Defining plastic-like materials: Controversy on the Single-Use Plastics Directive

1. The aim of this document

In recent policies, the definition of plastics has been intertwined with the definition of polymer. Often in discussions, they are used interchangeably: polymer equals plastic and plastic equals polymer. This can cause grave misunderstandings. Plastic is made of polymers, but not all polymers are plastics. Especially from the regulatory point of view, it is important that these terms are not used synonymously.

The definition of plastic in the **Single-Use Plastics Directive (SUPD)**[1] has raised important questions that must be addressed before subsequent policies and legislation regarding materials, especially bio-based and biosynthetic, are made. A major issue is the controversial definition of plastics. **If applied to future legislation, for example, regarding packaging materials or textiles, we risk losing the opportunity to sustainably utilize bio-based materials in these application areas.** Moreover, at worst, we risk closing doors for current and future innovative research and potential new sustainable solutions that can contribute to some of the most pressing environmental challenges that face us. We believe that this is neither the intention nor in the interest of the legislator.

If future legislation will consider new polymeric materials equal to fossil-based plastics, it will simply stabilize the status quo. Already now, the confusion on material acceptance in the future has turned a marked number of brands to consider recyclable fossil-based materials as the main alternative for their applications. The outcome of the described development is that the use of fossil-based general-purpose plastics continue their rapid growth, which is contradictory to the targets of the legislator and the EU Green Deal,[2] and especially, the aim to reduce secondary microplastic emissions.

To mitigate the issue of microplastics, actions on many levels are needed. Better waste management is of utmost importance but not enough, as microplastic emissions can occur also during production and use phases, for example, when opening plastic packaging[3,4] or washing textiles[5]. Moreover, in applications where reduction, reuse and recycling of plastics are not feasible, substitution of conventional plastics with materials that biodegrade and thus do not leave permanent microplastics behind, can play an important role in the mitigation of microplastics accumulation.[6,7]

The aim of this document is to provide a clarification on terminology, discuss benefits and disadvantages of certain materials as well as point out existing and foreseeable controversies and challenges in the regulatory environment.

2. Relevant definitions and observations

Polymers

EU's chemicals policy REACH regulation[8,9] defines *polymer as a substance consisting of molecules characterised by the sequence of one or more types of monomer units. Such molecules must be distributed over a range of molecular weights. Differences in the molecular weight are primarily attributable to differences in the number of monomer units.* See REACH regulation for further details.

Polymers are created in a process called polymerization which can occur both in nature and via a man-made process.

Synthetic (man-made) polymers

Synthetic polymers are not separately defined in the SUPD or REACH. They follow the polymer definition given above.

Currently, the vast majority of synthetic polymers is derived from fossil-based raw materials (i.e. crude oil) and are non-biodegradable. Thus, they are a potential source of microplastics, for example when being used or when eroding in the environment.

Natural polymers

Many polymers occur in nature and are often composed of either amino acids or sugars in proteins and polysaccharides, respectively. Examples of natural polymers include cellulose, starch, proteins, polyhydroxybutyrate (PHB), and even deoxyribonucleic acid, DNA. To simplify, we as well as all animals, plants, and microorganisms, are based on natural polymers.

In the SUPD, natural polymers are polymers, which are the result of a polymerisation process that has taken place in nature, independently of the extraction process with which they have been extracted (see chapter 3 for discussion). In addition, to be classified as a natural polymer in the SUPD, the polymer must not be chemically modified.

Chemically modified natural polymers

Chemically modified natural polymers are, as the name implies, natural polymers that have been chemically modified, and therefore man-made. In chemical modification, the chemical structure of the polymer is altered by creation of new covalent bonds, for example, to render it suitable for advanced applications or to improve its durability.

In the REACH / SUPD, the term "chemically modified substance" is defined inversely. According to Article 3(40) of the REACH regulation,[8] "not chemically modified substance" is defined as "a substance whose chemical structure remains unchanged, even if it has undergone a chemical process or treatment, or a physical mineralogical transformation, for instance to remove impurities". Thus, chemically modified natural polymers encompass all natural polymers which have been chemically modified, **regardless of the extent of modification or the properties of the resulting material.**

Plastics

In general, plastics encompass a wide range of synthetic or semi-synthetic materials that consist of polymers and possible additives. The plasticity of these materials makes it possible for them to be shaped by flow at some point of processing into solid objects. Figure 1 describes a way of classifying different plastic materials according to their raw material source and biodegradability. However, this is merely an indicative classification as, for example, biodegradability is a complex system-dependent property.

