DEFRA Report EV0422: Assessing the Environmental Impacts of Oxo-degradable Plastics Across their Life Cycle

Reply to the Response by the Oxo-degradable Industry

A report prepared for the Department for Environment, Food and Rural Affairs by Loughborough University

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Introduction

This report has been prepared by the authors of the DEFRA Report EV0422 ***Assessing the Environmental Impacts of Oxo-degradable Plastics Across their Life Cycle*** on behalf of DEFRA to reply to comments made by the Oxo-degradable industry. The principal UK producers of oxo-degradable plastics have raised various issues in a response report consolidated by the British Plastics Federation. These issues will be addressed under the various headings in which they appear in the response document – namely:-

- Mechanism of Oxidation
- Oxidation Products and their Biodegradability
- Timescale of Oxidative Breakdown
- Biodegradation studies
- Toxicity / Toxicological Impact
- Persistence in the Soil / Bio-accumulation
- Recyclability
- Conclusions

A number of miscellaneous comments are responded to in Annex 1.

Mechanism of Oxidation

The response document makes the following statement about the summary of the oxidation mechanism given in the DEFRA Report; *"whilst broadly correct, the summary is deficient in some ways and shows the fundamental lack of familiarity with the details of polyolefin oxidation which characterises much of the report."* However, in the paragraphs that follow the only specific criticism is that *" the statement in the DEFRA report, that transition metals do not catalyse the initial cleavage of the polymer chain, is perfectly correct but wholly irrelevant".* The statement given in the DEFRA report was part of the explanation of the oxidation mechanism and is relevant to readers not already familiar with the mechanism.

In the DEFRA report it is not disputed that oxo-degradable additives accelerate the degradation of polyolefins. In the response document it is stated that "*there appears to be no real need for us to present more evidence that the oxidation catalysts used in OBD technology do indeed function to accelerate the normal degradation processes*". Nevertheless, numerous studies are then cited to show that polyethylene films containing oxo-degradable additives degrade to lower molecular weight as a result of thermal or UV irradiation. The point is also made that oxidised PE has a significantly increased carbonyl content – as evidenced by the carbonyl index in FTIR. Again, this was not disputed in the DEFRA report.

Oxidation Products and their Biodegradability

The response document states that: *"in Annex 1 of the DEFRA report it is stated that 'it is claimed that the species RO. can lead to the production of biodegradable intermediates'. This is far more than a claim. It is a fact supported by large amounts of robust experimental evidence."* Some additional evidence is presented and discussed in Annex A2 of the response document. However, it is questionable to what extent evidence put forward to support biodegradability can be described as *robust* given that all studies require extensive accelerated aging of the oxo-degradable plastic films, either by exposure to ultra-violet light or to heat (50ºC - 70ºC), to accelerate the degradation process before biodegradation studies are carried out. As discussed in more detail below, it is very difficult to tell how such artificial weathering regimes correlate to actual environmental conditions.

The response document refers to studies showing that the low molecular weight species produced from accelerated oxidation of oxo-degradable plastics can be dissolved in acetone. This is not unexpected.

Chiellini and co-workers have developed this methodology further and have used the materials extracted in acetone to carry out biodegradability tests. For example, in one study (1) biodegradation of 48% after 90 days at room temperature was reported for a sample extracted with boiling acetone after thermal pre-treatment of oxo-degradable plastic. The equivalent biodegradation for the pre-oxidised film was only around 10%. This was discussed in the DEFRA report. This result indicates that it is the low molecular weight fractions of the degraded polymer that are biodegrading but cannot be described as *robust* evidence because it is not the biodegradability of the whole oxidised sample.

In the response document there is a graph (attributed to Chiellini – personal communication 2010) showing that the acetone extract of an oxidised oxodegradable PE reached 80% mineralisation in 480 days of soil burial at 25°C. This was compared favourably with cellulose as being biodegradable. However, the film itself showed much slower and lower levels of mineralisation, with only about 60% mineralisation being reached after 2 years of soil burial at 25°C, following on from the initial oxidation at elevated temperature.

