Review of standards for biodegradable plastic bags.

Other

Department for Environment Food & Rural Affairs

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Review of standards for biodegradable plastic carrier bags

Presented to Parliament pursuant to section 18 of the Single Use Carrier Bags Charges (England) Order 2015

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Executive summary

The Single Use Carrier Bags Charges (England) Order 2015 requires retailers to charge at least 5p for each single use carrier bag, except where exempted.

Under section 18 of that order, the Secretary of State must—

(a) complete a review of industry standards for the biodegradability of lightweight plastic material; and
(b) lay a copy of a report before Parliament setting out the conclusions of the review, in particular—

> (i) whether it appears to the Secretary of State that there exists an industry standard appropriate for the purposes of an exclusion from the obligations specified in Part 2 on grounds of biodegradability; and
>
> (ii) if so, how that exclusion would be implemented.

That review has now been completed. It found that there are a number of standards for plastic bag biodegradability. We will need to conduct further work before any of these could be used to exempt certain types of carrier bags on grounds of biodegradability.

By the end of May 2016 retailers are required to report the number of bags that have been supplied, and the uses to which the proceeds of the charge have been put, after reasonable costs are deducted. The Government will use that opportunity to consider the early impacts of the charge. The Government will continue to consider the technical specification for a genuinely biodegradable bag, and will at that point further report on how an exemption for such a biodegradable bag can be implemented.

Background

The mandate

The Single Use Carrier Bags Charges (England) Order 2015 requires that before 5th October 2015, the Secretary of State is to:

a) complete a review of industry standards for the biodegradability of lightweight plastic material; and
b) lay a copy of a report before Parliament setting out the conclusions of the review, in particular –
   (i) whether it appears to the SoS that there exists an industry standard appropriate for the purposes of an exclusion from the obligations to charge on the grounds of biodegradability; and
   (ii) if so, how that exclusion would be implemented.

When the 5p charge for single use plastic carrier bags was announced in 2013, it was also announced that the Government would work with industry to exempt “super biodegradable bags” from the charge.

The charge is intended to drive down the large numbers of single use plastic bags distributed which are often littered. Evidence from Wales and Northern Ireland suggests that we will see reductions of up to 80% in the major supermarkets. However, there will always be a need for some single use bags. Some of these bags will be disposed of to landfill or incineration, whilst increasingly we expect a proportion to be recycled whilst inevitably others continue to be littered. There is therefore a rationale for promoting bags which are made out of a biodegradable material.

There are existing bags which degrade in certain circumstances, for example:

- Oxo-biodegradable bags

  Bags made as normal single use plastic bags from plastics such as polyethylene with an additive to catalyse the degradation process (typically metal salts) in the presence of oxygen.

- Plant-based biodegradable bags

  Bags made of plant based material – typically starch, which break down in composting environments.

These bags have very different properties, degrade in different ways, and are likely to have different impacts when incorporated into recycled plastic reprocessing streams.

The intention of the review was to ensure that any bag exempted would biodegrade in a wide range of environments, including on land (in soil) and in rivers and the sea. The review was entirely technology neutral and does not support one particular technology over another.

Over the next three years obligated producers of plastic packaging will have to recycle 47%/52%/57% of the plastic packaging which they place on the market in the UK. Our expectation is that to meet these targets recycling of plastic films including single use carrier bags will need to increase and WRAP has worked with the industry and with local authorities to help this happen.

To ensure that world-wide confidence in UK plastic recyclates continues it is therefore important that any plastic film certified as biodegradable could either be separated out, or would not reduce the quality of the recyclate film.

Defra is not aware that a bag that does all of those things currently exists. This review therefore focused on defining criteria that would enable us to judge whether or not a bag could be classified as biodegradable.

The method

Defra convened a Technical Advisory Group (TAG) of eminent academics in the relevant fields that has reviewed the existing standards for biodegradability of lightweight plastic material. The work was split into five areas and five corresponding reports were compiled by relevant experts and peer reviewed across the group. The work packages are:

Work package 1 – The managed environment (Dr Carl Boardman, The Open University)

Work package 2 – Land and soil unmanaged terrestrial environments (Professor Richard Murphy, PhD DIC FIWSc, Director of the Centre for Environmental Strategy, University of Surrey)

Work package 3 – The aquatic environment (freshwater and marine) (Dr Jesse Harrison, PhD University of Edinburgh)

Work package 4 – Implications for Plastics Recycling and Processing (Professor Ed Kosior, B App. Sci. (App. Chem.) M. Eng. Sci, Dip. Ed, FSPE, MCIWM)

Work package 5 – Indirect physical test methods (Professor Jim Song, Brunel University London and Dr Anne-Marie Delort, PhD, Director of the ICCF Laboratory)

The TAG's objectives can be found at Annex A. The advice provided in the reports has been agreed across the whole group. The findings from those technical reports form the basis of this report for Parliament, alongside economic modelling, industry evidence and knowledge and stakeholder advice.

Technical reports

This section provides an overview of the main findings across the five workstreams of the Technical Advisory Group's (TAG) work as well as five more detailed non-technical summary reports for each of the five workstreams individually. The TAG members may publish their findings in the form of research papers, and the full technical TAG reports remain their intellectual property.

The only standard in place specifically for plastic carrier bags is EN13432, a compostable technical specification standard. The review has therefore examined a wide range of standards and test methods for the biodegradability of lightweight plastics in other applications. It would then be for industry to strive to meet the standard(s) using any existing or new technology if an exemption was put in place.

Overall summary of technical reports

This summary and the associated work-package summaries describe the TAG's main findings, the strengths and weaknesses of many of the standards reviewed, and any gaps in current knowledge and understanding. The recycling and reprocessing report mainly considers the issues that may arise for the filmic plastic processing industry should biodegradable plastic bags be encouraged through an exemption.

The work-package summaries refer throughout to aspects of the standardisation literature. Readers unfamiliar with the language and structure of the standardisation landscape may benefit from initially reading the 'Background to standardisation and certification' found in Annex B. A glossary is also provided in Annex C.

Main overarching conclusions

It is not currently possible to assemble a standard specification that would ensure that plastic bags claiming to be biodegradable would biodegrade in all environments, in particular in the open environment.

For some aquatic environments there are no established biodegradability standards on which to draw, for example, for unmanaged inland waters and for almost all marine habitats (other than open seawater). There is also a lack of authorised toxicity tests to ascertain the degree of toxicity of biodegrading plastics to aquatic organisms and the impact of micro-plastic particles on aquatic organisms. Considerable investment would very likely be required to establish the knowledge base that would correct these background evidence deficiencies to enable a discussion on a biodegradability specification to proceed.

