Biobased and/or biodegradable materials for the marine and maritime sector

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Biobased and/or biodegradable materials for the marine and maritime sector

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Outline

Executive summary

Plastic materials, typically derived from crude oil, have been known for almost a century and have become important materials in our daily lives. Also in the marine and maritime environment lots of different plastic materials are being used. Examples are textiles used as fishing fluff, ropes, sails and nets, and foils/films used as packaging materials. Each year more than 8 Mio tonnes of plastics enter our seas and oceans, the far majority (appr. 80%) originating from land based applications. Over the past decades the marine and maritime sector has very much become aware of this macroscopic and microscopic plastic pollution as international studies have demonstrated that these millions of tonnes of litter pose environmental, economic, health and aesthetic problems. As a result marine litter and plastic soup have become common words in our daily lives.

Since the beginning of the 21st century biobased polymers have slowly entered the stage. These novel materials are derived from naturally occurring biomass applying various types of (bio)chemical processes. As a result bioplastics are slowly becoming feasible alternatives to traditional petroleum-based plastics such as polyolefins (PE, PP), polyesters (PES) and polyamides (PA). In recent years, there has been a marked increase in interest in biodegradable materials for use in packaging, agriculture, medicine, and other areas. Today several biobased and/or biodegradable materials are available on industrial scale, and slowly find their way to various market applications. The belief is that biopolymer materials will further reduce the need for synthetic polymers, thus contributing to a more sustainable world.

In this document an extensive overview of fundamentals and recent advances of biobased and biodegradable materials is given. Apart from their properties and applications we will also discuss the mechanism of biodegradability and the various biodegradation standards. Finally we will describe 3 cases where biobased and biodegradable materials could be applied in the marine environment.

Definitions

A **polymer** or macromolecule is composed of large or very large molecules that are assembled by linking many small molecules called “monomers” together. Polymers can be produced by linking together hundreds to hundreds of thousands of monomers to make one polymer molecule.

Plastics contain polymers as principal ingredients, but plastics often contain a range of other ingredients (e.g. fillers, pigments, plasticizers, impact modifiers, etc.) that are added to modify plastic properties that are important for a given market and/or application.

Microplastics are very small (<5 mm) plastic particles formed through mechanical degradation of larger pieces of plastics.

Sustainable means meeting our own needs without compromising the ability of future generations to meet their own needs. The term sustainability is broadly used to indicate programs, initiatives and actions aimed at the preservation of a particular resource. However, it actually refers to four distinct areas: human, social, economic and environmental – known as the four pillars of sustainability.

A **renewable resource** is one that can be used repeatedly and does not run out as it is naturally replaced. A renewable resource, essentially, has an endless supply. Typical examples of renewable sources of energy are solar, wind, and geothermal energy but the same concept applies to material resources such as grass, maize, sugar cane or trees.

Biobased means that the material or product is (at least partly) derived from biomass. Biomass used for making bioplastics typically stems from plants such as corn, sugar cane or trees.

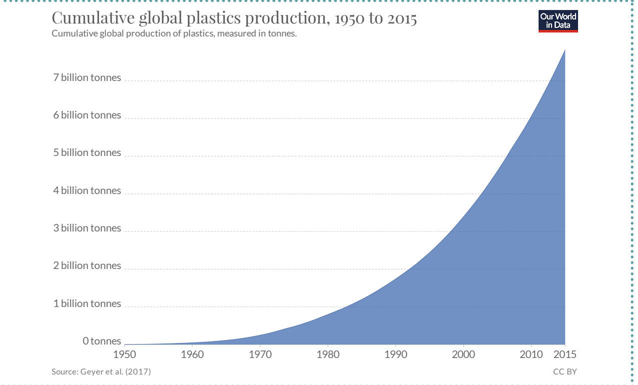
Biodegradable refers to a product breaking down into natural elements (carbon dioxide and water) under the influence of microorganisms such as bacteria and fungi.

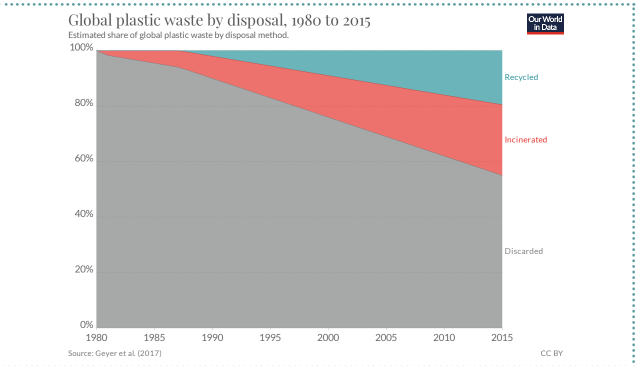
Compostable means that a product is capable of breaking down into natural elements in a compost environment. Because it is broken down into its natural elements it causes no harm to the environment. Plastic may be biodegradable but not compostable. For example, if a plastic biodegrades but leaves behind toxic residues it is not suitable for compost.

Recycling is the process of converting end-of-life/waste materials into new materials and objects. The recovery of energy from waste materials is often included in this concept. The recyclability of a material depends on its ability to reacquire the properties it had in its virgin or original state. It is an alternative to "conventional" waste disposal that can save material and help lower greenhouse gas emissions. Recycling can prevent the waste of potentially useful materials and reduce the consumption of fresh raw materials, thereby reducing energy usage, air pollution (from incineration), and water pollution (from landfilling).

Introduction

Plastic is a general name for synthetic, organic polymer materials made from crude oil. Its properties are ideally suited for a wide variety of applications, including packaging, building and construction, household and sports equipment, vehicles, electronics and agriculture. Plastic is cheap, lightweight, strong and malleable. About 400 million tonnes of plastic are produced every year, half of which is used to design single-use items such as shopping bags, cups and straws. Cumulative global plastic production from 1950 – 2015 was more than 7.8 billion tonnes. A total of 55% of this 7.8 billion tonnes went straight into landfill, whereas only 6-7% was recycled. Fortunately, today's recycling numbers are much better (typically 20-30% in Western Europe) but still there is still a long way to go to a circular plastics economy (see figure underneath).





Plastics have been known for almost a century and have become an important material in our daily lives. Also in the marine and maritime environment lots of different plastic materials are being used, among them:

- textiles such as ropes, sails, nets, etc.
- films used as packaging materials
- coatings and composite materials used for boats and marine structures (e.g. wind turbines)

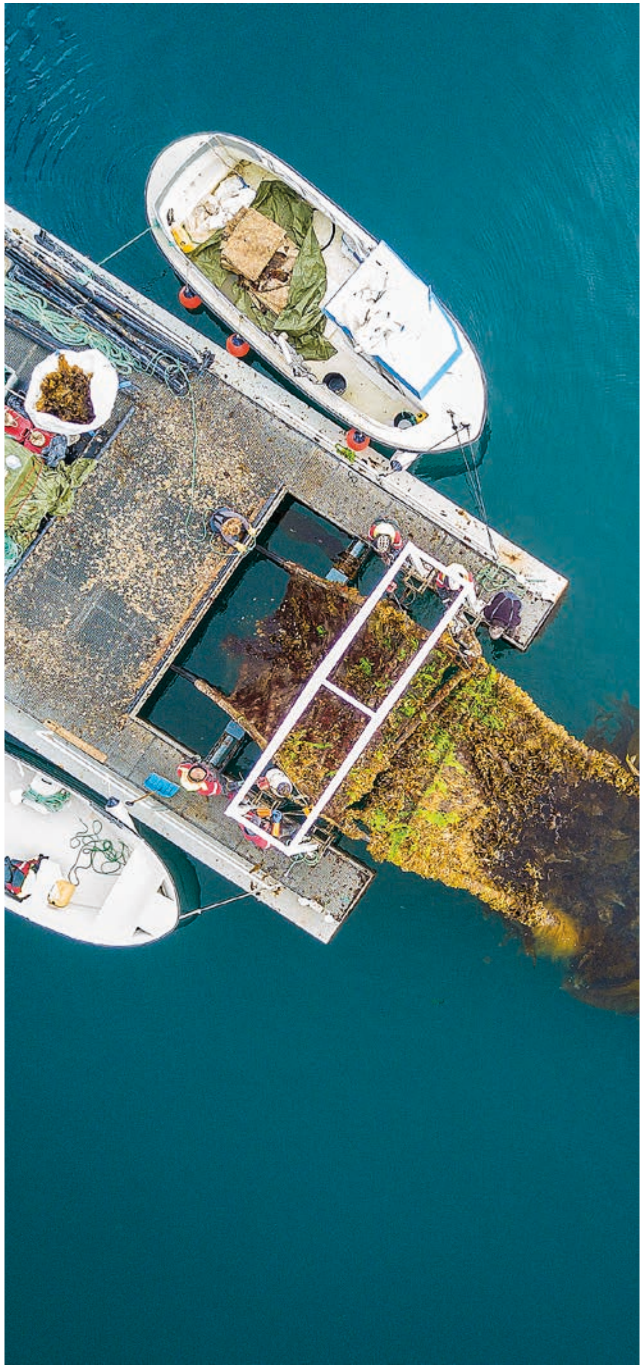
As our seas and oceans are mostly remote areas with little or no supervision these marine plastics often end up in the marine environment instead of being collected on land and being recycled. Over the past decades the social pressure to reduce plastics in our seas and oceans has grown exponentially. Photos of turtles, fish and seals entangled in plastic have strongly contributed to this. Yearly more than 8 Mio tonnes of plastics enter our seas and oceans, resulting in macroscopic and microscopic pollution. The facts on marine debris as listed on the right.

Overlooking all this info there is a need for more sustainable solutions for plastics that are used or end up in the marine environment. The use of biobased and/or biodegradable materials can be one of the solutions. In this document we will give an overview on the state of the art on biobased and biodegradable materials, what their pros and cons are, how they are produced, what their potential is in the marine environment, etc. Furthermore we will also bring up 3 case studies to underline the potential and importance of biobased and biodegradable plastics for the marine and maritime sector.

Facts on marine debris

- More than 8 million tonnes of plastic enter the seas and oceans each year, equal to dumping a garbage truck of plastic every minute
- Under the influence of solar UV radiation, wind, currents and other natural factors, plastic fragments into small particles, termed microplastics (particles smaller than 5 mm) or nanoplastics (particles smaller than 100 nm).
- As many as 51 trillion microplastic particles — 500 times more than the stars in our galaxy — litter our oceans and seas, seriously threatening marine wildlife
- Marine debris is harming more than 800 species. 40% of marine mammals and 44% of seabird species are affected by marine debris ingestion
- According to some estimates, at the rate we are dumping items such as plastic bottles, bags and cups after a single use, by 2050 oceans will carry more plastic mass than fish, and an estimated 99% of seabirds will have ingested plastic
- Plastic waste kills up to 1 million sea birds, 100,000 sea mammals, marine turtles and countless fish each year. Plastic remains in our ecosystem for years, harming thousands of sea creatures every day
- Abandoned, lost or otherwise discarded fishing gear in the oceans makes up around 10% (640,000 tonnes) of all marine litter. This gear continues to catch fish through so called "ghost fishing", and traps turtles, seabirds and marine mammals
- 80% of all pollution in seas and oceans comes from land-based activities
- There is an urgent need to explore the use of existing legally binding international agreements to address marine plastic pollution

Photos: Examples of materials that are used and/or end up in the marine environment: left - fishing fluff, right - PET bottles, PE bags and various other floating marine litter.



