From: [Redacted]@hutton.ac.uk>
Sent: 10 March 2022 18:11
To: [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk[Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@gov.scot>
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted]
I have been trying to estimate my time, based on the Objectives set out for this work.

There seems to be considerable literature around Objectives related to environmental impacts of *oxo-**bio**degradable* plastics (for example, using Google Scholar search, these impacts were on the basis of Environmental pollution, microbial action, GHG emissions, public attitudes that may lead to their rampant usage and effects of oxo-biodegradable Mulching films). I have not gone through these articles in any detail.

[Redacted] Meanwhile thought I will provide you with an indicative value.

Thank you
Kind Regards
[Redacted]

From: [Redacted]@gov.scot>
Sent: 08 March 2022 13:25
To: [Redacted]@hutton.ac.uk>; [Redacted]@gov.scot; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot; [Redacted]@gov.scot; [Redacted]@hutton.ac.uk>; [Redacted]@gov.scot; [Redacted]@gov.scot; [Redacted]@gov.scot
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted],

In advance of the meeting on Friday, are you able to give me some indication of the expected cost for this work? Ideally, we would like you to draw down the funding for the porject this month so that it is taken from the current financial year's budget.

Thanks
[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 03 March 2022 17:17
To: [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>;

[Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@gov.scot>
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted],

Thank you for contacting me.

Below are some dates and times over the next 2 weeks, when I am *not available*. I am okay with rest of the times & dates.
w/c 7th March:
7, 8,9th March-I am not available all days.
10th March-9 am-10:30 am

w/c 14th March:
14th-All day.

I am available any other day or time over the next two weeks, whichever suits you both best.

Thank you
Kind Regards
[Redacted]

From[Redacted]@gov.scot>
Sent: 03 March 2022 16:29
To: [Redacted]@hutton.ac.uk>; [Redacted]@gov.scot; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot; [Redacted]@gov.scot; [Redacted]@hutton.ac.uk>; [Redacted]@gov.scot; [Redacted]@gov.scot[Redacted]@gov.scot
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

[External email]
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Hi [Redacted],

Great to have you on board to deliver this review. [Redacted] and I would be happy to provide some additional background to the project. If you can provide us with some suggested dates when you'd be available for a conversation, we'll get something organised.

Best wishes,
[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 02 March 2022 12:20
To: [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk[Redacted]@gov.scot>;

[Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@gov.scot>
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted],

Thank you for the information on the requirements for the evidence review on oxo-biodegradable plastics.

Six to eight weeks is what I am thinking, to deliver this evidence review- as this will enable me to fit with my other work and should also help in assimilating the findings. Please let me know your thoughts about the timescale. Happy to work around it. Happy for a discussion with [Redacted]
.

Thank you
Kind Regards
[Redacted]

From[Redacted]@gov.scot>
Sent: 02 March 2022 10:56
To: [Redacted]@hutton.ac.uk>; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot; [Redacted]@gov.scot; [Redacted]@hutton.ac.uk>; [Redacted]@gov.scot; [Redacted]@gov.scot[Redacted]@gov.scot[Redacted]@gov.scot
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

[External email]
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Hi [Redacted],

I attach a short specification of what we require from this review. Essentially it is a review of evidence to establish the degree to which oxo-biodegradable plastic products cause pollution of the environment.

I am really not sure how much literature there is out there on the topic and therefore how long it will take you to complete. We would really appreciate for you to undertake the review as quickly as possible but are also mindful of your other work. If you are able to give an indication of the timeframe that you think you could do this in that would be great.

I am copying in my Single-Use Plastics Policy colleagues [Redacted] and [Redacted] who may be able to give you more details on the requirement. Perhaps a short conversation about it would be helpful to you for discussing scope and timings?

Thanks very much and look forward to hearing from you.

[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 25 February 2022 10:03
To: [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>; [Redacted]@sruc.ac.uk>; [Redacted]@sruc.ac.uk; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>; [Redacted]@sac.co.uk
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted],
Thank you, looking forward to working on this topic- evidence gathering on oxo-biodegradable plastics.

Thank you
Kind Regards
[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 25 February 2022 10:03
To: [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>; [Redacted]@sruc.ac.uk>; [Redacted]@sruc.ac.uk; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>; [Redacted]@sac.co.uk
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

[External email]
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Hi [Redacted],

That's great. Thanks a lot. [Redacted]I will follow up with you shortly.

Cheers

From: [Redacted]@hutton.ac.uk>
Sent: 23 February 2022 20:10
To: [Redacted]@gov.scot>; [Redacted]@sruc.ac.uk>; [Redacted]@sruc.ac.uk; [Redacted]@hutton.ac.uk>; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>; [Redacted]@sac.co.uk
Subject: Re: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted],
[Redacted](included in this reply) would be interested in taking on this work. This email is simply to make that connection. Over to you.
Cheers
[Redacted]

Get [Outlook for Android]

From[Redacted]@gov.scot>
Sent: Wednesday, February 23, 2022 4:48:34 PM
To: [Redacted]@hutton.ac.uk>; [Redacted]@sruc.ac.uk>; [Redacted]@sruc.ac.uk **Cc:** [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>; [Redacted]@sac.co.uk>
Subject: review into environmental impacts of oxo-degradable products - call down project

Dear [Redacted]

I am writing to you all as part of the RESAS SRP C4 circular economy research team as I am not quite sure who to direct this request to.

Our policy team are in need of an evidence review to support our implementation of Article 5 of the EU Single-use Plastics Directive. The Directive requires that all oxo-degradable products are banned. However, manufacturers of oxo-biodegradable products (a sub-set of oxo-degradables) claim that this substance is sufficiently different and better for the environment than oxo-degradables and so shouldn't be included in this ban. As a matter of urgency we need to determine if there is evidence to support this assertion.

We are therefore wondering if somebody from SRUC or JHI would be able to conduct a review of the evidence on this for us through the calldown budget? My sense is that there is probably limited evidence available but it would be good to know if this is indeed the case. I think the topic is materials science but I suppose a general review could be undertaken by a non-specialist.

I would be grateful if you could let me know if this is something that you might be able to help with? Happy to follow up with more details.

Thanks
[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 11 March 2022 14:02
To: [Redacted]@gov.scot>; [Redacted]@zerowastescotland.org.uk
Subject: RE: OPA response to the SG regulations consultation

Hi [Redacted]

Thank you

Kind Regards
[Redacted]

[Redacted]
Sent: 11 March 2022 13:49
[Redacted]
Subject: OPA response to the SG regulations consultation

[External email]
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Hi both

Link to the OPA response to the consultation that I sent in the Teams chat bar:

https://www.biodeg.org/wp-content/uploads/2021/01/OPA-response-to-Scottish-Consultation-31-12-20-2.pdf

Kind regards,

[Redacted]

PAS 9017:2020

Plastics – Biodegradation of polyolefins in an open-air terrestrial environment – Specification

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Foreword

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- Fera Science Ltd
- Impact Solutions
- Imperial College London
- Polymateria Ltd.
- WRAP

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It has been assumed in the preparation of this PAS that the execution of its provisions will be entrusted to qualified and experienced people, for whose use it has been produced.

Presentational conventions

The provisions of this PAS are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is "shall".

Commentary, explanation and general informative material is presented in italic type and does not constitute a normative element.

Where words have alternative spellings, the preferred spelling of the Shorter Oxford English Dictionary is used (e.g. "organization" rather than "organisation").

Contractual and legal considerations

This Publicly Available Specification does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a Publicly Available Specification cannot confer immunity from legal obligations.

0 Introduction

The use of plastics and particularly polyolefin-based plastics has significantly increased over the past decades in many applications.[1] Driven by low costs and strong supply chains, polyolefins have become the material of choice for many product applications. The result of this widespread use has meant that the end-of-life scenarios of these materials has come under ever-increased scrutiny. There are four major end-of-life scenarios of plastic materials. [2]

a) landfill;

b) incineration/waste-to-energy;

c) mechanical recycling; and

d) litter or leakage into the natural environment.

Whilst well-known standards and/or industry-accepted protocols exist for determining the applicability or performance of a plastic material in scenarios a), b) and c), previous standards in scenario d) have identified guidelines, but have not specified outcomes. In addition, they have sought to pre-determine the type of degradation process, rather than producing numerical criteria associated with the performance of the material under the stated test conditions.

***NOTE 1** Similarly to standards within scenarios a), b) and c) for end-of-life of plastic materials, which do not overlap with each other when evaluating a plastic material, this PAS does not overlap with standards relating to landfill, incineration or recycling of plastics. This PAS provides data on the material only related to the end–of-life scenario as stated in scenario d): littering or leakage into the natural environment.*

Within all plastic materials, polyolefin-based plastics are the most littered category (approx. 50% of total). [2] More specifically, 75% of all fugitive plastic is land based.[3][4] It is widely accepted that fugitive plastic on land goes through a process of weathering, normally resulting in the generation of microplastics, followed by limited soil biodegradation depending upon the environmental conditions.[3]

***NOTE 2** A definition of microplastics can be found in Annex G.*

The problem is that polyolefins are hydrocarbon-based materials that are resistant to environmental stimuli and inert to biological attack. Due to the ever-growing problem of plastic pollution and the need to innovate within current polyolefin-based packaging, additive-based solutions are being proposed as biodegradable innovations within polyolefinic materials. Although these additive-based innovations have been known for some time, previous standardization efforts have covered only specific aspects of polyolefin use, such as durability (via weathering testing), degradation or loss of physical properties due to aging over time or biodegradation under selected conditions. The primary objective of this PAS is to provide a standard specification that provides numerical data on the biodegradability of a given polyolefin containing a specific biodegradable additive under open-air terrestrial conditions. The PAS is specifically designed to simulate the overarching process of biodegradability in an unmanaged environment, as in the case of littering or unmanaged disposal. It does not provide data on how a polyolefinic material would perform under managed biodegradable end-of-life scenarios such as industrial or home composting, anaerobic digestion, or organic recycling.

***NOTE 3** Biodegradability in unmanaged aquatic or marine environments is not considered in this PAS. These environments will be considered upon revision of this PAS depending upon available standards and evidence.*

To achieve the objective of this PAS, internationally accepted existing standards in relation to the three key stages of concern with respect to biodegradability in an open-air terrestrial environment will be referenced accordingly. These standards will be further augmented in line with written protocols to specify the conditions and timeframes used for the testing at each stage. The three stages represented are:

1) weathering of the polyolefinic material under specific conditions and timeframes, after which chemical analysis proves that the polyolefinic material has been transformed into a wax containing a specified carbonyl index;

2) an assessment of the eco-toxicity of the wax using three sentinel species to determine that the wax presents no hazardous or inhibiting effects; and

3) biodegradation of the wax under mesophilic conditions using exclusively soil as the medium for the test to reflect unmanaged disposal conditions.

NOTE 4 *An overview of the approach and pass-fail criteria can be found in Annex A.*

NOTE 5 *Specifying that the biodegradation testing achieves a degree of mineralization greater than 90% avoids the generation of microplastics.*

The PAS aims to standardize the effectiveness of technologies that impart biodegradability within polyolefins by providing data on the performance of the tested technology under the stated conditions. Only by meeting the requirements of the standardized testing in all stages of this PAS is a technology within a given polyolefinic material composition deemed to be compliant.

This PAS does not specify the origin of the raw materials used in the polyolefin composition. Claims around bio-based content are to be made in accordance with relevant standards. In addition, the PAS does not specify the use-life or durability aspects of the polyolefinic material under evaluation.

NOTE 6 *If an assessment of the bio-based content of a polyolefinic material is desired, further reading of BS EN 16640 and BS EN 16785-1 is recommended.*

NOTE 7 *Compatibility of innovative polyolefin packaging entering the market with current recycling streams is covered by the protocols of Plastics Recyclers Europe (PRE).*

The PAS is not intended for making claims of biodegradability, nor for product (self-) declaration. Compliance with the PAS would provide the numerical evidence to support claims about the performance of the technology within polyolefins in alignment with BS EN ISO 14021.

NOTE 8 *Attention is drawn to the legal requirements of the territory of use of the polyolefinic material.*

1 Scope

This PAS specifies requirements of polyolefinic materials enhanced with an additive technology that imparts biodegradability in an open-air terrestrial environment. This PAS specifies the standards to be used for evaluating the performance of the tested polyolefinic material at each stage, whilst within these protocols it specifies the conditions and maximum timeframes the testing is to be conducted in. Furthermore, it specifies the chemical analysis and the numerical limits required to meet compliance with the PAS at the end of each stage of testing.

Thus, this PAS covers:

a) polyolefin composition and additive technology under evaluation;

b) alignment of specific standardized protocols for testing at each stage, notably:

   1) weathering exposure of test polyolefinic materials for a defined period of time, including chemical analysis to yield quantifiable measurement of chemical transformation into a wax;

   2) eco-toxicity testing upon the wax to ensure no hazardous substances are present; and

   3) biodegradation testing under mesophilic on soil conditions.

c) standardized testing protocol to be used at each stage of evaluation as well as for chemical analyses;

d) reporting of the data at the end of each stage of testing and the specifications to indicate compliance with the PAS.

This PAS does not cover:

- managed biodegradable end-of-life scenarios such as industrial or home composting, landfill and anaerobic digestion;
- unmanaged aquatic environments of freshwater of marine habitats, including the damage that bioaccumulation of plastic pollution creates in these ecosystems;
- durability testing of the polyolefinic material prior to any chemical or biological transformation;
- the suitability or compatibility of the polyolefinic material to be mechanically, chemically or organically recycled;
- the life cycle assessment analysis of the polyolefinic material combined with the biodegradable additive technology;
- self-declared claims of biodegradability outside the framework of an appropriate standard such as BS EN ISO 14021; or
- the requirement of the use of independent third-party certification for claims of conformance to the PAS.

This PAS is intended to be used by plastic or plastic technology manufacturers looking to obtain data as to the performance of the biodegradability of an additive technology within a polyolefinic material in an open-air terrestrial environment. In addition, this PAS provides testing laboratories with a standardized protocol to evaluate polyolefinic materials for conformance to the PAS.

In addition, other standards agencies, national laboratories or academic research groups could use the test method described in this PAS as a universal baseline methodology of evaluating the biodegradability of new technological discoveries within polyolefins.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes provisions of this PAS. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Standards publications

BS EN ISO 4892-1, *Plastics – Methods of exposure to laboratory light sources – Part 1: General guidance*

BS EN ISO 4892-2, *Plastics – Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps*

BS EN ISO 4892-3, *Plastics – Methods of exposure to laboratory light sources – Part 3: Fluorescent UV lamps*

BS EN ISO 17556, Plastics – Determination of the ultimate aerobic biodegradability of plastic materials in soil by measuring the oxygen demand in a respirometer or the amount of carbon dioxide evolved

BS ISO 16014-4, *Plastics – Determination of average molecular weight and molecular weight distribution of polymers using size-exclusion chromatography – Part 4: High-temperature method*

ASTM D2565-16, *Standard Practice for Xenon-Arc Exposure of Plastics Intended for Outdoor Applications*

ASTM D4329-13, *Standard practice for Fluorescent Ultraviolet (UV) Lamp Apparatus Exposure of Plastics*

ASTM D5988-18, Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in Soil

ASTM D6474-20, *Standard Test Method for Determining Molecular Weight Distribution and Molecular Weight Averages of Polyolefins by High Temperature Gel Permeation Chromatography*

Other publications

[N1] OECD Test No. 202, *Daphnia sp., Acute Immobilisation Test and Reproduction Test*

[N2] OECD Test No. 208, *Terrestrial Plant Test: Seedling Emergence and Seedling Growth Test.*

[N3] OECD Test No. 211, *Daphnia magna Reproduction Test*

[N4] OECD Test No. 222, *Earthworm Reproduction Test*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this PAS, the following terms and definitions apply. Definitions are aligned and based on international standards shown in Annex G. If definitions are non-PAS specific, this is indicated.