Biodegradability standards for the managed organic waste environments of industrial composting and anaerobic digestion are relatively mature and these could probably be drawn together to create a more harmonised approach to biodegradability standards for those sectors. Many of these standards benefit from utilising microbial respiration as a measure of biodegradation, which is a well-established method. But these standards could not be used to demonstrate biodegradability in the open environment, where conditions are more diverse. In fact, there is evidence that some aspects of these standards no longer fully align with (especially) industrial composting practices, and that they may be in need of review even for industrial applications.

Useful biodegradability standards and certification schemes exist for plastics in terrestrial soil, for example, for agricultural and horticultural mulch films. Mulch films have an important role in conserving water, suppressing weed growth and promoting better crop growth. However, these standards require the films to biodegrade at the location where they are deployed into service, with the films finally being dug back into soils. Therefore, the situation is very different from that of fugitive plastic bags released into the open environment. Some standardisation work for wood products in soil has been done which relates the results of accelerated test methods to longer-term biodegradation in the natural environment. These approaches might be helpful when considering biodegradable plastics in the open environment. But the additional field work required for plastics could not be done in the short term or without considerable expense, and would not necessarily have relevance for marine environments such as sediments.

In marine, organic managed, and land and soil situations, major questions arise on the scientific relationship between laboratory-based test methods and the open environment. Some authorised standards state that their laboratory test methods are not validated for the open terrestrial environment (with its diverse local geography) and that field testing should be performed to establish a relationship with any laboratory test results.

Any field trials designed to accompany laboratory biodegradability tests would require careful planning to ensure robustness and proper environmental protection. More research and consensus would be required to establish methods for validating the application of laboratory tests to the conditions of the open environment. For example, definitive, evidence-based identification of acceptable ecologically and biologically relevant timeframes for the biodegradation of plastic films in the unmanaged terrestrial environment is currently lacking and continues to be controversial.

The assessment k, of biodegradability in the open environment through standardised methods is extremely challenging, with virtually all existing standards being founded on a clear link to a plastic product’s end-of-life biodegradation environment. Since this link by definition does not exist for fugitive plastic bags in the open environment (i.e. littered bags) it would require a major undertaking to establish the data and principles required to support an exemption for plastic bags based on their biodegradability in all environments, in particular the open natural environments.

Finally, there are unresolved questions on the implications of biodegradable filmic plastics for the reprocessing industry. There is not enough evidence to support technical decisions on how manufacturers of higher specification warranted products, such as damp proof membranes, should manage any increase in the prevalence of biodegradable polymers in the recycling sector. The operational integrity of such warranted products must be maintained. Technical processing difficulties also occur when some biodegradable plastic films are mixed with conventional polyethylene, raising further questions on how best to manage any increase in the number of biodegradable films. Improvements to technologies for tackling the difficult problem of separating films in the waste stream are being sought and would be very helpful to the reprocessing sector in a situation where conventional and biodegradable bags become routinely mixed.

Review of existing standards for the biodegradability of lightweight plastic carrier bags: managed organic (waste) environments

(Summary based on a review by Dr Carl Boardman of the Open University)

Main conclusions

No existing test standards or specifications on the biodegradability of filmic plastics in aerobic compost, anaerobic digestion (AD) or anaerobic landfill could be used to support a carrier bag charge exemption on the grounds of biodegradability in the open environment.

All three waste management options do benefit from having standard biodegradability test methods for plastics, although the principles of the waste hierarchy and the circular economy would dictate that composting and AD are preferred over disposal by landfill. Industrial composting also benefits from having a standard specification for biodegradability and an independent certification scheme. A new harmonised standard specification based on existing standards for composting and AD would be relatively easy to create for managed organic waste and would likely require only modest investment in research and testing.

These existing biodegradability standards have the advantage of being based on microbial respiration, which is well established and could easily form the basis of a new specification for managed organic waste with only minor alterations. If these existing standards were to be harmonized into a new specification then the following points would need to be considered:

a) Especially for aerobic composting, existing published standards measure the biodegradability of plastic under idealised conditions and do not mirror current UK industrial practices.
b) The variation allowed in standard test procedures on the maturity of the inocula[1] that may be used, sometimes leads to inconsistencies in test results, and this issue should be resolved.
c) Existing standards also permit methodological flexibility for the form in which the test material is presented (e.g., powdered or filmic), introducing potential test result bias through manipulation of these key variables.

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[1] Inoculum here refers to the bacterial biomass within process fluids from an operational processing vessel, used to inoculate the test vessel that will contain the material undergoing assessment. Inocula can vary widely, potentially leading to inconsistencies.

Published standards and test procedures (composting)

Standards for the quality of compost already exist. For example, compost compliant with BSI PAS100 and the Compost Quality Protocol (CQP) specifications are no longer considered waste and may be spread to land without Environment Agency licensing. These specifications allow biodegradable bags and packaging to be introduced into the compost so long as they conform to the compostable criteria within BS EN 13432, BS EN 14995, ASTM D6400, DIN V 54900 or AIB-Vinçotte OK Compost programme.

The two main standard specifications used to demonstrate the biodegradability of plastics under simulated industrial composting conditions are BS EN 13432:2000 and ASTM 6400-12. Both require the test material to yield 90% of its organic fraction as evolved (microbially respired) CO_2 within 180 days. Other criteria cover the material's disintegration under test and its potential toxicity.

Strengths and weaknesses of published procedures and standards (composting)

There is a disparity between the timescale specifying 180 days for 90% biodegradation of plastics, and the typical UK industrial composting process, which rarely runs beyond 3 months. This issue would need to be accounted for should any reassessment or harmonisation of standards be attempted, since compliance with these common specifications does not guarantee 90% biodegradability in the much shorter industrial situation. Either the allowable threshold for biodegradability (e.g. 90%) or timescale values would require re-examination.

Other issues are also important when considering standards for plastics biodegradable in aerobic composting. For example, the test material is often permitted to be introduced in powdered form or as a filmic sheet, yet such variations in the surface area to mass ratio have been shown in some instances to influence both the rate and the ultimate biodegradability of materials.

Some standards also allow for variation in the nature of the inoculum, which may be created artificially using known microbial species or may be taken from fresh or end-of-process composting operations. Inocula from different sources will vary in their biological respiratory activity. These different inocula can have a marked influence over biodegradability results and create potentially large differences between test outcomes in the laboratory and outcomes in industrial practice. Inocula with high or inhomogeneous biological activity can also make it difficult to detect the relatively low respiration coming from biodegradation of the test material or can make it difficult to obtain consistent measurements from the control materials (often cellulose) against which test materials are usually compared.

