

OXO-DEGRADABLE PLASTIC PACKAGING IS NOT A SOLUTION TO PLASTIC POLLUTION, AND DOES NOT FIT IN A CIRCULAR ECONOMY



Oxo-degradable plastic packaging, including carrier bags, have in recent years been marketed as a solution to plastic pollution, with claims that such plastics, when they end up in land or aquatic environments, degrade into harmless residues within a period ranging from a few months to several years. However, a significant body of evidence indicates that oxo-degradable plastics simply fragment into small pieces, including microplastics, with the entire process of biodegradation into naturally occurring molecules requiring timescales often (far) in excess of those claimed by their manufacturers. The contribution of these plastics to microplastic pollution poses an environmental risk, particularly in the ocean. Furthermore, oxo-degradable plastics are not suited for effective long-term reuse, recycling at scale or composting. In summary, the evidence to date suggests oxo-degradable plastic packaging goes against two core principles of the circular economy: designing out waste and pollution; and keeping products and materials in high-value use. Therefore, we support applying the precautionary principle by banning oxo-degradable plastic packaging from the market. Similarly, existing evidence suggests this conclusion also holds for other plastic packaging that contains similar chemical additives, both organic and inorganic, for which claims of accelerated biodegradation are made, including enzyme-mediated degradable plastics.

DEFINITION

Oxo-degradable plastics are conventional polymers (e.g. LDPE) to which chemicals are added to accelerate the oxidation and fragmentation of the material under the action of UV light and/or heat, and oxygen.¹ The oxidation process enables a faster conversion of polymers into fragments. In theory, this fragmentation should then accelerate the process of biodegradation, i.e. the breakdown triggered by microorganisms into naturally occurring molecules such as carbon dioxide and water. This biodegradation process depends on multiple criteria, including the fragment size, the quantity of additives, and the environmental conditions to which the material is subjected (e.g. temperature, biotic factors) - conditions that vary significantly in practice.² Packaging applications of oxo-degradable plastics include carrier bags, blister packaging, bottles, labels, and caps.³ Oxo-degradable plastics and similar materials are marketed and referred to in different ways, including so-called oxo-biodegradable, photo/thermo-degradable, oxo-fragmentable or pro-oxidant additive containing plastics - a terminology prone to confuse consumers, policymakers and companies.⁴

ARGUMENTATION

Over the past decade, oxo-degradable plastics have gained attention as a potential solution to soil and marine pollution, with the material made mandatory in several countries and regions worldwide, and marketed in many more.⁵ Few experts support the claim of effective biodegradation of oxo-degradable plastics.⁶ However, a wide range of academics (from universities including California State University, Michigan State University, University of Loughborough), international and governmental institutions (e.g. UN Environment, European Commission, UK Government), testing laboratories (e.g. Organic Waste Systems), trade associations of plastics manufacturers, recyclers and converters (e.g. PlasticsEurope, SPI Bioplastics Council, European Plastics Converters), non-profit organisations (e.g. Sustainable Packaging Coalition) and multiple other experts have provided or collected evidence that oxo-degradable plastics are not a solution to plastic packaging pollution, and that they are not suited for effective long-term reuse, recycling at scale or composting.⁷

Oxo-degradable plastic packaging is not a solution to soil or marine pollution - on the contrary, it contributes to microplastic pollution and poses an environmental risk.

Oxo-degradable plastics are often marketed as a solution to littering by claiming they are degradable - a marketing statement which is prone to confuse consumers and the wider public and may actually incentivise littering.⁸ In the environment they fragment into smaller pieces, including microplastics.⁹ While these microplastic fragments can be invisible to the naked eye, this fragmentation is different from biodegradation. Studies show that the entire biodegradation process varies, as environmental conditions inevitably do, and often takes (much) longer than

claimed.¹⁰ During this time microplastics remain in the environment, including the ocean. As with all microplastics in ecosystems, there is a risk of bioaccumulation, including into the food chain, with potential negative impacts on human health and the environment.¹¹

Oxo-degradable plastic packaging is not suited for long-term reuse, recycling at scale or composting. Hence, it does not allow materials and products to be kept in high-value use.

