

Biodegradable and Compostable Packaging:

A review of the South African landscape

Prepared by The Moss Group on behalf of

The South African Initiative to End Plastic Waste

Assessment of the biodegradable and compostable packaging landscape in South Africa

Introduction

The South African Initiative to End Plastic Waste, through the Biodegradable and Compostable Packaging Working Group, initiated a process to evaluate the landscape with respect to the integration of biodegradable and compostable packaging in South Africa.

The objectives of this paper are two-fold:

- To provide a balanced perspective and consolidated view of the South African context with regard to biodegradable and compostable packaging, based on sound research and stakeholder inputs.
- To be used to inform players across the value chain, as well as other interested stakeholders around the responsible manufacture, use, management and disposal of biodegradable and compostable packaging.

This document focuses specifically on the country's current capacity to responsibly integrate these materials into the existing packaging economy and looks to provide direction on what is required going forward.

The SA Initiative to End Plastic Waste acknowledges that there are material types and applications of traditional plastics that are problematic and present specific challenges with respect to collection and recycling. The intention of this paper is not to compare the merits of traditional plastic relative to biodegradable and compostable alternatives.

Background

Plastic pollution, particularly in the marine environment [1], has become a focal point for campaigns highlighting the negative impacts of increased consumerism [2]. Globally, major players in the plastics value chain, brand owners, NGOs and governments have recognised the need to work collaboratively to address this issue. This has led to the launch of the New Plastics Economy [3], by the Ellen McArthur Foundation and the UN Environment Programme, and the Global Alliance to End Plastic Waste. In South Africa, over 20 key stakeholders have signed up as members of the recently launched SA Plastics Pact [4].

Consequently, there is an increasing drive toward reducing the amount of plastic packaging, eliminating problematic packaging types, increasing post-consumer collection and recycling and transitioning away from petrochemical-based materials to more sustainable alternatives. The desire for alternatives that deliver lower environmental impact than traditional plastics has created a growing market for biodegradable and compostable packaging.

Globally, the cost of biodegradable and compostable materials is currently substantially higher than traditional, petrochemical-based polymers in many cases, but this is expected to decrease as volumes increase [5].

South African context

The South African consumer packaging waste landscape has several defining factors that need to be considered when looking at integrating biodegradable and compostable packaging.

Formal municipal waste collection is not effective in capturing all post-consumer waste, with over 34% of households not having access to regular waste removal services [6]. Separation at source is not legislated, so is not widely practiced. Where it is, it tends to be limited to separation of paper and packaging for recycling (i.e. not separation of organic waste). Material sorting is primarily done by hand or density separation. Hand sorting may be beneficial as experienced sorters are able to separate a range of material types. Informal waste pickers are responsible for collecting a significant proportion of recyclable material, mostly from the environment, landfill and household refuse bins [7]. As a result, contamination of recyclable materials is often high. Waste pickers are paid by buy-back centres for the materials they collect, resulting in pickers mostly focussing their efforts on a select few, high value materials. The country has high levels of visible litter in the environment, much of which is lightweight packaging that has been irresponsibly disposed of by consumers and has little to no value to informal collectors.

Organic waste is predominantly disposed of with general waste and therefore ends up in landfill, where its degradation under anaerobic conditions leads to the undesirable release of methane, a potent greenhouse gas. There is currently limited household collection infrastructure, municipal or private, for organic waste. However, there is movement, led by the Western Cape government, to eliminate organic waste from landfill [8]. Composting facilities already exist around South Africa, with varying infrastructure and technologies in place. Plastic contamination is a challenge for most composters. It is important to note that, unlike recyclers, composters do not pay for waste entering their facilities and many charge a gate fee based on the composition of the material. The financial sustainability of composting at scale is under increasing pressure and several facilities have closed as a result.

There is currently very limited separation, collection and processing infrastructure to support the responsible post-consumer management of packaging made from biodegradable and compostable materials. Furthermore, informal pickers currently have no economic incentive to collect biodegradable or compostable packaging for processing, so they are likely to be overlooked, much like lightweight flexible and multi-layer products. However, due to poor labelling and the absence of clear identification these products, especially carrier bags, are being inadvertently collected with traditional plastics.

At present, there is very little legislation pertaining specifically to biodegradable and compostable materials in South Africa, with the exception of SANS 1728:2019 that relates to the requirements for the marking and identification of degradable plastics. In addition there are sections of the Consumer Protection Act that refer broadly to false claims relating to the performance of materials.

Most South African consumers have very limited awareness and understanding of what biodegradability and compostability mean and therefore what is required for responsible

post-consumer management. The absence of effective education and awareness can create the misconception that biodegradable materials decompose rapidly in the environment, potentially exacerbating the littering culture.

At this stage the majority of the raw materials (resins) and some finished products are imported, which has limited direct benefit for the South African economy.

Key terms and definitions

- **Fossil fuel-based polymers** are derived from petroleum, coal or natural gas products or by-products. The majority of plastics in use today are fossil fuel based.
- **Bio-based polymers** are defined as plastics that are derived from renewable (plant-based) sources. These may be identical to fossil fuel-based polymers (e.g. PET, PE, PP), where the monomeric units (e.g. ethylene) are produced from plant-based materials rather than fossil fuels, or may be so-called bioplastics (e.g. PLA, PHA, thermoplastic starch). These can be first generation, derived from food crops such as corn, potatoes and sugar cane, or second generation, derived from agricultural by-products, non-food crops or organic waste. Bio-PET, Bio-PE and Bio-PP can be recycled with conventional fossil fuel-based plastics.
- **Biodegradable materials** degrade by biological activity, resulting in a specific change in the chemical structure of the material. Degradation can occur under aerobic or anaerobic conditions. The end products are gas (carbon dioxide or methane), water, biomass and mineral components. Plastics labelled “biodegradable” break down at a faster rate than conventional plastics. The degradation of biodegradable materials does not necessarily imply that the material can be converted into good quality compost or that degradation will take place within a specified timeframe. Biodegradable materials can be produced from renewable feedstocks (biomass) or fossil fuels. In the sections that follow, the term “biodegradable” includes compostable, unless specifically stated.
- **Compostable materials** are a group of biodegradable materials that break down in an aerobic composting process through the action of naturally occurring microorganisms and do so to a high extent within a specified timeframe. The biological processes yield carbon dioxide, water, inorganic compounds and biomass, leaving no visible contaminants or toxic residues.
- **Industrial composting** refers to the breakdown of biodegradable materials under controlled conditions (50-70°C, forced aeration, managed humidity) in an industrial composting facility. Internationally, standards specify the conditions, timeframe and extent of degradation required for a material to be certified as “compostable”.
- **Home composting** refers to the breakdown of biodegradable material under conditions (temperature and moisture) found in domestic compost piles. There are fewer international standards for this.
- **Prodegradent additives** refer to materials that are added to traditional polymers to initiate the accelerated degradation of the plastic structure. There are two groups of additives, oxo-additives (e.g. d2w) which rely on oxygen, heat and UV light to accelerate

the initial fragmentation and bio-additives (e.g. Biosphere) which act as sites for microbial attack to accelerate biological degradation.