Finally, ecotoxicity test elements of specifications such as EN 13432 require a plant germination test, but inclusion of a test on invertebrates, such as earthworms, could also be advantageous and appropriate.

Published standards and test procedures (AD)

The AD sector generally benefits from the BSI PAS 110 quality scheme and a Biofertilizer Certification Scheme, which are designed to create the market for high quality digestate materials suitable for land application. These schemes contain limit values for contaminants; hence the industry uses de-packing and screening equipment to try to remove plastic materials. These processes are not full-proof so filmic plastic that biodegrades in AD conditions would bring some advantages.

There are currently no certification schemes or specifications for biodegradation of plastic materials in AD, although BS EN 13432 (familiar in the composting arena) does have an optional AD compatibility section for plants having a subsequent aerobic processing stage.

There are some test standards for measuring biodegradation of plastics during anaerobic digestion[2] and these differ according to the inocula, test temperatures and some other test conditions. However, they all employ a biodegradability measure based primarily on the conversion of carbon in the test material to biogas – gaseous carbon (ie, methane [CH_4] and carbon dioxide [CO_2]).

Strengths and weaknesses of published procedures and standards (AD)

In contrast to composting, AD biodegradability test procedures and conditions mirror UK industrial practice more closely. One notable exception is the absence in standard tests of a short (e.g. 1 hour) high temperature pasteurisation step for the feedstock (>70 °C), used in industry before digestion in order to inactivate particular pathogens. Inclusion of such a step would likely influence subsequent biodegradability of some test materials, enhancing biodegradation in some cases.

AD tests often allow test material to be added in powdered or sheet form, which can influence test results. Moreover, end-of-life bags are very unlikely to enter AD processes in powdered form, hence existing test standards may overestimate biodegradability of bags.

As with composting standards, a range of inocula is permitted, leading potentially to variation in results and differences in the amount of biodegradation observed between laboratory and industrial processes.

Since AD biodegradability tests are not specifications, there is no agreed threshold value for biodegradation which a test material must exceed. Since digestate is applied to land, should a specification for carrier bag biodegradation in AD be attempted, it would be appropriate to consider inclusion of an ecotoxicity measure, as done for compliance in composted plastics.

[2] For example, ASTM D5511, BS ISO 15985, ASTM D5210, BS ISO 14853 and BS ISO 13975.

Knowledge and research gaps

As outlined above, the managed organic waste environment is relatively mature, especially for aerobic composting, for which a specification already exists. Knowledge and research gaps are understandably fewer than for the unmanaged environments.

Should harmonisation of standards across these managed environments be attempted, research would need to focus on resolving some of the weaknesses outlined above, for example by clarifying the relationship between test conditions and the industrial process environment, and resolving the extent to which biodegradability is influenced by variable test parameters such as the type of inocula and the form in which test materials may be presented. Since no specification exists for biodegradable plastics in AD, tests would need to be conducted in order to establish appropriate biodegradability threshold values and measurable values for ecotoxicity.

Review of existing standards for the biodegradability of lightweight plastic carrier bags: land and soil unmanaged terrestrial environments

(Summary based on a review by Professor Richard Murphy)

Main conclusions

No current standards would predict the degree or time-scale of the biodegradability of plastic bags in the unmanaged land and soil environments, although some laboratory tests not validated for the open environment do provide methods for quantifying biodegradability within a particular time-frame. All current standards use ‘accelerated’ test environments where biodegradability happens much faster and in a narrower range of conditions than in or on natural land and soil.

Biodegradability standards for agricultural and horticultural mulch films deployed in the soil do exist and these have proved useful. These mulch materials do not so far appear to accumulate in the soil; but they are designed to be ploughed in as part of regular agricultural practice and are therefore dissimilar to fugitive bags released uncontrolled in the environment.

Standardised wood durability and wood preservative tests estimate natural decomposition through soil burial and complementary lab-based accelerometer tests. A similar approach might be useful for testing plastic bags, but extending currently available standards for application in the open environments could not be done quickly or at low cost in the near term.

Definitive, evidence-based identification of acceptable ecologically and biologically relevant timeframes for biodegradability of carrier bags in the unmanaged terrestrial environment is currently lacking and continues to be controversial.

Published standards and test procedures

The key current international standard is BS EN ISO 17556:2012 – “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”.

As with many standardisation documents, other standards cross-refer to 17556. For example, BS 8472:2011 ‘Methods for the assessment of the oxo-biodegradation of plastics and of the phyto-toxicity of the residues in controlled laboratory conditions’ draws its biodegradability element from the 17556 standard.

A certification/logo system for mulch film biodegradability (biodegradation must occur in the location of product use) has been produced. The Vinçotte 'OK Biodegradable SOIL' scheme was introduced and currently compliant materials and products are published online (http://www.okcompost.be/en/certified-products/).

French and Italian standards authorities have also produced standardised tests designed to verify that putative biodegradable mulch films biodegrade – for example AFNOR NF U52-001 and UNI 11495.

Other standards of relevance are BS EN 13432 and BS EN 14995 (compostability of plastics), but these are covered extensively in the sister report on biodegradability standards for the **managed** organic waste environment.

Strengths and weaknesses of published procedures and standards

There has not been extensive standardisation activity on biodegradation of plastics in soils; hence the number of standardised agreed tools for measuring biodegradation of plastics in soils is few.

BS EN ISO 17556:2012 testing enjoys ISO consensus, uses the widely accepted respirometric test methodology and is reasonably straightforward to conduct. The 17556 standard is the preferred biodegradation test used for demonstrating conformity to Vinçotte's 'OK Biodegradable SOIL' scheme. However, the standard applies to soil burial only, relies on accelerated conditions (e.g. temperature around 25 °C) and measures late stage "ultimate" biodegradation which may not occur in the same way in the open environment. The standard gives no advice on using the test to predict biodegradation across diverse conditions of natural variation.

Other standards refer to the 17556 document. For example, BS 8472:2011, which establishes a testing regime for oxo-biodegradable plastics, draws from 17556 to develop its biodegradability credentials. However, 17556 covers only a soil-based laboratory test and does not in itself establish any biodegradability credentials for the open environment, as the disclaimer in the standard states.

