymakers and environmentalists will certainly turn their attention primarily to large-volume applications, but for small-volume ones, environmentally friendly solutions can often be easily achieved with a little more awareness and policy regulation.

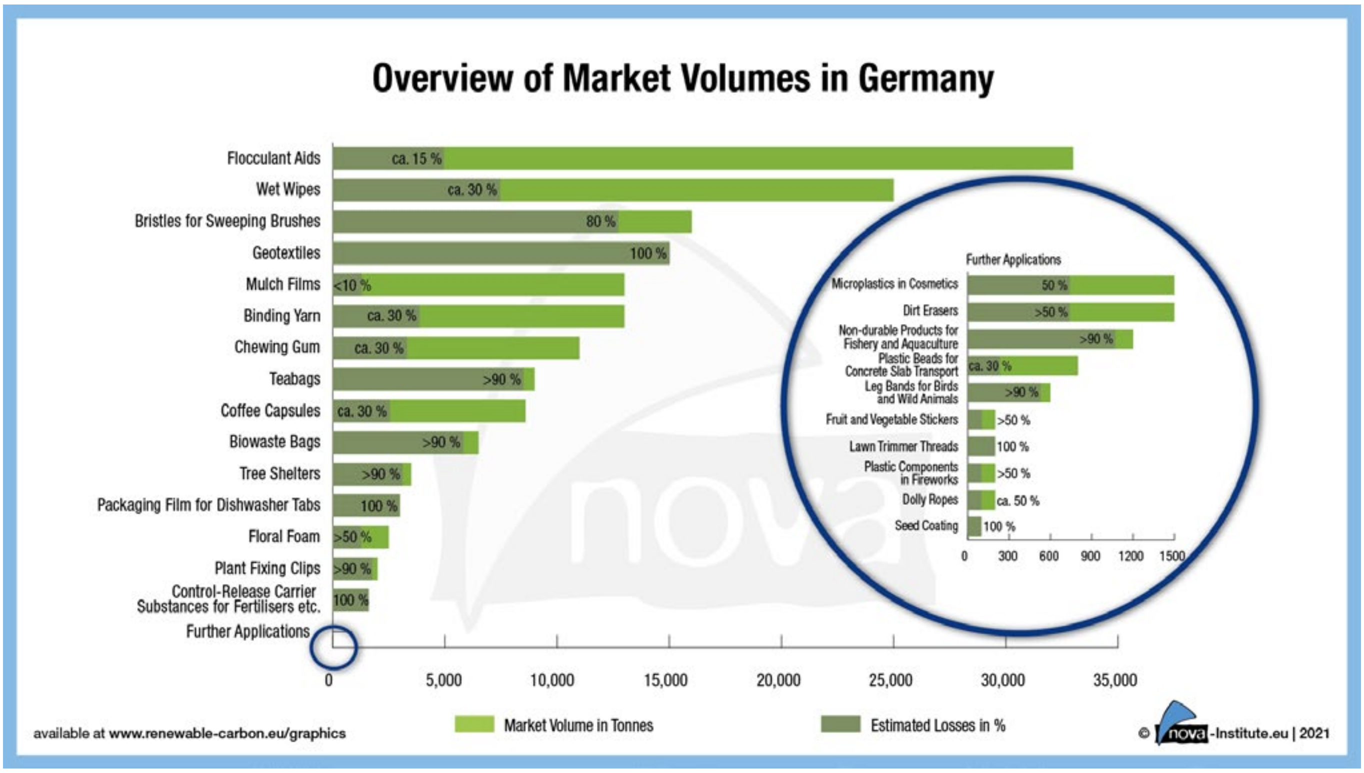


Figure 5: Overview of market volumes in Germany

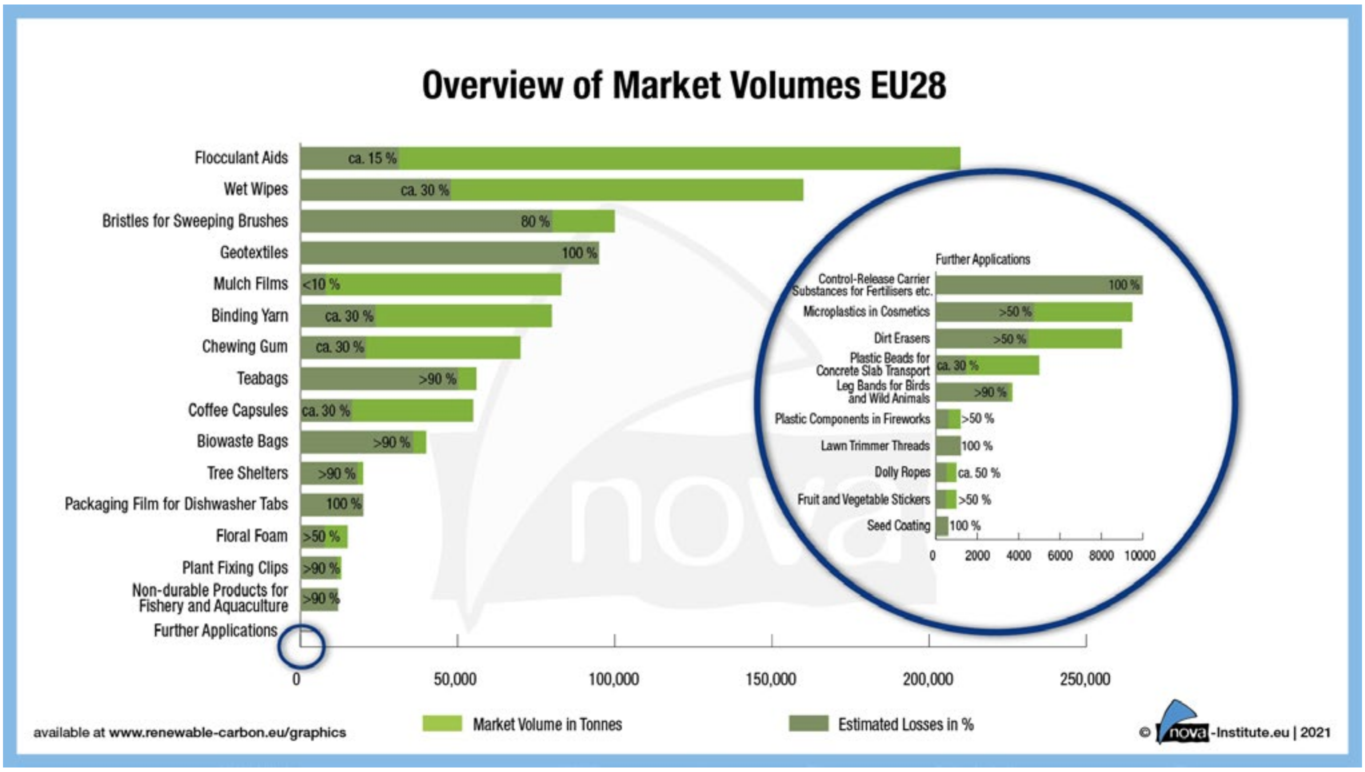


Figure 6: Overview of market volumes EU28

Tabelle 1: Estimated share of losses

Application / Product	Estimation of the extent of losses
Packaging film for dishwasher tabs	100 % wastewater
Lawn trimmer threads	100 % soil
Seed coating	100 % soil / nature
Control-release carrier substances for fertiliser ad-ditives	100 % soil / nature
Geotextiles	100 % soil / nature
Plant fixing clips	> 90 % soil / compost
Leg bands for birds and wild animals	> 90 % soil
Tree shelters	> 90 % soil
Teabags	> 90 % in compost / industrial compost
Biowaste bags	> 90 % in industrial compost
Non-durable products for fishery and aquaculture	> 90 % sea
Bristles for sweeping brushes	80 % soil / asphalt
Dirt erasers	> 50 %
Plastic components in fireworks	> 50 % soil / water
Fruit and vegetable stickers	> 50 % in compost / industrial compost
Floral foam	> 50 % in compost / industrial compost
Microplastics in cosmetics	> 50 % with treated water into nature
Dolly ropes	approx. 50 % in the sea
Wet wipes	approx. 30 % wastewater
Plastic beads for concrete slab transport	approx. 30 % soil / nature
Binding yarn	approx. 30 % soil / nature
Chewing gum	approx. 30 % soil /asphalt
Coffee capsules	approx. 30 % in compost / industrial compost
Flocculant Aids	< 10 % soil / water
Mulch films	< 10 % soil

9 Results and findings from the fact sheets

From its inception in 2019, the BioSinn project has met with a very positive response from industry and academic circles. The press release on the project launch was published in numerous print and online media and the call for proposals of applications for which biodegradation is a viable end-of-life option was eagerly received: more than 60 products have been proposed, from which 25 with the greatest potential to reduce macro- and microplastic release into the environment were selected. For nearly all these products, more than one possible substitute has been found and described in detail in the fact sheets. The only exception here is the “dirt eraser”. No suitable substitute for this could be found that completely matches its unique properties and can be used without loss of performance. Further research is needed in this area.

A few results and findings from the fact sheets are highlighted below.

The range of ways by which products enter the environment overlaps for some products and applications, meaning it has been particularly challenging, where it is not possible to predict where a product will end up, to find substitutes which biodegrade in the same way in each environment. This is the case, for instance, with the plastic components in fireworks, which either land on pavements, roads or natural areas or directly in bodies of water.

There is also a difference if a product is only designed for short-term use and should biodegrade according to the standards, or if it should have a long function life and should not biodegrade too rapidly. The certificates considered are all designed for biodegradation after a specific, fixed time and do not take later biodegradation into account. The need for differentiated certificates and standards has been confirmed.

For nearly all the products, we have concluded that policy pathways and frameworks such as legislative amendments can be valuable tools for change. While major issues such as the stream of bio-waste in Germany are already governed by law, there are often gaps or ambiguities which pose obstacles. A positive example of an almost perfectly functioning system of bio-waste is Italy, which has the highest proportion of collected bio-waste and very low rates of contamination of the compost with plastic particles. This is because collection is regulated uniformly throughout the country: Organic waste is permitted to be collected in biodegradable biowaste bags provided by municipalities. The population also receives all the necessary information from a central office – while, at the same time, checks are carried out to ensure that no incorrect bags have been used. The bags provided are accepted by all composting facilities and are not an obstacle to composting, as they are certified to biodegrade within the required timeframe with no residue expected. This has been achieved through close cooperation between politicians, industry and composters (see also the profile on bio-waste bags, section "Biowaste bags" on page 76). Consistent implementation of this kind is a necessary and desirable solution in other countries to address problems in the industrial compost stream.

Many products and applications are little known to the public, including many agricultural applications. This means there is little or no awareness of the problem. This project also aims to raise awareness among the general public. The example of microplastics in cosmetic products is a very good illustration of how public pressure and awareness can lead to changes to the root of the problem. Microplastics in cosmetics are already banned in some countries and are rejected by many consumers.

There is a great deal of potential to avoid the release of plastic into the natural environment in agricultural applications. In the agricultural sector, microplastic particles are systematically introduced into the soil of fields without any possibility of removing them again, though products such als seed coating, for example. Here, agriculture acts as both a source and a reservoir of microplastics. However, much of this could be avoided through tougher legislation and subsidies for environmentally friendly alternatives. Educating farmers and users about the problems of the products they use would also be an important key to initiating a change in thinking.

Chewing gum is a special case in two respects. Firstly, chewing gum often ends up on asphalt, on which biodegradation is very challenging; there are neither suitable certificates nor is it clear whether even the environmentally friendly alternatives actually fully biodegrade. Secondly, chewing gum is a declared foodstuff which surprisingly consists mostly of indigestible material.

The tea bag and coffee capsule applications considered here are very valuable for both industrial compost and home compost. Coffee grounds act as fertiliser and tea grounds are also rich in organic material. The use of biodegradable material for the bags and capsules even increases the value of the compost.

Often products were originally made from natural materials. Examples include agricultural applications such as binding yarn, bristles for road sweepers or chewing gum.

More detailed information can be found in the corresponding fact sheets.

10 Further reading

In the course of our project work and the associated literature research, we have identified a number of studies and reports that deal in detail with aspects of biodegradable plastics. The provide comprehensive detail for the separate parts of and the common thread that runs through the BioSinn project. The following current literature should be given prompt consideration when taking an in-depth look at biodegradable plastics.

10.1 EUNOMIA (2020): Relevance of Biodegradable and Compostable Consumer Plastic Products and Plastic Packaging in a Circular Economy

The EU as a whole is aiming to shift towards a functioning circular economy, where products are reused or recycled before they end up as waste. Biodegradable plastics may contradict this intention, as they directly strive towards "degradation" as an end-of-life-option. Therefore, the EUNOMIA study investigates to what extent biodegradation and compostability of plastics can nevertheless be beneficial for a circular economy.[7]

10.2 SAPEA Science Advice for Policy by European Academics (2020): Biodegradability of plastics in the open environment

The study examines the ways in which the existing regulatory framework, norms, standards and certification schemes are inadequate and in which they are sufficient. The aim is to create a functioning policy framework in the EU and to support this process. This report therefore highlights numerous aspects of biodegradable plastics that are relevant to this goal.[15]

10.3 Thünen Institute (2019): Final report on the project "Bioabbaubare biobasierte Kunststoffe – Handlungsempfehlungen für den Zweckmäßigen Einsatz (Biodegradable bio-based plastics – Recommendations for appropriate use"

This final report presents in detail the current state of knowledge on biodegradation, ecological benefits and potential applications of biodegradable bio-plastics. Two case studies explored the advantages and disadvantages of biodegradable bio-based mulch films for agricultural use and disposable tableware.[16]

15 SAPEA Science Advice for Policy by European Academies 2020: Biodegradability of Plastics in the open Environment. Sapea (Ed.), 14/12/2020. Download at https://ec.europa.eu/info/research-and-innovation/strategy/support-policy-making/scientific-support-eu-policies/group-chief-scientific-advisors/biodegradability-plastics-open-environment_en

16 Johann Heinrich von Thünen-Institut Federal Research Institute for Rural Areas, Forests and Fisheries 2019: Biodegradable bio-based plastics – Recommendations for appropriate use. 01/2020. Download at https://biowerkstoffe.fnr.de/projekte/projektuebersicht/projek-

10.4 Gutachten zur Behandlung biologisch abbaubarer Kunststoffe (Study on the treatment of biodegradable plastics)

The study from the Federal Environment Agency examines the possible uses of biodegradable plastics in three cases: mulch films, biowaste bags and in packaging. The study considers the current market situation for biodegradable plastics, the principles of their degradability and recommends action for optimal recycling in Germany; its focus is mainly on the comparison of different disposal concepts in Europe.

As examples, the different approaches to biodegradable plastics in the waste stream in Germany, Italy, France, the Netherlands and Sweden are considered.[2]

10.5 Wageningen University & Research (2020): The fate of (compostable) plastic products in a full scale industrial organic waste treatment facility

Although certified for industrial composting, plastics often present problems for industrial composting plants. Here, the focus is often on efficiency, which is why the composting times in the plants are too short to allow the plastics to degrade completely. A large-scale trial was carried out to investigate the degradation process in an industrial composting plant and the possible advantages in waste collection and processing when biodegradable plastics are used. Nine different plastic products were considered.[17] Selected materials were found to be highly biodegradable under industrial composting conditions over a period of eleven days. However, the majority of the tested products as well as their reference materials, require a composting time of more than eleven days in industrial compost to ensure complete decomposition.

te-details?fkz=22020716&cHash=e83870c4f20e844f2db4f0707565d344

17 Van der Zee, M. and Molenveld, K. 2020: The fate of (compostable) plastic products in a full scale industrial organic waste treatment facility. Wageningen Food & Biobased Research (Ed.), 02/2020. doi: 10.18174/514397

11 Fact Sheets

Agriculture and Forestry

The fact sheets are sorted by application. The following section contains the fact sheets of products and applications used or deployed in agriculture and forestry.

The market volumes in this area are high and the potential for avoiding plastic release into the environment is enormous. In Germany, approximately 70,000 tonnes of plastic are released into the environment every year. In various agricultural applications, the plastics are spread on arable land and remain in the soil, never to be retrieved. Special aspects are addressed in the respective fact sheets.

Binding Yarn

Microplastics from binding yarn can be avoided

Description

Binding yarn (also known as binder twine, baler twine) is used in agriculture to hold bales of straw, hay or silage in a compressed form. The baled material is mechanically bound with twine in the machine, a baler pulled by a tractor. The yarn is commercially available in various thicknesses on spools weighing up to nine kilograms.

Main material currently used

The main material currently used is polypropylene. The desired composition of the material is very precisely tailored to the baling presses. Even the natural fibre sisal, which was often used for this purpose in the past, is still occasionally used, as far as modern baling presses allow.[1]

Problematic

Within the balers, twine and fibre losses inevitably occur during wrapping and knotting, which then end up on the field and in the environment.[2] Lengths of the material can also end up in the environment if used twines are disposed of improperly.

Over time, the plastic yarns and fibres decompose into microplastics that can no longer be collected. They thus end up in the soil, in animal feed, in wastewater and possibly also in the sea via rivers.

Market volume in Germany / the EU

The market volume of twines in the EU is 80,000 tonnes[3], in Germany about 13,000 tonnes, rounded up.

1 dm-folien 2021: Pressengarne. Last accessed 08/01/2021. https://www.dm-folien.com/shop/seilerwaren/pressengarne

2 Wobser, T. 2019: Großballenpresse: Knoten ohne Garnreste. 11/09/2019. Last accessed 08/01/2021. https://www.wochenblatt.com/landwirtschaft/nachrichten/grossballenpresse-knoten-ohne-garnreste-11809609.html

3 Bosmans, W. 2020: European Policy on bio-based and biodegradable plastics. Presentation at the nova session Circular Economy and Plastic Policy, 29/10/2020, online.

Biodegradable products on the market

Sisal is the traditional material, used to be used frequently as baler twine and is still available (even if it cannot be used on all machines). However, it is about twice the price of the polypropylene alternative. Caution: In some cases, to be able to process the sisal fibres more easily and to increase their durability, they are softened with petroleum, which should not enter the soil.

Policy and regulatory considerations

Since the small plastic particles are produced in the field as the bales are made, the farmer must ensure that the soil is protected against harmful soil changes in accordance with the Federal Soil Protection Regulation. There are no precise definition of harmful substances or detrimental changes to the soil. Nor are there any limits, in the sense of the Federal Soil Protection Regulation, on microplastics in soil. According to the KrWG, the polypropylene twine used must be fed into the recycling cycle.

Other barriers

Price is a significant barrier. Polypropylene baler twine is significantly cheaper than sisal. In addition, sisal twines are not equally suitable for all baling operations: polypropylene twines are better for square bales, high-pressure bales and round bales.[18] Sisal is often too weak for modern machines and cannot be processed well through them, as the material is coarse compared to polypropylene. The pressing process often fails to yield the desired results. The sisal yarn can break during pressing and block the gears.

Technical requirements

The twine must be suitable for different bale shapes and machine types. It must be durable and resistant to storage and weathering. Even after a longer storage period, there must be no safety risk (premature tearing, possible damage to the baler). The tensile strength and stiffness must be high and it must be tear-resistant in the direction of the fibres. However, it must also be able to stretch well. The material must be capable of being processed into yarn (melt spinning). In the baler, the twines run at a high speed over

numerous deflection points, which they have to withstand. Even when the bales have been ready-tied in the field for a while, the twine must continue to meet all requirements. The shreds of yarn that fall to the ground should in turn be rapidly biodegraded.

Relevant standards and certificates

For biodegradability in the soil, which has been identified as the main destination for twines, the corresponding TÜV Austria certificate applies.

Possible substitutes

Sisal is already an available natural alternative. Other natural fibres such as flax or hemp were also used in the past and can in principle be considered, provided they can withstand the requirements of the baler twine.

Technical yarns made of viscose or lyocell can be adapted to many requirement profiles and could therefore be an interesting, biodegradable alternative.

PHB and PHB copolymers would be suitable and could meet the technical requirements after suit-

able modifications or blends within the degradation times in the certificates issued by TÜV Austria or DIN CERTCO .

PLA can only be proven to be compostable within the considered degradation periods set out in the certificates of TÜV Austria or DIN CERTCO under industrial conditions. In nature, the biodegradation of PLA is slower than specified in the certificates – but degradation does takes place. PLA or PLA blends with PBAT or PBS could also meet the technical requirements for baler twines. A composite with a core of sisal and a cover of PLA is also possible, and has already been patented.[4]

Biodegradation can also be promoted by combining the above polymers with organic fillers such as wood flour, natural fibres or even agricultural residues.

Outlook

Even though the quantities of twine and fibre residues entering the environment here are small compared to other applications, it is paradoxically in this sector, agriculture, that such residues of baler twine enter the agricultural process chain of soil, crop and fodder. There are currently no alternatives available on the market other than sisal, which can only be used to a limited extent on modern machines. However, various biodegradable alternatives could be further developed and introduced to the market. As the alternatives are more expensive, accompanying policy measures such as a ban on non-biodegradable fibres in this application would be helpful to generate the necessary demand.

4 Eispert, K., Schönung, T. 2006: Biodegradable binding twine. EP1842944A2.

Flocculant aids

Little-known, particularly heavy ingress of microplastics with high substitution potential

Description

The flocculants aids considered here are used in drinking water and sewage sludge treatment to condition the sludge prior to thickening or draining.

Sewage sludge is a waste product of wastewater treatment in wastewater treatment plants. It consists of water and a number of organic and mineral substances, excluding those removed in screens, sieves and grit traps.[1]

The agricultural use of sewage sludge as fertiliser keeps nutrients in the cycle and adds considerable amounts of organic matter to the soil.

Adsorption, flocculation, precipitation and sedimentation are physical and chemical processes that separate the treated wastewater from the sludge. Coagulants are responsible for primary flocculation. Flocculant aids then cause the flocs to agglomerate into larger flocs that can settle. Polymeric flocculant aids can induce greater flocculation by compensating for the surface charge of particles and forming bridges between individual flocs.[2]

Main material currently used

Synthetic, water-soluble and charged polymers are mainly used as flocculant aids. The predominant polymers currently used are fossil-based polyacrylami-

1 Federal Ministry of Justice and Consumer Protection 2017: Verordnung über die Verwertung von Klärschlamm, Klärschlammgemisch und Klärschlammkompost (Sewage Sludge Regulation – AbfKlärV). 19/06/2020. Download at https://www.gesetze-im-internet.de/abfkl_rv_2017/AbfKlärV.pdf

2 Kreuzinger, N. 2008: Flockungshilfsmittel – Wirkungsweise. Presentation at „KAN Sprechertagung“, 2008, Vienna, Austria.

des (95 %) and acrylamide-acrylic acid copolymers.[6] They can bear a cationic or anionic charge depending on the application and water quality.

Coagulants, on the other hand, can be either organic or inorganic. The most common materials used as coagulants are inorganic salts such as aluminium or ferrous salts.[6] Cationic polyamides may also be used as coagulants.

Problematic

The use of polyacrylamide has come under criticism. Its monomer acrylamide, which may be included in commercial polyacrylamide products, is reported toxic to humans and animals.[3 4]

After use as flocculant aids, synthetic polymers are distributed on the field with sewage sludge fertiliser, accumulate in the soil and passing into plants and seeds. Some may also end up in the groundwater.[5] Polymer residues can presumably be carried with the treated water from the sewage treatment plant into lakes and rivers and thus indirectly into the water supply network. The release of microplastics in agricultural soils amounts to up to 13,000 particles in one kilogram of soil substance, which corresponds to 4.5 milligrams by weight. According to recent evaluations by a German university, the microplastic release from sewage sludge is up to ten times higher than from mulch films.[6]

Market volume in Germany / the EU

The EU market for polyacrylamide is approximately 530,000 tonnes. Drinking water treatment accounts for about 40 % of this (approx. 210,000 tonnes).[7 8 9 10] For Germany, the calculated volume of polyacrylamide as a flocculant in drinking water treatment is about 33,000 tonnes; about 95 % of this remains in sewage sludge and 16,5 % is potentially spread on fields as fertiliser.[11 12] This results in about 5,200 tonnes for Germany and about 33,000 for the European Union.

Biodegradable products on the market

Flocculant aids based on chitosan and starch are available on the market.[13] A flocculant aid made of starch is currently sold by a French producer, albeit

3 Wang, D. 2018: Activated starch as an alternative to polyacrylamide-based polymers for in-line filtration of low turbidity source water. Journal of Water Supply, Vol. 67 (5). doi: 10.2166/aqua.2018.023

4 World Health Organization 2011: Acrylamides in Drinking-water. Last accessed 23/02/2021. https://www.who.int/water_sanitation_health/dwq/chemicals/acrylamide.pdf

5 Umweltbundesamt 2015: Kompost und Klärschlamm. 15/12/2020. Last accessed 23/02/2021. https://www.umweltbundesamt.de/themen/boden-landwirtschaft/umweltbelastungen-der-landwirtschaft/kompost-klaerschlamm#einfuhrung

6 Ronzheimer, M. 2021: Mikroplastik im Boden: Großer Forschungsbedarf. 09/01/2021. Last accessed 2021/04/16. https://taz.de/Mikroplastik-im-Boden/!5742494/

7 Kawaguchi, S. and Hasegawa, S. 2014: Polymer Flocculants. Encyclopedia of Polymeric Nanomaterials. Kobayashi, S and Müllen, K. Springer, (Ed.). Berlin, Heidelberg.

8 http://www.chemplan.ir/chemplan_demo/sample_reports/PAM_Profile.pdf

9 Global Market Insights 2020: Polyacrylamide Market Size By Product (Non-ionic [NPAM], Cationic [CPAM], Anionic [APAM]), By Application (Water Treatment, Petroleum, Paper Making), Industry Analysis Report, Growth Potential, Price Trends, Competitive Market Share & Forecast, 2019 – 2026. 01/2020. Last accessed 23/02/2021. https://www.gminsights.com/industry-analysis/polyacrylamide-market

10 Chemical Economics Handbook 2021: Acrylamides. 01/2021. Last accessed 23/02/2021. https://ihsmarkit.com/products/acrylamide-chemical-economics-handbook.html

11 Guzzo, J. and Guezennec, A. G. 2014: Degradation and transfer of polyacrylamide based flocculent in sludge and industrial and natural waters. Environ Sci Pollut Res (2015) 22:6387-6389. doi: 10.1007/s11356-014-3508-1

12 Destatis 2021: Drei Viertel des kommunalen Klärschlamms wurden 2019 verbrannt, ein Viertel stofflich verwertet. Pressemitteilung Nr. 036. 2021/01/27. Download at https://www.destatis.de/DE/Presse/Pressemitteilungen/2021/01/PD21_036_32214.html

13 Gütegemeinschaft Kompost e. V. 2018: List of permitted materials for the production of quality-assured sewage sludge. Sewage slud-

without an associated certificate for biodegradation in soil. According to the manufacturer, the product is both efficient and cost-effective and is currently used in several water treatment plants in the EU.

