OXO-BIODEGRADABLE PLASTIC TECHNOLOGY

OPINION

1 Introduction

1.1 I am instructed and paid by Symphony Environmental Technologies Plc ("Symphony") to review whether the evidence, particularly from recent scientific research, supports the following proposition: Oxo-biodegradable plastic technology, if employed in the manufacture of certain plastic products, has significant effectiveness and utility in facilitating the ultimate total molecular degradation of the plastic in air or seawater by bacteria, fungi or algae, so as to cause the plastic to cease to exist as such, far sooner than is the case when that technology has not been employed.

1.2 If that proposition is sound, the benefit is obvious of reducing future contributions to the scourge of plastic pollution of land and sea.

1.3 The technology is applied in the course of manufacture of such products as plastic bags, bottles and packaging from polyethylene ("PE") or polypropylene ("PP"). It involves adding substances assembled to form a 'masterbatch' which constitutes about 1 per cent of the volume of the plastic. Symphony is a producer of such a masterbatch, which it calls 'd2w', and Symphony is the leading member of the Oxo-biodegradable Plastics Association. It is not claimed that the technology is effective other than when the plastic is in air or water: for example, it is not claimed to be effective if the plastic is buried deep in soil.

1.4 In this Opinion I summarise:

1.4.1 the approach I have adopted for my review of the evidence: paragraph 2 below;

1.4.2 the processes of degradation of the plastic: paragraph 3 below;

1.4.3 recent published scientific research on the effectiveness of the technology in facilitating degradation in *air*: paragraph 4 below;

1.4.4 recent published scientific research on the effectiveness of the technology in facilitating degradation in *seawater*: paragraph 5 below;

1.4.5 the status of the 2016 Eunomia Report to the European Commission in the light of that published research: paragraph 6 below;

1.4.6 recently expressed views of eminent and internationally well-known researchers into degradation and biodegradation of plastics: paragraph 7 below;

1.4.7 objections expressed as to the utility of the technology: paragraph 8 below;

1.4.8 my overall conclusions: paragraph 9 below.

2 My Approach

2.1 The approach that I have been encouraged to adopt in writing this Opinion is to imagine that I have been appointed as the sole member of an independent tribunal with jurisdiction to review, on a balance of probabilities, and in the light of the available scientific evidence, the effectiveness and utility of Oxo-biodegradable plastic technology in facilitating the speedier final degradation of certain plastics.

2.2 I have accepted at the outset and I have complied with the obligation to produce my own independent and reasoned Opinion in the exercise of appropriate skill and care, while expressing any reservation I might have, and on the basis that this obligation overrides any other obligation to Symphony or to any other party with an interest in the outcome.

2.3 I am not aware of any conflict of interest on my part, and in particular I confirm that I have at no stage entered into any arrangement where the amount or payment of my fee for this Opinion is in any way dependent on its content or conclusions.

2.4 The only evidence that I have taken into account in writing this Opinion is the documentary evidence listed in Annexe 1 (pages 13 to 14 below).

2.5 I am not trained either as a scientist or as a technologist, and my only relevant expertise is that I have over 50 years' experience in England as a barrister in private practice (for over 20 years of which I have been practising as Queen's Counsel) involved in the critical analysis and evaluation of the cogency of expert evidence (including critical analysis and evaluation of the cogency of such evidence when tendered in support of the case advanced by the client on whose behalf I have been instructed); and that I have over 25 years' experience in England of sitting as a Recorder (a part-time deputy judge) in civil cases in the Technology and Construction Court branch of the High Court, and in the County Court, involving the evaluation of expert evidence. I have also more recently become a Fellow of the Chartered Institute of Arbitrators. A more detailed CV is attached as Annexe 2 (page 15 below).

3 The Processes of Degradation

3.1 The summary that follows I have mostly derived from the recent research papers summarised in paragraphs 4 and 5 below.

3.2 Oil-based polymers such as PE and PP comprise long, entangled chains of carbon and hydrogen. For present purposes, I have found it helpful to distinguish three stages in the life of such plastic.