With regard to biodegradation studies on fractions of pre-oxidised oxo-degradable plastic that have been extracted by dissolving in acetone, Eubeler et al (2) have commented on another study (3) in which this methodology was used. It is stated that: "*almost no biodegradation was observed with the films (below 10%). Only the acetone extractable fractions showed some* CO_2 *evolution, which may also be caused by the remaining acetone*."

Timescale of Oxidative Breakdown

The oxo-degradable industry response raises the following issues with respect to the DEFRA report:-

(i) It is stated that '*there are good reasons for believing that OBD materials can be made to degrade in shorter times than those criticised by the report's authors as unacceptably long*'.

(ii) It is suggested that a synergistic effect between oxidation and biodegradation should be considered. They state that '*another factor is that oven ageing tests ignore the synergism between oxidation and biodegradation in the real world.*'

(i) In our report it is recognised that the timescale of degradation can be controlled provided that the environmental conditions are also known, but when the plastics are in the environment, where conditions are neither controlled nor known, timescales of degradation cannot be defined. It is stated that: "*according to the additive producers, the time scale over which these materials degrade can be tailored according to the amount of additive in the formulation, particularly the active ingredient. Tests carried out under controlled conditions show this to be the case. However, the exact environment in which the product may end-up cannot be controlled, and so specific claims as to the time and extent of degradability cannot be justified.*" Therefore, although it may be possible to formulate a plastic that will degrade more quickly than the 2 to 5 years, this would have to be balanced against the requirement of a useful functional lifetime. The problem remains that the environmental conditions prevailing in the real world where the plastic ends up cannot be known accurately, consequently giving a wide range of possible lifetimes. The range of these lifetimes is discussed below with reference to the examples given in the response document and the papers published since the DEFRA report was released.

The examples given in the response document to support the idea that rapid breakdown is possible are Ojeda's study (4) and that of Jakabowicz (5). The rapid breakdown that was observed in Ojeda's study was in a sub-tropical climate with samples exposed at 30° inclination to the ground facing the equator. This is a much more extreme exposure to solar radiation compared with what might be expected in the UK, where there would be a much slower rate of breakdown, even if the plastic was out in the open exposed to the sun. If the plastics were buried, then solar radiation would not contribute to the degradation process and only thermal oxidative degradation would occur, which is not discussed in this paper.

The short life-times to oxidative failure of 65 to 330 days, taken from the Jakabowicz study, are for time taken to reach to 50 or 5% of the original elongation at break. Hence, although the plastics are no longer functional they must still be substantially whole in order for them to have been subjected to tensile testing. The time that the plastic would take to fragment would be much longer than these times for mechanical failure.

From the papers published more recently there are examples of rates of degradation measured at elevated temperatures being used to predict life-times at ambient temperatures. Use of the Arrhenius equation to make quantitative predictions of timescales of degradation at ambient temperatures relies on the assumption that it is valid to extrapolate the Arrhenius relationship over the whole range of temperatures because the same degradation mechanism applies i.e. it assumes a linear relationship over the whole temperature range. However, the Arrhenius plot (Figure 2) in the paper by Jakubowicz (5) clearly shows non-linear behaviour (curvature) and this is discussed in the paper. It is stated that "*it is well known that degradation of PE is caused by a number of different reactions. In the early stage of oxidation, hydroperoxides are formed and decomposed to alkoxy and hydroxy radicals. This reaction requires considerable activation energy, thus the rate increases with increasing temperature and is further accelerated by prodegradants. When the material is heavily oxidized, many other reactions occur simultaneously, including termination reactions, which is a plausible explanation for the non-Arrhenius behaviour".* The data in the Arrhenius plot show steepening of the curves at lower temperatures. This indicates that if activation energies determined using the higher temperature data are used to predict degradation rates at lower temperatures, an underestimate of the degradation time will result. Hence, if it is assumed that the Arrhenius relationship is linear across the whole range of temperatures, then **minimum** degradation times would be estimated.

