REVIEW OF INFORMATION ON ENZYME-MEDIATED DEGRADABLE PLASTICS

STUDY EUBP-2

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1 INTRODUCTION

The unmanaged disposal of plastic waste is a mounting environmental issue. Conventional non-(bio)degradable plastics, when unmanaged, are accumulating in nature, leaving behind an undesirable visual footprint. It is against this background that (bio)degradable plastics started to appear on the market and can, taken into account their end-of-life options, reduce both visual pollution and accumulation in nature.

Currently, two major groups of (bio)degradable plastics exist. "Biodegradable plastics" cover polymers like polyesters from fossil and renewable raw materials, potentially also in combination with starch and cellulose, polyhydroxyalkanoate (PHA) and others like polylactic acid (PLA) which degrade in one or more environments, depending on the conditions. The second group uses non-biodegradable conventional polymers and blends in one or more additives which would make the polymer biodegradable, eventually after being exposed to oxygen, heat and/or light.

The majority of these additivated plastics are "oxo-degradable plastics", conventional plastics enriched with inorganic additives based on transition metals that should cause the plastic to degrade by a process initiated by oxygen and accelerated by heat and/or light. A comprehensive study on the benefits and challenges on bio- and oxo-degradable plastics was commissioned by Plastics Europe in 2013 and an executive summary as well as the full report is publically available.[1]

Yet, a smaller but increasing share uses organic additives, resulting in so called "enzyme-mediated degradable plastics". The degradation process is claimed not to be initiated by heat, light, mechanical stress or oxygen, but by the micro-organisms themselves. According to the producers of "enzyme-mediated degradable plastics", the organic additive, together with its carrier material (e.g. ethylene vinyl acetate), is consumed by the micro-organisms, during which these excrete acids and enzymes that should break down the plastic into materials that are easily consumed by microbes.

It is claimed that the technology can be applied to both common as well as uncommon (conventional) plastics. The minimum loading rate is said to be 1%, although some producers recommend using higher concentrations, going as high as 10%. Furthermore, "enzyme-mediated degradable plastics" are also claimed to be recyclable, should have the same properties as conventional plastics and would be less expensive when compared to "biodegradable plastics".

To avoid confusion in the market and to add clarity to the term "biodegradable", OWS reviewed the publically available information on the biodegradability and compostability of these "enzyme-mediated degradable plastics". For this review, focus lays on the following 5 companies: Advanced Enzyme Science Limited (Enzymoplast®), ENSO Plastics (ENSO Restore™), Bio-Tec Environmental (EcoPure®), Biosphere Plastic and Earth Nurture (ENA). Basis for each review was the company's website and other publically available information.

[1] http://www.plasticseurope.org/information-centre/news/news-2013/bio-degradable-and-oxodegradable-plastics-comparative-study.aspx

2 OVERVIEW PRODUCERS

An overview of the most important producers of "enzyme-mediated degradable plastics" is shown below.

ADVANCED ENZYME SCIENCE Ltd – UK
Trademark: Enzymoplast®
Website: http://www.enzymoplast.com/

BIOSPHERE PLASTIC LLC – USA
Trademark: -
Website: http://www.biosphereplastic.com/

BIOTEC BAGS INDIA PRIVATE Ltd – India
Trademark: Biotec Bags™
Website: http://www.biotecbags.com/

BIO-TEC ENVIRONMENTAL LLC – USA
Trademark: EcoPure®
Website: http://www.goecopure.com/

EARTH NURTURE – USA
Trademark: ENA (Earth Nurture Additive)
Website: http://biogreenproducts.biz/

ECM BIOFILMS Inc - USA
Trademark: ECM Masterbatch Pellets™
Website: http://www.ecmbiofilms.com/

ECOLOGIC – USA
Trademark: Eco-One™
Website: http://www.ecologic-llc.com/

ENSO Plastics – USA
Trademark: ENSO Renew RTP™ and ENSO Restore™
Website: http://www.ensoplastics.com/

3 REVIEW INFORMATION

The claims on biodegradability and/or compostability made by Advanced Enzyme Science Ltd. (Enzymoplast®), ENSO Plastics (ENSO Restore™), Bio-Tec Environmental LLC (EcoPure®), Biosphere Plastic and Earth Nurture (ENA) are discussed more in detail below.

The information on biodegradability and/or compostability provided by these 5 producers can be considered as the most supported. Data from other (smaller) providers are (much) more vague or missing:

- Biotec Bags India Private: An India based company with no supporting data on their website to back up their claims on biodegradability and compostability;
- ECM Biofilms: An Ohio, USA based company with claims on biodegradability under both aerobic and anaerobic conditions, yet without any test results or reports available through their website besides a statement that biodegradation will occur in more than one year;
- Ecologic: A Wisconsin, USA based company producing Eco-One™ with claims on biodegradability in biologically active landfills based on 5-15% biodegradation results obtained in 30 days.

In order to allow a direct comparison, each producer has been granted two values. Even though this is a subjective evaluation from the authors, the values given are based on different parameters, including, but limited to:

Value on reliability:

- Availability of test data;
- Testing facility used: independent, certified and/or accredited;
- (Bio)degradation method(s) used: (inter)nationally recognized methods or other;
- Quantification of biodegradation: CO_2 production, mass loss, physical changes, etc.;
- Quality control: validation of test results via the use of a positive reference; and
- Validity of information shared on biodegradation and compostability.