3.1.1 % biodegradation

percentage conversion of the organic carbon in the test sample into carbon dioxide, calculated from the quantity of carbon dioxide evolution relative to the organic carbon content of the test sample prior to the start of the test

NOTE *For detailed description see ASTM D5988-18, Clause **12**, and BS EN ISO 17556:2019, Clause **9** and BS EN ISO 472:2013+A1:2018, Clause **2**.*

3.1.2 biodegradable additive

organic, inorganic or enzymatic chemical that promotes the chemical and biological change in the polyolefin plastic, rendering it biodegradable via the combined processes of weathering and on soil biodegradation

NOTE *For detailed description see PD CEN ISO/TR 21960:2020, **3.7**.*

3.1.3 open-air terrestrial environment

ecosystem relating to or on dry land, that is comprised of the interface of soil and air

NOTE *For the purposes of this PAS, it defines the unmanaged, dry land conditions in which plastic pollution accumulates within the environment.*

3.1.4 polyolefinic material

polyolefin sample or product in a defined form, e.g. a rigid container, a film or a fibre

3.1.5 polyolefin additive

chemical that changes the physical properties of the polyolefinic material through inclusion during the extrusion process ≤ 1% by weight, not related to biodegradation

3.1.6 polyolefin component

organic or inorganic compound, that changes the appearance or physical properties of the polyolefinic material through inclusion during the extrusion process ≤ 20% by weight

3.1.7 polyolefin fibres

polyolefinic material produced in the form of a fibre, string or cord

3.1.8 polyolefin filler

organic or inorganic material added to the polyolefin, which cannot exceed 80% by weight of the total weight of the overall polyolefinic material

3.1.9 polyolefin films

polyolefinic material (including polyolefin fibres) not thicker than 0.25 mm, produced via blown or cast film extrusion

NOTE *See also ASTM D883-20a.*

3.1.10 polyolefin pigments

substance, generally in the form of fine particles, that is used because of its colour or decorative properties by an inclusion during the extrusion process ≤ 10% by weight

3.1.11 polyolefin rigids

polyolefinic material (including polyolefin fibres) thicker than 0.25 mm and with a modulus of elasticity in flexure or, if that is not applicable, then in tension, greater than 700 MPa

NOTE *See also ASTM D883-20a and BS EN ISO 291.*

3.1.12 polyolefins

thermoplastic polymer produced by the polymerization or copolymerization of olefins

NOTE *See also BS EN ISO 472.*

3.1.13 wax

low molecular weight paraffinic hydrocarbon with a specified degree of carbonyl functionalization

3.1.14 weathering

exposure of plastics through contact with the earth's atmosphere, such as air, sunlight and moisture either through accelerated laboratory testing or natural outdoor exposure

NOTE *See also ASTM D883-20a.*

3.2 Abbreviations

3.2.1 Analytical abbreviations

3.2.1.1 CI

carbonyl index of polyolefinic material

3.2.1.2 ATR-FTIR

attenuated total reflection – fourier transform infrared spectroscopy

3.2.1.3 GPC

gel permeation chromatography

3.2.1.4 GPC-SEC

gel permeation chromatography – size and exclusion chromatography

3.2.2 Polymer specific abbreviations

M_n Number average molecular weight

M_w Weight average molecular weight

M_z Higher average molecular weight. The weightings average with respect to higher M_w

PE Polyethylene incl. all types

PP Polypropylene incl. all types

4 Weathering of polyolefins

4.1 Categorization of the polyolefinic material prior to weathering

This PAS shall be applied to polyolefin films or rigids and shall be applied to polyolefinic materials containing a biodegradable additive and/or component. This PAS shall also be applied to polyolefinic material containing a biodegradable additive and/or component that additionally contains a filler, a pigment or any other additive or component designed to aid in the functionality of the polyolefinic material.

***NOTE** The categorization of different polyolefinic materials based upon their composition, including examples, is described Table B.1 in Annex B.*

4.2 Selection of polyolefin samples

Samples shall either be the polyolefinic material intended for use or shall be a sample taken from the polyolefinic material intended for use. Laboratory samples or unique polyolefinic materials produced especially for testing shall not be tested as they do not represent the polyolefinic materials intended for use.

4.3 Weathering procedure for samples

4.3.1 Weathering procedure for films

4.3.1.1 Preparation of film samples for weathering

The film sample shall be prepared in accordance with the laboratory weathering standards of ASTM D4329-13 or BS EN ISO 4892-1. A sufficient sample shall be used such that the chemical analysis can be performed at the end of the weathering. Each film sample shall be tested in triplicate.

***NOTE 1** Sampling could be performed during the weathering process through sacrificial sampling to yield reproducible results.*

***NOTE 2** Where possible, the entire polyolefinic material should be tested. If not possible, sample testing is suggested.*

Polyolefin fibre-based materials shall be tested in accordance with the procedure for film samples, if their thickness is less than or equal to 0.25 mm.

4.3.1.2 Weathering apparatus and cycle settings for film samples

For film samples, UV-accelerated weathering apparatus capable of mounting and exposing the sample to a combination of air, heat and UV-light shall be used. The procedure for calibrating the machine and performing the tests shall be used as described in BS EN ISO 4892-3 or ASTM D4329-13. Reporting of the procedure of UV-accelerated laboratory weathering shall be reported in line with **4.6**.

The cycle of the UV-accelerated weathering tester equipment shall be set to the following:

a) irradiance: 0.8 W/m^2 (±0.02 W/m^2).
b) UV cycle time: 1 h.
c) dark cycle time: 23 h.
d) air chamber temperature: 60 °C (±2 °C).

***NOTE** More details are presented in Annex C.*

4.3.1.3 Time period for weathering film samples

The laboratory UV-accelerated weathering testing shall be conducted for no more than a total of 14 days. The time period of UV laboratory weathering of film samples shall be consecutive days of testing up to a total of 14 days.

***NOTE 1** Testing can be completed before the 14-day time period but should not be conducted for longer. More details are presented in Annex C.*

***NOTE 2** The specified weathering cycle and timeframe for weathering film samples has been demonstrated to equate to approximately 3 months of outdoor exposure under South Florida conditions.*[6]

4.3.2 Weathering procedure for rigids

4.3.2.1 Preparation of rigid samples for weathering

The rigid sample shall be prepared in accordance with the laboratory weathering standards of ASTM D2565-16 or BS EN ISO 4892-1. Enough sample shall be used in order to ensure that the chemical analysis can be performed at the end of the weathering. Each rigid sample shall be prepared in triplicate.

***NOTE** In addition, sampling can be performed during the weathering process through sacrificial sampling. More details are presented in Annex C.*

Polyolefin fibre-based materials shall be tested in accordance with the procedure for rigid samples, if their thickness is greater than 0.25 mm.

4.3.2.2 Weathering apparatus and cycle settings for rigid samples

For rigid samples, Xenon-arc accelerated weathering apparatus capable of mounting and exposing the sample to a combination of air, heat and Xenon-arc light shall be used. The procedure for calibrating the machine and performing the tests shall be used as described in ASTM D2565-16 or BS EN ISO 4892-2. Reporting of the procedure of UV-accelerated weathering shall be reported in line with **4.6**.

The cycle of the equipment shall be set to the following:

a) irradiance: 0.35 W/m^2 (±0.02 W/m^2) using daylight filter at 340 nm.
b) UV cycle time: 8 h.
c) dark cycle time: 16 h.
d) air chamber temperature: 60 °C (±2 °C).
e) uninsulated black panel temperature: 70 °C (±2 °C).

***NOTE** More details are presented in Annex C.*

4.3.2.3 Time period for weathering rigid samples

The laboratory Xenon-arc weathering testing shall be conducted for no more than a total of 28 days. Testing can be completed before the 28-day time period but shall not be conducted for longer. The time period of Xenon-arc laboratory weathering of rigid samples shall be consecutive days of testing up to a total of 28 days.

***NOTE 1** See Annex C for further details.*

***NOTE 2** The specified weathering cycle and timeframe for weathering film samples has been demonstrated to equate to approximately 4 months of outdoor exposure under South Florida conditions. [6]*

4.4 Chemical analysis procedures

4.4.1 Carbonyl Index (CI) determination

***NOTE 1** The carbonyl index (CI) is used to determine the relative level of chemical transformation that has occurred on and within the sample.*

The CI shall be calculated on every sample tested before the start of the testing and at the end of the testing. The CI for each test sample shall be reported as an average of three replicates. The CI shall be determined using the method specified in Annex D.

***NOTE 2** Intermediate CI determination can be recorded on sacrificial samples taken during the testing period.*

4.4.2 Molecular weight analysis

A molecular weight determination of the samples shall be conducted via gel permeation chromatography (GPC) or gel permeation chromatography – size and exclusion chromatography (GPC-SEC). It shall be conducted in terms of preparation according to BS ISO 16014-4 or ASTM D6474-20. The molecular weight analysis for each test sample shall be reported as an average of three replicates. The collection of an individual sample shall cover a third of the overall tested polyolefinic material. The sample shall be completely soluble in the chosen solvent used to perform the molecular weight analysis. Any insoluble residues shall lead to an invalid molecular weight analysis and therefore shall give an invalid test result, as per this PAS. Different solvents can be used, but complete solubility shall be achieved. In a scenario where no solvent is capable of completely dissolving the test sample, the test shall be deemed invalid. A test sample shall only be filtered to remove insoluble material in the scenario that a filler or component has been used in the polyolefinic material. The molecular weight of the sample shall be recorded at the start and at the end of the test. The key parameters of the sample to be determined shall be M_n, M_w, % loss of M_w and M_z. The absolute values shall be reported in Daltons (Da).

***NOTE** BS ISO 16014-1 and BS ISO 13885-1 are suggested for further reading.*

In cases where the test sample is a combination of a polyolefin plastic and a filler, such as a mineral or pigment, the sample shall be filtered to remove the insoluble material before the molecular weight analysis is performed. Depending on the ratio of filler to polyolefin plastic, the tested amount of sample shall be adapted in order to achieve a valid molecular weight determination.

4.5 Chemical analysis criteria to achieve after weathering

4.5.1 General

The following criteria shall be reported:

a) Carbonyl Index criteria.

*NOTE 1 See **4.5.2** for details.*

b) Molecular weight criteria.

*NOTE 2 See **4.5.3** for details.*

NOTE 3 For optional tensile strength tests, see Annex H.

4.5.2 Carbonyl Index criteria

For the test sample to be valid as per this PAS the CI determined shall be greater than 1 before or at the:

a) 14-day period of weathering for a film sample.

b) 28-day period of weathering for a rigid sample.

4.5.3 Molecular weight criteria

For the test sample to be valid as per this PAS:

- the M_n determined shall be less than 5,000 Daltons; the M_z shall be less than 30,000 Daltons; and the % M_w loss shall be greater than 90%, before or at the 14-day period of weathering for a film sample.
- the M_n determined shall be less than 5,000 Daltons; the M_z shall be less than 30,000 Daltons; and the % M_w loss shall be greater than 90%, before or at the 28-day period of weathering for a rigid sample.

4.6 Reporting of weathering tests and chemical analysis

The weathering testing and chemical analysis of the polyolefinic material shall be reported in accordance with Annex E.

5 Eco-toxicity evaluation and testing of samples

5.1 Assessment of potentially biologically hazardous substances upon the surface of the polyolefinic material before weathering

To demonstrate that no biologically hazardous substances have been applied or exist within the structure of the polyolefinic material, OECD 202 [N1] shall be performed on the polyolefinic material. The polyolefinic material shall be tested:

a) if the surface of the polyolefinic material is printed or inked at a coverage of greater than 50% of the total surface area of the polyolefinic material;

b) if the polyolefinic material contains a polyolefin component; and/or

c) if the polyolefinic material does not consist solely of a food-contact approved virgin polyolefin resin.

The test sample shall be deemed to be valid as per this PAS if it has met all the criteria as specified in the OECD guidelines of 202 [N1]. If a test sample fails to meet the criteria of any of the mentioned OECD guidelines, it shall be deemed invalid as per this PAS.

5.2 Assessment of eco-toxicity of wax after weathering

5.2.1 Eco-toxicity testing selection

To demonstrate that the wax created after weathering is not hazardous, ecotoxicology testing shall be performed on a sample of the wax. The terrestrial eco-toxicity shall be reported only on types or categories of representative polyolefinic materials that have achieved the criteria of **4.5**, rather than on individual polyolefinic materials.

NOTE *See Annex B for further information.*

5.2.2 Terrestrial eco-toxicity testing

The following tests shall be performed on the test sample as per the following:

a) OECD Test No. 222, *Earthworm Reproduction Test [N4] – Clauses* **3**, **8**, **25** and **41**;

b) OECD Test No. 208, *Terrestrial Plant Test: Seedling Emergence and Seedling Growth Test* [N2] – Clauses **2**, **6**, **19** and **30**.

The test sample shall be deemed to be valid as per this PAS if it has met all the criteria as specified in the named clauses of OECD guidelines of tests 208 [N2] and 222 [N4]. If a test sample fails to meet the criteria of any of the clauses in the OECD tests 208 and 222 as specified, it shall be deemed invalid as per this PAS.

NOTE *See Annex F for further information on conducting the tests.*

5.2.3 Eco-toxicity testing in freshwater

The following test shall be performed to ensure no hazardous substances leach out of the wax:

- OECD Test No. 211, *Daphnia magna Reproduction Test* [N3] – Clauses **4**, **8**, **20** and **51**.

The test sample shall be deemed to be valid as per Annex F of this PAS if it has met all the criteria as specified in named clauses in the OECD guidelines of 211 [N3]. If a test sample fails to meet the criteria of any of the clauses in the OECD test 211 as specified, it shall be deemed invalid as per this PAS.

5.3 Reporting of eco-toxicity testing

The eco-toxicity testing of the wax from the designated polyolefinic material shall be reported in accordance with Annex E.

6 Biodegradation of wax after weathering

6.1 Assessment of biodegradation

6.1.1 Selection criteria for biodegradation

Biodegradation testing shall be reported, as per Annex B, only on types or categories of representative polyolefinic materials that have achieved the criteria of **4.5**, rather than on individual polyolefinic materials.

6.1.2 Biodegradation testing conditions

Biodegradation testing shall be performed under mesophilic conditions using soil as the test medium. The biodegradation of the test sample shall be determined as the conversion through the process of mineralization of the carbon in the test sample to carbon dioxide, water and biomass. The methodology specified in ASTM D5988-18 or BS EN ISO 17556 shall be used to determine the % biodegradation of the test sample. The sample shall be deemed valid if it meets the requirements of these standards and the requirements of **6.1.3.**

NOTE *Mesophilic conditions are frequently suggested in cited standards. Additional testing conditions of temperature or soil might be relevant in selected regions and should be taken into account.*

6.1.3 Biodegradation test passing criteria

The test sample shall be deemed valid if 90% or greater of the organic carbon in the wax is converted to carbon dioxide by the end of the test period when compared to the positive control or in the absolute. The total maximum time for the testing period shall be 730 days (two years).