A more detailed description of the range of available materials, their key properties, application and research related to their environmental performance is available in the Appendix to this document.

Working group assessment

Based on the analysis of the information available in the public domain and academic literature, as well as the engagement with a range of stakeholders across the value chain, the working group has prepared the following As-Is assessment of the landscape relating to biodegradable and compostable materials. The document is structured using the value chain as a guide, as illustrated below.



Raw material and packaging production

- The local market for biodegradable and compostable packaging is still too small to justify significant investment in infrastructure to produce raw materials (e.g. resins). However, the potential for **developing local capacity** for the **production** of bio-based polymers and biodegradable **materials** should be continuously **assessed** and considered as **part of** the South African **Bio-economy Strategy** [9]. The assessment should consider **socio-economic** (job creation, food security, etc.) and **environmental implications**. This will become increasingly relevant as the demand for these materials grows.
- The current global market size for **biodegradable plastics** made from food crops is **too small to negatively impact food security** (0.016% of global agricultural land in 2018, according to European Bioplastics [10]). This position is unlikely to change in the medium term. However, it should remain a key consideration that is **evaluated regularly**.
- There is currently **no mandatory legislation** specific to the **material properties** of biodegradable and compostable plastics. A **South African National Standard (SANS) for Compostable Materials** based on **ISO 17088** is **currently open for public comment**. The SANS standard 1728:2019 does specify that relevant raw material technical data sheets should accompany these products, but **SANS 1728:2019 is not currently a compulsory standard**. There are provisions within the Standards Act of 2008 that prohibit businesses from operating in a manner that is likely to create the impression that products comply with a South African National Standard or other

publications of the SABS. In addition, sections of the **Consumer Protection Act** refer broadly to **false claims** relating to the performance of materials.

- There are a **number of products** on the market that **make claims** relating to biodegradability **without any reference to appropriate international standards**, as required by SANS 1728:2019. Stakeholders from within and outside the biodegradable materials value chain expressed concern that the importing of non-certified products could have **negative consequences for both the environment and the biodegradables industry**.
- **Biodegradable and compostable plastics** are currently marked with the **number 7 resin code**, which can lead to **confusion** as this code is used for traditional plastics that fall outside the six major polymer types. The suggestion for the **allocation of a unique resin code** for these materials was widely supported.
- **Food contact materials** need to be **tested and certified** to comply with the **same local and international food safety legislation**, detailed in the Foodstuffs, Cosmetics and Disinfectants Act, as traditional plastics to ensure that they have the necessary barrier properties to ensure **effective food protection**, that they contain **no contaminants** (including natural organic toxins) that may threaten food safety and that **material integrity** is not compromised by **extended shelf-life**.

Marketing and sales

- The **SANS 1728:2019 standard** specifies the **requirements for marking and identification of degradable plastics**. The requirements are applicable, but not limited to, biodegradable, compostable, oxo-biodegradable and water-soluble plastics. The requirements include:
 - The product must carry the internationally recognised polymer code, as a numeral inside the triangle, in conjunction with the description of the claim. The acronym for the material (e.g. PET, PLA etc.) along with the appropriate wording (i.e. biodegradable, compostable or oxo-biodegradable) must be displayed below the resin code.
 - If the product is made of multiple components and these are intended for different waste streams, the information must be clearly displayed on the package (e.g. closure – recyclable, PLA bottle – compostable).
 - The product must conform to the appropriate international standards if it is claimed to be biodegradable (DIN 38412:30 or ISO 14855-1), compostable (ISO 17088, EN 13432 or ASTM D6400) or oxo-biodegradable (ASTM D6954-04). Claims made by the manufacturer of the end product must be verified by accredited laboratories and supported by raw material technical data sheets, as per the appropriate standard.
 - If the entire product is not biodegradable or compostable the claim needs to identify the specific components that are. If separation of components is required, clear instructions on how to do this must be included.

- Vague or non-specific claims that imply the product has environmental benefits, such as “green”, “environment friendly”, “earth safe” etc. are not permitted.
- At this stage there are no definitive methods for measuring sustainability or confirming its accomplishment, so no claims of achieving sustainability should be made.
- If self-declared environmental claims are likely to result in confusion, an explanatory statement must accompany these.
- **Very few products** on the market **comply fully** with the requirements of SANS 1728.
- There is currently **little** in the way of **effective consumer education** around biodegradable and compostable plastics. Brand owners, retailers and consumers are typically unaware of the range of material types, their properties and the fact that different materials may only be certified to degrade or compost under specific, controlled conditions. The performance outside of these conditions is often poorly understood, but evidence suggests degradation rates are likely to be significantly slower.
- Several stakeholders raised the concern that **inadequate or misleading marketing**, coupled with **poor consumer education**, could **create incorrect expectations** with **respect to biodegradability** and therefore promote a “throw away” culture. This contention was broadly disputed by manufactures and distributors of biodegradable and compostable products.
- During the consultation process, producers and importers of biodegradable and compostable materials highlighted the **risk** to their industry posed by the **import and distribution of products that carry false or unsubstantiated claims**. The value of self-regulation, by an industry association, in this regard was widely acknowledged and discussions around the formation of an association have begun.

Waste collection

- There is currently no economic incentive for informal waste pickers to collect biodegradable or compostable plastics from the environment, landfill or household waste. Therefore, it is **highly unlikely** that these **materials will be collected** if they are **disposed of through conventional means**.
- At this point, there are **few systems** in place for the **separation and collection of biodegradable and compostable waste** to enable responsible post-consumer management of this packaging.
- While materials certified as compostable will degrade within a defined timeframe under controlled conditions, there is **limited information** on the **degradation rates** of different biodegradable materials **outside a controlled environment**. Academic literature suggests that biodegradation may be significantly slower in dry conditions (low humidity) [11] at lower temperatures, in marine and aquatic environments and

where microbial concentrations are low [12-17]. Under these unfavourable conditions most materials will persist for years to decades. Therefore, **biodegradable and compostable materials** are **unlikely** to provide an **immediate solution** to the problem of **visible litter** in the environment.