Value on relevance:

- Presence in the market;

Values given are on a total of 10 with 1 being the lowest value, representing the least reliable and relevant producer(s), and 10 being the highest value, representing the most reliable and relevant producer(s).

3.1 ADVANCED ENZYME SCIENCE LTD

Advanced Enzyme Science Ltd (AESL), with head office in the UK, is the producer of Enzymoplast®, an organic additive for polyethylene (PE) which was formerly distributed by Enzymoplast Limited Ltd. The company claims that the use of Enzymoplast® in a 4-10% concentration makes polyethylene 100% biodegradable and compostable.[2]

Even though a clear reference is being made to Shriram Institute for Industrial Research, an Indian ISO 17025 accredited testing laboratory where all biodegradability and compostability testing was performed on Enzymoplast® and which issued the corresponding certificate, scientific proof, under the form of test reports or scientific articles, is not readily available on AESL's website.

Furthermore, as reference is only being made to Shriram Institute for Industrial Research, it can be questioned whether results, if indeed positive, have been repeated in other accredited laboratories.

Nonetheless, clear claims are being made on biodegradability and compostability, more in particular for two additives:

- Enzymoplast® ENZO0001 Compostable Grade, claimed to comply with EN 13432 based on testing in accordance with ASTM D5988 "*Standard Test Method for Determining Aerobic Biodegradation of Plastic Materials in Soil*" and ISO 14855 "*Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions – Method by analysis of evolved carbon dioxide – Part 1: General method*", representing respectively biodegradation in soil and compost;

- Enzymoplast® ENZO0900 Biodegradable Grade, claimed to be biodegradable in aerobic conditions based on ISO 14855 testing.

The only 'proof' of true biodegradation and compostability and the accelerating effect of enzymes, which are both being claimed in a video feature available on AESL's website, is an indication of the biodegradation process over time. After 130 days, 60% biodegradation was reached, yet the accompanying picture shows only partial disintegration. After 180 days, 90% biodegradation is claimed to be obtained while still pieces of plastic can be distinguished. In addition, according to AESL, products containing Enzymoplast® will start to biodegrade from 90 days under composting conditions. However, all standards on industrial compostability require 90% disintegration within 84 days, which means that claims on compostability are not correct as prescribed criteria cannot be met.

The above referenced test methods are suitable for measuring the biodegradation or chemical degradation of materials. However, besides biodegradation, compostability also encompasses material characteristics, disintegration and plant toxicity. Despite the compostability claim, data or information on these other aspects of compostability are not available on the website. Only the above mentioned video feature shows incomplete disintegration after 180 days.

[2] The website of Advanced Enzyme Science Ltd (AESL) was consulted on April 15th, 2014.

In light of the planned 5p levy on single use polyethylene carrier bags, which is expected to come into effect in October 2015 in England, AESL launched two logos for its customers (see Figure 1). The biodegradable logo refers to ISO 14855. However, ISO 14855 is a test method and not a standard and therefore does not contain any criteria. Compliance with and hence certification based on ISO 14855 is therefore not possible.

The compostable logo makes reference to EN 13432, the harmonized EU standard on industrial compostability. In addition, it also mentions the certification number BG71054. To our knowledge, none of the certification bureaus working on industrial compostability are using a "BG number" for their certificates.

Several (inter)nationally recognized certification options exist for industrial composting, from which OK Compost and Seedling are the two most well-known logos in Europe. Yet, according to AESL, these schemes are used to certify biobased products only and tests published by these bodies are different from what is described in ISO and/or EN technical standards and have been tailored and adapted solely for biobased products. This is incorrect as many fossil based products are certified in line with EN 13432 or the international counterparts and do carry the OK Compost and/or Seedling logo. AESL incorrectly states that the origin of the material also determines the end-of-life option(s) of the material, which is not the case. Nonetheless, as Enzymoplast® is not biobased, AESL claims that it does not require any of these labels to conform to EN 13432 or any other compostability standard.

Figure 1. Biodegradable and compostable logo used by AESL

In parallel with the launch of the two logos shown in Figure 1, AESL also submitted evidence to the Environmental Audit Committee of the House of Commons responsible for identifying biodegradable and compostable plastic carrier bags which could be omitted from the 5p levy. This written evidence is publically available through the Parliament's website but does, although one would expect, not contain any scientific proof of biodegradation or composting of Enzymoplast® additivated polyethylene. Besides several claims, including one stating that once the biodegradation has started it will continue also in other environments like water and another one stating that heat is one of the criteria for the biodegradation process to take place, no test results or links to test data were included.[3]

Reliability: 2/10
Relevance: 5/10

[3] http://www.parliament.uk/business/committees/committees-a-z/commons-select/environmental-audit-committee/inquiries/parliament-2010/plastic-bags/?type=Written#pnlPublicationFilter

3.2 BIOSPHERE PLASTIC LLC

Biosphere Plastic, with head office in Oregon, USA, manufactures additives which are claimed to result in a faster and more efficient biodegradation process. The additives are said to render conventional polymers like PP, PE, PET and other major resin types biodegradable both in aerobic as well as anaerobic conditions and this within a period varying from 6 months to 10 years.[4]

Biosphere Plastic claims that their additives are poised to pass the ASTM D6400 testing standard. However, the only test report showing biodegradation results under controlled composting conditions reports only 12.2% biodegradation in 30 days (16.9% relative to the positive reference), while ASTM D6400 asks for 90% biodegradation within 180 days. This is proof of some biodegradation, but not of complete biodegradation. Results obtained after 30 days cannot be extrapolated to complete biodegradation. In other words, claims on compostability are incorrect as proof is clearly missing.

