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Factsheet Bioplastics

The history of plastic

Ivory from elephants and other mammals was historically used for piano keys, toiletry utensils or billiard balls, all products for which man-made plastics are used today. The first plastic, invented in the second half of the 19th century, was celluloid, produced from nitrocellulose and camphor. Bakelite was the first plastic based on repeating and identical building blocks, so-called monomers. Due to its unrivalled characteristics, Bakelite quickly found use in the rapidly growing automotive and electrical industries. Since then, "plastic" has been a major success and is found in practically all aspects of human life and in high-tech applications.

What is plastic?

Plastic is a generic term for man-made polymers. Polymers have high molecular masses and are composed of a large number of repeating units known as monomers, linked in a chemical process called polymerization (Figure 1). Plastics are shaped by flow and additives to improve performance or reduce costs. Plastic polymers include all thermoplasts and thermosets but no elastomers (e.g., rubbers). Silicones are of an inorganic nature and are therefore not covered in this factsheet.

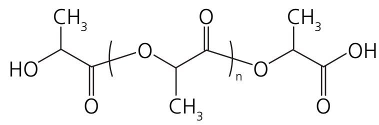

Figure 1
Schematic drawing of a polymer (polylactic acid) composed of numerous identical monomers (n > 10)

Applications and markets of plastic

Plastics are composed of a great variety of compounds, resulting in products with numerous different performance characteristics. Consequently, plastic is also used in very diverse markets and products, ranging from automotive to medtech, from aeronautics to packaging, and from clothing to furniture and other applications (Table 1). Numbers differ depending on the source, but approximately 400 million tons (+/- 50 million) of plastic are produced globally per year, up from a modest 1.5 million tons in 1950, 50 tons in 1976 and 100 million tons in 1989. After one year in use, these 400 million tons end up in landfills, after which they are recycled, are incinerated for energy recovery or end up as non-collected waste. On average, Switzerland consumes 120 kg of plastic per year per person, approximately 46% of which ends up as waste in the same year.

Sector	Percentage	Life span in years
Packaging	35.9	less than 0.5
Building and construction	16.0	35
Textiles	14.5	5
Health care, agriculture and others	11.6	5
Consumer products	10.3	3
Transportation	6.6	13
Electrical	4.2	8
Industrial machinery	0.1	20

Table 1: Applications of plastic in different sectors. The table shows the markets for plastic, the percentage of the globally produced plastic used per market and the life span of the plastic in the respective market. Source: National Geographic, June 2018

Why has plastic become a problem?

The problem of plastic is related to its advantage: durability. It does not degrade completely, instead breaking down into ever smaller micro- and nanoparticles whose fate and influence on ecosystems are not yet clear. As a result, plastic has become a major terrestrial and marine pollutant and is seen more as a curse than a blessing. The first consequences of such pollution are starting to show: the interdiction of selling certain plastic products on the market is being increasingly observed. The European Union, for example, decided to ban a number of single-use plastic products. The governments of 187 countries have agreed to control the movement of plastic waste between national borders in an effort to curb the world›s plastic crisis and have added plastic to the Basel Convention[1]. In addition, public awareness has been raised by campaigns such as the “planet or plastic” pledge[2].

What is a biopolymer?

Biopolymers are polymers completely synthesized by biological systems. Generally, they can be isolated from nature in a chemical process. Table 2 gives examples of relevant biopolymers.

Source	Examples
Animals	abyssal proteins, chitin, collagen, hyaluronic acid, silk, keratin
Plants	alginate, cellulose, cutin, starch, lignin, pullulan
Microorganisms	cyanophycin, polylactic acid (PLA), polyglycolic acid (PGA), polyhydroxyalkanoates (PHAs),

Table 2
Relevant polymers and their sources

Biopolymers are presently not able to compete with inexpensive oil-based polymers. Consequently, the market share of biopolymers will not increase unless regulations are effective that enforce a reduction in the overall amount of plastic produced and a replacement of non-degradable polymers by (bio)polymers degradable in the environment. High production costs and inconsistent quality are the biggest challenges to overcome.

What is bioplastic?

Bioplastic is a plastic material that is bio-based, degradable in the environment or both. Bio-based implies that renewable instead of oil-based raw materials are used for manufacturing and the fulfilment of EN 16640. Bio-PET, bio-polypropylene and bio-polyethylene are so-called drop-in commodity plastics that are identical to their petrochemical model but produced from bio-based precursors. Bioplastic products based on these polymers are not necessarily degradable in the environment. In addition to drop-in polymers, new mono-polymers and polymers based on renewable raw materials are increasingly used for the manufacturing of bioplastics. For example, polyethylene furanoate (PEF) is produced from furandicarbonic acid, which in turn can be produced from waste biomass. PEF has characteristics similar to those of PET but is less permeable to gas, which makes it attractive for the packing industry.

The exact percentage of bioplastic with respect to total plastic production is not known. Estimates vary between 1 and 2% of the total plastic market of 400 million tons. Bio-PET, bio-poly (butylene succinate) and polylactic acid are expected to show the highest growth rates in the near future.

What does biodegradable signify?

Biodegradation of plastic materials describes their degradation by microorganisms into carbon dioxide, water, inorganic compounds and biomass. Such bioplastics fulfil EN 13432. This process depends strongly on the environmental conditions. Biodegradability is related to the chemical structure of the polymer and does not depend on the origin of the raw materials.

