Comments on "Performance Evaluation of Environmentally Degradable Plastic Packaging and Disposable food Service Ware - Final Report" – California State University for CIWMB May 2007

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Introduction

The purpose of this California report is said to be to investigate plastic products that are claimed to decompose naturally in the environment or through composting. In practice only degradation during composting is considered in detail.

It is important to recognise that composting is an artificial man-devised process required to meet artificial tests set by the composting industry that have nothing to do with biodegradation in the natural environment. Consequently, the ASTM Standard, D 6400 and related standards[1] requires that the carbon in the polymer is "completely consumed", that is converted to carbon dioxide, water, minerals and a small amount of dead-cell biomass in 180 days or less.

This is not the way in which nature converts its waste to valuable soil improvers and fertilisers. In nature, lignocellulose, the most abundant biopolymer, is converted to low molar mass chemicals that are nutrients for micro-organisms. Expelling the carbon to atmosphere in 180 days provides no benefit to the natural environment in, but instead contributes to the "greenhouse effect."

Composting of plastics is in any event a marginal activity as there are very few suitable industrial facilities. Moreover, the difficulty of sorting the different kinds of plastic means that many composters do not want plastic of any kind – whether crop-based or oxo-biodegradable.

Oxo-biodegradable plastics are not normally marketed for composting, although they can be composted in suitable industrial facilities.

The following sections quoted refer to the headings in the report itself

Background information

There are a number of incorrect or unsupported statements in this section.

"Most petroleum-based polymers are not biodegradable"

[1] Eg European Standard 13432

The example given is polyethylene. However, the authors seem to be unaware that the non-biodegradability of commercial plastics is not an intrinsic property of ***the polymer itself***. It has been shown that both polyethylene and polypropylene biodegrade in compost after the antioxidants, added to the polymer during polymer conversion to provide durability during the use of the product have been removed[2]. Moreover the authors make no reference to abiotic degradation of polymers by oxygen in the environment, and in particular the important role of antioxidants in regulating their service life. It is the inhibition of abiotic oxidation that gives commercial polyolefins the reputation of "lasting" for a thousand years" or as Barry Commoner has stated[3] "every pound of plastic that has ever been produced is still with us if it has not been burned". In practice, the rate of biodegradation of polyolefin plastics can be varied from a few weeks to many years in the environment by formulating with a combination of transition metal prooxidants and antioxidants. The latter also determines their durability during service. In fact without them no synthetic commodity plastics would survive in the outdoor environment for even a hundred years and most packaging plastics would be completely bioassimilated by microorganisms into the soil within ten years.

"The fragmented plastic leaves small pieces in the soil and may take many decades to disappear."

This is pure speculation based on Greenpeace folk-lore. In practice we have found that "non-biodegradable" plastics, washed up on the sea-shore biodegrade in a pile of seaweed leaving no residues after several years This is because the antioxidants have been destroyed by exposure to the environment and the small oxidised molecules, similar to those produced from natural polymers, have been bioassimilated by microorganisms.

Biodegradable Plastics

"Biodegradation occurs when microorganisms break down the polymer chains"

This is a repetition of the myth that abiotic environmental factors play no part in the bioassimilation of polymers in the natural environment. In fact almost all polymers are changed abiotically by exposure to the environment with reduction in the molecular chain length and the formation of biodegradable products[4]. Thus microorganisms play a secondary role as scavengers of the degradation products but when the microorganisms have colonised the surface of the oxidised plastic, oxidase enzymes promote the peroxidation process and hence biodegradation.

"To be considered biodegradable, a practical time span is usually one growing season or 180 days"

180 days is an entirely arbitrary time scale, selected because most crop-based plastics comply with this requirement. It is quite different from the way nature bioassimilates

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[2] Pandey, J.K. and Singh, R.P., *Biomacromolecules*, **2**, 880-885, (2001)
[3] B. Commoner et al., "Breaking down the Degradable Plastics scam", ***Report for Greenpeace*** (1990)
[4] G. Scott in ***Atmospheric Oxidation and Antioxidants***, 2nd edition, ed. G. Scott, Elsevier, Chapter 6

its abundant lignocellulosic waste products. As an example straw, which is typical of agricultural waste, takes 10 years to completely biodegrade and some varieties of wood require hundreds of years to become bioassimilated into the natural environment.