Besides claims on aerobic biodegradation, Biosphere Plastic also states that their additives work under anaerobic conditions. Test data on ASTM D5511 testing performed at Eden Research Laboratory, which appears not to be certified nor accredited, is available on the website and shows 13.9% biodegradation for additivated PE after 18 days of testing. A second test shows 19.6% biodegradation (22.2% relative to the positive reference) for additivated PET after 47 days but also shows that the biodegradation is levelling off and a plateau has been reached after 40-45 days.

Biosphere Plastic makes several test reports available through their website, yet all are showing only partial biodegradation. Claims on biodegradation and compostability can therefore not considered to be valid.

Reliability: 4/10
Relevance: 4/10

[4] The website of Biosphere Plastic was consulted on May 16th, 2014.

3.3 BIO-TEC ENVIRONMENTAL LLC

Bio-Tec Environmental LLC, based in Albuquerque, New Mexico (USA), produces the organic additive EcoPure®, claimed to accelerate the biodegradation process of plastic products and packaging in a biologically active landfill and enhance the environmental sustainability of these products in their end-of-life. According to the producer, a dosage of at least 0.7% in PE, PP, PET, PVC, Polystyrol, HIPS, EVA, Polyesters, Polycarbonates, ABS, TPE, TPR, TPU, PU and Nylon is said to be sufficient. BME masterbatches is a distributor of EcoPure® and is based in Mainhausen (Germany).[5]

The degradation process is said to be initiated only when the plastic comes in contact with micro-organisms and does not require heat, light or oxygen. Depending on the conditions in which biodegradation needs to take place, full biodegradation is claimed to be reached within 1-5 years. Compostability is not being claimed.

Both Bio-Tec Environmental's website as well as BME Masterbatches' website state that significant biodegradation data is available coming both from in-house testing as well as from independent 3rd party laboratories. Bio-Tec Environmental claims that hundreds of tests have been performed from which the majority were in line with ASTM D5511. Amongst others, testing has been performed at the Fresenius Institute in Germany, which is an ISO 17025 certified laboratory and part of SGS, and Northeast Laboratories (USA), a laboratory mainly specialized in testing of drinking water and wastewater.

The manifold of test reports which are being referenced are however not available and can only be obtained on demand (although reports were, until now, not provided upon our request). Yet, some figures are being presented:

- BME Masterbatches refers to test data obtained through ASTM D5210 testing showing 4% decomposition after 253 days via FTIR, DSC and SEC. Although no significant change could be determined with the naked eye, results are presented as proof of biodegradation. However, physical changes in the structure are only proof of (some) degradation, but no proof of biodegradation;
- Bio-Tec Environmental does not include any figure on their website, yet state that if for ASTM D5511 testing the positive control continues to biodegrade, test results can be considered as valid. However, ASTM D5511 clearly states that the positive control needs to reach 70% biodegradation within 30 days as otherwise results cannot be validated. Information on whether this pass level was reached is not provided;
- A 2008 brochure from Bio-Tec Environmental states that EcoPure® allows microbes to break down the structure of PP and PE at significant levels up to 45% in 14 days. However, the brochure only shows degradation testing based on weight loss with an average of 25% in 14 days from which it is being concluded that LDPE Clear Film with 2% EcoPure® is biodegradable. As mentioned above, physical changes, like weight loss, is no proof of biodegradation.

Reliability: 2/10
Relevance: 7/10

[5] The websites of Bio-Tec Environmental LLC and BME Masterbatches were consulted on May 12th, 2014.

3.4 EARTH NURTURE

Earth Nurture, with head office in Washington, USA, is the producer of Earth Nurture Additive (ENA), a masterbatch claimed to make conventional plastics biodegradable in landfills, anaerobic digesters, compost facilities and in natural bodies of water (fresh and marine water). Accordingly, ENA can be applied to PP, PE, LDPE, HDPE, PET, PS, EPS, Nylon and PLA.[6]

Similar to most other producers, heat, light, mechanical stress and oxygen are said not to be required to start biodegradation.

Earth Nurture's website shows several test data obtained at independent 3rd party laboratories. A first set of data shows the evolution of the CO_2 production of LDPE treated with 0.8% ENA under controlled composting conditions in line with ASTM D5338 (see Figure 2). According to Earth Nurture, the data confirms that the sample biodegrades at a rate slightly above 2/3 of the rate of cellulose. However, it must be noted that Figure 2 does not show the percentage of biodegradation over time, but only the production of CO_2. Taking into consideration that the positive control (cellulose) contains less organic carbon compared to LDPE, the rate at which the sample actually biodegrades is (much) lower than 2/3 of the rate of cellulose.

Furthermore, Earth Nurture also states that in order to comply with the industrial compostability standards, a material needs to biodegrade for 60% within 180 days. Accordingly, a 0.714% biodegradation rate per day obtained as shown in Figure 2 proofs that the technology works as this is twice as high compared to the requirement of 0.333% per day.