Relevant standardisation work is ongoing, for example, through the ASTM "work item" (a proposed or revised standard under development) WK29802. This work-stream is currently entitled "New Specification for Virgin Plastics that Biodegrade in Soil under Aerobic Laboratory Conditions" and seems to apply to plastics that are placed in soil during their service life and are not manually removed after use. Information currently available on this work-stream suggests that ASTM will not validate the specification for the open terrestrial environment. ASTM will instead advise users that since results cannot be extrapolated to soil environments at the actual site of use (conditions vary with local geography), field testing should be performed to establish a correlation with the laboratory methods.

Any field trials designed to accompany laboratory biodegradability tests would require careful planning to ensure robustness and proper environmental protection. More research and consensus would be required to establish methods for validating the application of laboratory tests for the conditions of the open environment. For example, definitive, evidence-based identification of acceptable ecologically and biologically relevant timeframes for the biodegradation of plastic films in the unmanaged terrestrial environment is currently lacking and continues to be controversial.

Authorised documentation on laboratory-based standard methods often states that such test results would not validate biodegradation in the natural environment without additional research. But there is a lack of guidance on how to structure and apply that research in alignment with the standardised protocols.

Knowledge and research gaps

There are many research publications that have explored biodegradation of putative biodegradable materials in soil, and some of these are undoubtedly of use when considering standards for biodegradability. Research on mulch films is an interesting undertaking since these products have applications in environments that sit between fully managed and fully open environments. The research on mulch films mostly does not address the issue of fugitive plastic film released in the open terrestrial environment.

There has been no robust characterisation of ecologically relevant time-scales for biodegradability in the diversity of environments and environmental conditions in which unmanaged fugitive bags would be expected to be found.

There is no scientific consensus on the criteria and the application of any criteria through which a laboratory test could be reckoned to properly simulate biodegradation in the real world situation of unmanaged open environments. For example, authorised laboratory tests often employ a threshold criterion requiring 60-90% ultimate biodegradability of a test material. But there is no agreement or scientific evidence on how to proceed in the (likely) event that such thresholds are not met within a particular time-frame in the open environment.

Since a significant proportion of plastic waste materials and micro-plastics in freshwater and marine environments is thought to come from land, there is a surprising lack of knowledge on the processes responsible. This means that there is little knowledge on any relationship between the disintegration and biodegradation of plastics designed to decompose in terrestrial environments and the emergence of polluting micro-plastics in marine environments.

There is currently inadequate data on the quantities of all types of plastic filmic material escaping into the open environment from managed waste disposal facilities and other sources.

Review of standards for the biodegradability of lightweight plastic carrier bags: freshwater and marine environments

(Summary based on a review by Dr Jesse Harrison of the University of Edinburgh)

Main conclusions

No single existing standard test method or specification offers sufficient scope to establish an exemption on the grounds of biodegradability in the freshwater and marine environments.

- Existing standards cannot realistically predict the biodegradability of filmic plastic material across wastewater, river, stream, lake and marine zones because;
- There are no standards for unmanaged inland waters and marine environments (other than open seawater), yet plastic debris has been clearly shown to accumulate in such places, for example in sediments;
- The tests employed can underestimate significantly the time required for biodegradation, often because the tests operate under idealised laboratory conditions that don't adequately represent many river and marine habitats;
- There's a major lack of authorised toxicity tests to ascertain both the degree of toxicity of biodegrading materials to aquatic organisms and the impact of micro-plastic particles (small fragments that may arise as plastic is broken down) on aquatic organisms.

Published standards and test procedures

Freshwater zones

There are two active international protocols for measuring aerobic (in the presence of oxygen) biodegradation of plastic in wastewater and sewage sludge[3]. These two protocols measure either the amount of oxygen used up, or the amount of carbon dioxide evolved. These are measured because the amount of microbial respiration that occurs during the test corresponds to the degree of biodegradation of the test material. The microbes are using the test material as a source of carbon for growth.

Those two test protocols form part of a European standard (EN 14987) for evaluating the disposability of plastics, but this is aimed only at waste-water treatment plants. Conversely, the same two protocols are utilised in the Vinçotte OK Biodegradable WATER conformity mark, which certifies products as biodegradable “in a natural freshwater environment”.

[3] BS EN ISO 14851 (equivalent to BS EN 14048) and BS EN ISO 14852 (equivalent to BS EN 14047)

There are other test methods and standards designed to assess the biodegradability of organic compounds (e.g., chemical products) in some aqueous environments, but these are not designed or authorised for plastic materials.

There are some inactive or withdrawn standards that focused on plastics, but again, these were aimed at biodegradation in sewage sludge, hence more closely linked to the managed waste-water environment than natural freshwater environments.

There are two active international standardised test procedures[4] for the anaerobic (low or no oxygen present) biodegradation of plastic materials in waste-water and sewage sludge. Like the aerobic tests, these two procedures also include measurements of respiration gases (although the gases from anaerobic respiration are different). However, the temperatures utilised are high (35 or 55 °C), making them more suitable for high temperature managed environments, such as industrial anaerobic digesters.

There is also a US biodegradability test method[5] for the anaerobic biodegradation of plastics, again in waste-water and sewage, and again at high temperature (35 °C).

Despite these few authorised documents, there are no full specifications or certified conformity marks developed for the anaerobic biodegradation of plastic materials in waste-water or sewage sludge.

There are no active standards for the biodegradation of plastic materials within inland water bodies (including rivers, streams and lakes), although there are some aimed at organic compounds.

Marine zones

For the marine pelagic environment (aerobic open-ocean areas not near the bottom or the shoreline) there are no active relevant international standard specifications for plastics, although guidelines for determining aerobic biodegradability of organic compounds have been produced.

There is one active US biodegradability test method[6] authorised to determine the degree of biodegradation of plastics in aerobic seawater. The test shows some flexibility in that a suite of pre-selected microbes known to biodegrade particular materials can be used, although pre-selection, rather than using an inoculum of natural seawater, runs the risk of not being representative of natural environments.

One other active US test method[7] is designed as a supplementary test, measuring weight loss of plastic materials that have already been proven to biodegrade. It cannot be used to demonstrate biodegradability per se.

There was previously a US standard specification[8] for certifying whether a plastic material could be labelled as biodegradable for marine aerobic waters or anaerobic sediments. The

[4] BS ISO 13975 and BS EN ISO 14853
[5] ASTM D5210
[6] ASTM D6691
[7] ASTM D7473
[8] ASTM D7081-05

specification referred to many standard test procedures for ascertaining biodegradability. However, this specification has been withdrawn and there is no replacement. Moreover, although sediments and anaerobic environments were nominally included in the specification, the actual tests involved appear to be much more appropriate for aerobic aqueous conditions.

