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RESPONSE TO UN 2015 REPORT

Comment on: UNEP Report 2015 "Biodegradable Plastics & Marine Litter - Misconceptions, concerns and impacts on marine environments"

This paper was written by a geologist, not a polymer scientist. It confuses oxo-degradable with oxo-biodegradable plastic, and confuses "compostable" plastics which degrade by hydrolysis with those which degrade by oxidation. It contains other misconceptions relating to the science of abiotic and biotic degradation of polymers.

There are no references to the work of Jakubowicz, Scott, Ojeda and Lemaire or their university groups, all of whom have been actively involved in the science of oxo-biodegradation for more than twenty years, and only one reference to Chiellini. Also, scientific research has moved on since the Report was published in 2015, and its conclusions are even less valid today.

Oxo-biodegradable plastic has now been in use for more than twenty years in more than 80 countries worldwide. In some of those countries it is now mandatory to use oxo-biodegradable plastic for a wide range of everyday products, because their governments know that they cannot ban plastic and realise that for the foreseeable future they will not be able to prevent plastic waste getting into the open environment. We have heard no reports of any difficulty encountered in using or recycling these products.

Passages from the 2015 Report are quoted in italics.

One of the principal properties sought of many plastics is durability. This allows plastics to be used for many applications which formerly relied on stone, metal, concrete or timber. There are significant advantages, for food preservation, medical product efficacy, electrical safety, improved thermal insulation and to lower fuel consumption in aircraft and automotives. (p.5)

The development and use of synthetic polymers, and plastics has conferred widespread benefits on society. One of the most notable properties of these materials is their durability which, combined with their accidental loss, deliberate release and poor waste management has resulted in the ubiquitous presence of plastic in oceans. As most plastics in common use are very resistant to biodegradation, the quantity of plastic in the ocean is increasing, together with the risk of significant physical or chemical impacts on the marine environment.(p.3)

This is correct, and is the reason why oxo-biodegradable plastic was invented – to reduce the resistance to biodegradation at the end of useful life.

The process is temperature dependent and some plastics labelled as 'biodegradable' require the conditions that typically occur in industrial compositing units, with prolonged temperatures of above 50°C, to be completely broken down. Such conditions are rarely if ever met in the marine environment.(p.3)

This is correct in relation to plastics described as "compostable" and is the reason why they are not useful for dealing with the problem of plastic litter in the open environment. See also http://www.biodeg.org/wp-content/uploads/2019/04/opa-19-reasons-why.pdf

By contrast, the biodegradation of oxo-biodegradable plastic needs only oxygen and bacteria, which are abundant in the open environment. Heat and UV light will accelerate the process but they are not essential.

"Some common non-biodegradable polymers, such as polyethylene, are manufactured with a metal-based additive that results in more rapid fragmentation (oxo-degradable). This will increase the rate of microplastic formation but there is a lack of independent scientific evidence that biodegradation will occur any more rapidly than unmodified polyethylene.(p.3)

In the case of oxo-biodegradable plastics, complete breakdown of the polymer and biodegradation have been proved many times in published scientific work, before and since publication of the UNEP report. For example, Jakubowicz, Yarahmadi, & Arthurson (2011) demonstrated that degraded polyethylene made with a prodegradant catalyst showed more than 90% mineralisation in two years in standardised conditions designed and accepted to simulate soil conditions (ASTM 17556). This has also been demonstrated by Eurofins laboratory in Spain. Eyheraguibel et al., (2017) demonstrate rapid and near-complete (90%) biodegradation of the end-products of degradation.

It should be noted that in laboratory experiments, degradation is completed prior to beginning the biodegradation test; whereas in nature biodegradation of sufficiently degraded material would be expected to occur simultaneously and therefore to proceed more rapidly.

Before total biodegradation, the partially degraded polymer is identical to the conventional polymer which the oxo-biodegradable plastic has replaced, but it is likely that degradation has proceeded much more rapidly and to a greater extent, leading to a greater proportional conversion to biodegradable materials. Independent scientific evidence is now available, as cited in this commentary, proving beyond doubt that oxo-biodegradable plastic will become biodegradable much more rapidly than unmodified polyethylene.