A further reason why 180 days was selected was that it eliminated visible plastic particles in compost. This artificial definition of biodegradability does not accord with the requirements of EU Waste Framework Directive (1991) which defines the biological "reclamation" of wastes through composting to give soil improvers and fertilisers. Polymers that are 90% converted to carbon dioxide during composting do not comply with this requirement. The EU Standard EN 13432 for recovery of waste by composting makes it clear that plastic wastes may complete biodegradation after application to the soil, in spite of requiring mineralisation in 6 months in a biometric mineralisation test. In other words, this standard it is inconsistent, as are all the associated composting standards listed in **Current Standards for Biodegradable Plastics** (page 15 of the report).

"The key to understanding true biodegradability is to ensure that the plastic will behave like other organic materials in the soil i.e. like leaves and sticks."

This statement summarises nature's requirements outlined in the previous section. However this statement contradicts the mineralisation test in the compost standards mentioned above, which require that the rate of biodegradation should be similar to that of pure cellulose. This material, is not typical of nature's waste products, since it biodegrades many times faster than lignocellulose (e.g. straw).

Compostable Plastics

Although oxo-biodegradable polyethylene bags have been satisfactorily composted in industrial composting facilities[5], they do not satisfy the artificial (90% in 180 days) time-scale required by the composting standards. The deficiencies in this classification, as described in the previous sections, have been brought to the attention of CEN, ISO and ASTM. The composting standards were developed to match the bio-based plastics, but bio-based plastics are more expensive than oxo-biodegradable plastics and cannot be re-used or recycled in the waste stream. Consequently the industries that manufacture them rely almost exclusively on the fast mineralisation concept to gain acceptance and to gain an advantage in the market. They are therefore unwilling to consider science-based ecological arguments.

In fact, compostability is considered to be a minor advantage due the scarcity of in-vessel industrial composting facilities. Unlike the bio-based plastics, oxo-biodegradable plastics can be progammed to fragment and subsequently biodegrade to match their required lifetime. This is important, especially in relation to agricultural products (e.g. mulching films, baler twines and silage wrap films) which can to be programmed to match the application. The ability to plough-in the fragmented plastic as an alternative to manually removing it from the field for disposal brings economic

[5] G. Scott and D.M Wiles, ***Degradable Polymers: Principles and Applications***, 2nd Edition, ed. G. Scott, Chapter 13[5]

benefits to the farmer. In packaging, they can be reused or recycled with mainstream plastic wastes.

Degradable Plastic Products

"Compostable or recyclable"

Of the alternative recovery strategies for waste, re-use and recycling have traditionally taken precedence over composting[6] but the recycling industry has been slow to come to terms with this and it is not always understood that recovered plastics need to be looked upon as a new feedstock. This means that recyclate intermediates normally have to be re-formulated for new or secondary applications.

*"*Unfortunately, several plastic products with prodegradant additives…claim to be biodegradable, when they are not degraded by microorganisms*"*

This is quite simply incorrect. Oxo-biodegradable packaging certainly does fragment and begin to biodegrade during in-vessel composted at temperatures above 60^{o}C. It is even compliant with EN 13432 under those conditions.

"UV-degradable and oxo-biodegradable plastics are not certified as compostable by BPI"

This is no surprise, because the BPI is the Trade Association for the hydro-biodegradable plastics industry. In any event, as already explained, oxo-biodegradable plastics are not marketed for composting, and do not ***and should not*** satisfy the artificial mineralisation test imposed by BPI of 90% biodegradation in 180 days (see ***Biodegradable Plastics*** above). This test has no relevance to environmental safety and it has been demonstrated[5,7] that oxo-biodegradable plastics are not eco-toxic to growing plants and soil macroorganisms.