Although there are no current specifications for the disposal of plastic materials in marine environments and no standards or full specifications for determining biodegradability in non-pelagic zones (e.g., coastal areas, different sediment types, deep-sea habitats and brackish waters), there are some standards under development. Therefore, it is possible that additional published standards for marine environments will in future be established.

Strengths and weaknesses of published procedures and standards

The measurement of carbon dioxide and methane evolution from a biodegrading material, a method utilised in some of the standards reviewed, can provide reliable evidence for aerobic and anaerobic biodegradation. One approach offering a high degree of precision is the use of radiolabelled carbon (^{14}C)[9] in these respirometric tests, but radio-isotope labelling is very expensive. So long as the potential sources of uncertainty are properly managed, respirometric tests likely offer the best basis for development of tests for the biodegradability of plastics in the marine environment.

A small number of published tests consider exposure scenarios at the water-sediment interface rather than water-only exposures[10]. Considering the widespread distribution of plastic litter in non-pelagic habitats, these types of standards could provide a starting point for developing new types of scenario for assessing polymer biodegradation.

Some work has clearly been done on producing test protocols for the biodegradability of plastics in waste-water and sewage, and on conformity labelling for biodegradability under some aqueous conditions (e.g., Vinçotte OK Biodegradable WATER and OK Biodegradable MARINE).

An understanding of the biodegradability of filmic materials within natural ecosystems is likely to require a comparison of data from laboratory-based experiments with those obtained under more realistic conditions (e.g., flow-through systems, bioreactors, pre-exposure to a desired set of environmental conditions, and field trials).

However, standard test methods, specifications and conformity (certification) marks for plastics are currently absent for the majority of unmanaged aquatic environments (including all freshwater habitats and non-pelagic marine environments).

Where standards and test protocols are available, they are mostly

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[9] If a test material can be made that contains a known proportion of ^{14}C carbon, the ^{14}C fraction can readily be tracked through a respiration test protocol, revealing the amount of carbon that has been biodegraded and respired. Hence, the carbon from the test material is easily distinguished from any other sources of carbon in the test vessel.

[10] BS ISO Standards 14592-1 and 14592-2

a) conducted under controlled laboratory conditions

b) relying on pre-defined conditions

c) using static aqueous conditions, rather than ‘flow-through’ or natural conditions

d) deficient in accounting for the potential influence of natural solar radiation (or its absence) on biodegradation rates

There is no internationally agreed approach to the use of the inoculum[11], since no universal methodology is available and guidelines are limited. However, the inoculum is a key factor in these tests and an area that has received significant criticism in the scientific literature[12].

Some test protocols do not adequately address replication of the test procedure, so the tests may be conducted too few times to give satisfactory confidence in the results – at least 3 replicates should be done.

With the exception of the Vinçotte OK Biodegradable MARINE certificate, none of the active biodegradability standards and test methods included a requirement for toxicity testing, despite such tests being recommended by certain protocols (e.g., ASTM D5210) when low rates of biodegradation are observed.

The temperature ranges employed in biodegradability tests and guidelines do not account for seasonal fluctuations in environmental conditions and are particularly questionable on their relevance for biodegradability within temperate unmanaged waters, where temperatures are often lower than 14 °C (the lower temperature limit for current test protocols).

In general, filmic plastics are likely to exhibit lower rates of biodegradation within unmanaged aquatic habitats in comparison with managed scenarios. Hence the maximal durations of current biodegradability tests are likely to be too short for assessing polymer biodegradation within several aquatic zones (e.g., lake bottoms, deep-sea habitats, areas of low oxygen, nutrients and light).

Knowledge and research gaps

In order to further develop standardised tests and specifications for the biodegradation of filmic plastics in freshwater and marine environments a better understanding is required of:

- plastic biodegradation under lower temperatures
- the influence of low nutrient conditions on the biodegradability of plastics

[11] ‘Inoculum’ refers to the seawater or waste-water medium containing the biodegradative microbes and into which the plastic test material is placed

[12] For example, in Goodhead et alia (2014) Standard inocula preparations reduce the bacterial diversity and reliability of regulatory biodegradation tests. *Environmental Science and Pollution Research* 21, 9511–9521.

- the extent to which laboratory-based test results reflect those that would occur in natural conditions

- how best to improve and incorporate toxicity testing in standards

There is also a clear need to perform the research required for development of standardised test methods for a number of freshwater and marine zones for which we so far have a substantial lack of knowledge.

Review of existing standards for the biodegradability of lightweight plastic carrier bags: implications for plastics recycling and processing

(Summary based on a review by Professor Ed Kosior of Nextek)

Main conclusions

Conventional non-biodegradable polyolefins such as Low-density polyethylene (LDPE), Linear low-density polyethylene (LLDPE), and High-density polyethylene (HDPE) are typically recyclable once directed into a reprocessing stream, even when mixtures of such plastics are recycled.

The sorting of filmic waste streams continues to be relatively costly and difficult to do, although numerous recent studies have been done to improve the situation for the recycling of conventional polyethylene film.

Some plastic materials designed to degrade are incompatible with the reprocessing of polyethylene, causing process issues to arise during the production of recycled film. Waste management firms will sometimes landfill waste-streams containing degradable plastic bags, due to this process incompatibility.

Incompatible plastics not forming a homogeneous mixture form separate phases in the melted state during processing and cause weaknesses in the final recycled product. Generally, polymers of different chemical composition are incompatible. For example, simple mixtures of polypropylene and LDPE are incompatible and so are HDPE or LDPE when mixed with starch and cellulose. HDPE is incompatible with Polylactic acid (PLA) plastics. Therefore, the content of the recyclate stream is of considerable importance to recyclers.

Many recyclers believe more evidence is required on the impact of pro-oxidant additives (used to accelerate abiotic degradation in oxo-biodegradable films) on the longer-term durability of reprocessed products, and on manufacturers' liability responsibilities.

Published standards and test procedures

The only standardisation document relevant to the impact of degradable bags on plastics recycling was the 2012 USA Association of Postconsumer Plastics Recyclers (APR) "Degradable Additives and Polyethylene and Polypropylene Recycling, Technical Compatibility Testing Guidance".

This guidance suggests the outdoor testing of recycled products for lengthy periods (in Florida ambient conditions) to simulate the impact of the environment on materials. Bottles, pipe and plastic lumber products with (typically) 25% to 50% recycled content are evaluated. Evaluation criteria are defined to determine the impacts of the degradable additives.