Tannin-based coagulants are also available from the same manufacturer. The cost of chitosan-based alternatives is comparatively high, posing an obstacle to their distribution on the market. They are also not yet certified for biological degradation in soil.

Policy and regulatory considerations

The Sewage Sludge Regulation applies here (Klärschlammverordnung – AbfKlarV).[1] The limits set in the Fertiliser Regulation (DüMV)[14] and the Fertiliser Usage Regulation (DüV) apply[15].

According to the DüMV, since 01/01/2019 the amount of synthetic polymer applied in Germany may not exceed 45 kilograms of active substance per hectare within three years. This does not apply to synthetic polymers which degrade by at least 20 % in two years. This shows that biodegradability is considered desirable according to the DüMV, but the benchmark of 20 % degradability in two years is low. It is also unclear which polyacrylamide-based flocculant aids reach this value and are therefore still permitted.

The World Health Organization has conducted a study on acrylamide toxicity, recommending limits of 0.5 g/L acrylamide in drinking water.[4] Some countries in Europe and Asia have already restricted the use of polyacrylamide in water treatment.[16] France, for example, has introduced a legal limit of acrylamide in drinking water of 0.5 g/L, in line with WHO recommendations. This limit can be achieved by controlling the amount of acrylamide in the polyacrylamide and by restricting the use of polyacrylamide.

In the EU to date, only the amount of acrylamide in polyacrylamide for drinking water applications is limited, to 200 ppm (200,000 mg/L).[17] There is no limit for polyacrylamide for industrial water treatment.

Other barriers

There are many reasons why the use of biodegradable alternatives is currently still limited. Firstly, the problems associated with the use of polyacrylamide are not widely known. It can be assumed that farmers are not aware of the spreading of microplastics with the sewage sludge. The current low availability of biodegradable alternatives on the market is another barrier.

Since some of the alternative products are not more expensive, cost is not a barrier. The main barriers are lack of awareness, ignorance of existing alternatives and their poor availability.

Technical requirements

Flocculant aids require a charge to work properly. They can be cationic or anionic, depending on the application and water quality requirements. A substitute must be water-soluble and have a surface charge

ge mixtures and sewage sludge composts. 01/03/2018. Last accessed 01/03/2021. https://www.kompost.de/fileadmin/user_upload/Dateien/Guetesicherung/Dokumente_AS-Humus/Dok._KS-007-1_Verzeichnis_Einsatzstoffe_Klaerschlamm.pdf

14 Federal Ministry of Justice and Consumer Protection 2012: Verordnung über das Inverkehrbringen von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln (Fertiliser Regulation – DüMV). 02/10/2019. Download at https://www.gesetze-im-internet.de/d_mv_2012/DüMV.pdf

15 Federal Ministry of Justice and Consumer Protection 2017: Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis bei Düngen (Fertiliser Regulation – DüV). 26/05/2017. Download at https://www.gesetze-im-internet.de/d_v_2017/DüV.pdf

16 Veolia Water Technologies 2014: Brochure: Floculants biosourcés pour la clarification des eaux potables. 09/2014. Download at http://technomaps.veoliawatertechnologies.com/processes/lib/pdfs/2874,Brochure_A4_Hydrexfloculants_FR_LR.pdf

17 Luecking, I. and Tripard, E. (Veolia) 2020: Personal communication. 21/10/2020

to compensate for the surface charge of the floc. The purpose of coagulants is to initiate flocculation. Flocculant aids then make the flocs heavier by making them larger and denser: They compensate for the surface charge of the particles and form bridges between individual particles.[18]

Relevant standards and certificates

The agricultural use of sewage sludge can be subject to voluntary quality assurance (RAL quality assurance). This refers to soil-related utilisation in accordance with the Sewage Sludge Regulation, whose thresholds are in turn based on the Fertiliser Regulation.[19]

In addition, further relevant certifications are available for this and for the further life cycle of plastics. TÜV Austria issues certificates that cover biodegradability in soil and possibly also in water after agricultural application.

Possible substitutes

Polysaccharides such as chitosan, cellulose or starch can be used as flocculant aids in sewage sludge treatment. Starch or cellulose as a possible substitute must first be modified by functionalisation with cationic or anionic groups.[20] [21] An essential prerequisite here is that the modification of the structure does not

18 PRO-ENTEC Umweltschutz GmbH: Flockungshilfsmittel der POLYFLOC®- und EN-TEC®-Serie. Last accessed 23/02/2021. Download at https://pro-entec.de/wp-content/uploads/sites/4/Flockungshilfsmittel.pdf

19 Bundesgütegemeinschaft Kompost e. V.: Gütesicherung Verwertung von Abwasserschlamm. Last accessed 18/01/2021. https://www.kompost.de/guetesicherung/guetesicherung-verwertung-von-abwasserschlamm

20 ScienceDirect 2021: Flocculants. Last accessed 18/01/2021. https://www.sciencedirect.com/topics/engineering/flocculants

21 Koshani, R., Tavakolian, M. und van de Ven, T. G. M. 2020: Cellulose-based dispersants and flocculants. Journal of Materials Chemistry B, Vol. 8 (46), 10502-10526. doi: 10.1039/D0TB02021D

change biodegradability. Chitosan (made from chitin) is a cationic polysaccharide and meets the technical requirements for this application. It is a suitable flocculant that is already being used on a trial basis in drinking water treatment in China and is able to absorb heavy metal ions.[22 23] Large volumes of chitin is produced in the crab industry in the form of inedible shells, whose use has been limited to date.

Canadian and Chinese researchers were able to show in experiments that modified cationic lignin polymers could be successfully used as flocculant aids for inorganic colloidal particles.[24] PHB and copolymers can also be used in wastewater treatment to denitrify water.[25]

Outlook

The large total volume of this product suggests great potential to prevent plastic release into the natural environment. The release of microplastics via this pathway is significantly greater than the release of microplastics in cosmetics and care products or mulch films, only the input via this pathway is lesser known. In addition, the release of acrylamide into the environment and drinking water is a major concern, as this chemical is toxic. As good biodegradable alternatives are available, they should be popularised and made rapidly available on the market – accompanied by appropriate education campaigns in agriculture and sewage treatment plants, market introduction programmes or bans on polymers that do not biodegrade in soil.

22 Kangama, A., Zeng, D., Tian, X. und Fang, J. 2018: Application of Chitosan Composite Flocculant in Tap Water Treatment. Journal of Chemistry, Vol. 2018 (2), 1-9. doi: 10.1155/2018/2768474

23 http://www.wasser-wissen.de: Chitin, chitosan. Last accessed 18/01/2021. http://wasser-wissen.de/abwasserlexikon/c/chitosan.htm

24 Hasan, A. and Fatehi, P. 2019: Flocculation of kaolin particles with cationic lignin polymers. Scientific reports, Vol. 9 (2672). doi: 10.1038/s41598-019-39135-z

25 Ravenstijn, J. (GO!PHA) 2020: Personal communication. 30/07/2020

Plant fixing clips

High risk of entry into bio-waste and the environment –
easy to substitute with biodegradable plastics and biocomposites

Description

In viticulture, horticulture, tree nurseries and also in private gardens, plant fixing clips are used to define the direction of growth of plants, trees or individual branches and twigs.

Main material currently used

The most commonly used material is polypropylene.

Problematic

As practical and useful as plant fixing clips are for growing fruit, vegetables and wine – which is why they are so prolifically used – they cause problems after the harvest when disposing of leaves and stalks. When used in the cultivation of fruit and vegetables in greenhouses, the clips enter the organic waste stream, can only be removed with great effort, and in practice end up in composting and biogas plants. This means that the compost is contaminated with plastic clips and chippings from them.

When used outdoors, especially in viticulture, the clips enter the soil directly and thus escape into the environment. The level of care taken and machine equipment determines how many of these clips are collected; the rest remain permanently in the natural environment.

Market volume in Germany / the EU

The market volume in Europe is approximately 13,000 tonnes per year and approximately 2,000 tonnes for Germany. The calculation is based on a total global volume of plant fixing clips and support structures of 190,000 tonnes[1], 7 % of which is attributed to the EU, of which 16 % is calculated for Germany.

1 Eurostat database Prodcom 2021. Last accessed 21/01/2021. https://ec.europa.eu/eurostat/de/web/main/data/database

Biodegradable products on the market

Various plant fixing clips made of biodegradable plastics are available, some of which are biocomposites in combination with wood flour, wood or plant fibres or sunflower seed hulls. However, the products often lack biodegradation certification and it remains unclear whether they only degrade in industrial compost, in home compost or also in the soil. As these products end up in different waste streams, the lack of clear certification or labelling is a major weakness. One manufacturer offers a compound based on PHB or PHB copolymers with fillers, which is suitable for the production of plant fixing clips and is “OK Biodegradable SOIL” certified.

Policy and regulatory considerations

There are no regulations governing the use of plant fixing clips in the commercial cultivation of, for example, wine[2], fruit and vegetables. The Federal Soil Protection Act contains guidelines for agricultural practice from which it can be deduced that no plastic residues should be left in the soil, as good professional practice must ensure that soil quality is maintained.[3] According to BioAbfV, Annex 1, the disposal of biodegradable plastics from agriculture, horticulture, pond management, forestry, hunting and fishing is permitted in organic waste as long as the materials are certified according to DIN EN 13432. Covering foils are mentioned as an example. Since DIN EN 13432 is actually only applicable to packaging materials, it is not clear whether it is possible to dispose of the fastening clips in organic waste. This would require collection, thus not solving one of the main problems; at least, however, heavy contamination by soil and plant residues, which reduce the calorific value of non-recyclable waste, would not be a problem for composting.

Other barriers

The main barriers to greater market penetration are awareness and price. As there are only a few suppliers on the market so far, awareness of the products is limited, although horticulturalists are generally open to environmentally-friendly products and are also prepared to pay a higher price.[4] However, as these cost considerably more than standard products due to the more expensive materials and the small production volume, a hurdle remains for mass markets.

Technical requirements

The plant fixing clips must be weather resistant (UV, H_2O, heat, frost). Depending on the design, they must either have moderate stiffness or pronounced ductility so that they bend but do not break. They must also be impact resistant for when the farmer or wine grower drives a mower through the rows. Stress relaxation must take place as slowly as possible. The demands on the manufacturing process (injection moulding) for this mass-produced item are low, as plant fixing clips do not have a complicated geometries.

2 Federal Ministry of Justice and Consumer Protection 1994: Weingesetz (wine law). 08/07/1994. Download at https://www.gesetze-im-internet.de/weing_1994/

3 Federal Ministry of Justice and Consumer Protection 1998: Gesetz zum Schutz vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten (Federal Soil Protection Act – BbodSchG). 17/03/1998. Download at http://www.gesetze-im-internet.de/bbodschg/__17.html

4 Trumme, R. (Golden Compound) 2020: Personal communication. 24/06/2020

Relevant standards and certificates

The standards DIN EN 14995 and DIN EN 13432 are relevant for the clips. Certifications from TÜV Austria as well as DIN CERTCO can be applied here based on these standards.

Possible substitutes

PLA or PLA blends with PBAS, PBAT or PBS could meet the technical requirements for plant fixing clips.

Certified biodegradable plant fixing clips made of PLA and PLA blends are suitable if they end up in industrial compost, e. g. in greenhouse applications in fruit and vegetable cultivation.

When used outdoors, the clips remain on the on the ground and must biodegrade under the soil conditions. A number of biodegradable copolyesters such as PBAT, PBSA and PHB and PHB copolymers can be used here, as mixtures or as blends with starch. Biodegradation can also be promoted by combining the above polymers with organic fillers such as wood flour, natural fibres or even agricultural residues.

PLA can only be proven to be compostable within the considered degradation periods set out in the certificates of TÜV Austria or DIN CERTCO under industrial conditions. However, PLA will also biodegrade in soil in the long term – just not in the time specified in the certificates.

Outlook

Plant fixing clips are a promising application for biodegradable plastics: Relevant market volume, high technical feasibility and high risk of clips remaining at least partially in organic waste or soil. A high level of social and political acceptance can be expected. Due to the higher prices, accompanying measures ranging from information to bans on non-biodegradable clips in certain applications would be recommended to boost market share.

Control-release carrier substances for fertilisers and plant protection (pesticides), fertiliser additives

Non-biodegradable carrier polymers are a relevant problem that could easily be solved technically – and will probably have to be solved soon due to new legislation.

Description

Synthetic pesticides, first used in 1930, became widely used after World War II for higher agricultural yields. Controlled release technology for pesticides and fertilisers has proven its value as a tool to reduce the problems caused by direct release (excessive concentration of active substances that are harmful to plants, animals and humans).[1]

The controlled release of fertilisers or pesticides, for example, uses the special chemical and physical properties of coatings or capsules to slow the release of nitrogen into the soil. These are produced by forming a protective layer around conventional soluble fertilisers or pesticides or by encapsulation. In this way, water ingress and the dissolution rate can be controlled; nutrient release, e. g. nitrogen availability, can be better synchronised with plant demand; and pesticides can be applied at the right time.[2 3]

Microcapsules and coated granules for controlled release are available. Much of the research and development in this field is focused on microcapsules. In a microcapsule, an active ingredient is surrounded

1 Silva, V., Mol, H. G. J., Zomer, P., Tienstra, M., Ritsema, C. J., and Geissen, V. 2019: Pesticide residues in European agricultural soils – A hidden reality unfolded. Sci Total Environ, Vol. 653 1532-1545. doi: 10.1016/j.scitotenv.2018.10.441

2 Trenkel, M. E. 2010: Slow- and Controlled-Release and Stabilized Fertilizers: An Option for Enhancing Nutrient Use Efficiency in Agriculture. International fertiliser Industry Association (IFA) (Ed.), 2010. Download at https://www.fertiliser.org/images/Library_Downloads/2010_Trenkel_slow release book.pdf

3 Hasinoff, M. 2018: Pursell Agri-Tech. Presentation at "1st PHA platform World Congress", 05/09/2018, Cologne, Germany.

in the core by a shell or membrane. The polymer layer or polymer cover also improves the handling safety of fertilisers and pesticides.[4]

Main material currently used

Controlled-release microcapsule formulations typically contain several types of binders mixed together. Both natural polymers, which are biodegradable, and fossil polymers, which are not, are used. Unfortunately, the ratio is not known. Suitable natural polymers for control-release carrier substances for fertiliser additives include polysaccharides such as cellulose, alginates, starch or chitosan and proteins such as gelatine and albumin. The most commonly used fossil polymers are polystyrene, polyacrylamide, polymethacrylate, polyamides, polyesters, polyurethanes, polyvinylpyrrolidone, polyvinylidene chloride, polyethylene and polycyanoacrylate, and formaldehyde resins. Waxes and anti-caking agents are also used. Inorganic materials such as sulphur, silicon oxide or bentonite can also be mixed into the coating.[3] The type of coating depends on the type of pesticide or fertiliser and where it is to be released.

Problematic

The original purpose of controlled-release fertilisers or pesticides was to limit the accumulation of environmentally harmful active substances in soil, water and food and to significantly reduce environmental risks through controlled release and nutrient application.[5]

Unfortunately, in many cases non-biodegradable polymers are used as coatings or microcapsules. These pose an environmental problem because microplastics are released into the environment and subsequently remain in the soil and water, where they accumulate. A formulation made with environmentally compatible and biodegradable coating materials is therefore required from an environmental point of view.[6]

Market volume in Germany / the EU

The market volume amounts to 9,000 to 10,000 tonnes per year in the European Union,[7] making the volume attributable to Germany is about 1,600 tonnes.

Biodegradable products on the market

Controlled-release microcapsule formulations typically contain several types of the binders mentioned above, but to date we have been unable to find a product on the market that contains only biodegradable alternatives.

A Dutch company has recently released a new excipient for fertilisers and pesticides which claims to be biodegradable, but no certificate could be found. The excipient is used to increase the compatibility of the different components of the formulation.[8]

Policy and regulatory considerations

According to the Federal Soil Protection Act, it is generally the responsibility of farmers to keep the soil free of harmful substances.

In early 2019, the European Chemicals Agency (ECHA) published its first proposals to restrict the use of intentionally added microplastic particles in products. Because of the “direct and unfiltered emission

4 Roy, A., Singh, S., Bajpai, J. and Bajpai, A. 2014: Controlled pesticide release from biodegradable polymers. Open Chemistry, Vol. 12 (4), 453-469. doi: 10.2478/s11532-013-0405-2

5 Shaviv, A. 2001: Advances in controlled-release fertilisers. Advances in Agronomy, Vol. 71 1-49. doi: 10.1016/s0065-2113(01)71011-5

6 ScienceDirect 2021: Controlled-Release Fertiliser. 18/12/2020. Last accessed 18/12/2020. https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/controlled-release-fertiliser

7 European Chemicals Agency 2019: ANNEX XV RESTRICTION REPORT PROPOSAL FOR A RESTRICTION. European Chemicals Agency (ECHA) (Ed.), 22/08/2019. Download at https://echa.europa.eu/documents/10162/05bd96e3-b969-0a7c-c6d0-441182893720

8 Il Bioeconomista 2020: Nouryon introduced a sustainable adjuvant for the global agricultural market. 18/12/2020. Last accessed 18/12/2020. https://ilbioeconomista.com/2020/11/19/nouryon-introduced-a-sustainable-adjuvant-for-the-global-agricultural-market/

of microplastics", this includes non-biodegradable carrier polymers used as fertiliser additives or to control the release of fertilisers. To date, however, no final statement has been issued, let alone implementation of these ECHA recommendations in line with the REACH Regulation. If these recommendations were to be fully implemented, biodegradable products would therefore be mandatory.

In addition to this, according to the DüMV, since 01/01/2019 the amount of synthetic polymer applied in Germany may not exceed 45 kilograms of active substance per hectare within three years. This does not apply to synthetic polymers which degrade by at least 20 % in two years. Conversely, this means that biodegradability is not required, provided the limit of 45 kg per hectare is not exceeded in three years.[9] This shows that biodegradability is considered desirable according to the DüMV, but the benchmark of 20 % degradability in two years is low. It is also unclear which and how many of the crop protection applications with carrier polymers attain this value.

Other barriers

Farmers tend not to be aware of the composition of fertiliser and pesticide substances. Sometimes there is simply a lack of alternatives on the market.

Moreover, the topic has so far played only a subordinate role in public discussions on microplastics, and so public "pressure" is correspondingly low.

Technical requirements

Depending on the active ingredients and environmental conditions, different carrier polymers can be applied for the controlled release for fertilisers or pesticides, and so the technical requirements may vary depending on the application.

In general, polymers must be compatible with active ingredients. They must have a moderate permeability to water.

9 Bundesgütegemeinschaft Kompost e. V. 2018: Verzeichnis zulässiger Zusatzstoffe für die Herstellung gütegesicherter Klärschlämme, Klärschlammgemische und Klärschlammkomposte. 01/03/2018. Download at https://www.kompost.de/fileadmin/user_upload/Dateien/Guetesicherung/Dokumente_AS-Humus/Dok._KS-007-1_Verzeichnis_Einsatzstoffe_Klaerschlamm.pdf

The coating must exhibit abrasion resistance, ductility and resistance to weathering (heat, cold, water, UV radiation, etc.) to prevent premature cracking. The carrier polymers must also ensure a constant flow of active ingredient for the required period of time. Once their purpose is fulfilled, the alternative carrier substances for control-release carrier substances for fertiliser additives should biodegrade within a few months. The fertility of the soil, the purity of the groundwater and the quality of the harvest must not be impaired.

Relevant standards and certificates

As controlled release carrier polymers are mainly used in agricultural pesticides and fertilisers, biodegradability in soil under natural conditions is crucial for this application. The relevant certificates are also vital.

Possible substitutes

Starch or cellulose-based materials are interesting alternatives for controlled-release fertiliser and pesticide carriers, but these polymers may require some modifications in the coating design due to their hydrophilic properties.[5] Starch can also be an alternative when blended with synthetic biodegradable polymers such as PBAT or PCL. Natural polysaccharides such as agar, alginates or pectin are potential substitutes for encapsulation, as are the proteins gelatine and albumin.[3]

Chitin and chitosan are also non-toxic, biodegradable polysaccharides. Chitosan is extracted from chitin, the main component of the structure of some fungal cell walls and shrimp and crab shells. Chitosan is a carbon source for soil microbes and helps roots absorb nutrients. It can be used safely as a carrier polymer for fertilisers and pesticides.[5]

PHB or PHB copolymers can meet the technical requirements and act as a source of nutrients for plants. A study has proven that a formulation containing P3HB as a carrier polymer for fertilisers has an additional beneficial effect on the microbial community in the soil.[10]

Recently, German researchers published research results on the use of a PLA foam as a material for encapsulating urea fertilisers.[11] PLA is proven only to be industrially compostable within the degradation periods specified in the certificates of TÜV Austria or DIN CERTCO. However, PLA biodegrades in the soil over a long period of time.

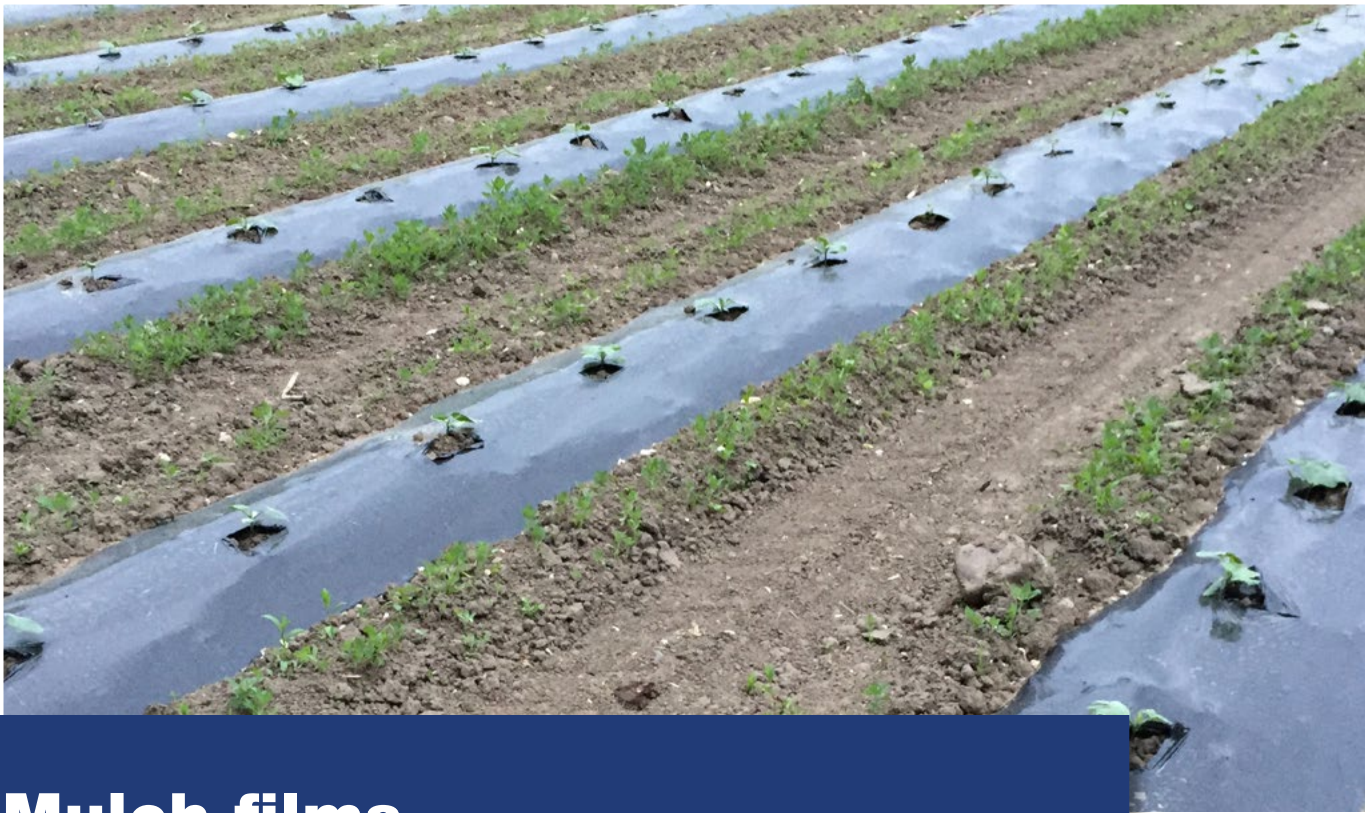
Various carrier polymer formulations for the market could be developed from these numerous biodegradable substitutes.

Outlook

The release of microplastics into agricultural soils could be significantly reduced by biodegradable carrier substances.
A variety of solutions are already available to the problem of finding environmentally-friendly carrier polymers for control-release carrier substances for fertiliser additives. Due to the expected restrictions arising from the recommendations of the European Chemicals Agency (ECHA), biodegradable substitutes will probably soon be required.

10 Volova, T. G., Prudnikova, S. V. and Boyandin, A. 2016: Biodegradable poly-3-hydroxybutyrate as a fertiliser carrier. Journal of the Science of Food and Agriculture, Vol. 96 (12), 4183-4193. doi: 10.1002/jsfa.7621

11 Ruhr University Bochum 2020: Controlled release of fertiliser using biopolymer chips. Press Release, 14/10/2020. Download at https://news.rub.de/english/press-releases/2020-10-14-environmental-technology-controlled-release-fertiliser-using-biopolymer-chips



Mulch films

Ecologically sensible solution, market barrier is the price

Description

Mulch films are used in agriculture to cover beds or arable land to protect crops against competition from weeds, to reduce evaporation of moisture from the soil and, where necessary, to protect plants against being dirtied by the soil, e. g. lettuce during heavy rainfall.

They are mostly used for vegetables, strawberries, in corn or rice cultivation or also in cutting propagation. Different types of mulch films (black, white, translucent) are used to achieve different effects. Films up to 25 micrometres (µm) are considered here, as thicker films can be reused.

Main material currently used

Conventional mulch films, which dominate the field of use with over 95 % market share, are based on polyethylene, typically 20 to 50 microns thick and designed to last from a few months to some years.

Since the early 2000s, biodegradable variants have also been on the market; these consist of starch or PLA blends, such as mixtures of PLA and PBAT or starch and PBAT-like copolyesters.[1]

Problematic

After their use, the conventional PE mulch films are removed from the soil and, in the process, film

1 Leibniz Institut DSMZ – Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH 2020: Bakterielle Arbeitsteilung beim Abbau von Plastik. 18/11/2020. Last accessed 21/01/2021. https://www.chemie.de/news/1168715/bakterielle-arbeitsteilung-beim-abbau-von-plastik.html?WT.mc_id=ca0065

residues remain on the field, especially in the case of thin mulch films, which break down into smaller and smaller pieces over time and eventually, after years, become microplastics. The thinner the film, the greater the environmental damage to it by environmental influences before it can be removed. The annual use of mulch films leads to an accumulation of plastics in the arable soil which can significantly affect soil quality. Plastic particles are also released into the crop.