Waste processing

- **South Africa** has a **well-established mechanical recycling industry** that provides a livelihood for a large number of people in the collection, transport and processing of recyclable plastics. Collection and recycling rates for certain material types, such as HDPE dairy packaging [18] (> 75%) and PET beverage bottles [6] (63%), are among the highest in the world. The **market for recycled polymer is dependent on confidence in the technical integrity** of the **recycled material**. Material sorting is primarily by hand or density separation. Therefore, **products made from incompatible materials** (e.g. PLA beverage bottles) that are difficult to distinguish from traditional polymers (e.g. PET beverage bottles) risk contaminating recycling streams, at least in the short to medium term.
- It is noted that **composting** is **not** necessarily the **only end-of-life solution** for biodegradable plastics. The Department of Science and Innovation (DSI) is currently funding research programmes under the broad title “End of life options for bio-based plastics”.
- **Bio-based, non-biodegradable polymers**, such as bio-PET and bio-HDPE, are essentially identical to the petrochemical-based materials. Therefore, they are deemed **acceptable within the current collection and recycling landscape** in South Africa.
- The effectiveness of **prodegradant additives** (oxo and bio) remains a matter of contention. Notwithstanding claims by the manufacturers [19] regarding biodegradability and supporting literature [20-22], there is a significant body of **academic literature** that **contests** the claims that prodegradant additives **accelerate the fragmentation and subsequent biodegradation** of the plastic in all environments [23-27]. No independent research was found that conclusively proves that prodegradant additives do **not result in persistent microplastics**.
- The **prevailing position** of the **majority of recyclers** in SA is that the presence of these **additives in recycled material is not desirable** and widespread use could have negative consequences for the industry. However, half of those consulted indicated that they may reconsider this position in the face of compelling evidence. Proponents of the additives refer to several reports [28,29] that indicate the additives will not compromise the structural integrity of recycled products, although other studies have come to a different conclusion [30].
- **Prodegradant additives** that require microbial activity to initiate fragmentation (i.e. not oxos) pose **less of a risk** to the **technical integrity** of recycled products as most are not designed for prolonged use in microbe-rich environments. The exception

would be applications where the recycled product is used in environments where exposure to high concentrations of bacteria and fungi is likely, such as irrigation piping.

Support

- There is currently no **producer responsibility organisation (PRO)** or similar structure to provide **oversight and promote the responsible sourcing, marketing and post-consumer management** of biodegradable and compostable materials.
- **Several manufacturers, importers and brand owners** of biodegradable and compostable packaging have acknowledged the importance of **Extended Producer Responsibility (EPR)**. They recognise their role in the establishment of systems and infrastructure to enable responsible post-consumer management.

Conclusion

Biodegradable and compostable materials have become a reality in South Africa, driven largely by consumer demand for alternatives that have improved environmental performance relative to traditional plastics. At this stage, the applications are primarily in food and drink containers, utensils and carrier and barrier bags for niche markets. Despite volumes being relatively low at this stage, post-consumer management of these products needs to be proactively considered due to the potential growth of this sector.

It is therefore critical that key stakeholders from industry, civil society and government collaborate to **develop a coherent master plan** for these materials that is appropriate and relevant to South Africa. **Six key principles** need to underpin this plan:

1. Biodegradable and compostable plastics that are **certified** and **verified** and are **part of an effective collection and processing system** can provide a responsible end-of-life option that is in line with circular economy principles.
2. The industry master plan and resultant decisions should be based on **robust research**. There is a substantial body of international research, but this should be critically evaluated to build on information that is **relevant to the South African context**.
3. The industry strategy should strive towards **strengthening the local economy**, supporting **transformation and job creation**.
4. Biodegradable and compostable plastics and the associated waste management systems and processes need to be implemented in a way that **enhances existing collection and recycling systems and improves consumer behaviour**.
5. All manufacturers, importers and brand owners need to actively participate in **Extended Producer Responsibility programmes**, which should include *inter alia* aspects relating to consumer education and awareness, certification and collection and processing infrastructure set up and management.
6. The status quo should not be viewed as a barrier to entry for alternate materials. However, the **acceptance** of alternative materials into the value chain is likely to be **accelerated** if these target **“fit for purpose” applications** and those where traditional

plastics are most problematic, rather than high volume applications that currently underpin the recycling sector, at least initially.

7. The plan should aim to **foster collaboration** between the **biodegradables sector and the traditional plastics industry** to address the serious challenges facing the packaging sector.

References – As-Is Assessment

- [1] Law, K.L. (2017) Plastics in the Marine Environment. *Annu. Rev. Mar. Sci.* **9**: 205-229.
- [2] Buranyi, S. (2018) The plastic backlash: What's behind the sudden rage – and will it make a difference. <https://www.theguardian.com/environment/2018/nov/13/the-plastic-backlash-whats-behind-our-sudden-rage-and-will-it-make-a-difference>.
- [3] Ellen McArthur Foundation – The new plastics economy. <https://www.newplasticseconomy.org>
- [4] <https://www.saplasticspact.org.za>
- [5] van den Oever, M., Molenveld, K., van der Zen, M. And Bos, H. (2017) Bio-based and biodegradable plastics – facts and figures. Wageningen Food and Bio-based Research, Wageningen, The Netherlands. DOI <http://dx.doi.org/10.18174/408350>.
- [6] Plastics SA (2019) National Plastics Recycling Survey 2018, Plastics SA
- [7] Godfrey, L., Strydom, W. and Phukubye, R. (2016) Integrating the informal sector into the South African waste and recycling economy in the context of extended producer responsibility. Briefing Note February 2016. CSIR Policy Brief and Briefing Note Series.
- [8] Western Cape Government (2019) A guide to separation of waste at source. Environmental Affairs and Development Planning, Western Cape Government.
- [9] Department of Science and Technology (2013) The Bio-economy Strategy. https://www.gov.za/sites/default/files/gcis_document/201409/bioeconomy-strategya.pdf
- [10] European Bioplastics. Land use estimates for bioplastics 2019 and 2024. <https://www.european-bioplastics.org/market/>
- [11] Ho, K-L.G., Pometto III, A.L. and Hinz, P.N. (1999) Effects of temperature and relative humidity on polylactic acid plastic degradation. *J. Environ. Polym. Degrad.* **7**: 83-92.
- [12] Nauendorf, A., Krause, S., Bigalke, N.K., Gorb, E.V., Gorb, S.N., Haeckel, M., Wahl, M. and Treude, T. (2016) Microbial colonization and degradation of polyethylene and biodegradable plastic bags in temperate fine-grained organic-rich marine sediments. *Mar. Pollut. Bul.* **103**: 168-178.
- [13] Urbanek, A.K., Rymowicz, W. and Mironczuk, A.M. (2018) Degradation of plastics and plastic degrading bacteria in cold marine habitats. *Appl. Microbiol. Biotechnol.* **102**: 7669-7678.
- [14] Pischedda, A., Tosin, M. and Degli-Innocenti, F. (2019) Biodegradation of plastics in soil: The effect of temperature. *Polym. Degrad. Stab.* **170**: 109017.
- [15] Accinelli, C., Sacca, M.L., Mencarelli, M. And Vicari, A. (2012) Deterioration of plastic carrier bags in the environment and assessment of a new recycling alternative. *Chemosphere* **89**: 136-143.