3.3 The first stage I call 'Useful Life', which is before any degradation occurs. This stage obviously needs to last for a reasonable period of time in order to enable the plastic to be used for its intended purpose.

3.4 The second stage is 'Abiotic Degradation' ('Abiotic' because it does not require intervention by any living organism whether bacteria, fungi or algae, and it therefore should not on its own be classified as '*bio*degradation'). Abiotic Degradation is a process of oxidation, during which oxygen, ultra violet sunlight and heat cause the plastic to degrade progressively. During this process the plastic may become capable of absorbing toxins, is an obvious source of pollution of the environment, and will enter the food chain if consumed by sea creatures. Eventually, Abiotic Degradation will reduce the residue of the plastic to fragments of a molecular weight of less than about 5,000 daltons: by comparison, one single molecule of water has a molecular weight of about 18 daltons. It is now thought that this may take decades, if not centuries, rather than a few years as used to be supposed, and of course the longer it takes, the more opportunity for absorption of toxins.

3.5 It is at the third and final stage, 'Biodegradation', when the plastic residues have already degraded to a molecular weight of less than about 5,000 daltons, that they are capable of being ingested and utilised by bacteria, fungi or algae. This Biodegradation is also a natural process, and it does not in itself require oxygen (and therefore should not in itself be classified as '*Oxo*-biodegradation').

3.6 The ultimate consequence of total degradation of the plastic is completion of a process of breakdown of the long, entangled chains of carbon and hydrogen atoms, freeing those atoms to link with oxygen to form respectively carbon dioxide and water, leaving some residue of 'biomass' of little significance in the present context. In effect the plastic ceases to exist as such.

3.7 The aim of Oxo-biodegradable plastic technology is that the masterbatch should take effect to speed up Abiotic Degradation (which I have designated as the second stage of degradation), so that decades or centuries do not need to elapse before Biodegradation (the third and final stage) may complete the total degradation of the plastic so that it ceases to exist as such.

3.8 Scientists who are testing the effectiveness of Oxo-biodegradable plastic technology adopt the technique of speeding up Abiotic Degradation by aging the plastic artificially, for example, by the use of more concentrated light or heat or both. This technique seems to me to be not only unavoidable as a matter of practice, but reasonable and appropriate. I do not consider that the reported results of the research may be suspect on the ground that this artificial weathering of samples in a laboratory may not match conditions found in real life, as noted by the authors of the January 2010 Loughborough University study (for DEFRA) entitled 'Assessing the Environmental Impacts of Oxo-degradable Plastics Across Their Life Cycle' (EVO422).

4 Degradation of plastic in *air*

4.1 As to the effectiveness of Oxo-biodegradable technology in promoting speedy degradation of plastic in *air*, the latest research to which I have had access concerns an experiment conducted by Eyheraguibel and 9 colleagues, as reported in the paper, 'Characterisation of oxidised oligomers from polyethylene films by mass spectrometry and NMR spectroscopy before and after biodegradation by a Rhodococcus rhodochrous strain', published on 23 May 2017 in the peer-reviewed journal 'Chemosphere', vol 184, page 366 (the more standard spelling of that particular strain of bacteria seems to be 'Rhodococcus rhodocrous'). As would be expected, this research acknowledged, took account of, and occasionally differed from the assumptions or conclusions of the previous scientific work cited in that paper, as well as answering some questions previously left open.

4.2 The authors exposed residues of artificially heat-aged high density PE ("HDPE") film to that particular strain of bacteria in air over a period of 240 days. The authors tested the extent to which the residues of HDPE film in the third and final stage of Biodegradation had been ingested and degraded by the bacteria so as to cease to exist as plastic. For the first time in this connection, they did so by using all three of the techniques of infra-red spectroscopy, mass spectrometry and nuclear magnetic resonance spectrometry, in order to "look" at the molecular structure of the residues of the HDPE film. This testing was necessarily of residues in a solution of water, but what was being tested was the results of prior degradation in *air*.

4.3 They authors found that that after only 4 days, the residues of the HDPE film had already been ingested by the bacteria, and ultimately degraded to the extent that some 60 per cent of it no longer existed as plastic.