Another problem with the removal of mulch films from the field is soil entrainment, which leads to soil loss (approx. 1.2 % of the organic content per year), increases the transport weight and makes the recycling of the films more difficult, as they have to be washed beforehand.

In recent years, the disposal of PE mulch films has become more difficult and more expensive. In individual cases, disposal companies have even refused to accept heavily soiled films. Thin, soiled films are are currently rarely recycled.

Market volume in Germany / the EU

The use of agricultural films for greenhouses, silage and mulch films, for example, is increasing rapidly worldwide. A study commissioned by the European Commission gives a figure of 83,000 tonnes for the EU.[2] [3] This adds up to about 13,000 tonnes for Germany (rounded off).

Biodegradable products on the market

There are various products from various producers on the market, most of which are certified by DIN CERTCO or TÜV Austria to confirm they biodegrade in soil. While the market share of biodegradable mulch films in Germany is only 1 to 2 %, in China they are already widely used.[4]

Policy and regulatory considerations

It is clear that collected mulch films cause problems with recycling, as described above. In these cases it is not unthinkable to let them be disposed of as organic waste. According to the Regulation on Bio-Wastes, plastic waste from agriculture is permitted in bio-waste if it is certified according to DIN EN 13432 or DIN EN 14995.[5] Covering foils are explicitly mentioned as permissible.

Interestingly, however, the BioAbfV actually goes one step further. The materials are exempt from the treatment and testing obligations pursuant to Section 10 (1) Nos. 1 and 2 if they are incorporated into the soil at the collection point. Under a strict interpretation, this would mean that said cover films, which only have to prove degradability in industrial compost, can legally be buried in the ground – where their degradability has not been proven.

Other barriers

The main barrier is the higher price of biodegradable mulch films. This is about 1.5 to three times the price of conventional mulch films.[3] However, this is actually balanced out by the considerably lower labour and disposal costs incurred. An FNR-funded project has developed a mulch film calculator which can be downloaded online and can be used by any farm to compare the costs of using biodegradable mulch

2 Hilton, M., Geest Jakobsen, L., Hann, S., Favoino, E., Molteno, and Scholes, R. 2020: Relevance of Biodegradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy. Directorate-General for Environment (European Commission), Eunomia (Ed.), 03/04/2020. doi: 10.2779/497376

3 Bosmans, W. (European Commission – DG Environment) 2020: European Policy on bio-based and biodegradable plastics. Presentation at the nova session Circular Economy and Plastic Policy, 29/10/2020, online.

4 Schlegel, K. (BASF) 2020: Personal communication. 08/07/2020, 06/11/2020

5 Federal Ministry of Justice and Consumer Protection and Federal Office of Justice 2017: Verordnung über die Verwertung von Bioabfällen auf landwirtschaftlich, forstwirtschaftlich und gärtnerisch genutzten Böden (Regulation on Bio-Wastes – Bioabfallverordnung – BioAbfV) 27/09/2017. Download at https://www.gesetze-im-internet.de/bioabfv/BioAbfV.pdf

films with those of PE films. However, the calculator does not factor in the follow-up costs of the pollution of arable soils through microplastics from PE film residues.[6]

Technical requirements

The films need guaranteed resistance to UV, H_2O, heat, frost and fertiliser for a certain period of time, as well as the property of being a good water vapour barrier. They must be toxicologically safe. They are manufactured by blown film extrusion and must feature elasticity, toughness, thermal stability, high viscosity and melt strength. They must not be too stiff, as they must be unrolled. The film is laid under tension. It must be elastic, tear-resistant and stretchable. The product life must be modifiable according to requirements: from a few weeks to a few months. Even with biodegradable films, an accumulation of particles that may remain in the soil over a longer period of time must be avoided. It must be possible to remove the films even at low temperatures.

Relevant standards and certificates

The standard DIN EN 17033 (Biodegradable mulch films for use in agriculture and horticulture) explicitly defines the requirements and test methods for biodegradable mulch films used in agriculture. DIN CERTCO certifies mulch films according to this standard. TÜV Austria has also issued certificates for the industrial compostability of plastics based on the DIN EN 13432 standard, which may also be relevant for mulch films if they are disposed of in the bio-waste stream. A certificate for degradation in soil is also available from TÜV Austria; this can also apply to mulch films. The standards and certificates are detailed in the general section (section 5).

6 Weihenstephan-Triesdorf University of Applied Sciences 2009: Mulchfolienrechner. Last accessed 21/01/2021. Download at https://www.gartenbausoftware.de/mulchfolienrechner.html

Possible substitutes

PLA blends, starch blends or even PHB and PHB copolymers can be blended with soil-biodegradable polyesters such as PCL, PBAT, PBSA, PBS or PBST to achieve the required properties. The biodegradability of these materials in arable soil in various climates has been proven and they also fulfil all technical requirements. In particular, mulch films made from PLA-PBAT blends are already available on the market, as are those made from starch blends. A product made of paper has also been developed.[7] A mixture of natural fibres and biodegradable plastics is also feasible.

German researchers recently published a study in which a blend containing nearly 70 % PHBV (polyhydroxybutyrate-co-hydroxyvalerate) and a smaller percentage of PLA with a biodegradable plasticiser was developed. The plasticiser is an acetyl tributyl citrate. It has been shown that the blend processes well in blown film extrusion and that the plasticiser does not affect degradability.[8]

By changing the formulation, the biodegradation rate of the materials can be roughly “adjusted”, e. g. set to four weeks or three months.[9]

Outlook

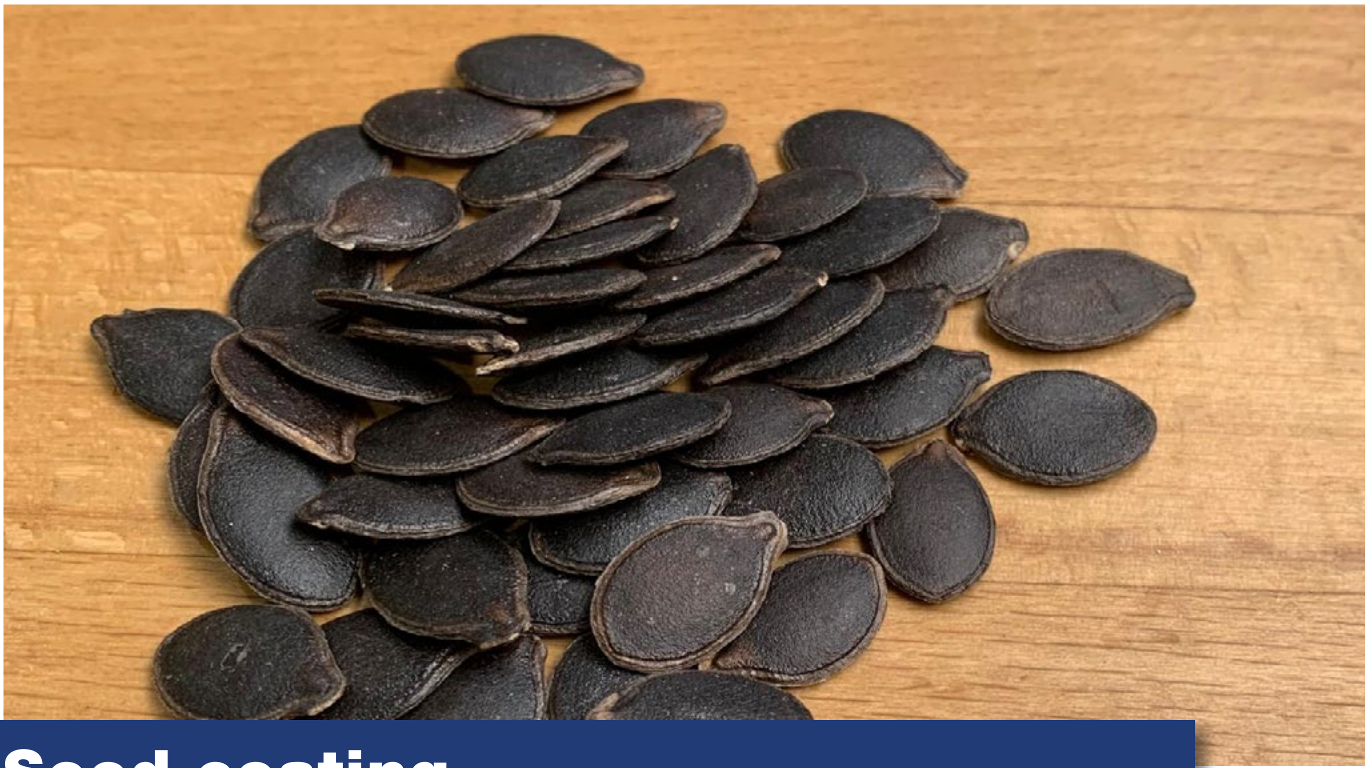
Biodegradable mulch films are a very useful product, with considerable ecological advantages. They are technically feasible and already available on the market, but unfortunately only hold a share of less than 5 % in a rather large and rapidly growing market. Measures to boost their market share would therefore be welcome. Since biodegradable mulch films are more expensive than PE films, their market share will not grow without awareness campaigns, market incentives, and even bans on non-degradable films. A high level of social acceptance can be expected for these measures. The iMulch project is contributing to research on this topic. [10]

7 avr – Nonwovens & Technical Textiles 2017: Neues, biologisch abbaubares Mulchpapier. 05/2017

8 Kunststoffe 2020: Bioabbaubar trotz Additiven. 09/2020

9 K-Zeitung 2012: Lebensdauer nach Wunsch. 43rd edition, No. 12, 22/06/2012

10 http://imulch.eu/projektdetails/



Seed coating

Unnecessary release of microplastics into arable soils can be avoided

Description

Seed coatings are materials applied to the surface of natural seed shells. This process is used to standardise the weight and size of the seed, to provide protection and improve germination. The seed coating may contain active ingredients such as fungicides, pesticides, protectants, nutrients or suitable mycorrhizal fungi[1] that are released after sowing.

The structural materials used in seed coatings are categorised as binders, fillers and active ingredients. Binders are polymers that provide adhesion and cohesion of the material to the seed and retention of active ingredients. Seed coatings are usually applied in liquid form; after drying, a continuous film forms surrounding the seed, the particles and the chemicals to be bound to it.

The properties of the various fillers in combination with the binders offer a wide range of possible mechanical and biological properties for coatings. In some cases, the change in seed morphology is minimal, but for morphologically uneven seeds, a thicker coat is often applied to reduce friction and improve flow.[2]

Main material currently used

In most cases, the seed coating consists of several components. The specific composition, i. e. the type of binder, is not usually disclosed. However, the most

1 Humintech: Schutzimpfung für Ackerpflanzen – mit Mykorrhiza-Pilzen die Ernste sichern. Last accessed 12/03/2021. https://www.humintech.com/de/agrarwirtschaft/blog/schutzimpfung-fuer-ackerpflanzen-mit-mykorrhiza-pilzen-die-ernte-sichern

2 Pedrini, S., Merritt, D. J., Stevens, J. and Dixon, K. 2017: Seed Coating: Science or Marketing Spin? Trends Plant Sci, Vol. 22 (2), 106-116. doi: 10.1016/j.tplants.2016.11.002

commonly used binders are polymers, most of which are of synthetic origin and non-biodegradable, such as polyvinyl alcohol (the ability of PVOH to fully biodegrade is under debate, more details are given in the fact sheet "packaging film for dishwasher tabs"), polyvinyl acetate, polystyrene and polyacrylate. More rarely, polymers of natural origin such as methyl cellulose, ethyl cellulose, chitosan, gum arabic and starch are also used. Mixtures of natural and synthetic ingredients are also available.

Inert powders such as bentonite, calcium carbonate, talc, diatomaceous earth, sand and wood dust are usually used as fillers. The active ingredients may be nutrients, fungicides, pesticides, etc.[1]

Problematic

The seed coating generally contains synthetic plastics that do not biodegrade in the soil. They remain permanently in the soil as microplastics. They can enter our food chain through both soil and water.

Market volume in Germany / the EU

According to ECHA (European Chemicals Agency), the market volume in the EU is around 250 to 1000 tonnes per year.[3] For Germany a share of about 100 tonnes is assumed based on the EU average of about 600 tonnes.

Biodegradable products on the market

Natural and biodegradable alternatives made from chitosan, cellulose and starch are already available and being used. A manufacturer from the Netherlands offers a bio-based and biodegradable starch-based seed coating. However, the product is not certified for biodegradation in soil. Another manufacturer advertises a microplastic-free seed coating, also without a certificate. A Swiss company has filed a patent for a seed coating containing cellulose and starch. However, the actual composition is not disclosed and other types of non-biodegradable polymers listed above could be part of the formulation.[4]

Policy and regulatory considerations

According to the Federal Soil Protection Act, the farmer is fundamentally responsible for keeping the soil free of harmful substances.

In early 2019, ECHA published its first proposals to restrict the use of intentionally added microplastic particles in products. This also affects non-biodegradable seed coatings because of the "direct and unfiltered emission of microplastics".

Other barriers

Lack of awareness and knowledge among farmers about the non-biodegradable polymers used in seed coating, which later remains in the soil as microplastics, is a barrier. The problem is also not very visible and the consequences are not directly apparent, so this application receives little attention in the public discussion on microplastics. Nevertheless, more research and development are taking place in this area, spurred on by the pending restrictions imposed by ECHA.

Technical requirements

Depending on the seed, different polymer layers can be applied, some of which serve as carriers of active ingredients and others as buffers to prevent direct contact between the "active layers" and the seed, the external environment or other active layers. Therefore, the technical requirements may vary depending on the layer.

Generally, binders and fillers must be compatible with both active ingredients and the seed shell and should have a positive impact on the germination and growth of a seed. They must be medium water permeable.[1]

3 European Chemicals Agency 2019: ANNEX XV RESTRICTION REPORT PROPOSAL FOR A RESTRICTION. European Chemicals Agency (ECHA) (Ed.), 22/08/2019. Download at https://echa.europa.eu/documents/10162/05bd96e3-b969-0a7c-c6d0-441182893720

4 Turnblad, K. M. and Ang Chen, Y. 1996: Insecticidal seed coating. US5849320A.

The coating must be easy to process, adhere well to the seed and have a fast drying time. The coating must also have a certain level of abrasion resistance, ductility and weather resistance to prevent premature cracking and chipping.[5] Biodegradation must not start before the coating has done its job (see page 59 describing the application).

Standards and certificates

Since coated seeds are mainly used in agriculture, biodegradation in soil under natural conditions is the key factor. The corresponding certificate from TÜV Austria can be consulted.

Possible substitutes

Biodegradable alternatives based on starch, chitosan and cellulose are already available and are good biodegradable alternatives. Other biodegradable polyesters such as PBAT or PBSA or PCL could also meet the technical requirements.

One study demonstrated that microbial strains added to a bio-based and biodegradable seed coating can increase the rate of degradation in soil.[6]

PHB or PHB copolymers could also meet the technical requirements of binders in seed coatings while also serving as nutrients for the plants. A study has demonstrated that a formulation with P3HB as a carrier polymer for fertilisers has an additional beneficial effect on the microbial community in the soil, something which could also be suitable for seed coating.[7]

Recently, German researchers published their research results on the use of a PLA foam as a material to encapsulate urea fertilisers, which could theoreti-

5 Hasinoff, M. 2018: Pursell Agri-Tech. Presentation at "1st PHA platform World Congress", 05/09/2018, Cologne, Germany.

6 Accinelli, C., Abbas, H. K., Shier, W. T., Vicari, A., Little, N. S., Aloise, M. R., and Giacomini, S. 2019: Degradation of microplastic seed film-coating fragments in soil. Chemosphere, Vol. 226 645-650. doi: 10.1016/j.chemosphere.2019.03.161

7 Volova, T. G., Prudnikova, S. V. and Boyandin, A. 2016: Biodegradable poly-3-hydroxybutyrate as a fertiliser carrier. Journal of the Science of Food and Agriculture, Vol. 96 (12), 4183-4193. doi: 10.1002/jsfa.7621

cally also be suitable for seed coating.[8] PLA is only proven to be industrially compostable within the degradation periods required in the certificates of TÜV Austria or DIN CERTCO. However, PLA biodegrades in the soil over a long period of time.

Various seed coating formulations for the market could be developed from these numerous biodegradable substitutes.

Outlook

More attention should be paid to the problems of this application with regard to the introduction of microplastics into agricultural soils, especially since the first alternatives are already available on the market. It is hoped that rules for intentionally added plastics in seed coatings will soon be adopted in REACH (see section 7.3), based on ECHA's proposals. In this case, the use of biodegradable polymers might even be mandatory in the future.

8 Ruhr University Bochum 2020: Controlled release of fertiliser using biopolymer chips. RUB Press release, 14/10/2020. Download at https://news.rub.de/english/press-releases/2020-10-14-environmental-technology-controlled-release-fertiliser-using-biopolymer-chips

Leg bands for birds and wild animals

Good solutions for poultry farming

Description

The ringing of birds is one of the most important methods of bird research. It allows individual birds to be identified and their whereabouts and behaviour to be studied across a wide area and over a long period – an indispensable tool in species and nature conservation, which can provide information about the population developments and migration behaviour of the animals.

Other applications include the ringing of urban pigeons, show animals and pets, and poultry breeding.

Main material currently used

The majority (over 90 %) of the classic ringing material for wild birds is aluminium[1] ranging from various aluminium alloys to stainless steel[2]. The other proportion of the rings applied to wild birds for individual identification is made of plastics such as PVC, PMMA, PP, POM, ABS, celluloid and elastomers such as natural rubber. Rings made of plastic-aluminium composites are also available.

Problematic

The ringing of breeding stock, racing pigeons, wild birds and pets is a way by which metals and plas-

1 Neuling, E. (NABU) 2020: Personal communication. 22/06/2020

2 Herrmann, C. (Landeszentrale für Umwelt, Naturschutz und Geologie MV – Beringungszentrale Hiddensee) 2020: Personal communication. 29/06/2020

tics are released into the environment. Pets such as parrots or canaries may be buried with their plastic rings, allowing their release into the soil. For wild animals, the rings remain in the nature at their end of life. Since wild birds do not respect national borders, ringing must be coordinated across countries.[3] In poultry farming, the rings can end up in the compost or biogas plant.

However, leg bands for birds and wild animals on wild birds should usually be recovered (if the birds are recaptured or found dead) and evaluated. To ensure retrievability over a certain period of time, a possible substitute should degrade slowly but leave no persistent microplastic behind. In fact, only just under 2 % of leg bands for birds and wild animals are recovered for research purposes; 98 % remain in the wild.

Market volume in Germany / the EU

In Europe, around four million wild birds are ringed each year.[2] For the EU28 this corresponds to approximately 2.7 million (67 %) ringed wild birds, which is equivalent to approximately 13 tonnes of material (at five grams per ring). In poultry farming, ringing of 10 % of the birds (7.5 billion birds in total in the EU per year[4]) is assumed. This results in a total ring volume of about 3,700 tonnes of material in the EU and about 600 tonnes in Germany.

Biodegradable products on the market

During the research, a cellulose-based product was uncovered. However, the manufacturer does not provide any information on possible biodegradability.

Policy and regulatory considerations

The Circular Economy Act applies to the ringing of wild birds for research and identification purposes; this stipulates that the producer of waste is responsible for returning the waste to the material cycle. This applies provided that the recovery of the waste is technically feasible and economically reasonable. This is not the case for the ringing of wild birds.

In livestock farms that fall under the umbrella of agriculture, the Regulation on Bio-Wastes[5] should apply in a similar framework to that use for mulch films, for example (section Mulch films on page 55). These may be disposed of as agricultural bio-waste, provided they are DIN EN 13432 or DIN EN 14995 certified. However, these certifications require biodegradation in the soil under certain conditions; bird ringing would first have to meet this requirement.

Other barriers

The reasons for the lack of options for biodegradable bird ringing to date are poor availability of suitable alternatives, low market volume, technical requirements and the expected higher prices.

3 EURING, The European Union for Bird Ringing 2011: Bird ringing for science and conservation. 2011. Download at https://euring.org/files/documents/brochure2007/EURING_brochure_german_2011.pdf

4 European Commission 2021: DR AGRI Dashboard Poultry Meat. 03/02/2021. Last accessed 05/02/2021. https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/poultry-meat-dashboard_en.pdf

5 Federal Ministry of Justice and Consumer Protection 1998: Verordnung über die Verwertung von Bioabfällen auf landwirtschaftlich, forstwirtschaftlich und gärtnerisch genutzten Böden (Regulation on the use of biological waste on agricultural and forestry soil) 21/09/1998. Download at https://www.gesetze-im-internet.de/bioabfv/__3b.html

For many wild bird species (such as seagulls and storks) it is also important that the rings last for a very long time (over 20 years in some cases) and that they can be retrieved and analysed after the death of the animal.[1] Currently, there is no standard or certification that covers applications where biodegradation may take several years in certain environments.

Technical requirements

The ringing must meet different requirements depending on the area of application. There are both open and closed rings. The open rings are put on adult birds and must be elastic, but still need to attach to the animal's leg. The closed rings are put on young animals and do not have to be malleable.[6] The rings must be sturdy, as some bird species try to tear off the rings. They must also be resistant to abrasion and ageing; if parts break off, there is a risk that the bird will injure itself. They also need to be long-lived, as some animals live for decades.[1] In poultry breeding, longevity is of less relevance.

Especially in avian research, ringing must be weather resistant (UV, H_2O, heat, cold) and resistant to field conditions such as saltwater and sand, as well as being skin friendly, guano resistant and lightweight. The material must be markable (e. g. by laser). This is a mass-produced item, manufactured by extrusion.

The alternative material should be biodegradable in industrial compost, biogas plants or in nature after its purpose has been fulfilled and depending on the bird species ringed.

Relevant standards and certificates

The certificates for biodegradation in soil from TÜV Austria as well as DIN CERTCO can be used here if it is assumed that the wild birds will probably lose the

6 Ruhr University Bochum 2020: Controlled release of fertiliser using biopolymer chips. RUB Press release, 14/10/2020. Download at https://news.rub.de/english/press-releases/2020-10-14-environmental-technology-controlled-release-fertiliser-using-biopolymer-chips

rings in the natural environment and they cannot be recovered. The certificates for industrial composting (TÜV Austria, DIN CERTCO) could be applied in poultry farming, alongside those for biodegradation in the sea or freshwater (TÜV Austria, DIN CERTCO) for marine regions and lakes, and for waterfowl in general. These requirements are based on DIN EN 14995 and DIN EN 13432.

There are currently no suitable certifications confirming biodegradation over a long period of time, as is sometimes required, so that the rings can still be collected and analysed.

Possible substitutes

Certified biodegradable rings can be made from PLA and PLA blends if the rings end up in industrial compost or biogas plants, which is usually the case, especially in poultry farming.

In the case of wild animals, the rings always remain in the wild at the end of life, unless they are found by bird researchers. The polymers PBSA and PHB and their copolymers can be used here, in each case in blends or as a blend with starch. PLA is certified compostable within the considered degradation periods set out in the certificates of TÜV Austria or DIN CERTCO under industrial conditions. This could be a particular advantage for PLA in this application as the biodegradation of PLA in nature is slower than specified in the certificates – but degradation does take place. If the rings of dead birds are still to be found, degradation must not take place too quickly – as is the case with PLA.

If the rings remain in the sea, the only practical options are PHB and copolymers.

Biodegradation can also be promoted by combining the above polymers with organic fillers such as wood flour, natural fibres or even agricultural residues.

These substitute plastics should meet the technical requirements as far as possible, but proof of technical feasibility in specific applications would be required, especially with regard to skin compatibility and long-term stability (wildlife).

Outlook

The ringing of animals in poultry farming is a sensible and technically feasible application for biodegradable plastics, which could be disposed of via industrial composting or a biogas plant after use. A high level of social and political acceptance is expected here. The problem, however, is the relatively small volumes in this application, meaning that it may not be worthwhile for suppliers to bring the materials and products to market. Here, legal regulations could help to develop the market.
Wild birds' rings must not biodegrade too quickly in the wild, as they are to be recovered and analysed for bird research purposes. Certain polymers such as PLA meet this requirement and biodegrade slowly, but so far there are no appropriate standards or certificates.

Tree shelters

Great potential for plastic reduction in the forest – certification and clear policy rules are still pending

Description

When young trees are planted, tree shelters are placed around the plants to protect them from deer browsing for five to seven years and to encourage growth over competing vegetation. Tree tubes are used in forestry, viticulture, landscaping and orchard-keeping.[1] Aside from their primary role in protecting from deer browsing, tree shel-ters have other benefits: A microclimate is created inside, which improves the growth of the young trees. This is done by increasing air temperature and humidity, which reduces the risk of frost damage, for example.[2] In addition, plants with tree shelters are easy to find during crop inspections and cultivation.[2] Tree shelters are becoming increasing popular in the fight against forest damage caused by drought, pest infestation or storms.

Main material currently used

The main material currently used is sheet polypropylene and polyethylene nets.[3] High density polyethylene or tree spirals made of rigid PVC are also used. The main additives are UV stabilisers to extend product life. As there has been a strong demand from users for biode-gradable materials for some time,

1 Hein, S. and Graf, Y. (Rottenburg University of Applied Forest Sciences / Silviculture) 2020: Personal communication. 30/06/2020

2 Federal Ministry of Justice and Consumer Protection 1998: Verordnung über die Verwertung von Bioab-fällen auf landwirtschaftlich, forstwirtschaftlich und gärtnerisch genutzten Böden (Regulation on the use of biological waste on agricultural and forestry soil) 21/09/1998. Download at https://www.gesetze-im-internet.de/bioabfv/__3b.html

3 Hein, S.; Graf, Y. 2019: Marktanalyse: Wuchshüllen in Deutschland. Holz-Zentralblatt (32)

"oxo-degradable" polypropylene tree shelters have made their way onto the market. However, these products do not biodegrade, but simply break down faster into microplastics.

Problematic

Due to the high pressure exerted by wild animals and the increasing use of deciduous trees, the demand for tree shelters is increasing. There are various reasons why most tree shelters are left in the forest once they have done their job. These include changes in forest vegetation (heavy vegetation, difficult access), lack of documentation of the applied tree shelters, long application periods of often well over five years and extensive forest management, resulting in long inspection intervals and information losses.[2] There are as yet no official concepts for the collection of old tree shelters[4] and in practice they therefore largely remain in the forest because of the work involved in collecting them, the costs incurred and a lack of personnel. Most tree shelters are thus left in the forest and can still be found there after 30 or 50 years. During this time, they often already break down into plastic fragments, which in the long term become microparticles. Many forest owners would like to use biodegradable tree shelters to avoid the hassle of collection.

