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Polymer - macromolecule composed of many repeating units.

A polymer (*poly-mer* from Greek: *poly* - many, *meros* - parts) is normally considered to be an organic compound although inorganic polymers are also known. Polymers can contain thousands of repeating units (monomers) arranged in a linear or branched fashion and can reach molecular weights above one million Daltons (Dalton = g/mol).
Polymers are found in nature or are man-made (artificial, synthetic). Natural polymers (= biopolymers) are specific and crucial constituents of living organisms. They are mainly polysaccharides (e.g. cellulose, starch, glycogen) and proteins (e.g. gluten, collagen, enzymes) although many other forms are also known such as lignin and polyesters. Man-made polymers are a large and diverse group of compounds not known in nature. They are synthesized through chemical or biochemical methods. The global annual production of man-made polymers is estimated to be 230 million tons in 2009 (Plastics – The Facts 2010).

The main use of man-made polymers is in the production of plastics.
Polymers are distinguished from plastics in that they are pure **compounds** whereas plastics are formulated **materials** ready for use.

BASIC
A simplified analogy of a polymer is a pearl necklace composed of individual pearls (as monomers) arranged in a linear fashion.

Biopolymer – polymer formed by living organisms.*

Biopolymers (= natural polymer) are crucial constituents of living organisms (including proteins, nucleic acids and polysaccharides). They are mainly ***polysaccharides*** (e.g. cellulose, starch, glycogen) and ***proteins*** (e.g. gluten, collagen, enzymes) although many other forms are also known such as lignin, polyesters etc.
Alternative 1: fully or partially biobased polymer (CEN/TR 15932:2009)

* Adapted based on: PAC, 1992, 64, 143 (Glossary for chemists of terms used in biotechnology (IUPAC Recommendations 1992)), definition on page 148

Plastic – polymer-based material that is characterized by its plasticity.

The main component of a plastic (from Greek: *plastikos* - fit for moulding, *plastos* - moulded) is a polymer, which is "formulated" by the addition of additives and fillers to yield the technological material – a plastic. Plastics are defined by their plasticity – a state of a viscous fluid at some point during its processing.

According to EN ISO 472: **Plastic** - Material which contains as an essential ingredient a high polymer and which at some stage in its processing into finished products can be shaped by flow.

Biodegradation – breakdown of a substance by biological activity.

Biodegradation must involve the action of living organisms in the degradation process, however it can be combined with other abiotic processes. Biodegradation occurs through the action of enzymes applied either as digestive systems in living organisms and/or as isolated or excreted enzymes. Organisms carry out biodegradation on substrates that are recognized as food and serve as a source of nutrients.
The end products of biodegradation are common products of digestion such as carbon dioxide, water, biomass or methane. This final step is known as ultimate biodegradability or biological mineralization.
For practical purposes the rate of biodegradation and the final products of biodegradation should be known.

Biodegradable plastic – plastic susceptible to biodegradation.

The degradation process of biodegradable plastics can include different parallel or subsequent abiotic and biotic steps however it **must** include the step of biological mineralization.
Biodegradation of a plastic takes place if the organic material of a plastic is used as a source of nutrients by the biological system (organism).
Biodegradable plastics can be based on renewable-biomass (e.g. starch) or nonrenewable-fossil (e.g. oil) feedstocks processed in a chemical or biotechnological process. The source or process, by which biodegradable plastics are produced do not influence the classification as biodegradable plastic.
The biodegradation rate of a plastic item depends, in addition to the specific plastic formulation, also on the on surface-to-volume ratio e.g. thickness etc.

BASIC
Microorganisms recognize biodegradable plastics as food and consume and digest it.

Compostable plastic – plastic that biodegrades under the conditions and in the timeframe of the composting cycle.

Composting is a manner of organic waste treatment carried out under aerobic conditions (presence of oxygen) where the organic material is converted by naturally occurring microorganisms. During industrial composting the temperature in the composting heap can reach temperatures up to 70 °C. Composting is done in moist conditions. The composting process takes place in months.
It is important to understand that a biodegradable plastic is not necessarily a compostable plastic (it can biodegrade over a longer time period or under different conditions) whereas a **compostable plastic is always a biodegradable plastic**. The definition of criteria for compostable plastics is important because materials not compatible with composting can decrease the final quality of compost.
Compostable plastics are defined by a series of national and international standards (e.g. EN13432, ASTM D-6900), which refer to industrial composting.
EN13432 defines the characteristics of a packaging material in order to be recognized as compostable and acceptable to be recycled through composting of organic solid waste. EN 14995:2006 broadens the scope to plastics used in non-packaging applications. These standards are the basis for a number of certification systems.