It should be emphasized that the material classes in Figure 1 do not imply anything about their sustainability. The environmental impact of bio-based and fossil-based plastics are typically in different impact categories.[10] Generally, usage of bio-based plastics leads to lower fossil-based energy use and greenhouse gas emissions. On the other hand, bio-based plastics generally have a higher impact in categories related to agriculture, such as eutrophication and acidification. There are large impact differences inside the categories of bio-based as well as the fossil-based plastics. **Therefore, no absolute rules can be given about the sustainability of these material groups: sustainability aspects of plastic materials should be studied case-by-case considering their whole life cycle.[10]** Thus, material selections should be made in an application-specific manner. In the modern material-intensive society, the end-of-life of materials should be carefully considered.

Fossil-based plastics

Fossil-based plastics (common plastics, traditional plastics) are composed of polymers made from petrochemicals, *i.e.* derived from petroleum or natural gas. The vast majority of fossil-based plastics used nowadays are not biodegradable, e.g., polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS). The amount of plastic produced in 2019 reached 368 million tons.[11]

Bioplastics

The term bioplastic is often loosely used to describe both *bio-based* and/or *biodegradable plastics,* whereas these terms should be used separately.

The vagueness of the definition causes bioplastics to cover also biodegradable fossil-based plastics. To avoid confusion and regulatory challenges, it is imperative to use terms that represent the raw material source and biodegradability of the materials.

Bio-based plastics

Bio-based plastics consist of polymers derived from biomass or issued from monomers derived from biomass and which, at some stage in their processing into products, can be shaped by flow.[12] The amount of bio-based plastics produced in 2019 was two million tons.[19] Examples of bio-based plastics include:

- Plastics made from polymers produced by living organisms such as starch, cellulose, or proteins as well as natural polymers replicated via fermentation, such as PHAs.

- Synthetically produced bio-polyesters: In contrast to natural polymers produced by living organisms, also synthetic biopolymers can be made from bio-based monomers (*e.g.* PLA, PEF[13])

- "Drop-in bioplastics": Essentially "bio-similar" copies of fossil-based plastics and thus not biodegradable.

Additional details can be found in recent literature.[14,15]

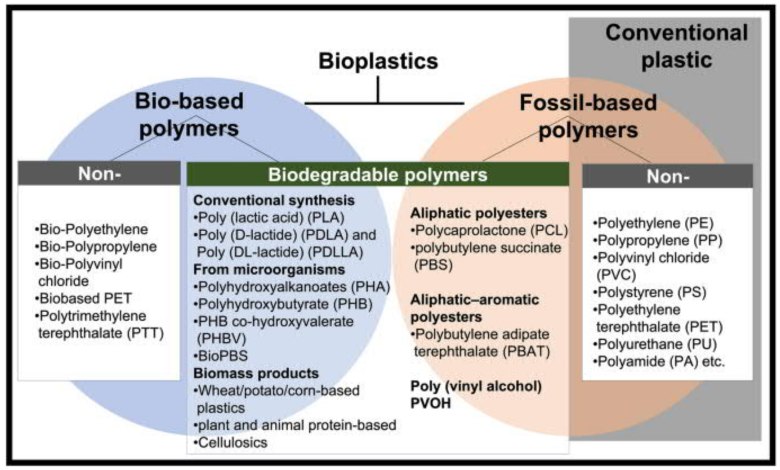

Figure 1. Simplified categorization of plastics with material examples.[15]

Biodegradable plastics and biodegradability

A biodegradable plastic can be defined as **plastic which can be decomposed by microorganisms into carbon dioxide, water, biomass, and mineral salts** (as well as methane in anoxic conditions), thus lowering the molar masses of the macromolecules that form the material. An important factor is the timespan: While biodegradable plastics can degrade in weeks or months, non-biodegradable plastics can take thousands of years to decompose. Thus, non-biodegradable plastics are a major contributor to landfills and pollution, and especially problematic to marine life.[16,17] **In addition to the chemical structure of the material, the rate at which plastics degrade depends on environmental conditions, such as temperature, amount of light and moisture, as well as the types of microorganisms present. These factors are essential when addressing biodegradability of plastics**.[18]

It is important to note that plastics' ability to biodegrade is independent of its raw material source; both bio- and fossil-based plastics can be either biodegradable or non-biodegradable (Figure 1). Examples of plastics that have shown biodegradation properties include polyhydroxyalkanoates (PHAs), polybutylene-based polymers (PBS, PBAT), polycaprolactone (PCL), and polyvinyl alcohol (PVA). In addition, e.g. polylactic acid (PLA) is a compostable polymer. The amount of biodegradable/compostable plastics produced in 2019 was slightly over one million ton.[19]

Compostable materials are biodegraded in specific composting conditions, leaving no harmful residues behind. To claim a material compostable in industrial composting facilities/plant, it has to meet the requirements of the standard EN 13432 (packaging products) or EN 14995 (plastics). These standards define testing schemes to determine the compostability of materials by addressing the rate of biodegradation, their disintegration during biological treatment, their effect on the biological treatment process and their effect on the quality of the resulting compost. For example, to meet the biodegradability criteria, 90% of the material must disintegrate in less than six months.