Market volume in Germany / the EU

Approximately 11 million new tree shelters, or about 3,500 tonnes, are used every year in the forestry sector in Germany.[2] For the EU, this results in an extrapolated volume of about 20,000 tonnes. There are no surveys available for the application in viticulture, horticulture and landscaping.[2]

Biodegradable products on the market

There are hardly any products available to date that actually degrade on the forest floor.

The first alternatives to conventional plastic tree shelters, which aim to be biodegradable, are now on the market.[2] Materials such as paper or jute have too short a lifespan, as well as other disadvantages – but they are biodegradable. Wooden slat constructions are not suitable for practical application due to economic and ergonomic reasons.

Among them are products certified for the composting of packaging according to DIN EN 13432, but which are not suitable for degradation under forest conditions due to the requirements of the test standard. Austrian compostable tree shelters made of various different paper structures combined with a compostable film or tubes made of nets of bioplastics are available, and have been certified "OK compost INDUSTRIAL". In Sweden, biodegradable solutions for tree protection are available, but do not hold certification for degradation in the forest soil. A

4 https://www.fnr.de/index.php?id=11150&fkz=2219NR425

manufacturer from the UK has developed a tree shelter based on natural fibres and biodegradable plastics. Laboratory and field tests are being run by OWS (Organic Waste Systems) to verify biodegradation.

Policy and regulatory considerations

A review of the Circular Economy Act, the Regulation on Bio-Wastes, the Federal Forest Act, the Federal Nature Conservation Act and the State Forest Acts of the states of Baden-Württemberg and North Rhine-Westphalia determined that so-called degradable tree shelters may only remain in the forest if they can be proven (according to the annex to the Regulation on Bio-Wastes, which refers to DIN EN 13432) to degrade there without residue – i. e. under forest conditions – and are largely of biological origin.[5] [6] Industrially compostable materials do not fulfil this requirement on the forest floor, so the design is not appropriate.[2] This poses a major hurdle to practical feasibility. In practice, however, non-biodegradable tree shelters that remain in the forest for decades are a common occurrence.

Tree shelters are also used in public forests (e. g. forests owned by the states and municipalities). To date, however, sustainability criteria in public procurement have not yet been designed for tree shelters. In addition, there are no criteria in the funding guidelines for forest management in the states (e. g. for forests in communal or private ownership) through which "biodegradable under forest conditions" tree shelters could be specifically promoted.

As one element of the plastic reduction strategy for forestry in Germany, new funding guidelines are to be drawn up in 2022 to meet the proposal to promote tree shelters that are certified fully biodegradable (i. e. residue-free) under forest conditions.[7]

PEFC and FSC certify sustainable forest management and set standards to which certified forest owners must adhere. In the new standards for sustainable forest management, PEFC requires that tree shelters that are no longer functional and that have fulfilled their purpose be removed from the forest and disposed of properly. Products whose materials originate from renewable raw materials are also to be used if they are available on the market and if they are eco-

5 Hein, S., Hafner, M., Schurr, C. and Graf, Y. 2021: Zur rechtlichen Situation von Wuchshüllen in der Waldbewirtschaftung in Deutschland: Teil 1. Definitionen, Rechtsrahmen, kreislaufwirtschaftsrechtliche Sicht und Bundesbodenschutzgesetz. Allgemeine Forst- und Jagdzeitung 2021a (191-04).

6 Hein, S., Hafner, M., Schurr, C. and Graf, Y. 2021: Zur rechtlichen Situation von Wuchshüllen in der Waldbewirtschaftung in Deutschland: Teil 2. Forst- und naturschutzrechtliche Sicht, Lösungsansätze und Folgerungen. Allgemeine Forst- und Jagdzeitung 2021b (191-04).

7 Graf, Y., Hein, S., Schnabl, A. and Gebauer, T. 2021: Förderung von Verbissschutz im Ländervergleich. Holz-Zentralblatt, 147th Edition (10)

nomically reasonable.[8] The FSC standard addresses the issue of tree shelters in indicator 10.12.1, in which they are considered waste and must be disposed of in accordance with local waste management regulations.[9]

Other barriers

In the past, some tree shelters have been labelled and sold as environmentally safe and biodegradable. In fact, these were "oxo-degradable" polypropylene tree shelters.[2] These tree shelters have no environmental advantage at all; they do not biodegrade completely but become microparticles. On top of that, they have given the term "biodegradable" a bad image.

Furthermore, there are no test standards or certification that prove biodegradability under forest conditions.[2] For applications in the forest, approximations need to be made using the certification "biodegradable in the soil", the associated standard DIN EN 17033 and a range of further tests with suitable content. However, the conditions of the latter do not do justice to the actual environmental conditions in the forest soil, as degradation takes much longer due to the lack of microorganisms and heterogeneous forest soil types.[10]

Forest owners are obliged to collect tree shelters after they have fulfilled their intended use and to cover the costs involved, but in reality, this is often not enforced. Provided that this changes in the future, tree shelters that are proven biodegradable in the forest may also offer economic advantages. A survey among forest owners in Baden-Württemberg showed that they would be willing to pay EUR 0.50 more for a biodegradable grow wrap. The current average price is about 2.00 EUR per grow wrap. A biodegradable grow wrap should therefore not cost more than EUR 2.50 per item, which is difficult to achieve.[2] Some companies in German-speaking countries are working on the development of corresponding products, but these developments are being held back by the absence of suitable certification systems.

Technical requirements

The time during which the tree shelters are fully functional and the time they take until they have degraded without residue at their place of use must be defined. They must protect from browsing and promote growth for at least five years.[2]

The tree shelters must be resistant to environmental influences such as heat, cold, rain, UV radiation and micro-organisms and have a stretchable structure that grows with the tree. Production takes the form of film or net extrusion: high melt strength, ductility and viscosity are required.

Relevant standards and certificates

There is neither a corresponding norm, nor (private) standards or certificates for biodegradability under forest conditions. Therefore, estimates using existing standards and certificates are required. The DIN EN 17033 standard developed for agriculture and horticulture defines and verifies the biodegradability of mulch films in the soil in a standardised manner. Findings from this standard can only be partially applied to the biodegradation of plastics in forest soil.

The certifications for the biodegradation of plastics in soil from TÜV Austria and DIN CERTCO can also be used as an approximation.

8 PEFC Deutschland e. V. 2020: PEFC-Standards für nachhaltige Waldbewirtschaftung. 01/12/2020. Download at https://pefc.de/media/filer_public/16/48/164824f5-c9ef-4b00-90e4-f4f5b213071c/pefc_d_1002-1_pefc-waldstandards_2020.pdf

9 German FSC Standard 3-0 2020: Umsetzungshilfe (Implementation Guide). 03/2020. Download at https://www.fsc-deutschland.de/preview.umsetzunghilfe-fsc-waldstandard.a-1498.pdf

10 Hein, S.; Graf, Y. 2020: Auf dem Weg zu einer Plastikreduktionsstrategie. Holz-Zentralblatt (49)

Possible substitutes

There are several materials that can be considered for use in tree shelters. Some of these materials even carry the "OK biodegradable SOIL" certification – although suppliers cannot guarantee that these materials can meet the technical requirements over a period of five to seven years. There is a need for more practical tests in this field. The materials range from cellulose fibres (Tencel) to PBS reinforced with sunflower seed hulls. Starch blends would also be a possible alternative as well as PHB, PHB copolymer blends and PBS blends that can biodegrade in soil. A multi-layer product with cellulose and PBS as a sealing layer would also be conceivable. A natural material, sheep's wool, is also suitable to provide browsing protection for young trees.

PLA is only certified compostable within the considered degradation periods set out in the certificates of TÜV Austria or DIN CERTCO under industrial conditions. This could be a particular advantage in this application as the biodegradation of PLA in nature is slower than specified in the certificates – but degradation does take place.

As an alternative for coniferous trees, so-called "chemical deer repellents" can be used, in which the tops of the young trees are coated annually with quartz sand or odorous substances from fish or sheep. This keeps animals away. The disadvantage is that this treatment must be repeated annually until the tree has reached a stable size.[11]

Outlook

Any walker with an alert eye will notice any number of tree shelters in the forest that have obviously done their job, remaining in the forest for decades and disintegrating into smaller and smaller pieces of plastic. However, whether biodegradable tree shelters will be able to prevail in the future over their counterparts that have been popular for many years depends significantly on the growing awareness of direct users and on the political framework. The positioning of the major certification systems in forestry, FSC and PEFC, public funding and the procurement guidelines of Germany's large state forestry companies will be crucial for this development. The use of biodegradable and at the same time bio-based tree shelters could be an important building block for a forestry strategy to reduce fossil-based and non-biodegradable plastics. Therefore, an additional certification for exactly these conditions would be urgently necessary for the further development of biodegradable tree shelters under forest conditions and their introduction to the market.

11 Maier, L. (Witasek Plant Protection) 2021: Personal communication. 26/08/2020

Household & Garden

This section covers the largest product group. The products and applications presented here are used in the home and garden. The users are almost exclusively end consumers. A production volume of about 60,000 tonnes of plastic per year is accumulated in Germany, a large proportion of which (see Table 1) ends up in various environments such as soils, the compost stream or bodies of water. Consumer awareness as a regulatory factor is as important here as political requirements.

Stickers for fruit and vegetables

Good technical feasibility and high social acceptance

Description

Stickers on fruit and vegetables are used in the retail trade for product and price labelling. In particular, goods that are difficult to distinguish, such as apple varieties, can be identified at the checkout with the PLU code. Often the variety, the producer or the characteristic “organic” is also noted on the label.

Main material currently used

The main materials currently used are printed paper and polyethylene and polypropylene films. In addition, non-biodegradable adhesives and printer inks are used.

Problematic

The stickers usually remain on the skin/rind of fruit or vegetables after they have been peeled and end up with them in the organic waste stream (home compost or organic waste bin and thus in industrial composting) or in the natural environment. Due to their small size and their adhesion to the fruit and vegetable peels, the stickers can only be separated from the organic waste in the composting plant with extreme effort; in practice, this does not happen.

If the stickers, the adhesive and the inks on the sticker are made of non-biodegradable plastics, the bio-waste stream will be contaminated with these plastics or they will remain permanently in the environment.

Market volume in Germany / the EU

For Germany, we estimate the total market for vegetable and fruit stickers at around 170 million stickers per year.[1] Each sticker has a weight of about one gram. This gives an approximate market volume of 200 tonnes for Germany and 1,000 tonnes for the EU.

Biodegradable products on the market

There are suppliers in Germany and other European countries who have been offering certified com-

1 Searle, F. 2019: Retailers reducing plastic packaging use. 18/12/2019. Last accessed 09/02/2021. http://www.fruitnet.com/fpj/article/180497/retailers-reducing-plastic-packaging-use

postable stickers for fruit and vegetables for years, but mostly industrially compostable, with only a few cases also home compostable. In this case, the entire sticker, consisting of plastic film, printing inks and adhesive, must meet the relevant requirements.

Other compostable alternatives include labels made from cellulose that are also often certified for industrial composting only. Labels made from grass fibres and wood pulp were also found during the research.

There are also questionable alternatives on the market, such as stone paper (calcium carbonate and PE) or bio-PE, neither of which is biodegradable.

Policy and regulatory considerations

Recycling of biodegradable plastics for fruit and vegetable labels in industrial compost is precluded by the BioAbfV, which, as described in the overarching section on regulatory frameworks, prohibits these materials from ending up in the organic waste bin.

In 2013, a petition calling for mandatory biodegradability regulations for fruit and vegetable stickers was rejected. The reason was that labels do not play a major role in bio-waste recycling in terms of weight and volume.[2] As long as the remaining plastic particles have a diameter of less than 2 millimetres, or account for less than 0.5 %, they are permissible according to the BioAbfV (Section 4, Para. 4).

According to current law, the labels must be brought into the recycling cycle (KrWG). However, this is done only to a very limited extent.

At the European level, fruit and vegetable labels are an issue. This is addressed by a recent independent

study commissioned by the European Commission which advocates biodegradable options.[3]

Other barriers

The main barriers to greater market penetration of biodegradable products are awareness and price. As there are only a few, smaller suppliers on the market so far, awareness of the products is limited. Furthermore, given the more expensive materials and the small production volume, the price is considerably higher than that of standard products.

Technical requirements

The stickers must be resistant to UV radiation, water and adhesives, and must be toxicologically safe and food safe. The material must be printable and several components must be compatible: the adhesive, the

2 Petitions Committee of the German Bundestag 2013: Neuigkeiten zu Verbraucherschutz – Biologisch abbau-bare Aufkleber für Obst und Gemüse. 21/03/2013. Download at https://www.openpetition.de/petition/blog/verbraucherschutz-biologisch-abbaubare-aufkleber-fuer-obst-und-gemuese

3 Hilton, M., Geest Jakobsen, L., Hann, S., Favoino, E., Molteno, and Scholes, R. 2020: Relevance of Bio-degradable and Compostable Consumer Plastic Products and Packaging in a Circular Economy. 03/04/2020. Directorate-General for Environment (European Commission), Eunomia. doi: 10.2779/497376

film and the dye. The adhesive layer also has to adhere to a waxed fruit surface.

Relevant standards and certificates for biodegradability

The DIN EN standards 13432 (Packaging – Requirements for packaging recoverable through composting and biodegradation) and 14995 (Plastics – Evaluation of compostability) contain standards for biodegradability. In the case of the fruit and vegetable labels, these are applicable to disposal through the organic waste bin collected by waste contractors, but not to home composting. Based on these standards, various certifications from TÜV Austria and DIN CERTCO for biodegradability in various environments can be applied.

Possible substitutes

The stickers often remain on the fruit and vegetable peels and end up with them in the organic waste or home compost. PLA blends with copolyesters such as PBAT or starch blends with copolyesters such as PBAT are particularly suitable for industrial composting.

Other materials that also biodegrade in home composting include PBSA, PHB copolymers and certain home compostable starch blends as well as paper coated with the aforementioned polymers.

Biodegradable adhesives, e. g. based on starch or PHB and PHB copolymers, and (plant-based) dyes are necessary to ensure complete biodegradability of the product.

A complete replacement of the stickers by means of laser branding is another option which is already being practised.

Outlook

Fruit and vegetable labels are a promising application for biodegradable plastics, adhesives and inks: the technical feasibility and chance to completely avoid non-biodegradable stickers in the bio-waste stream are good. Moreover, a high level of social and political acceptance can be expected. A rapid ban on non-biodegradable stickers would be recommended from this point of view.

Biowaste bags

More bio-waste collected and less contaminated with non-biodegradable plastics

Description

Biowaste bags are used in private households to dispose of food waste. Compostable waste, such as kitchen waste and food leftovers[1], is filled into the bags and then disposed of together with the bag in the organic waste bin.

Main material currently used

Since the end of the 1990s, retail outlets and even some municipalities[2] have been offering paper bio-waste bags, occasionally reinforced with biodegradable plastics, or biodegradable plastic bags. The biodegradable plastics are special blends, usually of starch and PBAT[3] or of PLA and PBAT.

The problem in practice is that PE bags are often used for the collection and disposal of organic waste (see below).

Problematic

In many German households, organic waste, mostly organic kitchen waste, is collected separately. To get it from the kitchen to the (often shared) organic waste bin, there are three options: In the collection container, which gets very dirty, in paper bags, which are not very moisture-proof, or in a plastic bag, which is the most practical and hygienic.

To make the paper bags more resistant to moisture, they are sometimes coated with wax-like substances.

1 Depends on the municipality; cooked food waste is not permitted for disposal in the organic waste bin everywhere.

2 Reske, J. (INTERSEROH) 2020: Personal communication. 02/09/2020, 27/01/2021

3 Leibniz Institut DSMZ – Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH, 2020: Bakterielle Arbeitsteilung beim Abbau von Plastik. 18/11/2020. Last accessed 26/01/2021. https://www.chemie.de/news/1168715/bakterielle-arbeitsteilung-beim-abbau-von-plastik.html?WT.mc_id=ca0065

However, data from various studies show that citizens prefer waterproof plastic bags that retain their strength when wet and therefore often use conventional PE bags, which then contaminate the compost with non-biodegradable plastics. Where compostable bio-waste bags are permitted and available, significantly fewer PE bags are used to collect bio-waste. About half of the food and kitchen waste produced in German households is disposed of in the non-recyclable waste bin, as PE bags can be used here. To increase the amount of organic waste collected, it would be beneficial for compostable waste bags to become established, as these are easy to handle for consumers, motivating them to separate organic waste.

With today's practices, it is not surprising to find a large number of plastic bags and particles in bio-waste bins. If the plastics used are not biodegradable, as is usually the case, they lead to considerable contamination of bio-waste and also of the resulting compost, since the films and film residues cannot be completely filtered out before composting. During the composting process, the films are increasingly shredded, making them all the more difficult to separate from the compost. To transfer as little plastic as possible into the compost, a considerable portion of the larger pieces is sieved off and then burned – with compost material lost in the process. The remaining portion remains in small pieces in the compost. If the plastic proportion in the finished compost is too high, there may even be distribution problems. Neither private individuals nor farmers want to use compost with visible plastic particles or microplastics.

In particular, the light plastic bags for fruit and vegetables ("t-shirt bags"), which are available free of charge in supermarkets, are frequently re-used by consumers to collect organic waste, despite bans by local authorities. These PE bags could be replaced by compostable bags. However, they are officially "packaging" and would have to be re-declared to be disposed of in the organic waste bin – in addition to being biodegradable.

Market volume in Germany / the EU

The market volume for biodegradable bio-waste bags in the EU is around 40,000 tonnes per year[4], Germany's quotient around 6,500 tonnes. If one includes the "t-shirt bags", which could potentially become bio-waste bags, the market volume would even be around 150,000 tonnes per year in Europe.[5]

Biodegradable products on the market

Biodegradable bio-waste bags made of corn starch or potato starch are offered by a large number of producers and almost all retail chains on the market. The bags are certified as industrially compostable accor-

4 Bio-based News 2016: Compostable plastic bags carry goods and hopes for the future. 05/04/2016. Last accessed 18/02/2021. https://news.bio-based.eu/compostable-plastic-bags-carry-goods-and-hopes-for-the-future/

5 From Hesler, F. (Novamont) 2020: Personal communication. 03/07/2020

ding to DIN EN 13432, in some countries also by DIN CERTCO or TÜV Austria for home composting, and are made of biodegradable plastics or paper.

However, no home-compostable bags are available made from pure paper. Only some coated paper bags are certified as industrially compostable, as the requirements can only be met by very high-quality paper types.[1]

The standard DIN EN 13432 was adopted 1:1 in the national standards of the member states. In Germany, for example, only products certified according to this standard may be labelled with the protected compostability mark “Seedling”.

There are only a few bio-waste bags on the market that also have a certificate for home composting. A company from Hamburg, for example, offers a bio-waste bag made of a starch blend with the “OK Compost HOME” certificate.

Policy and regulatory considerations

According to Annex 1 of the Regulation on Bio-Wastes, waste bags certified in accordance with DIN EN 13432 are permitted for disposal in the organic waste bin.[6] In practice, however, many municipalities do not accept the waste bags in their bio-waste streams[7], mostly due to their spending too long in the plant – the degradation times in the composting plant are often not in conformity with the specified degradation time of the bio-waste bags according to the standard. There is a long-running dispute between composters and other experts as to whether this is a real problem. The fact is, however, that in many municipalities the bio-waste bags are sorted out of the waste stream and should not be used.

Other barriers

The most important barriers in Germany are the higher price as well as the locally very differing acceptance of the waste management companies. What is readily accepted in one city or municipality is a reason not to empty the organic waste bin in another. Each of the approximately 400 public waste management authorities in Germany regulates the disposal of bio-waste in its own area. In many places in Germany, no distinction is made between biodegradable and normal plastic and all plastic is prohibited in organic waste. This is partly justified by the fact that DIN EN 13432 assumes excessive waiting times for bio-waste in composting. However, there seems to be a lack of cooperation here, as in other countries biodegradable bio-waste bags work well and are accepted by waste management companies. For example, a consistent policy in Italy, where only biodegradable bio-waste bags are allowed, results in the lowest levels of non-degradable plastic contamination in bio-waste in Europe.[8] A new study also shows that the compostable bio-waste bags do not impair the quality of the compost.[9]

The consumer is often not sufficiently informed, is confused by the rules of the waste management companies and is put off by the higher price.

6 Federal Ministry of Justice and Consumer Protection and Federal Office of Justice 2017: Verordnung über die Verwertung von Bioabfällen auf landwirtschaftlich, forstwirtschaftlich und gärtnerisch genutzten Böden (Regulation on Bio-Wastes – BioAbfV) §2 Annex 1. 27/09/2017. Download at https://www.gesetze-im-internet.de/bioabfv/BioAbfV.pdf

7 See, for example, the recommendations of the Abfallwirtschaftsbetriebe Köln. Last accessed 18/02/2021. https://www.awbkoeln.de/?id=13

8 Italian Composting and biogas Association 2017: Annual Report on Bio-waste Recycling. 11/2017. Download at https://www.compost.it/wp-content/uploads/2019/08/Rapporto-CIC-2017-Eng-v-2.6-web-version.pdf

9 Il Bioeconomista 2020: New German study: compostable bio-waste bags are not a threat for the quality of compost. 27/07/2020. Last accessed 26/01/2021. https://ilbioeconomista.com/2020/07/27/new-german-study-compostable-bio-waste-bags-are-not-a-threat-for-the-quality-of-compost/

must also have high tensile strength, elasticity and ductility. The bags are made via blown film extrusion so the material used should have a good thermal stability and high viscosity and melt strength.

Relevant standards and certificates for biodegradability

The standard DIN EN 13432 (Packaging – Requirements for the recovery of packaging by composting and biodegradation) and DIN EN 14995 (Plastics – Assessment of compostability) contain specifications for complete biodegradability under defined conditions within a limited period of time (maximum twelve weeks). In the case of bio-waste bags, these apply to disposal via the food waste bin, which is collected by the waste management companies. Another relevant and crucial standard is in draft form and will be published soon: DIN EN 17427: Requirements and test methods for home compostable carrier bags.[12]

"OK compost INDUSTRIAL" and "HOME" from TÜV-Austria and the "Seedling" are important certifications. DIN CERTCO is currently developing a new specific certification system: DINplus biowaste bags. The seal limits the degradability of the bag to a maximum of six weeks instead of the previous twelve weeks, which is a significant improvement for composting plants in Germany.[13]

A recently published study from Germany shows that even with the very short treatment times in German fermentation and composting plants, the certified bio-waste bags are completely degraded.[10] Other experiments show that even banana peels may take longer to biodegrade than material made from PLA.[11] The longer biodegradation times result from the fact that DIN EN 13432 tests a maximum film thickness of 100 to 150 micrometres, whereas bio-waste bags today are usually thinner than 25 micrometres.[1]

Technical requirements

High functionality is required for bio-waste bags as they must be able to withstand decomposing food waste and liquids. The bio-waste bags must therefore be sufficiently resistant to water, fats and acids and have barrier properties against water and oxygen before they end up in the compost stream. They

10 Kern, M., Neumann, F., Siepenkothen, H.J., Turk, T. and Löder, M. 2020. Kunststoffe im Kompost – Praxisversuche zur Bestimmung der Polymerzugehörigkeit. Müll und Abfall 05-20, pp. 245-251

11 Van der Zee, M. and Molenveld, K. 2020: The fate of (compostable) plastic products in a full scale industrial organic waste treatment facility. Wageningen Food & Biobased Research (Ed.), 02/2020. doi: 10.18174/514397

12 https://www.beuth.de/de/norm-entwurf/din-en-17427/308813180

13 Verbund kompostierbarer Produkte e. V. 2020: Bioabfall-Beutel: Neues DIN-Zertifikat garantiert vollständigen Abbau im Kompost in maximal sechs Wochen. Press release Verbund kompostierbarer Produkte e. V., 11/11/2020. Download at https://www.derverbund.com/download/pm_verbund_dinplus_12112020_end.pdf

Possible substitutes

Industrially compostable biowaste bags are made from a variety of biodegradable polymers, often mixed in blends. Starch blends with biodegradable copolyesters such as PBAT, PBSA, PLA or also PHB and PHB copolymers are well-established. Blends of PLA and PBAT, PBSA or PBST are also possible. These materials meet all technical requirements, in particular moisture and water resistance and tear strength, are reasonably priced and are already established on the market. They also meet existing biodegradation standards, although these are not always recognised or practical (see above). Biowaste bags made of special starch blends or PBAT blends with e. g. PHB or PHB copolymers are equally biodegradable and even certified for home composting.

Paper bags produced without plastic reinforcement do not meet the requirements for moisture/water resistance and tear strength. Here, the above-mentioned biodegradable polymers in combination with paper could be a solution.

Outlook

The use of biodegradable biowaste bags makes sense from various points of view, but can only be a success if there is cooperation between politicians (standards, specifications), local authorities, composting companies and producers, in order to gear the products to the technical requirements of composters on the one hand and to achieve acceptance among composters and local authorities on the other. In addition, consumers must be adequately informed. If this succeeds, as is the case in Austria, France and above all Italy, it will be possible to offer consumers easily manageable solutions, open up large markets and reduce the burden on the environment. The proportion of non-degradable plastic film residues in the compost could be drastically reduced and at the same time significantly more of the bio-waste collected put to sensible use as compost, thus achieving biomass recycling. This would also be in line with the announcement by the German Conference of Environment Ministers that 30 % of bio-waste, which is currently lost through disposal in non-recyclable waste, is to be used for bio-waste by 2025.

Floral foam

Biodegradable alternatives relieve home compost and bio-waste streams

Description

Floral foam is a product from the floristry supplies sector and is used in floristry for arranging flower arrangements. A distinction is made between wet or fresh flower foam and dry flower foam. Wet foam is used for arrangements with fresh flowers, such as wedding decorations or wreaths. The foam can absorb water to fill a large proportion of its volume and thus ensures that water is supplied to the flowers. Dry foam is suitable for craft flower arrangements and Advent wreaths that do not require water.[1]

Main material currently used

Synthetic resin foams such as polyurethane or polystyrene are used for dry foam. Phenol formaldehyde foam is mainly used for wet foam.[2] The colour of the foam can vary due to the addition of pigments (e. g. carbon black).

Problematic

The foam is often disposed of in the bio-waste stream along with the wilted flowers either because the users are negligent or because they believe it to be biodegradable. This is often underpinned by the green colour or the texture. It also takes time, or is difficult, to separate the flowers from the foam. Another problem is that the porous and brittle structure means that small particles can be released into the environment when the product is processed and used.[3]

1 grosshaendler.org: Blumensteckschaum in der Floristik. Last accessed 18/02/2021. http://www.grosshaendler.org/informationen-warengruppen-floristik

2 European Phenolic Resins Association 2021: Foams. Last accessed 07/01/2021. https://epra.eu/en/phenolic-resin/application-areas/foams/

3 Madadi, A. 2013: Schaumstoffe verunsichern Gärtner. 03/01/2013. Last accessed 08/01/2021. https://www.abendblatt.de/hamburg/bergedorf/vier-und-marschlande/article112631710/Schaumstoffe-verunsichern-Gaertner.html

Market volume in Germany / the EU

Based on an estimated floral foam consumption of approximately 60 grams (this corresponds to a block of 25x11x7 centimetres) per household per year, the market volume in Germany is 2,500 tonnes per year (incl. events). Extrapolated to Europe, this results in an annual market volume of about 15,000 tonnes.