Life Cycle Assessment of Biodegradable and Conventional Plastics

This section makes no mention of the competition between bio-based plastic manufacture from crops and global food supplies. This will become critical in the near future and bio-based plastics will be limited to niche markets unless major advances are made in the utilisation of nature's waste products for the viable production of the biopolymer intermediates[8]. Also, crop-based plastics, being thicker and heavier, require more trucks to transport them, which use more fuel, emit more CO2 and occupy more road space.

Current Standards for Biodegradable Plastics

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[6] G. Scott, ***Polymers and the Environment***, Royal Society of Chemistry (1999), Chapter 4

[7] S. Yang and C. Wu, "Degradable Plastic films or agricultural applications in Taiwan", ***Degradability, Renewability and Recycling***, eds. A-C Albertsson et al, Wiley-VCH, (1999), 101-112

[8] G. Scott in ***Degradable Polymers: Principles and Applications, 2nd Edition,*** Kluwer Academic Publishers, 2002, Chapter 1.

It is astonishing that there is no mention of ASTM D 6954-04 ***"Standard Guide for Exposing and Testing Plastics that Degrade in the Environment by a Combination of Oxidation and Biodegradation"*** in this list of Standards. ASTM 6954-04 refers to oxo-biodegradable plastics, although this term is not used in the Standard. It is, however, directly relevant to the report and I would have expected it to be given precedence to ASTM D 6400 which is concerned with just one aspect of biodegradability, namely composting. This brings into question the objectivity of the Report itself and raises the possibility that the California Integrated Waste Management Board has been unduly influenced by the bio-based plastics industry (BPI). This also reflects on the academic reliability of the report as a whole, which was "Produced *under contract* by California State University"

Degradation, Residuals, toxicity and Safety of Degradable Plastics

This section refers to oxo-biodegradable plastics as "violating" ASTM D6400 but the only reference is to the BPI website, not an entirely unbiased source of information, being the Trade Association for the bio-based industry! There is no reference to the Trade Association for the oxo-biodegradable industry (**www.biodeg.org**) nor to the extensive peer-reviewed literature describing the science and applications of oxo-biodegradation, nor to ASTM D 6954-04 (see above). A list of relevant references is given below.

There is a reference to the "safety" of oxo-biodegradable plastics on p. 23. This describes the "dithiocarbamates as a probable carcinogen". In fact these materials are not used in applications, such as packaging. Cobalt is similarly referred to as "a possible human carcinogen", quoting the EU REACH regulations, which refer to the "classification and labelling of dangerous substances".

If the authors had read the REACH regulations, they would have seen that this specifically says that polymers containing these substances should not be included in the regulations unless they pose threats to human health or the environment. In fact, all the transition metals used in oxo-biodegradable plastics have been subjected to risk analysis by the UK Food Standards Agency[9] and all of them have been shown to be found in agricultural soils in much higher concentrations than could be released from oxo-biodegradable plastic residues. All are also present in human foods and drinking water. Cobalt is an essential trace element and CEN TC 249 WG9 has accepted that the REACH regulations do not apply to degradable plastics.

Biodegradation Testing Plan

"Compost can be produced by three techniques, namely aerated static pile, turned windrows or in-vessel container"

Windrow and pile composts like garden compost are not ***uniformly aerated*** and as in the case of landfill, they can produce methane, which is over twenty times more

[9] Food Standards Agency Expert Group on Vitamins and Minerals (2003), Risk Assessment.

effective than carbon dioxide as a “greenhouse gas”. Mechanical turning increases aeration but at the same time it reduces the temperature of the mass below that required to provide consistent sanitisation from pathogenic organisms. Full-scale industrial in-vessel composting plants avoid these difficulties since they normally operate at temperatures between 60^{o}C and 80^{o}C but are expensive to operate and are not generally accessible.