NOTE *The 90% limit is chosen based on internally accepted norms, including BS EN 13432 and ASTM D6400-19, as the limit for complete biodegradation of the organic carbon of the test material. The remaining organic carbon is assumed to be converted into carbon in biomass, as in BS EN 13432 and ASTM D6400-19.*

6.2 Reporting of biodegradation testing

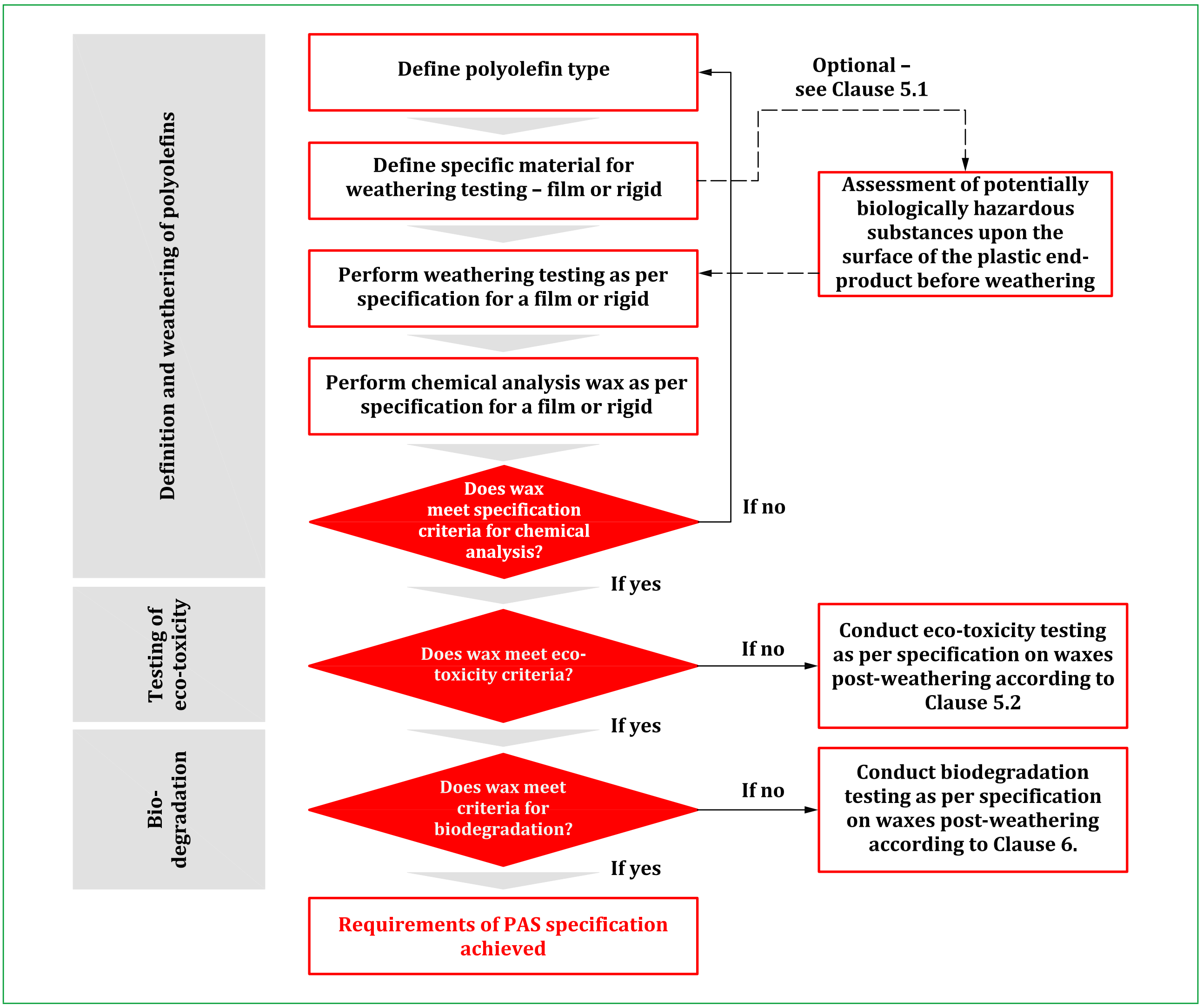
The biodegradation testing of the wax from the designated polyolefinic material shall be reported in accordance with Annex E.

Annex A (normative) Flow diagram for testing to PAS 9017

For each step of the process shown in Figure A.1, a selection of pass criteria shall be applied.

NOTE 1 These pass criteria are summarized in Table A.1.

Figure A.1 – Flow diagram for testing to PAS 9017



NOTE 2 The PAS process shown in Figure A.1 does not include a fail option. If a material fails the test at any stage, the process needs to be repeated with a new material from the beginning of the process.

Table A.1 – Overview of pass criteria in requirements to reach PAS 9017 specification

	Pass criteria for PAS
Weathering of polyolefins (Clause 4)	**For film samples:** • the CI determined shall be greater than 1 before or at the 14-day period of weathering for a film sample; and • the M_n determined shall be less than 5,000 Daltons; the M_z shall be less than 30,000 Daltons; and the % M_w loss shall be greater than 90%, before or at the 14-day period of weathering for a film sample. **For rigid samples:** • the CI determined shall be greater than 1 before or at the 28-day period of weathering for a rigid sample; and • the M_n determined shall be less than 5,000 Daltons; the M_z shall be less than 30,000 Daltons; and the % M_w loss shall be greater than 90%, before or at the 28-day period of weathering for a rigid sample.
Eco-toxicity pre-weathering (Clause 5)	For a test to be valid, the following performance criteria shall be met [in the control(s)]: • OECD Test No. 202, *Daphnia sp., Acute Immobilisation Test and Reproduction Test* [N1] – Clauses **3**, **6**, **14**, **20**.
OECD 202 [N1] (included in Clause 5) (pre-weathering)	**Daphnia SP, Acute immobilisation test** For a test to be valid, the following performance criteria shall be met [in the control(s)]: • not more than 10% of the daphnids have been immobilized in the control, including the control containing the solubilizing agent; • the dissolved oxygen concentration at the end of the test is greater or equal to 3 mg/l in control and test vessels. ***NOTE 1*** *There is no statistical difference between the treatment group (at the maximum concentration as a limit test) and the untreated control group for all ecotoxicological endpoints stipulated in the guideline.*
OECD 208 [N2] (included in Clause 5) (post-weathering)	**Seedling Emergence and Seedling Growth test** For a test to be valid, the following performance criteria shall be met [in the control(s)]: • the seedling emergence is at least 70%; • the seedlings do not exhibit visible phytotoxic effects (e.g. chlorosis, necrosis, wilting, leaf and stem deformations) and the plants exhibit only normal variation in growth and morphology for that particular species; and • the mean survival of emerged control seedlings is at least 90% for the duration of the study. ***NOTE 2*** *There is no statistical difference between the treatment group (at the maximum concentration as a limit test) and the untreated control group for all ecotoxicological endpoints stipulated in the guideline.*
OECD 211 [N3] (included in Clause 5) (post-weathering)	***Daphnia magna* Reproduction Test** For a test to be valid, the following performance criteria shall be met [in the control(s)]: • the mortality of the parent animals (female *Daphnia*) does not exceed 20% at the end of the test; • the mean number of living offspring produced per parent animal surviving at the end of the test is > 60; and • the dissolved oxygen concentration at the end of the test is greater or equal to 2 mg/l in control and test vessels. ***NOTE 3*** *There is no statistical difference between the treatment group (at the maximum concentration as a limit test) and the untreated control group for all ecotoxicological endpoints stipulated in the guideline.*

Table A.1 – Overview of pass criteria in requirements to reach PAS 9017 specification *(continued)*

	Pass criteria for PAS
OECD 222 [N4] (included in Clause 5) (post-weathering)	**Earthworm Reproduction Test (Eisenia fetida/ Eisenia andrei)** For a test to be valid, the following performance criteria shall be met [in the control(s)]: • each replicate (containing 10 adults) have produced ≥ 30 juveniles by the end of the test; • the coefficient of variation of reproduction is 30%; and • adult mortality over the initial 4 weeks of the test is 10%. ***NOTE 4*** *There is no statistical difference between the treatment group (at the maximum concentration as a limit test) and the untreated control group for all ecotoxicological endpoints stipulated in the guideline.*
Biodegradation testing (Clause 6)	For a test to be valid, there shall be at least 90% biodegradation within less than or equal to 730 days (2 years) of testing.

Annex B (normative)
Definition of polyolefinic material categories

NOTE 1 Table B.1 provides a non-exhaustive list of polyolefinic material categories.

Table B.1 – Overview of polyolefinic material categories

Polyolefin + Biodegradable Additive (BA)	+ Filler	+ Pigment	+ Other additive (OA)	+ Component (C) (≦20 wt.%)
PE (+BA)	PE (+BA) + Filler	PE (+BA) + Pigment	PE (+BA) + OA	PE (+BA) + C
PP (+BA)	PP (+BA) + Filler	PP (+BA) + Pigment	PP (+BA) + OA	PP (+BA) + C
Combination of Polyolefins (+BA)	Combination of Polyolefins (+BA) + Filler	Combination of Polyolefins (+BA) + Pigment	Combination of Polyolefins (+BA) + OA	Combination of Polyolefins (+BA) + C

Each polyolefinic material category represents a different polyolefinic material that shall be tested against this PAS. Any combination of the above categories shall create a new category of polyolefinic material that shall be tested as per this PAS in its entirety.

If a sample under evaluation is in a category with the same biodegradable additive at the same or higher addition rate and has already successfully met the criteria of this PAS, it shall be tested against the weathering and chemical analysis clauses (**4.4**) only.

If a sample containing a filler, pigment, other additive or component under evaluation falls into a category with the same biodegradation additive that has already successfully met the criteria of this PAS it shall only be tested for weathering and chemical analysis, as long as the addition of the filler, pigment, other additive or component is equal to or less than the addition rate of the previously tested sample.

NOTE 2 See Annex A.

In the case of a polyolefin containing a biodegradable additive and a filler, where the polyolefin has already met the specification of the PAS, if the filler used is an inorganic material, only an assessment of terrestrial eco-toxicity shall be performed. If the filler used is an organic material, both an assessment of terrestrial eco-toxicity and biodegradation testing shall be performed.

NOTE 3 *The following examples help to illustrate the method:*

Example 1: Sample A with a BA at 2% by weight should be tested as per the entire PAS specification. Sample A with a BA at 3% by weight should be tested as per the weathering and chemical testing criteria of the PAS specification. The test report of this sample should include the test report of Sample A with the BA at 2% by weight. Sample A with a BA at 1% by weight should be tested as per the entire PAS specification.

Example 2: Sample B with a BA at 2% by weight and a filler of 50% by weight should be tested as per the entire PAS specification. Sample B with a BA at 2% by weight and a filler of 40% by weight should be tested as per the weathering and chemical testing criteria of the PAS specification. The test report of this sample should include the test report of Sample A with the BA at 2% by weight and a filler of 50% by weight. Sample B with a BA at 2% by weight and a filler of 60% by weight should be tested as per the entire PAS specification.

Example 3: Sample C with a BA at 2% by weight and a pigment of 4% by weight should be tested as per the entire PAS specification. Sample C with a BA at 2% by weight and a pigment of 3% by weight should be tested as per the weathering and chemical testing criteria of the PAS specification. The test report of this sample should include the test report of Sample A with the BA at 2% by weight and a pigment of 4% by weight. Sample C with a BA at 2% by weight and a filler of 5% by weight should be tested as per the entire PAS specification.

NOTE 4 *Polyolefin fibres should be specified as a new polyolefinic material + biodegradable additive category and should follow the same specification with respect to testing for the optional inclusion of fillers, pigments, other additives or components as that for films and rigids depending upon thickness.*

NOTE 5 *The following are examples of polyolefinic fillers, pigments, other additives and components:*

Name	Definition	Examples (non-exhaustive list)
Fillers	**3.1.8**	Inorganic minerals, such as chalk, talc, etc. Organic fillers such as starch, cellulose, recycled polyolefinic material. Either internal production scrap, or postconsumer recycling polyolefinic material. Blends of polyolefin fibres and viscose fibres.
Pigments	**3.1.10**	Colour masterbatches or liquid drop-in additives, usually added during the extrusion process.
Other Additives	**3.1.5**	Thermal processing aids, UV stabilizers, antioxidant stabilizers, clarifying agents.
Components	**3.1.6**	EvOH, PvOH, thermoplastic starch, recycled plastic content, tie-layers, metallized layers.

Annex C (normative) Preparation and testing of film and rigid samples for weathering

C.1 Instruments for film or rigid weathering testing

Films shall be tested for changes in their physical properties during weathering according to BS EN ISO 4892-3 or ASTM D4329-13 to study the impact of sunlight, heat and moisture on the material. Rigid samples shall be tested according to ASTM D2565-16 or BS EN ISO 4892-2 for impact by the full spectrum of natural light (UV, visible light and infrared energy). The used instruments shall be calibrated as defined per individual instrument by the producer of the instrument.

NOTE 1 *Ideally, the instrument is calibrated before each measurement.*

NOTE 2 *UV-accelerating weathering machines should be used for films and a Xenon-arc accelerating weathering machine for rigids. Other instruments are available, but any equipment used should conform with the methodologies described in the nominated ASTM and ISO standards.*

NOTE 3 *Other weathering cycles, which include condensation, humidity or spray, can be considered either for UV- or xenon-arc accelerated weathering.*

Other weathering cycles, which could include condensation, humidity or spay, shall be considered only if the weathering cycle is demonstrated to be equivalent to the correlated timeframes of the weathering cycles specified in this PAS, i.e. no longer than the equivalent of 3- or 4-months outdoor exposure under South Florida conditions.

C.2 Sample preparation of film or rigid samples

C.2.1 Film sample preparation during ASTM D4329-13/ BS EN ISO 4892-3 based measurements

Samples shall be cut into uniform shapes and inserted into the holders, depending on the chosen instrument. Samples shall be secured in the holders so that they are not lost during testing and can be recovered for analysis. Samples shall be treated in a uniform way prior, during and after the weathering.

C.2.2 Rigid sample preparation during ASTM D2565-16/ BS EN ISO 4892-2 based measurements

Samples shall be cut into uniform shapes and inserted into the holders, depending on the chosen instrument. Samples shall be secured in the holders so that they are not lost during testing and can be recovered for analysis. Samples shall be treated in a uniform way prior, during and after the weathering.

C.3 Parameters for weathering equipment

C.3.1 Parameters for weathering of rigid samples

The parameters for weathering equipment for exposure shall be as per ASTM D2565-16/BS EN ISO 4892-2:

a) light/dark cycle: 8 h UV and 16 h dark;
b) uninsulated black panel temperature: 70 ± 2 °C;
c) chamber air temperature: 60 ± 2 °C (for dark and light cycle);
d) irradiance: 0.35 ± 0.02 W/m^2 at 340 nm using daylight filters;
e) maximum total test time allowed: 672 h.

C.3.2 Parameters for weathering of film samples

The parameters for weathering equipment for exposure shall be as per BS EN ISO 4892-3.

Cycle duration: 1 h UV at 0.80 W/m^2 at 60 °C and 23h dark at 60 °C for 14 days.

C.4 Film or rigid sample handling

C.4.1 Film sample handling during BS EN ISO 4892-3/ ASTM D4329-13 based measurements

*COMMENTARY ON **C.4.1***

The following intervals for testing might be used: 3, 6, 7, 10, 12 and 14 days.

Samples shall be rotated every three days to ensure the uniformity of light exposure. At least three samples per tested material shall be tested in parallel.

NOTE 1 *Samples should be placed on labelled petri dishes for 48 h for conditioning at room temperature before performing any analysis.*

NOTE 2 *Samples should be labelled and areas with targeted exposure marked with a pen.*

NOTE 3 *Sampling could be performed during the weathering process through sacrificial sampling to yield reproducible results.*

C.4.2 Rigid sample handling during ASTM D2565-16/ BS EN ISO 4892-2 based measurements

*COMMENTARY ON **C.4.2***

The following intervals for testing might be used: 7, 14, 21 and 28 days.

Samples shall be rotated every three days to ensure the uniformity of light exposure. At least two samples per tested material shall be tested in parallel.