Another important point about the use of the Arrhenius equation for oxo-degradable plastics is that it is used to predict times to degradation at ambient or room temperature i.e. 23°C or 20° C . This is the temperature of the laboratory but not the average outdoor temperature of northern European countries, such as the UK. According to the Met Office (6) the mean annual temperature over most of the UK is 10°C or less. Hence this would be a more realistic temperature to take when using the Arrhenius equation to estimate degradation times of plastics in the environment. We have used this temperature to recalculate some of the Arrhenius predictions cited in the response document, as discussed below.

For example, using an activation energy of 100 kJ/mol, Fontanella et al (7) estimated an equivalent degradation time of 2-3 years at room temperature for their oxidative treatment of 300 h at 60°C. However, using the same activation energy, the estimated equivalent aging time at 10°C is 20 years. In Jakubowicz paper (5), the treatment of 10 days at 65°C that brought about a reduction in molecular weight to 8800, would be equivalent to about 9 years at 10°C (using their value of 84 kJ/mol for the activation energy). The treatment in Husarova's paper (8) of 40 days at 70°C would be equivalent to 60 years at 10°C (using an activation energy of 85 kJ/mol). While, using the same activation energy, the 44 days at 55°C reported in Chiellini's paper (9) would be equivalent to about 16 years at 10°C. In most cases these heat treatments are carried out as a precursor to biodegradation studies, indicating that until this level of degradation is reached, the authors of these papers do not expect significant levels of biodegradation to occur. This emphasises the point that the degrading plastic will be present in the environment for many years, either as pieces of film or as a particulate solid.

(ii) The response document refers to work by Corti et al. (10) in which pre-oxidised plastic was exposed to a biotic environment and then thermally oxidised a second time. They found that the carbonyl index of the biotically treated pre-oxidised sample increased at about a 20% higher rate than the oxidised sample that had not undergone biotic treatment. There was no indication what effect this treatment had on the rate or extent of mineralization, and there is no evidence relating to biodegradation in a natural environment.

The study carried out at Chiellini's laboratory (annex 2#5 in the response document) showed greater mineralisation for a sample that had been both thermally treated and incubated with an organism (S.griseus), however the pre-treatment conditions with the organism were not given. With biological pre-treatment being carried out before a second thermal or biodegradation treatment there is a significant risk that the polymer will have a biofilm on the surface which will affect the following treatment stage. Neither paper nor report indicates whether a biofilm was removed from the plastic. For this reason and the fact that the sequential lab-based experiments carried out are far from realistic, it is not clear that there would be a synergistic interaction between oxidation and biodegradation "*in the real-world*".

Biodegradation studies

The oxo-degradable industry response criticises the DEFRA report because:-

(i) They allege that '*one false impression that permeates much of the report is that biodegradability and compostability are the same thing'*.

(ii) They cite results from a recently published paper asserting that '*it is possible to create LDPE based materials that will almost completely biodegrade in soil within two years'.* They then claim that *'it is perfectly possible to produce commercial materials which oxidise and mineralise in acceptable timeframes'.*

(i) This is untrue. In our report we clearly explain the difference between biodegradability and compostability in section 1.4 (pages 8 and 9). It is stated that *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”.* Whereas *a* ***compostable*** *plastic is defined by the ASTM D 6400 standard as: “a plastic that undergoes degradation by biological processes during composting to yield CO_2, water, inorganic compounds and biomass at a rate consistent with other known compostable materials and leaves no visible, distinguishable or toxic waste”. Composting is defined in the British standard PAS 100:2005 “Specification for Composted Materials” as a “process of controlled biological decomposition of biodegradable materials under managed conditions that are predominantly aerobic and that allow the development of thermophilic temperatures as a result of biologically produced heat”.*

It was clearly stated in the DEFRA report that oxo-degradable plastics were not claimed to be compostable. However, there was a genuine concern expressed by stakeholders that oxo-degradable plastics would enter the composting stream and this was one of the reasons for considering compostability in the report. We note that in their response, the oxo-degradable industry state that no reputable manufacturer makes claims of compostability for OBD plastics. Certainly, that should be the case because it would be wrong and misleading for manufacturers to state that these plastics are compostable.