Biodegradable products on the market

Several suppliers sell products which they claim to be biodegradable. However, none of the products conforms to a common standard or has a certificate. The material used in these products is not identified.[2]

Policy and regulatory considerations

Currently, floral foam must be properly disposed of with non-recyclable waste.

Other barriers

The biggest barriers to the introduction of biodegradable floral foam are the lack of awareness among consumers and the lack of disposal instructions on the product, as the floral foam is usually handed over by the florist together with the flowers without any further instructions. In addition, terms such as "arranging moss" can mislead the consumer, as this is usually not natural moss but artificial foam.

Technical requirements

The material must be foamable and therefore have a high ductility and viscosity. Hydrolysis resistance is required. The foams are relatively weak and brittle, which is a prerequisite for the application, as a flower stem should easily penetrate the foam structure. At the same time, the foam must have sufficient strength and dimensional stability to hold the flower arrangements.[1] Wet foam must also be porous and able to absorb water to prolong the life of fresh flowers. Small particles that can enter the environment, as well as the whole foam that are often disposed of in the biowaste stream, should be able to biodegrade rapidly.

Relevant standards and certificates

Since floral foam is often disposed of in organic waste, biodegradation under composting conditions is required here. There are relevant certificates from TÜV Austria and DIN CERTO for both home and industrial composting.

Possible substitutes

PLA foams are suitable as substitutes and biodegrade in industrial composting. PHB copolymer foams could also meet the technical requirements and would even be suitable for certified home compostability.

Foams based on cellulose acetate could also be technically suitable and there are varieties that also biodegrade in industrial composting.[4]

Another alternative to polymers for flower arrangements is real moss. This is even commercially avail-

4 Izallalen, M. 2020: Eastman Cellulose Esters Polymers in the Circular Bioeconomy. Presentation at the conference "13th Conference on Bio-based Materials", 13/05/2020, online.

able, though very expensive, and availability is very limited. In addition, the use of moss is to be criticised in order to ensure biotope protection. As a natural material, natural clay or sand can also be used as a substitute for dry foam in certain applications, though at least for sand, disposal via the organic waste bin is not permitted.

Outlook

Floral foams represent an interesting application for biodegradable plastics. On the one hand, because a large proportion of them end up with the flowers in the home compost or organic waste, and on the other hand, because there are biodegradable alternatives. As awareness among customers and florists is low and the alternatives are more expensive, information campaigns and political guidelines would be important to bring about changes in use.

Wet wipes

Improper disposal by the consumer requires products made of cellulose and natural fibres

Description

Wet wipes are disposable nonwoven cloths soaked with liquids and lotion. They are packaged in plastic packs or dispensers and are intended for many different uses as a convenience item for travel or household use. This product includes baby wipes, make-up removal wipes for skin cleansing, cleaning wipes, disinfecting wipes, refreshing wipes and moist toilet paper.

Main material currently used

Most tear-resistant wet wipes, such as baby wipes and make-up removal wipes, are made of up to 80 % synthetic fibres such as polypropylene or polyester fibres, mixed with a small proportion of cellulose fibres (viscose or lyocell).[1] The wet wipes consist of fibres processed into a nonwoven fabric, in some cases by hydroentanglement ("spunlace technology"), which is used to achieve a special softness and high volume. The exact composition of a wet wipe can vary depending on the area of application and the manufacturer. Softer wet wipes are suitable for skincare and contain a higher proportion of cellulose fibres such as viscose and/or lyocell. Wet wipes for floor cleaning, on the other hand, must be stronger and contain a higher proportion of synthetic fibres such as polypropylene and polyester.[2] Wet wipes are soaked with liquid (e. g. lotion, water, perfume, alcohol or care products). The mix of ingredients varies – from natural gentle skincare products to harsher cleansers and disinfectants.

1 Carus, M. 2019: Experten sagen JA! Zu holzbasierten Cellulosefasern. Last accessed 07/01/2021. https://itsinourhands.com/content-pages/its-in-our-hands/experten-sagen-ja-zu-holzbasierten-cellulosefasern

2 Quinn, P. 2019: Wet wipes: keeping them out of our seas (and sewers). 16/01/2018. Last accessed 07/01/2021. https://friendsoftheearth.uk/plastics/wet-wipes-keeping-them-out-our-seas-and-sewers

Problematic

Tear-resistant wet wipes lead to major problems in sewage treatment plants and to the pollution of rivers and the oceans when they are improperly disposed of down the toilet, as they contain non-biodegradable plastic fibres. Unlike toilet paper, they do not disintegrate, but form “fatbergs” and thus clog sewers and sewage treatment plants.[3] When they enter rivers, lakes and the sea through wastewater, they remain there, releasing first macroplastics and then microplastics. Up to 8 % of plastic litter found on marine shores is made up of wet wipe fabric[4], or taking the UK as an example, 19.2 wet wipes or their remains per 100 metres of beach.[5] Additionally, wet wipes are sometimes improperly disposed of in the nature.

Market volume in Germany / the EU

The market in the EU is approximately 160,000 tonnes per year.[6] This would suggest about 25,000 tonnes for Germany.

Biodegradable products on the market

There are many cellulose-based products on the market which are described as biodegradable. However, these are usually not certified or only industrially compostable. An Austrian manufacturer offers certified cellulose fibres to produce nonwoven fabrics. They completely biodegrade after a few months in soil, compost or water.

Policy and regulatory considerations

There are no clear legal provisions or labelling requirements governing the disposal of wet wipes containing plastics or banning wet wipes that are not biodegradable. The ingredients listed for the wet wipes are usually only the additives such as oils and lotions added to the nonwoven fabric. In many cases this results in “hidden plastics”, leaving the consumer ignorant about how to properly dispose of the product. A consumer survey showed that about 85 % of those surveyed did not know that wet wipes contain fossil-based non-biodegradable plastic fibres.[7]

The pressure from municipalities and wastewater companies is high. Many municipalities have significantly higher costs due to the additional cleaning effort, which are ultimately passed on to the population.

When the 2019 European Single-Use Plastics Directive [Directive (EU) 2019/904] comes into force in July 2021, manufacturers of wet wipes made of plastic fibres will be required, among other things, to share the additional costs of disposal and cleaning, and to help improve consumer awareness of proper disposal (e. g. better labelling and instructions on packaging).[8]

3 Environment Journal 2019: Zopfstoffe Teil 1: Millionenschäden durch Feuchttücher. 17/01/2019. Last accessed 07/01/2021. https://www.umwelt-journal.at/zopfstoffe-teil-1-millionenschaeden-durch-feuchttuecher/

4 Lenzing AG 2020: Plastik in Feuchttüchern? Lenzing zeigt: Es geht auch anders. Press release. 05/03/2020. Download at https://www.lenzing.com/index.php?type=88245&tx_filedownloads_file %5bfileName %5d=fileadmin/content/PDF/01_Medien/Presseaussendungen/DE/PA_2020_03_05_DE_Plastik_in_Feuchttuechern._Lenzing_zeigt_Es_geht_auch_anders.pdf

5 Marine Conservation Society 2019: Great British Beach Clean 2019 Report. 28/11/2019. Download at https://www.mcsuk.org/media/mcs-gbbc-2019-report-digital.pdf

6 Businesswire 2020: Global Wet Tissue and Wipe Market 2020-2024. Last accessed 07/01/2021. https://mms.businesswire.com/media/20200819005467/en/813722/5/IRTNTR40002.jpg?download=1

7 Science ORF 2019: Feuchttücher: Unterschätze Plastikquelle. 15/11/2019. Last accessed 07/01/2020. https://science.orf.at/v2/stories/2994475/

8 The European Parliament and The Council of the European Union 2019: Directive on the reduction of the impact of certain plastic products on the environment. Article 8(3). Official Journal of the European Union (Ed.), 05/06/2019. Download at https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0904&from=EN

Other barriers

The biodegradable alternatives made of 100 % cellulose fibres are generally more expensive than conventional products containing plastics. As there is no labelling obligation, it is difficult for consumers to identify suitable products.

Most consumers also lack the necessary awareness and information that most wet wipes, such as tear-resistant baby wipes, contain plastic fibres, are not biodegradable and so may not be flushed down the toilet.

Technical requirements

Wet wipes for skincare must be suitable for skin and potentially also mucous membranes. This applies to the material the wipe itself is made of and the fluid or lotion in which it is soaked. The material should be spinnable and the fibres should be processable for the production of nonwovens. The nonwoven fabric must be soft, tear-resistant and absorbent. The product does not, in principle, need a long service life; the biodegradable alternative material should degrade at a certain point after use.

Relevant standards and certificates

The leading association for the nonwoven fabric and allied industries, EDANA, has released a new version of its Guidelines for Assessing the Flushability of Disposable Nonwoven Products in 2018. This defines various criteria ranging from decomposability and flushability to the additional energy consumption of the sewage treatment plant pumps as well as the biodegradability of the nonwovens with the respective test methods, which examine the disposal via household toilets.[9]

There is also the product certificate from TÜV Austria "OK Biodegradable WATER" and "MARINE", which certifies the biodegradability of wet wipes and their base materials in freshwater and seawater respectively.

Possible substitutes

Possible substitutes should ideally degrade quickly in wastewater if they are wrongly flushed down the toilet and should have similar properties to normal toilet paper. The natural substitutes in this case must not be too strong, as they could otherwise block sewage plants and sewers despite being biodegradable.

Moist toilet paper that can be flushed down the toilet is made of a small proportion of short cellulose fibres mixed with cellulose pulp produced by a process called "wet-laid spunlacing". These are 100 % cellulose fibres with a low tear strength. They quickly degrade when they are flushed down the toilet and are biodegradable.[10] The fibres may be made of wood from controlled sustainable forestry, fibre plants or agricultural waste such as straw. Mixtures of cellulose pulp and a small amount of lyocell or viscose short fibres are also feasible, are biodegradable and can be flushed down the toilet.[11]

9 INDA and EDANA 2018: Guidelines for Assessing the Flushability of Disposable Nonwoven Products. Edition 4. 05/2018. Download at https://www.edana.org/docs/default-source/product-stewardship/guidelines-for-assessing-the-flushability-of-disposable-nonwoven-products-ed-4-finalb76f3ccdd5286df88968ff0000bfc5c0.pdf?sfvrsn=34b4409b_2

10 Eizinger, J. (Lenzing) 2020: Personal communication. 08/09/2020

11 Lenzing AG 2019: #ItsInOurHands: New eco-initiative for biodegradable wipes. Press release. 25/10/2019. Download at https://www.

Other types of wet wipes, however, even if they are theoretically biodegradable, should be disposed of in the non-recyclable waste to relieve the burden on sewage treatment plants – and not flushed. Wet wipes are made of long fibres or cellulose fibres in multi-layer systems with different fibre orientation, which results in greater nonwoven strength and therefore, when flushed, causes blockages in the pumping and the sewerage system. Long natural fibres such as hemp, flax, jute or kenaf fibres may be suitable as pulp reinforcement.[12] Cellulose-based wet wipes can also be reinforced with bio-based and biodegradable long plastic fibres. This is possible with PLA-based fibres and has already been patented.[13] However, the rapid biodegradability of PLA in water has not be demonstrated yet.

Nonwoven fabrics with PHB and PHB copolymer-based adhesive are also a possible substitute. They degrade relatively quickly in water. A patent for this application has already been filed.[14]

Washcloths made of cotton or cellulose fibres, which can be washed and reused almost as often as required, are a tried and tested alternative to wet wipes for many applications.

Outlook

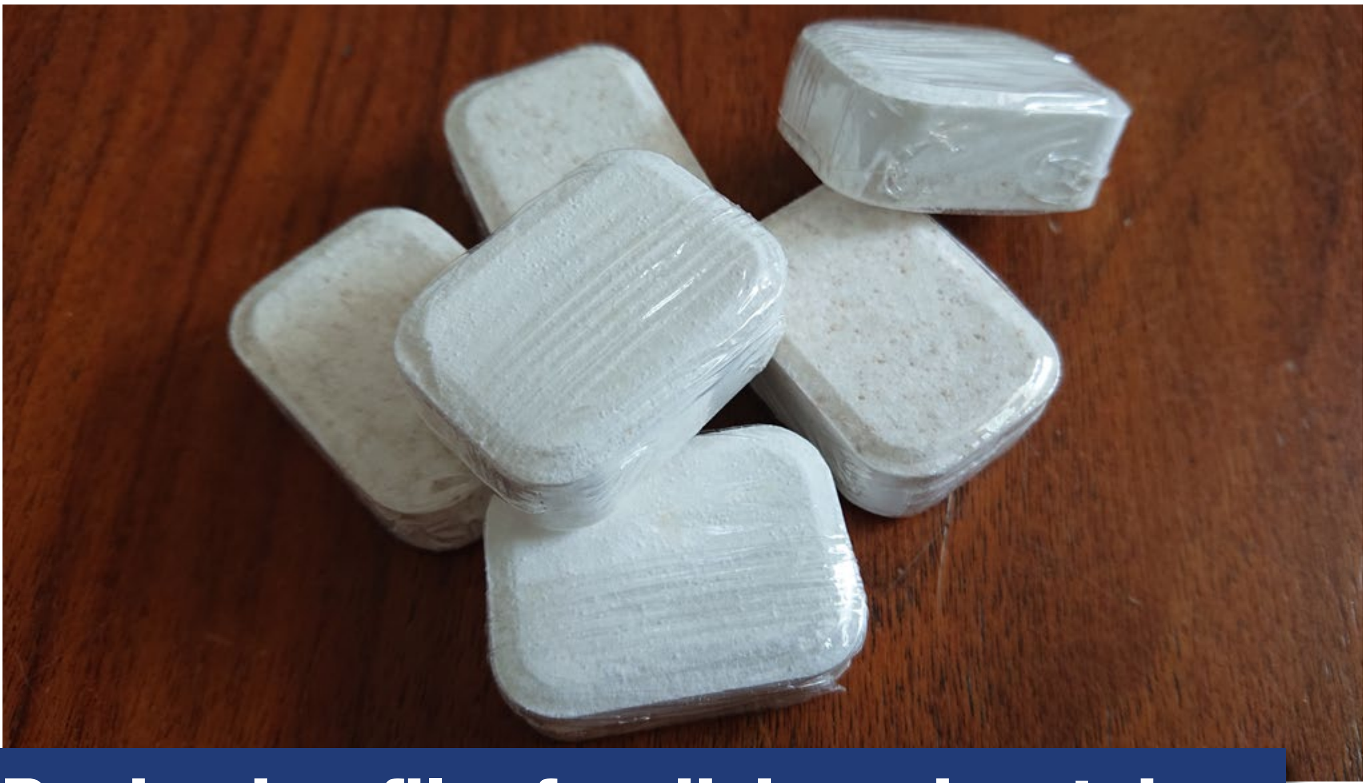
Due to the very large quantities of non-biodegradable wet wipes, frequent improper disposal via the toilet and the lack of labelling or legal requirements, politicians and industry need to take urgent action. Since there are functional alternatives made of cellulose and natural fibres on the market (possibly reinforced with biodegradable polymers), the release of plastics into the waters and oceans could be drastically reduced while still meeting consumer demand.

lenzing.com/newsroom/press-releases/press-release/itsinourhands-new-eco-initiative-for-biodegradable

12 Bast Fibre Technologies Inc. 2020: Georgia-Pacific and Bast Fibre Technologies Inc. Enter into Global Licensing Deal for Nonwoven Sustainable Fibre Applications. 25/02/2020. Last accessed 07/01/2021. http://news.bio-based.eu/georgia-pacific-and-bast-fibre-technologies-inc-enter-into-global-licensing-deal-for-nonwoven-sustainable-fibre-applications/

13 Fingal, L., Tondkar, K. and Stralin, A. 2012: Flushable moist wipe of hygiene tissue and a method for making it. EP2737119A1.

14 Noda, I. 1996: Nonwoven materials comprising biodegradable copolymers. US5685756A.



Packaging film for dishwasher tabs

A relevant environmental problem could be solved quickly through legislation

Description

Many dishwasher tabs are packaged in water-soluble films that do not need to be removed before use. This makes them very easy and convenient for the consumer to handle, skin contact is avoided and different ingredients like detergent, salt and rinse aid can be combined in the tab.

Films that must be removed before use because they do not dissolve in water are also available. These are made mostly of polypropylene and can be recycled. These are not considered further here.

Main material currently used

Currently, the water-soluble films are mostly made of PVOH. These can have a layer thickness of between 30 and 50 µm.[1]

Problematic

PVOH is water-soluble but there are different opinions whether it is able to fully biodegrade or not. Some claim that it can fully biodegrade in waste water or in water. Others disagree by saying that it cannot biodegrade under normal conditions – in the wastewater of a standard household dishwasher – but only in artificially created conditions in the presence of special microorganisms and added enzymes, which do not occur in normal wastewater.[2] Others agree

1 Van Vliet, P. 2004: Cleaning agent for automatic dishwasher comprises powder in cold water-soluble packaging. NL1025384C2.

2 Van der Zee, M. 2014: Methods for Evaluating the Biodegradability of Environmentally Degradable Polymers. in C Bastioli (ed.), Handbook

that PVOH is validated to be fully biodegradable by many labs but that PVOH in practice is often blended or copolymerised with other polymers to make it processable which inhibits its ability to biodegrade. If it cannot fully biodegrade in the given environment, it will release microplastics into the wastewater stream.[3] Another side problem may be the use of methanol as a solvent for the production of PVOH. Methanol is harmful to health and PVOH films may always contain a small residual amount which is then released into the environment. Suppliers generally limit this residual amount per tab, but the accumulation of methanol into the environment could have longterm harmful consequences.[4]

Market volume in Germany / the EU

The EU market for dishwasher tabs with water-soluble film is around 400,000 tonnes per year, which corresponds to 20 billion tabs of 20 grams each. The film itself weighs less than 1 gram, which puts its total volume in the EU at around 20,000 tonnes, and in Germany at around 3,000 tonnes per year.

However, if one adds up the total production volume of the largest manufacturers of PVOH films for all relevant products (pods filled with detergent for the washing machine and all chemicals for the household and garden, such as chlorine tablets for the garden pond), this amounts to well over 100,000 tonnes per year in Europe, and rising.[3]

Biodegradable products on the market

Some manufacturers offering water-soluble PVOH state that their PVOH is biodegradable, but without proof or certification. A major PVOH manufacturer now offers a product with the "OK biodegradable WATER" seal of approval, but this is currently mainly used for 3D printing. This PVOH is water-soluble and certified biodegradable in water.[5]

There are also entirely new developments: A French supplier produces a casein-based packaging film for dishwasher tabs, the product being "OK bio-degradable WATER" certified by TÜV Austria. Austrian and German suppliers also provide biodegradable films with the EU Ecolabel for their products. Biodegradability is proven according to the criteria of the EU-Ecolabel, where water-soluble films are considered as part of the content.[6]

of Biodegradable Polymers. 2nd edn, Smither Rapra, Shawburry, pp. 1-28.

3 Boyano, A., Kaps, R., Medyna, G. and Wolf, O. 2016: Revision of six EU Ecolabel Criteria for detergents and cleaning products. Joint Research Centre, European Commission (Ed.), 06/2016. Download at https://ec.europa.eu/environment/ecolabel/documents/JRC104463_detergents_without watermark.pdf

4 Huber, A. (Huber4zero-Lab) 2020: Personal communication. 12/11/2020

5 Kuraray 2018: Kuraray at Fakuma 2018: Hochleistungskunststoffe für jede Herausforderung. Fakuma 2018. Download at http://www.evalevoh.com/media/172170/kuraray_presseinformation_vorschau-fakuma2018_de.pdf

6 European Commission 2017: DECISION (EU) 2017/1216 – establishing the EU Ecolabel criteria for dishwasher detergents. 17/06/2017. Download at https://eur-lex.europa.eu/legal-content/DE/ALL/?uri=CELEX:32017D1216

Policy and regulatory considerations

Since the film is water-soluble and enters the sewage system, the Wastewater Regulation (AbwV) must apply here. No corresponding limits are specified here.

There are in general no legal requirements that would support or even mandate the use of biodegradable films.

Other barriers

The main barriers to greater market penetration are awareness, price and consumer ignorance of the difference between water solubility and biodegradability of such products. As there are only a few suppliers of biodegradable film on the market so far, awareness of the products is limited. In addition, since the materials are more expensive and the production volume small, the price of the film and thus also of the tabs is considerably higher than that of standard products with a film that is only water-soluble.

Technical requirements

The material must be stable in storage and resistant to the active ingredients of the tab (enzymes, surfactants, bleach, salt and rinse aid). It should be water-soluble, flexible and have suitable tensile strength. In general, the film should be transparent and have relatively high gloss. Since the films are produced via film extrusion, the material used required a high melting capacity, ductility and viscosity.

Relevant standards and certificates

Once the films are dissolved in water after use, the dissolved polymer chains are disposed of with the wastewater. In principle they should biodegrade there or later on in fresh or sea water to prevent microplastics from being released into the environment. Therefore, the certificates “OK biodegradable WATER” and “SOIL” and potentially also “MARINE” from TÜV Austria are suitable to guarantee biodegradation in the specific environment.

Possible substitutes

Casein and starch are potential substitutes as both are water-soluble and biodegradable in water. Water-soluble cellulose foils are also suitable.[1] Alginate-based foils are feasible, as alginate is a natural water-soluble polysaccharide.[2]

The biodegradation of PVOH itself is still being discussed (see above) and could also release small amounts of methanol in the environment. However, one manufacturer has managed to develop a TÜV-Austria-certified PVOH for biodegradation in water.[7] A variant without film could use kraft paper as the outer packaging for the tabs.

Another option is to avoid using tabs altogether and use dishwasher powder instead.

Outlook

Due to the large quantities of films that enter the wastewater through dishwasher tabs and the certified biodegradable alternatives already available on the market, a relevant environmental problem could easily be solved here through legal requirements. Until that time comes, consumer education can accelerate the substitution of critical products.

7 TÜV Austria 2021: Database of certified products. Last accessed 07/01/2021. https://www.tuv-at.be/green-marks/certified-products/

Coffee capsules

Using the fertilising effect of coffee and avoiding microplastics

Description

Coffee capsules are disposable products for use in single portion coffee makers. They are usually a single-serving package containing the amount of coffee powder for a single cup.

Main material currently used

Most coffee capsules are made of aluminium or polypropylene; other polymers found on the market are PBT, PE and also bio-based PLA. Coffee capsules are single-layer or multi-layer systems. In the latter, for example, PP is combined with EVOH to achieve better barrier properties.

Problematic

Used coffee capsules pose a significant disposal problem due to their large volume. Given the composite materials used (e. g. PP-EVOH-PP plus aluminium lid), material recycling is practically impossible. The coffee grounds in the capsule, which are wet after use, are also not very suitable for thermal recycling in the waste incineration plant; incineration also means the valuable substances contained in the coffee grounds are also lost. Disposal via the organic waste bin or home compost would be possible solutions to these problems, but in the case of the currently non-degradable coffee capsules would lead to considerable contamination by plastics, which in time would turn into microplastics.

Market volume in Germany / the EU

In Germany, about 4.3 billion cups of coffee were drunk from capsules in 2019. This corresponds to about 8,600 tonnes of pure capsule material, assuming a capsule weight of 2 grams. For the EU, this means a market volume of about 55,000 tonnes. If you add the coffee that they contain (5.3 grams), this amounts to more than 31,000 tonnes of potentially compostable mass for Germany alone.[1]

Biodegradable products on the market

There are at least ten coffee capsules on the market from different manufacturers or suppliers that advertise biodegradability. However, this is often done without being able to present a corresponding certificate. When certificates are presented, they refer to industrial compostability according to DIN EN 13432, with one exception from Germany; only one product has so far been certified as home compostable.

The materials of the industrially compostable capsules on the market are diverse: various bioplastics, sometimes in combination with each other, such as PLA, PBS, PBSA, PHB (copolymers) or starch, sometimes filled with wood flour, lignin or cellulose. The home compostable capsule is made of ground sunflower seed hulls, PBS and PBSA.

Policy and regulatory considerations

According to the Packaging Act (VerpackG), coffee capsules are not packaging (§3 Paragraph 1, Annex 1)[2] and are therefore not subject to recycling obligations. Nevertheless, the waste hierarchy also applies to these materials, according to which material recycling would be preferable to thermal recycling or composting. The problems with material recycling and thermal recovery have already been described above.

According to the BioAbfV, coffee capsules made of biodegradable plastic are nevertheless not to be disposed of with organic waste, as the exceptions for degradable plastics only apply to biowaste bags and certain materials from horticulture, agriculture, etc.

Other barriers

A major issue is the differences between regulatory requirements and consumer preferences regarding the desired disposal of capsules. From the regulatory side, disposal is prescribed exclusively via non-recyclable waste, while many consumers would prefer the option of industrial or home composting. This leads to misunderstandings, in part due to misleading and inadequate labelling concerning the best possible disposal on the product. Capsules labelled as 'compostable' often end up in home compost, where they are usually not biodegraded, or even in industrial composting, where they may not biodegrade at a sufficient rate and are also prohibited under BioAbfV. The higher price of biodegradable products can also be considered as a barrier.

1 Trumme, R. (Golden Compound) 2020: Personal communication. 21/04/2020; 24/06/2020; 15/01/2021

2 Federal Ministry of Justice and Consumer Protection 2020: Gesetz über das Inverkehrbringen, die Rücknahme und die hochwertige Verwertung von Verpackungen (Packaging Act – VerpackG) §3 Definitions. Download at https://www.gesetze-im-internet.de/verpackg/__3.html

Technical requirements

Coffee capsules are made of multi-layered materials (composite materials) because they have to meet many different requirements: they must have excellent barrier properties to best protect the aroma of the coffee, must be suitable for contact with food and must be able to withstand high pressure and high temperatures. The capsules must be resistant to short-term temperature peaks, withstand boiling water and steam and be toxicologically safe. They are made of one or more injection moulded parts; the exterior should look aesthetically pleasing and be able to be coloured. The material requires high strength and medium stiffness. The lid must adhere to the capsule like a seal.

Relevant standards and certificates

The DIN EN standards 13432 (Packaging – Requirements for packaging recoverable through composting and biodegradation) and 14995 (Plastics – Evaluation of compostability) contain standards for biodegradability. For coffee capsules, these apply to disposal through the organic waste bin collected by waste management companies, but not to home composting.