NOTE *Samples should be labelled and areas with targeted exposure marked with a pen.*

Annex D (normative) Carbonyl Index (CI) determination

D.1 Instruments for CI determination

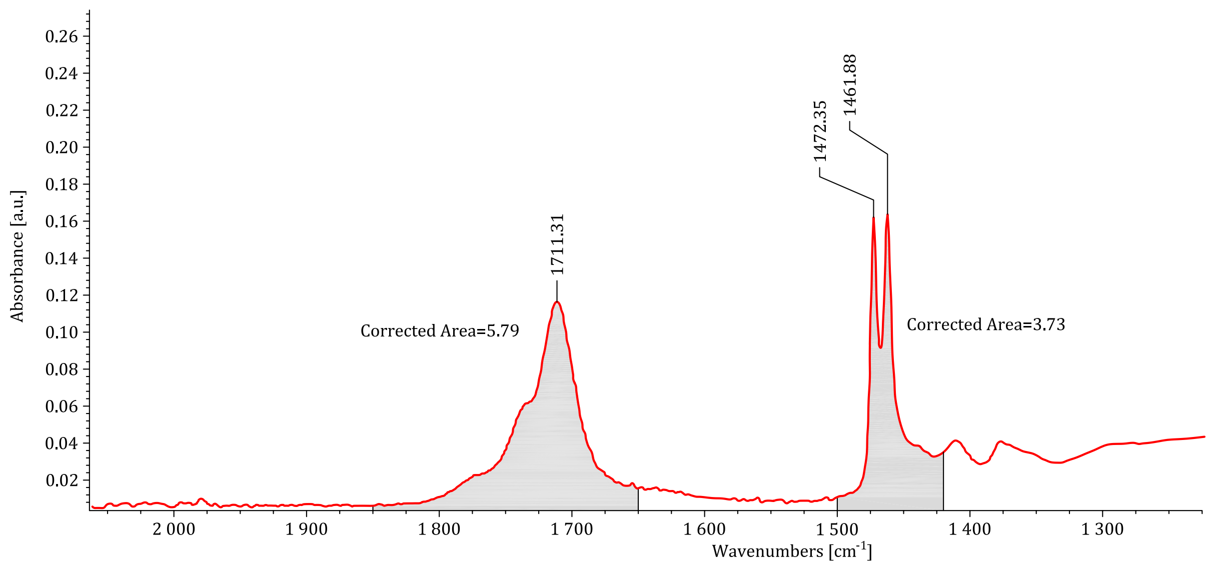
The CI shall be determined using an infrared (IR) spectroscopy measurement and the resulting IR spectrum. The spectrum shall be measured from a wavenumber of 0 to 4000 cm^{-1}, where the region of 500 to 3000 cm^{-1}, particularly the regions of 1420 – 1500 and 1650 – 1850 cm^{-1}, are in focus. The instrument shall be set up with a resolution of 4 cm^{-1} or lower and the number of scans shall be set to 32 or more. This method of recording the CI shall be the only method allowed by this PAS, as it has been demonstrated in literature. [5]

***NOTE** Several instrument types of this measuring technique are known across industries and in the plastics industry, as shown in BS ISO 20368, BS ISO 15063 or BS ISO 15064. The measurements should be performed on an ATR-FTIR.*

D.2 Measurement of IR spectrum

Instruments shall be calibrated before each measurement series, using the respective method described for the instrument chosen. Background noises shall be removed. A software able to integrate peak areas shall be used. Each CI per sample shall be measured at least three times.

Figure D.1 – IR spectrum of a polyolefin used as an example for determining CI



D.3 Calculation of the CI

To calculate the CI, the integral value of the peak area between 1850 – 1650 cm^{-1} and 1500 – 1420 cm^{-1} shall be determined using capable software.

***NOTE** Figure D.1 gives an example of a potential outcome of an integration.*

Based on the following equation, the CI shall be calculated using the following equation:

$$\textit{Carbonyl Index (CI)} = \frac{\textit{Area under band } 1850 - 1650\ cm^{-1}}{\textit{Area under band } 1500 - 1420\ cm^{-1}}$$

***NOTE** The value per area will be in the unit: arbitrary unit [a.u.].*

The average CI for each sample shall be determined from the three replicate spectra collected. The error shall be calculated as the standard deviation of the three CI values and presented with the CI.

Annex E (normative) Reporting in line with PAS 9017

E.1 Weathering and chemical analysis report

A written report containing all weathering and chemical analysis data created through the process specified in this PAS shall be produced. The report shall include the following:

a) the name of the manufacturer of the polyolefinic material, description and material composition – including polyolefin type and any other additives, pigments and components added;

NOTE 1 A detailed polyolefinic material composition stating resin grades and batch numbers might be included.

b) the date of polyolefinic material manufacture;

c) the name, type and % weight of biodegradable additive(s);

d) the names and addresses of all testing laboratories used;

e) the report on the weathering of the film samples in accordance with BS EN ISO 4892-1;

f) the report on the weathering of the rigid samples in accordance with ASTM D2565-16 or BS EN ISO 4892-1;

g) the total and applied timeframe for the weathering of films or rigid samples;

h) the CI of the film or rigid samples at the start and at the end of the weathering testing;

i) the CI as the average of three replicates and its standard deviation;

NOTE 2 The CI measurements during the weathering test might be reported in addition to the start and end values.

j) the molecular weight values for each film or rigid sample under test as per the stated ASTM or ISO guidelines cited in this PAS;

NOTE 3 If a different guideline is used, it should be named, and the information reported as stated within.

k) the number average molecular weight (M_n) and higher average molecular weight (M_z) in Daltons (Da); and

l) the % loss of weight average molecular weight (M_w). In addition, the start and end M_w values in Daltons (Da).

The weathering report and all chemical analysis reports shall be included with the PAS report as annexes.

E.2 Terrestrial toxicity report

A written report containing all terrestrial toxicity data created through the process specified in this PAS shall be produced. The report shall include the following.

a) If the sample is within a polyolefinic material category (see Annex B) where an eco-toxicity report has already been produced, the sample shall be reported in relation to this evaluation and the aforementioned report included.

b) The full report of the PAS of the correlated sample (previously tested) in the same polyolefinic material category in combination with the test report of the sample under evaluation.

c) If no previous PAS report exists for a similar polyolefinic material in the same polyolefinic material category as the sample under evaluation, an eco-toxicity report shall be produced.

The report shall state that the sample shall be deemed not biologically hazardous to terrestrial organisms if it meets all the criteria of the eco-toxicity tests.

An annex to the PAS report shall be included that contains the report of the eco-toxicity testing, which shall be produced in accordance with the OECD guidelines in **5.1** and **5.2** of each stated eco-toxicity test.

E.3 Biodegradation report

A written report containing all data created through the process specified in this PAS shall be created. The report shall include the following:

a) If the sample is within a polyolefinic material category (see Annex B) where a biodegradation report has already been produced, the sample shall be reported in relation to the aforementioned biodegradation report.

b) The full report of the PAS specification of the correlated sample (previously tested) in the same polyolefinic material category in combination with the test report of the sample under evaluation.

c) If no previous PAS report exists for a similar polyolefinic material in the same polyolefinic material category as the sample under evaluation, a biodegradation report shall be produced.

The report shall state that the sample shall be deemed to be in accordance with this PAS if it achieves greater than or equal to 90% biodegradation within 730 days (2 years).

An annex to the PAS report shall be added that contains the report of the biodegradation testing, which shall be produced in accordance with ASTM D5988-18/BS EN ISO 17556 guidelines for each sample tested.

Annex F (normative) Eco-toxicity testing

F.1 Specified concentrations of the samples to be tested

Limit level tests shall be conducted as per specified OECD guidelines in Table A.1. For the specification of this PAS, each eco-toxicity test shall be performed at a single maximum concentration as stated in the respective OECD guideline. These concentrations shall be:

OECD 202 [N1] and 211 [N3] – 100 mg per sample per 1 l of water.

OECD 208 [N2] and 222 [N4] – 1,000 mg per sample per 1 kg of soil.

F.2 Specified species to be tested in OECD 208 [N2]

For clarity, when performing OECD 208 [N2] on wax samples after weathering, two species shall be tested as per OECD 208 [N2] guidelines. The species shall be chosen exclusively from Annex 2 in OECD 208 [N2]. One species shall be chosen from the list of monocotyledonae species and one species shall be chosen from the dicotyledonae species.

Annex G (informative) Definitions from other sources

G.1 additive – from PD CEN/ISO TR 21960:2020

chemicals added to polymers to improve/change the individual properties of the specific plastic material

G.2 biodegradation – from BS EN ISO 472:2013+A1:2018

degradation caused by biological activity, especially by enzymatic action, leading to a significant change in the chemical structure of a material

G.3 biodegradation phase – from BS EN ISO 472:2013+A1:2018

time, measured in days, from the end of the lag phase of a test until about 90% of the maximum level of biodegradation has been reached

G.4 filler – from BS EN ISO 472:2013+A1:2018

relatively inert solid material added to a plastic or to an adhesive to modify its strength, permanence, working properties or other qualities, or to lower costs

***NOTE 1** Two classes of filler are used:*

- *chemically inert fillers, e.g. china clay or wood-flour;*
- *reinforcing fillers like silicates, carbon black, fibrous materials or aluminium powder that markedly enhance the performance of a polymer.*

***NOTE 2** A filler only used to reduce cost is termed an "extender". An extender can also be a liquid.*

G.5 film in plastics – from ASTM D883-20:1985

an optional term for sheeting having an average thickness not greater than 0.25 mm

G.6 land – from BS ISO 14055-1:2017

terrestrial bio-productive system that comprises soil, plant cover, other biota and the ecological and hydrological processes that operate within the system

G.7 microplastics – from the European Chemicals Agency [7]

material consisting of solid polymer-containing particles, to which additives or other substances may have been added, and where ≥ 1% w/w of particles have (i) all dimensions 1nm ≤x≤ 5mm, or (ii), for fibres, a length of 3 nm ≤x≤ 15 mm and length to diameter ratio of >3mm

G.8 pigment – from ISO 8604:1988

a substance, generally in the form of fine particles, that is substantially insoluble and is used because of its colour or decorative properties

G.9 polyolefins – from BS EN ISO 472:2013+A1:2018

thermoplastic polymer produced by the polymerization or copolymerization of olefins

***NOTE** Examples of olefins include ethylene, propylene.*

G.10 rigid plastic – from BS EN ISO 472:2013+A1:2018

plastic that has a modulus of elasticity in flexure or, if that is not applicable, then in tension, greater than 700 MPa

***NOTE** materials are usually classified at standard temperature and relative humidity in accordance with BS EN ISO 291.*

G.11 weathering – from ASTM D883-20a

exposure of plastics through contact with the earth's atmosphere, such as air, sunlight and moisture either through accelerated laboratory testing or natural outdoor exposure

Annex H (informative) Optional tensile strength testing for film samples

Tensile strength testing of films is optional and recommended if such information is desired. If desired, this PAS specifies that the tensile strength of film test samples should be recorded using elongation at break to determine the physical deterioration of the sample. The tensile strength should be recorded as the % elongation break of the sample and performed as the methodology described in ASTM D882-18 and BS EN ISO 527-3. The tensile strength of the film samples should be recorded at the start and at the end of the test. If at the end of the weathering test period or at any point during the weathering, the test sample becomes too brittle to record an elongation at break, the test sample should be assumed to be less than 5% elongation at break as denoted in ASTM D882-18 and BS EN ISO 527-3. If the film test sample records an elongation break value of less than 5% at the start of the test, prior to any form of weathering, the test should be deemed invalid. The elongation at break for each test sample should be reported as an average of three replicates.

NOTE 1 *Even if desired, this PAS does not specify the use of tensile strength testing for rigid test samples because other methods of determining the physical properties can vary depending on the type of rigid polyolefinic material being evaluated. Physical property measurements of a rigid, polyolefinic material under evaluation could be reported optionally as tensile strength, 3-point bend, impact force, etc., if related to the type of polyolefinic material under evaluation. The optional physical property measurement of the rigid sample should be reported at the start and end of the weathering to demonstrate the difference.*

NOTE 2 *Elongation at break measurements can be reported optionally on polyolefinic, fibre-based materials in cases where meaningful measurements can be recorded.*

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Hazardous Substances Advisory Committee

HSAC review of oxo-degradable plastics

July 2019

Summary

Largely in response to concerns over the unsightly consequences of visible littering, oxo degradable plastic forms were first invented in the 1970s. Current commercial oxo degradable plastics appear to be largely related to single-use polyethylene and polypropylene packaging and agricultural films. Within the parent material are embedded what are known as prodegradants which appear to be chiefly metal-organic complexes which help catalyse light and heat stimulated fragmentation of the polymer sheets. Thus, the intention is to speed up the natural fragmentation processes. Although this fragmentation into smaller and smaller plastic particles should be a helpful precursor to biodegradation, this has rarely been observed in a convincing manner outside laboratory conditions. There is no guarantee that oxo degradable plastics would receive the necessary pre-treatment of light and heat to start the fragmentation process. There is very little helpful literature available either on long-term field trials of biodegradation or ecotoxicity tests on a range of organisms for these plastics. Although there is worldwide concern over microplastic pollution of the environment, it remains the case that lethality to wildlife is more closely associated with large and intact plastic material. Nevertheless, a plastic which disintegrates more readily, may be at odds with the current strategy of controlling losses to the environment and might compromise the quality of recycled plastics.

Objectives of this review

In April 2019 Defra asked HSAC to review the topic of oxo-degradable plastics with special reference to:

- **The fate and environmental impact of oxo-degradable plastics in**
  - **the open environment, particularly marine; and**
  - **in the waste management system, including landfill, the recycling system or any other route;**
- **The plausibility of manufacturers' claims regarding the biodegradability of oxo-degradable plastics in light of this.**

The review was not meant to be exhaustive but to obtain an overview of the topic that reflects current knowledge.

Contents

Background

1.1 Disposable or single-use plastics

Many of the advantages, conveniences and indeed environmental benefits of modern life brought to us over the past 70 years has been thanks to the employment of plastics. About 4% of our fossil fuels go towards plastics manufacture (Hopewell *et al.*, 2009). Single use items such as disposable packaging are believed to represent 37% of the approximately 300 million tonnes annual production of plastic www.plasticseurope.org (Hopewell *et al.*, 2009). It is now recognised that these disposable or single use plastics represent a real challenge in waste management and environmental pollution. However, such plastics are not without environmental benefits. Plastic films and packaging have provided health and safety benefits, reduced food waste and lowered the costs of transportation (Andrady & Neal, 2009). Such applications typically employ plastics from the polyolefin family (long chain polymers formed from alkanes) and include polyethylene and polypropylene. We use linear low density polyethylene (LLDPE) films as plastic sheeting in agriculture and both low and high density polyethylene (LDPE and HDPE) in single-use plastic bags. The benefits of these plastics come from their properties of durability, flexibility, water repellence and light weight. These very same properties mean they can end up being dispersed far and wide and have extremely poor biodegradation properties in the natural environment (Albertsson & Karlsson, 1990, Ohtake *et al.*, 1998). They have molecular weights from tens of thousands to hundreds of thousands, are hydrophobic and their repeating C-C and C-H bonds are largely resistant to microbial attack (Koutny *et al.*, 2006). Based on existing studies, it might be predicted that it would take 300 to 500 years for the complete breakdown of an LDPE or HDPE product (Table 1).

Table 1: Assessing the rate of breakdown of standard polyolefins

Reference	**Form of plastic**	**Form of degradation**	**Medium**	**Incubation**	**Outcome**
Albertsson & Karlsson (1990)	PE	mineralisation	soil	10 years	<0.2% CO2
Ohtake *et al.* (1998)	LDPE	Generation of low MW by-products	soil	32 years	Predict 300 years needed for complete degradation of film

Restrepo-Florez *et al.* (2014)	LDPE	mineralisation	Soil or mineral media	30 d to 10 years	0.1-7.5% weight loss
Restrepo-Florez *et al.* (2014)	HDPE	mineralisation	Soil or mineral media	1-2 years	0.4-1.6% weight loss

Largely in response to the amenity impact of plastic litter, there has been interest in the development of plastics which fragment more rapidly than the standard commercial forms (Koutny *et al.*, 2006, Ammala *et al.*, 2011). Efforts to design more readily degradable plastics go back to the origins of plastics. There have been a number of strategies proposed to make the polyolefins more degradable with the first patents apparently dating back to the birth of these plastics in the 1940s and many appearing in the 1970s (Ammala *et al.*, 2011). These usually involve the use of additives called prodegradants within the polymer.

There is a now a worldwide realisation that plastics, particularly those associated with single use applications, are accumulating in the environment due to their poor degradative characteristics. This is particularly notable in the marine environment (Thompson *et al.*, 2009), where the problem appears to be getting rapidly worse (Ostle *et al.*, 2019). The plastic litter includes intact material, large fragments, microplastics and nanoplastics (Andrady, 2017). Although intact material and large fragments have been shown to be lethal to animals and birds in the marine environment (Azzarello & Vanvleet, 1987, Gregory, 2009, de Stephanis *et al.*, 2013), it is microplastics which receive the most attention. There are currently 1,830 papers on Web of Science with the word 'microplatics' in the title. Since 2014, the growth in the number of such publications has been exponential. It is possible to find microplastics routinely in the gullets of fish and molluscs (EFSA, 2016, Horton *et al.*, 2018). There have been a range of compounds and mechanisms which have been suggested to make microplastics harmful to wildlife (Thompson *et al.*, 2009). Whilst not a toxic effect, microplastic ingestion can be an energetic drag on organisms (Bour *et al.*, 2018). Some have argued that it is the additives within some plastics, such as phthalates and bisphenol A that could convey toxicity (Thompson *et al.*, 2009). The key step in any risk assessment is the comparison of such effect concentrations with levels found in the environment. Generally, the view is that the environmental levels of microplastics in water environments remain below effect levels except in exceptional circumstances (Connors *et al.*, 2017, Adam *et al.*, 2019).

