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Biodegradable and Biobased Polymers: Definitions, Standards, and Future Perspectives

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Abstract: The growing concern of plastics disposal at the end of their life cycle has induced the addressing of specific standards and normatives to promote reuse, recycling and final disposal of the plastics with the aim to minimize the use of resources and select the best possible option for final disposal of the material, thus promoting recovering in terms of materials itself (mechanical or chemical recycling), energy, or biomass. Similar criteria has been considered also in materials production, thus promoting both the preferential use of renewable versus petro sources and a green chemistry approach for the synthesis of polymers and additives. The industrial production of commodity non biodegradable polymers from bio-based resources has induced some confusion in the definition of bio-based polymers versus biodegradable ones. In addition, the general assessment of biodegradability of a plastic is not sufficient for granting the fulfilment of the requirements of consolidated international standards for composting. Thus, it is important to have a clear idea of the definition of bio-based, biodegradable, and compostable as well as to be aware of the current legislation and of the sustainability concepts. Indeed, if not properly planned and addressed, the production of compostable materials might result as being less sustainable than that of petro derived, not biodegradable polymers. The present chapter reviews the current definition of bio-based, recyclable, biodegradable and compostable materials and refers to current standards and legislation. The definition of sustainable production for plastic materials and the methods currently adopted to evaluate the sustainability of products are also addressed.

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1. Introduction

There is a growing awareness worldwide of the issue of plastic disposal since wastes produced by the use of plastics based on not degradable polymers are solid, visible, and usually quite persistent. This issue is particularly bound to plastic waste generated by packaging disposal. The management of plastic waste can be made by following different options. However, waste policy in most countries follows the so-called waste hierarchy concept, which also represents the European Commission's preferences towards different waste management options.

For this policy, the best options are:

- Reduction of waste by prevention of waste production,
- Recycling (organic or material recycling),
- Energy recovering,
- Disposal in landfill.

In Europe, this is expressed by the Waste Framework Directive 2008/98/EC, 19 November 2008 [1], of the European Parliament that gives specific attention to prevention, reuse and recycling. The option of recycling includes composting and anaerobic digestion as a type of organic recycling. For organic waste, the waste framework legislation encourages recycling in agriculture through composting, since this is considered the most environmentally friendly option for organic waste management. In addition, recycling as re-processing of production scraps in industries is highly recommended.

The Council Directive 1999/31 of 26 April 1999 on the landfill of waste [2], which considers the worst possible option for waste disposal, states that the European Member States are encouraged to plan a national strategy for the implementation of the reduction of biodegradable waste going to landfills. This can be achieved by means of organic recycling (composting and anaerobic digestion), material recycling and/or energy recycling (incineration with energy recovery).

Starting from 1999, the target of organic waste going to landfills at 75%, after five years was indicated, 50% after eight years, 35% after 15 years. This directive aims at reducing the amount of methane gas produced by anaerobic degradation of organic waste in landfills, and consequently supported the introduction of separate collection of biodegradable waste, by a proper sorting and consequent possibility of recovery and recycling.

More recently, the European Commission has adopted an ambitious Circular Economy Package, which includes revised legislative proposals on waste to stimulate Europe's transition towards a circular economy, which will boost global competitiveness, foster sustainable economic growth and generate new jobs. This revised legislative proposal on waste [3] sets clear targets for reduction of waste and establishes an ambitious and credible long-term path for waste management and recycling.

Key elements of the revised waste proposal include:

- A common EU target for recycling 65% of municipal waste by 2030;
- A common EU target for recycling 75% of packaging waste by 2030;
- A binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030;
- A ban on landfilling of separately collected waste;

- Promotion of economic instruments to discourage landfilling;
- Simplified and improved definitions and harmonised calculation methods for recycling rates throughout the EU;
- Concrete measures to promote re-use and stimulate industrial symbiosis, turning one industry's by-product into another industry's raw material;
- Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (e.g., for packaging, batteries, electric and electronic equipment, vehicles).

In the field of materials recycling, the plastic materials represent the fraction most difficult to be managed. In fact, several different polymers are currently employed in packaging in order to respect the requirements necessary for different foods and beverages protection. Poly(ethylene), poly(propylene), poly(ethylene terephthalate) and poly(styrene) are the most employed, but also multilayer packaging are currently used. These plastic materials, usually derived from petrol, cannot be recycled without being separated from each other. Each polymer can be recycled by processing it at high temperature to obtain a viscous melt. However, if a preliminary separation is not carried out, polymer blends showing very low properties are obtained because of the immiscibility and incompatibility of the different polymers. Many efforts have been made to organize the recycling of the different types of plastics. Currently, poly(ethylene terephthalate) (PET) and rigid polyolefins are well recovered and recycled in active industrial chains, but some plastic fractions are still difficult to be recovered and recycled, especially those employed in multilayer packaging. The replacement of such complex fraction of packaging with a biodegradable one, managing its end life by composting, could be an interesting alternative.