4.4 By the end of the experiment, after 240 days, the residues of the HDPE film had been ingested by the bacteria and ultimately degraded to the extent that some 95 per cent of it no longer existed as plastic.

4.5 I consider that this comparatively recent experiment provides clear and compelling evidence in support of the proposition that if Oxo-biodegradable plastic technology is used, Abiotic Degradation in air, and thus also ultimate final degradation, is very significantly speedier than is the case when that technology is not used. I cannot imagine that such significantly speedier final degradation occurs later than 'within a reasonable time', however that expression might be defined.

5 Degradation of plastic in *seawater*

5.1 As to the effectiveness of Oxo-biodegradable technology in promoting speedy degradability of plastic in *seawater*, the latest research to which I have had access concerns an experiment conducted by Dussud and 14 colleagues, as reported in the paper 'Colonisation of Non-biodegradable and Biodegradable Plastics by Marine Organisms', published on 18 July 2018 in the peer-reviewed journal 'Frontiers in Microbiology'. Again as would be expected, this research acknowledged and took account of the previous scientific work cited in that paper.

5.2 The authors conducted an experiment to try to see whether there was any material difference between the way that bacteria commonly found in seawater interacted with waste plastic, depending on whether Oxo-biodegradable technology had been employed or not. The experiment lasted some 6 weeks, and involved keeping sample plastics, each in a separate aquarium shielded from light, each containing seawater from the French coast of the Mediterranean at the same temperature as in the open sea, with the seawater being renewed every half hour.

5.3 Four types of plastic were used for the experiment. I can summarise the meticulous description in the published paper of each type as follows:

5.3.1 low-density PE ("LDPE") film of the type commercially available and commonly used for plastic bags, and which the authors classify as 'non-biodegradable';

5.3.2 LDPE film mixed at manufacture of the film with Symphony's d2w masterbatch, and which the authors designate as "OXO", not subjected to artificial aging to simulate Abiotic Degradation; and which the authors also classify as 'non-biodegradable';

5.3.3 LDPE film which had been artificially aged to simulate Abiotic Degradation, and which the authors designate as "AA-OXO"; and which the authors classify as 'biodegradable';

5.3.4 as a control, "PHBV", a plastic fabric (polyester) synthesised by bacteria, and commonly used in speciality packaging, orthopaedic devices and for the controlled release of drugs; and which the authors also classify as 'biodegradable'.

5.4 The experiment employed the equipment, techniques, protocols, software and controls described in detail in the published paper, including the techniques which the authors believe to have been the first attempt to count the number of bacteria involved. One of the authors, Perry Higgs, whose role is identified in the published paper as having been involved in the design of the equipment for the experiment, is a research chemist employed by Symphony, but Symphony did not otherwise contribute to the conduct or funding of the experiment.

5.5 The purpose of the experiment was to observe any differences in how the various types of plastic supported growth of bacteria naturally occurring in that seawater, and in particular of bacteria called by the authors 'putative hydrocarbonoclastic bacteria' (meaning that they are seemingly capable of ingesting, utilising and thus ultimately degrading the residues remaining after Abiotic Degradation).

5.6 The authors found that throughout the experiment, all of the plastic attracted colonisation by greater concentrations of bacteria than are found in the surrounding seawater.

5.7 In the first week of the experiment, they observed that pieces of plastic of the various types attracted similar concentrations of similar species of bacteria, resulting in each case in a similar 'biofilm' of colonies of bacteria opportunistically adhering to the surface of the plastic.

5.8 As concentrations of bacteria continued to increase during the further 5 weeks of the experiment, the authors observed that the 'biodegradable' plastics were colonised by some 30 times higher concentrations of putative hydrocarbonoclastic bacteria than were the 'non-biodegradable' plastics (and usually by different species of bacteria than had predominated in the first week).

5.9 The authors suggest that perhaps in the later stages the higher concentrations of putative hydrocarbonoclastic bacteria adhering to the biodegradable plastics, as opposed to the non-biodegradable plastics, might have been the result of differences arising during Abiotic Degradation in the surface characteristics of the different types of plastic, such as roughness, wetness (measured in terms of 'contact angle'), and delay in reaction to change (hysteresis), but said that the mechanics and interactions involved are complex, and are not yet fully understood.