To evaluate the biodegradability in different open environments, more standards are needed. Despite the existence of international and national standards for assessing biodegradability in aquatic systems,[20] more research as well as standardisation efforts are needed to take properly into consideration the complexity and variability of natural environments.[21] For example, to date, there is no European standard for assessing biodegradability in marine environments.[22] However, standards are being developed for testing biodegradability in specific marine environments.[23]

Definition of plastic in the SUPD

The SUPD defines plastic as "*a material consisting of a polymer* (as defined in REACH Article 3(5))*, to which additives or other substances may have been added, and which can function as a main structural component of final products, with the exception of natural polymers that have not been chemically modified*". Therefore, plastics made using chemically modified natural polymers, or manufactured from bio-based or fossil starting substances are all addressed by the SUPD, **regardless of their properties or consideration of their life cycle**. The SUPD even specifically mentions that it covers plastics regardless of whether they are intended to biodegrade over time. Only unmodified natural polymers are exempt from the SUPD regulation.

Sustainability

Sustainability is a very broad concept including environmental, economic, and societal aspects.[24] Most commonly, sustainability is linked to the following principles: "an action that can be continued indefinitely without causing harm" and "meeting the current generation's needs without compromising those of the future".

However, misuse or narrow use of the term often lead to deceptive assessments of materials' sustainability. For example, end-of-life of materials as well as their economic and environmental impacts are often not considered or addressed.

3. Controversy related to the Single-Use Plastics Directive

In the SUPD, unmodified natural polymers are exempt from regulation. However, all other man-made plastic-like materials are put into one regulatory basket, **regardless of their properties, sustainability of their production and use, or environmental fate**. The division of polymers in two groups, natural and man-made does not seem very appropriate in the modern context. The criteria for natural polymer being that the polymerization has taken place in nature is problematic in many ways. It means that man-made polymers having the same structure as their natural equivalents end up defined as plastic. For example, polymers produced through industrial fermentation, artificial cultivation or biosynthesis are not considered as natural polymers by SUPD even though the processes are similar to those happening in nature and the so-formed polymers would be virtually identical to polymers existing in nature. This classification cannot be considered beneficial to the purpose of legislation or future research.

Regulation of materials should be based on their properties, such as biodegradability in specific environments and safety of the material, and ultimately the sustainability of the material, considering the whole life cycle.

In addition to natural polymers, the SUPD exempts all polymers which do not act as a main structural component of the final material. Such components include e.g. paints, inks, and adhesives, which can be based on any type of polymers. For example, if making a paper cup and adding polymeric additives to pulp, they are not considered as main structural components. Thus, even though the additives would be man-made polymers, this type of product is not considered to contain plastics according to the SUPD.

On the other hand, the SUPD has no threshold for the amount of plastic in the final product. Thus, adding a thin polymer layer coating to a paper cup to, for instance, increase its water retention capability renders the product to be classified as plastic, as the coating is considered a main structural component. This creates confusion in terminology as, for example, multilayer structures common in food packaging become plastics, regardless of the amount of plastic. **Even more importantly, as previously addressed, this classification does not consider the properties of the added polymer, such as biodegradability.**

While the aim of the SUPD is excellent, the definition of plastic in the directive hinders the development of environmentally friendly solutions to plastic litter and microplastics accumulation. Chemically modified natural polymers are a good example. It is true that chemical modification can affect the biodegradation properties of natural polymeric materials. However, these effects largely depend on the extent and type of chemical modification.[25,26] Thus, classifying all chemically modified natural polymers as plastics in the SUPD, irrespective of the extent of modification and the properties of the materials, is contrary to common sense, and will hinder the utilization and further development of a number of sustainable polymeric materials.