Consequently, both in producers and consumers, there is a growing interest versus the use of "bio-polymers" for the production of "bio-plastic". Scientific efforts toward the design, synthesis, and production of sustainable or green materials have expanded tremendously in the last two decades [4]. At present, biopolymers share about 1% of the total market of polymers [5].

Governments are getting involved in promoting bio-based materials through initiatives such as the Lead Market Initiative (European Union, Brussels, Belgium) and BioPreferred (USA). The Lead Market Initiative actions range from improving the application of bio-based products to standardization, certification and labeling. The BioPreferred procurements refers to a preferential purchasing policy based on the public procurement program stating that bioplastic version is to be preferred if available versus a petro derived counterpart. As a consequence, federal agencies are obliged to use products from a stated BioPreferred list [6].

These initiatives are expected to facilitate the growth of innovative markets, such as that of bio-based materials, with high economic and social value and encourage its potential increase. Thus, a worldwide demand for replacing petroleum derived raw materials with renewable resource-based raw materials for the production of polymers has raised interest.

2. Definition

Even if bio-plastics already play an important role in the fields of packaging, agriculture, gastronomy, consumer electronics and automotive, to name a few, the industry for production and marketing of biodegradable and bio-based plastics is relatively young and growing fast. Also for this reason, in the area of bio-plastics, there is actually a lot of confusion on terminology. In Europe and worldwide, there are several industrial associations related to bioplastics.

We report some definition from the main associations in the sector.

SPI Plastic Industry Trade Association, Bioplastics Council [7]:

- Bioplastics: plastic that is biodegradable, has bio-based content, or both.
- Biodegradable Plastic: a plastic that undergoes biodegradation (process where the action of naturally-occurring micro-organisms such as bacteria, fungi, and algae induce the degradation of the material) accepted as industrial standards.
- From 2008, accepted industry standard specifications are: ASTM D6400, ASTM D6868, ASTM D7081 or EN 13432 [8–11].
- Bio-based content: fraction of the carbon content made up of biological materials or agricultural resources versus fossil carbon content, where the bio-based content is measured following the procedures set by ASTM D6866, where a product's bio-based carbon content is reported as a fraction of total organic carbon content (TOC) and not on its weight [12], while other analytical standard methods such as EN 16440 and ISO 16620-2 allow bio-based results to be reported as a fraction of total carbon (TC) that specifies a calculation method for the determination of the bio-based carbon content in monomers, polymers, and plastic materials and products, based on the ^{14}C content measurement [13,14].
- European Bioplastics [15]
- Bio-based: material or product (partly) derived from biomass (plants).
- Bioplastic: the term bio-plastics encompass a whole family of materials that are bio-based, biodegradable, or both.

Thus, it is clear that bio-based and biodegradable have not the same meaning. We can summarize that the term "bio-based" means just that the material or product is (partly) derived from biomass (plants), but its biodegradability has to be assessed. Some bio-based products can biodegrade in municipal or commercial composting facilities, home composting, and aquatic and roadside environments, while others will only biodegrade in very specific environments and some will not biodegrade at all. For example, poly(lactic acid) is compostable while bio-poly(ethylene) is not. Biodegradation refers to a chemical process carried on by micro-organisms that are present in the environment. These micro-organisms convert the organic carbon in the materials into natural substances such as water, carbon dioxide, and compost.

The process of biodegradation depends on the surrounding environmental conditions (e.g., location or temperature), on the material and on the application.

When defining a material to be biodegradable, we should also specify in which environment. Thus, some polymers can biodegrade in compost, but not in soil, some degrade in marine water and some not, etc.

Composting is considered as an organic recycling of material, where industrial composting is performed under controlled composting conditions at high temperature in large-scale composting plants, while home composting is performed at ambient temperature in a reduced scale.

3. Standards and Directives

The Packaging Directive 94/62/EC [16], and most recent amendments, set minimum recovery and recycling targets for each type of packaging product. This Directive address the amounts of biodegradable waste that can be land-filled or incinerated, and thus also compliance with the Landfill Directive, but does not affect recycling of bio-waste as defined in the Waste Framework Directive.