- [16] Karamanlioglu, M., Preziosi, R. and Robson, G.D. (2017) Abiotic and biotic environmental degradation of the biolistic polymer poly(lactic acid): A review. *Polym. Degrad. Stab.* **137**: 122-130.
- [17] Emadian, S.M., Onay, T.T. and Demirel, B. (2017) Biodegradation of bioplastics in natural environments. *Waste Man.* **59**: 526-536.
- [18] The Moss Group (2019) Quantification of the recycling rate for HDPE dairy packaging.
- [19] Symphony Environmental (2019) d2w a scientifically proven biodegradable technology. Special Report, July 2019. Symphony Environmental.
- [20] Chiellini, E., Corti, A., D'Antone, S.D. and Baciù, R. (2006) Oxo-biodegradable carbon backbone polymers – Oxidative degradation of polyethylene under accelerated test conditions. *Polym. Degrad. Stab.* **91**: 2739-2747.
- [21] Vazquez-Morillas, A., Beltran-Villavicencio, M., Alvarez-Zeferino, J.C., Osada-Velazquez, M.H., Moreno, A., Martinez, L. and Yanez, J.M. (2016) Biodegradation and ecotoxicity of polyethylene films containing pro-oxidant additive. *J. Polym. Environ.* **24**: 221-229.
- [22] Rose, R-S., Richardson, K.H., Latveanen, E.J., Hanson, C.A., Resmini, M. and Sanders, I.A. (2020) Microbial degradation of plastic in aqueous solutions demonstrated by CO₂ evolution and quantification. *Int. J. Mol. Sci.* **21**: 1176.
- [23] Thomas, N.L., Clarke, J., McLauchlin, A.R. and Patrick, S.G. (2012) Oxo-degradable plastics: degradation, environmental impact and recycling. *Waste Resour. Man.* **165**: 133-140.
- [24] Musiol, M., Rydz, J., Janeczek, H., Radecka, I., Jiang, G. and Kowalczyk, M. (2017) Forensic engineering of advanced polymeric materials Part IV: Case study of oxo-biodegradable polyethylene commercial bag – Aging in biotic and abiotic environment. *Waste Man.* **64**: 20-27.
- [25] Portillo, F., Yashchuk, O. and Hermida, E. (2016) Evaluation of the rate of abiotic and biotic degradation of oxo-degradable polyethylene. *Polym. Test.* **53**: 58-69.
- [26] Selke, S., Auras, R., Nguyen, T.A., Castro Aguirre, E., Cheruvathur, R., and Liu, Y. (2015) Evaluation of biodegradation-promoting additives for plastics. *Environ. Sci. Technol.* **49**: 3769-3777.
- [27] Gomez, E.F. and Michel Jr, F.C. (2013) Biodegradability of conventional and bio-based plastics and natural fiber composites during composting, anaerobic digestion and long-term soil incubation. *Pol. Degrad. Stab.* **98**: 2583-2591.
- [28] Jakubowicz, I. and Enebro, J. (2012) Effects of reprocessing oxobiodegradable and non-degradable polyethylene on the durability of recycled materials. *Pol. Degrad. Stab.* **97**: 316-321.
- [29] Roediger, A. (2012) Recycling report on d2w oxo-biodegradable plastics. Report for Symphony Environmental.

[30] Hann, S., Ettliger, S., Gibbs, A. and Hogg, D. (2016) The impact of the use of “oxo-degradable” plastic on the environment. Final report for the European Commission DG Environment. Project conducted under Framework Contract No ENV.A.2/FRA/2015/0008.

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Appendix: Biodegradable and compostable plastics: Material types and applications

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Context

This document has been prepared to support the position paper developed by the Biodegradable and Compostable Materials Working Group, under the South African Initiative to End Plastic Waste. The document is intended to provide more detailed information on the wide range of materials that are being applied in biodegradable packaging, highlighting the raw material sources, manufacturing process, properties of the polymers, range of applications and end of life fate.

Polymer production, particularly at large scale, is a complex process and multiple steps are required to get from raw feedstock (fossil fuel or biomass) to the purified polymer. In some cases, the feedstock may be similar, but the production processes can be very different, producing end products that have very different structures and properties, applications and propensity to biodegrade. For example, polylactic acid (PLA) and polyhydroxybutyrate (PHB) are both biodegradable polymers that can be produced by the microbial fermentation of cornstarch. However, in the case of PLA the lactic acid monomers are secreted into the fermentation medium, are purified and then polymerised into the final product over a chemical catalyst. The PHB polymer is synthesised within the bacterial cells as a secondary storage product and is purified from the growth media after the cells have been disrupted. The polymer structures and properties are also very different.

There is a considerable amount of on-going research in the field of biodegradable and compostable plastics, with new polymers and polymer blends being developed, particularly from second generation (non-food crop) biomass sources. Many of these are showcased in the popular press or on social media platforms, often with enthusiastic pronouncements that this material can solve the plastics crisis. Fundamental research will continue to play a critical role in the development of viable alternatives to traditional plastics, but an appreciation of the complexity and challenges associate with bridging the gap between laboratory research and commercial application will help to manage expectations.

Manufacturers of biodegradable materials and those who market them can make exaggerated claims regarding the performance of their products. There is a tendency to highlight research that supports the claims, while ignoring research that comes to less convincing or contradictory conclusions. This document aims to present a balanced overview of some of the pertinent research and provide useful information that retailers, brand owners and converters can draw on when presented with new materials.

The document begins with a high-level overview of the different materials, then proceeds to present more technical detail on the main classes of polymer.

Glossary

Carbonyl group: A functional group composed of a carbon atom double bonded to an oxygen atom (C=O). The oxygen molecule is more electronegative than the carbon, so there is some polarity across the bond, making it more reactive than a carbon-carbon (C-C) bond. The introduction of carbonyl groups into plastics increases their potential for biodegradation. Carbonyl groups include aldehydes, ketones, carboxylic acids and carboxylic esters.

Carbonyl index (CI): The CI is measured by infrared spectroscopy and is defined as the ratio between carbonyl and methylene absorbances. An increase in CI represents an increase in the number of carbonyl groups and is indicative of the degree of oxidative degradation of the polymer.

Enzyme: A specific class of protein that speeds up the rate of chemical reactions (building or breaking).

Enzymatic hydrolysis: The cleaving of chemical bonds with the addition of elements of water (OH and H), catalysed by a specific enzyme.

Glass transition temperature: Temperature range above which the properties of a plastic change from a hard and relatively brittle state to a viscous or rubbery state.

Melt flow index (MFI): A measure of the ease of flow of a thermoplastic polymer. It is defined as the mass (g) of polymer flowing through a capillary of specific diameter in 10 minutes at a specified temperature and pressure. MFI is an indirect measure of molecular weight.

Polyester: A group of polymers that contain an ester (R-COO-R') functional group in their main chain. They are typically formed by the reaction of an alcohol with a carboxylic acid.

Retrogradation: A process by which gelatinous starch recrystallises upon cooling, usually with the expulsion of water. The process is undesirable and reduces the plasticity, making the resulting product brittle.

Thermoplastic: A polymer, typically with high molecular weight, that becomes mouldable above a certain temperature and solidifies upon cooling. They are used in processing techniques such as injection moulding, compression moulding, extrusion and calendaring.