It is well understood that conventional plastics undergo rapid degradation in the environment, particularly if exposed to sunlight (Gewert, Plassmann, & MacLeod, 2015), but fragmentation of conventional polymers occurs at a relatively high molecular weight (Andrady, 2011). It was found by Ter Halle et al. (2017) that fragmented plastic particles collected from the open environment demonstrated average molecular weights between 140,000 and 70,000 g mol-1 – much too high to be biodegradable.

It is well established that the reduction of molecular weight of even conventional plastics does result in increased biodegradability, but conventional plastics will take much longer to become biodegradable, and biodegradation is therefore enhanced when molecular weight reduction is promoted by use of a prodegradant catalyst. Jakubowicz (2003) found that, following oxidation and molecular weight reduction, polyethylene films containing a manganese-based prodegradant catalyst showed 60% mineralisation; similarly Chiellini et al (2003) observed 50-60% bioassimilation of oxidised prodegradant-containing LDPE films. Weiland, Daro, & David (1995) demonstrate increased microbial colonisation with reduced molecular weight.

Arráez et al (2018) demonstrated that the inclusion of a prodegradant additive induced oxidative degradation in both amorphous and crystalline regions of polypropylene film, but conventional polypropylene without the catalyst showed no degradation sufficient to enable biodegradation.

Eyheraguibel et al., (2017) characterised the water-soluble fraction of a degraded oxo-biodegradable plastic and identified a range a short chain compounds with a molecular weight between 105 and 850 Da, consisting of a maximum of 55 carbons and between 0-10 oxygens. This showed 95% biodegradation in 240 days.

The timescale for biodegradation of plastic depends upon how quickly the material degrades abiotically (by oxidation) so as to become biodegradable, and it is well established that the use of a prodegradant catalyst accelerates the rate of abiotic degradation. Chiellini, Corti, D'Antone, & Baciu (2006) demonstrate the action of a prodegradant additive in inducing the oxidative degradation of the polyethylene carbon back-bone, resulting in molecular weight reduction.

Exposure of plastic samples in natural seawater by Dussud et al (2018) demonstrated that the oxidation and increased hydrophilicity caused by the prodegradant catalyst significantly increases the ability of microorganisms to colonise the plastic material - concluding that that the change created by the additive not only increases the ability of the organisms to populate the surface, but also increases the polymer's ability to act as a source of nutrition for the microorganisms. Rose (2019) demonstrated that molecular-weight reduction caused by the prodegradant catalyst resulted in up to 90 times more mineralisation compared to ordinary plastic aged for the same period.

As indicated above, conventional plastics rapidly degrade until the point of fragmentation, but if those fragments, which still possess a relatively high molecular weight, are occluded from sunlight, the degradation slows or stops (Gewert et al., 2015) – This is a major reason why microplastics formed from the erosion of conventional plastics remain persistent for so many decades.

By contrast, in addition to accelerating the rate of abiotic degradation, the use of a prodegradant catalyst in oxo-biodegradable plastics enables degradation and molecular weight reduction to continue (Vogt & Kleppe, 2009) after they are removed from sunlight. In fact such performance is a specific requirement of the French standard for oxo-biodegradable plastics AFNOR AC T51-808.

A further disadvantage of the more widespread adoption of 'biodegradable' plastics is the need to separate them from the non-biodegradable waste streams for plastic recycling to avoid compromising the quality of the final product.(p.3)

This is correct for bio-based "compostable" plastics, but confusion is caused by the author's failure to distinguish between these plastics and oxo-biodegradable plastics, which can be safely recycled. See below under 3.4

In addition, there is some albeit limited evidence to suggest that labelling a product as 'biodegradable' will result in a greater inclination to litter on the part of the public. (p.3)

It is often claimed that biodegradable plastics are likely to encourage littering, but this is mere speculation, and is rarely advanced as an objection to bio-based plastics. The Eunomia Report says, "rather than speculation, objective behavioural research is required to move this topic forward in a constructive manner."