The following European standards provide a framework within which these standards can be used together to support the claim that packaging is in compliance with the essential requirements for packaging to be placed on the market as defined in the following directives:

- EN 13431:2000—Packaging. Requirements for Packaging Recoverable in the Form of Energy Recovery Including Specification of Minimum Inferior Calorific Value.
- EN 13432:2000—Packaging. Requirements for Packaging Recoverable Through Composting and Biodegradation. Test Scheme and Evaluation Criteria for the Final Acceptance of Packaging.
- CR 13695-1—Packaging. Requirements for Measuring and Verifying the Four Heavy Metals (Cr, Rd, Hg, Pb) and Their Release into the Environment, and Other Dangerous Substances Present in Packaging.
- EN 13427:2000—Packaging. Requirements for the Use of European Standards in the Field of Packaging Waste ("Umbrella Norm").
- EN 13428:2000—Packaging. Requirements Specific to Manufacturing and Composition. Prevention by Source Reduction.
- EN 13429:2000—Packaging. Reuse

- EN 13430:2000—Packaging. Requirements for Packaging Recoverable by Material Recycling.

The norm EN 13432 has been endorsed by the European Commission and therefore is a harmonized EU standard with a juridical value for defining a product as compostable.

A product can be defined as compostable as required by EN 13432 (2000) if it respects specific characteristics:

- The product must contain at least 50% organic matter and may not exceed the heavy metal limits specified in the standard.
- The products should mineralize for at least 90% within six months under controlled composting conditions, where mineralization is defined as the conversion of the organic C to Carbon dioxide (CO2) and biomass, and this characteristic is linked to the chemical composition of the sample.
- The product, in the form which enters the market, should, within a timeframe of 12 weeks, fragment in parts smaller than 2 mm under controlled composting conditions. It has to be outlined that this requirement refers to the physical form of the product instead of to the chemical composition. These characteristics are connected mostly to the thickness and the physical construction (e.g., laminate, coating, etc.) of the sample, and can result tricky to be met al.so for packaging based on biodegradable materials.
- The compost obtained at the end of the composting trial, which can also contain some no degraded residuals from the product, must not have any negative effects to the germination and growth of plants.

Thus, we can say that compostability comprises more than just biodegradability. A packaging that is compostable is always biodegradable, while a packaging which is biodegradable may not be compostable (since it might be too thick for disintegration or might release in the compost toxic substances). In order to avoid confusion on terminology and standards to be applied, several authorities have decide to promote (or even mandate) the definition "compostable" versus the definition "biodegradable".

In Europe, there are several certification logos used by institutes for industrial compostability. One of them is the 'Seedling' logo of European Bioplastics, issued by the certification institutes of Din Certco (Berlin, Germany) [17] and the Ok Compost of Vinçotte (Ghent, Belgium) [18] (Figure 1).

Figure 1. Logos for compostable materials.

Concerning home compostability, there is currently no international norm in place that defines the criteria to be adopted. Thus, contrast to industrial composting, which is a harmonised and controlled waste treatment option operated under specific and controlled conditions in specific plants with explicit permits and resulting compost as a regulated product, home composting is a gardening practise carried out by citizens on a voluntary basis, without permits and without obligations. The conditions in each garden compost pile and the actual treatment methods vary greatly, making it difficult to standardise this process [19].

Organizations that have defined criteria for home compostability include the certifier Vinçotte (Luxemburg, Belgium) with the Ok Compost Home programme (Figure 2) offers a certification scheme, while DIN CERTCO offers a certification for home compostability according to the Australian standard AS 5810 "Biodegradable plastics suitable for home composting". Italy has a national standard for composting at ambient temperature, UNI 11183:2006 "Plastic Materials Biodegradable At Room Temperature—Requirements And Test Methods". In November 2015, the French Standard NF T 51-800 "Plastics—Specifications for plastics suitable for home composting" was introduced.

Figure 2. Logo of Ok Compost in the Home program.

In the United Kingdom, we can find the Association for Organic Recycling with a home compostable certification scheme identical to the OK Compost Home programme, while there is a recent law in France that requires some single use items such as tableware, to be home compostable from 2017 with a minimum bio-sourced content of 30% (increasing progressively in subsequent years to 60% in 2025) [20].