1.2. Theory of polyolefin degradation and biodegradation

To facilitate complete microbial mineralisation it is necessary for the material to be broken down into smaller particles, suggested to be at least a maximum of 5000 Da in order to pass a cell membrane (Reddy *et al.*, 2009) and for the introduction of hydrophilic groups to increase water solubility (Ammala *et al.*, 2011). Thus, an oxo-degradable plastic might ultimately offer the potential for a more rapid disintegration into smaller particles and thanks to an increase in more hydrophilic groups, biodegradation might be encouraged.

Although the standard polyolefins are difficult to biodegrade, they can be disrupted by mechanical stress, high temperatures and most notably by photodegradation. In this case, the absorption of UV light leads, via the formation of CH-OOH hydroperoxide groups, to the generation of free radicals (short-lived molecules with an unpaired electron) which then react further with the polymer chain. These oxidation reactions can be detected as an increase in carbonyl groups ($R-(C=O)-R^{i}$) in the polymer, the proliferation of carbonyl groups increases its instability leading to further degradation (Ammala *et al.*, 2011). The mixture of photochemical and thermal abiotic degradation has been shown to lead to the formation of hydrophilic oligomers from the parent polymer (Eyheraguibel *et al.*, 2018).

This abiotic degradation mechanism is well known by the manufacturers and, ironically, it is common for plastics to contain additives to reduce propensity for this form of degradation. To this end, antioxidants are added to slow down abiotic degradation. These can be sterically hindered phenols to mop up free radicals and/or phosphites, phosphonites and thioesters to neutralise hydroperoxides. To reduce UV absorption, sterically hindered amine light stabilisers might be employed (Ojeda *et al.*, 2011).

2.0 Review of oxo-degradable plastics

2.1. Oxo-degradable plastics introduction

On the assumption that the disintegration of polyolefins into fragments is desirable in removing visible litter and may be a precursor to biodegradation, chemists have sought to enhance the natural photodegradation (and thermal breakdown potential) by adding molecules that speed up this natural process.

The most common prodegradant agents are the transition metals Fe, Co or Mn, introduced in trace quantities into the polymer product in a range of salts, fatty acid esters, amides, dithiocarbamates, ferrocene and metal oxides. It would appear that most of the current commercial oxo degradable plastics contain 1-5% by weight of a prodegradant including Fe, Ce, Co, Mn, Cu, Co or Ni within organic complexes (Ammala *et al.*, 2011). Fe is seen as being a particularly successful photo-inducer providing free radicals to start the abiotic reaction and Mn as catalysing further breakdown under heat (60 °C) ((Fontanella *et al.*, 2013). It would seem that temperatures above 40 °C are necessary for the heat activated reaction to be effective (Bonhomme *et al.*, 2003).

Other approaches include the introduction of organic groups that reduce stability in light, heat or moisture such as more carbonyl groups, oxo-hydroxy groups, unsaturated alcohols and esters, benzophenones, γ-pyrones, β-diketones, polyisobutylene, amines and peroxides. It is not clear if these organic prodegradants are present in the current commercial oxo-degradable plastics and no literature on their degradative potential in commercial products was found.

In the aspiration of stimulating microbial degradation as well as adding weaknesses to the plastic structure, substrates like starch may be added to the plastic (Lee *et al.*, 1991). Apparently the Reverte product from Wells Plastics Ltd contains micronized cellulose (Ammala *et al.*, 2011). These plastics may be called oxo-biodegradable plastics, although it is not clear if such terms have been standardised.

2.2. Oxo-degradable plastics and biodegradation

Both natural and oxo-degradable plastics degrade very slowly (Table 1 and 2). Given the very long timescales involved in biodegradation, from several to hundreds of years, it is common for researchers to simply demonstrate some level of biodegradation has happened rather than it being complete. Thus, a demonstration of degradation, or biodegradation being underway can be reported as an increase in carbonyl groups, a reduction in tensile strength, a reduction in molecular weight, additional CO_2 being generated or by the presence of microorganisms within the plastic structure itself (Table 2). These signals of partial degradation are different to the demonstration of the complete loss of the parent material.

Table 2: Assessing the degradation and biodegradation of polyolefins with prodegradants

(A) Examples of pre-treatment followed by incubation with microbial strain					
Reference	**Form of plastic**	**Treatment**	**Medium**	**Incubation**	**Outcome**
Albertsson *et al.* (1995)	LDPE with Fe prodegradant & starch	Heat then lab incubation with *Arthrobacter spps*	Lab medium and *Arthrobacter spps*	460 d	Microorganism consuming small MW by-products
Reddy *et al.* (2009)	LLDPE with or without prodegradant	14 d at 50-70 °C then 30 °C incubation with *P. aeruginosa*	Lab mineral medium and *P. aeruginosa*	42 d	Small improvement in biodegradation
Fontanella *et al.* (2010)	Variants of HDPE, LDPE and LLDPE with range of prodegradants	Photo-aging in lab and or 60 °C heat treatment then	*R. rhodochrous* in lab mineral medium	180 d	*R. rhodochrous* obtained energy from Fe and Mn prodegradant versions but not with Co

		incubation at 27 °C			
Fontanella *et al.* (2013)	Variants of PP with range of prodegradants	Photo-aging in lab and or 60 °C heat treatment then incubation at 27 C	*R. rhodochrous* in lab mineral medium	180 d	*R. rhodochrous* obtained energy from PP with Fe and Mn prodegradant versions but not with Co
Abrusci *et al.* (2013)	LDPE with Fe, Mn and Co stearate prodegradants	45-70 °C heat treatment for 9 d then irradiation for 10 d then culture incubation 30-45 °C	Different *Bacillus* spps and *Brevibacillus* in mineral medium at 30 or 45 C	90 d	Convincing abiotic changes with prodegradants present. Subsequent microbial incubation caused up to 45% mineralisation
(B) Examples of pre-treatment followed by incubation with soil or compost					
Reference	**Form of plastic**	**Treatment & pre-treatment**	**Medium**	**Incubation**	**Outcome**
Fontanella *et al.* (2010)	Variants of HDPE, LDPE and LLDPE with range of prodegradants	Photo-aging in lab and or 60 °C heat treatment then soil or compost incubation at 25 or 60 °C	Soil or compost incubation.	352 d	Soil gave 9-12% mineralisation and compost 16-24% (after 317 d) for Fe and Mn additives, but Co caused inhibition
Jakubowicz (2003)	PE with different quantities of prodegradant	Different heat 50-70 °C and O_2 for 70 d	Soil in lab at 29 or 60 C	70 d abiotic then 210 d	Abiotic degradation more influenced by heat than O2

		before soil incubation			level, then 60% mineralisation in soil in 210 d
Jakubowicz *et al.* (2011)	LLDPE with or without Mn prodegradant	40-70 °C then compost or soil incubation	Compost at 58 C or soil at 23 C	607 d	43% mineralisation in compost and 79% in soil after 607 d
Weiland *et al.* (1995)	LDPE with Co prodegradant	70 °C pre-treatment then incubation with cultures or composted	Lab or compost	83-150 d	Evidence of biodegradation
Husarova *et al.* (2010)	LLDPE with Mn & Fe prodegradant	70 °C oven 40-80 d then soil 25 °C or compost at 58 °C	Compost or soil	500 d	10-15% mineralisation in soil or compost
Ojeda *et al.* (2009)	HDPE and LLDPE with Mn prodegradant (d2W)	Held in open air for 1 year then composted at 58 °C	Air followed by compost	1 yr in air then 90 d composting	Prodegradant variety disintegrated/changed more readily in air and led to 12% mineralisation during composting
Chiellini *et al.* (2003)	LDPE & prodegradant from EPI	44 d at 55 °C heat pre-treatment then incubated in soil at 20 C or compost at	Soil or compost	525 d	50% mineralisation in soil and 80% in compost

		55 °C			
Ojeda *et al.* (2011)	HDPE and LLDPE with Co prodegradant vs same with antioxidants	Held in open air	air	270 d	Significant reductions in mass and increase in carbonyl groups with the prodegradant
Benitez *et al.* (2013)	PE vs LDPE & LLDPE with prodegradant	Heat 60 °C or air	air	260 d for air	Range of end-points show better degradation of the prodegradant variety
(C) Fate in the field following pre-treatment					
Reference	**Form of plastic**	**Treatment & pre-treatment**	**Medium**	**Incubation**	**Outcome**
Corti *et al.* (2012)	LLDPE with prodegradant	Sunlight exposure then burial	soil	830 d	5% more degradation than control LLDPE over 27 months
Chiellini *et al.* (2007)	LDPE & prodegradant from EPI	70 °C heat pre-treatment then incubated in river	river	100 d after heat treatment	10-30% mineralisation
Yashchuk *et al.* (2012)	Compared simple PE with PE with range of commercial prodegradant	50 or 110 °C then UV pre-treatment then composted	compost	90 d	No long-term difference over 90d (24% biodegradation)
(D) Fate in the field without pre-treatment					

Reference	Form of plastic	Treatment & pre-treatment	Medium	Incubation	Outcome
Musiol *et al.* (2017)	PE bag with Fe, Ce & Co prodegradant (TDPA)	4 m deep in real composting pile at 64 °C or water	Compost	70 d	Only minor changes
O'Brine & Thompson (2010)	PE bag with Fe, Ce & Co prodegradant (TDPA)	0.6 m deep in seawater	Sea water	280 d	Little discernible advantage in breakdown compared to standard PE
Napper & Thompson (2019)	HDPE control and two with prodegradants	Field study incubations	Kept in air or buried 25 cm in soil or 1 m deep in sea	830 d	One model of prodegradant had faster air disintegration than straight PE. Also more significant reduction tensile strength in soil and marine

2.3. Assessing the degradation and biodegradation potential of oxo-degradable plastics in laboratory environments

The evidence from the literature (Table 2 parts A and B) would suggest that provided a suitable pre-treatment has taken place, that is an exposure to natural or induced UV light and/or a thermal treatment, then some level of biodegradation of oxo-degradable plastics can be achieved subsequently under controlled conditions. The most complete biodegradation results were 45% mineralisation in 90 d using pure bacterial cultures in the laboratory (Abrusci *et al.*, 2013), 60% mineralisation in soil after 210 d (Jakubowicz, 2003) and 80% mineralisation in compost after 525 d (Chiellini *et al.*, 2003). All of these studies took place in controlled environments and involved quite extensive or aggressive pre-treatment conditions e.g. 70^{o}C. Where comparative studies have taken place in the laboratory, the breakdown performance has been better than for the same plastics without prodegradants.

2.4. Assessing the degradation and biodegradation potential of oxo-degradable plastics in natural environments

There have been few studies where biodegradation has been studied in the field following or in the absence of pre-treatment (Table 2 parts B and C). The lack of reported studies on the potential for oxo-degradable plastics to biodegrade (alongside standard polyolefins) under realistic field situations is disappointing. From the limited evidence available, there is little consensus on the advantageous biodegradation of oxo-degradable plastic from realistic field studies. For example, over 830 d the prodegradant LLDPE was 5% more degraded than the control (Corti *et al.*, 2012) but Yashchuk *et al.* (2012) saw no difference over 90 d. Without pre-treatment and in sea water O'Brine & Thompson (2010) saw no advantage in breakdown between PE bags with and without prodegradants. In general, there are surprisingly few published studies in the literature of systematic, replicated 'field trials' of oxo-degradable plastics in which specimens are monitored for breakdown and/or biodegradation under various naturally fluctuating conditions of temperature, light and moisture such as in soil, on soil surfaces, above ground, in fresh or sea water over prolonged periods (many months or years).

2.5. Toxicity and risks from oxo-degradable plastics

It is a struggle to find information in the scientific literature on whether oxo-degradable plastics themselves have harmful toxic properties. An agricultural tunnel plastic from Envirocare (believed to contain metal Fe, Ce and Co stearates) did not harm *Daphnia* or earthworms following OECD based tests (Bonora & De Corte, 2003).

The popular commercial oxo-degradable plastics including TDPI from EPI, Renatura from Nor-X industries, AddiFlex from Add-X Biotech and d2W from Symphony Environmental all contain metal complexes with different quantities of Fe, Mn, Cu and Ni (Ammala *et al.*, 2011). It should be noted that in a review of the relative risk of 71 different chemicals found in Britain's rivers, Cu came 1st (highest danger), Mn came 7th, Fe came 8th and Ni 12th in terms of risk (Johnson *et al.*, 2017). Consequently, the dispersion of more of these metals into the environment, particularly if they were to enter water courses would be unwelcome.

2.6 The case of the biodegradability of an alternative polymer, PVOH

As described in the introduction, single use plastics involved in packaging are typically from the polyolefin family. Plastic carrier bags being usually made from one of the varieties of polyethylene. This alternative product does not have the prodegradants present in oxo-degradable plastics, but proposes a different polymer altogether, that of polyvinyl alcohol (PVOH). Unlike PE, the PVOH is hydrophilic which should make biodegradation a more viable prospect (biodegradative enzymes being water-soluble themselves). The study by Boardman *et al.* (2017) describes carrying out a series of laboratory biodegradation experiments simulating industrial composting in both aerobic and anaerobic conditions, soil and marine environments. Biodegradation in most cases being judged by carbon loss through CO_2 and CH_4 generation compared to controls. In addition, they tested the toxicity of dissolved plastic on aquatic invertebrates and algae.

In aerobic conditions PVOH did fragment but little or no biodegradation occurred. The most positive results were associated food or wastewater derived anaerobic digestion (better than LDPE), although this did not lead to complete breakdown in the time allowed. No marine biodegradation was noted, although incubation in soil for a year was inducing a structural change in the polymer as judged by infra-red absorbance. Dissolved PVOH film did not harm the alga or *Daphnia magna*. No harmful effects were noted when juvenile lobsters were fed PVOH mixed as microplastic as 20% of their food stuff other than a possible reduction in growth rate.

2.7 The European Commission report on oxo-degradable plastics, April 2017

The European Union has decided to restrict the use of oxo-degradable plastics (Commission, 2018). A report was prepared in 2017 which reviewed the topic of oxo-degradable plastics and the environment (Hann *et al.*, 2017) to help inform The Commission. This report started by reviewing the wide range of EU and international standards on the biodegradability of materials in environments from composting to wastewater, marine and soil. The majority of these tests require evidence of substantial biodegradation within one year. The review supported the position that oxo-degradable plastics would be subject to faster abiotic degradation compared to standard polyolefins. The report reviewed biodegradation in compost where the evidence was seen as contradictory but they acknowledged that the manufacturers association made no claims on the product being compostable. The report went on to examine the potential for oxo-degradable plastics to biodegrade in the open environment. The authors were somewhat optimistic in their analysis, although it was acknowledged that biodegradation rates would inevitably be very slow. They noted that the industry had no specific standard to meet which left the ground open to claims that may be confusing to consumers. With regard to landfill, the authors thought it safest to assume no significant biodegradation would occur. With respect to marine biodegradation, the authors had insufficient evidence to come to a conclusion, although they were pessimistic as to the likelihood of this occurring. The authors did not come to a definite conclusion on whether oxo-degradable plastics and their fragments would be harmful to the soil ecosystem. The preoccupation of the authors in this case was with Co prodegradants (they did not refer to Fe, Mn or Ce prodegradants). The authors also reviewed whether the fragmentation of oxo-degradable plastics would reduce harm to wildlife in the marine environment. The authors acknowledged the potential benefits of reducing lethal impacts of wildlife being entrapped in intact plastics. They recognised that the breakdown of plastics into microplastics would lead to wider exposure to different trophic levels and inevitably to humans. They speculated that some toxic chemicals in microplastics would have wider environmental impacts. The other components of the report were related to recycling and consumer issues.