The certificates “OK compost HOME” and “OK compost INDUSTRIAL” from TÜV AUSTRIA are important benchmarks here, as are “DIN-tested biodegradable compost” and “DIN-tested biodegradable home” from DIN CERTCO and “Seedling”.

Possible substitutes

Combining these technical material properties with biodegradability is most certainly a challenge. For certified industrial composting, PLA, PLA blends and starch blends with PBAT could provide the desired properties. When it comes to home composting, the only certified material mix available to date is PBS/PBSA with ground sunflower-seed hulls. Other polymers such as PHB or PHB copolymers and in principle also multilayer systems, e. g. made of paper coated with PLA blends or starch blends, are suitable for home composting.

Reusable systems for refilling, mostly made of aluminium or stainless steel, offer another solution.

Outlook

Consumers are interested in both industrially compostable and home-compostable coffee capsules. The former are on the market, but still have to contend with legal and political hurdles. As soon as politicians accept biodegradation as a solution, create binding rules and set appropriate standards, large markets will open up here. This could prevent the release of non-degradable plastics into compost streams, allow the use of nutrients from coffee on site and reduce waste transport.

Lawn trimmer threads

Avoiding unnecessary microplastics in the garden

Description

Trimmers are often used to trim and cut grass, weeds and other shrubs. Here, a motor drives a fast-rotating cutting tool that mows the plants. Usually, one or more robust threads made of nylon (lawn trimmer threads) are attached to the strimmer head for this purpose.

Main material currently used

The plastics that predominate at present are polyamides, in particular nylon. Nylon is the most commonly used plastic for lawn trimmer threads because it is easy to work with, durable, impact resistant and abrasion-resistant. Sometimes it is reinforced with wire, aluminium or another polymer.[1]

Problematic

When trimming the lawn, the strimmer string wears out continuously, even more so when it encounters stones or wood that it cannot cut. This results in several metres of lawn trimmer threads being consumed in the garden each year and then remaining in the garden soil as small pieces of thread or micro-particles that can no longer be removed.

Market volume in Germany / the EU

The European Prodcom database contains data on the production of lawn trimmer threads in the EU.[2] It records the market volume of lawn trimmer threads at about 1,200 tonnes per year, corresponding to about 200 tonnes for Germany.

Biodegradable products on the market

Several small producers advertise that their products are biodegradable, but usually do not have any certificates to verify this. These include companies offering so-called “oxo-degradable” plastics, which rapidly fragment into microparticles when exposed to

1 Blankenburg, E. What Is a String Trimmer Line Made Of? Last accessed 11/01/2021. https://www.ehow.com/info_8410259_string-trimmer-line-made.html

2 Eurostat database Prodcom 2021. Last accessed 21/01/2021. https://ec.europa.eu/eurostat/de/web/main/data/database

UV radiation, but do not biodegrade. These materials will be banned in the European Union from 2021.[3]

Policy and regulatory considerations

Lawn trimmer threads are thus subject to the KrWG, which does not refer about for biodegradation but only about recycling via the waste stream. However, the nature of the application does not permit this. The Federal Soil Protection Act can be applied insofar as, for example, all property owners are obliged to prevent damage to the soil. It was not possible to conclusively clarify whether plastic particles are considered harmful substances within the meaning of the law. *De facto*, however, the Federal Soil Protection Act does not apply.

Other barriers

Lack of consumer awareness and knowledge and higher prices are barriers. Furthermore, the provision so far is not convincing due to its lack of certification. Certainly, the high technical requirements combined with the requirement for biodegradation in soil are also a significant barrier, as are opaque and misleading claims by manufacturers.

Technical requirements

Lawn trimmer threads must be resistant to water, heat and fertiliser during use. The outer material is supposed to be hard, but the core a little softer and ductile. The high rotational speeds of the gardening tools generate high tensile or centripetal forces, so the material must have high stiffness and sufficient strength in the direction of the fibres. It must be able to withstand great tensile stress. When a stone is hit, the fibre must not break or snap off immediately, which means that high impact strength is required. Abrasion resistance to grass and weeds must also be provided, but abrasion may occur against rigid materials such as fences or trees. As soon as the thread pieces or microparticles enter the garden soil, the material should be rapidly biodegradable.

Relevant standards and certificates

There are no standards for the biodegradability of plastics in soil – except for mulch films – and therefore there is no applicable standard for this use case and its described persistence in the environment. For biodegradable alternatives, however, certificates from TÜV Austria on degradation in soil and freshwater are available and can be used here.

3 European Parliament and Council 2019: Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment (Text with EEA relevance). Official Journal of the European Union (Ed.), 05/06/2019. Download at https://eur-lex.europa.eu/eli/dir/2019/904/oj

Possible substitutes

Only a few polymers can be used as substitutes. In particular, PHB copolymers[4] and cellulose acetate are certified for degradation in soil. The technical feasibility of PHBH has already been demonstrated and it meets all technical requirements. However, it is not yet available on the market.[5]

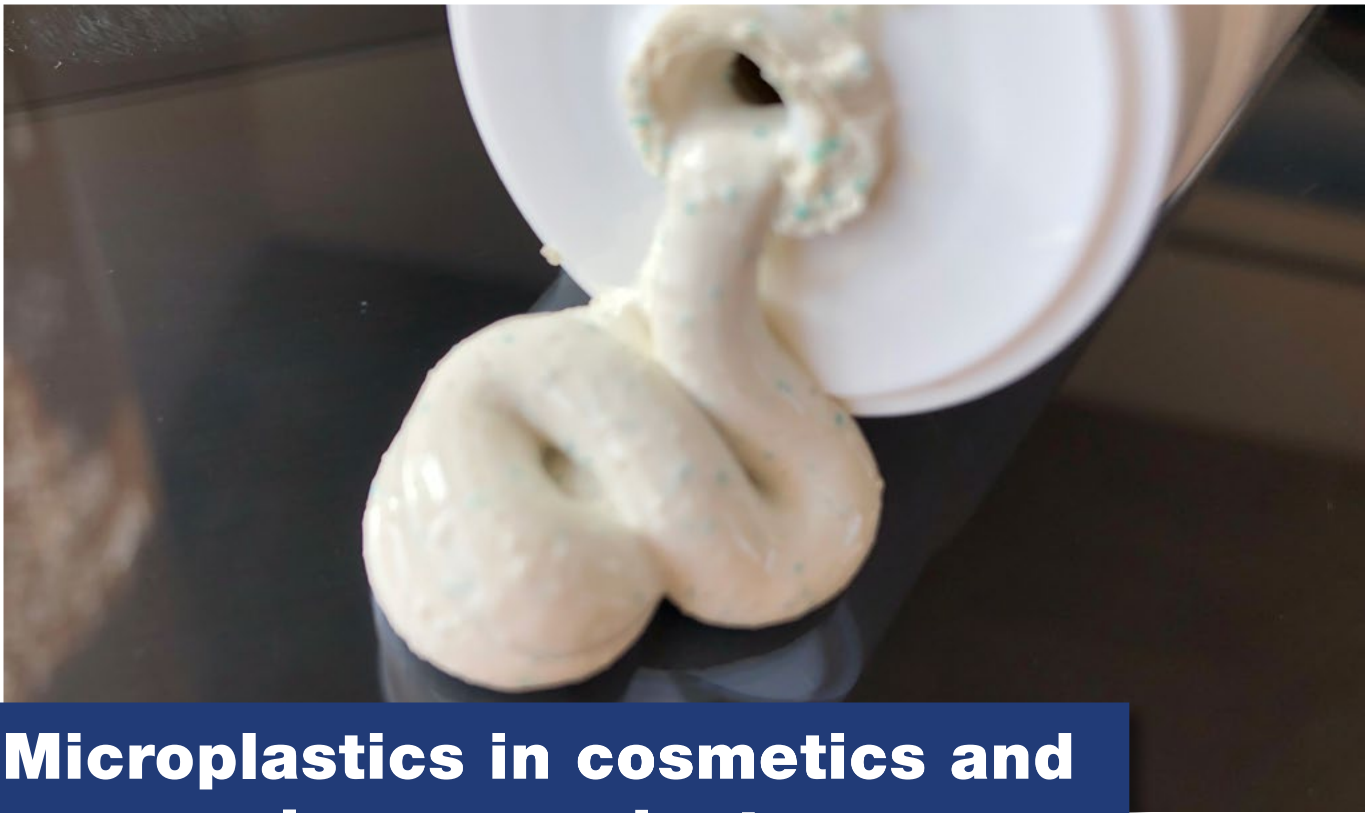
PLA can only be proven to be compostable within the considered degradation periods set out in the certificates of TÜV Austria or DIN CERTCO under industrial conditions. However, PLA will also biodegrade in soil in the long term, but not in the time frame of the certificates mentioned. PLA or PLA blends with PBS would meet the technical requirements for lawn trimmer threads. Natural fillers and natural and cellulose fibres are also options.

Outlook

As soon as certified biodegradable lawn trimmer threads is sufficiently available on the market, it could become a great success. Informed garden owners would certainly prefer degradable lawn trimmer threads. Information campaigns and market launch programmes could have a major impact here. Bans on non-degradable lawn trimmer threads would lead to complete substitution and would presumably meet with a high acceptance rate among the population.

4 Kaneka 2017: Kaneka Biodegradable Polymer PHBH Brochure. 11/2017

5 Ravenstijn, J. (GO!PHA) 2020: Personal communication. 30/07/2020



Microplastics in cosmetics and personal care products

Consumer education, responsible companies and soon legislation will end the problem

Description

Microplastics[1] can be designated as "primary" or "secondary". Primary particles are intentionally added to the product to fulfil a desired property. Secondary particles, on the other hand, are detached fragments of larger pieces of plastic. Microplastics in cosmetics therefore fall into the "primary" category.

Microplastics are used in cosmetics and personal care products as viscosity regulators, emulsifiers, film formers, opacifiers, fillers, exfoliating particles, abrasives or for the controlled release of various active ingredients. Other uses include shelf-life extension, waterproofing for makeup, nail polish and hair cosmetics.[2] Due to their small size, the use of microplastics in cosmetics and personal care products is a significant environmental problem that should be more strictly regulated and restricted in the future.

1 ECHA definition: ECHA defines microplastics as solid polymer-containing particles to which additives or other substances may have been added and where ≥ 1 % w/w of the particles have (i) all dimensions 1 nm ≤ x ≤ 5 mm or (ii) in the case of fibres, a length of 3 nm ≤ x ≤ 15 mm and a length to diameter ratio of >3.

2 Scudo, A., Liebmann, B., Corden, C., Tyrer, D., Kreissig, J. and Warwick, O. 2017: Intentionally added microplastics in products. Amec Foster Wheeler (Ed.), 10/2017. Download at https://ec.europa.eu/environment/chemicals/reach/pdf/39168 Intentionally added microplastics – Final report 20171020.pdf

The focus of this profile is on solid microparticles. Soluble, gel-like or liquid polymers are also used in cosmetic applications. These polymers are not considered here.[3 4]

Main material currently used

Due to increasing public awareness, the use of polyethylene as microbeads has been greatly reduced within a few years. Microbeads refers to microplastics which are used as abrasives, i.e. for peeling or cleaning. However, it is sometimes still used in cosmetic products such as eyeliner, lipstick, mascara, skin cleansers and skin care products. [1 5] In addition, a wide range of other synthetic polymers are also used: polypropylene, polystyrene, polytetrafluoroethylene, polymethyl methacrylate, polyurethane, nylon, or PET. These are used for various purposes. Solid silicone particles, which are not water-soluble, are often used because of their good film-forming properties.

Problematic

The microparticles enter the wastewater after use and cannot be completely filtered out in the wastewater treatment plant. From there, they can be released directly into the environment when they are discharged with the treated wastewater into surrounding waters.[5] The microplastics remaining in the sewage treatment plant can also accumulate in the sewage sludge and be spread on fields as fertiliser.[6] In the sea, the microplastic particles are absorbed by living creatures and even end up in the human food chain. The long-term effects of microplastics in the environment are currently difficult to assess in detail.

Market volume in Germany / the EU

Depending on the polymer form (microbeads only or also as dispersions, for example) of microplastics considered and whether it is a “rinse-off” or a “leave-on” product, a different market volume was found in different studies. Rinse-off products are rinsed directly into the water after use and include shower gel, hair shampoo or scrub. Leave-on products initially remain on the skin, and include body lotion or hairspray.[7]

In early 2019, the European Chemicals Agency (ECHA) published its first proposals to restrict the use of intentionally added microplastic particles in products. This affects both rinse-off and leave-on cosmetics. In the EU, about 9,500 tonnes of microplastics are produced annually for rinse-off and leave-on cosmetics, of which about 3,800 tonnes can enter the environment via various pathways. Calculating for Germany alone, this totals a production volume of about 1,500 tonnes, of which about 600 tonnes are released into the environment.[6]

3 Leslie, H. A. 2014: Review of Microplastics in Cosmetics. Scientific background on a potential source of plastic particulate marine litter to support decision-making. IVM (Institute for Environmental Studies) and Dutch Ministry of Infrastructure and the Environment (Ed.), 07/2014. Download at http://www.ivm.vu.nl/en/Images/Plastic_ingredients_in_Cosmetics_072014_FINAL_tcm234-409859.pdf

4 Bertling, J., Hamann, L. and Hiebel, M. 2018: Mikroplastik und synthetische Polymere in Kosmetikprodukten sowie Wasch-, Putz., und Reinigungsmitteln Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT and NABU (Nature and Biodiversity Conservation Union of Germany) e. V. (Ed.), 09/2018. Download at https://www.umsicht.fraunhofer.de/content/dam/umsicht/de/dokumente/publikationen/2018/umsicht-studie-mikroplastik-in-kosmetik.pdf

5 Schöttner, S. 2017: Von Waschbecken ins Meer, Zu den Umweltfolgen von Mikrokunststoffen in Kosmetik- und Körperpflegeprodukten. Greenpeace (Ed.), 20/05/2017. Download at https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/s02031-greenpeace-report-plastik-kosmetik-oekotox-21070522.pdf

6 European Chemicals Agency 2019: ANNEX XV RESTRICTION REPORT PROPOSAL for a restriction of intentionally added microplastics, version 1.2. European Chemicals Agency (ECHA) (Ed.), 22/08/2019. Download at https://echa.europa.eu/documents/10162/05bd96e3-b969-0a7c-c6d0-441182893720

7 Cosmetics Transparent, 2015: Leave-on products. 01/04/2015. Last accessed 16/02/2021. www.kosmetik-transparent.at/explandict/leave-on-produkte/

Biodegradable products on the market

There are both natural and conventional cosmetics on the market that do not contain synthetic and non-biodegradable plastics. They are replaced by different types of organic or inorganic materials, which are explained in more detail in the section "possible substitutes".

Policy and regulatory considerations

In Germany, the federal government agreed on a "Cosmetics Dialogue" in 2013, which focuses on a voluntary withdrawal of microplastics in the cosmetics industry. By 2017, microplastics had already decreased by 97 % in many relevant products.[8] Since 2015, the European Cosmetics Association has been recommending that its members voluntarily phase out microbeads.[149]

In many countries, they are already banned by law: for example, in France and Canada since 2018, in Thailand and Italy since 2020[9]

In early 2019, ECHA published the first draft of a comprehensive ban on microplastics at an EU level. Numerous amendments have to date been requested by the industries concerned.[10] The ban could come into force in 2022.[11]

Important regulations are the EU Cosmetics Regulation EC 1223/2009, the Detergents and Cleaning Agents Act, the Detergents Regulation EC 648/2004 and 906/2006 and the EU Regulations REACH 1907/2006 and CLP 1272/2008[12]. However, these do not yet sufficiently regulate the use of microplastics.

Other barriers

Many consumers are aware that plastic pollutes the environment. Microparticles in peelings, for example, are being used less and less because consumers recognise them and no longer want to use them. However, consumer awareness of microplastic particles that are not immediately visible is not yet sufficiently high. The INCI (International Nomenclature for Cosmetic Ingredients) labelling requirements currently do not sufficiently consider the environmental aspects of polymers in cosmetics.[2]

Technical requirements

The substitutes must meet numerous requirements such as skin compatibility, resistance to fats and solvents and insolubility in water, and must also be suitable for microgranulation. In principle, they must also be colourless, odourless and tasteless. There are significant differences between the requirements for different products. An additive in a peeling, for

8 Federal Ministry for the Environment, Nature Conservation and Nuclear Safety: Maßnahmen für weniger Plastik und mehr Recycling. Last accessed 07/01/2021. https://www.bmu.de/wenigeristmehr/vorschlag-verpackungsgesetz/

9 Middleton, H. and Sommer, J. 2020: Microplastics and microbeads: The impact of the proposed EU ban. 01/09/2020. Last accessed 16/02/2021. https://www.medicalplasticsnews.com/news/microplastics-and-microbeads-the-impact-of-the-proposed-eu-b/

10 European Environmental Bureau 2020: EU microplastics ban: How industry pressure led European Chemicals Agency to dilute its proposals. EEB (European Environmental Bureau) (Ed.), 01/09/2020. Download at https://eeb.org/library/eu-microplastics-ban-how-industry-pressure-led-european-chemicals-agency-to-dilute-its-proposals/

11 Holdinghausen, H. 2020: Mikroplastik in Gewässern: Großer Wirbel um kleine Teilchen. 01/09/2020. Last accessed 15/12/2020. https://taz.de/Mikroplastik-in-Gewaessern/!5710400/

12 European Chemical Agency, CLP legislation. Last accessed 11/11/2020. https://echa.europa.eu/de/regulations/clp/legislation

example, should ideally be spherical and waterproof with a balanced hardness and stiffness; polymers for lipstick or nail varnish, on the other hand, must have good film-forming properties.

Relevant standards and certificates

In principle, the substitutes should not be soluble in water but should be biodegradable. The established certification from TÜV Austria can be used for biodegradability in freshwater and marine environments. Furthermore, there are some standards and certifications specifically for natural cosmetics. However, these labels do not consider biodegradability; they focus mainly on extraction and production of the raw materials, processing and sale. However, since certified natural cosmetics represent a holistic concept and only natural ingredients are permitted, the use of persistent plastics is practically ruled out.

Possible substitutes

Numerous natural substitutes are already available and already used in various cosmetics and can replace microplastics specifically added for exfoliation: clays, organic waxes such as castor oil wax, ground nut shells or fruit stones, coffee, jojoba beads, cellulose powder, charcoal or sugar. PHB and PHB copolymers are also good alternatives.[13] Other inorganic and mineral products are also suitable and e. g. allowed in natural cosmetics for this use: chalk, silica, pumice, common salt or calcium carbonate. Although the mineral substitutes are not biodegradable, they are of natural origin and therefore environmentally and water-friendly substitutes.

Starch and cellulose, also in the form of cellulose acetate can, for example be used as thickeners or film formers. Chitosan has beneficial properties for cosmetics such as moisturiser, thickener, film formers or antimicrobial agents. Organic materials such as silica or boron nitride are possible options as fillers. Gelatine, keratin, collagen and hydrolysed silk are already used in hair conditioners and as moisturisers.[2]

Recently, PHB has also been used in sunscreens because of its UV filtering capacity.[14]

Outlook

Many companies have already voluntarily committed themselves to eliminating microplastics from their products. However, as this voluntary commitment has to date failed to fully resolve microplastic problem in cosmetics and personal care products, the planned ban on microplastics at a European level is to be welcomed. Numerous unproblematic substitutes are already available, so consumers do not have to relinquish any options.

13 Ökotest Magazin. 2020: Plastikfrei peelen. 09/2020. Last accessed 03/09/2020.

14 bioplastics MAGAZIN 2018: New sun protection technology from Bio-on based on biodegradable polymers. 2018/04/18. Last accessed 2021/04/15. https://www.bioplasticsmagazine.com/en/news/meldungen/20180418New-sun-protection-technology-from-Bio-on-based-on-biodegradable-polymers.php

Dirt erasers

No chance for substitutes

Description

Dirt erasers are household sponges that can be used wet or dry to erase various types of stains. In contrast to classic cleaning agents, which act as chemical aids to dissolve dirt, dirt erasers rely on a mechanical cleaning principle. They act as an abrasive, their cleaning effect being based on a hard and abrasive resin. In theory, they can remove any kind of dirt: encrusted dirt on stove tops, crayon marks on wallpaper, on tiles, leather, etc.[1]

Main material currently used

The material used is a formaldehyde melamine resin foam. It is actually used as a sound- and heat-absorbing insulating material in buildings, trains and aeroplanes.[2] It is an open-cell, thermoset foam with a 3D structure and a very thin synthetic resin filament structure. The material becomes almost as hard as glass when cured. The hardness of the material acts like sandpaper and can rub off dirt particles. Thanks to the open-cell structure, the foam still remains soft and flexible.[3]

Problematic

Formaldehyde-melamine resin cannot be recycled and is not biodegradable; it is therefore essential that it be disposed of with the general waste. If this general waste is not thermally recovered, but goes to landfill, residues can enter the groundwater.

1 Pedriza, B. 2003: Scotch-Brite™ Melamine Foam. Technical Data. 03/2003. Download at https://multimedia.3m.com/mws/media/4405550/scotchbrite-melamine-foam.pdf

2 Weiss, J. 2020: What to Know About Magic Erasers. 07/02/2020. Last accessed 07/01/2021. https://www.familyhandyman.com/article/what-to-know-about-magic-erasers/

3 BASF 2020: The Magic Eraser Made from Basotect®. Last accessed 07/01/2021. https://plastics-rubber.basf.com/global/en/performance_polymers/downloads.html

The dirt erasers gradually fully break down during use and are thus released into the environment in the form of plastic particles. This allows microparticles to be released into dust and the air. Used in the bathroom or kitchen, they can enter the wastewater via the drain.[4] Even if the exact effects of plastics fragmented into micro- or nanoplastics and released into the environment are still to some extent unknown, the German Federal Institute for Risk Assessment (BfR) believes that melamine resins should be treated with particular caution. Thresholds are in place for foods and animal foodstuffs, as the higher temperatures allow concerning amounts of melamine and formaldehyde to be released, posing a health risk.

Unless the dirt eraser is completely used up, it belongs in the non-recyclable waste. The material cannot be recycled.

Market volume in Germany / the EU

The annual market volume in the EU is approximately 9,000 tonnes[5], in Germany proportionately about 1,500 tonnes.

Biodegradable products on the market

Some products on the market are declared as environmentally friendly and even biodegradable because they contain a part of degradable cellulose. However, they do not have the corresponding certificates. The melamine content also remains non-biodegradable in any case. Consumers are being misled.

Several variations are now available, even including one sponge stabilised by another (equally non-biodegradable) plastic in the middle. However, this has no effect and ultimately more money is paid for a poorer performance. Consumers are yet again deceived.[6]

4 Recyclebank 2017: What Are Magic Erasers? 07/03/2017. Last accessed 07/01/2021. https://livegreen.recyclebank.com/column/because-you-asked/what-are-magic-erasers

5 Eurostat database Prodcom 2021. Last accessed 21/01/2021. https://ec.europa.eu/eurostat/de/web/main/data/database

6 Welfare, M. 2019: Schmutzradierer – Anwendungshinweise und praktische Tipps zum Wunderschwamm. 10/01/2019. Last accessed 07/01/2021. https://rsw24.de/faq/schmutzradierer-anwendungshinweise-und-praktische-tipps-zum-wunderschwamm

Policy and regulatory considerations

The use of melamine resins in erasers, which pose a health risk, is not regulated by law, so there is no incentive to use alternative products.

Other barriers

The most important barrier is that no environmentally friendly alternatives to melamine resins are yet available on the market and that there are no corresponding labels.

Dirt erasers are often marketed as environmentally friendly cleaners because they do not use chemicals. However, buyers are unaware of what the material is, how it works, and that the eraser does not "disappear" after use, but is released into the environment as non-biodegradable resin particles.

Technical requirements

The material must be foamable and have a high melt strength and viscosity. It must be kind to the skin and hard enough to ensure optimum abrasion resistance. The microscopic structure should be suitable for absorbing dirt particles. Degradation should only start after use, i. e. after abrasion.

Relevant standards and certificates

A dirt eraser produced by a major manufacturer is certified according to OEKO-TEX Standard 100 (for the subcategory foams). This certificate proves that the material contains no harmful substances. However, it is open to question and not apparent whether the behaviour of the material after heating was tested. The labelling additionally fails to refer to biodegradation. Since the particles are released in an uncontrolled manner and consequently end up in the environment, certification according to TÜV Austria or DIN CERTCO for biodegradability is required.

Possible substitutes

Pencil erasers can already be made from PHB or PHB copolymers, but they do not meet the technical requirements for dirt erasers. This product has been developed so specifically to use the properties of melamine resin that a biodegradable version does not currently exist; there is a considerable need for further research and development.

Possible substitutes are cellulose-based sponges together with environmentally friendly detergent.[7]

Outlook

Currently, the only recommended approach is to abandon dirt erasers and conduct further research, as there is so far no biodegradable alternative with an equivalent function. The necessary hardness of the material cannot yet be achieved by any biodegradable material substitute.

7 Umbra 2016: Are those magic sponges terrible for the environment? 16/12/2016. Last accessed 07/01/2021. https://grist.org/living/are-those-magic-sponges-terrible-for-the-environment/

Plastic components in fireworks parts

Preventing the permanent release of plastics into the environment with innovative materials

Description

The custom of driving away evil spirits at the turn of the year with loud noises and bangs originates from pagan times.[1] Firework rockets are widely popular despite growing criticism of their environmental effects. A firework transports what is known as the effect charge into the sky, where it burns off. After that, the remaining parts of the now broken rocket fall back to the ground.

Main material currently used

There are various designs used for this application. The tube is usually made of glued paper and more rarely of plastic or plastic fibres. Other parts of the missile, especially the safety cap, the propellant charge case and the missile head, are made of plastic;[2] the predominant plastic used is high-density polyethylene and polypropylene. ABS and PVC are also used for professional fireworks.[3]

1 Norddeutscher Rundfunk 2020: Silvester-Bräuche: Warum feiern wie den Jahreswechsel? 30/12/2020. Last accessed 21/01/2021. https://www.ndr.de/ratgeber/verbraucher/Silvester-Warum-feiern-wir-mit-Feuerwerk,silvester742.html

2 Pyroland 2021: Technischer Aufbau von Feuerwerkskörpern. Last accessed 21/01/2021. https://www.pyroland.de/Feuerwerkskoerper-Wissen

3 SAPEA Science Advice for Policy by European Academies 2020: Biodegradability of Plastics in the open Environment. Sapea (Ed.), 14/12/2020. Download at https://ec.europa.eu/info/research-and-innovation/strategy/support-policy-making/scientific-support-eu-policies/group-chief-scientific-advisors/biodegradability-plastics-open-environment_en

Problematic

The plastic parts of spent components in fireworks spread widely in the environment. Some of the parts that end up on streets and pavements are picked up by sweepers and put into the recycling stream; here they should be recyclable with the rest of the materials. However, most end up and remain in the natural environment, gardens or sewers for decades until the plastic pieces are broken down by the forces of nature into smaller pieces or even microplastics.[1]

Market volume in Germany / the EU

The volume of rocket fireworks produced in the EU is about 6,000 tonnes[4] per year, 20 % of which will be plastic, i. e. about 1,200 tonnes. Germany thus accounts for around 200 tonnes of plastic parts. About 128,000 tonnes of fireworks are imported into the EU from China every year.