Anyway, as recalled before, it must be considered that the biodegradability of a material is related to the environment and is frequently very different in compost, soil, anaerobic conditions, and particularly in water. This is related to the different microorganism present in the different substrates and also to differences in temperature, pHs, etc. Thus, specific standards have been made for the evaluation of the biodegradability in different environments. For example, to achieve the requirements for logos such as Ok Biodegradable Soil, a material should present more than 90% absolute or relative biodegradation within two years in soil, while for Ok Biodegradable Water, an aquatic biodegradability test, it is prescribed to reach 90% biodegradation within 56 days.

4. Bio-Based Materials

The use of materials that are bio-based is as well valuable since it allows saving petro resources and can valorize by-products or waste products of agriculture. Products on the market are made from a variety of natural feedstock including corn, potatoes, rice, tapioca, palm fiber, wood cellulose, wheat fiber and bagasse. Products are available for a wide range of applications in packaging such as cups, bottles, cutlery, plates, bags, film, etc.

The first generation of bio-based polymers was based on agricultural feedstock such as corn, potatoes, and other carbohydrate feedstock. Most recently, the focus has shifted versus by-products and waste product of agriculture with the aim to move away from food-based resources, this was supported also by advancement in biotechnology such as the use of bacterial fermentation processes.

Bio-based polymers can be produced from renewable resources in different ways:

- From natural bio-based polymers with eventually chemical modification to meet the requirements (starch, cellulose, chitosan, proteins, and their derivatives)
- Production of bio-based monomers by fermentation/conventional chemistry followed by polymerization (polylactic acid, polybutylene succinate, polyethylene)
- Production of bio-based polymers by bacteria (polyhydroxyalkanoates).
- Among bio-based polymers that are not biodegradable polyethylene (PE) produced from ethanol derived ethylene is the most important due to the large market sector involved. 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.

There are several products on the market that report the label of bio-based products. Braskem is producing polyetheylene from bio-based feedstock, sugarcane ethanol, in Brasil (Figure 3).

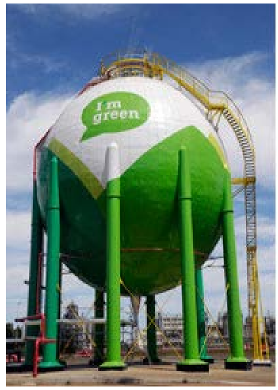

Figure 3. Biobased polyethylene (PE) Triunfo, Braskem, Brasil.

Braskem was able to produce bio-based PE and bio-based polyvinyl chloride (PVC) from bioethanol already in the 1980s, but, in that time, there was not such an issue in the use of petro sources for the production of polymers, and the limitation in biotechnology made the process not economically advantageous [21]. At present, bio-based green PE is produced by dehydration of ethanol that is derived by microbial fermentation of biomass. In this process, the juice of sugarcane is used that has a high content of sucrose. The juice is anaerobically fermented to produce ethanol. The ethanol produced is distilled to remove water, and it yields an azeotropic mixture of hydrous ethanol. A solid catalyst is used to dehydrated ethanol at high temperatures; in this way, it is produced ethylene and, subsequently, polyethylene [22,23].

On the market, we can also find bio-based poly(ethylene terephthalate), which is used for the production of bottles as publicized by the Coca-Cola Company (Figure 4).

Figure 4. Bottles produced with bio-based polyethylene terephthalate (PET).

Condensation polymerization of ethylene glycol (EG) and terephthalic acid (TA) is commonly used to produce PET. Petro derived EG can be replaced with a bio-based feedstock, as proposed by the suppliers of the Coca-Cola plant bottles. Anyway, terephthalic acid is still petro-derived, thus the resulting bio-based carbon content achieves a range of 28%.

In the context of the "Lead Market Initiative for Europe", the European Commission created the Mandate M/429 [24] addressed to the European Standardization bodies (CEN, CENELEC and ETSI) for the development of horizontal European standards for bio-based products. CEN initiated a new Technical Committee CEN/TC411 on "Bio-based products", which started working in the beginning of October 2011.

The main active institutes in this field are Vinçotte (Belgium) and Din Certco (Germany). They both have a ranking system based on the bio-based carbon content. Vinçotte has created a ranking system with stars, which are featured in the logo:

One star	20% < Biobased < 40%,	☆
Two star	40% < Biobased < 60%,	☆☆
Three star	60% < Biobased < 80%,	☆☆☆
Four stars	80% < Biobased.	☆☆☆☆

The corresponding logo is reported in Figure 5.