Biobased and/or biodegradable materials

Biomaterials or bioplastics can be divided into biobased and biodegradable compounds. The word biobased refers to the 'origin of life' or 'where did the carbon come from?' Biodegradable refers to 'end of life' or 'disposal'. Plastics can be divided into 4 segments as shown in the figure underneath. In the first quadrant one finds biomaterials based on renewable resources that are biodegradable under certain conditions (e.g. PLA, PHA, etc.). One can consider these as true biomaterials. In the second quadrant one finds materials that are oil-based and biodegradable. PCL and PBAT are the best-known examples. Oil-based and non-biodegradable polymers are typical synthetic plastics such as polyethylene (PE), polypropylene (PP) and polyester (PES) as shown in the third (red) quadrant. Some of these traditional polymers are also available in a biobased version such as bio-PE and bio-PES (fourth quadrant). Although this last group of plastics is based on renewable resources, they have the same characteristics as their oil-based analogs. Further on, we will discuss these materials in more detail.

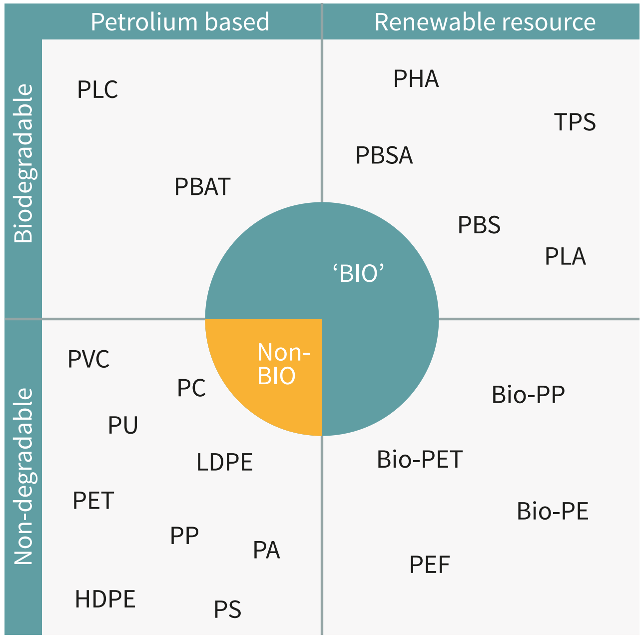


Figure: Four classes of materials based on their origin (petroleum or renewable resource) and whether they are biodegradable or not.

What is a biobased material?

Biobased materials refer to products that mainly consist of a substance (or substances) derived from living matter (biomass) and either occur naturally or are synthesized, or it may refer to products made by processes that use biomass. Following a strict definition, many common materials, such as paper, wood, and leather, can be referred to as biobased materials, but typically, the term refers to modern materials that have undergone more extensive processing. Most frequently used biomasses include wood, corn, sugar cane and other agricultural crops but also more 'exotic' biomasses such as algae/seaweeds and municipal solid waste are being used.

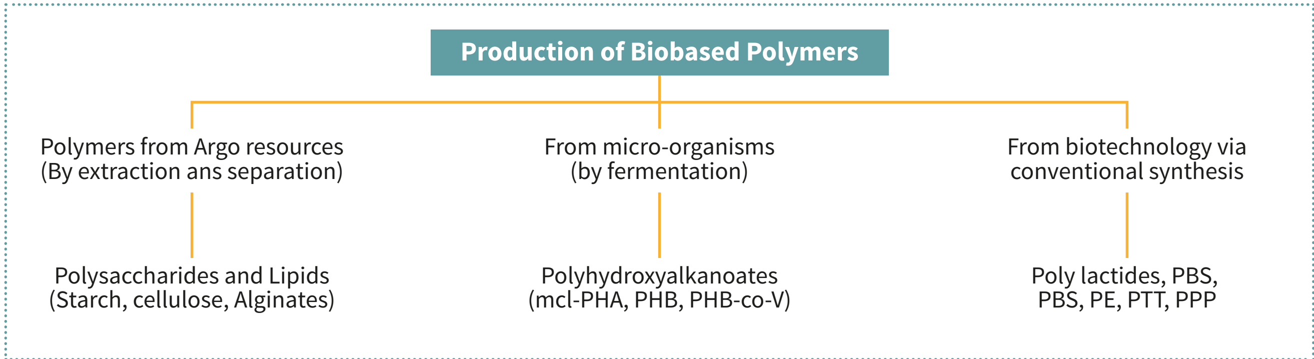
Materials from biomass sources include bulk chemicals, platform chemicals, solvents, plastics/polymers, textiles and composites (some materials may fall under more than one category). The many processes to convert biomass components to value-added products and fuels can be classified broadly as biochemical or thermochemical processes. In addition, biotechnological processes that rely mainly on plant breeding, fermentation, and conventional enzyme isolation are also included. Biobased materials are perceived as potentially more sustainable alternatives than their petroleum-based counterparts; however, this claim is being scrutinized closely. Although a (sustainably sourced) biobased plastic can help improve the sustainability, other aspects of the product lifetime also have an impact on the overall product sustainability. Biobased alternatives for conventional plastics are chemically identical and therefore have a lot of the advantages of conventional plastics, but also the drawbacks (i.e. microplastics) of their conventional counterparts.
New biobased materials that may compete with conventional materials are emerging continually, and the opportunities to use them in existing and novel products are just beginning to be explored.

In the last two decades, biobased materials have been subjected to a strong growth for the sustainable plastics industry, due to the recent trends in the consumer market that have moved towards greener materials, more sustainable processes, and reduction of waste. Nowadays, the issue of sustainability is high, encouraging academia as well as industry to develop sustainable alternatives for preserving resources for future generations, focusing on biodegradable and bio-renewable materials.

Production of the main types of biobased materials

Various biobased materials have been developed over the past decades. The figure underneath gives an overview of the main types of biobased materials and how they are produced. There are 3 main pathways:

1. Simple extractive separation from agro resources (e.g. starch from maize or alginate from brown seaweeds),
2. fermentation of agro resources by means of micro-organisms (e.g. PHA's from corn),
3. biotechnology via conventional synthesis (e.g. bio-PE from sugar cane).



What is a biodegradable material?

In contrast to biobased materials/plastics that are made of renewable raw materials the term "bioplastics" is used in the academic literature to describe both plastics that are biobased and/or plastics that are biodegradable. Polymers that are biodegradable describe materials that degrade completely when exposed to microorganisms, in aerobic or anaerobic processes. The term 'biodegradable plastic' thus refers to an intrinsic property of the material and tells nothing about the origin of the material which can be biobased and/or fossil based and is not necessarily sustainable.

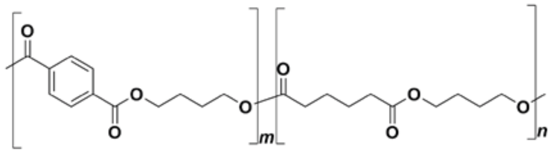
Biobased plastics: major focus is on the 'origin of life' or where did the carbon come from?
Biodegradable (compostable) plastics: focus is on 'end of life or disposal' (independent of carbon source)

Petroleum-based biodegradable materials

Petrochemical plastics are derived from petroleum, which is obtained from fossil crude oil, coal or natural gas. The most widely used petrochemical plastics, such as polyethylene terephthalate (PET), polyethylene (PE), polypropylene (PP), and polystyrene (PS), are not biodegradable. However, the following petrochemical plastics are biodegradable.

Polybutylene adipate terephthalate (PBAT)

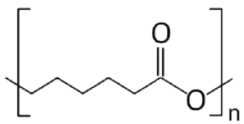
Polybutylene adipate terephthalate is a biodegradable random copolymer, more specifically a copolyester of adipic acid, 1,4-butanediol and terephthalic acid (from dimethyl terephthalate).



PBAT is produced by several manufacturers and may be known by the brand names ecoflex®, Wango, Ecoworld, Eastar Bio, and Origo-Bi. It is also called poly(butylene adipate-co-terephthalate) and sometimes polybutyrate-adipate-terephthalate[1] (a misnomer) or even just "polybutyrate". It is generally marketed as a fully biodegradable alternative to low-density polyethylene, having many similar properties including flexibility and resilience, allowing it to be used for many similar uses such as plastic bags and wraps.

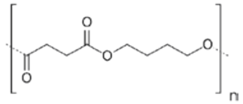
Polycaprolactone (PCL)

Polycaprolactone has gained prominence as an implantable biomaterial because the hydrolysis of its ester linkages offers its biodegradable properties. It has been shown that firmicutes and proteobacteria can degrade PCL. Penicillium sp. strain 26-1 can degrade high density PCL; though not as quickly as thermotolerant Aspergillus sp. strain ST-01. Species of clostridium can degrade PCL under anaerobic conditions.



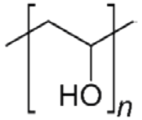
Polybutylene succinate (PBS)

Polybutylene succinate is a thermoplastic polymer resin that has properties comparable to propylene. It is used in packaging films for food and cosmetics. In the agricultural field, PBS is used as a biodegradable mulching film. PBS can be degraded by Amycolatopsis sp. HT-6 and Penicillium sp. strain 14-3. In addition, Microbispora rosea, Excellospora japonica and E. viridilutea have been shown to consume samples of emulsified PBS.



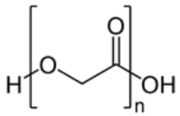
Poly(vinyl alcohol) (PVOH)

Poly(vinyl alcohol) is one of the few biodegradable vinyl polymers that is soluble in water. Due to its solubility in water (an inexpensive and harmless solvent), PVA has a wide range of applications including food packaging, textiles coating, paper coating, and healthcare products.



Polyglycolic acid (PGA)

Polyglycolic acid is a thermoplastic polymer and an aliphatic polyester. PGA is often used in medical applications such as sutures due to its biodegradability. The ester linkage in the backbone of polyglycolic acid results in a certain hydrolytic instability leading to its biodegradable properties. Hydrolysis of said ester linkages leads to depolymerization of the PGA chain into its nontoxic monomer, glycolic acid. This process can be expedited with esterases. In the body, glycolic acid can enter the tricarboxylic acid cycle, after which it is excreted as water and carbon dioxide.

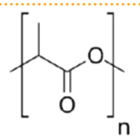


Biobased and biodegradable materials

The following materials are biobased and biodegradable.