Biodegradable products on the market

The essential parts of the fireworks consist of cardboard tubes, which are basically biodegradable (provided that the glues and paints used are also biodegradable). Classic rocket fireworks that are also fully biodegradable are currently only offered by one Turkish producer, who markets them as biodegradable (and halal). However, no certificates are available. Nevertheless, the trade is showing interest in this product. A producer from Spain sells a product that also has no certificate for biodegradation on soil.

Small manufacturers market alternative fireworks made of paper and clay as so-called "eco-bangers".

Policy and regulatory considerations

Fireworks are already banned in some cities and areas, though not necessarily because of the waste produced, but because of the considerable fine dust pollution.[5] In principle, the waste produced is subject to the KrWG, which does not mention biological degradation. However, according to current knowledge, a large proportion of fireworks end up in the natural environment, where biodegradation would be beneficial.[1]

Other barriers

Lack of environmental awareness regarding fireworks and higher prices are the main barriers. In fact, environmentally conscious segments of the population tend to avoid fireworks altogether. It is therefore doubtful whether more expensive missiles would meet with approval among the remaining segments of the population.

Technical requirements

The material must be flame retardant and impervious to moisture. The base material must first be free-flowing, as the parts are processed with thin walls in an injection moulding process. Since it is a mass-produced seasonal product with a short life span, it should be cheap. It must have structural stability with the option for an attractive exterior and colourful

4 Eurostat PRODCOM database. Last accessed 21/01/2021 https://ec.europa.eu/eurostat/de/web/products-eurostat-news/-/EDN-20191231-1

5 Dauert, U., Straff, W., Gerwig, H., Myck, T. and Kuntze, D. 2020: Zum Jahreswechsel: Wenn die Luft „zum Schneiden" ist. German Federal Environmental Agency. 11/2020. Download at https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/hgp_wenn_die_luft_zum_schneiden_ist_2019.pdf

design. The parts should be rapidly biodegradable when released into the environment.

Relevant standards and certificates

Since the rocket parts land uncontrollably in the environment, it is not so easy to determine the degradation site precisely. In addition to soil, degradation in water and the sea is also relevant. So far, there is no scientific standard on biodegradability in soil, except specifically for mulch films. Therefore, there is also no applicable standard governing parts of fireworks and their described persistence in the environment. The certificates for biodegradation in soil, water and marine environment from TÜV Austria and DIN CERTCO are relevant for this application.

Possible substitutes

Possible substitutes are PHB or PHB copolymers in blends. Certain PHAs are biodegradable in soil, have good heat and moisture resistance and can be coloured. PHAs can be processed by injection moulding. Flame protection could be achieved with lignin derivatives. Other possible substitutes would be starch blends with copolyesters such as PBAT. Since there are already smoke grenades from PHB[6], technical feasibility has been demonstrated.

PLA can only be proven to be compostable within the considered degradation periods set out in the certificates of TÜV Austria or DIN CERTCO under industrial conditions. However, PLA will also biodegrade in the soil in the long term – just not in the time specified in the certificates – and is therefore also suitable for use.

Outlook

Fireworks not only cause noise and dust emissions, but also discharge plastic parts into the environment. The latter problem could be almost completely avoided if they were made of paper and PHAs. However, as this would entail considerable additional costs, it will hardly be possible to develop this market without political guidance.

6 Hänggi, U. (Biomer) 2021: Personal communication. 08/02/2021

Tea bags, tea, hot chocolate and coffee pods

Traditional solutions based on natural and cellulose fibres are still the best

Description

Tea bags are small filtration bags that usually contain a single serving of tea. Most are provided with a thread so that the bags can be easily removed from the cup, as well as a small paper label at the end of the thread to identify the variety, manufacturer, brewing time or similar. Tea pods, coffee pods and hot chocolate pods fall under the same category, as they are also made of filter material. Such pods, also filled with a single portion of coffee, tea or cocoa, are designed for use in a machine designed to dispense the corresponding beverage.

Main material currently used

The predominant materials used today are cellulose and manila fibres and abaca fibres, often reinforced with polypropylene fibres for heat-sealable bags. Other tea bags are closed by folding and sewing with cotton fibres. Another common design is pyramid tea bags, made of polyamide (nylon), PET or PLA.[1]

Problematic

Tea bags and tea, cocoa and coffee pods give most consumers the impression that they are made only of natural fibres or cellulose fibres – as they historically were and still are in some cases – and are therefore readily biodegradable. Accordingly, these products are usually disposed of with organic waste which they can contaminate with plastic fibres. This applies to both tea bags made from natural fibres or cellulose fibres to w hich plastic fibres have been added, and to tea bags made entirely from plastic fibres (see also “other barriers“ on page 108). A 2019 study showed that billions of micro and nano plastic particles are released per cup.[2]

1 Wagner, P. 2018: Einmal Tee ohne Plastik, bitte! 07/03/2018. Last accessed 21/01/2021. https://enorm-magazin.de/wirtschaft/plastik/einmal-tee-ohne-plastik-bitte

2 Hernandez, L. M., Xu, E. G., Larsson, H. C. E., Tahara, R., Maisuria V. B., and Tufenkjji, N. 2019: Plastic Teabags Release Billions of Micro-

Market volume in Germany / the EU

Approximately 47 billion cups of tea were consumed in Germany in 2019. Assuming that about 65 % of tea is consumed in bags[3], this translates into about 30 billion cups prepared with a tea bag and correspondingly 30 billion tea bags. With a typical weight of 0.3 grams per tea bag[4] (bags without tea), the total quantity would thus be about 9,000 tonnes of tea bags (bags without tea) per year in Germany and about 56,000 tonnes for the EU28. For coffee pods, the market volume was 29,300 tonnes (including content) in Germany in 2019.

Biodegradable products on the market

Classic tea bags made of paper, natural fibres (especially abaca) and cellulose fibres are biodegradable and can be disposed of in the compost. Tea bags made from PLA are only certified for industrial composting.

There are a number of suppliers of tea bags (fewer for coffee pods) who advertise that straightforward compost disposal is possible. However, during research, few products were found that certified compostability.[5]

Policy and regulatory considerations

The interpretative aid provided by the Federal Ministry for the Environment to supplement the Regulation on Bio-Wastes indicates that tea bags can be disposed of as organic waste.[6] In fact, however, problems arise in the composting plant due to the plastic content, so this recommendation should be questioned given the materials currently used in tea bags. However, it is not a barrier to the introduction of biodegradable materials, as it clearly demonstrates that industrial compostability is desired as a disposal route for tea bags. Therefore, a recommendation of this kind would actually be an ideal justification for stricter material specifications by policy makers.

Other barriers

Most tea bags, even supposedly high-quality products which wish to set themselves apart from classic tea bag, nowadays release plastics that are not always industrially, let alone domestically compostable. These include the pyramid tea bag which is supposed to give the tea more room to develop its flavour. The lack of consumer awareness about tea and coffee packaging materials is an obstacle.[7]

Many modern production facilities process tea bags with a heat-sealing process. However, this requires a tea bag with a heat-sealable material. Bags made only of natural fibres do are not processable in production lines of this kind. There, a small amount of polymer is required for the bag to be heat-sealable. This is one reason why plastics are also widespread in tea bags made from cellulose fibres.

Technical requirements

The bags must be tear- and water-resistant and, at least for a short time, be able to withstand a tempe-

particles and Nanoparticles into Tea. Environ. Sci. Technol, Vol. 53 (21), 12300-12310. doi: 10.1021/acs.est.9b02540

3 German Tea and Herbal Tea Association 2020: Tea Report 2020. German Tea and Herbal Tea Association (Ed.), 2020. Download at https://www.teeverband.de/files/bilder/Presse/Marktzahlen/TeeReport_2020_ES.pdf

4 Van der Zee, M. and Molenveld, K. 2020: The fate of (compostable) plastic products in a full scale industrial organic waste treatment facility. Wageningen Food & Biobased Research (Ed.), 02/2020. doi: 10.18174/514397

5 Pandya, O. Plastic Free Tea Bags: 5 Solutions Tea Providers Are Using. Last accessed 11/01/2021. https://www.greyb.com/plastic-free-tea-bags/#

6 Federal Ministry for the Environment, Nature Conservation and Nuclear Safety 2020: Das gehört in die Biotonne. Last accessed 11/01/2021. https://www.bmu.de/themen/wasser-abfall-boden/abfallwirtschaft/abfallarten-abfallstroeme/bioabfaelle/das-gehoert-in-die-biotonne/

7 Widmann, E. 2019: Teebeutel geben große Mengen Mikroplastik ab. 25/09/2019. Last accessed 11/01/2021. https://www.nzz.ch/panorama/teebeutel-geben-grosse-mengen-mikroplastik-ab-ld.1511030

rature which may exceed 100 °C. They must be water permeable (filter quality according to existing standards), toxicologically harmless and food safe. If the fabric is made of synthetic fibres, the material for its manufacture must have a low viscosity. In many modern production facilities, the bags are heat-sealed; this demands a heat-resistant material, if necessary reinforced with a (biodegradable) polymer.[8]

Relevant standards and certificates

The DIN EN standards 13432 (Packaging – Requirements for packaging recoverable through composting and biodegradation) and 14995 (Plastics – Evaluation of compostability) govern the biodegradability of plastics. However, these are limited purely to industrial compostability, which is equivalent to disposal via the organic waste bin. Tea bags are not generally considered to be packaging, which is why they are not directly covered by DIN EN 13432. However, there are several certificates from TÜV Austria and DIN CERTCO that certify industrial compostability on the basis of DIN EN 13432. There are also applicable certifications (TÜV Austria and DIN CERTCO) for disposal via home compost.

Possible substitutes

Obvious substitutes for non-degradable plastic fibres, as they are already in use, are biodegradable cellulose and abaca fibres, which are closed by folding and sewing with cotton fibres. These alternatives meet the technical requirements and the use of plastics is not necessary *per se*. However, for production lines where the tea bags are heat-sealed, a small part of polymer is necessary, as this is not an option for natural fibres.[6] PLA is a suitable alternative to conventional plastics for heat-sealed bags and is already used by some brands. To offer pyramid bags or other special shapes made of a material certified for home composting, other polyester fibres would be suitable, such as PBSA, PBAT or PHB copolymers. However, proof of technical feasibility has yet to be provided.

Outlook

Back to the roots is the motto here. For centuries tea bags were made from abaca fibres. These natural fibres retain their tensile strength even in hot water and are also biodegradable in home compost. Later, solutions with cellulose and cotton fibres were added. Biodegradable solutions are also already available for heat-sealed tea bags or special shapes.

8 Mohan, S. (Unilever) 2020: Personal communication. 28/09/2020

Fishery

The products and applications in the following section are used in fisheries. This product group is small in the context of the project (by far the largest share comes from so-called ghost nets, which were not considered in the project as there are no biodegradable alternatives), but due to the global and incalculable scale it is very important and relevant to prevent plastic release into water.

Dolly ropes

Alternatives here are as important as they are difficult to implement

Description

In the fishing industry, high-quality fishing nets are dragged across the seabed by trawlers. As they trawl the sandy seabed, the nets are subject to heavy abrasive wear by stones or other larger objects such as anchors and shipwrecks. To prevent wear and damage to the nets, they are protected with ropes. These ropes are called "dolly ropes" and are made of thin plastic threads. The fishermen knot the dolly ropes or attach them to the nets with cable ties before fishing. As they trawl, the ropes spread out into tiny threads and form a kind of protective cushion between the nets and the seabed.[1]

Main material currently used

The predominant material used is polyethylene. 99 % of the finds of dolly rope fragments prove this.[2] Dolly ropes made from polyamides such as nylon and polypropylene are also available on the market.

Problematic

As they protect the actual fishing net from stones or other objects that cannot be located by GPS, the dolly ropes inevitably wear out. They only last a few weeks. The torn-off parts of the dolly ropes and their microplastic debris persist in the sea. Seabirds incorporate vast numbers of single filaments into their

1 Lost fishing nets, which account for a large proportion of the annual 640,000 tonnes of plastic discharged into the oceans worldwide, are not considered in detail in this project. This problem is well known, but requires a different solution: longevity of the material and recycling are better options in this circumstance than biodegradation, especially since no suitable biodegradable material solution is known to date.

2 Möllmann, N. (NABU) 2020: Personal communication. 06/07/2020

nests. As a consequence, birds get trapped and die of exhaustion or strangulation trying to free themselves.[3]

Biodegradability of the detached and abraded fragments could considerably reduce these problems.

In principle, it is possible to fish without the use of dolly ropes, but then the nets are then less protected against contact with stones or larger objects, are subject to much greater abrasion and tear more easily. This also means additional plastic enters the sea.

Market volume in Germany / the EU

Data on the annual market volume of dolly ropes in the EU is unknown. Figures are only available for Belgium and the Netherlands. For these two countries alone, an annual volume of 100 to 200 tonnes is estimated.[4] Dolly-ropes are prohibited in the Baltic Sea; in German coastal fisheries about 30 % of fishing boats use dolly-ropes.[3]

France, England and Ireland fish with dolly ropes, but the market volume is difficult to measure. Dolly ropes are not generally used in southern Europe.[1]

The total market volume for dolly ropes in the EU is likely to be around 1000 tonnes per year.

Biodegradable products on the market

So far, there are no biodegradable dolly ropes on the market. A company from the Netherlands is currently running a project to develop biodegradable dolly ropes made of bio-based polymers. The product is expected to be launched in 2021.

Policy and regulatory considerations

To date there are no political or regulatory requirements for the use of particular materials in fishing nets or other marine equipment. Commission Regulation (EC) No 356/2005 on the marking and identification of passive fishing gear and beam trawls[5] only requires that fishing vessel gear be clearly marked so that it can be attributed to a specific vessel in the event of loss. Here, great importance is actually attached to durability, as the markings should be permanently recognisable.

Directive 2019/904 of the European Parliament and of the Council on reducing the impact of certain plastic products on the environment (Single-Use Plastics Directive) also addresses the impact of fishing gear on the marine environment. However, it focuses on the collection of fishing gear, or the use of alternative materials instead of plastic. These measures do not cover accidental abrasion of fragments that cannot be collected.

The Single-Use Plastic Directive does not consider biodegradation in the sea as a solution, as there is to date no accepted European standard for biodegradation in the sea. As long as this remains the case, there is a regulatory barrier to the use of such products.

Other barriers

The technical requirements combined with marine biodegradability present a significant barrier. For this reason, there is as yet no product on the market. Only if the current Dutch project is successful will it be possible to test whether the balancing act between mechanical properties and biodegradability in the sea has been achieved.

Technical requirements

It must be possible to produce the dolly ropes as fibre. They have a short life span of about two to three weeks. The material must therefore be UV-resistant, abrasion-resistant as well as tear-resistant for a short period of time. They also have to withstand in this short period of time very cold seawater and the ab-

3 Weisheng, L., Charles, P.O. 2001: Environmentally friendly chewing gum bases including polyhydroxyal-kanoates. US6194008B1.

4 Nijhoving, G. (Senbis Polymer Innovations) 2020: Personal communication. 15/05/2020, 12/07/2020

5 Bag-like nets trawled along the seabed for catching North Sea shrimps and flatfish in the Wadden Sea

sence of oxygen. When the dolly ropes detach from the net, they should ideally biodegrade rapidly.

Relevant standards and certificates

There is currently no standard that describes the biodegradability of a product in water or seawater. The certification system of TÜV Austria for marine environments can be used for this field of application.

Possible substitutes

Very few polymers are biodegradable under marine conditions: these include cellulose (fibres), PHB and PHB copolymers and special cellulose acetates (although these do so relatively slowly). In principle, all three should be suitable for dolly ropes, but PHB and PHB copolymers in particular are very expensive for this application. Products made of natural materials (yak leather, natural rubber, wood) and natural fibres (hemp, flax, sisal) are also being tested – as well as composites of natural fibres and the aforementioned polymers and polycaprolactones.

Copper threads are also being tried as an, albeit questionable, alternative.[3]

Other net designs as well as abandoning the use of dolly ropes altogether are also being tested. In principle, technical modifications to the fishing method could also make the use of dolly ropes partly superfluous.[6]

Outlook

As important as it is to reduce the amount of plastic entering the sea and use only plastics for dolly ropes and other fishing products that are biodegradable in this environment, there are still a number of technical hurdles to overcome in developing suitable products. A standard on the biodegradation of plastics in the sea would also have to be developed, preferably at an international level. Without political guidelines and research, it will be difficult to develop this market.

6 Thünen-Institut, 2018-2020: Verringerung von Kunststoffmüll aus der Krabbenfischerei durch Netzmodifikationen (DRopS). Last accessed 26/01/2021. https://www.thuenen.de/de/of/projekte/fischerei-surveytechnik/verringerung-von-kunststoffmuell-aus-der-krabbenfischerei-durch-netzmodifikationen-drops/

Non-durable products for fishery and aquaculture

Only international agreements can bring about change

Description

Non-durable products for fishery and aquaculture are used in leisure and commercial fisheries. These include fishing devices such as lures, floats and lines, which can easily be lost in the water.

Main material currently used

Fishing lures and floats may be made of a range of materials such as steel, polyurethane, silicone, polyester, ABS or wood. Fishing lures made of biocomposite materials are also available. As well as plastic bait, which is used exclusively to catch predatory fish, there is a range of natural baits which have proven valuable to catch both predator and prey species. These are often made of cereal seeds, vegetables, fruit or products such as bread or cheese.[1] Fishing lines are usually made of nylon, polyethene fibres or aramid fibre.

Problematic

10 %[2] to one third[3] of the plastic pollution in the sea stems from fishing. A large part of this comes from commercial fishing nets, which are among the ten most commonly found plastic products on beaches.[4]

1 Rhein-angeln 2021: Angelköder. Letzter Zugriff 2021-02-05. http://www.rhein-angeln.de/angelkoeder.htm

2 Thomas, K, Dorey, C., Obaidullah, F. 2019: Ghost Gear: The abandoned fishing nets haunting our oceans. Greenpeace Deutschland (Ed). 2019-11. Download unter https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/20190611-greenpeace-report-ghost-fishing-ghost-gear-deutsch.pdf

3 WWF 2018: Geisternetze – tödliche Gefahr. 2018-08-17. Letzter Zugriff 2021-02-05. https://www.wwf.de/themen-projekte/meere-kuesten/plastik/geisternetze

4 Addamo, A., Laroche, P., Hanke, G. 2017: Top Marine Beach Litter Items in Europe. Download at https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108181/technical_report_top_marine_litter_items_eur_29249_en_pdf.pdf

However, such nets are not considered further here as they are generally designed for longer-term use compared to the non-durable products for fishery and aquaculture in this profile. The focus here is rather on fishing lures and other short-lived products such as floats and fishing lines.

The plastic fibres and particles enter the sea and are eaten as macroplastics by fish and marine mammals and, after decomposition into microplastics, also by microorganisms, thus endangering animal life and the equilibrium of the marine ecosystem.

Market volume in Germany / the EU

11,000 tonnes per year of fishing products are uncontrollably released into the seas in the EU[5]; the German share of this is estimated at about 10 %, i. e. 1,100 tonnes. We estimate that about 90 % of fishing products are lost. This gives us a total production volume of around 12,000 tonnes for the EU and 1,200 tonnes for Germany.

Worldwide, a total of around 640,000 tonnes[6] of old fishing gear ends up in the oceans every year; this figure includes ghost nets, buoys, lines, traps and baskets.[7]

Biodegradable products on the market

Several manufacturers claim to sell biodegradable fishing lures, but without proof of biodegradability. For example, one manufacturer sells silicone fishing lures claiming that they are biodegradable. Biocom-

5 European Commission 2018: New proposal will tackle marine litter and "ghost fishing". 28/05/2018. Last accessed 05/02/2021. https://ec.europa.eu/fisheries/new-proposal-will-tackle-marine-litter-and-"ghost-fishing"_en

6 German Bundestag 2019: Specific questions on plastic fishing nets. Scientific Services 2019. Download at: https://www.bundestag.de/resource/blob/651440/8691240faf14560c609f871dc461c33d/WD-8-038-19-pdf-data.pdf

7 Thünen-Institut, 2018-2020: Verringerung von Kunststoffmüll aus der Krabbenfischerei durch Netzmodifikationen (DRopS). Last accessed 26/01/2021. https://www.thuenen.de/de/of/projekte/fischerei-surveytechnik/verringerung-von-kunststoffmuell-aus-der-krabbenfischerei-durch-netzmodifikationen-drops/

posite fishing lures based on cellulose and PHA are available in Scandinavia.[8] In the course of our research, we found a manufacturer that offers PHA-based fishing lures certified as "OK biodegradable WATER" and "MARINE" (TÜV Austria).[9] [10]

A few years ago, several companies tried to sell biodegradable fishing lines. They claimed that their product was biodegradable, but this was not proven. These products are no longer on the market today.[11]

Policy and regulatory considerations

A large number of regulations and recommendations at national, regional and international levels deal with lost and discarded fishing products for commercial fishing.

These are often transnational and either present inadequacies or major loopholes in their implementation and enforcement. They are also mainly concerned with long-lasting fishing gear such as nets and traps lost at sea, although they do, in principle, cover short-lived fishing gear. Overall, they cannot cope with or relevantly reduce the scale and impact of ghost nets and losses from fishing.[7]

Recreational fisheries mainly use short-lived fishing products, which often end up first in fresh water and then possibly in the sea; these are addressed by different regulatory tools. Lost fishing gear used in recreational fishing is generally covered by the Circular Economy Act. However, this states that the producer of waste is only obliged to return the waste to the material cycle if it is technically possible and economically reasonable to do so. In the case of lost fishing gear in water, collection is often not feasible.

Other barriers

International waters require global policy rules to protect them from plastic pollution. These are, however, yet to be devised. The UN has recognised this gaping loophole in maritime policy and is currently negotiating an agreement within the framework of the United Nations Convention on the Law of the Sea (UNCLOS). There are also no internationally recognised standards on biodegradation in marine environments. There exist only the private sector classifications "OK biodegradable MARINE" and "WATER" from TÜV Austria. Furthermore, biodegradable fishing products should not encourage anglers and fishers to dispose of products in the sea or freshwater. As biodegradability in the sea and other bodies of water can only be achieved with specific materials, availability and price are further obstacles.

8 Finnish Environment Institute 2019: Only some biodegradable plastics actually decompose rapidly in the Baltic sea. 14/11/2019. Last accessed 28/01/2021. https://www.syke.fi/en-US/Current/Only_some_biodegradable_plastics_actuall(52751)

9 Sherman, L. M 2015: First Totally Biodegradable Fishing Lure Soon to Debut. Last accessed 22/01/2021. https://www.ptonline.com/blog/post/first-totally-biodegradable-fishing-lure-soon-to-debut

10 Danimer Scientific 2021: Our PHA Resin Has Been Certified as Biodegradable and Safe for Use in Food-Contact Applications. Last accessed 05/02/2021. https://danimerscientific.com/pha-certifications

11 RealReel Fishin 2020: biodegradable fishing line – everything you need to know. Last accessed: 22/02/2021. https://www.realreelco.com/post/biodegradable-fishing-line

Technical requirements

The fishing products must withstand environmental influences while in use (heat, cold, sea-water, fresh-water, UV radiation and microorganisms) and must not biodegrade prematurely. Bait should be very dense, abrasion-resistant and have high impact strength. Materials for fishing lines should exhibit good tensile strength and elasticity and be made of fibres. Fishing lines should also have a relatively high density and be available in different colours. The requirements for biodegradation in salt and freshwater are very demanding.

Relevant standards and certificates

So far, only TÜV Austria offers the certifications "OK biodegradable MARINE" and "OK biodegradable WATER". To discourage the disposal of products with this certification in the sea or freshwater, TÜV Austria does not allow the proof of certification to be applied to the final products. For degradation in freshwater, the certification may only be applied to products intended for use in that environment, i. e. freshwater. In the case of marine degradation, certification may only be labelled on products where biodegradation provides an additional environmental benefit. This is explicitly the case for fishing products.

Possible substitutes

The low density of bacteria and fungi in seawater means that the requirements for biodegradation in the sea are much higher than under almost all other environmental conditions – apart from desert sand. Only a few, special materials are rapidly biodegraded under these conditions.

Starch blends can be used for fish bait. PHB and PHB copolymers are equally suitable as substitutes and are already available on the market.

Amateur anglers can even prepare gelatine-based fishing lures at home.[12]

A patent describes a biodegradable material for fishing lures based on a polysaccharide such as starch, a natural protein such as gelatine, casein whey or gluten, and a water-soluble natural gum.[13] Some mineral or metallic fillers are also suitable where high density is needed.

In the case of fishing lines, only a few biodegradable polymers meet the high technical re-quirements and properties allowing degradation under marine conditions that would allow them to be used as substitutes. PHB copolymers and special cellulose acetates could meet the specification. Composites with natural fibres such as hemp, flax, jute or sisal would also be suitable.

Outlook

10 % to one third of the plastic pollution in the sea is due to fishing, mainly large fishing nets. But non-durable products for fishery and aquaculture are also lost in the sea, where they can endanger animals and become microplastics. International agreements are needed to achieve the potential for reduction; these are already being discussed at the UN. In fresh and saltwater, biodegradable fishing lures, floats and lines could reduce the amount of plastic entering the water.

12 Instructables: Biodegradable Fishing Lures. Last accessed 12/03/2021. https://www.instructables.com/Biodegradable-Fishing-Lures

13 Ollis, H. D., Diaz-Version, S., Bell, L. N., Weese, J. O., Wei, C. I., and Wright, R. A. 2002: Biodegrada-ble fishing lure and material. US6753004B2

Others

The following products and applications fall into other application areas. They are used commercially and by the end user and end their lives in different environments

Bristles for sweeping brushes

Previously overlooked: Substantial plastic release due to sweeping bristles – alternatives available

Description

Road sweepers are implements for picking up dirt on the road or paths. They have roller or disc brushes with plastic bristles on the side or underneath the vehicle, which transport the swept material into the internal dirt container.

Main material currently used

The most commonly used material varies from cleaning company to cleaning company and depending on the location.[1] It can be flat wire (steel or iron), but also polypropylene. There are also bristles made of polyester, polyamide (like nylon) as well as combinations of these materials.[2]

Problematic

When the streets are cleaned, the bristles wear down continuously, releasing pieces of bristles and microparticles in the form of abrasion into the environment. The bristle pieces decompose over time to microplastics and enter the soil, pass into the wastewater system in rain run-off or are swept by rivers into the sea. The bristle loss rate for road sweepers is 80 %.[3] This abrasion ends up in the environment unhindered.