Strengths and weaknesses of published procedures and standards

The APR guidance could not be adapted into a short-term test because it explores impact on long-term mechanical properties. Moreover, APR has commented that no organisation with interests in degradative additives has responded to the “Degradable Additives and Polyethylene and Polypropylene Recycling, Technical Compatibility Testing Guidance” during the four years since its creation. Wider debate on this type of guidance may be beneficial.

Knowledge and research gaps

The key knowledge gap is on the long-term impact of pro-oxidant additives used in oxo-biodegradable plastics on the products made from recycled plastics. There is a knowledge gap in understanding the liability issues surrounding the introduction of pro-oxidant additives into plastics that end up in the recycling stream. These oxo-biodegradable materials are compatible with polyethylene plastics chemically. However, there is a concern that these additives could open up liability issues for businesses that make certified products such as moisture proofing membranes, pipes and plastic lumber used in building construction and which have expected lifetimes of decades. Although stabilizers are added to these plastic products these are not necessarily of the correct type or proportions to counteract the presence of residual pro-degradants. Plastic bags can be made from LDPE or HDPE, but there is a lack of firm evidence on the proportions of these different polyethylene materials entering reprocessing operations. Hence the implications of having increased numbers of oxo-biodegradable bags require further investigation.

Since many biodegradable materials are hygroscopic (absorb ambient moisture), they produce steam during processing at high temperatures and gas bubbles in the product, which weakens the physical properties. Many bio-based plastics are water-absorbing and require special drying processes if they are to be recycled, whereas conventional polyethylene does not. Therefore, there is a need to separate these materials during recycling. This is still a difficult task and is the subject of current research and development.

Review of existing standards for the biodegradability of lightweight plastic carrier bags: indirect physical test methods

(Summary based on a review by Professors Jim Song (Brunel University) and Dr Anne-Marie Delort (Institute de Chimie de Clermont-Ferrand))

Main conclusions

Some physical test measurements are inexpensive and simple to perform, making them popular investigative tools in some research teams. However, tests of physical changes on their own are not sufficiently robust to measure biodegradability, although they can provide useful supplementary information.

Visual inspection is a crude, qualitative yet simple method to assess whether biodegradation of bioplastics can take place in a given environment. It relies on visual inspection of changes in surface features, signs of disintegration and the loss of test material into the inoculum. Visual inspection alone is generally inconclusive, even if significant changes in surface features are observed.

Weight or mass loss is a quantitative method that can correlate well with the amount of gas evolution (an established measure of biodegradation based on microbial respiration). There are potential errors of measurement, hence tests must be done on dry material and interruption of the biodegradation process must be avoided.

Measureable changes in mechanical properties (e.g., loss of strength, rigidity) may be attributable to biodegradation. However, such changes may arise for reasons other than biodegradation, reductions in those values do not usually correspond to respiratory gas evolution (an established direct measure of biodegradation), and these tests are only useful during the early stages of biodegradation, since strongly deteriorated material can no longer easily be handled and subjected to physical tests.

To counter the limitations of many of these physical methods other analytical techniques are sometimes also used. For example, spectroscopy and chromatography are common laboratory methods utilised to measure chemical changes, including changes in polymer structure.

Adenosine tri-phosphate (ATP) tests, which in principle should give results correlated with the total metabolic activity of a sample, may be useful in standardised regimes for measuring biodegradability, although further research is needed to establish their applicability in standards for natural environments

Published standards and test procedures

Physical indirect measures or indicators of biodegradability are recommended in a small number of ASTM biodegradability standards.

Visual inspection is recommended in some ASTM standards[13] to assess the resistance of plastic materials to certain microorganisms and in one other[14] to provide visual evidence of biodegradation in seawater, or seawater and sediment.

Weight or mass loss monitoring is recommended in some ASTM biodegradability standards[15].

Change in mechanical properties is recommended in one ASTM biodegradability standard[16].

ATP measurement is the biodegradability metric used in the Agrément certificate AC T 51-808 AFNOR (2012) used for the assessment of the oxo-biodegradability of polyolefin materials containing pro-oxidant additives.

Strengths and weaknesses of physical test procedures and standards

One reason that physical measures are often inadequate is that these test protocols are not directly related to the biological activities responsible for biodegradation processes. Some of these physical measurable outcomes may occur in the absence of biodegradation.

Visual inspection is an inexpensive procedure that can reveal whether degradation or fragmentation has occurred. However, it runs high risk of being inconclusive on biodegradability and can lead to different conclusions between different visual assessors.

Mass loss measurements of the test material are useful when significant microbial respiration is occurring, and can correlate well with biodegradation. This may be because microbial assimilation becomes increasingly possible as the molecular weight of the polymer is reduced during decomposition (very large polymeric molecules cannot readily pass through microbial cell walls). However, mass loss tests have the following weaknesses:

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[13] ASTM G21-90 and ASTM G22-76

[14] ASTM D7473

[15] For example, ASTM D5247-92 (Aerobic biodegradability of degradable plastics by specific microorganisms), ASTM D6003-96 (determination of weight loss from plastic materials exposed to simulated municipal solid-waste aerobic compost environment) and ASTM D7473 (biodegradation of plastic materials in seawater, or seawater and sediment)

[16] ASTM D5247-92 (aerobic biodegradability of degradable plastics by specific microorganisms)

a. many bioplastics are hygroscopic (readily absorb water vapour from the atmosphere), particularly those based on starch, and this can interfere with mass measurements of the plastic. The problem may be countered by adopting drying procedures so that mass change is monitored on *dry* samples of material.

b. since moisture is crucial to microbial activity, the drying procedure may interrupt the continuity of the biodegradation process each time samples are extracted from the test inoculum. This may be mitigated by putting a surplus of samples in the inoculum and extracting only some representative samples for the dry mass measurement while allowing biodegradation of the other samples to continue.

c. fragmentation of sample materials may lead to loss of particles into the inoculum, introducing error in mass loss measurements. This can be prevented by using suitable containers such as nylon mesh bags to retain all particles.

Changes in mechanical properties (strength, rigidity and ductility) may be attributable to reductions in the molecular weight of the material that has occurred as part of a biodegradation process.

Tensile strength is much easier to measure than respiratory gas evolution by microbes, but strength reduction is meaningful only for detection of the onset of biodegradation. During the intermediate and later stages of biodegradation the measurement of mechanical properties becomes increasingly compromised and unreliable. Unsurprisingly, changes in mechanical properties do not correlate well with mass loss or respiratory gas evolution measures of biodegradability.