Polylactic acid (PLA)

Polylactic acid has been known since 1845 but was not commercialized until early 1990. PLA belongs to the family of aliphatic polyesters with the basic constitutional unit lactic acid. The monomer lactic acid is the hydroxyl carboxylic acid which can be obtained via bacterial fermentation from corn (starch) or sugars obtained from renewable resources. Although other renewable resources can be used, corn has the advantage of providing a high-quality feedstock for fermentation which results in a high-purity lactic acid, which is required for an efficient synthetic process. l-Lactic acid or d-lactic acid is obtained depending on the microbial strain used during the fermentation process.



PLA can be synthesized from lactic acid by direct polycondensation reaction or ring-opening polymerization of lactide monomer. However, it is difficult to obtain high molecular weight PLA via polycondensation reaction because of water formation during the reaction. Nature Works LLC (previously Cargill Dow LLC) has developed a low-cost continuous process for the production of PLA. In this process, low molecular weight pre-polymer lactide dimers are formed during a condensation process. In the second step, the pre-polymers are converted into high molecular weight PLA via ring-opening polymerization with selected catalysts.

Depending on the ratio and stereochemical nature of the monomer (l or d), various types of PLA and PLA copolymers can be obtained. The final properties of PLA produced are highly dependent on the ratio of the d and l forms of the lactic acid.

PLA is a commercially interesting polymer as it shares some similarities with hydrocarbon polymers such as polyethylene terephthalate (PET). It has many unique characteristics, including good transparency, glossy appearance, high rigidity, and ability to tolerate various types of processing conditions.

PLA is a thermoplastic polymer which has the potential to replace traditional polymers such as PET, PS, and PC for packaging to electronic and automotive applications. While PLA has similar mechanical properties to traditional polymers, the thermal properties are not attractive due to low Tg of 60°C. This problem can be overcome by changing the stereochemistry of the polymer and blending with other polymers and processing aids to improve the mechanical properties, e.g., varying the ratio of l and d isomer ratio strongly influences the crystallinity of the final polymer. However, much more work is required to improve the properties of PLA to suit various applications.

PLA is widely used in many day-to-day applications. It has been mainly used in food packing (including food trays, tableware such as plates and cutlery, water bottles, candy wraps, cups, etc.). Although PLA has one of the highest heat resistances and mechanical strengths of all biobased polymers, it is still not suitable for use in electronic devices and other engineering applications. NEC Corporation (Japan) recently produced a PLA with carbon and kenaf fibers with improved thermal and flame retardancy properties. Fujitsu (Japan) developed a polycarbonate blend with PLA to make computer housings. In recent years, PLA has been employed as a membrane material for use in automotive and chemical industry.

The ease of melt processing has led to the production of PLA fibers, which are increasingly accepted in a wide variety of textiles from dresses to sportswear, furnishing to drapes, and soft nonwoven baby wipes to tough landscape textiles. These textiles can outperform traditional textiles made from synthetic counterparts. Bioresorbable scaffolds produced with PLA and various PLA blends are used in implants for growing living cells. The US Food and Drug Administration (FDA) has approved the use of PLA for certain human clinical applications. In addition, PLA-based materials have been used for bone support splints.

Polyhydroxyalkanoate (PHA)

Polyhydroxyalkanoates are a family of polyesters produced by bacterial fermentation with the potential to replace conventional hydrocarbon-based polymers. PHAs occur naturally in a variety of organisms, but microorganisms can be employed to tailor their production in cells. Polyhydroxybutyrate (PHB), the simplest PHA, was discovered in 1926 by Maurice Lemoigne as a constituent of the bacterium Bacillus megaterium.

PHA can be produced by varieties of bacteria using several renewable waste feedstocks. A generic process to produce PHA by bacterial fermentation involves fermentation, isolation, and purification from fermentation broth. A large fermentation vessel is filled with mineral medium and inoculated with a seed culture that contains bacteria. The feedstocks include cellulosics, vegetable oils, organic waste, municipal solid waste, and fatty acids depending on the specific PHA required. The carbon source is fed into the vessel until it is consumed and cell growth and PHA accumulation is complete. In general, a minimum of 48 h is required for fermentation time. To isolate and purify PHA, cells are concentrated, dried, and extracted with solvents such as acetone or chloroform. The residual cell debris is removed from the solvent containing dissolved PHA by solid-liquid separation process. The PHA is then precipitated by the addition of an alcohol (e.g., methanol) and recovered by a precipitation process

More than 150 PHA monomers have been identified as the constituents of PHAs. Such diversity allows the production of biobased polymers with a wide range of properties, tailored for specific applications. Poly-3-hydroxybutyrate was the first bacterial PHA identified. It has received the greatest attention in terms of pathway characterization and industrial-scale production. It possesses similar thermal and mechanical properties to those of polystyrene and polypropylene. However, due to its slow crystallization, narrow processing temperature range, and tendency to 'creep', it is not attractive for many applications, requiring development in order to overcome these shortcomings. Several companies have developed PHA copolymers with typically 80% to 95% (R)-3-hydroxybutyric acid monomer and 5% to 20% of a second monomer in order to improve the properties of PHAs. Some specific examples of PHAs include the following:

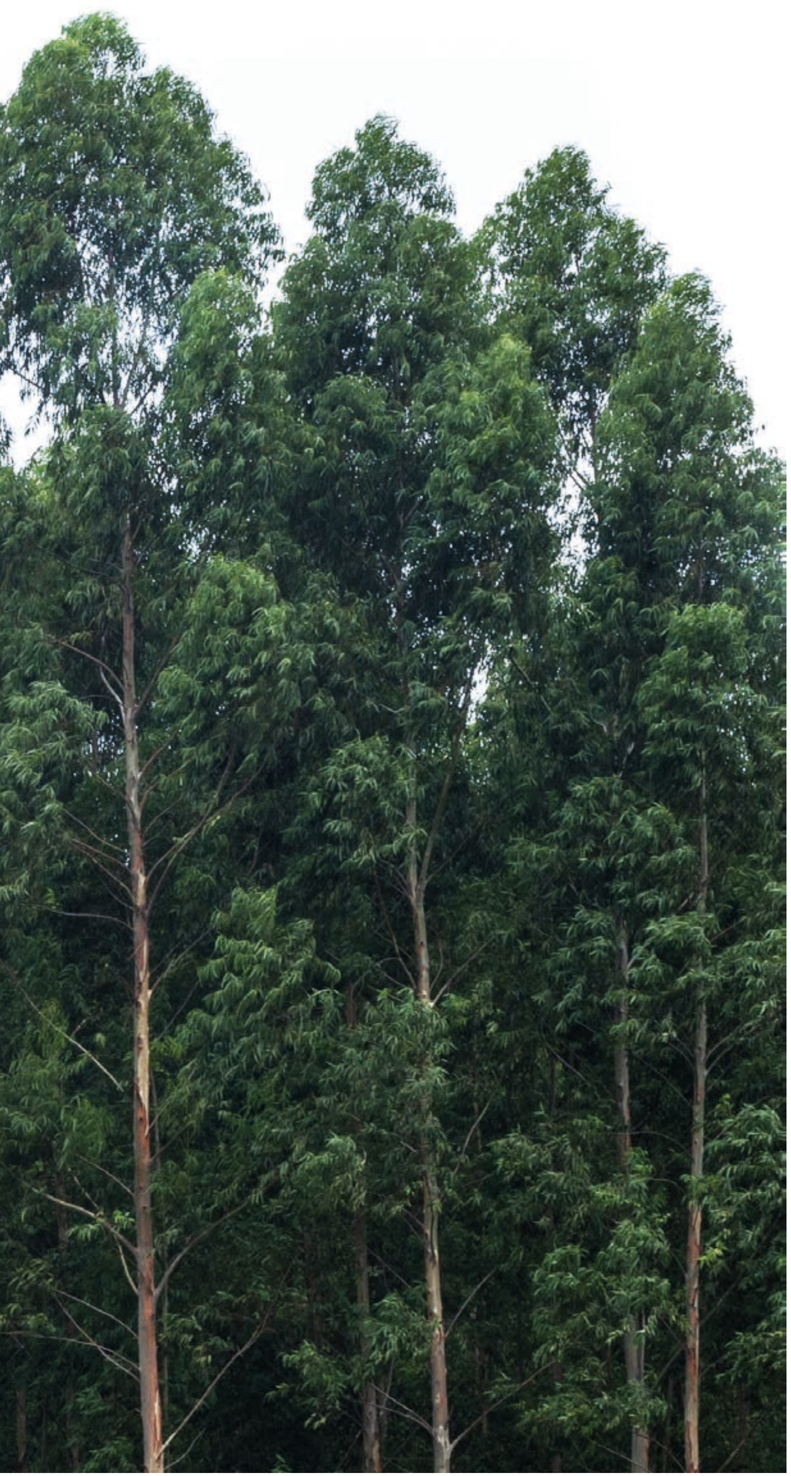
- Poly(3HB): Poly(3-hydroxybutyrate)
- Poly(3HB-co-3HV):
  Poly(3-hydroxybutyrate-co-3-hydroxyvalerate), PHBV
- Poly(3-HB-co-4HB):
  Poly(3-hydroxybutyrate-co-4-hydroxybutyrate)
- Poly(3HB-co-3HH):
  Poly(3-hydroxyoctanoate-co-hydroxyhexanoate)
- Poly(3HO-co-3HH):
  Poly(3-hydroxyoctanoate-co-hydroxyhexanoate)
- Poly (4-HB): Poly(4-hydroxybutyrate).

The copolymer poly(3HB-co-3HV) has a much lower crystallinity, decreased stiffness and brittleness, and increased tensile strength and toughness compared to poly(3HB) while remaining biodegradable. It also has a higher melt viscosity, which is a desirable property for extrusion and blow molding.

The first commercial plant for PHBV was built in the USA in a joint venture between Metabolix and Archer Daniels Midland. However, the joint venture between these two companies ended in 2012. Currently, Tianan Biologic Material Co. in China is the largest producer of PHB and PHB copolymers. Tianan's PHBV contains about 5% valerate which improves the flexibility of the polymer. Tainjin Green Biosciences, China, invested along with DSM to build a production plant with 10-kton/year capacity to produce PHAs for packing and biomedical applications

PHA polymers are thermoplastic, and their thermal and mechanical properties depend on their composition. The T g of the polymers varies from −40°C to 5°C, and the melting temperatures range from 50°C to 180°C, depending on their chemical composition. PHB is similar in its material properties to polypropylene, with a good resistance to moisture and aroma barrier properties. Polyhydroxybutyric acid synthesized from pure PHB is relatively brittle and stiff. PHB copolymers, which may include other fatty acids such as beta-hydroxyvaleric acid, may be elastic.