5.10 So here again, I consider that this very recent experiment provides clear and compelling evidence in support of the proposition that with use of Oxo-biodegradable plastic technology, Abiotic Degradation in seawater, and thus also ultimate final degradation, is very significantly speedier than is the case when that technology is not used. Here again, I cannot imagine that such significantly speedier final degradation occurs later than 'within a reasonable time', however that expression might be defined.

6 The Eunomia Report to the European Commission

6.1 It is now more than 2 years since the Final Report dated 7 August 2016 by Eunomia Research & Consulting Limited on 'The Impact of the Use of "Oxo-degradable" Plastic on the Environment' ("the Eunomia Report") was produced for the European Commission's Directorate-General for Environment.

6.2 The conclusion reached in August 2016 was that there was no firm evidence either way that Oxo-biodegradable technology could be successful, in the face of doubt at that time whether Abiotic Degradation could speedily result in residues of molecular weight low enough to be capable of being ingested and utilised by bacteria, fungi or algae.

6.3 Of course the Eunomia Report cannot be criticised for failing to anticipate the results of the experimental work reported in 2017 and 2018, outlined in paragraphs 4 and 5 above.

6.4 However, the Eunomia Report's conclusion in 2016 that there was no evidence either way, has clearly been overtaken by the subsequent research described in paragraphs

4 and 5 above, with the result that it is no longer tenable to conclude that there is 'no firm evidence either way' whether Oxo-biodegradable plastic technology is effective. I have already explained why I consider that this research provides clear and compelling evidence that Oxo-biodegradable plastic is indeed effective in facilitating very significantly speedier degradation than is the case when that technology is not used.

7 Recently expressed views of other respected scientists in the field

7.1 In or about May 2018 each of a number of eminent and internationally well-known researchers into Oxo-biodegradable technology was moved to write to the European Chemicals Agency urging it not to impose any restriction on the use of that technology.

7.2 I have read such letters from:

7.2.1 Dr Ruth Rose (London) (who also referred to her yet unpublished further research, then undergoing peer review);

7.2.2 Prof Emo Chiellini (Pisa, Italy);

7.2.3 Prof Ignacy Jakubowicz (Borås, Sweden);

7.2.4 Dr Graham Swift (Chapel Hill, NC, USA);

7.2.5 Prof Telmo Ojeda (Porte Alegre, Brazil);

7.2.6 Dr Adriana Reyes-Meyer (Jiutepec, Morelos, Mexico).

8 Objections to the utility of the technology

8.1 Regardless of the effectiveness of Oxo-biodegradable plastic technology as demonstrated by the recent research outlined in paragraphs 4 and 5 above, the technology has been criticised as lacking utility. This is the focus of a substantial part of the discussion and conclusions of the Eunomia Report, and also of the Ellen McArthur Foundation's variously published contentions regarding 'The New Plastics Economy: Rethinking the future of plastics', as in particular expressed in an article with that title published in November 2017.

8.2 One criticism alleges that Oxo-biodegradable plastic technology is incompatible with the decidedly useful and beneficial technology of dealing with waste by recycling. However:

8.2.1 the Report by Transfercenter für Kunstofftechnik GhbH (Wels, Austria), 'Effect of mechanical recycling on the properties of films containing oxo-biodegradable additive' dated 17 March 2016, commissioned and paid for by Symphony, concluded from simulated recycling of LDPE treated with Symphony's d2w masterbatch and a control, that "it is viable to recycle ... oxo-biodegradable materials into other short service lifed products like trash or shopper bags";

8.2.2 a further Report by the same body, 'Weathering study on LDPE (with and without d2w/oxobiodegradable additive)' dated 27 July 2016, again commissioned and paid for by Symphony, concluded from comparable testing of similar material and of a control, that recycled plastic was appropriate for long-term outdoor use of such products as "plastic lumber, garden and municipal furniture and signage posts", provided that a UV stabiliser is added to the recycled plastic before re-use, because "thick cross-section plastic products intended for use outdoors should always contain a UV stabiliser whether or not they contain any oxo-biodegradable recyclate";

8.2.3 in any event, and as with some other materials (such as ordinary black plastic), Oxo-biodegradable plastic may easily be made identifiable by the supplier of the masterbatch adding detectable chemical markers so that the plastic can be sorted before recycling;

8.2.4 furthermore, the answer to the cited risk of using recycled Oxo-biodegradable plastic for such critical applications as damp-proof membranes in the construction industry, is that it is unsound practice to use recycled plastic of unknown provenance for any critical application.