In contrast, oxodegradable polymers – passing US Norm ASTM D6954 – are not considered biodegradable because additives break down the polymer chains, resulting in polymers that persist in the environment[3].

Are all plastics non-biodegradable and all bioplastics biodegradable?

The surprising answer is no! As shown in Table 3, there are examples of bioplastics that are not biodegradable (e.g., bio-polyethylene and bio-PET), and vice-versa, oil-based plastics such as polycaprolactone and poly (butylene succinate) that are biodegradable. In general, bioplastics based on natural biopolymers such as polylactic acid, polyhydroxyalkanoates, silk and cellulose are biodegradable and compostable even though polylactic acid needs industrial composting for efficient biodegradation.

[1] https://edition.cnn.com/2019/05/11/world/basel-convention-plastic-waste-trade-intl/index.html
[2] https://www.natgeo.com/plasticpledge
[3] https://docs.european-bioplastics.org/2016/publications/fs/EUBP_fs_standards.pdf

	non-biodegradable	biodegradable
renewable sources	bio-polyethylene terephthalate (bio-PET) bio-polyamide (bio-PA) bio-polyethylene (bio-PE)	cellophane chitosan silk polyhydroxyalkanoates (PHAs) polylactic acid (PLA)
oil-based sources	acrylonitrile-butadiene-styrene (ABS) polyamide (PA) polyethylene (PE) polyethylene terephthalate (PET) polypropylene (PP) polyvinylchloride (PVC)	polybutene adipate terephthalate (PBAT) polybutylene succinate (PBS) polycaprolactone (PCL) polyvinyl alcohol (PVA)

Table 3
Overview and classification of polymers, the source of their raw material and their degradability

Can all plastics be recycled?

Not all plastics can be recycled. However, as shown in Table 4, the majority of plastic products can be more or less easily recycled. Since the degradation rates are partly poor, biodegradability becomes important.

Abbreviation	Full name of polymer	Applications	Recyclability
ABS	acrylonitrile butadiene styrene	car dashboards, electric enclosures, wheel covers	yes
LDPE	low-density polyethylene	agricultural film, flexible bottles, shopping bags	yes
HDPE	high-density polyethylene	milk bottles, pipes, shampoo bottles, toys	yes
PA	polyamide (Nylon)	carpets, clothing	yes
PBAT	polybutylene adipate terephthalate	agriculture, coating in cups, packaging	yes
PBS	Polybutylene succinate	disposable products, packaging	yes
PCL	polycaprolactone	implantable materials, medtech, prototyping	yes
PE	polyethylene	ice cream lids, tubing, squeeze bottles	yes
PET	polyethylene terephthalate	bottles of multiple purposes	yes
PHA	polyhydroxyalkanoate	medtech, packaging	yes
PLA	polylactic acid	golf balls, medtech, packaging	yes
PMMA	polymethylmethacrylate	car windows, dental fillings, LED lamps	yes
PP	polypropylene	automotive parts, drinking straws, microwave containers	yes
PS	polystyrene	disposable shavers, insulation, plastic foam cups, toys	difficult
PTFE	polytetrafluoroethylene (Teflon)	non-sticking coating	yes
PVC	polyvinylchloride	credit cards, inflatable pools, pipes, window frames	very difficult
PUR	polyurethane	insulation foams, mattresses, pillows	yes
PVOH	polyvinyl alcohol	coating, strengthening of paper and textiles	yes

Table 4
Summary of polymers used most frequently in the production of plastic, their applications and their recyclability

Do biopolymers need regulation?

Even though the market volume of biopolymers has increased steadily, its share remains low because of the constantly growing total polymer market. How can this situation be changed? Would it make sense to introduce steering mechanisms? Do we need more directed R&D to change the situation?

The difference in the lifespan of plastic products ranges from a few months to several decades (Table 2). Moreover, the wide choice of monomers, bio-based and non-bio-based, biodegradable and non-biodegradable, and, finally, the facility for recycling shows that a coherent strategy for a more sustainable future for plastic in various markets and applications is a challenge. Improving plastic sustainability requires not only a careful assessment of and differentiation between mass products and specialties but also unbiased information and education of consumers and government.

The first SATW Innovation Forum on "Biopolymers" and conclusions

The first SATW Innovation Forum on "Biopolymers" took place in November 2018. Invited stakeholders from academic research institutions, industry and administration discussed the current situation and possible shortcomings in Switzerland and charted possible scenarios for development. The afternoon was dominated by discussions on consumer goods and convenient plastics. It became clear that Switzerland has very limited opportunities in the field of bulk (bio)plastics. It can, however, serve as a role model, develop high-tech solutions and "educate" customers. Development and application of high-tech, specialty biopolymers should be the primary targets for the Swiss economic space.

An unbiased view based on facts and numbers is a prerequisite for further activities and leads to various questions. Who are all the stakeholders? What are the market numbers and R&D activities in Switzerland? Do oil-derived plastics or hybrids indeed have better environmental performance than plastics derived entirely from a natural origin? Bio-based and biodegradable plastics are more expensive than fossil-based plastics on a weight basis – but how could costs and prices develop in the future? A future workshop is intended to give answers to these questions and clarify the realistic options for Switzerland.

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