In the DEFRA report we point out that that labelling of oxo-degradable plastics as biodegradable may lead to confusion on the part of consumers and lead to possible contamination of the composting waste-stream with oxo-degradable plastics. This has in fact happened at a composting facility in the UK when oxo-degradable bags were used for collection of garden waste (11). The resulting compost did not pass the criteria of PAS100 and was therefore rejected for use as compost. The rejected compost and oversize bag fragments had to be consigned to landfill at considerable cost. The composting facility subsequently changed their policy to allow only certified ‘compostable’ bags and since then have not had any recurrence of the problem.

The other reason for considering the composting process was that it is a relatively rapid biodegradation process carried out under standard conditions.

As a matter of fact, examples given in the response document include studies carried out in controlled composting environments (annex 2#7 and 8). These studies all required pre-oxidation of the OBD plastics before mineralisation could be achieved.

(ii) Because they are not compostable and they are not permitted for use as mulch films by the Environment Agency, the most likely disposal route for oxo-degradable plastics in the UK, apart from landfill, is as litter. In fact oxo-degradable plastics are generally promoted as a solution to the litter problem. Hence in the response document there is a focus on a particular paper by Jakubowicz et al (5), which is claimed to show that biodegradation of an oxidised oxo-degradable plastic in soil at 23°C was quicker than in compost at 58°C and that it is possible to create LDPE materials that will almost completely biodegrade in soil within two years. This study was financed by P-Life Japan Inc, an oxo-degradable additive manufacturer.

In this study, as in virtually all studies on biodegradation of oxo-degradable plastics, artificial aging of the sample was carried out before biodegradation studies were commenced in order to reduce the molecular weight of the polymer. It is unclear to what extent such accelerated weathering regimes correspond to or can be correlated with the conditions actually experienced in the environment.

During the subsequent biodegradation studies, it was found that in soil at 23°C there was initially a very slow rate of degradation for the first 300 days (reaching less than 10% mineralisation) followed by a greater rate of mineralisation for the following year. The final level of mineralisation after 2 years at 23°C was high, about 90%. It is then claimed that that '*it is possible to create LDPE based materials that will almost completely biodegrade in soil within two years'.* The assertion by the oxo-degradable plastics producers that these experimental results prove that oxo-degradable plastics can biodegrade in soil in the environment in acceptable timescales is mistaken. They fail to point out that these biodegradation studies were carried out in a laboratory at a constant temperature of 23°C, which is a temperature much higher than the average annual temperature of countries such as the UK. They also fail to acknowledge that the samples used for these trials had already experienced an accelerated aging regime to oxidise the plastic and reduce its molecular weight from 131,500 to 8,800 before the start of the trials. How long this process would take under genuine field conditions is not addressed. However, as discussed above, using the Arrhenius extrapolation method advocated in the paper, at an annual average temperature of 10°C this time would be about 9 years.

Toxicity / Toxicological Impact

In our report we found no evidence of a toxicological impact of oxo-degradable additives. The claims made by the additive producers that the transition metals used are present in such small quantities as not to significantly increase the metal ion concentration already in the soil seems reasonable. Also there was no evidence that compost containing oxo-degradable polyethylene had an adverse effect on the growth and germination of seeds. Hence it is unnecessary to make further comment on this section.

Persistence in the Soil / Bio-accumulation

In this section the oxo-degradable additive manufacturers criticise our report because we discuss concerns that have been raised regarding what happens to the degraded plastic fragments in the soil. They also revert to discussing the toxicity of the additives and the effects of transition metals in the soil – but this was already dealt with in the previous section, so will not be further discussed here.

Specific criticisms by the oxo-degradable industry of our report are the following:-

(i) they allege that we "*argue (incorrectly) that the oxidised fragments of ODB plastics will stop degrading/biodegrading and persist in soil or water, or that the particles which have oxidised but not yet mineralised are a hazard".*

(ii) they maintain that we speculate "*that fragments of OBD plastics are harmful in the environment because they will blow around in the wind, adsorb pesticides or wash out into rivers or the sea".*

(i) In our report we highlight concerns that have been raised regarding what happens to the degraded fragments of plastic in the soil. We refer to a study by Feuilloley et. al. (12), who retrieved numerous polyethylene fragments from soil to which an oxo-degradable polyethylene mulch had been applied two years previously. These fragments were found to be insoluble in hot xylene (90°C) and this was taken as strong evidence that the polyethylene had become cross-linked due to the degradation process and would therefore persist in the soil. The oxo-degradable plastic used in this trial had not been previously exposed to either UV light or high temperatures. The authors concluded that "*a very low degree of biodegradation of the commercial PE films is achieved"* and that "*cross-linked PE micro-fragments are found in soil after a very long period of time"*.