3.0 Conclusions

3.1. General Observations

- Standard polyolefins will photodegrade to fragments if held in the light. However, it would appear that it is common for commercial polyolefins to contain antioxidants or UV blockers to slow this process down.
- Standard polyolefins biodegrade very poorly if at all.
- There are a range of prodegradant chemicals available which when present in oxo-degradable plastics could theoretically speed up abiotic degradation of polyolefins. However, it appears the current range of prodegradants (as of 2011) rely on metal-based complexes.
- There is evidence that given suitable pre-treatment, involving exposure to light and or heat, in the presence of oxygen, that oxo-degradable plastics undergo a series of changes including fragmentation and the formation of many carbonyl groups which could facilitate subsequent biodegradation.
- Following suitable pre-treatment involving exposure to light and/or heat the oxo-degradable plastics can act as a substrate for some bacterial species and be used as a carbon and energy source under laboratory conditions.

3.2. Weaknesses in our understanding

We only appear to have evidence on the fate of oxo-degradable plastics containing metal-based complexes and not for those with organic prodegradants. It is not clear if organic prodegradants are present in commercial products.

It would be useful to know if the incorporation of biodegradation promoters such as cellulose or starch offer benefits to the biodegradation of polyolefins.

There is no guarantee that discarded oxo-degradable plastics will receive sufficient light and or thermal pre-treatment before they enter waste disposal systems to facilitate degradation. It is not clear what this minimum desirable light and/or heat pre-treatment should be.

There are very few field studies on long-term degradation of oxo-degradable plastics with standard plastics under the typical fluctuating and diverse conditions.

3.3. Returning to the Defra questions:

- **The fate of oxo-degradable plastics in**
  - **the open environment, particularly marine;**

There are few studies on the degradation of oxo-degradable plastics in the natural environments of terrestrial, river and marine. To a large degree, the results depend on whether sufficient pre-treatment of UV exposure and or heat was applied before the environmental biodegradation study took place. This pre-treatment step did not happen with a recent soil and marine degradation study (Napper & Thompson, 2019). However, it is clear that the marine environment is not conducive to the abiotic degradation of oxo-degradable plastics due to bio-fouling and sinking which reduce UV exposure whilst the low temperatures also reduce abiotic degradation (O'Brine & Thompson, 2010). In other words, the oxo-degradable plastics approach is not a solution to plastic litter once it is within the marine environment.

- **The environmental impact of oxo-degradable plastics in**
  - **the open environment, particularly marine;**

It would seem retrogressive to be introducing more metals into the terrestrial or freshwater environments, although the quantities involved are not clear, nor is it clear whether metals would indeed be released. However, it may be that some oxo-degradable plastic products since 2011 do not use metal complexes and do not have this deficit, but we do not have this product information.

The disintegration of plastic litter into microplastics will increase the chances of exposure to wildlife. This does not necessarily lead to bioaccumulation, since it is likely that microplastic particles will also be excreted. Except in cases of very high exposure, we do not yet have evidence that microplastics are or could be harming wildlife. This does not imply safety, simply that experiments showing serious impacts at environmentally relevant levels are not yet abundant in the literature.

Currently the strongest evidence for harm to wildlife is from intact or large fragments of plastic harming apex predators and omnivores (Azzarello & Vanvleet, 1987, Gregory, 2009, de Stephanis *et al.*, 2013). These effects are largely linked to entrapment and prevention of food ingestion leading to starvation. Such harmful impacts on these animals may reduce if plastics did reduce to small particles more quickly.

  - **in the waste management system, including landfill, the recycling system or any other route;**

Ideally, all plastic, in both developed and developing worlds would be captured and treated inland, either recycled or used as an energy source. However, the mixture of oxo-degradable plastics with those plastics without prodegradants might potentially compromise the recycled product. In the developing world, in countries without refuse collection, landfill or recycling facilities, a high proportion of single use plastics end up in the ocean (Rhodes, 2018). It is clear that due to weaknesses in institutions and governance, this source of plastics is not going to be curbed soon (Dauvergne, 2018). In such cases, the breakdown of polyolefins that make up single use packaging, into smaller and smaller particles before they are carried to the sea might lead to a helpful reduction in lethal cases of entanglement and smothering.

Treatment via composting and heat, ensuring oxygen is present is an essential precursor to the oxo-degradable plastic biodegradation. Nevertheless, whilst composting might start the process, biodegradation remains a lengthy affair and so a compost product is still likely to contain plastic fragments. Studies of polyolefins in landfills show little detectable degradation over time (Hamilton *et al.*, 1995) and it would seem that oxo-degradable plastics do not show any improvement on this situation, at least from a one year study (Adamcova & Vaverkova, 2014). Most parts of a landfill are entirely anaerobic and this would not permit the necessary oxidation needed for oxo-degradable plastics fragmentation.

- **The plausibility of manufacturers' claims regarding the biodegradability of oxo-degradable plastics in light of this;**

The literature describing controlled laboratory conditions would support the theory behind the biodegradability of oxo-degradable plastics. However, the evidence for convincing biodegradation under entirely natural conditions (outside the laboratory) is very sparse and much less clear. More realistic studies in a range of natural environments are strongly recommended to properly understand the long-term degradation and/or biodegradation of these plastics in the open environment over reasonable time periods. The literature as a whole suggests that current oxo-degradable plastics have not been demonstrated to provide a substantial improvement in terms of complete biodegradation or breakdown over existing standard plastics in the open environment.

Avoiding the use of plastic packaging where possible and maximising the recovery and recycling of such plastics should remain the central planks of our management strategy.

Competing interests

The lead author has declared no competing interests.

Glossary

Oxo-degradable plastic: A plastic (usually a polyolefin) containing agents which help catalyse oxidation reactions to weaken and fragment the plastic. The industry would now prefer to use the term 'thermo- or photofragmentable plastics'

Oxo-biodegradable plastic: Poorly defined term that may reflect the claim that oxidising agents and fragmentation will lead to biodegradation or the presence of other agents that specifically stimulate biodegradation

PAC Plastic: Pro-oxidant additive containing plastic (another description of oxo-degradable plastic)

Degradation: The breakdown by either biotic or abiotic means of a substance

Biodegradation: The breakdown by purely biotic means of a substance. This process is carried out by bacteria or fungi. This does not imply anything about the rate, or completeness of the process

Mineralisation: This is where the original substance is converted to simple molecules like CO2 and H2O

Polyolefins: Family name for simple plastic polymers such as PE and PP. These are often associated with films, packaging, bags and containers

Prodegradant: General term for additive present in the plastic which promotes degradation (abiotic or biotic)

PE: Polyethylene is a classic long chain CH2-CH2-CH2 polymer

HDPE: High density polyethylene which is a form of PE with a density of greater or equal to 0.941 g/cm3 and has a low degree of branching. Used in items like bottles, toys and water pipes

LDPE: Low density polyethylene which is a form of PE with a density range of 0.910–0.940 g/cm3 containing both short and long-chain branching. Can be used in containers, plastic bags and film wrap

LLDPE: Linear low density polyethylene which is a form of PE with density of 0.915–0.925 g/cm3 and contains significant numbers of short branches. Transparent and robust, it is often used in agricultural films and bubble packaging

PP: Polypropylene a polymer of CH2-CH(CH3)-CH2with a density between 0.895 and 0.92 g/cm^3. Applications include bottles and containers

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From: [Redacted]@zerowastescotland.org.uk>
Sent: 11 March 2022 13:58
To: [Redacted]@hutton.ac.uk
Cc: [Redacted]@gov.scot>
Subject: Oxo degradables research

[Redacted]

It was really good to meet you and thank you for looking into this. I've attached a couple of documents that may help, the PAS document is one of the 'standards' I mentioned and the HSAC document that I mentioned.

Give me a shout if there is anything else I can help with.

[Redacted]

PAS 9017.pdf

hsac-non-branded-ox
odegradables (3) (1).p

[Redacted]

From: [Redacted]@gov.scot
Sent: 16 March 2022 14:19
To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk
Cc: [Redacted]@gov.scot>
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

8 weeks is OK for us thanks [Redacted].

From: [Redacted] @hutton.ac.uk>
Sent: 16 March 2022 14:18
To: [Redacted] @gov.scot>; [Redacted] @zerowastescotland.org.uk
Cc: [Redacted] @gov.scot>
Subject: FW: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted]

I am almost ready with the Project plan and about to send it for an internal review before sending it to you. In my email to [Redacted] (please see below), I had mentioned 6-8 weeks as the delivery timescale. I realise that at our meeting on Friday, I mentioned the delivery time scale as 6 weeks. Would it be okay to change this to 8 week timescale? Will that inconvenience you? That will give me a chance to use some holidays I have accrued before end of March. I am available to start the project immediately once all required formalities are complete.

Please let me know if the 8-week delivery timescale is going to inconvenience you and I shall stick to the 6-week delivery time scale, everything else being the same.

Thank you

Kind Regards

[Redacted]

From: [Redacted] @hutton.ac.uk>
Sent: 02 March 2022 12:20
To: [Redacted] @gov.scot>; [Redacted] @hutton.ac.uk>
Cc: [Redacted] @gov.scot>; [Redacted] @gov.scot>; [Redacted] @hutton.ac.uk>; [Redacted] @gov.scot>; [Redacted] @gov.scot>; [Redacted] @gov.scot>; [Redacted] @gov.scot>
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted],

Thank you for the information on the requirements for the evidence review on oxo-biodegradable plastics.

Six to eight weeks is what I am thinking, to deliver this evidence review- as this will enable me to fit with my other work and should also help in assimilating the findings. Please let me know your thoughts about the timescale. Happy to work around it. Happy for a discussion with [Redacted]

Thank you

Kind Regards

[Redacted]

From[Redacted]@gov.scot>
Sent: 02 March 2022 10:56
To: [Redacted]@hutton.ac.uk>; [Redacted]@hutton.ac.uk>
Cc: [Redacted]@gov.scot; [Redacted]@gov.scot; [Redacted]@hutton.ac.uk>; [Redacted]@gov.scot; [Redacted]@gov.scot; [Redacted]@gov.scot; [Redacted]@gov.scot
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

[External email]
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Hi [Redacted],

I attach a short specification of what we require from this review. Essentially it is a review of evidence to establish the degree to which oxo-biodegradable plastic products cause pollution of the environment.

I am really not sure how much literature there is out there on the topic and therefore how long it will take you to complete. We would really appreciate for you to undertake the review as quickly as possible but are also mindful of your other work. If you are able to give an indication of the timeframe that you think you could do this in that would be great.

I am copying in my Single-Use Plastics Policy colleagues [Redacted]who may be able to give you more details on the requirement. Perhaps a short conversation about it would be helpful to you for discussing scope and timings?

Thanks very much and look forward to hearing from you.

[Redacted]

From: [Redacted]

From: [Redacted] @hutton.ac.uk>
Sent: 25 February 2022 10:03
To: [Redacted] @gov.scot>; [Redacted] @hutton.ac.uk>; [Redacted] @sruc.ac.uk>; [Redacted] @sruc.ac.uk; [Redacted] @hutton.ac.uk>
Cc[Redacted] @gov.scot>; [Redacted] @gov.scot>; [Redacted] @hutton.ac.uk>; [Redacted] @sac.co.uk
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted],

Thank you, looking forward to working on this topic- evidence gathering on oxo-biodegradable plastics.

Thank you

Kind Regards

[Redacted]

From[Redacted] @gov.scot>
Sent: 25 February 2022 09:43

To: [Redacted] @hutton.ac.uk>; [Redacted] @sruc.ac.uk>; [Redacted] @sruc.ac.uk; [Redacted] @hutton.ac.uk>; [Redacted] @hutton.ac.uk>
Cc: [Redacted] @gov.scot; [Redacted] @gov.scot; [Redacted] @hutton.ac.uk>; [Redacted] @sac.co.uk
Subject: RE: review into environmental impacts of oxo-degradable products - call down project

[External email]
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Hi [Redacted],

That's great. Thanks a lot. [Redacted]I will follow up with you shortly.

Cheers

[Redacted]

From: [Redacted] @hutton.ac.uk>
Sent: 23 February 2022 20:10
To: [Redacted] @gov.scot>; [Redacted] @sruc.ac.uk[Redacted] @sruc.ac.uk; [Redacted] @hutton.ac.uk>; [Redacted] @hutton.ac.uk>
Cc: [Redacted] gov.scot>; [Redacted] @gov.scot>; [Redacted] @hutton.ac.uk>; [Redacted] @sac.co.uk
Subject: Re: review into environmental impacts of oxo-degradable products - call down project

Hi [Redacted],

[Redacted] (included in this reply) would be interested in taking on this work. This email is simply to make that connection. Over to you.

Cheers

[Redacted]

Get Outlook for Android

From: [Redacted]@gov.scot>
Sent: Wednesday, February 23, 2022 4:48:34 PM
To[Redacted]@hutton.ac.uk>; [Redacted]@sruc.ac.uk>; [Redacted]@sruc.ac.uk

Cc: [Redacted]@gov.scot>; [Redacted]@gov.scot>; [Redacted]@hutton.ac.uk>; [Redacted]@sac.co.uk>
Subject: review into environmental impacts of oxo-degradable products - call down project

[External email]
Do not click links or open attachments unless you recognise the sender and know the content is safe

Dear [Redacted]

I am writing to you all as part of the RESAS SRP C4 circular economy research team as I am not quite sure who to direct this request to.

Our policy team are in need of an evidence review to support our implementation of Article 5 of the EU Single-use Plastics Directive. The Directive requires that all oxo-degradable products are banned. However, manufacturers of oxo-biodegradable products (a sub-set of oxo-degradables) claim that this substance is sufficiently different and better for the environment than oxo-degradables and so shouldn't be included in this ban. As a matter of urgency we need to determine if there is evidence to support this assertion.

We are therefore wondering if somebody from SRUC or JHI would be able to conduct a review of the evidence on this for us through the calldown budget? My sense is that there is probably limited evidence available but it would be good to know if this is indeed the case. I think the topic is materials science but I suppose a general review could be undertaken by a non-specialist.

I would be grateful if you could let me know if this is something that you might be able to help with? Happy to follow up with more details.

Thanks
[Redacted]

REVIEW OF EVIDENCE ON OXO-BIODEGRADABLE PLASTIC PRODUCTS

Background

EU Directive 2019/904 requires member states to ban all Single-use plastic products (SUP) as covered by Article 5 of the Directive, which came into effect from 3 July 2021. These SUPs include 'oxo-degradable' plastic products. The Directive defines Oxo-degradable plastics as '*plastic material that include additives which, through oxidation, lead to the fragmentation of the material into micro-fragments or to chemical decomposition'* [1]. This implies oxo degradable products only physically degrade but do not biodegrade i.e., naturally occurring microorganisms are unable to assimilate these materials. They are also not fully compostable (i.e., under controlled conditions they do not completely degrade to carbon dioxide or methane, water and inorganic compounds) [2,3]. This can result in potential accumulation of microplastics in the environment. The Directive also states that, all plastic producers should be encouraged to strictly limit formation of microplastics in their products.

Oxo-**bio**degradable plastics, a subset of oxo-degradable plastics, use (proprietary) pro-oxidant additives, typically salts of transition metals like nickel, iron, manganese, cobalt, to first break down the polymer into smaller fragments, so that microorganisms can subsequently process these fragments. Manufacturers of oxo-biodegradable plastics claim that as these are biodegradable, they should not be included in the ban [4]. Although the presence of pro-oxidants (prodegradants) undoubtedly accelerate the fragmentation process, the main issue with this category of plastics however is that they are expected to 'bio'degrade in the open environment (where oxygen is present) or landfill, but they are not fully compostable within specified timescales. This leads to the issue of lack of clarity of suitable standardised tests for biodegradability, similar to ASTM D6400, which is being used for conventional compostable plastics. Unlike controlled compostable environments, natural environments are more complex with many factors contributing to rate of degradation. This may lead to potential for increased littering and consequently, build-up of oxo-biodegradable plastics fragments, including microplastics in the environment. This is against the principles of EU Directive which promotes circular economy to reduce plastic waste generation and leakage of plastic waste in the environment, while prioritising sustainable and non-toxic re-usable products rather than single-use products.

Project Scope

- As specified in the Scottish Government Policy Call down document, this research will focus on gathering evidence focussing on only oxo-biodegradable category of plastic products and materials, including Mulching films
- The project will be a desk-based study drawing evidence from peer reviewed publications and grey literature (from Google, Google Scholar and Web of science).
- While the risks and impacts from microplastics that may be derived from oxo-biodegradable products will be discussed in this review (backed by literature evidence), it may not be possible to gather exhaustive literature evidence on the environmental impacts associated with microplastics which is an on-going field of research.