1 Berggötz, T. (Kärcher) 2020: Personal communication. 26/11/2020

2 Schill, S. (Abfallwirtschaftsbetriebe Köln) 2020: Personal communication. 14/12/2020

3 Ollis, H. D., Diaz-Version, S., Bell, L. N., Weese, J. O., Wei, C. I., and Wright, R. A. 2002: Biodegrada-ble fishing lure and material. US6753004B2

Market volume in Germany / the EU

Assuming a market in the EU of 250 million brushes for all types of sweepers, with each brush weighing on average of 500 grams, the total volume is 100,000 tonnes. For Germany, this is the equivalent of around 16,000 tonnes.[4] Calculating the volume of losses based on abrasion up to 80 %, you reach 80,000 tonnes for the EU and around 13,000 for Germany.

Biodegradable products on the market

There are at least two manufacturers from Germany that offer biodegradable bristles made from starch and PLA. According to their own manufacturer, they are even compostable according to the DIN EN 13432 standard, but they cannot verify this with a certificate.

Policy and regulatory considerations

The bristles are theoretically subject to the Circular Economy Act (KrWG), as is the waste produced during use due to abrasion and fallen bristles. According to the KrWG, the obligation to recycle waste must be met in as far as technically possible and economically reasonable. However, this is not the case with bristle abrasion, so that the bristle pieces usually remain in the environment.

Other barriers

The low price of polypropylene bristles compared to a biodegradable alternative (additional cost of about 10-15 EUR per broom disc, depending on the model)[5] is the crucial barrier. Indeed, a lack of awareness of the problem and suitable alternatives are also barriers for the responsible cleaning companies and other users.

Technical requirements

Sweeper bristles must be resistant to environmental influences (heat, cold, rain, UV, microorganisms), and to oil, diesel or petrol. The stiffness should be adjustable depending on the application. The most important properties are the necessary high abrasion resistance, elongation at tear and toughness. Durability is also required. The bristles should be sufficiently firm, but should not break even when sweeping. The small particles that may be released into the environment should biodegrade rapidly.

Relevant standards and certificates

Bristle particles and debris pass via the surface of the ground into various environments where they are expected to biodegrade (soil, wastewater). Therefore, the certificates from TÜV Austria are relevant according to the respective degradation sites.

Possible substitutes

PHB copolymers and some types of cellulose acetate could be technically suitable.

4 Eurostat database Prodcom 2021. Last accessed 21/01/2021. https://ec.europa.eu/eurostat/de/web/main/data/database

5 Instructables: Biodegradable Fishing Lures. Last accessed 12/03/2021. https://www.instructables.com/Biodegradable-Fishing-Lures

PLA is only certified to be compostable within the considered degradation periods set out in the certificates of TÜV Austria or DIN CERTCO under industrial conditions. The biodegradation of PLA in nature is slower than the certificates allow – although it does take place. PLA or PLA blends with PBAT, PBS or starch could meet the technical requirements for bristles.

Biodegradation can be promoted by combining the above polymers with organic fillers such as natural fibres, wood flour or agricultural residues such as sunflower seed hulls.

Steel is also a durable substitute, and used often to be employed for this purpose, but was then displaced by plastic.

The natural material used was originally brushwood.[6] However, it is likely that this material cannot be used commercially in modern road sweepers.

Outlook

Every municipal street cleaning service needs bristles for its sweepers. These machines are also used in industry and for private use. The abrasion of the bristles results in considerable amounts of plastic and microplastics being released into the environment. Biodegradable bristles could significantly reduce the load. However, as these alternatives are more expensive, accompanying policy measures would be very helpful.

6 Donner, C. 2020: Die historische Entwicklung der Kehrmaschine. 10/2020. Last accessed 08/01/2021. https://kehrmaschine-kaufen.de/ratgeber/die-historische-entwicklung-der-kehrmaschine/

Chewing gum

Natural alternatives will eventually biodegrade and disappear from streets

Description

Chewing gum is an easily deformable and chewable mass. Flavourings such as corn syrup or menthol give the chewing gum a sweet or minty taste. Chewing results in an increased flow of saliva, which neutralises food residues and acids that are harmful to teeth. This increases the pH value in the mouth and so stops bacteria from reproducing. What is often not known is that the "chewing mass" consists of persistent, non-biodegradable or even digestible material – quite unique for a food.

Main material currently used

Chewing gum consists essentially of petroleum-based polymers such as PVA, styrene-butadiene rubber, isobutene-isoprene rubber (also known as butyl rubber), polyisobutylene or polyethylene.[1] Waxes such as paraffin are also used.[2] For consumers, the ingredients are usually not broken down and manufacturers only have to list "chewing mass" as an ingredient.[3] Many consumers are now aware that conventional chewing gum is made of plastic.[4 5 6]

1 Lindsay, J. 2018: Did you know most chewing gum contains plastic? 02/08/2018. Last accessed 21/01/2021. https://metro.co.uk/2018/08/02/know-chewing-gum-contains-plastic-7790722/#metro-comments-container

2 Codgell, C. 2019: Lifecycle of Chewing Gum. 03/12/2019. Last accessed 21/01/2021. http://www.designlife-cycle.com/new-page-48

3 Thielking, H. 2019: Merchandise Sales Gum. 18/01/2019. Last accessed 21/01/2021. https://lebensmittelpraxis.de/warenkunden/23805-warenverkaufskunde-kaugummi-2.html

4 Jötten, F. 2015: Kaugummis-"Die Kaumasse besteht vor allem aus Kunststoff". 11/03/2015. Last accessed 21/01/2021. https://www.spiegel.de/gesundheit/diagnose/aus-was-besteht-kaugummi-a-1022838.html

5 Verbraucherzentrale Bayern e. V. 2019: Woraus besteht Kaugummi? – Essen, Trinken und Genuss – hätten Sie's gewusst? 18/04/2019. Last accessed 21/01/2021. https://www.verbraucherzentrale-bayern.de/wissen/haetten-sies-gewusst/woraus-besteht-kaugummi-35635

6 Chesnokova, O. 2020: Was alles in Kaugummis steckt. 22/10/2020. Last accessed 21/01/2021. https://www.gesundheit.de/ernaehrung/rund-ums-lebensmittel/kaugummi-kauen

Problematic

Used and sticky chewing gum can be seen everywhere, especially in urban environments. It ends up on the floor in public areas or even on seats in public transport, in the cinema, on a chair in the bistro or a bar stool in the pub. Chewing gum is one of the products most often carelessly disposed of in the environment.[7] Stuck chewing gum remains visibly stuck to the ground for years until it finally breaks down into microplastics and remains in the environment.

The removal of chewing gum is complex and is usually done by freezing or superheated steam or with special cleaning agents that dissolve the gum. In the process, the cleaning agents often remain in the natural environment. The cleaning costs for removing chewing gum from public spaces are enormous: one to three euros per piece. This corresponds to an extrapolated total of approx. 900 million euros for Germany, based on ten chewing gums per square metre in public places, in some places even up to 80 pieces per square metre.[8]

Market volume in Germany / the EU

The market volume in the EU amounts to 70,000 tonnes per year[9]; this suggests a German contribution of about 11,000 tonnes.

Biodegradable products on the market

A few small companies or start-ups have developed chewing gum based on natural raw materials such as chicle gum and (to an extent) traditional recipes and introduced them to the market. They advertise "biological degradation", but usually without proof or certification.

Policy and regulatory considerations

Although it contains no biodegradable ingredients, chewing gum is classified as a food according to the General Food Law.[10] However, there is no provision in either the KrWG (Closed Substance Cycle Waste Management Act) nor the BioAbfV (Regulation on Bio-Wastes) for the disposal of chewing gum. So it theoretically has to be disposed of in general waste.

Other barriers

The main barriers are the market dominance of a few large chewing gum brands that do not offer biodegradable varieties. Consumers are often also un-

7 Umweltbundesamt 2020: The level of waste in the environment remains very high. 05.28/2020. Last accessed 21/01/2021. https://www.umweltbundesamt.de/themen/weiterhin-sehr-hohes-aufkommen-von-abfaellen-in-der

8 Salt 2016: Mit Heißdampf gegen Kaugummis. 20/07/2016. Last accessed 21/01/2021. https://bi-medien.de/fachzeitschriften/galabau/kommunaltechnik/mit-heissdampf-gegen-kaugummis

9 Eurostat database Prodcom 2021. Last accessed 21/01/2021. https://ec.europa.eu/eurostat/de/web/main/data/database

10 European Parliament and Council 2002: REGULATION (EC) No 178/2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety Official Journal of the European Communities, 01/02/2002. Download at https://www.bfr.bund.de/cm/343/2002_178_de_efsa.pdf

aware that chewing gum is usually made from petroleum and that natural alternatives are available without compromising enjoyment. Alternative chewing gum manufacturers have so far had such a small market share that they are hardly known – but this could slowly change in the context of the microplastic discussion.

Technical requirements

The product requires food approval and must be resistant to saliva and hydrolysis. It must have high elasticity and elongation at break properties and be tough. Even after some chewing time, the gum must still be firm. Basically, flavour neutrality is useful because flavours should be added individually. Once it has served its purpose, the biodegradable chewing gum should be able to degrade within a few months when exposed to UV and weathering.

Relevant standards and certificates

Since chewing gums often remain on the ground, stones or especially asphalt after use, a standard for biodegradability would be required for these conditions. However, for asphalt in particular, there is currently no applicable standard on degradability. However, the certification for biodegradation in soil and freshwater by TÜV Austria could be used as a guideline, even if the actual degradation times for asphalt, for example, are likely to be longer due to the lower biological activity.

Possible substitutes

Possible environmentally friendly substitutes are various natural gums such as chicle gum or jelutong (milk sap of the tree species Dyera costulata), which were originally used for chewing gum. Natural waxes are also available (e. g. candelilla waxes). At least three products made with a chicle chewing mass are already available on the market, but do not have a certificate regarding biodegradability because no suitable standard exists.[11] A patent on environmentally friendly chewing gum based on PHA (homopolymers and copolymers) has already been filed, but so far without any concrete commercial application.[12]

Another approach is to find a material that will dissolve on asphalt at least enough (e. g. by UV radiation) to be washed away with the rain and then biodegrade in the water. However, this has not yet been further researched.

Outlook

Society has become accustomed to finding chewing gum everywhere, which does not biodegrade and remains permanently in the environment. The first products made of environmentally friendly material show that there are new approaches: chewing gum can theoretically biodegrade in certain environments and quickly disappear from the environment, but there are still no standards that include persistence on asphalt. As soon as the public, environmental groups and politicians recognise this option, large markets for alternatives could open up and considerable cleaning costs could be saved.

11 Rau, L. 2020: Plastikfreie Kaugummis aus Baumsaft. 26/10/2020. Last accessed 21/01/2021. https://enorm-magazin.de/lebensstil/nachhaltige-produkte/plastikfreie-kaugummis-aus-baumsaft

12 Weisheng, L., Charles, P.O. 2001: Environmentally friendly chewing gum bases including polyhydroxyalkanoates. US6194008B1.

Geotextiles and ground spikes

Opportunities for natural fibres, biodegradable plastics and biocomposites

Description

Geotextiles and erosion protection films are a subcategory of technical textiles and describe textiles or textile structures that serve as building materials in civil engineering, water engineering and road construction and are an important aid for geotechnical reinforcement. They help to avoid the process of land erosion by wind, flowing and falling water. This is a necessary and beneficial step when the soil is not naturally stabilised by plants and roots. Even "extreme" locations can be developed using geotextiles.

This fact sheet also looks at geotextiles for hydraulic engineering, used for bank protection, as well as film fastening pins, known as ground spikes. Ground spikes fix the textiles and films in the ground.

Main material currently used

The most commonly used material at present is polypropylene. PET is also widely used. Depending on the requirements (e. g. specific density), mixtures are also used.[1]

Geotextiles made of natural fibres such as reed, jute, coconut, hemp or flax are also available. Combinations of synthetic materials and natural fibres are also used.

Ground spikes are made of round steel bars, aluminium or also polypropylene. Solid wood ground spikes are mainly used in private gardens.

Problematic

Geotextiles and erosion protection made of PP and PET fibres or films remain largely unchanged in the

1 Mählmann, J. (STFI Chemniz) 2020: Personal communication. 29/09/2020

soil for a long period of time before breaking down into larger particles and finally into microplastics.

Natural fibres are only used when biodegradation is desired. However, the decomposition time cannot be easily determined. As the 100 % bio-based natural fibre fabric has only a short life (often less than 12 months), plants have to become established within one vegetation period, which is often too short for stabilisation. To achieve this, the natural fibre mats are reinforced with PP fibres, making them more manageable and durable;[6] However, the PP fibres then remain in the soil permanently, while the natural fibre biodegrades.

Market volume in Germany / the EU

The market volume of geotextiles in the EU is around 95,000 tonnes, and an estimated 15,000 tonnes for Germany. This was calculated based on the price of USD 2.90 per kilogram of geotextile (both natural fibre and synthetic) and a total market of USD 460 million.[2] The global market is valued at USD 8.7 billion.

In Germany, 15,000 km of riverbanks and waterways (about 7,300 km of waterway, on both sides) are protected by geotextiles and aquatextiles.[3]

Biodegradable products on the market

Natural fibres such as reed, jute and coconut fibres and even sheep's wool are well established in the market for less demanding applications. As well as being biodegradable, natural fibres have other advantages over synthetic fibres: they can absorb and store water. Natural fibres are supple, adapt ideally to any unevenness in the floor and can therefore be processed very well. Certified material made from a blend of a biodegradable polymer and a compostable polymer is also available.

Ground spikes are also already being made from biodegradable bioplastics. However, these usually do not have certification for biodegradation in soil.

Political and regulatory framework

For waterways in Germany, there are guidelines issued by the Federal Waterways Engineering and Research Institute (BAW).[4] Currently, the guidelines here state that biodegradable geotextiles may not be installed because a minimum durability is prescribed. The guidelines are currently being revised.[5]

Biodegradable geotextiles (straw, jute, coconut fibres, etc.) are considered "geosynthetics", in German, despite the fact that they are not plastics. Another contradiction in German law is that if a "biodegradable geotextile" has a plastic mass content of less than 4 %, it is no longer subject to declaration.[6]

Depending on the area of application, both the regulations and the requirements for the geotextile are different. On steep slopes, for example, a more stable material is prescribed than in traffic route construction. Only a few applications currently allow geotextiles to be actually biodegradable.

2 Global Market Insights, INC. 2018: Geogrids Market in Europe to exceed $460 mn by 2024. 24/07/2018. Last accessed 07/01/2021. https://www.globenewswire.com/news-release/2018/07/24/1540966/0/en/Geogrids-Market-in-Europe-to-exceed-460-mn-by-2024-Global-Market-Insights-Inc.html

3 Fleischer, P. 2020: Von wegen guter Rutsch! – Biokunststoffvlies stabilisiert Gewässerböschungen – Entwicklung definiert abbaubarer Geotextilien zur Anwendung als temporäre Filter in technisch-biologischen Ufersicherungen an Binnenwasserstraßen. Presentation at „BIO.NRW.webinar: Kunststoffe der Zukunft – Innovation trifft Kreislauf", 28/08/2020, Online.

4 BAW bulletins, recommendations and guidelines 2019: BAW leaflet. Anwendung von geotextilen Filtern an Wasserstraßen. Federal Waterways Engineering and Research Institute (BAW). Germany. 04/2019. Download at https://izw.baw.de/publikationen/merkblaetter/0/mag.pdf

5 Borelbach, P. (Fraunhofer UMSICHT) 2020: Personal communication. 17/09/2020

6 Eurostat database Prodcom 2021. Last accessed 21/01/2021. https://ec.europa.eu/eurostat/de/web/main/data/database

Various geotextiles even require a specific type approval.[6]

Other barriers

The main barrier is that the available biodegradation certificates do not have suitable degradation times for this application. A completely new certificate would be necessary, which would also cover degradation over several years. It is therefore important to differentiate and define areas where biodegradable geotextiles offer particular advantages. The degradation time must be easily defined to avoid safety risks.

Technical requirements

Biodegradable geotextiles must be resistant to environmental influences (heat, cold, rain, UV radiation) but still be water-permeable. Depending on the location, they should be long-lasting or biodegrade slowly (e. g. three years after installation until plants and their root systems naturally stabilise the area sufficiently). They must have good root penetration and suitable tensile strength and crush resistance to adapt to subsoil deformations. Ground spikes made of plastic or composite must be rigid and strong. It must be possible to process the material by an injection moulding process.

Relevant standards and certificates

The two standards DIN EN 12226 and DIN EN 12225 deal with the stability of geotextiles. However, this does not refer to biodegradable geotextiles. Standards for testing biodegradable geotextiles do not yet exist.

In principle, certifications for biodegradation in soil, such as those offered by TÜV Austria and DIN CERTCO, would be suitable. However, the maximum biodegradation time in these standards is two years. Geotextiles need to last longer in many applications and thus biodegrade more slowly to allow nature time to naturally stabilise the soil. The certification mentioned is also unsuitable for protecting the banks of watercourses, because the geotextile needs to last at least three years due to the high mechanical stress caused by wave impact.

In a German project involving the development of biodegradable geotextiles for bank protection, the researchers have developed their own tests for geotextiles.[7]

Possible substitutes

Biodegradable geotextiles made of natural fibres or sheep's wool are already established on the market for less demanding applications.

In addition to natural fibres such as jute, coconut or even sheep's wool, straw or reeds, cellulose acetate,

7 Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V. – Fraunhofer UMSICHT 2020: Sequentiell biologisch abbaubare Geotextilien für technisch-biologische Uferbefestigungen an Binnenwasserstraßen (Bioshoreline). 08/10/2020. Download at https://www.fnr-server.de/ftp/pdf/berichte/22000815.pdf

PLA, PCL, PHB or PHB copolymers, PBAT, PBS and starch can be used, in each case in blends with natural fibres or as polymer fibres. The different components of the textile should ideally biodegrade at different rates. At the beginning, when the roots are slowly growing, the natural fibres should biodegrade first. The polymer fibres should degrade more slowly to ensure the stability of the soil until vegetation takes over the task of securing it.[8] A prototype made of PLA and natural fibres is currently being tested for river embankments. The prototype must guarantee the requirements for three years from installation and then completely biodegrade. Proof of technical feasibility has yet to be provided.

Ground spikes can be made from solid wood and from various biodegradable polymers, perhaps blended with natural fibres or wood flour to form biocomposites.

Outlook

Plastics and microplastics can be introduced into soils via geotextiles made of non-biodegradable plastics. With appropriately adjusted guidelines and regulations, some of which today are still mutually conflicting, natural fibres in combination with biodegradable plastics could be increasingly used in geotextiles and the amount of plastic released into the environment reduced. Technical development projects are still necessary for demanding applications designed to provide several years of stability.

8 Deter, A. 2016: Neue bioabbaubare Mulchfolien und Geotextilien entwickelt. 25/10/2016. Last accessed 07/01/2021. https://www.topagrar.com/acker/news/neue-bioabbaubare-mulchfolien-und-geotextilien-entwickelt-9857483.html

Plastic beads for concrete slab transport

Few opportunities without regulatory requirements – despite potential in the construction secto

Description

Plastic beads are often used for the transport of concrete slabs. This is spread between the plates to prevent friction and thus damage.

Main material currently used

The material used today is usually low-density polyethylene.[1]

Problematic

Once the concrete blocks are laid, the plastic beads have done their job and are then, in the best case, vacuumed or swept up. A residue of plastic beads always remains – to an extent determined by the care taken and the wind – in soil cracks, wastewater or garden soil, where it cannot be collected and is released into the environment. Over years, mechanical abrasion and other environmental influences turn the plastic beads into microplastic particles.

Market volume in Germany / the EU

The market volume in Germany in 2020 was about 800 tonnes.[2] Based on this figure, the demand in the EU is approximately 5,000 tonnes.

Biodegradable products on the market

At least one company offers relevant quantities of industrially c.compostable beads for concrete slab

1 Plastiker 2019: LWF Steinl: Biofibre-Streugutgranulat schützt Betonstein-Oberflächen. 09/10/2019. Last accessed 06/01/2021. https://plasticker.de/news/shownews.php?nr=35979&nlid=58565.w.h.2019-10-09

2 Glammert, C. (biofibre) 2020: Personal communication. 17/10/2020

transport made from PLA. Such beads possessing one of the available certifications for biodegradation in soil could not be found during research.

Policy and regulatory considerations

Granulate disposal is subject to the Circular Economy Act (KrWG), which does not mention for biodegradation.

The Federal Soil Protection Act can be applied to the extent that, for example, all landowners have a duty to prevent damage to the soil. It was not possible to conclusively clarify whether plastic particles are considered harmful substances within the meaning of the law. Currently, no limits for microplastics in soil have been defined, nor are any applicable limits set out in the Federal Soil Protection Act.

Other barriers

Lack of awareness among users, higher prices and low availability in the market are the main barriers.

Technical requirements

The beads must protect the concrete products from scratches and defects. Therefore, they must have a high energy absorption capacity and compressive strength. They should also have high strength and impact resistance to prevent the concrete slabs from coming into contact with each other. Otherwise, the beads do not need to have any other special mechanical properties. They have a short life in the case they are not reused and should be.

Relevant standards and certificates

TÜV Austria's certifications for biodegradation in soil and other environments where the application may end up are relevant for this application.

Possible substitutes

One possible substitute is bio-based polyester (e. g. PBSA or PBAT), possibly reinforced with natural fibres or cellulose. Suitable materials are already available on the market and meet the technical requirements but are not certified.

Another alternative could be starch reinforced with natural fibres, for example. Proof of technical feasibility has yet to be provided. A granulate of sunflower seed hulls and bio-PBS is also possible[3] as are PHA-based beads.[4]

If biodegradation which takes longer than envisaged in the above-mentioned certificates is also accepted PLA beads could also be used.

Another reusable option that is already deployed in practice is rubber mats. These are placed between the concrete plates and rolled up again after transport and reused many times.[5]

Outlook

Technically, it would be possible to use soil-biodegradable polymers for this application. However, as these alternatives are significantly more expensive, they could only achieve relevant market shares if corresponding regulatory requirements were issued. These should then also apply to other, corresponding applications in the construction sector.

3 Trumme, R. (Golden Compound) 2020: Personal communication. 24/06/2020

4 Ravenstijn, J. (GO!PHA) 2020: Personal communication. 30/07/2020

5 Dreser, S. (betonpunk) 2020: Personal communication. 12/03/2020

12 Glossary

Abbreviation	German name	English name
AbfKlärV	Klärschlammverordnung	Sewage Sludge Regulation (Germany)
ABS	Acrylnitril-Butadien-Styrol-Copolymer	Acrylonitrile butadiene styrene
AbwV	Abwasserverordnung	Waste Water Regulation (Germany)
ALDFG	aufgegebenes, verlorengegangenes und weggeworfenes Fanggerät	Abandoned, lost or otherwise discarded fishing gear
BAW	Richtlinien der Bundesanstalt für Wasserbau	Guidelines of the Federal Waterways Engineering and Research Institute (Germany)
BfR	Bundesinstitut für Risikobewertung	German federal institute for risk assessment
BioAbfV	Bioabfallverordnung	Organic Waste Regulation (Germany)
Bundes-Boden-schutzgesetz	Bundes-Bodenschutzgesetz	Federal Soil protection Act (Germany)
CA	Zellulose-Acetat	Cellulose acetate
DüMV	Düngemittelverordnung	Fertiliser Regulation (Germany)
ECHA	Europäische Chemikalienagentur	European Chemical Agency
EU	Europäische Union	European Union
EK	Europäische Kommission	European Commission
EVOH/ EVAL	Ethylen-Vinylalkohol-Copolymer	Ethylene vinyl alcohol
FAO	Ernährungs- und Landwirtschafts-organisation der Vereinten Nationen	Food and Agriculture Organisation
H_2O	Wasser	Water
HDPE	Polyethylen hoher Dichte	High-Density Polyethylene
IIR	Isobuten-Isopren-Kautschuk (Butylkautschuk)	Isobutylene-isoprene rubber (Butyl rubber)
INCI	Internationale Nomenklatur für kosmetische Inhaltsstoffe	International Nomenclature of Cosmetic Ingredients
KrWG	Kreislaufwirtschaftsgesetz	Recycling Management Act (Germany)
LDPE	Polyethylen niedriger Dichte	Low-Density Polyethylene
LLDPE	Lineares Polyethylen mit niedriger Dichte	Linear low-Density Polyethylene
MEPC	Ausschuss für den Schutz der Meeresumwelt	Marine Environment Protection Committee
PA	Polyamid	Polyamide
PBAT	Polybutylenadipat-terephthalat	Polybutylene adipate terephthalate
PBS	Polybutylensuccinat	Polybutylene succinate
PBSA	Polybutylensuccinat-adipat	Polybutylene succinate adipate
PBSAT	Polybutylensuccinat-co-adipat-co-	Polybutylene succinate adipate terephthal-
PBST	Polybutylensuccinat-terephthalat	Polybutylene succinate terephthalate
PBT	Polybutylenterephthalat	Polybutylene terephtalate

PET	Polyethylenterephthalat	Polyethylene terephtalate
PHA	Polyhydroxyalkanoate	Poly(hydroxyalkanoate)
PHB	Polyhydroxybutyrat	Poly(hydroxybutyrate)
PHBH	Poly(3-hydroxybutyrat-co-3-hydroxyhexanoat)	Poly(3-hydroxybutyrate-co-3-hydroxyhexanoate)
PHBV	Poly(3-hydroxybutyrat-co-3-hydroxyvalerat)	Poly(3-hydroxybutyrate-co-3-hydroxyvalerate)
PIB	Polyisobutylen	Polyisobutylene
PLA	Polylactid	Polylactic acid
PLU-Code	Preis-Nachschlage-Code	Price look-up code
PMMA	Polymethylmethacrylat	Poly(methyl methacrylate)
POM	Polyoxymethylen	Polyoxymethylene
PP	Polypropylen	Polypropylene
PS	Polystyrol	Polystyrene
PTFE	Polytetrafluoroethylen	Polytetrafluoroethylene
PVAC/ PVA	Polyvinylacetat	Polyvinyl acetate
PVC	Polyvinylchlorid	Polyvinyl chloride
PVOH/ PVAL	Polyvinylalkohol	Polyvinyl alcohol
SBR	Styrol-Butadien-Kautschuk	Styrene-butadiene rubber
SUPD	Einwegplastik-Richtlinie	Single-Use Plastics Directive
UN / UNO	Vereinte Nationen	United Nation Organisation
UNCLOS	UN-Seerechtsübereinkommen	UN-Convention on the Law of the Sea
UV-Licht	ultraviolettes Licht	Ultraviolet-Light
WHO	Weltgesundheitsorganisation	World Health Organisation

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For mentions by name, see the footnotes of the report.

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