However, while in the past ASTM D6400 and ASTM D6868 did indeed refer to 60%, albeit only applicable for homopolymers, the most recent version of both standards as well as all other international standards on industrial compostability require 90% biodegradation in 180 days. In addition, and as mentioned above, while the 90% biodegradation is expressed as percentage of biodegradation, Figure 2 shows the volume of CO_2 produced, which is not the same. Finally, Earth Nurture's reasoning also implies that biodegradation is a continuous process which continues at the same rate until complete biodegradation is obtained. Extrapolation is, however, scientifically not correct and conclusions drawn are invalid and thus misleading.

In other words, data shown in Figure 2 are at most proof of only partial biodegradation, while it can also not clear whether the positive control reached the validation criteria of 70% biodegradation within 45 days as prescribed by ASTM D5338.

Finally, testing was performed at Biosystems America, a US based independent testing facility with activities centered around research and development on biological systems. Biosystems America is accredited by the American Council of Independent Laboratories and is listed on ASTM's International Directory of Testing Laboratories, yet, is apparently not ISO 17025 certified.

[6] The websites of Earth Nurture, from both the US and European division, were consulted on May 16th, 2014.

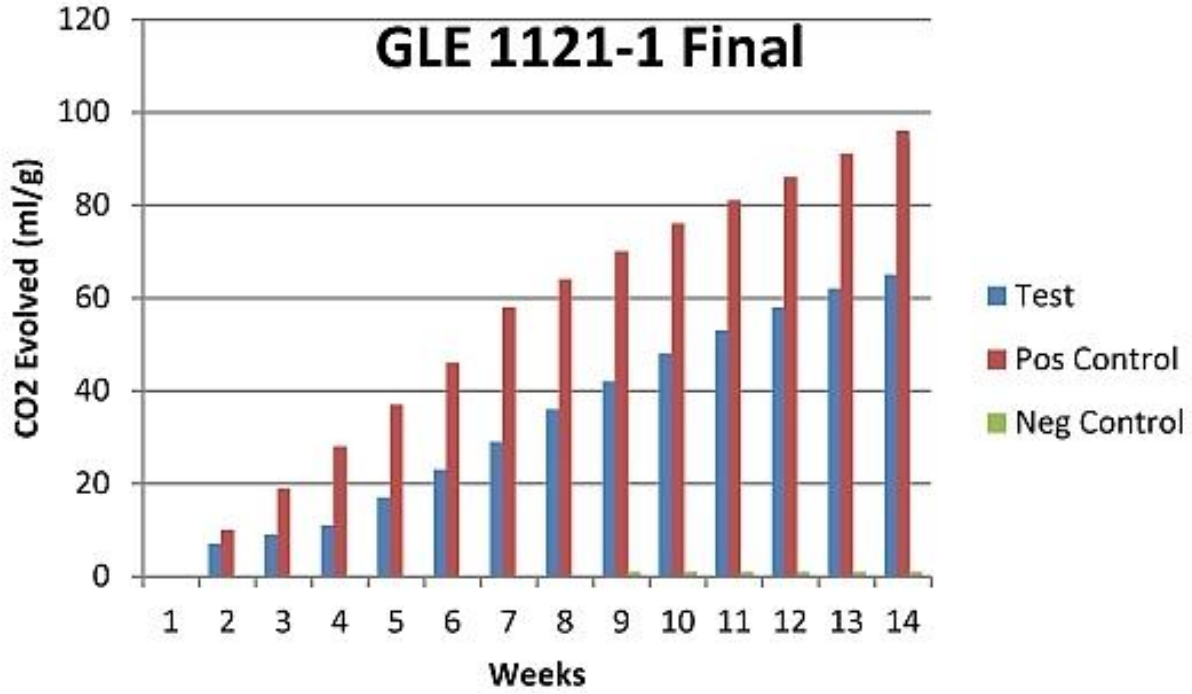
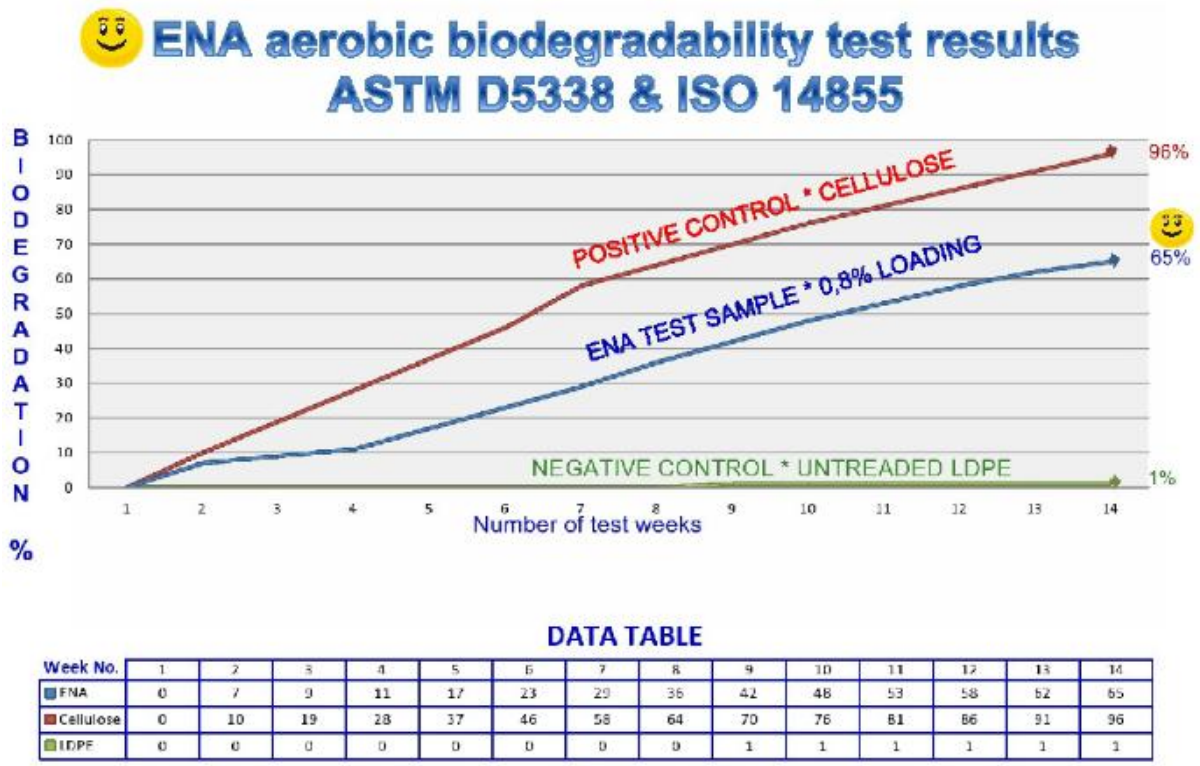