“A polyethylene plastic sheet…was used as a negative control”

Why was not a commercial oxo-biodegradable material ***after exposure to simulated environmental exposure***, not used as a ***“positive”*** control? This would have provided a reference biodegrading at a rate similar to nature’s prolific lignocelluslosic waste.

Laboratory Tests

The biometer shown in fig. 1of the report appears to rely on aeration from the surface of the compost mass. This is not adequate and probably results in the formation of methane.

Carbon Dioxide Concentration Results

None of the “reference materials” referred to are found in significant quantity as natural waste materials and there is no scientific basis for using them. This makes their selection an entirely arbitrary process to meet commercial requirements.

Biodegradation results

“The oxodegradable bag had negligible degradation and was similar to the control material”

This is just what would be expected since the samples had not been subjected to ageing or weathering in the environment.

Marine Testing, Results

“..after 30 days in ocean water….there was no disintegration of the oxodegradable plastics trash bags”

There is no evidence from the testing procedures that the samples were exposed to light before or during biodegradation testing in water. This is particularly important for oxo-biodegradable plastics, since they are exposed to light in the surface of the sea, where they undergo rapid photooxidation. Testing them without pre-exposure is meaningless in this case since the known abiotic formation of carbonyl species is critical to the initiation of biodegradation of these materials. We agree with the conclusion that “future experiments should be modified to improve (make more realistic!) the measurement techniques”

Anaerobic Digestion

Results

"…oxo-biodegradable …bags did not produces any additional biogas after 15 days, indicating very little biodegradation occurred"

Oxo-biodegradable plastics, as the name implies, require oxidation before they can be biodegraded. Thus, in the surface of a landfill they abiotically embrittle due to light, heat and oxygen to particles, whereas in the lower recesses of a landfill, they remain inert. This is a considerable advantage, since unlike bio-based hydro-biodegradable plastics they do not emit methane to the atmosphere not only from landfill but also from windrow, and pile composting.

They do not produce methane in anaerobic digesters and are not intended to do so, but if the AD residue is incinerated with heat recovery it will provide the same energy as the petroleum products from which they were originally manufactured.

Contamination Effects of Degradable Plastics on Recycled Plastics

"Oxo-degradable plastics …increased the elongation at break between 23 and 28%"

No information was provided on the previous history of the "appropriate recycled plastic material" In particular what additional antioxidants, if any had been added during reprocessing? The increased elongation at break would normally imply that an additional processing stabiliser had been added to the polymer blend to improve the performance of the recycled product, but if this was not added earlier, it must have come from the additive combination in the degradable plastic.

A similar phenomenon has been observed previously[10] and this is believed to be due to the effect of the processing stabiliser that is a constituent of the pro-degradant additive used in the biodegradable plastic[11]. The studies referred to above[10] show that oxo-biodegradable polyethylene can be collected with regular PE waste for recycling without any adverse effects on the quality of the recycled products.

They also illustrate the importance of understanding the chemistry of induced biodegradability of polyolefins, and the intention to carry out further testing (p. 50, last sentence) is welcomed. This should be done in cooperation with the OPA (**www.biodeg.org**) and not just the BPI. However it is important that the authors of the report do this after they have read the references on the scientific principles of oxo-biodegradable plastics (see references provided below).

Conclusions and Recommendations

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[10] Al-Malaika, et al., ***J. Macromol. Sci., Pure App.Chem***, **A 32 (4),** 731.
[11] G. Scott, ***Polymers and the Environment***, Royal Society of Chemistry (1999), Chapter 5

“However, degradable plastics could contaminate the existing plastics recycling stream if they are not properly collected…”

This certainly applies to hydro-biodegradable plastics but does not apply to oxo-biodegradables, since these recycle with mainstream waste as effectively as regular plastics.