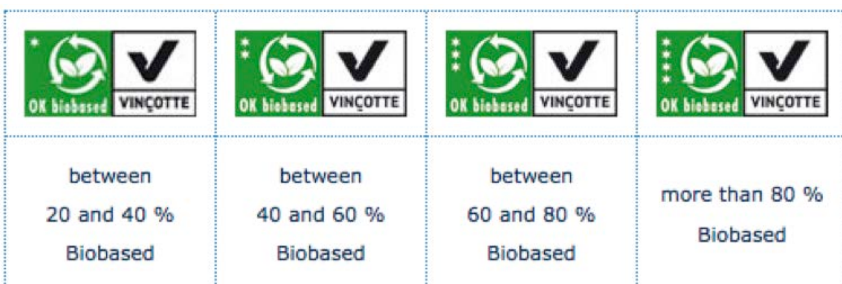

Figure 5. Bio-based certification by Vincotte.

The system of Din Certco is based on a numbering of the bio-based carbon content (Figure 6).

Figure 6. Biobased Logo by Din Certco.

In the USA, the United States Department of Agriculture (USDA) sets the percentage of bio-based components required for a product to be defined to as bio-based, on a product-by-product basis. A minimum threshold of 50 percent of bio-based content for products to be considered bio-based has been recommended to USDA by the Institute for Local Self-Reliance (ILSR).

An image of the logo for bio-based products by USDA is reported in Figure 7.

Figure 7. Bio-based certification by United States Department of Agriculture (USDA).

Thus, summarizing, some materials can be compostable even if produced by petro sources, considering that also poly(lactic acid) (PLA) can be produced by petro sources. This group includes several synthetic polyesters produced by BASF, Mitsubishi.

While some materials can be both compostable and bio-based such as starch and some of its derivate, cellulose and some of its derivate, other polysaccharides such as chitosan, and polymers synthesized by micro-organisms such as the family of polyhydroxyalkanoates. Some other materials can be just bio-based but not compostable such as PE, PET and polyamides. Some examples are reported in Table 1.

Table 1. Some example of polymers being either: compostable petro sourced, compostable bio-based, bio-based not compostable.

Compostable Petro Sources	Compostable Bio-Based	Bio-Based Not Compostable
Poly(caprolactone) Poly(lactic acid) Poly(butylene succinate) Poly(butylene adipate—*co*-terephthalate)	Starch Based Poly(lactic acid) Polyhydroxyalkanoates Cellulose Based Chitosan/Chitin Animal and vegetal proteins	PE from bioethanol PET from bioethanol Polyamide 4, 10 or Polyamide 11

5. Sustainability

Being bio-based or compostable does not necessary mean that the material considered is more environmentally sustainable than the counterpart petro sourced or not compostable, but, for example, recyclable. For this reason, it is important to evaluate the sustainability and ecological benefits of a bio-based polymer in term of raw materials, production, application and end of life of the bio-based materials. This evaluation can be performed through a Life Cycle Assessment (LCA) study. The LCA represents an internationally standardised methodology that consists of four phases (ISO 14040, 2006 and ISO 14044, 2006) [25,26]:

1. Goal and scope definition,
2. Life cycle inventory analysis,
3. Life cycle impact assessment,
4. Life cycle interpretation.

The definition of the goal and scope includes decisions about the functional unit, which forms the basis of comparison, the product system to be studied, system boundaries, allocation procedures, assumptions made and limitations. The life cycle impact assessment (LCIA) converts the emissions and the raw material requirements from the life cycle inventory analysis into potential environmental impacts. Outputs with comparable effects (e.g., all acidifying components) are aggregated by use of so-called characterisation factors. This leads to a limited number of parameters, called impact categories (=Characterisation Step).

The collection, evaluation and discussion of the data are usually performed in line with the "International Reference Life Cycle Data System" (ILCD) Handbook and ISO standards (ISO 14040, 14044). The ILCD impact assessment method is applied to calculate the environmental impacts of the products under study. The method ILCD is a midpoint method, and includes 16 impact categories covering a broad range of environmental issues, not only the potential emissions of Green House Gases (GHG), those are: climate change; ozone depletion; human toxicity;

cancer effects; human toxicity, non-cancer effects; particulate matter; ionizing radiation HH (human health); ionizing radiation E (ecosystems); photochemical ozone formation; acidification; terrestrial eutrophication; freshwater eutrophication; marine eutrophication; freshwater ecotoxicity; land use; water resource depletion; mineral; fossil and renewable resource depletion.