Even if there were a label describing a product as oxo-biodegradable, it is unlikely that the people who cause litter will look for the label before deciding to throw a plastic item out of a car window. Further, even if it were true that biodegradability encourages littering, and supposing that there would be 10% more litter - is it preferable to have 110 plastic items in the environment which will degrade and biodegrade in a few years or even months, or 100 plastic items which will lie or float around for decades?

It is not acceptable to continue debating this speculative proposition any longer, while thousands of tonnes of conventional plastic are getting into the environment every day, which will undoubtedly accumulate and pollute the environment for decades into the future. New plastic products need to be urgently upgraded with oxo-biodegradable technology.

A Life-cycle Assessment by Intertek shows that when the litter metric is included OBP is actually the best material for making carrier bags. See http://www.biodeg.org/New%20LCA%20by%20Intertek%20%20-%20Final%20Report%2015.5.12(1)%20(1).pdf

In conclusion, the adoption of plastic products labelled as 'biodegradable' will not bring about a significant decrease either in the quantity of plastic entering the ocean or the risk of physical and chemical impacts on the marine environment, on the balance of current scientific evidence.(p.3)

This conclusion is not correct. Nobody is suggesting that the adoption of plastic products labelled as 'biodegradable' will bring about a significant decrease in the quantity of plastic entering the ocean. This depends on consumer behaviour and on more effective waste-management.

As to the risk of physical and chemical impacts on the marine environment, it has been demonstrated beyond doubt that oxo-biodegradable plastic will become biodegradable much more quickly than ordinary plastic without causing any toxicity. The main benefit is the reduced dwell-time in the environment, so that the plastic may never get into the sea at all, or if it does it will remain there for a very much shorter time, thereby reducing the opportunity for wildlife to come into contact with it. As the UNEP report says at p.6 *"The environmental impact of discarded plastics is correlated with the time taken for complete breakdown of the polymer."*

Environmental biodegradation is the partial or complete breakdown of a polymer as a result of microbial activity, into CO2, H2O and biomasses, as a result of a combination of hydrolysis, photodegradation and microbial action (enzyme secretion and within-cell processes).(p.6). "Biodegradable plastics are polymers that are capable of being broken down quite readily by hydrolysis."(3.3)

This is correct in relation to "compostable" plastics which degrade by hydrolysis, but not in relation to oxo-biodegradable plastics, which degrade by oxidation.

A material may be labelled 'biodegradable' if it conforms to certain national or regional standards that apply to industrial composters.(p.6) and "If a products is marketed as biodegradable it should conform to a recognised standard defining compostability, for example ASTM 6400 (USA) , EN 13432 (European) or ISO 17088 (International) (p.19).

“Biodegradable” is not the same as “Compostable.” Again, the author confuses plastics which are designed to biodegrade in the special conditions found in industrial composting, and those which are designed to biodegrade if they get into the open environment as litter. The correct Standard for oxo-biodegradable plastic is ASTM D6954, but it is not mentioned in the Report.

“Some items, such as plastic shopping bags supplied for groceries, may be labelled as ‘biodegradable’. However, it is quite possible that the item will only degrade appreciably in an industrial composter. Such polymers will not ‘biodegrade’ in domestic compost heaps or if left to litter the environment.”

This is correct in relation to “compostable” plastic.

Definitions Page 10, Table 2.1, and p22 para. 3.4

The Report is correct that “There is great scope for confusion in the terminology surrounding ‘plastic’ and its behaviour in the environment.” Unfortunately this report adds to the confusion.

“Oxo-degradation” is defined by CEN in TR15351 as “degradation identified as resulting from oxidative cleavage of macromolecules.” This describes ordinary plastics, which do not normally contain prodegradant additives, but will nevertheless rapidly degrade on exposure to sunlight. They do not however become biodegradable except over a very long period of time.

“Oxo-biodegradation” is not defined in the UNEP paper, but is defined by CEN as “degradation resulting from oxidative and cell-mediated phenomena, either simultaneously or successively.”

Authors should stop using the terms “oxo-degradable” or “biodegradable” plastics when they are actually referring to oxo-biodegradable plastics.