8.3 Another criticism alleges that Oxo-biodegradable plastic technology is incompatible with another decidedly useful and beneficial technology of dealing with waste, namely by composting. I am instructed by Symphony that the technology is not marketed as suitable for composting. In any event, many other waste products (including conventional plastic) may be unsuitable for composting and require to be excluded. As already stated, Oxo-biodegradable plastic may be made identifiable for sorting by the supplier of the masterbatch adding detectable chemical markers.

8.4 Yet another criticism alleges that Oxo-biodegradable plastic is more prone to become toxic. However, this allegation was disproved by the tests undertaken by Eurofins Product Testing Spain SL, commissioned and paid for by Symphony, and set out in the 'Summary of Testing' dated 25 July 2017, of LDPE film. Samples of LDPE film treated with Symphony's d2w was composted. After 121 days of Abiotic Degradation the LDPE film demonstrated nearly 90 per cent reduction to fragments of molecular weight less than about 5,000 daltons. The compost was then tested to see if it was toxic to plants or earthworms. No toxicity was found, confirming the results of a number of other reported similar tests.

8.5 The amount of carbon dioxide produced as a result of the final degradation is clearly not of a magnitude to have an appreciable effect on global warming.

8.6 The criticism alleging that Oxo-biodegradable plastic technology would materially encourage littering I can only regard as fanciful and unrealistic.

9 Conclusions

9.1 I adhere to the approach with which I started, that I should imagine that I have been appointed as the sole member of an independent tribunal with jurisdiction to review, on a balance of probabilities, and in the light of the available scientific evidence, the effectiveness and utility of Oxo-biodegradable plastic technology in facilitating the speedier ultimate degradation of certain plastics.

9.2 Using that approach, it seems to me that the most recent scientific research (outlined respectively in paragraphs 4 and 5 above) has produced clear and compelling evidence of the effectiveness of Oxo-biodegradable plastic technology in promoting significantly speedier ultimate degradation in air or seawater than is the case when the technology is not used; that this evidence supersedes earlier conclusions about lack of evidence (referred to in paragraph 6 above); and that the continuing use of the technology is supported by each of a number of respected researchers (named in paragraph 7 above).

9.3 As regards the utility of the technology, testing has shown that its use does not preclude recycling for short-term use, or even for long term outdoor re-use when stabiliser is added before re-use; research has shown no increased toxicity, and other criticisms seem fanciful; as in each case outlined in paragraph 8 above.

Peter Susman QC

PETER SUSMAN QC

Henderson Chambers
2 Harcourt Buildings
Temple
London EC4Y 9DB

2 November 2018

A N N E X E 1

Materials taken into Account

(in reverse chronological order)