Summary of bio-based, additive containing and biodegradable plastics

Name	Feedstock	Properties	Applications	Biodegradable	Industrial composting	Home composting	Mechanical recycling
Bio-PET/PE/PP/PVC	Ethanol	Identical to fossil fuel-based analogues	Wide range of rigid and flexible packaging applications	X	X	X	✓
Plastics with oxo-additives	Fossil fuels or ethanol	Similar to base polymer with accelerated fragmentation when exposed to UV and heat	Similar applications to base polymer	Contested	X	X	Uncertain
Plastics with bio-additives	Fossil fuels or ethanol	Similar to base polymer, less hydrophobic, accelerated degradation due to microbial attack (aerobic and anaerobic)	Similar applications to base polymer	Uncertain	X	X	Uncertain
PEF	Glucose from vegetables and potentially from lignocellulosic biomass	Similar to PET, with improved thermal and barrier properties for oxygen, CO ₂ and water vapour	Similar to those for PET	X	X	X	✓
TPS	Food crops	Typically blended with other materials to improve properties. Can be glassy or rubbery	Rigid and flexible packaging, service ware and agricultural products	✓	✓	✓	X
PGA	Fermentation of starch or petrochemical	High melting point, high crystallinity, relatively high glass transition temperature	Biomedical applications and potential as an interlayer in films to improve barrier properties	✓	✓	X	X
PLA	Food crops, potentially agricultural waste or fossil fuels	Isomer blends allow variety of properties, ranging from PS to PET	Rigid and flexible packaging, service ware and textiles	✓	✓	X	X
PHAS	Fermentation of renewable feedstocks	Mechanical properties similar to PP. Good UV stability and barrier properties	Flexible packaging, films, carrier bags, food trays and disposable cutlery	✓	✓	✓	X
PBS/PBSA	Renewable feedstocks or fossil fuel	Similar properties to PP	Flexible packaging and agricultural/horticultural applications	✓	✓	X	X
PBAT	Fossil fuels	Low crystallinity, tough, flexible, similar to LDPE	Flexible packaging (films and bags), waterproof coatings, additives	✓	✓	✓	X
PCL	Fossil fuels	Semi-crystalline, resistant to water, oil, solvents and chlorine	Biomedical applications or blended with starch to improve properties	✓	✓	✓	X

Modified from The Green House - Decision Tree for Biodegradable Plastic

Material types and applications

Bio-based biodegradable plastics

These plastics are derived from renewable biomass that may either be classified as first generation or second generation. First generation feedstocks are agricultural crops such as corn, wheat or potatoes, while second generation refers to non-food crops (switch grass, algae etc.) or the non-edible residues from feed crops (bagasse, rice bran etc.). Biodegradable materials can be broken down to their constituents as a result of microbial activity. Compostable materials biodegrade beyond a threshold level under specified conditions within a defined time period.

Poly(lactic acid) (PLA)

Raw material source and production

PLA is a polyester that can be synthesised from either lactic acid (by direct condensation) or lactide (by ring-opening polymerisation) monomers. The monomers are produced by the fermentation of starch, typically derived from agricultural crops such as corn, wheat, sugar beet, potatoes, sugar cane and tapioca.

The global market for PLA is currently around 220 000 tons. PLA resin sells for between \$3500 and \$4500 per ton.

Basic properties

PLA is a thermoplastic with a melting temperature of 150-170°C and a density of 1.24. The monomers can have different conformations (D- and L- isomers) and manipulating these during polymer formation allows the production of different grades, with different properties (MFI from 6-50).

PLA has a glass transition temperature of between 55°C and 65°C, although heat resistant variants that can tolerate up to 110°C have been produced.

The basic mechanical properties are between those of polystyrene and PET.

Applications

A variety of grades are available that allow PLA to be used in a number of processes, including injection moulding, thermoforming, extrusion and the production of fibre and films.

The majority of PLA is used in the production of rigid packaging (cups, trays etc), with significant amounts also used in flexible packaging (bags), textiles and service ware (disposable cutlery, straws etc).

End of life

PLA has the potential to be mechanically or chemically recycled, although this is less likely for PLA packaging. It is not currently recycled in South Africa.

The majority of PLA packaging products available in South Africa are marketed as compostable. The material may be compostable under industrial composting conditions, but is not suitable for home composting, unless it has been blended with other materials, such as polycaprolactone (PCL). A number of

microorganisms have been shown to produce enzymes that are capable of degrading PLA. PLA does not degrade in the absence of oxygen (anaerobic), so is unlikely to break down in a landfill.

PLA can also degrade in the absence of bacteria, by hydrolysis and photodegradation (UV), but the rates are very slow at ambient temperature.

Concerns/challenges

PLA is indistinguishable from PET (density 1.38) and can only be easily separated using expensive near-infrared (NIR) technology. Both materials will sink. A small amount of PLA can contaminate a PET recycling stream rendering the recycle unusable.

The degradation rate of PLA outside of industrial composting facilities is very slow, particularly in environments where the temperature is low, there is limited oxygen or low numbers of the appropriate microbes, such as the ocean or aquatic sediments. There is limited information on the degradation rates in the terrestrial environment.

PLA is typically produced from food crops. While this has little impact on land use and food security at current volumes it may become a concern if demand increases substantially.

Polyglycolic acid (PGA)

Raw material source and production

PGA is the simplest linear polyester produced from glycolic acid monomers. Traditionally, the majority of glycolic acid has been produced from petrochemical sources. More recently, microbial fermentation of renewable biomass has been developed as an alternative.

The current market for PGA is small.

Basic properties

PGA is a thermoplastic with a melting temperature of 225-230°C and a density of 1.53. The polymer has a glass transition temperature of between 35°C and 40°C.

PGA typically exhibits a high degree of crystallinity (45-55%), which means it is insoluble in water. However, the chemical structure means it is prone to hydrolysis (breakdown in water).

Applications

The hydrolytic instability of PGA has limited the range of applications, which have been dominated by biomedical applications, such as absorbable sutures and other implants.

The high degree of crystallisation means the PGA has very good gas barrier properties. High molecular weight PGA is finding applications in packaging, particularly as an interlayer between PET to improve shelf life of perishable foods and carbonated drinks. This may become more important as packaging is further light-weighted.

PGA is also being investigated as a replacement for foil layers to allow the production of fully biodegradable films that still have good barrier properties.

End of life

Pure PGA will degrade relatively rapidly in water and this process is accelerated by microbial enzymes.

Concerns/challenges

There are currently relatively few applications for PGA in packaging and these are predominantly as a component of other biodegradable materials, so this material is not a major concern.

Thermoplastic starch (TPS)

Raw material source and production

TPS is derived from starch, which is typically extracted from maize, wheat, potatoes and other starch-rich agricultural crops, although second generation sources such as rice straw are being investigated.