Changes in mechanical properties may not arise from biodegradation at all. For instance, certain starch-based bioplastics can become brittle with time due to changes in their crystalline structure.

Infra-red spectroscopy may be used to derive the carbonyl index for a material, a measure of the degree of oxidation that has taken place during degradation. Carbonyl groups are increasingly formed as oxidation proceeds. However, the capacity to form carbonyl groups following oxidation is determined by the structure of the polymer, hence the measurement is not appropriate for all materials.

ATP tests are sometimes suggested as alternatives to measurements of microbial respiration. ATP is the form of stored energy used by all living cells during all metabolic processes. Therefore, measures of ATP should in principle relate to the biological activity associated with the total metabolism occurring in a sample, regardless of the microbial species involved. ATP tests are inexpensive, sensitive and quantitative, hence they show much promise. In these tests control measures must be tightly managed and carbon from sources other than the test material eliminated or kept to a minimum, which may be significant in some samples, e.g., soils, which are typically rich sources of organic material. Further research is required on the feasibility of using ATP tests for plastic biodegradability in the unmanaged open environment.

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Annex A: objectives of the Technical Advisory Group

1. The Technical Advisory Group (TAG) was established in December 2014 for Defra's Resource, Atmosphere and Sustainability programme. It was not an official standards committee but has the role of providing advice to **government**.

2. The TAG was tasked with reviewing the existing standards for the biodegradability of lightweight plastics and assessing their appropriateness to be used for an exemption from the carrier bag charge on the grounds of biodegradability. Defra was looking if possible for a standard (or group of standards or authorised tests) that would:

   a) ensure that exempted plastic bags fully biodegrade in a reasonable period of time when littered in all environments without causing harm.
   b) ensure that exempted bags have a clear optimum waste management route.
   c) ensure that exempted bags do not compromise the recycling of non- biodegradable single use carrier bags and films, or the treatment of food waste by composting or anaerobic digestion when exempted biodegradable bags are used for the collection of food waste.
   d) be technology-neutral and focus only on the biodegradability[17] aspects of the performance of any material and those aspects of current standards that deal with biodegradation.
   e) take account of the wider environmental, social and economic context in which this policy area sits.

3. Defra accepts that it may not be possible to create a standard that fully meets all parts of the policy aspiration. The TAG will identify gaps in the standards landscape, explore the most achievable options for filling such gaps and report on the likelihood and suggested ways of achieving the overall aims through standardisation.

4. The TAG did not have decision making powers but arrived at its conclusions through its combined technical capability and especially its knowledge of biodegradability science. The group produced advice in the form of reports, on:
   a) the appropriateness and the strengths and weaknesses of current standardised biodegradability criteria for establishing a standard for biodegradable carrier bags.
   b) the appropriateness and the strengths and weaknesses of current standardised test methods for biodegradability.

[17] 'Biodegradation' alludes to the general principles that underlie most definitions by biologists, namely, complete degradation performed by microbes, giving rise to simple gases, minerals and with microbial biomass and any other residues being unharmful.

c) the strengths and weaknesses of scientific and research findings underlying existing standards and test methodologies.
d) criteria that might be included within a standard designed for the exemption.
e) practical barriers that might prevent a filmic material in practice from meeting biodegradability criteria.
f) any relevant gaps in technical knowledge that might hinder development of standard(s) for a biodegradable carrier bag.

5. The group had a closed membership and was restricted to those invited.

Annex B: background to standardisation and certification

This section briefly explains some of the features of the standardisation landscape that may help the reader to understand and interpret the summary reports. There are already some published documents explaining the development and role of standards, for example the BSI 'standard for standards'[18].

Some authorised standards take the form of standardised test procedures, sometimes called methods. These test procedures are employed by technicians and researchers to obtain a test result usually quantifying the degree to which a material exhibits a particular property. For example, such a test might reveal that at least 60% of a material biodegrades within a certain time period and under particular test conditions. There are not usually any pass or fail criteria. These standards are based on agreed ways to measure something.

Other standards could more properly be termed specifications. These often draw together and rely on standardised test methods and set out the procedures that must be followed in order to establish whether or not a material complies with the criteria set out within a particular specification. Therefore, a specification usually contains some sort of requirement for compliance. Some standard specifications include pass or fail criteria and they are often agreed by a wider sector, for example an industrial sector.

Standards can also take the form of guidance or good practice guides which set out options for reaching a particular outcome. They are likely to be voluntary although they may be very well informed and readily used by practitioners. The BSI PAS600:2013[19] document – Bio-based Products, Guide to Standards and Claims – gives "guidance and recommendations" and provides a helpful review of relevant biodegradability and other standards that might be utilised in that industrial sector.

Finally, standardised tests and specifications are often referred to by certification authorities, who may authorise that a material or product can display a particular logo or label indicating that it has met a particular standard. Certification bodies are not often the same organisations as those that authorise the standardised tests and standard specifications. Certification schemes may help the public to understand or gain confidence in some property exhibited by a material or product.

Standards are often created through a mixture of scientific and industrial stakeholder activities, although some standards are also related to legislation, for example, the

[18] http://www.bsigroup.com/LocalFiles/en-GB/standards/bs0-pas0/BSI-BS0-Standard-for-Standards-UK-EN.pdf
[19] http://shop.bsigroup.com/en/ProductDetail/?pid=000000000030262005

National Instruments[20] required by various Directives or international law. Industry acceptance of standards is very often critical to ensure participation in the use of the standard. There is often a need for some form of consensus. The cost of complying with the standard, including paying for tests, is also likely to be important.

Many standards are developed with a particular disposal route or other final outcome in mind. For example, there are standard tests to measure how much a material biodegrades in an anaerobic digester inoculum. The 'inoculum' is simply some of the process fluids taken from an anaerobic digester vessel. Such a standard test could be developed to measure whether a material is likely to biodegrade during a real industrial anaerobic digestion (AD) process. Because AD processes operate under very low or zero oxygen levels, the test would also need to employ similar conditions, to reliably simulate what might happen to the material if it was placed in a real AD vessel.

Hence, where a standard is needed in order to validate whether a material will biodegrade in one or more natural environments, it is especially challenging to design inexpensive laboratory tests that convincingly simulate those natural environments in which the material is expected to decompose and the time periods over which decomposition might occur in nature. Conversely, the use of field-based tests runs the risk of simulating a particular environment so closely that the test may be much less useful for the many other types of environment that will undoubtedly exist. Consideration of this relationship between a standardised test and the final disposal or recovery destination for a material is an important line of reasoning and enquiry.