- **Reuse:** Oxo-degradable plastics are designed to start fragmenting within a few months or years. Therefore, even though the addition of stabilisers can delay the intended fragmentation effect, oxo-degradable plastic packaging is - by its very design - not meant for long-term reusable applications.¹²
- **Recycling:** Recyclers and converters have widely recognised that oxo-degradable plastics negatively affect the quality and economic value of plastic recyclates, and are advising against their use.¹³ They reported that oxo-degradable plastic packaging cannot be detected by current technology at sufficient scale to be sorted out from conventional plastics. While the intended fragmentation effect can be delayed, this is not a long-term solution for recycling at scale: it is difficult to estimate the proportion of stabilisers added and the extent of degradation already induced in the material - a challenge expected to worsen with every recycling loop.¹⁴
- **Composting:** Oxo-degradable plastics do not fulfill the requirements of relevant international standards for plastic packaging and plastics recovery through composting, such as ISO 18606, EN 13432, ASTM D6400, AS 4736 or GreenPla, as their biodegradation takes too long, and plastic fragments can remain in the compost.¹⁵ If added to a composting stream, they adversely affect the quality and market value of the compost, and potentially enable the release of plastics into the natural environment.¹⁶ Therefore, oxo-degradable plastic packaging should not be included in the material stream intended for composting. This incompatibility is also clearly stated by many manufacturers of oxo-degradable additives and by the Oxo-biodegradable Plastics Association.¹⁷

In summary, the evidence to date suggests that oxo-degradable plastic packaging goes against two core principles of the circular economy: designing out waste and pollution; and keeping products and materials in high-value use. In addition, claims made about benefits of oxo-degradable plastics in landfills have been shown to be misleading.¹⁸

RECOMMENDATION

We support applying the precautionary principle by banning oxo-degradable plastic packaging from the market until extensive, independent third-party research and testing based on international standards (as used by ISO, CEN and ASTM), possibly combined with technological progress and innovation, clearly confirms sufficient biodegradation of the plastic fragments in different environments, and over a time-scale short enough for particles not to accumulate in ecosystems. Based on the existing evidence, this recommendation also holds for plastic packaging that contains similar chemical additives, both organic and inorganic, for which claims of accelerated biodegradation are made, including enzyme-mediated degradable plastics.

To create a system in which plastic packaging never becomes waste, we support innovation that designs out waste and pollution, and keeps products and materials in high-value use.

This statement is the result of extensive consultation with scientists, testing laboratories, companies, NGOs and trade associations and is endorsed by the following organisations and individuals:

Businesses and industry associations



**Development
Alternatives
(India)**

TerraCycle

Non-governmental organisations and associations:



Kentucky Environmental Federation

Ciudad Saludable (Peru)

Danmarks Naturfredningsforening

VšĮ "Žiedinė ekonomika" (Zero Waste Lithuania)

Public institutions, Research organisations and scientists:



- Mr. Richard C. THOMPSON, Professor, Marine Biology, Plymouth University, UK
- Prof. Dr. Ramani NARAYAN, University Distinguished Professor, Department of Chemical Engineering & Materials Science, Michigan State University, USA; Fellow, National Academy of Inventors; Fellow ASTM International,
- Prof. Dr. Joseph P. GREENE, Department Chair and Professor, Department of Mechanical and Mechatronic Engineering and Sustainable Manufacturing, California State University, Chico, USA
- Mr. Joao SOUSA, Biotechnology Engineer, International Union for Conservation of Nature (IUCN), Switzerland
- Dr. François GALGANI, Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), France
- Mr. Marco RICCI, Chair of the ISWA working group on biological treatment of waste
- Prof. Dr. Jorge EMMANUEL, Faculty Fellow and Adjunct Professor, Institute of Environmental and Marine Sciences, and College of Engineering and Design, Silliman University, Dumaguete, Philippines; Former Chief Technical Advisor on global environmental facility projects and on persistent organic pollutants for the United Nations Development Program (UNDP).
- Mr. Anant Trivedi, National Network For India Trust (NNFI), New Delhi, India
- Wageningen Food & Biobased Research, Wageningen University and Research, The Netherlands: Mr. Christiaan Bolck MSc, Program manager “materials”, Dr. Maarten van der Zee, Senior scientist “biodegradable materials”, Dr. Harriëtte Bos, Program director “resource use efficiency”/expertise leader “sustainable chains and systems analysis”, Mrs. Karin Molenveld MSc, Expertise leader “sustainable plastics technology”