Starch is composed of amylose (15-30%), a linear polymer of D-glucose, and amylopectin (70-85%), a highly branched polymer of D-glucose. The higher the amylopectin fraction the greater the crystallinity and this differs between crop types.

Thermoplastics are typically processed by heating to above their melting point to allow viscous flow. Native starch degrades at temperatures below the melting points, so the addition of plasticisers is required to produce thermoplastic starch. Water is the most common plasticiser, but is typically not used alone as it results in undesirable mechanical properties and can lead to retrogradation. More commonly, glycerol or a mixture of glycerol and water are used. Another method used to combat retrogradation involves blending starch with other polymers. These may be biodegradable, such as PLA, PHB or PCL, to produce a fully biodegradable product, or non-biodegradable (PE, PVA and polyesters). Blending is typically accomplished by twin-screw extrusion at elevated temperatures.

Starch blends make up over 40% of the biodegradable plastics market, with current demand exceeding 385 000 tons. TPS pellets sell for between \$3500 and \$4500 per ton.

Basic properties

Native starch degrades at temperatures below the melting point, so needs to be treated with plasticisers or blended with other polymers to produce a thermoplastic. Depending on the nature of the blend, the thermal and mechanical properties of the product can vary significantly.

Native starch has a density of 1.5, so most thermoplastic blends will also have densities in excess of 1. The glass transition temperature depends on the nature of the blend and can vary from below freezing to above 100°C. Therefore, blends can be produced that are either glassy (brittle, transparent, rigid) or rubbery (tough, flexible, resistant to reagent attack) at ambient temperature.

Applications

The range of available blends means that TPS can be processed by a variety of mechanisms, including kneading, compression moulding, injection moulding, blow moulding, thermoforming, extrusion and the production of films.

Thermoplastic starch is predominantly used in the production of flexible packaging (bags), with significant amounts also used in rigid packaging, service ware (disposable cutlery), agriculture, consumer goods and coatings.

End of life

The biodegradability of TPS blends depends greatly on the formulation. Native starch is completely biodegradable and fully degradable products can be produced by blending with other biopolymers (e.g. cellulose) or biodegradable polymers (PCL, PVA).

The general mechanism of starch degradation by enzymatic hydrolysis involves the attachment of the enzyme to the substrate surface, followed by cleaving of the bonds. Therefore, the rate is dependent on the chemical structure of the polymer, surface area, pH, temperature, moisture content, type and abundance of microorganism, wettability etc. Altering the chemical structure of starch by blending or including additives will typically reduce the degradability. Similarly, blending starch with non-biodegradable polymers will produce a material that is only partially biodegradable.

Concerns/challenges

Due to the versatility of starch blends it is possible to produce materials that appear physically similar to traditional polymers that could have a negative impact on mechanical recycling streams.

Polyhydroxyalkanoates (e.g. PHA, PHB, PHV)

Raw material source and production

PHAs are a group of polyesters that are produced in nature by a wide range of bacteria, often via the fermentation of sugars or lipids (oils). More than 150 different monomers can be combined to form this group of polymers, giving a wide range of material types. They are typically accumulated as energy storage molecules when there is a deficiency of a nutrient required for active growth (e.g. phosphorous, nitrogen or trace elements), but an abundance of the carbon source. During production by industrial fermentation the conditions initially favour rapid cell growth after which the medium is manipulated to promote PHA accumulation. The simplest and most commonly produced PHA is poly-3-hydroxybutyrate (P3HB),

PHAs are deposited as granules within the cells and can make up as much as 80% of the cell mass. The cells need to be disrupted in order to recover the granules, which increases the complexity and cost of manufacture.

The market for PHAs is still relatively small, around 29 500 tons, but is expected to grow by over 80% in the next five years. The majority of PHAs are used to manufacture flexible packaging. PHA pellets sell for between \$2 000 and \$4 500 per ton.

Basic properties

PHA polymers are thermoplastics and can be processed using conventional machinery, most commonly by extrusion and injection moulding. The properties differ according to their composition (homo- or co-polymer) and which fatty acids are incorporated.

The PHAs are more UV stable than most bioplastics and has good aroma and water barrier properties.

The most common PHA (P3HB) has a density between 1.18 and 1.26, depending on the degree of crystallinity, a melting point of 180°C and a glass transition temperature of 4°C. The mechanical properties and tensile strength are similar to those of polypropylene, although the extension to break (5%) is substantially lower than PP (400%), so P3HB appears stiffer and more brittle.

Increasing the amount of valeric acid in the polymer reduces the stiffness and increases the impact strength and flexibility, making the material more attractive for flexible packaging.

Applications

By manipulating the co-polymer blends, PHAs can be produced with similar properties to PVC (flexible, ductile and moisture and oxygen barrier) for films, LDPE (flexible, tough, ductile) for carrier bags, PP (tough, high operating temperature) for food trays and high impact PS (strong, stiff, high softening temperature) for disposable cutlery.

At present, the majority of PHA is used in flexible packaging applications.

End of life

PHAs are readily biodegradable in aerobic and anaerobic environments. A number of bacterial and fungal species have been shown to produce extracellular PHA-degrading enzymes (PHA depolymerases), which hydrolyse the polymer into water-soluble molecules that can be transported into the cells. The rate of PHA degradation depends on the degree of crystallinity (slower for high crystallinity) as well as the concentration and properties of the enzyme and reaction conditions.

Based on the relative ease of degradation most PHA-based products are compostable under industrial and home composting conditions.

Concerns/challenges

The versatility of PHA co-polymer blends means that they can potentially be used for a range of applications (e.g. water bottles) that are currently dominated by material types that have high collection and recycling rates. PHAs are not compatible with PET or PP so there is a danger of contamination of recycling streams if the products are indistinguishable.

Polybutylene succinate (PBS)

Raw material source and production

PBS is a linear polyester produced from succinic acid and butanediol monomers. Traditionally, the monomers were produced by chemical synthesis, but genetically engineered strains of bacteria and yeast have been developed to produce succinic acid by fermenting glucose.

The current market for PBS is around 100 000 tons per year. Virgin PBS resin sells for between \$3000 and \$4000 per ton.

Basic properties

PBS is a thermoplastic with a melting temperature of 115°C and a density of 1.26. It has similar properties to polypropylene.

Applications

The majority of PBS is currently used in flexible packaging and agricultural/horticultural applications.

End of life

PBS will degrade under industrial composting conditions within about 90 days. Under home composting conditions degradation should occur within 12 months and under normal soil conditions in around two years.

PBS and PBS blends do not readily degrade under anaerobic conditions.

As with most biodegradable polymers the rate of degradation is influenced by factors such as temperature and the prevalence of bacteria and fungi. Therefore, in low-temperature marine environments, where bacterial concentrations are low and fungi are often absent PBS-based materials can persist for extended periods.

Concerns/challenges

Misleading labelling of fossil fuel-based PBS as bio-based.

Biodegradable, fossil fuel-based plastics

These materials are produced from monomers derived from fossil fuels but are still biodegradable and may be compostable.