3.1 The degradation process

Fragmentation and biodegradation proceeds through a combination of photo- (UV) and thermal-oxidation and microbial activity. In the marine environment UV radiation is the dominant weathering process. It causes embrittlement, cracking and fragmentation, leading to the production of microplastics (Andrady 2011). This means that fragmentation is greatest when debris is directly exposed to UV radiation on shorelines. Higher temperatures and oxygen levels both increase the rate of fragmentation, as does mechanical abrasion (e.g. wave action). Once plastics become buried in sediment, submerged in water or covered in organic and inorganic films (which happens readily in seawater) then the rate of fragmentation decreases rapidly.

This is a correct description of the degradation of ordinary plastics, and this is why there is so much pollution of the oceans by microplastics. However, the author fails to understand the fundamental property of polymers which is responsible for both fragmentation and biodegradability, namely molecular weight (ter Halle et al., 2017; Rose et al., 2019).

In oxo-biodegradable plastics a prodegradant catalyst is used to not only accelerate the reduction in molecular-weight, but also to remove dependence on sunlight (Vogt & Kleppe, 2009) so that unlike conventional plastics the reduction may continue in all conditions, and render the material biodegradable in a much shorter time.

3.4 Oxo-degradable plastics p22

These are conventional polymers, such as polyethylene, which have had a metal compound (e.g. manganese) added to act as a catalyst, or pro-oxidant, to increase the rate of initial oxidation and fragmentation (Chiellini et al. 2006). They are sometimes referred to as oxy-biodegradable or oxo-degradable. Initial degradation may result in the production of many small fragments (i.e. microplastics), but the eventual fate of these is poorly understood (Eubeler et al. 2010, Thomas et al. 2010).

As indicated above, oxo-degradable plastics do not normally contain a catalyst or pro-oxidant, and it is true that they result in the production of many small fragments (i.e. microplastics). This is the reason why oxo-biodegradable plastic was invented. The eventual fate of oxo-biodegradable plastic is well understood. See above.

Nobody would want to sell or buy oxo-biodegradable plastics if all they did was to create fragments of plastic, but this is not the case. The oxo-biodegradation process is described by Professor Ignacy Jukubowicz as follows:[1] "The degradation process is not only a fragmentation, but is an entire change of the material from a high molecular weight polymer, to monomeric and oligomeric fragments, and from hydrocarbon molecules to oxygen-containing molecules which can be bioassimilated."

Eubeler et al (2010) incorrectly classify Oxo-biodegradable as "polyolefin polymers that have predetermined breaking points inserted into the polymer backbone by carbonyl groups" confusing them with certain types of degradable fragmentable plastics such as polyethylene carbon monoxide copolymers which are an early form of degradable plastics specifically engineered to fragment in the environment. However, unlike oxo-biodegradable plastics which use a catalyst to bring about chain cleavage, their degree of molecular weight reduction in the environment is limited to the location and number of functional groups added at extrusion and so cannot proceed to full biodegradation.

Thomas et al. (2010) confirm that biodegradation of oxo-biodegradable plastics can occur after fragmentation. A large body of work done before and since 2015 and referred to in this commentary, demonstrates the reduced molecular weight and increased biodegradability of oxo-biodegradable plastics, compared to the equivalent conventional plastics. Thomas et al. (2010) concede that oxo-biodegradable plastics will degrade in 2-5 years; which is a much shorter time frame that it is expected for conventional plastics to degrade, and presents a significant advantage over normal plastics which they are intended to replace.

As with all forms of degradation the rate and degree of fragmentation and utilisation by microorganisms will be dependent on the surrounding environment. There appears to be no convincing published evidence that oxo-degradable plastics do mineralise completely in the environment, except under industrial composting conditions.

1 http://www.biodeg.org/Reply%20to%20Ellen%20MacArthur%20Foundation%20from%20Prof%20Ignacy%20Jakubowicz%20-%2021-8-17.pdf

Industrial composting conditions do not occur in the open environment, and "compostable" plastics must therefore be collected and taken to an industrial composting unit. For this reason "compostable" plastics do not address the problem of plastic litter in the open environment.