Member of the European Parliament:

- Mr Philippe LAMBERTS (Belgium)
- Mrs Margrete AUKEN (Denmark)
- Mr Pascal DURAND (France)
- Mrs Simona BONAFÈ (Italy)
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- Mr Claude TURMES (Luxembourg)
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<https://newplasticseconomy.org/>

ENDNOTES

1. European Standards Organisation (CEN), CEN/TR 15351:2006 Plastics - Guide for vocabulary in the field of degradable and biodegradable polymers and plastic items: Oxo-degradation (or oxidative degradation) is defined as degradation identified as resulting from oxidative cleavage of macromolecules.
2. A biodegradable plastic is defined in EN ISO 472:2001 as degradable plastic in which degradation results in lower molecular weight fragments produced by the action of naturally occurring microorganisms such as bacteria, fungi and algae; DEFRA, Loughborough University, Assessing the Environmental Impacts of Oxo-degradable Plastics Across Their Life Cycle (2010); European Commission, Eunomia, Study to provide information supplementing the study on the impact of the use of "oxo-degradable plastic" on the environment (2017); European Bioplastics, Background, "Oxo-biodegradable" plastics and other plastics with additives for degradation (2015).
3. Other common applications, packaging and others, include closures, clamshells, agricultural mulch films, landfill covers, lids, milk pouches, pallet and shrink wrap, and trays.
4. Ministry of Agriculture, Fisheries, Food and the Environment, Draft Royal Decree on reducing the consumption of plastic carrier bags and creating a register of product producers; EU Commission, *ibid.*: The EU uses the term "Pro-oxidant Containing (PAC) Plastic" whereas the additives industry introduced the term "oxo-biodegradable" plastics; US Federal Trade Commission (FTC), FTC Issues Revised, Green Guides (2012), Claim 260.8: it is deceptive to misrepresent, directly or by implication, that a product or package is degradable, biodegradable, oxo-degradable, oxo-biodegradable, or photodegradable; US FTC Website, FTC Staff Warns Plastic Waste Bag Marketers That Their "Oxodegradable" Claims May Be Deceptive: The FTC sent letters warning 15 marketers of "oxodegradable" plastic waste bags that their oxodegradable, oxo biodegradable, or biodegradable claims may be deceptive.; State of California, Laws AB1972 prohibiting the sale of plastic bags labelled as "compostable" or "marine degradable" that do not meet ASTM standards, and the labelling of "biodegradable", "degradable", "decomposable" plastic bags if these do not deliver their claims.; S. Deconinck, B. De Wilde, OWS, Review of information on enzyme-mediated degradable plastics (2014); European Bioplastics, Enzyme-mediated degradable plastics (2014).
5. Countries where oxo-degradable plastics are mandatory for certain applications, including in the United Arab Emirates, Saudi Arabia, areas of Pakistan, Yemen, Ivory Coast, South Africa, Ghana and Togo; EPI website: EPI additive TDPA® is currently marketed in over 70 countries; Symphony website: Symphony serves 100 countries; Oxo-degradable Plastics Association website: the OPA counts members in 97 countries.; In this paper, references to environment pollution encompass all terrestrial and aquatic environments, including freshwater and marine environments.
6. Experts who seem to be positive on the effectiveness of oxo-degradable plastics include I. Jakubowicz, E. Chiellini, A. Corti, T.F.M. Ojeda, J. Lemaire, amongst others. However, the conclusions on the extent of biodegradation of oxo-degradable plastics to be drawn from their studies are not to be interpreted as proving effective biodegradation in reality, for a range of reasons, including: the methodology used, as some tests were performed at temperatures which do not reflect real life environments; some show that a threshold in molecular weight reduction is reached after a certain period of time without proving that the biodegradation process will continue and thus be completed (similarly, some conclude effective biodegradation in a potential future by extrapolation of the results); some tests do not make the data on the amount of additive concentration added to the polymer for the test available, although these elements have been proved to highly influence the rate of molecular weight reduction - and hence the extent of biodegradation. Finally, some of these studies were not performed independently, but on behalf of oxo-degradable additives manufacturers.
7. California State University, Chico Research Foundation, Performance Evaluation of Environmentally Degradable Plastic Packaging and Disposable Food Service Ware - Final Report (2007): independent study proving the oxo-degradable carrier bags on the market showed no biodegradation; R. Narayan, Fundamental Principles and Concepts of Biodegradability - Sorting through the facts, hype and claims of biodegradable plastics in the marketplace, Bioplastics Magazine, Vol. 4 (2009); N.L. Thomas, J. Clarke, A.R. McLauchlin and S.G. Patrick, Loughborough University, Oxo-degradable plastics: degradation, environmental impact and recycling, Proceedings of the Institution of Civil Engineers Waste and Resource Management 165, Issue WR3, Pages 133-140 (2012); United Nations Environment Programme (UNEP), Biodegradable Plastics and Marine Litter. Misconceptions, concerns and impacts on marine environments; European Commission, Eunomia, Study to provide information supplementing the study on the impact of the use of "oxo-degradable plastic" on the environment (2017); Department for Environment, Food & Rural Affairs of the UK Government (DEFRA) (2010), *ibid.*; Plastics Europe, Organic Waste Systems (OWS), Benefits and challenges of bio- and oxo-degradable plastics - A comparative literature study (2013); European Plastics Converters (EuPC), TCKT, Impact of Degradable and Oxo-fragmentable Plastic Carrier Bags on mechanical recycling (2012); Susan Selke et al., Evaluation of Biodegradation-Promoting Additives for Plastics (2015); Sustainable Packaging Coalition (SPC), Position against Biodegradability Additives for Petroleum-Based Plastics (2015); Society of the Plastics Industry (SPI) Bioplastics Council, Position paper on degradable additives (2016).
8. EU Commission, *ibid.*; DEFRA (2010), *ibid.* UNEP, in European Bioplastics, 2015, *ibid.* SPC, *ibid.* NAPCOR, Degradable Additives to Plastic Packaging: A Threat to Plastic Recycling (2013); SPC, *ibid.*; SPI, *ibid.*; Southeast Recycling Development Council (SERDC), Position Statement on Degradable Additives to Plastic Packaging.; South African Plastics Recycling Organisation (SAPRO), Why the plastics recycling industry is not supporting oxo-degradable additives? (2009).
9. European Commission, *ibid.*: Microplastics are defined by the European Commission as plastics that have been fragmented or manufactured to a size smaller than 5mm; United Nations Environment Programme (UNEP), Biodegradable Plastics and Marine Litter: Misconceptions, concerns and impacts on marine Environments (2015); DEFRA, *ibid.*; European Bioplastics Website, Scientific view on the plastic bag debate by Fraunhofer UMSICHT.
10. European Commission, *ibid.*; N.L. Thomas et al. (2012), *ibid.*: The length of time to degradation of oxo-degradable plastic cannot be predicted accurately because it depends on the environmental conditions. It is suggested that oxo-degradable plastics left in the open environment, in the UK, degrade to small fragments in two to five years, and they will still remain visible as litter before they start to fragment; DEFRA, *ibid.*: Degradation reactions leading to fragmentation of polythene films will occur much more quickly in Florida, compared with the UK, because of the