Polycaprolactone (PCL)

Raw material source and production

PCL is a biodegradable linear polyester that is produced from fossil fuel-based chemicals. The primary method of production is the ring opening polymerisation of ϵ -caprolactone over a metal catalyst. ϵ -caprolactone is synthesised via a series of chemical reactions, beginning with the conversion of benzene to cyclohexane, the oxidation of cyclohexane to cyclohexanone and finally the oxidation of cyclohexanone with peracetic acid.

The current market for PCL is estimated at around \$500 million, with the majority of the demand for use in the production of specialised polyurethanes. PCL resin sells for between \$1000 and \$3000 per ton.

Basic properties

Polycaprolactone is a thermoplastic with a melting temperature of 60°C, a glass transition point of -60°C and a density of 1.145. PCL imparts good resistance to water, oil, solvents and chlorine. It is semi-crystalline and the crystallinity decreases with increased molecular weight.

Applications

Native PCL degrades as a result of the hydrolysis of the ester linkages, so has been widely used in the biomedical industry for implantable devices and controlled drug release devices. It is more crystalline than PLA, so takes longer to degrade within the body.

For bioplastic applications PCL is typically blended with starch to reduce the cost, improve the barrier properties and biodegradability.

End of life

Native PCL will degrade within 2-4 years by abiotic hydrolysis, but this is accelerated in enzyme-rich and acidic environments. Starch-PCL blends are typically compostable under industrial and home composting conditions.

Concerns/challenges

As PCL is fossil fuel-based it is subject to the several of the concerns raised about the sustainability of traditional petrochemical-based polymers.

Bio-based, non-biodegradable plastics

These polymers are produced from monomers derived from renewable biomass that are identical to those derived from fossil fuels, so have the same material properties and resistance to biodegradation.

Bio-PET/PP/PE/PVC

These bio-based polymers, also referred to as drop-ins, are produced from monomeric units derived from bioethanol. They are structurally and functionally identical to the fossil fuel-based polymers and are therefore not biodegradable or compostable, but can be recycled along with the traditional polymers using the existing recycling infrastructure.

Polyethylene furanoate (PEF)

Polyethylene furanoate (Polyethylene 2,5-furandicarboxylate) is an aromatic polyester that can be produced by polycondensation of 2,5-furandicarboxylic acid (FDCA) and ethylene glycol. PEF is an analogue of PET that was first patented in 1951. It has become the subject of renewed interest since the US Department of Energy identified the FDCA monomer as a potential bio-based alternative to purified terephthalic acid (PTA).

PEF offers superior thermal and gas barrier properties to PET, making it an attractive alternative, particularly for small (250-330 ml) carbonate beverage bottles. In addition, a life cycle assessment by Eerhart and co-workers in 2012 indicated that PEF significantly outperformed PET with respect to greenhouse gas emissions and non-renewable energy use.

Recently, research in the field of advanced catalysis has demonstrated the potential of extracting glucose from the lignocellulosic fraction of plant biomass and number of European companies intend scaling up the conversion of the glucose to FDCA and then fully bio-based PEF.

PEF is not biodegradable, but can be mechanically recycled to rPEF in a similar way to the recycling of PET to rPET. It has been reported that a small amount of PEF will can be processed with PET. PEF and PET can be distinguished and separated using infra-red based automated separation, but this technology is not yet widely available in South Africa.

At this stage, commercial production facilities for bio-based PEF are still being developed and are expected to produce around 75 000 tons by 2023.

Plastics with prodegradant additives

Prodegradant additives are added in small amounts to conventional polymers during processing and are intended to accelerate the degradation of the polymer under oxidative conditions (oxo-additives) or due to microbial degradation (bio-additives).

Oxo-degradable additives

These are a group of additives, often metal salts of carboxylic acids and dithiocarbamates, that are marketed on the hypothesis that they accelerate the degradation of the polymer structure to produce fragments with a molecular weight low enough that they can be broken down to carbon dioxide and water by microorganisms. On this basis materials containing the additives are often referred to as oxo-biodegradable.

The mechanism of action has been widely reported. Heat, oxygen, UV exposure and stress are responsible for the generation of hydro-peroxide groups. The decomposition of these groups is catalysed by the metal salts used in the additives and results in free radical formation. The radicals react with other polymer chains to form carbonyl groups, including ketones. These can cause chain scission, which results in a loss of mechanical properties and the polymer becomes brittle and prone to disintegration into small fragments.

There has been a substantial amount of industry-funded and independent research conducted on the efficacy and potential environmental risks associated with oxo-degradable additives, with widely varying results.

The most direct measurement of biodegradation under aerobic conditions is the conversion of polymer to carbon dioxide. Proponents of oxo-degradable additives frequently cite research conducted by Chiellini and co-workers. In these studies the additive containing films were first subjected to artificial weathering conditions (UV light and/or heating at 50-70°C) prior to the biodegradation studies. Results indicated a lag phase of around 150 days, after which carbon dioxide evolution increased, achieving calculated degradation rates between 45 and 60% after 600 days.

However, a number of other studies have presented conflicting results. A study by Portillo and co-workers that applied the ASTM D-5208 protocol to PE films with and without oxo-additives, after initial treatment under accelerated oxidation conditions (UV and elevated temperature). While the additive did induce degradation under the accelerated oxidation conditions, including a reduction in molecular weight, mechanical weakening and increase in carbonyl index (CI of 5.6 vs 0.59 for native PE) there was no significant difference in subsequent biodegradation between native and additive containing material over the 90 day test period. Other studies, which investigated the degradation of oxo-additive containing materials in soil and aquatic (marine and freshwater) environments, without prior exposure to accelerated oxidation conditions found very limited degradation.

A review of oxo-degradable plastics by Thomas and co-workers concluded that it is the low molecular weight components of the oxidised oxo-degradable polymers that are capable of undergoing some biodegradation. However, they note that it is difficult to extrapolate the accelerated oxidation conditions to real world exposure, where UV, temperature and oxygen availability vary significantly. The review concluded that under UK conditions oxo-degradable plastics in the environment would fragment in 2-5

years and subsequent biodegradation of the fragments would proceed very slowly, many times slower than compostable plastics. There is no data on degradation rates under South African environmental conditions.

The second major concern associated with oxo-degradable additives is the formation of microplastic fragments that persist in the soil or aquatic environment, where they can be ingested by earthworms, birds and fish. The potential for cross-linking of fragments, increasing their stability, has also been raised as a concern. An associated concern is the potential of these fragments to concentrate pesticide residues in the soil or the ocean, as has been shown for fragments of PP and PE. The tests typically performed to assess biodegradability were not developed to investigate fragmentation, but the limited extent of biodegradation observed in most studies strongly indicates the persistence of plastic fragments.