The overall aim of this research is to review evidence of environment impact of oxo-biodegradable plastic products to support Scottish Government (SG) policy officials and analysts in implementing Article 5 of the Directive (EU) 2019/904. Also, to determine the type and size of oxo-biodegradable products currently available in the market. This will be achieved through the following objectives set out in the SG specification document:

Objective1: An explanation of how oxo-biodegradable plastic products differ in comparison to oxo-degradable plastic as defined in the EU SUP Directive.

To get a clear understanding of the specific differences between oxo-degradable and oxo-biodegradable plastics, the EU SUP Directive [1] and any references there in, will be used. Where required, information will also be gathered from materials such as journal publications and information from manufacturer's specifications. The research will look into differences such as abiotic/biotic degradations, type of additives used for each category, types of polymer backbone, Standards/Test method and conditions used for degradability.

Objective2: What oxo-biodegradable plastic products are on the market in Scotland.

The types of different oxo-biodegradable commercial products currently available in Scottish market, will be reviewed. We will include information on the availability and usage of oxo-biodegradable mulching films (muching films are considered as a significant source of microplastics to the terrestrial environment).
Product manufacturers and retailer details will also be gathered. Where possible, information will be obtained of each product's market size if available as open-source information.

Overall, this objective should provide an indication of product re-usability, life cycle, littering and potential for microplastic build-up in the environment.

Objective3: The environmental impact of oxo-biodegradable plastic products

Any available evidence will be reviewed on the environmental impact, both terrestrial and marine, from specifically oxo-biodegradable products.
Risks and impacts will include but not limited to, rates of microplastics formation, their residence times in the environment, preferential microbial assimilations based on polymer types, Greenhouse gas emissions, accumulation/toxicities of transition metal additives in the environment used in these products, life cycle analysis. Also, any evidence available on in terms of human behaviour, i.e., our perception to usage and disposal of oxo-biodegradable products that can lead to increased littering (instead of recycling or reusing) will also be reviewed.

Objective4: Any differences in environmental impact between oxo-degradable and oxo-biodegradable materials

Available evidence on differences/similarities in chemical and physical properties of oxo-degradable and oxo-biodegradable polymer materials and their associated environmental impacts, will be reviewed.
Some of the questions this evidence will try to find answers for, on the differences between oxo-degradable and oxo-biodegradable materials, include but not limited to:

- what are the differences in the types of additives used, their roles in causing oxidative/biological degradation?
- what types of polymers are used for each category and whether these are petroleum based?
- does microbial preference for assimilation differ between petroleum-based polymer fragments and renewable derived polymer fragments?

- what test conditions were used for degradability/biodegradability; whether these test conditions are suitable to Scottish environmental conditions, i.e., landfill/open environment, where oxo-degradable and oxo-biodegradable end life products are expected to end up; whether the tests were conducted using virgin or end-of-life polymeric materials?

Project Lead

[Redacted]

Project timescale and costs

Project stage	Week1	Week2	Week3	Week4	Week5	Week6	Week7	Week8
Project plan submission; confirm scope	■							
Literaure review, evidence gathering	■	■	■	■	■	■	■	
Mid-term discussion Meeting with Policy team				■	■			
Draft final report(including feedback from internal review & Scottish Government team)						■	■	
Final Report (including PowerPoint presentation, if requested)								■

This project would require 14 days of [Redacted] time and 8 weeks delivery timescale. [Redacted] is available to commence the project from 21st March (assuming all formalities are complete by then), with final report submission by 13th May 2022.

Reporting

The project will produce a short report (c. 10-15 pages) in non-academic style and tailored to the reporting requirements of the Scottish Government. About mid-way, from the start date of the project (w/c 18th April), we will organise a meeting with Scottish Government policy members to discuss progress, findings, and obtain feedback. It was discussed that for any quick clarifications, the Scottish Government policy members involved in this project can be contacted, in between. Upon completion of evidence gathering, we will organise another meeting (w/c 2nd /9th May), to finalise the report structure. The James Hutton Institute has an internal review policy in place, to ensure all publications are of good quality. [Redacted] would be willing to present the findings as a PowerPoint presentation at the final meeting.

References

1. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L09042.
2. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/817684/review-standards-for-biodegradable-plastics-IBioIC.pdf
3. Polymers for Advanced Technologies 2021;32:1981-1996
4. https://www.biodeg.org/wp-content/uploads/2021/01/OPA-response-to-Scottish-Consultation-31-12-20-2.pdf

From: [Redacted]@hutton.ac.uk>
Sent: 17 March 2022 14:13
To: [Redacted]@gov.scot>; [Redacted]@zerowastescotland.org.uk
Cc: [Redacted]@gov.scot>
Subject: Project Plan

Hi [Redacted]

Please find attached the Project plan. I have passed on the required details to our Projects Office who deal with the Costings etc. I will let you know the project start date once I hear from them. Please let me know if you require any clarification in the Project plan.

EU SUP
Oxo-degradables Proj

From: [Redacted]@gov.scot
Sent: 11 April 2022 11:26
To: [Redacted]@hutton.ac.uk>
Subject: RE: Project Plan

Teams thanks [Redacted].

From: [Redacted]@hutton.ac.uk>
Sent: 11 April 2022 11:10
To: [Redacted]@gov.scot>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot>
Cc: [Redacted]@gov.scot>
Subject: RE: Project Plan

Hi [Redacted],
Yes, I am available- for the meeting request, would Webex be okay or do you prefer MS Teams?

Thank you
Kind Regards
[Redacted]

From: [Redacted]@gov.scot>
Sent: 11 April 2022 11:06
To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot
Cc[Redacted]@gov.scot
Subject: RE: Project Plan
From: [Redacted]@gov.scot>
Sent: 11 April 2022 11:06
To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot
Cc[Redacted]@gov.scot
Subject: RE: Project Plan

Hi [Redacted]

Are you available at 11am on Thursday this week?

Regards,

[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 11 April 2022 09:52
To: [Redacted]@gov.scot>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot>
Cc: [Redacted]@gov.scot>
Subject: RE: Project Plan
As per the project plan, would it be possible to have a mid-term discussion meeting anytime this week or next? I am available all days except 20th.

If you can let me know a suitable date, I will send the meeting request.

[Redacted]

From: [Redacted]@gov.scot>
Sent: 29 March 2022 13:46
To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot
Cc: [Redacted]@gov.scot
Subject: RE: Project Plan

[External email]
Do not click links or open attachments unless you recognise the sender and know the content is safe

And to confirm – No concerns from an SG perspective either thanks [Redacted].

Regards,

[Redacted]

From: [Redacted] @hutton.ac.uk>
Sent: 28 March 2022 15:36
To: [Redacted] @zerowastescotland.org.uk>; [Redacted] @gov.scot>; [Redacted] @gov.scot>
Cc: [Redacted] @gov.scot>
Subject: RE: Project Plan

Thank you [Redacted].
Kind Regards
[Redacted]

From: [Redacted] @zerowastescotland.org.uk>
Sent: 28 March 2022 14:28
To: [Redacted] @hutton.ac.uk>; [Redacted] @gov.scot; [Redacted] @gov.scot>
Cc: [Redacted] @gov.scot
Subject: RE: Project Plan

[External email]
Do not click links or open attachments unless you recognise the sender and know the content is safe

Hi,

Apologies for the late reply but this project plan looks great, thanks [Redacted].

[Redacted]

[Redacted]

From: [Redacted] @hutton.ac.uk>
Sent: Wednesday, March 23, 2022 11:44 AM
To[Redacted] @gov.scot; [Redacted] @zerowastescotland.org.uk>; [Redacted] @gov.scot>
Cc: [Redacted] @gov.scot
Subject: RE: Project Plan

Thank you [Redacted]. I was informed by the Hutton Projects office that the project has now been set up (with start date as 21st March).

Kind Regards
[Redacted]

From: [Redacted]@gov.scot>
Sent: 21 March 2022 15:27
To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot
Cc[Redacted]@gov.scot
Subject: RE: Project Plan

[External email]
Do not click links or open attachments unless you recognise the sender and know the content is safe

Thanks [Redacted], we'll come back with any comments by early next week. [Redacted] is off on annual leave at the moment.

Kind regards,

[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 17 March 2022 14:13
To: [Redacted]@gov.scot>; [Redacted]@zerowastescotland.org.uk
Cc: [Redacted]@gov.scot>
Subject: Project Plan

Hi [Redacted]
Please find attached the Project plan. I have passed on the required details to our Projects Office who deal with the Costings etc. I will let you know the project start date once I hear from them. Please let me know if you require any clarification in the Project plan.

Thank you
Kind Regards
[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 13 May 2022 13:32
To: [Redacted]@gov.scot>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot>
Subject: RE: Project Plan

Hi [Redacted]

Hope you are doing well.

I am in the process of finishing the Evidence Review Report. I have completed writing a reasonably good portion of it, but unfortunately I am unable to submit the final report version today, although today is the official closing date for the Project.

I intend to send the report for internal review to colleagues on Monday, with whom I have already discussed. Once I receive their feedback I will shall submit the final version, which should be sometime next week.

Hope that is okay with you and apologies for not making it today .

[Redacted]

From: [Redacted] @hutton.ac.uk>
Sent: 19 July 2022 12:10
To: [Redacted] @gov.scot>; [Redacted] @zerowastescotland.org.uk
Cc: [Redacted] @gov.scot>; [Redacted] @gov.scot>
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

Hi [Redacted],
Thank you. I will be happy to discuss the findings with SEPA, you and [Redacted]in the call.

Kind Regards
[Redacted]

From: [Redacted]@gov.scot>
Sent: 19 July 2022 10:10
To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk
Cc: [Redacted]@gov.scot; [Redacted]@gov.scot
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

[External email]
Do not click links or open attachments unless you recognise the sender and know the content is safe

Thanks [Redacted], I'll get this over to you at the end of the week.

Could you confirm if you'd be available to join a call with the Scottish Environment Protection Agency and talk them through your findings? They have an interest in the environmental impact of these products. Myself and [Redacted]would also be on the call.

Kind regards,

[Redacted]

From[Redacted] @hutton.ac.uk>
Sent: 15 July 2022 12:54
To: [Redacted] @gov.scot>; [Redacted] @zerowastescotland.org.uk
Cc: [Redacted] @gov.scot>; [Redacted] @gov.scot>
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

Hi [Redacted],

Sorry for the delay in getting back to you as details of the publication process needed to be first discussed internally.

The work will be published on both Hutton e-Outputs webpage as well as my webpage. However, we need input from you in relation to the context for James Hutton undertaking this work. For example "This work was commissioned by the Scottish Government based on a specific set of questions. Any questions around policy can be directed to [Redacted]." You probably have this kind of standard text.

I will keep you in the loop until the publication is completed.

Thank you

Kind Regards

[Redacted]

From: [Redacted]@gov.scot>
Sent: 07 July 2022 10:20
To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk
Cc: [Redacted]@gov.scot; [Redacted]@gov.scot
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

[External email]
Do not click links or open attachments unless you recognise the sender and know the content is safe

Hi [Redacted]

Apologies for the long delay in getting back to you, combination of sickness and workload.

Publication by the JHI would be preferable thanks, bearing in mind the work could attract significant attention if we were to progress a ban on oxo-degradable plastic products, whatever approach you think is best to do this.

Could you let me know what you need from us? I can be the SG contact for any queries and provide any information you require.

Kind regards,

[Redacted]

From: [Redacted] @hutton.ac.uk>
Sent: 16 June 2022 14:36
To: [Redacted] @gov.scot>; [Redacted] @zerowastescotland.org.uk; [Redacted] @gov.scot>
Cc: [Redacted] @gov.scot>
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

Hi [Redacted],

Having discussed this internally, it was advised that it would be better if SG can publish it as SG are in a better position to provide the context for commissioning the study and also answer any subsequent policy related enquiries.
If you wish, one alternative might be that I could upload the Review on my Hutton webpage, but this would have a narrower reach. Also, if that is the case, I would need more information from you such as project reference/contact details of somebody from policy division, to handle subsequent related enquiries.

Please let me know how you wish to proceed.
(Happy to have a quick chat, over the phone if you wish).

Thank you
Kind Regards
[Redacted]

From: [Redacted]@gov.scot>
Sent: 13 June 2022 17:22
To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot
Cc: [Redacted]@gov.scot
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

[External email]
Do not click links or open attachments unless you recognise the sender and know the content is safe

Hi [Redacted]

Apologies, only just getting a chance to look at this now. Could you confirm if JHI plans on publishing this? Not sure we got to the bottom of that previously.

If not, [Redacted] could you please confirm if it's possible/standard practice for SG to publish this work? Bearing in mind we might want to refer directly to it when explaining our reasoning behind policy decisions.

Thanks,

[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 27 May 2022 10:34
To: [Redacted]@gov.scot>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot>
Cc: [Redacted]@gov.scot>
Subject: Evidence Review on Oxo-biodegradable plastic products-Final

Hi [Redacted]

Please find attached the Evidence Review on Oxo-biodegradable plastic products.
Apologies for the delay (as I sent it for internal review only last week and it took a week to produce this final version).
Please let me know if there is any other formality to complete.
Happy to provide any clarification.
Thank you very much for the nice discussions we had. I enjoyed working with you.

Thank you
Kind Regards
[Redacted]

From: [Redacted]@hutton.ac.uk>
Sent: 10 August 2022 08:50
To: [Redacted]@gov.scot>; [Redacted]@zerowastescotland.org.uk
Cc: [Redacted]@gov.scot>; [Redacted]@gov.scot>
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

Hi [Redacted],

Wanted to let you know that the Report is now published in the Hutton website: https://www.hutton.ac.uk/sites/default/files/files/publications/Review-evidence-on-Oxo-biodegradable-Plastic-Products-SDevalla.pdf

(Also on my webpage: https://www.hutton.ac.uk/staff/sandhya-devalla).

Thankyou

Kind Regards

[Redacted]

From[Redacted] @gov.scot>
Sent: 27 July 2022 16:17
To: [Redacted] @hutton.ac.uk>; [Redacted] @zerowastescotland.org.uk
Cc[Redacted] @gov.scot; [Redacted] @gov.scot
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

[External email]
Do not click links or open attachments unless you recognise the sender and know the content is safe

Hi [Redacted],

Here's some context lines as requested:

This work was commissioned by the Scottish Government to support their commitment to align with or exceed the standards of the Directive (EU) 2019/904 on the reduction of certain plastic products on the environment.

Any Scottish Government policy related queries can be directed to [Redacted] at supd@gov.scot.

Kind regards,

[Redacted]

From: [Redacted]@gov.scot

Sent: 19 July 2022 10:10
To: [Redacted] @hutton.ac.uk>; [Redacted] @zerowastescotland.org.uk
Cc: [Redacted] @gov.scot>; [Redacted] @gov.scot>
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

Thanks [Redacted], I'll get this over to you at the end of the week.

Could you confirm if you'd be available to join a call with the Scottish Environment Protection Agency and talk them through your findings? They have an interest in the environmental impact of these products. Myself and [Redacted]would also be on the call.

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I will keep you in the loop until the publication is completed.

Thank you

Kind Regards

[Redacted]

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To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk
Cc[Redacted]@gov.scot; [Redacted]@gov.scot
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

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Publication by the JHI would be preferable thanks, bearing in mind the work could attract significant attention if we were to progress a ban on oxo-degradable plastic products, whatever approach you think is best to do this.

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Sent: 16 June 2022 14:36

To: [Redacted] @gov.scot>; [Redacted] @zerowastescotland.org.uk; [Redacted] @gov.scot>
Cc: [Redacted] @gov.scot>
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

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Thank you

Kind Regards

[Redacted]

From: [Redacted]@gov.scot>
Sent: 13 June 2022 17:22
To: [Redacted]@hutton.ac.uk>; [Redacted]@zerowastescotland.org.uk; [Redacted]@gov.scot
Cc: [Redacted]@gov.scot
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

[External email]
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Cc: [Redacted] @gov.scot>
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Please let me know if there is any other formality to complete.