PHAs can be processed in existing polymer-processing equipment and can be converted into injection-molded components: film and sheet, fibers, laminates, and coated articles; nonwoven fabrics, synthetic paper products, disposable items, feminine hygiene products, adhesives, waxes, paints, binders, and foams. Metabolix has received FDA clearance for use of PHAs in food contact applications. These materials are suitable for a wide range of food packing applications including caps and closures, disposable items such as forks, spoons, knives, tubs, trays, and hot cup lids, and products such as housewares, cosmetics, and medical packaging



Biobased natural polymers

This group consists of naturally occurring polymers such as cellulose, starch, chitin, and various polysaccharides and proteins. These materials and their derivatives offer a wide range of properties and applications. Some of these natural biobased polymers and their applications in various fields are discussed underneath.

Cellulose

Cellulose is the predominant constituent in cell walls of all plants. Cellulose is a complex polysaccharide with crystalline morphology. Cellulose differs from starch where glucose units are linked by ß-1,4-glycosidic bonds, whereas the bonds in starch are predominantly α-1,4 linkages. The most important raw material sources for the production of cellulosic plastics are cotton fibers and wood. Plant fiber is dissolved in alkali and carbon disulfide to create viscose, which is then reconverted to cellulose in cellophane form following a sulfuric acid and sodium sulfate bath. There are currently two processes used to separate cellulose from the other wood constituents.
These methods, sulfite and pre-hydrolysis kraft pulping, use high pressure and chemicals to separate cellulose from lignin and hemicellulose, attaining greater than 97% cellulose purity. The main derivatives of cellulose for industrial purposes are cellulose acetate, cellulose esters (molding, extrusion, and films), and regenerated cellulose for fibers.

Cellulose is a hard polymer and has a high tensile strength of 62 to 500 MPa and elongation of 4%. In order to overcome the inherent processing problems of cellulose, it is necessary to modify, plasticize, and blend with other polymers.
The mechanical and thermal properties vary from blend to blend depending on the composition. The Tg of cellulosic derivatives ranged between 53°C and 180°C Eastman Chemical is a major producer of cellulosic polymers.

There are three main groups of cellulosic polymers that are produced by chemical modification of cellulose for various applications. Cellulose esters, namely cellulose nitrate and cellulose acetate, are mainly developed for film and fiber applications. Cellulose ethers, such as carboxymethyl cellulose and hydroxyethyl cellulose, are widely used in construction, food, personal care, pharmaceuticals, paint, and other pharmaceutical applications. Finally, regenerated cellulose is the largest biobased polymer produced globally for fiber and film applications. Regenerated cellulose fibers are used in textiles, hygienic disposables, and home furnishing fabrics because of its thermal stability and modulus.

Chemically pure cellulose can be produced using a certain type of bacteria. Bacterial cellulose is characterized by its purity and high strength. It can be used to produce articles with relatively high strength. Currently, applications for bacterial cellulose outside food and biomedical fields are rather limited because of its high price. The other applications include acoustic diaphragms, mining, paints, oil gas recovery, and adhesives. However, the low yields and high costs of bacterial cellulose represent barriers to large-scale industrial applications

Cellulose, a polysaccharide, is one of the most commonly used biopolymers for alternative natural packaging material. Cellulose is composed of D-glucose subunits and cellulose polymers are obtained from plant material. In its native form, cellulose has a very low water solubility and thus is rather unsuitable for packaging. However, cellulose can be modified by plasticizing, surface modification or coating and blending to become water soluble, thus, modified cellulose with the addition of plasticizers provides a raw material for packaging film formation. (Hu, 2014) Recently, nanocellulose fibers have been developed from cellulose by acid hydrolysis or mechanical grinding.

Chitin and chitosan

Chitin and chitosan are the most abundant natural amino polysaccharide and valuable biobased natural polymers derived from shells of prawns and crabs. Currently, chitin and chitosan are produced commercially by chemical extraction process from crab, shrimp, and prawn wastes. The chemical extraction of chitin is quite an aggressive process based on demineralization by acid and deproteination by the action of alkali followed by deacetylated into chitosan. Chitin can also be produced by using enzyme hydrolysis or fermentation process, but these processes are not economically feasible on an industrial scale. Currently, there are few industrial-scale plants of chitin and chitosan worldwide located in the USA, Canada, Scandinavia, and Asia.

Chitosan displays interesting characteristics including biodegradability, biocompatibility, chemical inertness, high mechanical strength, good film-forming properties, and low cost. Chitosan is being used in a vast array of widely varying products and applications ranging from pharmaceutical and cosmetic products to water treatment and plant protection. For each application, different properties of chitosan are required, which changes with the degree of acetylation and molecular weight. Chitosan is compatible with many biologically active components incorporated in cosmetic product composition. Due to its low toxicity, biocompatibility, and bioactivity, chitosan has become a very attractive material in such diverse applications as biomaterials in medical devices and as a pharmaceutical ingredient. Chitosan has application in shampoos, rinses, and permanent hair-coloring agents. Chitosan and its derivatives also have applications in the skin care industry. Chitosan can function as a moisturizer for the skin, and because of its lower costs, it might compete with hyaluronic acid in this application

Starch

Starch is a unique biobased polymer because it occurs in nature as discrete granules. Starch is the end-product of photosynthesis in plants - a natural carbohydrate-based polymer that is abundantly available in nature from various sources including wheat, rice, corn, and potato. Essentially, starch consists of the linear polysaccharide amylose and the highly branched polysaccharide amylopectin. In particular, thermoplastic starch is of growing interest within the industry. The thermal and mechanical properties of starch can vary greatly and depend upon such factors as the amount of plasticizer present. The T g varies between −50°C and 110°C, and the modulus is similar to polyolefins. Several challenges exist in producing commercially viable starch plastics. Starch's molecular structure is complex and partly nonlinear, leading to issues with ductility. Starch and starch thermoplastics suffer from the phenomenon of retrogradation - a natural increase in crystallinity over time, leading to increased brittleness. Plasticizers need to be found to create starch plastics with mechanical properties comparable to polyolefin-derived packaging. Plasticized starch blends and composites and/or chemical modifications may overcome these issues, creating biodegradable polymers with enough mechanical strength, flexibility, and water barrier properties for commercial packaging and consumer products

The Italian company Novamont is one of the leading companies in processing starch-based products. The company produces various types of starch-based products using proprietary blend formulations. There are other companies around the world producing starch-based products in a similar scale for various applications,

Applications of thermoplastic starch polymers include films, such as for shopping, bread, and fishing bait bags, overwraps, flushable sanitary product, packing materials, and special mulch films. Potential future applications could include foam loose-fill packaging and injection-molded products such as 'take-away' food containers. Starch and modified starches have a broad range of applications both in the food and non-food sectors. In Europe in 2002, the total consumption of starch and starch derivatives was approximately 7.9 million tonnes, of which 54% was used for food applications and 46% in non-food applications.

The largest users of starch in the European Union (30%) are the paper, cardboard, and corrugating industries. Other important fields of starch application are textiles, cosmetics, pharmaceuticals, construction, and paints. In the medium and long term, starch will play an increasing role in the field of 'renewable raw materials' to produce biodegradable plastics, packaging material, and molded products.

Starch is a biopolymer produced by the photosynthesis of plants. Similar to cellulose, starch is composed of D-glucose monomers. Commercial starch is usually obtained from potatoes. Since starch crystallizes more and more over time, modifications are required to make it possible to use starch as a packaging material without any further modifications because of increasing brittleness with time. In order to use starch for industrial applications, a treatment with plasticizers is needed to improve the mechanical strength and the barrier against water.

‘Green washing’

Finally there is a group of bioplastics that were known for decades as conventional plastics but for which chemical pathways were developed starting from biomass. Bio-PE is the best-known example from this group of materials, directly followed by bio-PET and bio-PP. Often the main reason for developing these materials was to ‘green wash’ their image. The bio-PE story underneath is a nice example of this.

Bio-polyethylene

Polyethylene (PE) is an important engineering polymer traditionally produced from fossil resources. PE is produced by polymerization of ethylene under pressure, temperature, in the presence of a catalyst. Traditionally, ethylene is produced through steam cracking of naphtha or heavy oils or ethanol dehydration. With increases in oil prices, microbial PE or green PE is now being manufactured from dehydration of ethanol produced by microbial fermentation. The concept of producing PE from bioethanol is not a particularly new one. In the 1980s, Braskem made bio-PE and bio-PVC from bioethanol. However, low oil prices and the limitations of the biotechnology processes made the technology unattractive at that time.

Currently, bio-PE produced on an industrial scale from bioethanol is derived from sugarcane. Bioethanol is also derived from renewable feedstocks, such as sugar beet, starch crops such as maize, wood, wheat, corn, and other plant wastes through microbial strain and biological fermentation processes. In a typical process, extracted sugarcane juice with high sucrose content is anaerobically fermented to produce ethanol. At the end of the fermentation process, ethanol is distilled in order to remove water and to yield azeotropic mixture of hydrous ethanol. Ethanol is then dehydrated at high temperatures over a solid catalyst to produce ethylene and, subsequently, polyethylene.

Biobased polyethylene has exactly the same chemical, physical, and mechanical properties as petrochemical polyethylene. Braskem (Brazil) is the largest producer of bio-PE with 52% market share, and this is the first certified bio-PE in the world. Similarly, Braskem is developing other biobased polymers such as bio-polyvinyl chloride, bio-polypropylene, and their copolymers with similar industrial technologies. The current Braskem biobased PE grades are mainly targeted towards food packing, cosmetics, personal care, automotive parts, and toys.

Dow Chemical (USA) in cooperation with Crystalsev is the second largest producer of bio-PE with 12% market share. Solvay (Belgium), another producer of bio-PE, has 10% share in the current market. However, Solvay is a leader in the production of bio-PVC with similar industrial technologies. China Petrochemical Corporation also plans to set up production facilities in China to produce bio-PE from bioethanol.

Bio-PE can replace all the applications of current fossil-based PE. It is widely used in engineering, agriculture, packaging, and many day-to-day commodity applications because of its low price and good performance.

Market aspects of biomaterials

Society is changing rapidly and so is the need for more sustainable materials. The use of biobased and/or biodegradable materials is one of the solutions. Overlooking the list of biobased and/or biodegradable polymers, they all have one common feature: they are more expensive than traditional synthetic polymers such as polyethylene (PE), polypropylene (PP) and polyester (PES). The figure underneath gives an idea about the prices of conventional polymers (right table) and bioplastics (left table) and their producers.

Polymer	Price (€/kg)
PLA	3,0 - 5,0
PBAT	3,5 - 5,5
PCL	9,0 - 12,0
PBS(A)	2,7 - 3,5
PHA	5,0 - 12,0

Polymer	Price (€/kg)
PES	1,3 - 2,0
PVC	1,1 - 1,3
PP	1,0 - 1,6
PE	0,9 - 1,5
PA	2,5 - 3,5

Figure: Overview of suppliers and prices for conventional polymers and biopolymers.