differences in the intensity of the sunlight.; T. O'Brine, R. C. Thompson, Degradation of plastic carrier bags in the marine environment, *Marine Pollution Bulletin* (2010): Tests conducted proved that samples of oxo-degradable and standard polyethylene in the water received around 90% less UV light after 40 weeks in comparison to samples not immersed in water, reducing the oxidation process. After 40 weeks, only 2% of surface area of oxo-degradable and conventional plastics was lost, whereas compostable plastics degraded entirely under similar conditions; California State University, Chico Research Foundation, *ibid.*: Plastics with oxo-degradable additives did not biodegrade successfully in marine environments during the tests conducted. ASTM D669109 Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in the Marine Environment: requires that plastics must have converted at least 30% of their carbon content into carbon dioxide within six months; Tosin, Maurizio et al., Laboratory Test Methods to Determine the Degradation of Plastics in Marine Environmental Conditions, *Frontiers in Microbiology* 3 (2012), in SPC, *ibid.*: Many additives designed to enable biodegradation in terrestrial conditions are not designed to be effective in marine conditions facing wider variability in temperature, microbial and nutrient availability, and exposure to sunlight in open oceans; Plastics Europe, OWS, Executive summary: Benefits and challenges of bio- and oxo-degradable plastics - A comparative literature study (2013); OWS, Expert statement: (Bio)degradable mulching films (2017); J. Greene, *ibid.*: Tests carried out in marine laboratory environment showed that oxo-degradable plastic bags, UV-degradable plastic ring and certain compostable plastics kept at 30°C for 60 days did not biodegrade; R. Narayan, *ibid.*: eventual biodegradation is not acceptable; Sustainable Packaging Coalition (SPC), Position against Biodegradability Additives for Petroleum-Based Plastics (2015); Biodegradable Products Institute (BPI), BPI assessment of oxo-degradable films (2003); Society of the Plastics Industry (SPI) Bioplastics Council, *ibid.*; Claims of the pro-degradant additive industry: EPI Environmental's website, Frequently asked questions webpage: TDPA® technology safely degrade and biodegrade plastic bags within a few months to two to three years in landfill or as litter; Symphony Environmental Website, IK Working Group Q&A - Proves they know nothing about oxo-biodegradable plastic webpage: Under normal conditions biodegradation will happen in less than two to five years; Oxo-biodegradable Plastics Association (OPA), The relevance of biodegradable plastics: Typically degradation will not start for six months in the case of a bread wrapper, or 18 months for a plastic shopping bag.