“Propose a law requiring the development of an identification code for compostable bags…”

It is primarily important to identify ***biodegradable*** packaging. Compostability is an option that will require modification of the 180 day mineralisation test that dominates the current compostable protocols. Composting protocols are at present biased toward hydro-biodegradable plastics and they do not comply with the concept of “recovery”.

“Evaluate….oxo-biodegradable material in aerobic in-vessel composting”

This is particularly important because other methods of composting (e.g. windrow, pile and garden) are susceptible to anaerobic conditions with methane formation. The qualification in EN 13432 that biodegradation can be completed in the soil must be adhered to.

“Further investigate degradability in marine environments …..and better understand the biodegradation of biodegradable polymers in the marine environment”

It is particularly important to recognise the significance of abiotic as well as biotic influences in the marine environment.

“Further evaluate the effects of contamination by degradable plastics during reprocessing operations”

This should include a careful study of existing data on the compatibility of hydro-biodegradable plastics (starch, polyesters,etc) with segregated plastics waste streams.

Final comments

1 **It is important to consider the impact of existing or new bio-based polymers on food production in a world that is already beginning to run short of commodity foods. In addition, the production process of crop-based plastics is itself a heavy user of fuel-oils and a producer therefore of additional CO2.**

2 **Other recovery processes such as re-use, materials recycling and energy recovery must be taken into account in any legislation.**

Key scientific papers on the biodegradation of polyolefins

Experimental Studies

1. Oxidative Degradation and Molecular Weight Change of LDPE Buried under Bioactive Soil for 32-37 Years, Y. Ohtake et al*., **Journal of Applied Polymer Science*** **70**, 1643-1659 (1998).
2. Studies on biodegradation of LDPE - observation of LDPE films scattered in agricultural fields or in garden soil, Y. Ohtake et al. ***Polym. Deg. Stab.*** **60**, 79-84 (1998).
3. Molecular Weight Changes and Polymeric Matrix Changes Correlated with the Formation of Degradation Products in Biodegraded Polyethylene, A-C Albertsson et al., ***J. Environ. Polym. Deg.,*** **6,** 87-195 (1998).
4. Biodegradable Polymers and Environmental Interaction, S. Karlsson and A-C Albertsson, ***Polymer Engineering and Science*****,** **38**, 1251-1253 (1998).
5. C.David et al., ***Angew Makromol Chem***, **216**, 21-35. (1994)
6. C.David et al., ***Polym. Deg. Stab***. **48**(2), 275-89 (1995),
7. Biodegradability of Scott-Gilead Photodegradable Polyethylene and Polyethylene wax by microorganisms, F.Kawai, M.Shibata, S.Yokoyama, S.Maeda, K.Tada and S.Hayashi, ***Degradability, Renewability and Recycling, 5th International ScientificWorkshop on biodegradable Plastics and Polymers, Macromolecular Symposia,*** eds. A-C.Albertsson, E.Chiellini, J.Feijen, G. Scott and M. Vert, (1999), 73-84**.**
8. R.Wassenbauer et al., ***Biomaterials*****,** **11**, 38 (1990)
9. In vivo UHMWPE biodegradation of retrieved prostheses, L.Costa, M.P.Luda, L.Trossarelli, E.M.Brach del Prever, M.Crova and P.Gallinaro, ***Biomaterials***, **19**, 1371 (1998).
10. Unacceptable biodegradation of polyethylene *in- vivo*, E.Brach del Prever, M..Crova, L.Costa, A.Dallera, G.Camino and P. Gallinaro, ***Biomaterials,*** **17**, 873 (1996).
11. Photooxidation and Biodegradation of Commercial Photodegradable Polyethylenes, R.Arnaud, P.Dabin, J.Lemaire, S.Al-Malaika, S.Chohan, M.Coker, G.Scott, A.Fauve and A. Maarooufi, ***Polym. Deg. Stab***., **46**, 211-224 (1994).
12. The Mechanisms of Biodegradation of Polyethylene, A-C.Albertsson, S.O.Andersson, and S.Karlsson, ***Polym. Deg. Stab***., **18,** 73-87 (1987).
13. Dicarboxylic acids and Ketones formed in Degradable Polyethylenes by Zip Depolymerisation through a Cyclic Transition State, S.Karlsson, M. Hakkarainen and A-C. Albertsson, ***Macromolecules*****,** **30**, 7721-7728 (1997).
14. Degradation Product Pattern and Morphology Changes as Means to Differentiate Biotically and Abiotically Aged Polyethylene, A-C.Albertsson, C.Barenstedt, S.Karlsson and T.Lindberg, ***Polymer*****,** **36**, 3075-3083 (1995).
15. Evaluation of biodegradable polyethylene (PE), I. Jakubowicz, ***Polym. Deg. Stab***., **80**, 39-43 (2003).
16. Biodegradation of thermally oxidised, fragmented low-density polyethylenes, E. Chiellini, A. Corti and G. Swift, ***Polym. Deg. Stab***., **81**,341-351.
17. Environmental biodegradation of polyethylene, S.Bonhomme, A. Cuer, A-M. Delort, J. Lemaire, M.Sancelme and G.Scott, ***Polym. Deg. Stab***., **81**, 441-452 (2003).