PLA and the oil-based polymers PBAT and PBS(A) are relatively low-priced in comparison to PHA and PCL. Especially PLA, being a maize-based product that is industrially biodegradable, has gained a lot of interest for applications such as plastic bags and other single use applications. Unfortunately PLA ends up with other plastics at its end-of-life and is being incinerated rather than being biodegraded in an industrial composting unit.

Today there are two main producers of PLA: Nature Works and Total-Corbion. NatureWorks has a 150 ktonnes PLA production plant in the USA that uses genetically modified corn starch. Total-Corbion has a 75 ktonnes PLA factory in Thailand that uses sugar cane as feedstock. In China there are several 30-40 ktonnes PLA production plants. Total-Corbion plans to open an additional 100 ktonnes PLA plant in France in 2024. All PLA suppliers have various grades that differ in Mw, D/L ratio, etc.

Prices for PLA grades typically range from 2.5 – 4.5 EUR per kg for granulates, depending on the exact composition. In Belgium several companies produce packaging films using PLA.
The textile company Sioen produces PLA based yarns and the corresponding textiles.

Photo: Industrial composting unit with automated turner.

Today there are two main producers of PLA: Nature Works and Total-Corbion. NatureWorks has a 150 ktonnes PLA production plant in the USA that uses genetically modified corn starch. Total-Corbion has a 75 ktonnes PLA factory in Thailand that uses sugar cane as feedstock. In China there are several 30-40 ktonnes PLA production plants. Total-Corbion plans to open an additional 100 ktonnes PLA plant in France in 2024. All PLA suppliers have various grades that differ in Mw, D/L ratio, etc.

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The textile company Sioen produces PLA based yarns and the corresponding textiles.

Another important class of biopolymers is PHA. Currently, PHA represents 1.4% (29,000 tonnes) of the global production capacities of bioplastics in 2018. The market presence of PHAs is still limited compared to other materials mainly due to the price level (5€/kg for a density of 1,200 – 1,250 kg/m^3). However, different ways are being explored to lower the price of PHA, including using waste as a feedstock or up-scaling of biotechnological production. By 2023, it is foreseen that PHA will reach a share of 4.5% (117,000 tonnes).

In 2019 Danimer Scientific opened one of the world's largest commercial PHA production facilities in Winchester, KY. The plant has an annual production capacity of 10,000 tonnes. Their PHA biopolymer, named Nodax, is used to manufacture drinking straws, food packaging, cups, bottles, shopping bags, plates, trash bags, labels and more. Another important producer of PHA's is Kaneka.

- Two main PLA producers: NatureWorks, TOTAL | Corbion
- 2,5 - 4,5 €/kg
- Appr. 240,000 ton PLA production per year (vs 80 Mio ton PES produced per year)

Figure: Details about PLA.

Plastics vs bioplastics

If one compares the 240,000 tonnes annual production of PLA or the 29,000 tonnes of PHA with the 80 Mio tonnes production of polyester, one immediately understands at what stage non-natural bioplastics are: the early beginning.

The overall global plastics production was approximately 370 Mio tonnes in 2019. The total global bioplastics production was 2.11 Mio tonnes, divided into 55.5% being biodegradable (e.g. starch blends) and 44.5% being non-biodegradable (e.g. bio-PE).

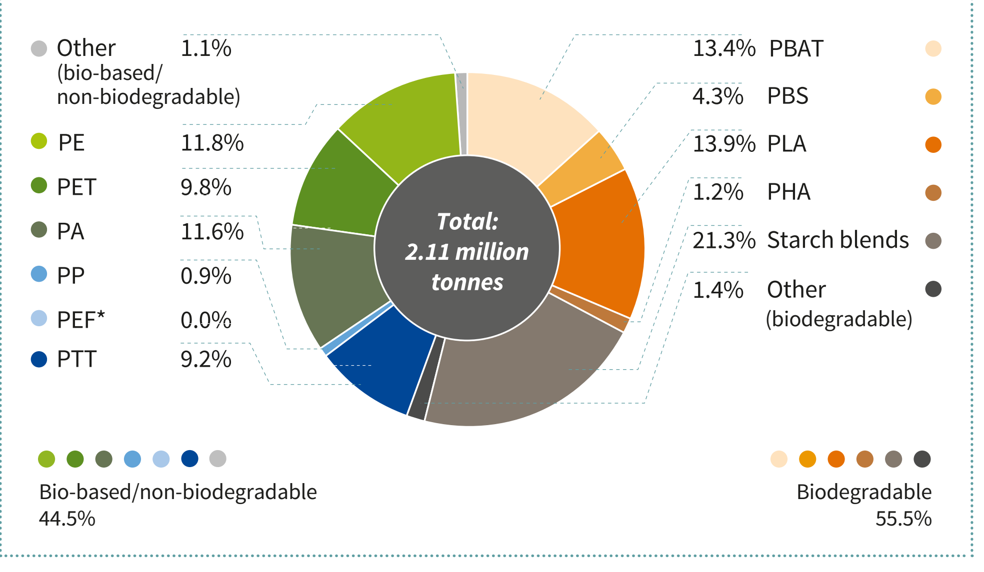


Figure: Global production capacities of bioplastics 2019 (source: NOVA Institute)

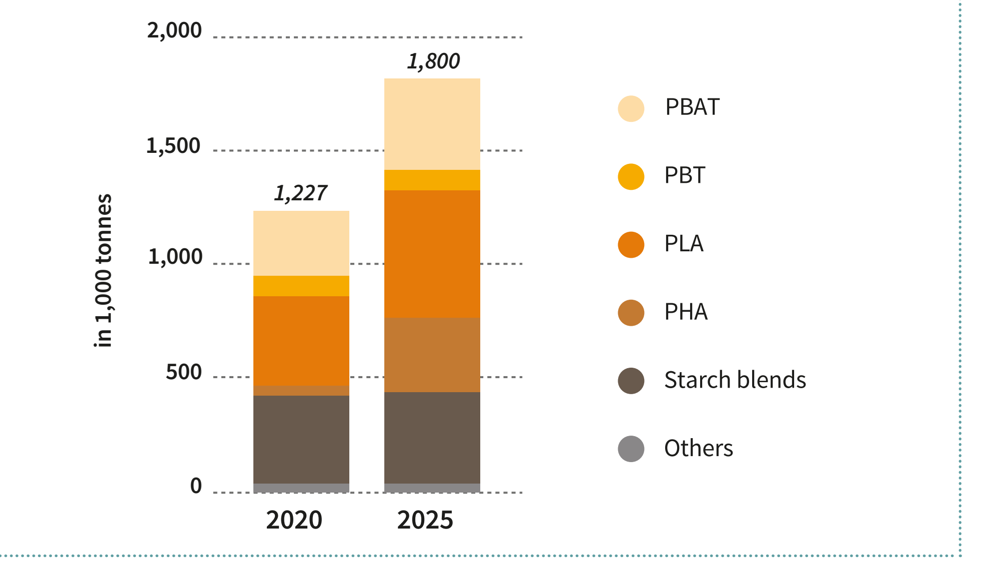


Figure: Expected growth (2020-2025) for the main biodegradable biopolymers.

Biodegradation mechanism

Biodegradation is the breakdown of organic matter by microorganisms, such as bacteria and fungi. The process of biodegradation can be divided into three stages: biodeterioration, biofragmentation, and assimilation. Biodeterioration is sometimes described as a surface-level degradation that modifies the mechanical, physical and chemical properties of the material. This stage occurs when the material is exposed to abiotic factors in the outdoor environment and allows for further degradation by weakening the material's structure. Some abiotic factors that influence these initial changes are compression (mechanical), (UV) light, temperature and chemicals in the environment. While biodeterioration typically occurs as the first stage of biodegradation, it can in some cases be parallel to biofragmentation.

Biofragmentation of a polymer is the lytic process in which bonds within a polymer are cleaved, generating oligomers and monomers in its place. The steps taken to fragment these materials also differ based on the presence of oxygen in the system. The breakdown of materials by microorganisms when oxygen is present is called aerobic digestion, and the breakdown of materials when oxygen is not present is called anaerobic digestion. The main difference between these processes is that anaerobic reactions produce methane, while aerobic reactions do not (however, both reactions produce carbon dioxide, water, some type of residue, and a new biomass). In addition, aerobic digestion typically occurs more rapidly than anaerobic digestion, while anaerobic digestion does a better job reducing the volume and mass of the material. Due to anaerobic digestion's ability to reduce the volume and mass of waste materials and produce a natural gas, anaerobic digestion technology is widely used for waste management systems and as a source of local, renewable energy.

In the final assimilation stage, the resulting products from biofragmentation are then integrated into microbial cells ('eaten'). Some of the products from fragmentation are easily transported within the cell by membrane carriers. However, others still have to undergo biotransformation reactions to yield products that can then be transported inside the cell. Once inside the cell, the products enter catabolic pathways that either lead to the production of adenosine triphosphate (ATP) or elements of the cells structure.

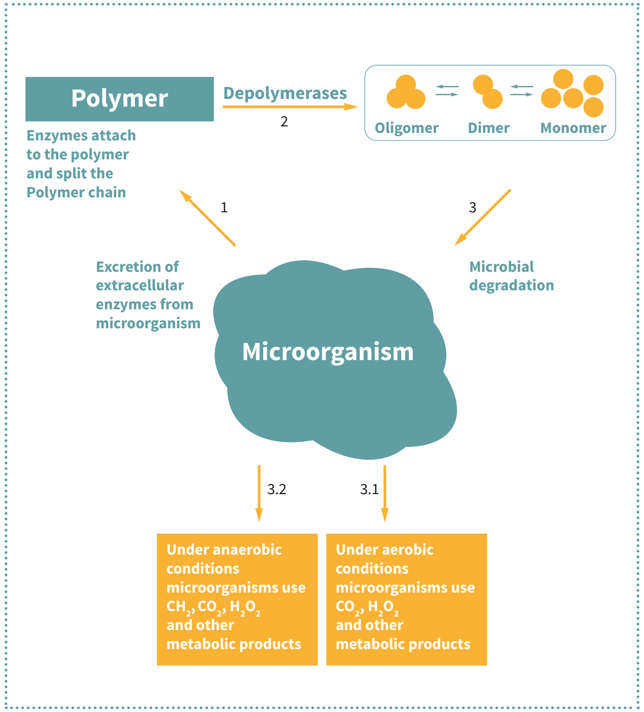


Figure: Three-stage mechanism of biodegradation.

Standards for biodegradation of bioplastics

Standardization is an effort of industrial stakeholders to define criteria for the description of products and services. The idea is to ease the competition and the commercial growth by overcoming barriers that result from unclear or incompatible specifications. The use of standards is voluntary, which means that it is within the sovereignty of a company to seek the compliance with a standard or not. In the latter case, however, it is not allowed to make the reference to the standard. Standards specify for example how measurements of biodegradability or renewability of a given material need to be made, or which criteria need to be fulfilled. A product or service that fulfils these requirements can legitimately claim compliance to the specific standard.