Further evidence in our report for cross-linking is given by a study (13) in which photodegradable polyethylene samples were exposed to sunlight for 6 and 12 weeks before being subjected to biodegradation testing. The results indicated that the biodegradation of the 12-week sample was significantly lower than that of the unexposed sample and the 6-week sample, suggesting that the longer exposure to sunlight had made the material less biodegradable rather than more.

Counter evidence is presented by the oxo-degradable industry relying on a recent study undertaken by Chiellini (Annex 2 #5) in which oxo-degradable polyethylene was first thermally degraded and then subjected to a soil burial test. At the end of the test boiling xylene was used to extract the remaining polyethylene fragments from the soil and it was reported that only small traces, if any, could be found. This was taken as evidence that no residues remained. However, as reported above, if the polyethylene fragments had become crosslinked, then they would not have been soluble in the xylene in any case.

In a recent publication in Environmental Science & Technology (14), the authors point out "*that usually, laboratory experiments for investigating degradation are performed in air ovens, where possibility of cross-linking is reduced. However, the actual field conditions may be completely different, resulting in formation of larger amount of cross-linked polymers".*

Another recent paper (2) has examined the environmental biodegradation of synthetic polymers and discussed the paucity of evidence for the biodegradation of oxo-degradable PE. The authors conclude that "*as no evidence on real biodegradation is available, oxo-degradables should be used carefully because the fragments may accumulate in the environment".*

(ii) Nowhere in our report do we say that fragments of degraded oxo-degradable plastic "*will blow around in the wind".* However, we do point out that these fragments may become mistaken for food and become ingested by earthworms, other insects, birds or animals. It is also possible that they may enter watercourses or end up in the marine environment and become ingested by marine organisms, fish or birds.

There is evidence that fragments of plastic can be ingested by a range of marine organisms, such as amphipods, lugworms, barnacles and mussels (15,16). Recent research (17) has reported that in the marine environment oxo-degradable plastics could disintegrate into small pieces of plastic that are not in themselves any more degradable than conventional plastic due to fouling. Hence oxo-degradable fragments could persist in the marine environment.

Narayan (18) has pointed out that oxo-degradable fragments might act to concentrate pesticide residues in the soil, as has been shown for PE and PP debris found in the marine environment (19-21).

In our report we make it clear that no evidence was found that oxo-degradable fragments have a harmful bio-accumulative effect but neither was there evidence that they do not. Hence we concluded that this is a topic requiring more research.

Recyclability

The oxo-degradable industry response takes issue with the conclusions in the DEFRA report on recyclability because of the following:-

(i) they allege *'a biased view of the report from the Environment Department of Quebec'* – which is the only evidence given to support their case

(ii) they maintain that oxo-degradable plastics *'are entirely compatible with recycling streams and have no deleterious effect on lifetime'*

(i) The Quebec report (22) examined the recyclability of two different sources of oxo-degradable poly(ethylene) bags both in terms of processing and of the effect on the properties of the recycled product. This study was not about post-consumer recycling because it is made clear that "*in order to control the history of each bag, all the bags used in the course of the project were new"* (23).

In our report in Annex B6 we summarised the findings of the Quebec report as follows.

"In one experiment, unaged oxo-degradable polyethylene bags from two suppliers were combined with virgin polyethylene bags to make new material. In a second experiment, the oxo-degradable polyethylene was aged for 28 days before combining with the virgin material. Shopping bags were made from both batches. The effect of the unaged and aged oxo-degradable material on the processing stage and on the final bags was assessed in terms of the ease of processing and the performance of the bags. The performance was assessed by filling the bags with water and suspending them for over 100 days in a controlled environment.