11. N.L. Thomas et al., *ibid.*; UNEP, *ibid.*; European Commission, *ibid.*; Narayan, *ibid.*; R.C. Thompson et al., Plastics, the environment and human health: current consensus and future trends, *Phil. Transactions, Royal Society of London* (2009); S.L. Wright, R.C. Thompson, T.S. Galloway, The physical impacts of microplastics on marine organisms: A review, *Environmental Pollution* (2013); K. Tanaka, H. Takada, Microplastic fragments and microbeads in digestive tracts of planktivorous fish from urban coastal waters. *Scientific Reports* (2016); S. Mosko, Bioplastics: Are They the Solution?, *Algalita Marine Research & Education* (2015), in SPC, *ibid.*: degradation does not prevent the fragmented plastics to transport through oceans during this process, potentially impacting aquatic organisms through ingestion during that timeframe; SPI Bioplastics Council, *ibid.*; BPI, *ibid.*; SERDC, *ibid.*; Similarly to oxo-degradable films, oxo-degradable mulch films used in agricultural applications have been shown not to biodegrade in a reasonable timeframe, with plastics fragments remaining in the soil, as explained in the following documents amongst several others: Station d'Essai et de Vieillessement Naturel de Bandol, Test report - Synthesis after 3 years, of studies conducted on oxo-degradable agricultural products (2010); OWS, Expert statement: (Bio)degradable mulching films (2017).
12. In line with the SPC, *ibid.*, Association of Postconsumer Plastic Recyclers, APR Position Statement on Degradable Additives Use in Bottles, Forms, and Films (2013), National Association for PET Container Resources (NAPCOR), Degradable Additives to Plastic Packaging: A Threat to Plastic Recycling (2013); K. Marek, J. Lemaire and A. M. Delort, Biodegradation of Prooxidant films with Prooxidant Additives, *Chemosphere* 64 (2006) in Society of the Plastics Industry (SPI) Bioplastics Council, Position paper on degradable additives (2016): peer-review research study mentioning that even with some content of stabilising additives, PE film with degradable additives loses its mechanical properties rather fast, especially when exposed to sunlight; European Commission, *ibid.*
13. Such as the British Plastics Federation, Website/BPF Recycling group, in DEFRA response to OPA (2012), The Industry Council for research on Packaging and the Environment (INCPEN), Foodservice Packaging Association; Recycling Of Used Plastics Limited (RECOUP), Plastic Packaging: Recyclability by Design (2006) along with the European Plastic Trade Packaging Associations including Plastics Recyclers Europe (EuPR), Oxo-degradable additives are incompatible with mechanical recycling, Press release (2009); APR, Position Statement on Degradable Additives Use in Bottles, Forms, and Films (2013); APR, Degradable plastics - A recycling coordinator's guide to managing new types of plastics; NAPCOR, Degradable Additives to Plastic Packaging: A Threat to Plastic Recycling (2013); Transfercenter für Kunststofftechnik (TCKT), Impact of Degradable and Oxo-fragmentable Plastic Carrier Bags on Mechanical Recycling, European Plastics Converters (EuPC) (2012): Tests conducted showed that as little as 2% oxo-fragmentable or degradable materials in the recycling stream can affect the quality of recyclates; EuPC press release, EuPC calls on legislator to support separate collection of degradable plastic materials and ban oxo fragmentable plastics (2013); SAPRO, *ibid.*; SERDC, *ibid.*; SPI Bioplastics Council, *ibid.*; NAPCOR, Degradable Additives to Plastic Packaging: A Threat to Plastic Recycling (2013); Institute of Scrap Recycling Industries (ISRI), ISRI Position on the Use of Degradable Additives in Plastic Packaging (2017); European Bioplastics (2015), *ibid.*; Hornitschek (2012) in UNEP, *ibid.*
14. European Commission, *ibid.*; DEFRA, *ibid.*; TCKT, *ibid.*; Roediger Agencies, Recycling Report on d2w Oxo-Biodegradable Plastics, Report conducted for the Oxo-biodegradable Plastics Association (2012), in European Commission, *ibid.*: this report commissioned by the degradant additives industry concluded that d2w containing plastic can be mixed with conventional plastic film with no detriment to products made with the recyclate. However, both the heat and UV aging tests were performed on samples that were 'recycled' (blown into film and then re-pelletised) in-house from primary materials rather than from recovered post-consumer waste material. Therefore, this does not demonstrate the effects of any oxidation as a result of UV ageing that has occurred during use, and/or between disposal and being recycled as in real world environments. Moreover, the oxidation of oxo-degradable plastic can lead to lower molecular weight, but for practical reasons this was not measured, only the carbonyl index was.
15. European Commission, *ibid.*; European Bioplastics website, Harmonised standards for bioplastics webpage; European Bioplastics, Fact sheet - Bioplastics, industry standards and labels (2016); Plastics Europe, *ibid.*; California State University, Chico Research Foundation, Performance Evaluation of Environmentally Degradable Plastic Packaging and Disposable Food Service Ware - Final Report (2007): study proving the oxo-degradable carrier bags on the market remained intact and did not show any sign of biodegradation; J. Greene, "Biodegradable and Oxodegradable Plastics Degradation in Compost and Marine Environments" Proceedings of the 8th World Congress of Chemical