After many years of development and intensive discussions in normalization committees, requirements for industrial compostability have become well established and have been firmly fixed in several norms. The table underneath shows the various standards that have been developed for industrial compostability.

	WORLDWIDE	EUROPE	US	AUSTRALIA
PLASTICS	ISO 17088	EN 14995	ASTM D6400	AS 4736
PACKAGING	ISO 18606	EN 13432		
PAPER COATING			ASTM D6868	

Table: Overview of the various standards for industrial compostability (source: OWS)

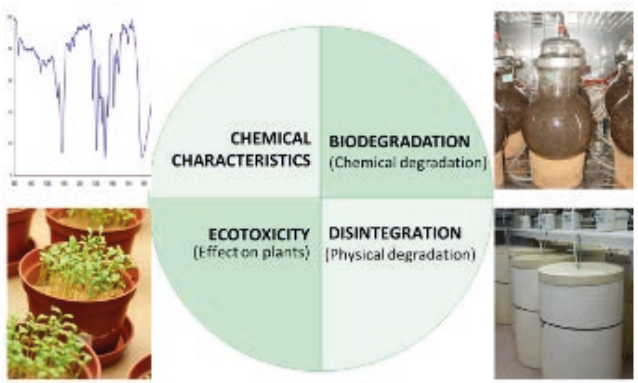


Figure: Four stages of biodegradation testing (source OWS).

Biodegradation shows quantitatively the inherent characteristic of the material to be consumed by microorganisms and protects the environment by showing that the material will not accumulate in nature. Biodegradability is therefore linked to the chemical composition of a material and represents the % of solid organic C converted to gaseous C under the form of CO_2.

Biodegradability testing can be performed under 'certification' or 'screening' conditions. Certification conditions are required in case results will be used for certification and/or making public claims. Screening conditions are suggested in case of early research and when results will only be used internally.

Testing is performed conform ISO 14855, ASTM D 5338 and/or EN 14046 (in compost), ISO 17556, ISO 11266 and/or ASTM D5988 (in soil), ISO 14851, ISO 9408, EN 29408, ASTM D 5271, OECD 301C, OECD 301F, OECD 302C and/or OECD 302F (in fresh water) and ISO 14851 and/or ASTM D 6691 (in marine water).

Disintegration measures whether the material breaks down and falls apart, thereby protecting the compost plant operator. In other words, the disintegration of a material is linked to its physical form and is therefore strongly affected by its thickness, grammage and/or density. For certification purposes, a precise mass balance is prepared and the exact % of disintegration calculated after sieving and hand-picking of the remaining material at the end of the test. Testing is performed conform ISO 16929 and/or EN 14045.

Ecotoxicity testing determines whether the material residuals, which are left behind after composting, show any inhibition on plant growth or the survival of soil fauna. Plant toxicity testing is a part of all norms on industrial compostability and prescribes the use of 2 plant species. Ecotoxicity testing can be performed on materials, intermediates, final products, inks, adhesives, varnishes, masterbatches, additives, etc. Plant toxicity testing is performed conform OECD 208 and EN 13432, earthworm toxicity testing is performed conform ASTM E 1676, OECD 207, ISO 11268 and/or AS 4736.

Figure: Example of disintegration test (source OWS).

Finally, the c**hemical characteristics**, more specifically levels the **heavy metals**, need to be quantified to assure that the material will have no negative effect on the quality of the end-product (compost). Each norm has his own set of heavy metal limits, with EN 13432 and AS 4736 as the most stringent ones

Depending on the application for which the bioplastic will be used, one can certify this material according to different biodegradation standards, each with its own specific conditions. These conditions are very important for the rate of biodegradation as the temperature, types of micro-organisms, level of oxygen, etc. can/will differ. The five main environmental conditions for biodegradation of materials are (see also figure underneath):

- Industrial compostability
- Home compostability
- Biodegradation in soil
- Biodegradation in fresh water
- Biodegradation in sea water

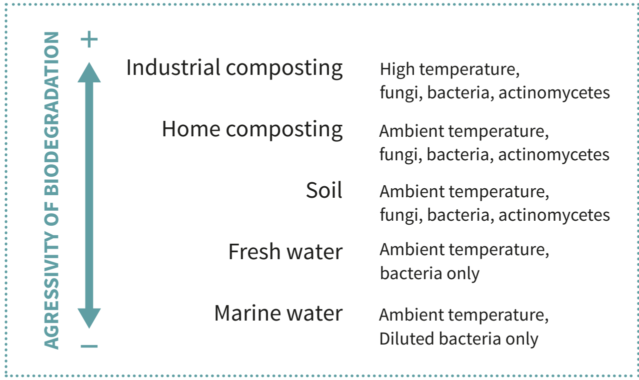


Figure: Aggressivity of different biodegradation conditions, industrial composting being the most aggressive and marine water being the least aggressive method of biodegradation.

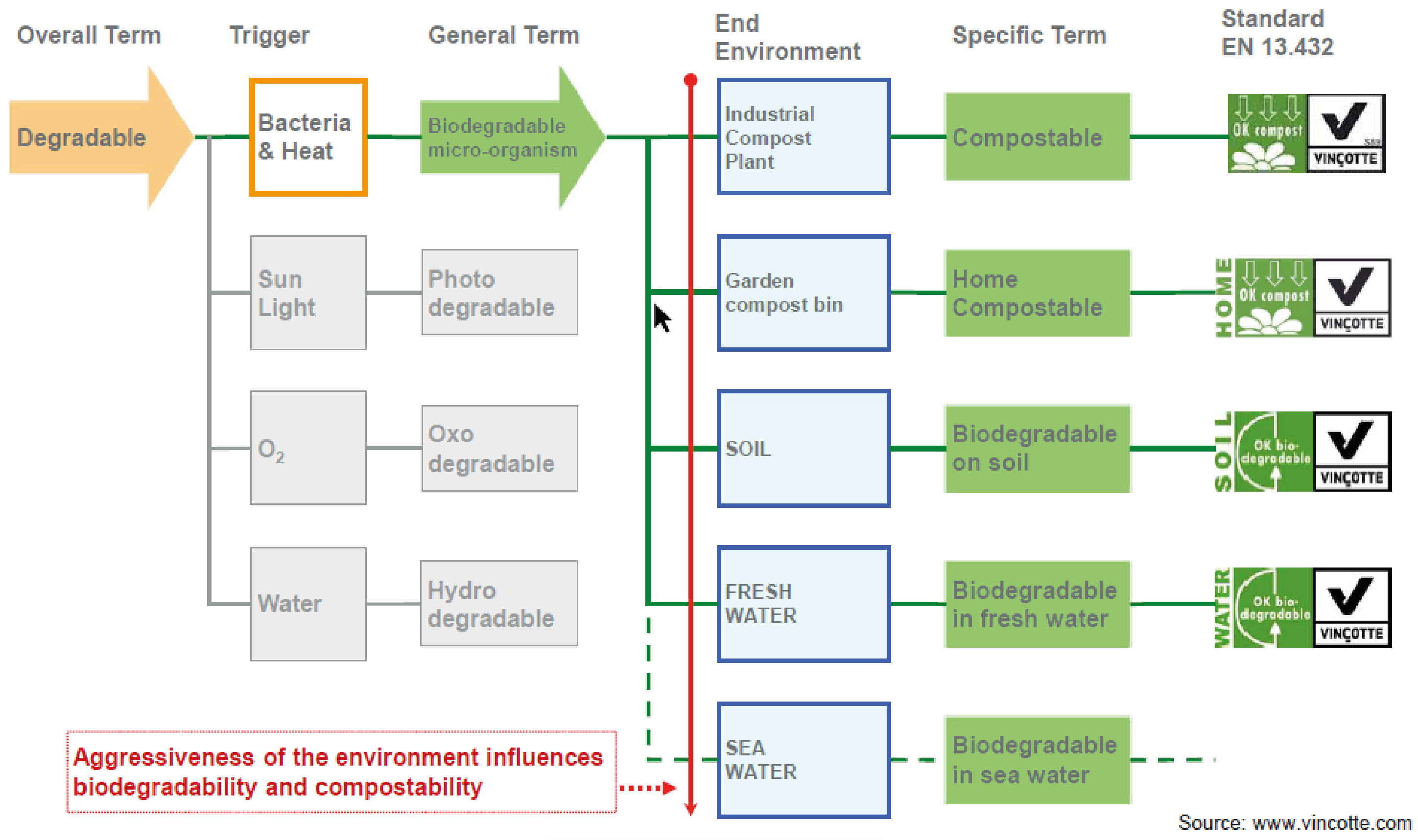


Figure: Different types of biodegradation.

The following standards are the most frequently applied biodegradation tests for the above discussed environments:

- Biodegradation in soil (ISO 17556, ISO 11266 and/or ASTM D5988)
- Biodegradation in fresh water (ISO 14851, ISO 9408, EN 29408, ASTM D 5271, OECD 301C, OECD 301F, OECD 302C and/or OECD 302F)
- Biodegradation in marine water (ISO 14851 and/or ASTM D 6691)
- High-solids anaerobic digestion (ISO 15985 and/or ASTM D 5511)
- Accelerated landfill test (ASTM D 5526)

The following figure gives a clear overview of the biodegradation properties of the main types of biopolymers. PBS and PLA are both industrially compostable, but PLA can also be anaerobically digested. Cellulose can be biodegraded under all certified conditions, just like cellulose, PHB and some others. PBAT and PBSA can only be biodegraded under industrial, soil and home composting conditions.

In line with the theme of this document we go a little deeper into biodegradation under marine conditions. Marine biodegradation is typically a slow process as the number of micro-organisms is limited, temperature is relatively low and oxygen levels can be rather low (depending on the depth). Cardboard for example takes about 2 months to degrade in seawater whereas a PET bottle can take up to 100 years to fully degrade. The official standard for marine biodegradability tests is ISO 14851 and/or ASTM D 6691. This is a standard test method for determining aerobic biodegradation of plastic materials in the marine environment by a defined microbial consortium or natural sea water inoculum. During the disintegration test the temperature is maintained at 30 ± 2°C and the test item is put in a shaking unit during the entire duration of the test (84 days).

MARINE BIODEGRADATION

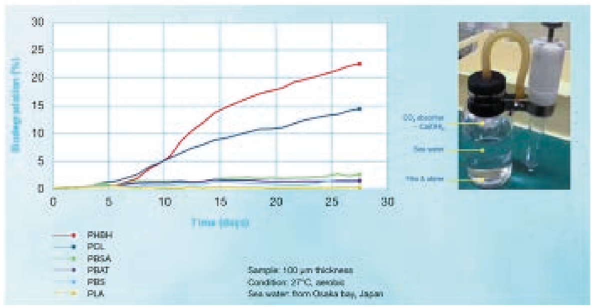


Figure: Marine biodegradable logo (left) and example of biodegradation curves for differet polymers in seawater (right).