The conclusions from this study were that oxo-degradable and conventional material were compatible in the recycling processing stage and there was very little effect of the oxo-degradable plastic on the processing.

The shopping bags made from blends of unaged oxo-degradable and virgin material resisted water leakage for more than 100 days. This was true for blends containing up to 50% oxo-degradable material.

The shopping bags made from blends of aged material (28 days accelerated weathering) showed a large loss of properties depending on the original manufacturer. Bags from one supplier caused a severe deterioration and were considered to be incompatible, while the bags from the other supplier were considered to be compatible with the virgin polyethylene."

This report shows clear evidence that oxo-degradable material is capable of causing deterioration in the properties of recycled plastic. The oxo-degradable additive producers have suggested that the poorly performing oxo-degradable material was either 'not well specified' or it may have already started to degrade before entering the recycling stream. The point is that these materials are designed to degrade so it is not surprising when they do so. In post-consumer recycling, the recycler would have no knowledge about either the formulation or the history of the oxo-degradable material.

(ii) In our report we conclude that oxo-degradable plastics are unsuitable for recycling with conventional plastics because the presence of oxo-degradable additives renders the product susceptible to degradation. We therefore recommend that that the safest solution is to keep oxo-degradable plastics out of mainstream plastics recycling processes.

We are aware that the oxo-degradable additive producers maintain that stabilisers (anti-oxidants) can be added to offset the effect of the oxo-degradable (pro-oxidant) additives. However, the problem for the recyclers would be knowing how much stabiliser to add, given that the oxo-degradable potential of the material is unknown. There is clearly also a problem if the oxo-degradable plastic has already undergone some degradation because this degradation cannot be reversed by addition of stabiliser.

It is a legitimate concern among plastics recyclers that if oxo-degradable plastics are included with other plastics to be recycled, the product will also be prone to degradation. This could be particularly damaging for long-life applications such as membranes used in construction, where recycled plastic is often used. It was our remit when writing the report to express the views of end-of-life stakeholders and we are voicing the genuine and reasonable concerns of the plastics recycling industry.

Poly(ethylene) bags are not widely recycled in the UK. However, Trex is a large recycler of plastic bags in the USA and uses these to make plastic wood. They have issued the following statement (24) regarding oxo-biodegradable polyethylene (OBPE). "*Trex's main concern is with the long term impact of this type of engineered polymer on our finished products. Trex warrants it's products for 25 years. Unless and until the long term durability testing concludes that the OBPE will not have an adverse effect on our product, Trex cannot support the introduction of OBPE materials into traditional recyclable Polyethylene streams".*

Concern from recyclers about degradable plastics is widespread and this has been voiced by the European Plastics Recyclers Association (EuPR), who back in 2009 (25) urged manufacturers to exercise caution over using oxo-degradable additives, warning that they could do more harm than good to the environment and put plastics recycling at risk. In a strategy document published in 2010 (26) entitled 'How to Increase the Mechanical Recycling of Post-consumer Plastics' the EuPR expressed apprehension that both oxo-degradable plastics and bioplastics could jeopardise mechanical recycling and therefore recommended that collection systems are set up to create separate streams for both of these types of new materials.

In our report we also highlighted that there is more potential for a negative impact on the quality of recycled plastic in existing recycling schemes because oxo-degradable technology was starting to be developed for use in other plastics, such as polyethylene terephthalate (PET), and for other applications, such as bottles. This is clearly a worrying development for the National Association for PET Container Resources (NAPCOR) in the USA, who have also urged caution in the use of oxo-degradable additives in PET. They state that these additives cannot be detected by commonly used sorting technologies (which can identify and eliminate plastics other than PET from the recycling stream) and the additives may adversely affect the functionality and life-span of the products into which the PET is recycled (27-30). Second generation PET products are often long-life products, such as carpeting, clothing or strapping (e.g. for holding a pallet of bricks on the back of a truck) and it is very important that the quality of such products is not compromised, otherwise there could be serious consequences. It is possible that the entire recycled plastics industry might be threatened.

NAPCOR also point out that not only can the use of degradable additives in PET packaging jeopardise the recycling of PET but also that use of such materials is against the principles of sustainability and sound environmental stewardship (28).