Engineering, Montreal, Canada (2009): Tests carried out in laboratory compost conditions at 58°C for 180 days showed no fragmentation or degradation of oxo-degradable and UV-degradable plastic bags, whereas compostable plastics fully degraded; UNEP, *ibid.*; G. Davis et al., Open windrow composting of polymers: an investigation into the rate of degradation of polyethylene, *Resources, Conservation and Recycling*, 40 (2004): a two year pilot study which concluded that oxo-degradable plastic bags did not degrade at the same rate as organic matter, resulting in a finished compost with a highly visible proportion of plastic, leading to its landfilling; SPI Bioplastics Council, *ibid.* OPA, Standards for Testing Oxo-biodegradable Plastics: Composting standards.

16. DEFRA, *ibid.*; ISWA, Key Issue Paper, Biodegradable Plastics An Overview of the Compostability of Biodegradable Plastics and its Implications for the Collection and Treatment of Organic Wastes (2015); European Commission, *ibid.*; NAPCOR, *ibid.*
17. European Commission, *ibid.*; OPA website: "Oxo-biodegradable plastic is not intended for composting".
18. J. Greene, *ibid.*: Oxo-degradable plastics, biodegradable plastics and compostable plastics do not biodegrade in landfill conditions within 25 to 30 years; U.S. Federal Trade Commission (FTC), Docket No. 9358 (2013): the U.S. FTC qualified specific claims on the acceleration of biodegradability in landfill of the company ECM Biofilms, Inc, selling additives as deceptive, supported by scientific tests; European Commission, *ibid.*: In landfill, oxo-degradable plastics are shown not to degrade under the anaerobic conditions in deeper layers, although fragmentation may occur due to previous exposure to light, heat and oxygen.; Hence, while it is sometimes claimed that the fragmentation of oxo-degradable plastics in landfill allows a better compaction of these plastic materials, and thus optimisation of landfill storage capacity, the latter remains marginal; EPI website, webpage Benefits of TDPA® Technology.