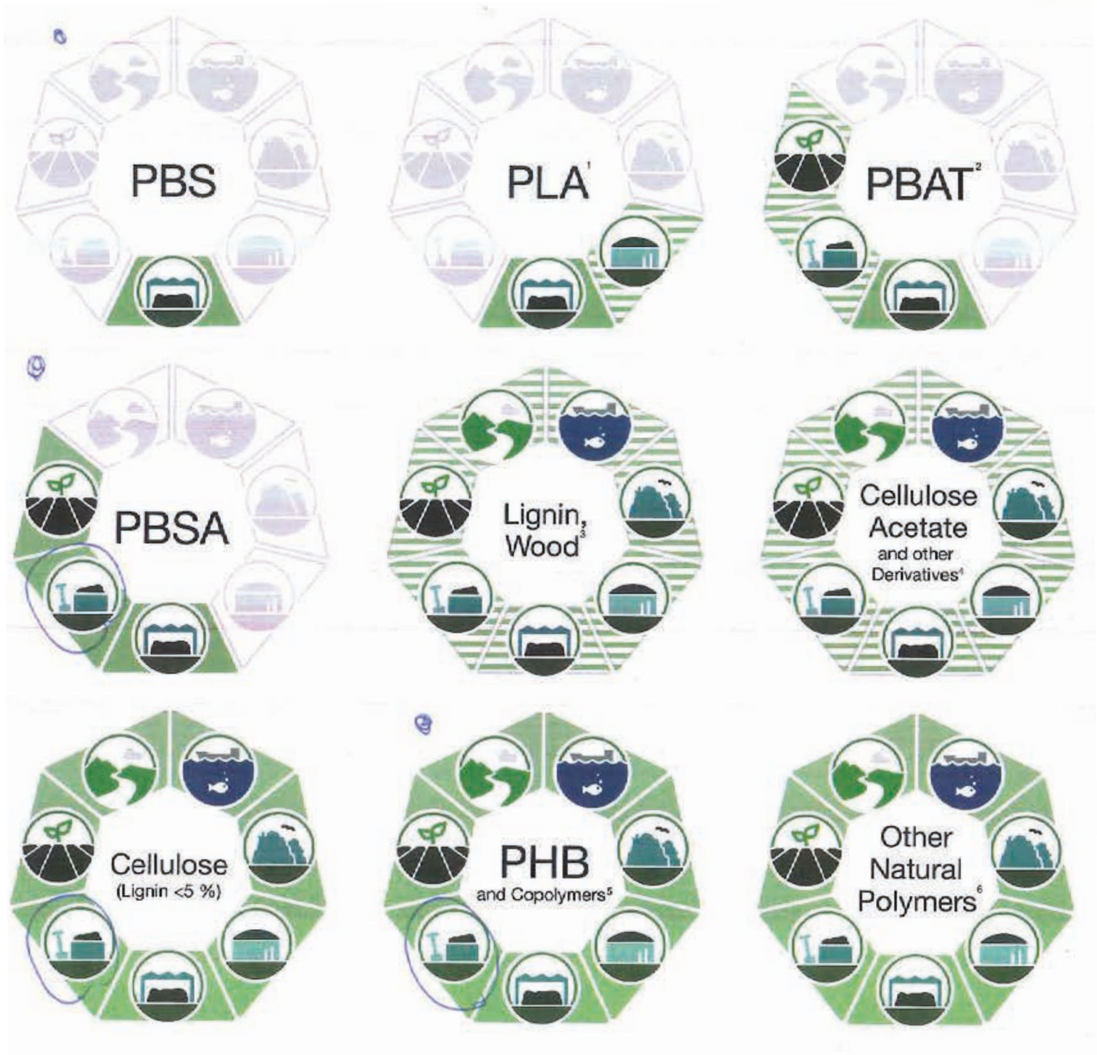


Figure: Biodegradation properties of the main biopolymers under specific conditions.

Applications for biomaterials in the marine and maritime sector

Over the past decades the marine and maritime sector has very much become aware of plastic pollution, as demonstrated by the keywords 'marine litter' and 'plastic soup'. Marine litter is a global concern, affecting all the seas and oceans of the world. Every year, millions and millions of tonnes of litter end up in the ocean worldwide, posing environmental, economic, health and aesthetic problems. Poor practices of solid waste management, wastewater (including storm water) collection and treatment, lack of infrastructure and awareness of the public at large about the consequences of their actions aggravate substantially the situation. Cleaning up the oceans is one option; it is however not the most efficient method against marine litter. You could compare it to scouring the sand in the desert and this is simply something that no country or private party could afford as long-term solution. The more efficient solution is to tackle the problem at its source. Marine litter is a clear symbol of a resource inefficient economy. Valuable materials are polluting our beaches and damaging our environment instead of being pumped back into our economy. Therefore, a circular economy approach which puts the emphasis on preventing waste and on recycling and reuse of materials and products in the first place, is the best solution to the marine litter problem.

Main sources of marine litter are:

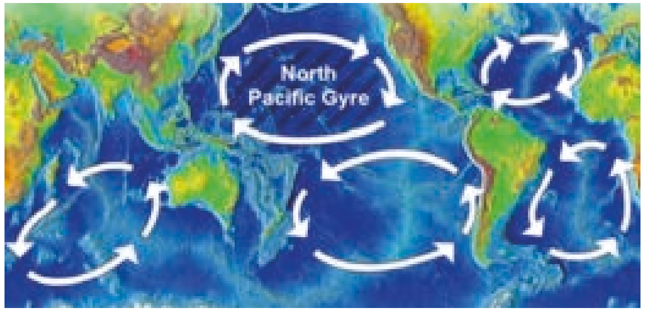
Land-based (80%):
- landfills and littering of beaches and coastal areas (tourism)
- rivers and floodwaters
- industrial emissions
- discharge from storm water drains
- untreated municipal sewerage

Sea-based (20%):
- fishing and aquaculture
- illegal or accidental dumping at sea from shipping (e.g. transport, tourism)
- offshore mining and extraction

It is estimated that more than 150 million tonnes of plastics have accumulated in the world's oceans, while 4.6-12.7 million tonnes are added every year. According to recent studies, the annual flow of plastic waste into the ocean could almost triple by 2040 to 29 million metric tonnes per year, equivalent to 50 kg of plastic for every meter of coastline worldwide. It is broadly assumed that approximately 80% of marine litter is land-based, with regional fluctuations (for example, in the Northeast Atlantic, shipping and fishing are very important litter sources); at the same time sea-based sources receive increasing attention, both because of the quantities of e.g. lost or abandoned fishing gear, but also of the damage to marine life and negative impacts on fishing and economy. Marine litter can indeed cause serious economic damage: losses for coastal communities, tourism, shipping and fishing. Considering its accumulation and dissemination, marine litter may be one of the fastest growing threats to the health of the world's oceans.

Plastic soup is a term referring to pollution of the sea by plastics in general, ranging from large pieces of fishing gear that can entrap marine animals to the microplastics and nanoplastics that result from the breakdown or photodegradation of plastic waste in surface waters, rivers or oceans.

The term was coined by Charles J. Moore in 1997, after he found patches of plastic pollution in the North Pacific Gyre between Hawaii and California. This Great Pacific Garbage Patch had previously been described in 1988 by scientists who used the term neuston plastic to describe "The size fraction of plastic debris caught in nets designed to catch surface plankton (hereafter referred to as neuston plastic)", and acknowledged that earlier studies in the 1970s had shown that "neuston plastic is widespread, is most abundant in the central and western North Pacific, and is distributed by currents and winds".



Marine biodegradation is typically a slow process as the number of micro-organisms in seawater is limited, the temperature is relatively low and oxygen levels can be rather low (depending on the depth). The table alongside gives an overview of the approximate time for compounds to biodegrade in the marine environment. Cardboard for example takes about 2 months to degrade whereas a PET bottle can take up to 100 years to fully degrade.

Taking all this information into account it is clear that there is a huge opportunity for biobased materials and for marine biodegradable materials. In the following chapter we will discuss three case studies for biobased and/or marine biodegradable materials.

Product	Time to Biodegrade
Paper towel	2–4 weeks
Newspaper	6 weeks
Apple core	2 months
Cardboard box	2 months
Wax coated milk carton	3 months
Cotton gloves	1–5 months
Wool gloves	1 year
Plywood	1–3 years
Painted wooden sticks	13 years
Plastic bags	10–20 years
Tin cans	50 years
Disposable diapers	50–100 years
Plastic bottle	100 years
Aluminium cans	200 years
Glass bottles	Undetermined

Case studies

In this final chapter we will discuss three case studies that underline the potential and importance of biobased and/or marine biodegradable materials for various marine and maritime applications:

- Ropes and nets based on biobased/biodegradable materials
- Biodegradable gravity anchors
- Biodegradable wick drains for geotechnical applications

Case study 1 : Ropes and nets based on biobased/biodegradable materials

In 2020 more than 8 Mio tonnes of plastic entered in seas and oceans around the world. This marine pollution, often referred to as marine debris or plastic soup, has its origin from marine transport, tourism, fisheries and aquaculture, and comes from land via rivers. Examples are fishing nets, ropes and fishing fluff (spekking or vispluis in Dutch). Fishing fluff consists of polyethylene monofilaments that protect fishing nets from abrasion when used for fishing on the seafloor.

Looking at the situation in the North Sea bassin, each year about 20.000 tonnes of plastics end up in the North Sea. 70% of this waste drops to the seabed. Each year Belgian fishermen buy 90-130 tonnes of fishing fluff to protect their fishing nets. At least 50% of this amount, i.e. 55 tonnes of polyethylene, gets lost in the sea during fishing activities. If one adds ropes and nets (typically made of nylon, polyethylene, polypropylene, polyester, etc.), one gets to hundreds of tonnes of marine textiles that enter the North Sea each year from Belgium.

Ropes and nets can be made of natural, biobased and/or marine biodegradable materials. Natural materials such as hemp, cotton and sisal typically degrade very fast (weeks/ months) in the marine environment. PLA is fully biobased and does not biodegrade in seawater. PHB and PBS are marine biodegradable on the time scale of months to years.

Currently, there are 2 Blue Cluster projects, i.e. CoastBusters 2.0 and BlueMarine3.com, that investigate biobased and/or marine biodegradable materials. The CoastBusters 2.0 project targets the design and development of mussel reefs as sustainable, nature-inspired coastal protection systems.
As partner in this project, Sioen Industries develops biobased and marine biodegradable dropper ropes for the collection and grow-out of mussel spat. Once the droppers drop down onto the seabed the mussels will generate a mussel reef whereas the marine biodegradable rope will biodegrade in time. Within the BlueMarine3.com project, Sioen Industries develops sustainable cultivation substrates for seaweed cultivation. In this project the focus is more on biobased than on biodegradable. The initial focus will be on PLA based hybrid substrates. Materials as developed in these projects have multiple spin-off applications in the marine environment.