While natural polymers are exempt from the SUPD regulation, the current definition of plastic causes a vast variety of materials to go under one regulatory term. However, as the SUPD is already finalized, changing this definition will be challenging. Rather, **a new classification/definition should be established for environmentally benign man-made polymeric materials,** as future material needs will not be met by natural polymers alone. This class of materials could encompass, for example, polymers produced via fermentation that are identical to natural polymers. In addition, the class should include natural polymers that are chemically modified by sustainable and green chemistry methods and retain their biodegradability. In contrast, chemically modified natural polymers that show significantly hampered biodegradation properties, such as cellulose acetate, should be classified as plastics. Moreover, the definition of materials must go far beyond how something is made. **The sustainability of material production and its use must be evaluated considering the whole life cycle, especially end-of-life.**

Importance of biodegradability

The aim of the SUPD is to reduce the impact of certain plastic products on the environment, in particular the marine environment. Naturally, improving waste management, circularity, and recycling infrastructure are absolute priorities in solving the problem of marine litter. Plastic waste should not end up in nature. However, the vast majority of marine litter originates from highly populated countries where waste management infrastructure is far from being capable of handling all the plastic used in consumer products or single-use applications. Thus, an EU-wide band of certain single-use plastic products is far from enough to tackle this global problem. Additionally, this ban enforced by the SUPD hampers the development of environmentally friendly alternative products.

In addition to visible plastic litter in the environment, emissions of microplastics are becoming a widely recognized environmental and human safety issue. Microplastic particles are found in nearly all types of environments ranging from oceans to lakes to various foodstuffs, as well as the air we breathe. They originate from plastic materials e.g. when exposed to mechanical stress, such as squeezing a plastic bottle.[3] These non-biodegradable particles end up in various human organs such as kidneys, lungs, hearts and brains, and have even been found in the placentas of pregnant women.[27] It must be emphasized that future studies are needed to assess potential dangers and especially long term effects of microplastics to human health. However, there is preliminary evidence that microplastics accumulating in the human body can contribute to disruption of the gut microbiome and inflammation in tissue.[28]

The European Chemicals Agency has imposed EU-wide restrictions on the use of primary microplastic particles, *i.e.* purposefully produced microplastic particles for e.g. cosmetic products. While this is a good initiative, it is of utmost importance to realize that the majority of microplastic particles in nature originate from secondary microplastics emissions, *i.e.* via abrasion of plastic materials. The main sources of such microplastics include e.g. vehicle tyres, road surfaces, paints, packaging items as well as textiles.[29] However, **biodegradable materials are rarely brought up as a potential solution for secondary microplastics emissions, despite their potential in reducing the accumulation of plastics and microplastics in the environment.** As recently pointed out by the European Commission's independent Group of Chief Scientific Advisors (SAPEA), while biodegradable plastics are not a 'silver bullet' to solve the problem of plastic pollution, they may have benefits over fossil plastics in applications where it is challenging or prohibitively expensive to avoid fragments ending up in the open environment.[7] The advantage of biodegradable polymers is that upon degradation, they do not erode into harmful permanent secondary microplastics. This is because most natural environments on earth habit microbes that can enzymatically degrade these kinds of polymers. To illustrate the importance of these microbes, without them dead trees would remain for tens of thousands of years in the forest without degrading.

To reach the aims of the SUPD as well as to address the microplastics problem, **biodegradability should be recognized to have an important role in combating the issue of environmental plastic pollution**. As the marine environment is in the focus of the SUPD and generally considered the most challenging environment for biodegradation, exempting plastics that biodegrade in marine environments from the SUPD seems like an obvious step towards fulfilling the aim of the legislation. While this was not included in the SUPD due to lack of knowledge and standards on biodegradability, this topic needs to be reconsidered when the SUPD will be revised in 2027. This is of great importance, as there are very few ways to address the growing concern of plastic and especially secondary microplastic emissions. Incentivising the development and use of materials that neither produce plastic pollution nor microplastic emissions is crucial in addressing this global problem.

In order to get started, establishing standards for biodegradability in especially marine environments is important, as recently pointed out by the European Commission's independent Group of Chief Scientific Advisors.[7] This SAPEA report recognizes the importance of materials' 'residence time in nature' as one aspect of environmental risk analysis. The risks associated with materials lasting, for example, 1-5 years in the environment, versus thousands of years, are likely to be different.

It is important to realize that, currently, complete replacement of conventional plastics by biomass-derived biodegradable plastics is not feasible simply based on the magnitude of the needed materials and their properties, as well as lack of needed manufacturing capacity. Thus, parallel efforts are needed to tackle the challenges related to plastics, such as development of chemical and mechanical recycling and plastic pyrolysis. However, regulation should be formulated in such a way that it does not hinder development of sustainable material solutions.

Effect on the material solutions of the future

The other problem with the definitions in SUPD is that **such definitions are easily applied to future policies and regulation as well**. If applied in future legislation regarding, for example, packaging materials or textiles, we risk to lose the opportunity to utilize bio-based material alternatives in these application areas and obstruct the European bio-based materials research as well as synthetic biology research aiming to novel materials. This can lead to hampering of future sustainable material innovations and their commercialization.