These concerns are also shared by the Association of Postconsumer Plastic Recyclers (APR), which is an association representing the recyclers of 90% of the post-consumer plastics recycling in the North America. There is anxiety that degradable additives can weaken products and hence shorten the useful life of recycled plastics. This could have a strongly negative impact on postconsumer recycling of plastics (31).

In the UK, the British Plastics Federation on their own website (32) raises concerns about recycling of degradable plastics of all sorts (biodegradable and oxo-degradable). It is stated that "*if degradable material enters the conventional plastics stream and fully degrades in the recycling process it may change the characteristics and specification of the conventional material it is be mixed with. Equally if it does not fully degrade it may continue to do so in the finished recycled product, leading to premature failure".*

According to the BPF Recycling Group: “*the general view of the recycling industry is that conventional and degradable plastics should never be mixed and that specific applications for degradable materials should be selected to ensure that this never happens”* (32). The BPF Recycling Group “*believes that degradable plastics should only be used in applications where they will not become mixed with conventional plastics at end of life”.*

Conclusions

The response report makes the particular criticism of the DEFRA report that “*the conclusions drawn for OBD plastics in relation to recycling, biodegradation, and other issues are not supported by available evidence”*.

We refute this criticism. We have carefully reviewed the available evidence and further material supplied in the response report and stand by the original conclusions of the DEFRA report. The conclusions are supported by the evidence reviewed.

The conclusions of the DEFRA report are included in Annex 2 for completeness.

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Annex 1 – Miscellaneous Comments and Criticisms

A number of miscellaneous comments and criticisms in the response report are addressed below. Points (i) and (ii) are from the Summary section, whereas points (iii), (iv) and (v) are extracted from the body of the report and seem to have no purpose apart from being apparent criticisms.

(i) *"The level of stakeholder input into the preparation of the report was significantly and unfairly lower than for similar projects conducted by DEFRA in this area. Industry was not given appropriate opportunities to comment and to supply supporting data and information during the development of the report."(p2)*

Although we are not in a position to comment on other DEFRA projects, we can confirm that during the preparation of report EV0422 the oxo-degradable industry were given the opportunity to express their views in exactly the same way as other stakeholders and were contacted for this purpose. This was done through emails, telephone calls and face-to-face interviews. Furthermore considerable information was obtained as to their opinion by reviewing material published by them on their own websites and in academic and commercial journals and this formed a major part of the data collection exercise undertaken by Loughborough University; not least because the vast majority of the literature is published by those promoting this technology.

(ii) *"Concerns have been raised with regards to the expertise of the authors in the area of degradable plastics and biodegradation as the report gives inaccurate descriptions of OBD technology and mechanisms." (p2)*

This concern has already been discussed under the heading of 'mechanism of oxidation' where only one specific criticism was raised. Between us, we, the authors, have many years experience of working on a wide range of polymers both in academia and in the plastics industry. While we may not have the detailed, in depth knowledge of oxo-degradable plastics of those people who have developed and promoted the technology for many years or of those who profit from selling the technology, nevertheless we have the advantage of being able to step back and take an objective view of the environmental impact of this technology and to consider the views of other stakeholders.

(iii) *"Some mock the concept of an individual cucumber being wrapped in plastic shrink-wrap but that simple action permits a shelf life of 14 days in comparison to 3 days without wrapping." (p3)*

It is unclear to what this relates and whether this shrink-wrap is made of oxo-degradable packaging or not.

(iv) *"In referring to EN13432 and ASTM D6400, the report states (p.8) that 'it is stated explicitly that the degradation is brought about by the action of living organisms rather than physical or chemical processes.' This is a fundamental misunderstanding of the nature of biodegradation of polymers of whatever origin." (p4)*

The statement refers to the essential role of living organisms in the biodegradation process, as expressed in the two standards. *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". In the American standard ASTM D 6400-04 it is defined as: "a degradable plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae".* Any contention that the authors of the DEFRA report were asserting that degradation cannot or does not precede biodegradation is just wrong.