Figure 2. Evolution of CO_2 production of ENA treated LDPE under aerobic conditions

Also on the European website of Earth Nurture the same test data are being shown. However, while Figure 2 shows the CO_2 evolution in the Y-axis, the European website shows the same data but mentions the percentage of biodegradation on the Y-axis (see Figure 3).



Week No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ENA	0	7	9	11	17	23	29	36	42	48	53	58	62	65
Cellulose	0	10	19	28	37	46	58	64	70	76	81	86	91	96
LDPE	0	0	0	0	0	0	0	0	1	1	1	1	1	1

Figure 3.Percentage of biodegradation, according to Earth Nurture Europe, of ENA treated LDPE under aerobic conditions

A second set of data shows the outcome of a biodegradation test under anaerobic conditions in line with ASTM D5511 (see Figure 4). In addition to Figure 4, Earth Nurture also mentions that the straight line extrapolation of a 3 mm thick sample would completely mineralize in 12 years based on the production of 1.2% biogas after 53 days. As mentioned above, biodegradation results cannot and may not be extrapolated as this is not scientifically correct. Nevertheless, besides assuming that biodegradation follows a straight line profile, Earth Nurture also extrapolate results to smaller thicknesses stating that the results obtained for a 3 mm thick sample implicate that a 12.5-15 µm thick shopping bag would completely biodegrade in approximately one month. This is incorrect as it cannot be guaranteed that biodegradation will indeed proceed, be it at the same rate and until complete biodegradation is obtained. Secondly, also thickness cannot be extrapolated as also the fragmentation of the product does not follow a linear profile.

The test data as shown in Figure 4 were obtained at Stevens Ecology, a laboratory located in Oregon, USA which appears not to be certified nor accredited.