However, as indicated above, published evidence does exist to prove that oxo-biodegradable plastics do biodegrade completely under conditions expected in the open environment. This is not the same as saying that they completely mineralise (ie convert completely to CO2), because some of the carbon is sequestered by the microorganisms for their own metabolism.

The biodegradability of the products of abiotic degradation is studied in the laboratory in order to demonstrate that the material is biodegradable, and mineralisation is used as an indicator of biodegradation. Mineralisation has been demonstrated in both thermophilic composting (Jakubowicz, 2003; 60% biodegradation and increasing after 180 days) and also mesophilic soil biodegradation conditions (Jakubowicz et al., 2011; 91% mineralisation in two years) confirming bioassimilation of the polymer.

The mechanism and products of degradation of an oxo-biodegradable plastic material are identical to an equivalent conventional plastic material, therefore until complete biodegradation is achieved the impact and residues can be no worse than in the case of a conventional plastic product. However by incorporating a prodegradant additive the extent of molecular weight reduction and the corresponding biodegradable proportion will be much greater than for an equivalent conventional plastic product, resulting in a reduction of plastic or microplastic litter in the environment.

The use of a catalyst will invariably tend to restrict the applications the plastic can be used for as it will alter the mechanical properties.

Prior to the onset of degradation and for the duration of the product's intended useful-life, an oxo-biodegradable plastic product retains identical mechanical properties to the equivalent conventional product.

The recommended solutions for dealing with end-of-life oxo-degradable plastics were incineration (first choice) or landfill. In addition, the authors observed that: '... as the [oxo-degradable] plastics will not degrade for approximately 2-5 years, they will still remain visible as litter before they start to degrade'. (Thomas et al. 2010)

Of course a plastic product will remain visible until it has completely degraded, but the choice is between ordinary plastic which takes many decades to degrade, or oxo-biodegradable plastic which will have biodegraded and returned to nature in a few years.

Oxo-biodegradable products are not intended to be littered and, unlike compostable plastics, degradation is not their intended disposal route. Oxo-biodegradable plastics are specifically designed to remain stable in storage, and for a pre-determined time in use, in order to facilitate reuse and proper disposal, which are preferred. The purpose of using a prodegradant additive is so that if the product is accidentally or deliberately littered and is not collected, it will degrade and become biodegradable in the environment in a period of time very much shorter than the equivalent plastic material, which may take many decades to degrade.

The rate of degradation will depend on the specific disposal conditions, however it is certain that for any given condition in the open environment, an oxo-biodegradable product will degrade and become biodegradable in a much shorter time frame than the equivalent conventional plastic which it has replaced.

Plastics containing pro-oxidants are not recommended for recycling as they have the potential to compromise the utility of recycled plastics (Hornitschek 2012).

TCKT (the organisation who performed the Hornitschek 2012 work) subsequently reported on the performance of LDPE films incorporated with various levels of oxo-biodegradable recyclate, and found that they could be safely recycled with ordinary plastic. A similar conclusion was reached by Roediger laboratories in South Africa. See http://www.biodeg.org/recycling-and-waste/

Oxo-biodegradable plastic products can therefore be recycled, but in practice they are short-life disposable products such as packaging, drinking straws etc. It does not normally make sense in economic and environmental terms to recycle them, and conventional versions of these products are instead being dumped in forests. Oxo-biodegradable plastic can nevertheless by recycled if so desired.

There has been debate on the need for legislation to control the marketing of products made with oxo-degradable polymers in the state of California and within the European Union.

California has not banned the sale of oxo-biodegradable plastic products.

The European Commission acted under Article 69 of the REACH Regulation to ask the European Chemicals Agency (ECHA) to study what they called "oxo-degradable" plastics, because the Commission thought that they created microplastics, but on 30th October 2018 (ten months into the study) ECHA advised that they were not yet convinced that microplastics were formed. The Commission then terminated ECHA's enquiry.