(v) *"All polymers derive their mechanical properties, especially toughness from the entanglement of their long chains."* (p 4, 10, 11)

This statement is repeated three times in the response document and it is unclear why. It should be known to anyone with the most basic knowledge of polymers.

Annex 2 – Conclusions from DEFRA Report EV0422

The overall conclusion of this review is that incorporation of additives into petroleum-based plastics that cause those plastics to undergo accelerated degradation does not improve their environmental impact and potentially gives rise to certain negative effects.

Degradation and biodegradation

- The length of time to degradation of oxo-degradable plastic cannot be predicted accurately because it depends so much on the environmental conditions. It is suggested that oxo-degradable plastics left in the open environment in the UK degrade to small fragments in 2 to 5 years.

- Biodegradation of oxo-degradable plastics, if it occurs at all, occurs only after fragmentation has occurred and then proceeds very slowly, for example, at a rate many times slower than that of a compostable plastic.

- Oxo-degradable plastics are not compostable, according to standards EN13432 and ASTM 6400. Oxo-degradable plastics should not be included in waste going for composting, because the plastic fragments remaining after the composting process will adversely affect the quality and saleability of the compost. It is thought that labelling the oxo-degradable plastics as biodegradable may lead to confusion on the part of the consumer and possible contamination of the composting waste-stream with oxo-degradable plastics.

- The fact that the term “biodegradable” can be applied to materials with extremely widely differing rates of biodegradation demonstrates that the term is virtually meaningless unless the rates of biodegradation and conditions under which it is measured are specified, preferably with reference to a widely recognised standard.

Bio-accumulation of plastic fragments in the environment

The fate of plastic fragments that remain in the soil is an area of uncertainty. Although these are regarded as beneficial by the producers, concerns have been raised that these particles of plastic may be ingested by insects, birds, animals or fish. No evidence was found in this study that oxo-degradable fragments have a harmful bio-accumulative effect but neither was there evidence that they do not.

Toxicological Impact

No evidence of a toxicological impact of oxo-degradable additives was found in this literature review. It is concluded that the transition metals used are present in such small amounts that they will not significantly increase the concentrations naturally present in the soil at expected levels of usage.

Re-use

The fact that they are degradable limits the re-use of oxo-degradable bags: they are unsuitable for storing items for an extended length of time.

Recycling

Oxo-degradable plastics are not suitable for recycling with main-stream plastics. The recyclate will contain oxo-degradable additives that will render the product more susceptible to degradation. Although the additive producers suggest that stabilisers can be added to protect against the oxo-degradable additives, it is problematic to determine how much stabiliser needs to be added and to what extent the oxo-degradable plastic has already degraded.

Disposal

The potential for problems to be caused by incorrect disposal of oxo-degradable plastics means that any packaging should be clearly labelled with the appropriate means of disposal. Life cycle analysis suggests that the best means of disposal for oxo-degradable plastics is incineration. If incineration is not available then landfill is the next best option.

Recommendations

The recommendations regarding oxo-degradable plastics made on the basis of all the evidence reviewed in this study from the peer-reviewed literature, non-peer-reviewed literature (reports and websites) and also from stakeholder interviews are given below.

- The term 'biodegradable' does not indicate the environment or timescale required for biodegradation to occur and is therefore problematic for labelling packaging.

  There are two possible solutions to this:-

  (i) One solution is that if the term 'biodegradable' is used then it is necessary to define the disposal environment, extent of biodegradation in a short given time period or the time taken to complete biodegradation.

  (ii) The other solution is not to use the term 'biodegradable' for labelling packaging at all, but to only label with instructions on the means of disposal.

- The fate of oxo-degradable plastic after it has fragmented to a fine powder is not clear. Therefore it is recommended that further research is carried out to determine whether complete degradation to carbon dioxide and water is achieved, and if so, over what time scale. If the fine particles are found to persist in the environment for a long period of time, the potential for harm is such that research should be carried out to determine the effect of the particles on plants, invertebrates and animals.

- The uncertainties surrounding the effect of oxo-degradable plastics on the conventional plastics recycling process means that the safest solution would be to keep oxo-degradable plastics out of mainstream plastics recycling processes.