Photos: fishing fluff, typically blue or orange, forms a significant part of marine debris in the North Sea.

Photos: plough anchor, screw anchor and gravity anchor, resp.

Case study 2: Biodegradable gravity anchors

In the marine environment various types of anchors are being used such as plough anchors, screw anchors and gravity anchors.

The function of such an anchor is to immobilize a structure for a certain period of time. The structure can be a vessel, a salmon farm or a multipurpose platform. Gravity anchors are the most popular anchors as they are low cost and easy to produce. However, due to the strongly increasing ecological awareness in society there is a need to replace gravity anchors based on plain concrete or metal blocks by more sustainable solutions. Therefore Sioen Industries has developed a concept for a temporary gravity anchor based on biobased and biodegradable materials.

The concept is based on a combination of sand and a biobased and biodegradable polymer binder. The sand acts as the weight whereas the biobased and biodegradable polymer acts as the « glue » to keep the sand together. Depending on the type of biobased and biodegradable polymer being used one can create a gravity anchor that slowly degrades in time (months to years scale). The biobased and biodegradable polymer-based anchor is totally harmless for the environment and is slowly being converted into sand and CO_2 in time.

Small scale lab tests have shown the proof of concept (see photos underneath). Depending on the type of biobased and biodegradable materials being used the anchor will degrade in 6 months to several years.

Further studies will be required to identify the exploitability of this concept.

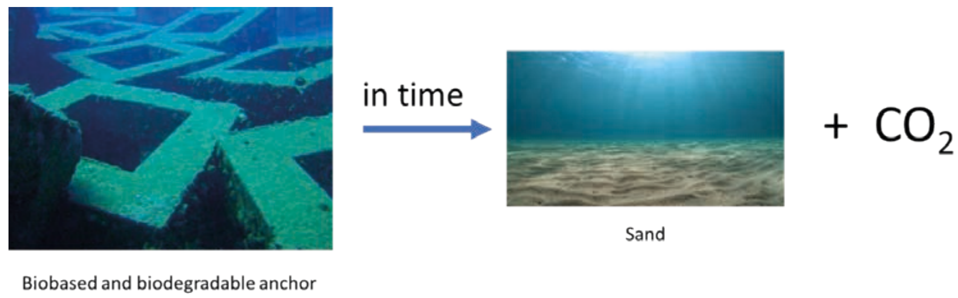


Figure: Temporary, biobased and biodegradable gravity anchor concept where the anchor is slowly being converted into sand and CO_2 in time.

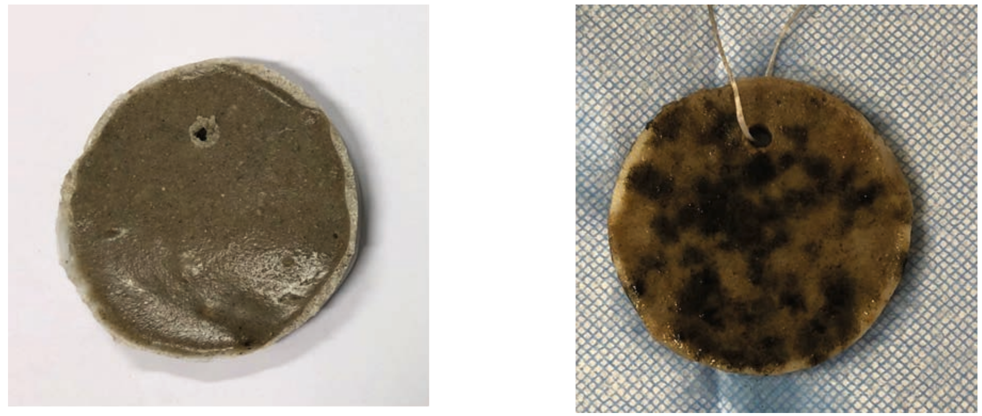


Figure: Small scale tests have shown that the concept of a temporary, biobased and biodegradable gravity anchor works; after 3 months in seawater at 22°C we observed 7-9% weight reduction of the sample. On the sample one observes clear growth of microorganisms.

Case study 3: Biodegradable wick drains for geotechnical applications

Highly permeable soils like sand can adjust rapidly to loads and the corresponding compression / reduction in voids due to the ability to easily drain the excess porewater. Low permeable soils like (silty) clay and peat do not have this ability and show a delayed compression with the dissipation of the excess pore water. This process of dissipation of excess pore pressures, also known as consolidation, can take up to years depending on the thickness of the deposit. Vertical drains or also known as wick drains are used to shorten the dissipation path of the excess pore water and to accelerate the consolidation process to a few months or even weeks when the wick drains are placed at close center to center distances.

Since the late 1970's infrastructural projects such as construction of roads, railways, dikes and airports, land reclamation, harbor construction and urban and industrial sites often use vertical drainage systems to reduce soil consolidation and settlement time from years to months. A vertical drainage system, spaced at about 1 to 3 meters apart, allows for faster removal of excess pore water, thus decreasing the risk of slip plane failure. Without vertical drains, soil consolidation and settlement can take a very long time, time that a project does not usually have.

Wick drains (see photo), also called prefabricated vertical drains (PVD), band drains or strip drains, are strips consisting of non-woven filter wrapped around a polypropylene core. The core is extruded into a shape that transmits a maximum water flow on both sides of the core. The filter is ultrasonically welded together at the edges and will prevent the core from being blocked with soil particles.

How it works? Wick drains can be installed vertically to depths up to 65 meters (typically between 5 m and 35 m). The water, under pressure in excess of hydrostatic, flows through the filter fabric of the prefabricated vertical wick drain and into the channels of the wick drain core where it can flow vertically out of the soil. This flow may be either up or down to intersecting natural sand layers or to the surface where a sand drainage blanket or prefabricated horizontal strip drains are provided. The water in the soil has only to travel the distance to the nearest prefabricated vertical wick drain to reach a free drainage path.

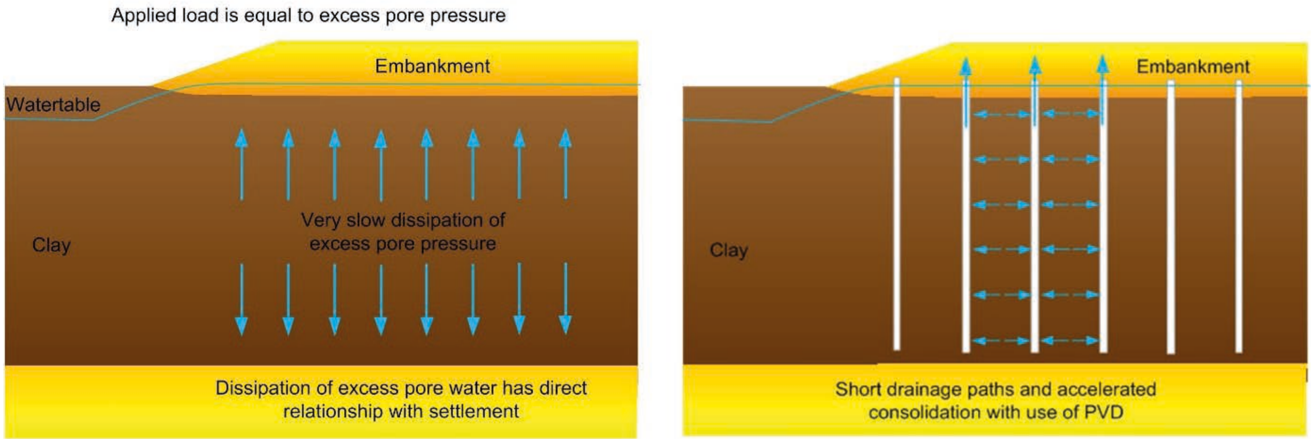
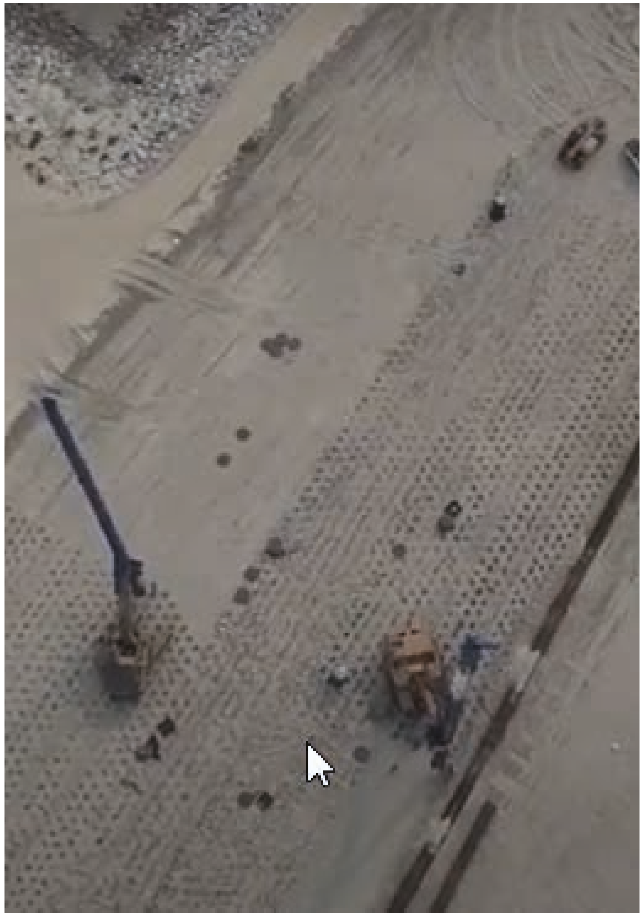


Figure: Upon land reclamation projects or other infrastructural projects the use of wick drains supports the dissipation of the excess pore water, resulting in reduction of soil consolidation and settlement time from years to months.

The installation of wick drains will drain out the water fast to reduce settlements and will reduce the pore pressure to prevent liquefaction. Therefore, it only takes weeks or months instead of years for the water to escape. The soil will settle fast and will be capable to support the new loads of infrastructural works. Surfaces can drop for several meters upon the use of wick drains.

As mentioned above, wick drains are typically made of a polypropylene nonwoven filter wrapped around a polypropylene core. Once installed in the soil wick drains stay there for many decades. It would be a huge step forward if land reclamation projects could make use of wick drains that are made of biobased and preferably also biodegradable materials. The biodegradability should be in the order of 1-3 years such that the primary function of the wick drain is fully maintained during its lifetime. The Blue Cluster member Sioen is currently developing such biobased and biodegradable wick drain materials.

Figure: Wick drains are installed using specialized equipment called stitchers.



Example: During the land reclamation project in Port Dickson, Malaysia, a 54 ha sand platform was reclaimed to create a working platform. Over a 2 months period a total of 13 Mio m (13,000 km) of wick drains was installed (source: CeTeau).

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