Reviews

1. Environmental Biodegradation of Hydrocarbon Polymers, G.Scott, ***Biodegradable Plastics and Polymers***, Eds.. Y.Doi and K.Fukuda, Elsevier Science BV, 1994, pp 79-91.
2. Abiotic control of Polymer Biodegradation, G.Scott, ***Trends in Polymer Science***, **5**, 361-368 (1997).
3 Antioxidant Control of Polymer Biodegradation, G.Scott, in ***Degradability, Renewability and Recycling; 5th International Scientific Workshop on Biodegradable Plastics and Polymers***, Macromolecular Symposia, Eds. A-C. Albertsson,

E.Chiellini, J.Feijen, G.Scott and M.Vert, Wiley-VCH, Weinheim, 1999, 113-125.

4 Degradable Polymers in Waste and Litter Control, G.Scott and D.Gilead in ***Degradable Polymers: Principles and Applications***, Chapman & Hall, 1995, Chapter 13.

5. Plastics and the Environment, J.Guillet, in ***Degradable Polymers: Principles and Applications***, Chapman & Hall, 1995, Chapter 12.

6. Biodegradable Polymers, G.Scott, ***Polymers and the Environment***, Royal Society of Chemistry, 1999, Chapter 5.

7 The role of Environmentally Degradable Polymers in Waste Management, G.Scott***, Wastes Management***, May 1999, 38-39.

8. 'Green Polymers', G.Scott, ***Polym. Deg. Stab***., **68**, 1-7 (2000)

9. Environmentally degradable polyolefins: When, Why and How, G.Scott in ***Expert group meeting on Environmentally degradable plastics, Present Status and perspectives***, ICS-UNIDO, Trieste, 2001, p. 37-48.

10. Why degradable polymers, G.Scott in ***Degradable Polymers: Principles and Applications***, 2nd Edition, Ed. G. Scott, Kluwer Academic Publishers, 2002, Chapter 1, p. 1-15.

11. Degradation and stabilisation of carbon-chain polymers, G.Scott in ***Degradable Polymers: Principles and Applications***, 2nd Edition, Ed. G. Scott, Kluwer Academic Publishers, 2002, Chapter 3, p. 27-50.

12. Degradable hydrocarbon polymers in waste and litter control, G. Scott and D.M.Wiles in ***Degradable Polymers: Principles and Applications***, 2nd Edition, Ed. G.Scott, Kluwer Academic Publishers, Chapter 13, p.449-479.

13. Science and Standards, G.Scott in ***Biodegradable Polymers and Plastics***, Eds. E.Chiellini and R.Solero, Kluwer Acadademic Publishers, Chapter 1, pp.3-32.