Happy to provide any clarification.

Thank you very much for the nice discussions we had. I enjoyed working with you.

Thank you

Kind Regards

[Redacted]

Review of Evidence on Oxo-Biodegradable Plastic Products

Commissioned by the Scottish Government in support of EU Directive 2019/904 on *reduction on certain Single-use plastic products*

18/08/2022

The James Hutton Institute

[Redacted – Personal information]

EU Directive 2019/904 definition

- Requires member states to ban those Single-use plastic items as covered in Article 5 of the Directive
- **Ban includes all 'oxo-degradable' (OD) plastic products**
- EU SUP Directive -2019/904 **definition of OD** plastics
  - *"plastic materials that include additives which, through oxidation, lead to the fragmentation of the plastic material into micro-fragments or to chemical-decomposition"*
- No separate definition for Oxo-biodegradable (**OBD**) plastics

EU Directive 2019/904 reason for ban

- Because this type *“does not properly biodegrade and thus contributes to microplastic pollution in the environment, is not compostable, negatively affects the recycling of conventional plastic and fails to deliver a proven environmental benefit”* [Section 15].

- However, manufacturers of oxo-**bio**degradable plastics claim that these are different to oxo-degradable plastics and should not be included in the ban.
- **Are OD plastics different to OBD plastics??**

UK and Scottish Government Circular economy targets

- Recycling rate of plastics in UK is just ~45% with the remaining ending up in landfills or littered
- The Scottish Government has set a target that 70% of all waste is to be recycled/composted/prepared for re-use by 2025
- Targets have also been set for waste going into landfill to be no more than 5% by 2025
- The Scottish Government is also supporting the ambitious target that 100% for all plastic packaging is to be recyclable or compostable by 2025, in association with the UK Plastics Pact

https://wrap.org.uk/taking-action/plastic-packaging/Key-Resources/plastic-bags-and-wrapping
https://www.gov.scot/publications/delivering-scotlands-circular-economy-proposals-legislation

Objectives set out in Call down specification

1. **How oxo-biodegradable (OBD) plastic products differ in comparison to oxo-degradable (OD) plastic.**
2. What oxo-biodegradable plastic products are on the market in Scotland (market value).
3. The environmental impact of oxo-biodegradable plastic products.
4. Any differences in environmental impact between oxo-degradable and oxo-biodegradable materials.

Similarity between OBD and OD plastics

OBD	OD
Fossil based	Fossil based
Polymer backbone-Polyethylene, polypropylene	Polymer backbone-Polyethylene, polypropylene
Additives-transition metals salts (Fe, Mn, Ni, Co)-propietary	Additives-transition metals salts (Fe, Mn, Ni, Co)
1-5% concentration	1-5% concentration
Low value products- bags/packaging made from plastic films	Low value products- bags/packaging made from plastic films
First stage degradation-physical fragmentation to very small molecules	First stage degradation-physical fragmentation to very small molecules
Second stage - microbial assimilation simultaneously	Second stage?? No mention

Int J. Polymer Sci, 2018, Article ID 2474176
Polym Adv Technol. 2021, 32: 1981-1996

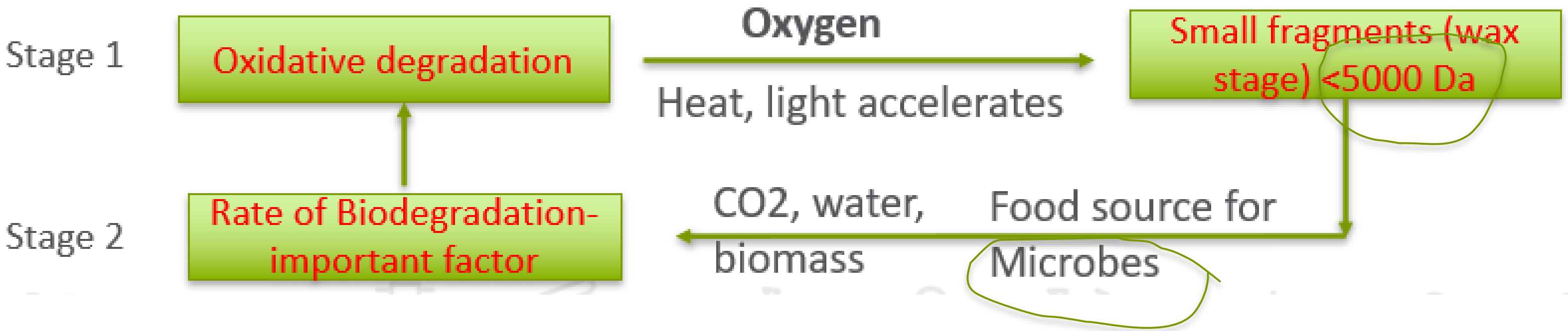
Objective 1- OBD and OD plastics -2

- Use of pro-degradants for petroleum-derived polymers is an old technology (dated back to 1940s); gained commercial importance in recent years

(An overview of degradable and biodegradable polyolefins. Progress in Polymer Science, 2011, 36(8), 1015-1049)

- Manufacturers prefer to use OBD (to emphasis biodegradation process)
- **Designed to degrade in open environments**

Degradation mechanisms of OBDs



Several factors can affect (total) degradation in open environments: Microbial (density & diversity) Temperature, intensity and duration of sunlight, moisture levels, soil organic matter, pH, depth of burial in soil...

Rate of degradation under Scottish climate conditions has not been studied; expected to be slower in colder climates compared to than warmer

Objective 1: Some sources of evidence

- DEFRA (*http://sciencesearch.defra.gov.uk/)-*
  - *"Oxo-degradable plastics are often marketed as being 'degradable', 'bio-degradable' or 'oxo-biodegradable"*
- International journal of molecular sciences, 2020, 21(4), 1176- key paper quoted by manufacturers as evidence of biodegradability
  - *This paper has referred both OD plastics and OBD plastics as pro-oxidant additive-containing (PAC) plastics*
- *Progress in Polymer Science, 2011 36(8), 1015-1049 -An overview of degradable and biodegradable polyolefins –*
  - *History of prodegradant technology, same 2-stage degradation mechanism, refers to additives such as TDPA™ produce oxo-degradable polyolefinic products (whereas TDPA™ manufactures refer to these plastics as oxo-biodegradable)*
- *Standards for bio-based, biodegradable and compostable plastics*
  - plastics containing prodegradant additives aimed at aiding biodegradation process are referred to as *"oxo-degradable or oxo-biodegradable plastics"*

https://www.gov.uk/government/consultations/standards-for-biodegradable-compostable-and-bio-based-plastics-call-for-evidence

- **More definitions from Academic publications as well as manufacturer’s can be found in the Report :**

https://www.hutton.ac.uk/sites/default/files/files/publications/Review-evidence-on-Oxo-biodegradable-Plastic-Products-SDevalla.pdf

OBD Additives Main Manufacturers

Manufacturer	Additive Tradename	Weblink	Examples finished Products that use Additives
Symphony Environmental (U.K.)	d2W	https://www.symphonyenvironmental.com/	Bin bags, Food bags, Refuse sacks
EPI (U.S)	TDPA	https://epi-global.com/	TDPA™ for Single-use plastics, Mulch films
Wells Plastic Limited (U.K.)	Reverte	https://www.reverteplastics.com/	Carrier bags, bin liners, Bread bags, plastic netting, Mulch films
Renatura (Norway)	Nor-X industries	http://www.nor-x.no/ (https://gb.kompass.com/c/nor-x-industry-as/no061216/)	Not much information was available (contains iron-based proprietary ingredient used for biodegradation of polyolefins
AddiFlex (Sweden)	Add-X Biotech	https://www.add-xbiotech.com/ (https://www.packaging-gateway.com/contractors/materials/add-x-biotech/)	food packaging & food service items, carrier bags & waste disposal bags

Objective 2: OBD Products on Market in Scotland

The James Hutton Institute

- **Majority of OBD items being sold are low-value products such as various types of bags**-bin bags, nappy sacks, food bags etc made of polyethylene.
- **Large on-line market for stationery items,** largely made of polypropylene (may be more re-usable compared to low-value single-use bags.
- **Not much evidence was available on the use of OBD mulching films,** which are manufactured only on request as they do not have long shelf lives.

Main types of OBD products available online on market in Scotland

More details can be found in the Annex Section of the online Report

Category	Types of Products	Main Tradenames
Bags (Various)	Bin bags, liners, Nappy Sacks, Dog Poo bags, Carrier bags etc	Ecozone, Beaming Baby, Enov, d2w Bags, Shalimar, TDPA™, Beco
Stationery	Punched Pockets, Popper Wallets, Folders, Envelops	Stewart Superior/SECO, Ampac, Snopake
Netting	Christmas tree netting, Netting sleeve	BioXnet
Health Sector	Overshoes	epi's TDPA
Catering	(Flexy) Glasses	Likely imported from China

Objectives 3 & 4: Environmental impacts of oxo-biodegradable plastic products

The James Hutton Institute

- End-of-Life disposal concerns for OBDs
- Lack of evidence on completeness of degradation
  - suitability of current **degradation** standards
- Environmental impact Risks due to incomplete degradation of OBD plastic products

Environmental impact: End-of-Life Concerns for Single-use OBDs

- OBD products- have been **designed to degrade in open environments** (oxygen availability)
- Although manufacturers claim OBD products – Re-usable, Re-cyclable, Compostable and suitable for landfill
- ***Re-usability***
  - Usually low-value products, designed for Single-use,
  - often contaminated with biological matter,
  - additives cause in embrittlement

Environmental impact: End-of-Life Concerns for Single-use OBDs

The James Hutton Institute

- ***Re-cyclability***
  - **Post-consumer recycling** – not effective due to biological contamination;
  - Production cost lower than recycling;
  - **Pre-consumer recycling –** more feasible; Concerns that additive-containing plastics alongside regular plastics could affect the quality of the resulting products.
  - Especially those requiring long life – e.g., Damp-proof membranes

Environmental impact: End-of-Life Concerns for Single-use OBDs

The James Hutton Institute

- ***Landfills***
  - Slower rates of degradation expected due to low oxygen levels & light (especially when buried in lower layers);
  - Inherent heterogeneity of waste in landfills increases complexity of biodegradation

- ***Composability***
  - Current composting standard BS13432 is not suitable (6 months duration);
  - Manufacturers claim OBDs can be composted over longer timeframes or under Windrow composting
  - However, slower degradation was found in composting conditions compared to soil environment (as designed for open-air); lack of completeness of degradation in windrow composting

Polymer degradation and stability, *96*(5), 919-928.
Final report benefits and challenges of bio-and oxo-degradable plastics a comparative literature study, 2013;
https://www.ows.be/publication/benefits-and-challenges-of-bio-and-oxo-degradable-plastics/

Environmental impact: Lack of evidence on completeness of degradation

The James Hutton Institute

Studies often quoted by Symphony Environmental for Biodegradability

OXMAR Study

- 5 year by French Agency for National Research, May 2021
- Marine environment; Cobalt-containing additive toxicity.
- Also microbes from the marine environment evolved over millions of years using crude oil as food source where low temperatures, lack of light, ~600 000 tonnes annually discharged

(https://pubs.acs.org/doi/10.1021/acs.est.5b03333; (Zettler ER, Mincer TJ and Amaral-Zettler LA, 2013. Life in the "plastisphere": microbial communities on plastic marine debris. Environmental Science and Technology, 47, 7137–7146).

Queen Mary University, London Study

- Testing biodegradation of LDPE containing Symphony's d2w technology
- OBDs degrade 90 times faster than conventional LDPE)
- Unaged LDPE & oxo-LDPE showed very slow biodegradation;
- Beyond 450 hrs of artificial UV exposure, decrease in degradation observed

(Rose, Ruth-Sarah, et al. "Microbial degradation of plastic in aqueous solutions demonstrated by CO2 evolution and quantification." International journal of molecular sciences 21.4 (2020): 1176)

Environmental impact: Lack of evidence on completeness of degradation

Underwriting by Manufacturers

- https://www.reverteplastics.com/oxobiodegradibility.php

"Biodegradation can only occur (whether this is for Reverte™ plastics or for grass cuttings) in environments which have warmth, bacterial activity and moisture. This fact is often overlooked when marketing oxo-biodegradable or hydrobiodegradable materials".

- https://epi-global.com/tdpa-oxo-biodegradable/environmental-claims-usa/

"*Under U.S. laws, products with TDPA™ may not be biodegradable or compostable, depending on the conditions of disposal and the specific product*".

Environmental impact: Suitability of Current Degradation Standards

For more detailed information, please refer to published Standards

BSi 8472:2011- *Methods for the assessment for the oxo-biodegradation of plastics and of the phyto-toxicity of the residues in controlled laboratory conditions*

- *Not a specification; only a guidance; Timeframe to reach required biodegradation level is not defined*
- *Test carried out under laboratory condition; no pass/fail criteria*

ASTM D6954-18 - *Standard guide for exposing and testing plastics that degrade in the environment by a combination of oxidation and biodegradation*

- *Not a specification; only a guidance; Tested temperature range: 20 °C–70 °C (not suitable to Scottish weather conditions); ≥ 60% biodegradation to be reached but timeframe to reach this level is not defined*

BS 13432 (ASTM D6400)- *Packaging – Requirements for packaging recoverable through composting and biodegradation – Test scheme and evaluation criteria for final acceptance of packaging*

- ***OBD plastics do not pass this compostability standard***

Environmental impact: Suitability of Current Degradation Standards

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None of the above standards test degradation suitable for open-air especially under Scottish weather conditions

PAS 9017:2020- *Plastics-Biodegradation of polyolefins in an open-air terrestrial environment-**Specification***

- *Standard designed for Biodegradability testing in open-air terrestrial environment within 2 years*
- *To best of knowledge, applicability against this Standards yet to be tested*
- *Comments to above standard by Wells Plastics Limited: "Timeframe to achieve biodegradation levels is restricted and therefore not representative of the variability of the conditions found in the natural environment".*

Environmental impact Risks from OBD plastics

The James Hutton Institute

- **Risks from fragments and Microplastics** (Ingestion by living organisms; vectors for pollutants; uptake into food-chain; nanoplastics etc).
- **Risks from longer-term accumulation of transition metals in soils-**
  - Cobalt toxicity-highlighted in several studies
  - review article published by DEFRA on OBD plastics highlighted concerns over the potential risk from OBD metal additives accumulating in the environment ; of 71 different chemicals found in U.K.'s rivers, copper-1st, Mn-7th, Fe-8th, Ni-12th
  - Longer term accumulation risk is more of concern
- **Greenhouse gas emissions**
  - Higher greenhouse gas emissions attributed to fossil-based plastics especially those designed for single-use

Summary

- There is **no difference** between oxo-degradable and oxo-biodegradable plastics- terminologies to describe conventional plastics (PE, PP) that transition metal additives.
- Main categories of oxo-biodegradable products on the market in Scotland are different types of **low-value single-use bags** and **stationery items**. Information on their market size was not readily available.
- Environmental impact is inversely related to the rate of degradation of OBDs in specific environment (e.g., open-air, composting, landfill); The rate of degradation is dependent on several factors related to weather, soil and microbial conditions and is not easily predictable based on laboratory testing conditions alone as specified in most degradation testing standards.

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Summary

- No doubt that OBDs degrade at a faster rate compared to conventional plastics; however, **completeness of degradation** specific to Scottish climate conditions within a specified timescale has not been proven.

- Since oxo-biodegradable plastics have been primarily designed to degrade in open-air (where there is oxygen availability), sustainable **end-of-life options** such as composting, recycling, landfill are ambiguous.

- This Report only focussed on OBD plastic Products- does not compare OBDs with other types such as bio-based/Compostable/conventional Plastics

Thank You! Happy for Discussions!

From: [Redacted]@hutton.ac.uk>
Sent: 18 August 2022 17:35
To: [Redacted]@gov.scot>; [Redacted]@zerowastescotland.org.uk
Cc: [Redacted]@gov.scot>
Subject: RE: Evidence Review on Oxo-biodegradable plastic products-Final

Dear All,

Please find attached the ppt presentation from this morning, as requested.

oxobiodegradable
plastics 180822.pptx

Thank you

Kind Regards

[Redacted]