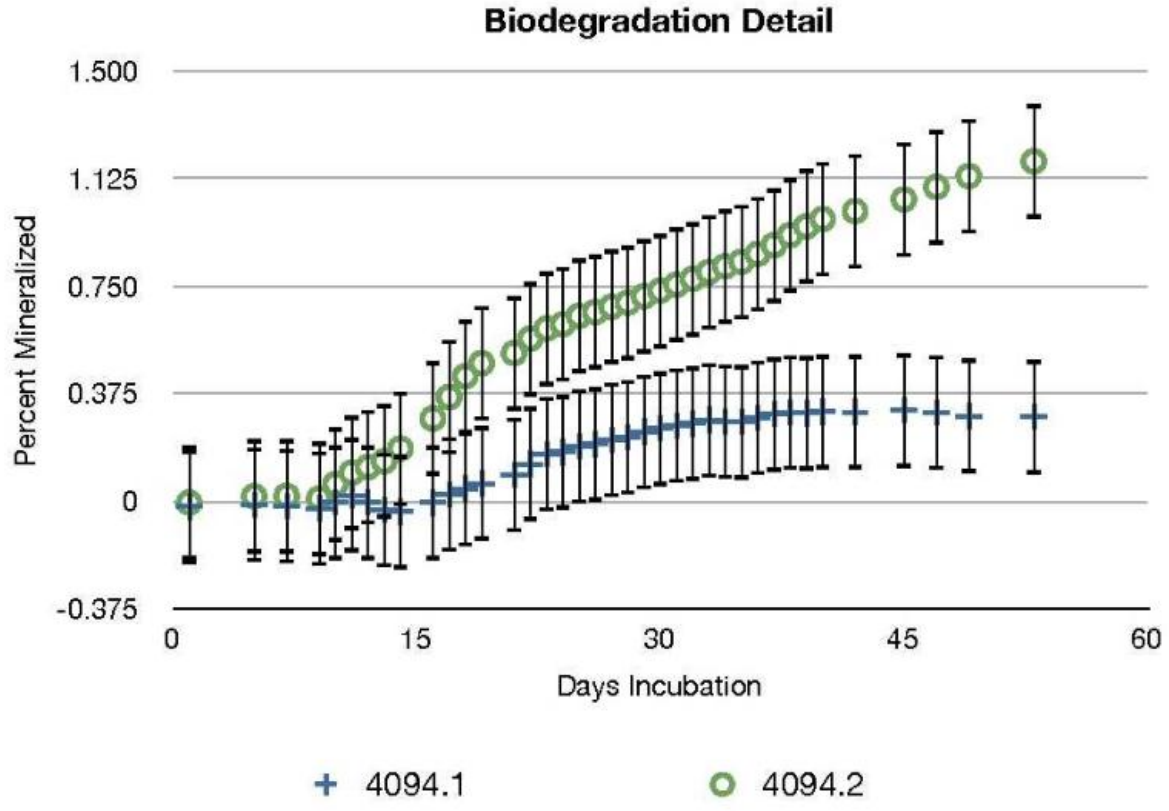


Figure 4. ASTM D5511 biodegradation results of an ENA additivated conventional polymer (4094.2 is claimed to be the test sample)

Finally, the European division of Earth Nurture also mentions that more biodegradability and compostability tests were started at Fraunhofer Institute in Germany in August 2013 and that results should be available in February/March 2014. Mid May 2014, results were not yet available.

Reliability: 3/10
Relevance: 6/10

3.5 ENSO PLASTICS

ENSO Plastics, with head office in Arizona, USA, is the producer of ENSO Restore™, an organic additive to be used in very thin films and lightweight packaging and claimed to be able to provide a full spectrum of solutions of compostable, landfill biodegradable and marine degradable materials.[7]

ENSO Restore™, said to be used up to as little as 1%, is claimed to enhance the biodegradation of traditional materials, including PET, HDPE, LDPE, EVA, PS, PVC, nitrile, rubber, latex, phenol, PP and adhesives. More specifically, according to ENSO Plastics, materials enhanced with ENSO Restore™ biodegrade 90% faster than without ENSO Restore™, although evidence is missing or not available, and biodegradation is said only to occur when placed in a waste environment where micro-organisms naturally occur. Light, heat, moisture and oxygen are said not to affect the (bio)degradation process.

With explicit claims on biodegradation in compost, landfill and marine conditions, ENSO Plastics stresses on their website that it is imperative that the public is informed and educated on the value biodegradable products can have in our environment and how to best utilize them to making a difference. In addition, ENSO Plastics also highlights that all plastics claiming biodegradability, compostability or degradability should be backed up by 3rd party testing using test methods from internationally recognized standards boards. Nevertheless, ENSO Plastics also states that industry specific certification organizations are not appropriate for validating such standards, which is surprising as these certification bodies verify whether testing performed by the 3rd party laboratories are indeed in line with the internationally recognized standards, an aspect which is, as mentioned above, key for ENSO Plastics.

In this context, reference is being made to biodegradation results obtained at different laboratories said to be independent and certified. Laboratories listed on ENSO Plastics' website are:

- LabWorks in Mansfield, MA, USA: LabWorks is claimed to be certified by ISTA, an accreditation body focusing on packaging and more specifically on the proper transporting of packaging, yet, does not appear on the list of ISTA certified laboratories. Furthermore, according to ENSO Plastics, LabWorks is also recognized for quality and accurate testing performed to ASTM standards, yet, does not appear on ASTM's International Directory of Testing Laboratories. A website or any further information on LabWorks could not be found through the worldwide web;
- Eden Research Laboratory in Albuquerque, NM, USA: While the laboratory's website claims to be independent, it does not refer to any kind of certification or accreditation. Therefore, although being stated differently, it cannot be guaranteed whether the internationally recognized test methods are being followed rigorously;
- Northeast Laboratories Inc. in Berlin, CT, USA: According to ENSO Plastics, Northeast Laboratories holds licenses and certification from the FDA, USDA, EPA, NELAP, State of CT and NY, yet, a closer look learns that these licenses and certifications apply mainly to drinking water and waste water testing.

[7] The website of ENSO Plastics was consulted on April 16th, 2014.

More specifically, although no reference is being made to the laboratory at which these results were obtained or at which concentration the additive was applied, it is claimed that independent 3rd party testing has shown up to 24.7% biodegradation within 160 days in optimized conditions. It is unclear under which conditions these results were obtained, although it can be assumed it was under anaerobic (landfill) conditions, if testing was indeed in line with ASTM International test methods, whether testing was validated through the use of a positive reference and if biodegradation was still increasing or reached a plateau after a certain time. Detailed results or reports are not available on the website to back this claim up.

In addition to the above claim, the brochure for Enso Restore™, which is publically available on ENSO Plastics' website, mentions that independent 3rd party testing has shown up to 32.7% biodegradation in 10 months in optimized conditions. While again stressing out that it is important that claims are accurate, the brochure shows the two figures as shown in Figure 5 and Figure 6. While the figures do not back up the claim on biodegradation made in the brochure (32.7% in 10 months), neither the ones made elsewhere on their website (24.7% in 160 days and complete biodegradation in compost in 10 days), only partial biodegradation is being obtained. The ASTM D5511 test (Figure 5) shows a biodegradation percentage of approximately 19% after about 210 days, while the ASTM D5526 test (Figure 6) shows a biodegradation percentage of approximately 7% after about 225 days.