The global population and therefore the need for materials such as packaging items and textiles is increasing. Reuse and recycling are important concepts to lengthen the material cycles, but alone they are not sufficient. There are always losses in the material cycle, and therefore virgin material input is inevitably needed. The guiding principle should be to minimize the use of virgin fossil carbon and instead use bio-based carbon, carbon directly from CO_2, or recycled fossil carbon.

Breaking away from fossil fuel and material dependency is crucial to combat climate change and resulting issues like microplastic emissions. The energy sector is currently undergoing decarbonization and moving towards renewable energy solutions. However, the material sector cannot be decarbonized. To move away from a fossil-based material economy, bio-based materials have a pivotal role towards truly sustainable circular bioeconomy.

Natural polymers such as cellulose, lignin and hemicellulose are examples of untapped raw material resources for new sustainable materials, through which the dependency on fossil-based materials can be decreased. Bio-based materials offer versatile possibilities in materials applications from wood construction to pulp and paper production, to sustainable consumer products, and further to advanced applications enabled by novel lignocellulose material fractions. To maximize the environmental benefit, utilization of biomass should follow cascading use principles: natural resources should be used and recycled for as long as possible and allocated to the most valuable purposes at each stage.[30]

In addition, new biotechnological methods of polymerization are seen to hold promise in truly sustainable circular bioeconomy. Producing safe bio-based materials through biotechnology is also a potential way of creating added value from forest industry residues and side streams.

Many of the materials used today in, for example, consumer products are made of (often fossil-based) polymers. If fossil-based polymers are replaced with other types of materials, they will, in many cases, inevitably also be polymers. While imposing plastic bans on certain single-use products is a good starting point to start moving towards a cleaner planet, alternative environmentally friendly material solutions should not be simultaneously obstructed by regulation.

Example: Textiles

What happens if the plastic definition in the SUPD is applied to future policies regarding other types of consumer products? The EU Commission is currently preparing the EU strategy for sustainable textiles.[31] Thus, textiles can be considered as a timely example.

Amount of textile waste prompts us to increase the use of bio-based fibres that are sourced from renewable resources and can be fully recycled or biodegraded at the end of their life cycle. Currently, the majority (~60%) of textile fibres are made from fossil-based plastics such as polyester, while ~30% of textile fibres are made from cotton and 1% from wool. However, all these fibres have major issues: commonly used fossil-based textile fibres lead to generation of microplastics, cotton growing is highly area-, and water-intensive, and wool is not scalable. The remaining ~6% of textile fibre market originates from man-made cellulose-based fibres. Some of these textile fibres can overcome above-mentioned issues, and thus hold promise for a sustainable textile industry.

If the plastic definition from SUPD would be directed to textiles, it could mean a major blockage for man-made cellulose-based textiles. Depending on the strictness of the interpretation of whether chemical modification has or has not happened during the textile fibre manufacturing process, some cellulosic man-made fibres can be classified as plastics and some as natural polymers. Based on the latest information about the interpretation of SUPD, textiles manufactured using Lyocell-type technology could be classified as natural polymers while, for example, viscose-type fibres might fall into the plastic category. Thus, possible future restrictions based on this classification may limit the market volume of cellulose-based fibres as well as the material quality variations that are essential in textile applications.

4. Conclusions

Raising societal awareness of environmental issues associated to the single-use plastics is a very important initiative to ensure a sustainable future. However, a true change can only take place if clear guidelines are formulated, resulting in a new specification for environmentally benign polymeric materials. To avoid deterioration of the existing environmental problems, material regulation should focus on promoting sustainability in terms of materials themselves and their production, use, and recycling. Moreover, the sustainability of materials should be evaluated individually, considering their whole life cycle, too. This will ensure and improve the development of truly sustainable material solutions.

To summarize:

- The controversial definition of plastics in the SUPD should not be applied in future legislation regarding, for example, packaging materials or textiles.
- Therefore, European Commission should initiate an effort to establish a new definition/category for benign bio-based and/or biodegradable man-made polymeric materials, considering that:
    - Regulation should be based on material properties, assessing also biodegradability in specific environments and safety of the material, and ultimately on the sustainability of the material.
    - The evaluation of the materials' sustainability must consider their whole life cycle, including production, utilization, and end-of-life.
    - In view of end-of-life, biodegradability should be recognized to have an important role in combating the issue of environmental plastic pollution. However, standardization efforts are needed to enable transparent assessment of material biodegradability in the open environment.

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