According to EN 13432 a compostable material must possess the following characteristics:
- *Biodegradability*: a capability of the compostable material to be converted into CO_2 under the action of microorganisms. This property is measured through the standard EN 14046 (also published as ISO 14855 biodegradability under controlled composting conditions). In order to demonstrate complete biodegradability a biodegradation level of at least 90% must be reached in less than 6 months.
- *Disintegrability*: physical fragmentation and loss of visibility in the final compost measured in a pilot scale composting test (EN 14045)
- *Absence of negative effects on the composting process*
- *Low levels of heavy metals* and *absence of negative effect on the final compost*

Home composting differs from industrial composting by the lower temperature in the composting heap. A plastic material must be specially tested to prove compostability under home composting conditions.

BASIC
Compostable plastics biodegrade under conditions of industrial composting.

Bioplastic – a plastic material that is biodegradable, biobased or both.*

The term in the primary definition is widely used in the plastics industry and less in the scientific community.

Alternative use 1: may also mean biocompatible plastic (CEN/TR 15932)
Alternative use 2: natural plastic material. There are very few known bioplastics. A leading example are polyhydroxyalkanoates – natural thermoplastic polyesters.

* European Bioplastics

Biobased plastic – a plastic based on biomass (excluding fossilized biomass).

A plastic can be fully or partially based on biomass (= renewable resources). The use of renewable resources should lead to a higher sustainability of the plastic.
Although fossil sources are natural they are not renewable and are not considered a basis for biobased plastics. For defining the extent to which a plastic is biobased see **Biobased carbon content.**
Biobased materials are often referred to as biomaterials although in professional use the terms are not synonyms (see **Biomaterial**). The use of this term as a synonym to the term biobased plastic should thus be discouraged as inappropriate.

Biomass – material of biological origin excluding fossilized and geologic materials (= renewable resources)

The terms ***biomass*** and ***renewable resource*** describe the same from the aspect of source and time of replenishment.

Renewable resource is a resource that is replenished at a rate comparable to its exploitation rate.

Biomass can be of animal, vegetal or microbial origin.

Biobased – derived from biomass.

Biobased carbon content – content of biomass-derived carbon as mass fraction of total organic carbon in material.

Biobased carbon content is precisely determined by measurement of C14 isotope content. (C14 in renewable resources is much higher than in fossil sources and the half-life is 5730 years). This method is the basis for the ASTM D-6866 standard: *Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis.* More standards on this basis are currently under development.
Certificates and certification logos based on ASTM D 6866-08 are available for materials of different biobased content.
“Biobased content” has the same meaning according to ASTM D 6866-08. Closely related “biomass content”

is defined as mass fraction of biomass sourced material (CEN/TR 15932:2009).

Biomaterial – material for biomedical applications

See definitions issued by the international Society for Biomaterials: http://www.biomaterials.org/index.cfm

Sustainability – a general term that describes the resource burden of a process or product.

There are two main scopes in which sustainability is presented. The narrower focuses exclusively on the use of material and energy resources. The broader takes account of wider social aspects and considers sustainability to be composed of economic, social and resource sustainability. The latter definition is seen as less well defined due to the arbitrary nature of parameters and criteria used while the former has a more technical aspect.
Sustainability is most commonly described by the definition that arose at the Rio conference on climate change: *The use of resources without jeopardizing the ability of future generation to do so as well.* A different definition focusing on material and energy renewability was coined by R. Baum: *Sun based in real-time*. The point in both definitions is that sustainability is not compatible with terminal and exhaustive consumption of resources. The second definition acknowledges the sun as the sole source of energy (also needed for biomass creation).

Key tools identified to evaluate sustainability can be grouped into four main categories:
1. Tools for Sustainable Governance (e.g. GGP);
2. Methods and tools for assessing environmental, economic and social impacts (e.g. LCA);
3. Tools for environmental management and certification (e.g. EMAS);
4. Tools for sustainable design (e.g. ecodesign).

Sustainability is commonly measured by the use of Life Cycle Assessment (LCA) a systematic and objective method for evaluating and quantifying the energy and environmental consequences and potential impacts associated with a product/process/activity throughout its entire life cycle, from the acquisition of raw materials until its end of life (“from cradle to grave”). In this technique, all phases of a production process are considered as related and interdependent, making it possible to evaluate the cumulative environmental impacts. At an international level, LCA is governed by the ISO 14040 and ISO 14044 standards. LCA is the main tool for implementing ‘Life Cycle Thinking’ (LCT). LCT is fundamental as a cultural approach because it involves considering the entire product chain and identifying which improvements and innovations can be made to it.
LCA is also known as life-cycle analysis, ecobalance, and cradle-to-grave analysis.

BASIC
A simplified material based example of sustainability can be given by the following two examples. A sustainable process is the flow of a river. In theory it is inexhaustible and will continue year after year. An example of a non-sustainable process is mining. After the ore will be removed from the earth and used it will be terminally consumed and will never reappear.

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