Some standards deal with different aspects of the same disposal or recovery route, and some materials or products may be designed to achieve well on a number of different performance criteria. This raises the possibility that a particular material may be tested using several different standards, in order to demonstrate the full range of the material's performance. A material may turn out to be compliant with one standard but not another, even though they both measure some aspect of the same thing, e.g., biodegradability.

There are country, regional and international standardisation bodies whose acronyms are usually found at the front-end of their authorised standards. For example, the British Standards Institution (BSI) is the UK National Standards Body; the European Committee for Standardisation (CEN – *Comité Européen de Normalisation*) operates within the European economy – a CEN-authorised standard has EN in its name, e.g., EN13432; the American Society for Testing & Materials (ASTM International) is a US based voluntary standards organisation; and the International Organisation for Standardisation (ISO) develops standards internationally. The ISO receives input from well over a hundred national standards bodies from around the world, including the BSI.

[20] http://www.ni.com/support/cert/prod_cert_details.htm

Annex C: glossary of terms[21]

Abiotic	Without life or living organisms. Abiotic features of the environment include light, temperature and atmospheric gases.
AD	Anaerobic Digestion - processes by which microorganisms break down biodegradable material in the absence of oxygen.
Aerobic	In the presence of oxygen.
Biodegradable	Susceptible to biodegradation
Biodegradation	The decomposition of a compound or material by micro-organisms into harmless products such as carbon dioxide, minerals, water and additional microbial biomass. Complete biodegradation of this sort is sometimes referred to as 'ultimate biodegradation'.
BSI	British Standards Institution
Carbonyl index	A value applied to a polymer on the basis of the ratio of its absorbance of infrared light between carbonyl and methylene groups, a measure of the material's oxidation
Cellulose	Natural organic polymer and important structural component of plants, often used as a control or reference material in tests of biodegradability
CEN	European Committee for Standardisation
Certification	An activity whereby a legally registered certificate is issued under the procedures of a third-party certification body to indicate that a manufactured material or product conforms to the requirements of a particular standard or specification

[21] For technical terms this glossary has benefited from standardised vocabulary guidance, such as found in PD CEN/TR 15351:2006 'Plastics – Guide for vocabulary in the field of degradable and biodegradable polymers and plastic items'. Some definitions are adjusted for the sake of brevity and to enhance contextual relevance. Further information defining many technical terms used in standardisation documents can be obtained from the ISO online browsing platform https://www.iso.org/obp/ui/ – select 'Terms & Definitions' and enter any term of interest.

Chromatography	Chromatography is a chemical separation method in which a mixture or solution of substances is passed through a medium in which the substances move at different rates, indicating the type and amounts of substances present
Compostable	Susceptible to decomposition and biodegradation in composting conditions
Compostable bags	A type of biodegradable bag made of materials like thermoplastic starch, polylactic acid (PLA), polyhydroxyalkanoates (PHA) and others. They are designed to decompose in a defined time period (usually less than six months) and used in short-lived applications such as in agriculture, catering products, packaging, or thin bags.
Conformity mark	Legally registered visible certification mark or logo, particularly useful for consumers, applied or issued by a third party certification body to indicate that a manufactured material or product is in conformity with a particular standard or specification
Control	In standardised tests a control procedure provides the data against which data from other experimental procedures is compared. For example, the measurable biodegradability of a putative biodegradable material is often compared against the biodegradability of a standard control material already known to fully biodegrade, such as cellulose.
Degradation	Breaking down but not necessarily fully (as in ultimate biodegradation) and not necessarily through the actions of microbes
Digestate	A nutrient-rich residual material, often highly aqueous, left over following industrial AD and often spread to land
EANCB	Equivalent Annual Net Cost to Business defined on p46 of the Better Regulation Framework manual here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/421078/bis-13-1038-Better-regulation-framework-manual.pdf

Ecotoxicity	The potential for biological, chemical or physical stressors to affect ecosystems, including the biota within
HDPE	High-density polyethylene – a petroleum based plastic
Hygroscopic	Absorbing moisture from the air.
Inoculum	A sample of a medium (e.g., seawater or waste-water) containing biodegradative microbes and into which plastic test material is placed
ISO	International Organization for Standardization
LCA	Life cycle assessment is a technique for assessing the 'cradle-to-grave' environmental impacts of a product or service by compiling an inventory of all relevant inputs and outputs, such as energy use, water.use and pollution emissions.
LDPE	Low-density polyethylene – a petroleum based plastic
Mulch film	Plastic film used in agriculture and horticulture to suppress weeds, conserve water and enhance crop growth; some biodegradable films have been designed to break down in the location in which they are used
Oxo-biodegradation	Degradation resulting from abiotic oxidation and microbial biodegradation
Oxo-fragmentation	The first phase of oxo-biodegradation wherein fragments of plastic are produced before biodegradation occurs.
Pathogens	Biological agents that cause disease
PE	Polyethylene – a common plastic typically used to make plastic bags
Pelagic	Water in the open sea or lakes not close to the bottom or the shore

Polymer	A natural or artificial substance consisting of large molecules made from many smaller and simpler chemical units (e.g., individual monomers)
Polyolefin	An older term for polyalkene, an alkene being any of a group of unsaturated hydrocarbon molecules (olefins) such as ethylene, from which the common plastic polyethylene is produced.
Pro-degradant	Additive used to accelerate the oxidation of a plastic and promote its breakdown
Radio isotopic labelling	A technique for incorporating and then tracking a chemical isotope that has been used to replace specific atoms in a reactant or material. Because the isotope is very similar to the atom it replaces it acts in much the same way in any experiments, but is readily detected because the different isotopes of an element and their relative abundance is known. Hence radio-isotope-labelled carbon in a test material can be detected (and distinguished from other sources of gaseous carbon) if it is respired by microbes that metabolise the polymer.
Respirometric tests	Tests which measure the degree and nature of respiration, for example the consumption or generation of respiratory gases by microbes during metabolism
SAG	Defra's Stakeholder Advisory Group made up of industry group representatives from across the supply chain. The group provided advice to Defra but did not have decision making powers.
Specification	A type of standard usually containing criteria for assessment of the performance of a material, product or service. A specification typically refers to standard test methods that provide the means to examine performance achievements.
Spectroscopy	Spectroscopy measures the interaction between matter and energy (usually) at some position within the electromagnetic spectrum, for example, the degree of absorption of infra-red light by a particular

	material
TAG	Defra’s Technical Advisory Group made up of academic experts who carried out the review of industry standards for biodegradability.