Producers of oxo-degradable additives claim that the additives do not negatively impact the mechanical recyclability of the plastic. While this is strictly true, to the extent that even partially degraded plastic can be re-melted and pelletised, recyclers have raised concerns around the mechanical integrity of the recyclate. To date, oxo-additives have predominantly been used in films where there is limited post-consumer collection and recycling, so potential impacts are limited. Application of the additives in PET or HDPE bottles would substantially increase the potential for negative impacts. In South Africa, the previous experimentation with oxo-additives in bread bags resulted in recyclers no longer accepting these products and the recycling rate has not recovered over the last decade. Recent engagement with recyclers confirmed that their attitude to oxo-additives has not changed.

Bio-additives

These are a group of propriety molecules (e.g. BioSphere) that are proposed to function by accelerating the degradation of the polymer structure, followed by the microbial degradation of the small fragments. Therefore, the overarching mechanism is similar to that for oxo-degradable materials, with the major difference that the initial degradation is not induced by heat, UV and oxygen, but rather by microbial action. The additives are said to reduce the hydrophobicity of the plastic, making it easier for microbes to attach and initiate the degradation process.

Bio-additives have not been on the market for as long as oxo-additives and there have been no independent scientific studies to verify the claims by the manufacturers. Internal and industry-commissioned studies have shown slow degradation under anaerobic conditions, based on methane production rates.

The manufacturers claim that the additives do not promote fragmentation in the same way oxo-additives, but have not been able to provide definitive evidence to support this claim. In the absence of this, it can be assumed that the plastic is likely to fragment and that the biodegradation of the fragments will proceed at a similar rate to those induced by oxo-additives.

Summary of commercially available biodegradable plastics

Company	Product	Feedstock	Certification
Thermoplastic starch blends			
Novamont	Materi-Bi	Starch-PCL/PVOH blends Vegetable and/or fossil fuel raw material	Biodegradable Industrial composting Home composting
Rodenberg	Solanyl	Partially fermented starch Second generation potato starch	Bio-based Biodegradable Industrial composting
Biotec	Bioplast	Starch polyester blend Potato starch	Renewable feedstock Biodegradable Industrial composting Home composting
Limagrain	Biolice	Starch polyester blend Cereal and maize	Industrial composting
Plantic	Plantic HP	Corn starch	Bio-based Biodegradable Home compostable
BiologiQ	NuPlastiQ	Thermoplastic starch Potato, corn and sugar beet	Bio-based Industrial composting Marine biodegradable
Polyhydroxyacids			
Tianan Biologic	ENMAT (Y1000P)		Biodegradable Industrial composting
Danimer Scientific	Noadx		Bio-based Biodegradable Industrial composting Home composting
PLA			
Total Corbion		Cane sugar and sugar beet	Bio-based Industrial composting
Natureworks	Ingeo	Cassava, corn starch, sugar cane Investigating 2 nd generation feeds	Bio-based Industrial composting
Untika	Terrmac		Bio-based Biodegradable
Bonnie Bio		Corn starch	Biodegradable Industrial composting
PBS/PBSA			
Showa Highpolymer	Bionolle	Renewable starch/fossil fuels	Biodegradable Industrial composting
IRe	Enpol		Biodegradable Industrial composting
PCL			
Perstorp	CAPA	Fossil fuels	Biodegradable Industrial composting
PBAT			
BASF	Ecoflex	Fossil fuel, partial biomass	Biodegradable
IRe	Enpol G8060	Fossil fuel	Biodegradable Industrial compostable

Modified from The Green House - Decision Tree for Biodegradable Plastics

References: Material types and applications

- Accinelli, C., Sacca, M.L., Mencarelli, M., Vicari, A. (2012) Deterioration of bioplastic carrier bags in the environment and assessment of a new recycling alternative. *Chemosphere* **89**: 136-143.
- Bastioli, C. (1998) Properties and applications of Mater-Bi starch-based materials. *Polymer Degradation and Stability* **59**: 263-272.
- Chiellini, E., Corti, A., D'Antone, S., Baicu, R. (2006) Oxo-biodegradable carbon backbone polymers – Oxidative degradation of polyethylene under accelerated test conditions. *Polymer Degradation and Stability* **91**: 2739-2747.
- Chiellini, E., Corti, A., Swift, G. (2003) Biodegradation of thermally-oxidized, fragmented low-density polyethylenes. *Polymer Degradation and Stability* **81**: 341-351.
- European Bioplastics, Nova Institute (2018)
- Gewert, B., Plassmann, M.M., McLeod, M. (2015) Pathways for degradation of plastic polymers floating in the marine environment. *Environmental Science Processes & Impacts* **17**: 1513-1521.
- Horodytska, O., Valdes, F.J., Fullana, A. (2018) Plastic flexible films waste management – A state of art review. *Waste Management* **77**: 413-425.
- Kostakova, E.K., Meszaros, L., Maskova, G., Blazkova, B., Turcsan, T., Lukas, D. (2017) Crystallinity of Electrospun and Centrifugal Spun Polcaprolactone Fibers: A Comparative Study. *Journal of Nanomaterials* 2017. Article ID 8952390, 9 pages, 2017. <https://doi.org/10.1155/2017/8952390>.
- Martinez-Romo, A., Gonzalez-Moto, R., Soto-Bernal, J.J., Rosales-Candelas, I. (2015) Investigating the Degradability of HDPE, LDPE, PE-BIO and PE-OXO Films Under UV-B Radiation. *Journal of Spectroscopy* 2015. Article ID 586514, 6 pages, <http://dx.doi.org/10.1155/2015/586514>.
- Mitrus, M., Moscicki, L. (2009) Physical properties of thermoplastic starches. *International Agrophysics* **23**: 305-308.
- Musiol, M., Rydz, J., Janeczek, H., Radecka, I., Jian, G., Kowalczyk, M. (2017) Forensic engineering of advanced polymeric materials part IV: Case study of oxo-biodegradable polyethylene commercial bag – Aging in biotic and abiotic environment. *Waste Management* **64**: 20-27.
- Numata, K., Abe, H., Iwata, T. (2009) Biodegradability of Poly(hydroxyalkanoate) Materials. *Materials* **2**: 1104-1126.
- Ojogbo, E., Ogunsona, E.O., Mekonnen, T.H. (2019) Chemical and physical modifications of starch for renewable polymeric materials. *Materials Today Sustainability* in press.
- Saibuatrong, W., Cheroennet, N., Suwanmanee, U. (2017) Life cycle assessment focussing on the waste management of conventional and bio-based garbage bags. *Journal of Cleaner Production* **158**:
- Symphony International (2019) d2w A Scientifically Proven Biodegradable Technology, Special Report, July 2019 Edition.
- Thomas, N.L., McLauchlin, A.R., Clarke, J., Patrick, S.G. (2012) Oxo-degradable plastics: degradation, environmental impact and recycling. *Waste and Resource Management* **165**: 133-140.

Portillo, F., Yaschuko, O., Hermida, E. (2016) Evaluation of the rate of abiotic and biotic degradation of oxo-degradable polyethylene. *Polymer Testing* **53**: 58-69.

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