18 Jul 2018	Dussud and 14 colleagues: Paper, 'Colonisation of Non-biodegradable and Biodegradable Plastics by Marine Organisms', published in 'Frontiers in Microbiology' (peer-reviewed)
10 May 2018	Dr Graham Swift of Duke University, North Carolina, USA: Comment on Oxo-Biodegradable Plastics
9 May 2018	Dr Prof Emo Chiellini, Pisa University, Letter to the European Chemicals Agency
4 May 2018	Dr Adriana Reyer-Mayer, a Mexican research scientist, Letter to the European Chemicals Agency
3 May 2018	Dr Ruth Rose, Letter to the European Chemicals Agency
18 Apr 2018	Prof Ignacy Jakubowicz: Comments on the request to the European Chemical Agency to prepare a restriction to oxo-biodegradable plastics
28 Jan 2018	Oxo-Biodegradable Plastics Association: 'The New Plastics Economy, Rethinking the future of plastics' *Comment: The Chairman of this Association is Michael Stephen, Deputy Chairman of Symphony Environmental Technologies Plc*
16 Jan 2018	Report from the European Commission to the European Parliament and the Council on the impact of the use of oxo-degradable plastic, including oxo-degradable plastic carrier bags, on the environment COM(2018)35 final
7 Dec 2017	Arráez and 2 colleagues: Thermal and UV degradation of polypropylene with pro-oxidant. Abiotic characterisation', published in Journal of Applied Polymer Science (peer-reviewed)
Nov 2017	Ellen McArthur Foundation and others, The New Plastics Economy: Rethinking the future of plastics
21 Aug 2017	Prof Ignacy Jakubowicz, Letter to the Ellen MacArthur Foundation.
25 July 2017	Eurofins Product Testing Spain BU: Summary of Testing (of LDPE containing additive, for toxicity)
23 May 2017	Eyheraguibel and 9 colleagues, Paper, 'Characterisation of oxidised oligomers from polyethylene films by mass spectrometry and NMR spectroscopy before

	and after biodegradation by a *Rhodococcus rhodochrous* strain, published in Chemosphere (peer-reviewed), vol 184, page 366
Jan 2017	Richardson and 2 colleagues: An investigation into the biodegradation of plastics by *Alcanivorax borkumensis* and *Rodococcus rhodochorous*
7 Aug 2016	Eunomia Research & Consulting Limited's (final) Report to the European Commission's Directorate-General for Environment
27 July 2016	Transfercenter für Kunstofftechnik GhbH (Wels, Austria), Report: Weathering study on LDPE (with and without d2w/oxobiodegradable additive)
17 Mar 2016	Transfercenter für Kunstofftechnik GhbH (Wels, Austria), Report: Effect of mechanical recycling on the properties of films containing oxo-biodegradable additive
27 Feb 2015	Selke and 5 colleagues, Article, Evaluation of Biodegradable-Promoting Additives for Plastics, published in 'Environmental Science & Technology' (peer-reviewed)
21 May 2012	Roediger Agencies cc (Stellenbosch, South Africa), Recycling Report on d2w Oxo-biodegradable Plastics
Mar 2010	Statement by Prof Telmo Ojeda, Professor of Chemistry, Instituto Federal de Educação Ciência e Tecnologia Sul-RioGrandense, Brasil: On Loughborough University Report EV0422: "Assessing the Environmental Impacts of Oxo-degradable Plastics Across Their Life Cycle."
Jan 2012	Loughborough University (for DEFRA), 'Assessing the Environmental Impacts of Oxo-degradable Plastics Across Their Life Cycle', EVO422, Reply to the Response by the Oxo-degradable Industry
Jan 2010	Loughborough University (for DEFRA), 'Assessing the Environmental Impacts of Oxo-degradable Plastics Across Their Life Cycle', EVO422

A N E X E   2

CV of Peter Susman QC

Education

Dulwich College (1953-61)

Lincoln College, Oxford (1961-4, Oldfield Law Scholar, MA)

University of Chicago Law School (1964-5, British Commonwealth Fellow, Fulbright Scholar, JD)

Professional career

Research into French labour law in aid of a worldwide study (1965 for 6 months for Seyfarth Shaw, attorneys (in Chicago)

Called to Bar by Middle Temple (1966)

Practice at Bar (1967 to present, apart from 1970-1 for 18 months corporate law associate with Debevoise Plimpton, attorneys (in New York City))

Recorder sitting in TCC, County Court and Crown Court (1987-2016)

Queen's Counsel (appointed 1997)

Standing counsel to Ofcom (half time, 2004-5)

Bencher of Middle Temple (elected 2006)

Master of Middle Temple Library (2014 to date)

Fellow of Chartered Institute of Arbitrators (2016)

Main focus of current practice at Henderson Chambers: contract litigation, particularly concerning complex commercial or high technology areas, including construction and engineering, information technology, the regulation of business and of professionals, and other disputes involving foreign and domestic parties, more than one area of law, complicated issues or facts, or other difficulties