Methods such as "ReCiPe" enables the normalisation and weighting of the outputs and the aggregation of the endpoint impact categories in three damage categories;

1. Human Health (unit: DALY = Disability adjusted life years; this means different disability caused by diseases are weighted)
2. Ecosystem Quality (unit: PDF $\times$ m^2 year; PDF = Potentially Disappeared Fraction of plant species)
3. Resources (unit: MJ surplus energy = Additional energy requirement to compensate lower future ore grade).

The environmental modelling is completed by the calculation of the total scores for the three damage categories. In several cases, further steps are not needed since these results provide sufficient information.

For example, "normalization" and "weighting" steps are referred to as "optional elements" in the ISO 14042 documents.

The weighting step is not used in some studies, in particular when comparative assertions are made, and planned to be disclosed to the public. The user of this methodology to decide if and how the damage assessment is applied, and if it is necessary to follow or deviate from the ISO standards.

The LCA completes the study on the environmental impact related to a bio-based material.

6. Future Perspectives

Actually, many bio-based polymers are produced on an industrial scale with good mechanical performance and stability. The large marketing of bio-based polymers in many applications is hindered by the performance-to-price ratio when compared with their conventional petro-derived counterparts. This remains a significant challenge to overcome for bio-based polymers.

The increasing in the demand for food and energy can induce a competition for renewable resources, since the global demand will increases over time. Thus, at present, the renewable feedstock used for manufacturing bio-based monomers and polymers often compete with the demand of resources for food-based products. The first-generation of bio-based fuel production is in expansion and consequently it will induce an unsustainable demand of biomass. Thus, will be a problem for the sustainability of biochemical and biopolymer production versus the use of biomass for food production [27].

Key Performance Indicators (KPIs) set out in the Strategic Innovation and Research Agenda (SIRA) Bio-Based Industries (BBI) roadmap [28].

By replacing fossil-based products with bio-based products, which tend to have a smaller carbon footprint, bio-based industries can make a critical contribution to Europe's climate goals.

Several initiatives are under consideration for using ligno cellulosic or cellulose-based feedstock for the production of usable sugars for biofuels, biochemicals, and biopolymers [29].

Thus, in the future, we envisage a growing production and use of bio-based products with a focus on those bio-based materials produced by renewable resources that are not in food competition such as by-products or waste products of agro-food production. In particular, the new trend of promoting production of bio-based polymers from no food resources is reducing the concern on the opportunity to utilize biomass for the production of plastic. For those polymers produced from edible sources, including starch and PLA, the favourite choice is using their production crops grown in lands that are not suitable for the production of edible crops. These lands can be used for the production of crops to be devoted to industrial manufacture, and the valorization of depressed areas is important where land is not used for agriculture anymore since it is not profitable.

Modern economies use a huge amount of plastics and, consequently, in Europe, the plastic consumption is very high, in the range of 50 million tons per year; in contrast, only 25% of plastic waste in Europe is currently recycled and the larger share is incinerated or even landfilled [30].

Considering the objectives of EC’s policy of achieving a resource efficient recycling society, the landfilling of nearly 50% of plastic waste is a tremendous waste of resources [31], and an issue to be seriously approached, even considering that bioplastics still have a very limited share among plastics (approximately 1%), thus a large potential for growth [32,33]. Thus, bioplastics have the advantages of allowing a switch to renewable non-fossil feedstocks, preferably selected among waste, bio-products or over production biomasses, offering also the plus of and end of life modularity. This is important especially for those short-term single use applications, which, by nature (e.g., shoppers, mulching films, lightweight nets) or due to contamination (food, oils, fertilizers, ect), are hardly collectable and sometimes not recyclable (mechanically or organically) when non-biodegradable. To achieve these targets, more research and development have to be invested in further improving bioplastics’ specific functionalities, and more cost-competitive solutions have to be found to ease the eventual large-scale superior performance and market-driven uptake.

7. Conclusions

In the last decade, there has been much interest towards bio-plastics and this brought about many rapid changes in the knowledge and classification of these materials. Their introduction on the market pushed the institutions to promulgate new regulations and a technical-scientific community to increase the knowledge and standardization of materials and tests. The replacement of commodity polymers currently employed in many sectors is still on-going and the necessity of projecting materials and goods as a function of both their origin and present end life is underlying this competition.

In some applications, bio-based polymers are close to replacing conventional polymers in the market. In particular, bio-based polymers can be employed in many applications, from commodity to hi-tech applications, due to advancement in biotechnologies, with consequent improvement of polymer quality as well as public awareness of the importance to use materials derived from renewable resources. Significant progress has been achieved in terms of production, processing, collection and bio recycling of bio-based compostable polymers.

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