Furthermore, besides the absence of proof of complete biodegradation, Figure 5 and Figure 6 also show no data for the positive reference, from which it can be questioned whether a positive reference was taken along or why results are not shown. Both ASTM D5511 and ASTM D5526 require the use of a positive reference to validate the test conditions and obtained results. For ASTM D5511, 70% biodegradation needs to be obtained within 30 days, while also for ASTM D5526 70% biodegradation needs to be obtained at the end of the test.

Besides the (few) data which have been made publically available by ENSO Plastics, the BPI commissioned OWS in 2009 to analyze the Aquamantra bottle produced from ENSO material. OWS performed testing in triplicate conform ASTM D5511 for 60 days under thermophilic conditions (52°C). At the end of the test, no significant biodegradation was measured after 60 days for the Aquamantra bottle, while the positive reference cellulose obtained a biodegradation level of more than 80% within one week (see Figure 7).

OWS, an international recognized and ISO 17025 accredited laboratory specialized in biodegradability and compostability testing, also monitored the visual degradation during anaerobic conditions and observed no fragmentation over time.

Reliability: 2/10
Relevance: 8/10

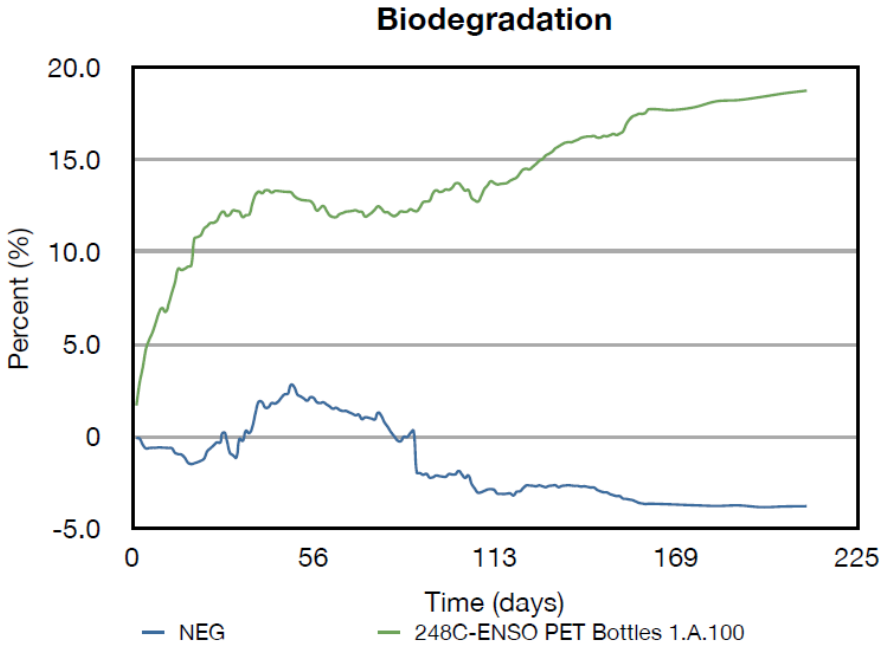


Figure 5. Biodegradation results for ENSO Restore RTP™ using ASTM D5511 (as shown in the brochure)

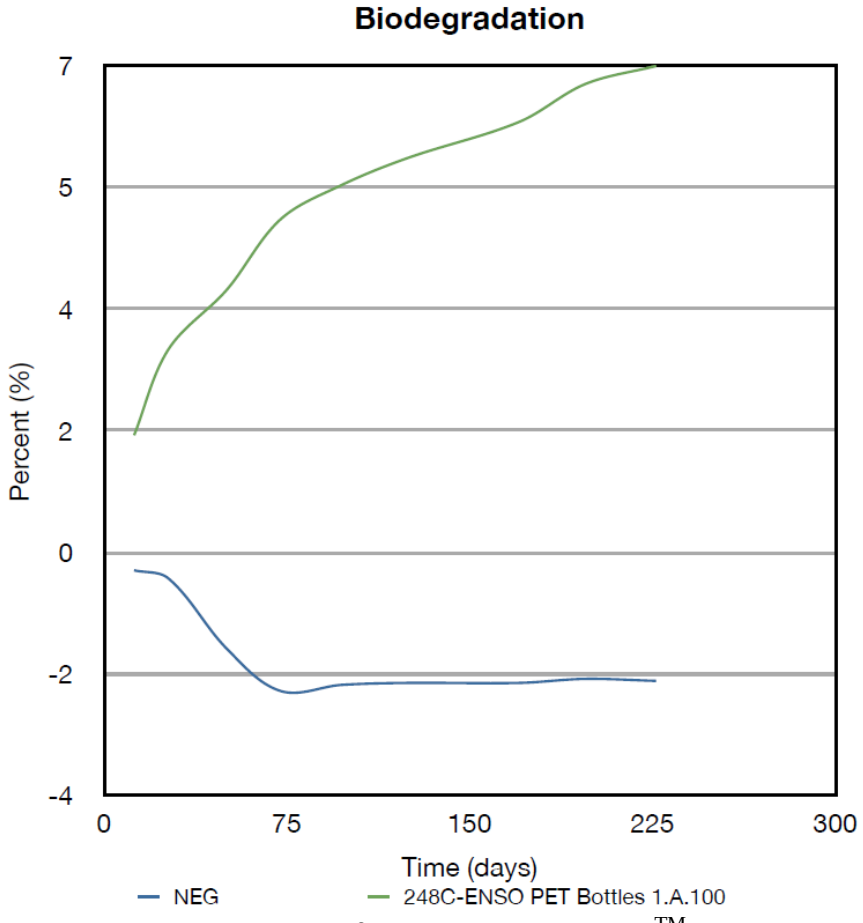


Figure 6. Biodegradation results for ENSO Restore RTP™ using ASTM D5526 (as shown in the brochure)