If, and only if, ECHA had recommended a restriction, supported by a scientific dossier under Annex XV, it would have had to be considered by two committees under Articles 70 and 71, and there would have had to be a public consultation under Art 71(1), before any restriction could be proposed under Art. 73. None of this has been done, and there is no scientific justification from the EU's own scientific experts for any restriction.

4.2 Biodegradable plastics in the marine environment will behave quite differently than in a terrestrial setting (soil, landfill, composter) as the conditions required for rapid biodegradation are unlikely to occur. (p.25)

This is not correct. Oxo-biodegradable technology is used in PE, PP and PS, which have a specific gravity of less than 1, and they will therefore float on the surface, where oxygen and bacteria are abundant. If these are present then oxo-biodegradation will occur. They are also likely to be exposed to sunlight, which will accelerate the abiotic process but is not essential.

According to Dr. Jean-François Ghiglione "OBP will float and be at almost all times subjected to UV light, which accelerates the abiotic phase of degradation. This is not always the case on land, where plastic pieces are often covered by soil, leaves etc. and are less exposed to UV light." He points out that "there are specific bacteria living in the "seasurface microlayer" (the top millimetre of the ocean surface), where bacteria are different from those further below the surface. The bacteria in the sea-surface microlayer are particularly adapted to a hydrophobic environment (e.g. where oil materials are floating) and these bacteria are known to present a high capability for hydrocarbon degradation. These bacteria are therefore potential OBP-degraders, and such an environment does not exist at the surface of soil. These bacteria are probably less abundant and less diverse in the ocean than in soil, but probably more effective to degrade OBP."

"Some marine bacteria, such as Alcanivorax borkumensis and R. rhodochorous are noted for their ability to biodegrade hydrocarbons and they are ubiquitous in the oceans. They occur in low concentrations in unpolluted seas but are observed to accumulate in waters polluted by oil spills. When presented with a source of carbon which is recognisable to the microorganisms as food, it seems therefore that they will respond with increased populations. The relatively low concentrations of microorganisms found in unpolluted oceans is not therefore a reason for expecting slow biodegradation of OBP."

Evidence is available - from tests done in real time at Bandol on the coast of France that OBP will degrade to low molecular-weight materials under natural conditions in water, and samples aged under those conditions were studied in 2016 at Queen Mary University London where the abiotically degraded plastic was presented as the only source of carbon available to the bacteria. The samples were proved to be biodegraded by bacteria commonly found in the oceans, and separate samples were biodegraded by bacteria commonly found on land. The degraded plastic was also proved to be non-toxic to those bacteria.

Interactions with species p26
Perhaps the most relevant study examined the degradation of plastic carrier bags in gastrointestinal fluids of two species of sea turtle: the herbivore Green turtle (Chelonia mydas) and carnivore Loggerhead turtle (Caretta caretta) (Műller et al. 2012). Fluids were collected from the stomach, the small intestine and large intestine of freshly dead specimens. Three types of polymer were used: conventional HDPE, oxo-degradable, and a biodegradable PBAT/Starch blend (Mater-Bi™). Changes in polymer mass were measured over 49 days (standard test procedure) after which weight losses were as follows: HDPE – negligible, oxodegradable – negligible, and biodegradable – 4.5 – 8.5%. This is much slower that the degradation rates claimed by the manufacturers for industrial composting. The study demonstrated that degradation of plastic was much slower than for normal dietary items. The lower rate of degradation in the Loggerhead may be due to differences in diet and associated enzyme activity.

This study is irrelevant to oxo-biodegradable plastic, because the benefit to creatures in the terrestrial and marine environments is the reduced dwell-time of plastic litter in the environment and the reduction in the concentration of plastic, thus reducing the probability of interactions with wildlife.

Biodegradable polymers tend to be significantly more expensive. Their adoption, in place of lower-cost alternatives, for well-justified purposes (e.g. key components of a fishing trap) may require financial inducement.(p.31)

This is not the case with oxo-biodegradable plastic products, which can be made by existing factories at little or no extra cost.

On the balance of the available evidence, biodegradable plastics will not play a significant role in reducing marine litter.(p.31)

For the reasons set out above, this conclusion does not apply to oxo-biodegradable plastics.

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