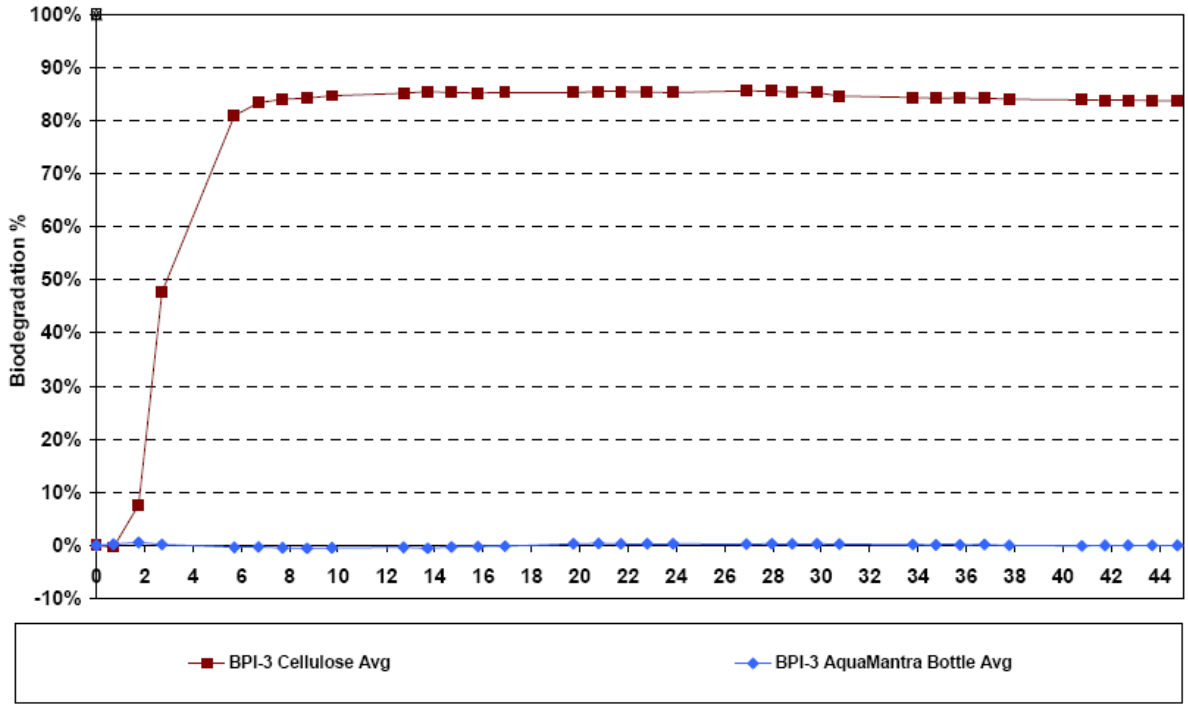


Figure 7. Biodegradation results for a PET bottle additivated with ENSO material (conform ASTM D5511 and as measured by OWS in 2009)

4 CONCLUSIONS

General

- There are no scientific articles available on the biodegradation behavior of enzyme-mediated degradable plastics. Also the basic principle of how such a degradation process would work, is nowhere scientifically explained. Only a vague, general and superficial idea is given;
- None of the available data show complete biodegradation. At most, partial (bio)degradation is obtained;
- Test results are in most cases coming from laboratories which are not certified nor accredited, which means that it cannot be assured that testing has been performed completely in line with the internationally recognized test method(s);
- In some cases test results are being extrapolated, assuming biodegradation is expected to continue following a straight line profile. Extrapolation is scientifically incorrect as it cannot be guaranteed that biodegradation will indeed continue, be it at the same rate;
- Data on the biodegradation of the positive control is not always included and/or testing is not always run until the minimum level of biodegradation is obtained for the positive control. Validation of test results is therefore not always possible;

Discussed producers

- While all discussed producers claim complete biodegradation and/or compostability, not all provide test results via their website, from which it can be questioned whether results are indeed available and/or whether these are valid;
- Some of the discussed producers also claim compostability, yet, data shown only covers biodegradation – which is always incomplete – while data on heavy metals, disintegration and plant toxicity is never included;
- The only correct parameter for biodegradation is the conversion of organic carbon to carbon dioxide. Some of the discussed producers refer to mass loss and/or changes in physical structure to claim biodegradation. However, this is no proof of biodegradation, merely of (some) degradation;
- Based on the information mentioned on a few websites, it appears that some of the discussed producers are not well informed and seem not to understand the difference between biobased and biodegradation and/or what biodegradation actually means;

Following the above, it can be concluded that there is no proof that the biodegradability and/or compostability claims made by the producers of enzyme-mediated degradable plastic additives are correct. In addition, a lot of flaws can be seen in the explanations and results given on the producers' and distributors' websites.

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