RECYCLING

Recycling is often advanced as an objection to making plastic degradable, but it is obvious that plastic cannot be recycled unless it has been collected.

Recycling does not therefore address the principal concern about plastics around the world – how to deal with the plastic which has escaped into the oceans and elsewhere in the open environment from which it cannot realistically be collected, and is therefore accumulating every day for many decades.

Pro-oxidant masterbatches such as d2w should therefore be put into the manufacture of polyethylene (PE) and polypropylene (PP) products to make them biodegradable at the end of their useful life, so that they will not lie or float around for decades.

Even if the plastic can be collected, Greenpeace reported in October 2022 https://www.greenpeace.org/usa/reports/circular-claims-fall-flat-again/ that “mechanical and chemical recycling of plastic waste fails because plastic waste is extremely difficult to collect, virtually impossible to sort for recycling, environmentally harmful to reprocess, often made of and contaminated by toxic materials, and not economical to recycle.”

Recycling is also a source of microplastics. A report in Journal of Hazardous Materials Advances https://www.sciencedirect.com/science/article/pii/S2772416623000803 says “Raw recycling wash water was estimate to contain microplastic counts between 5.97 106 – 1.12 × 108 MP m−3 (following fluorescence microscopy analysis). The microplastic pollution mitigation (filtration installed) was found to remove the majority of microplastics >5µm, with high removal efficiencies for microplastics >40µm. However, Microplastics <5µm were generally not removed by the filtration and subsequently discharged, with 59-1184 tonnes potentially discharged annually.”

Polyethylene (PE) and polypropylene (PP) are made from a by-product of oil or natural gas. These are primarily extracted from the ground to make fuels and would be extracted whether plastics existed or not. For the foreseeable future there will still be a demand for oil and gas as fuels, so it makes sense to use the by-product instead of promoting uneconomic recycling or growing crops to make plastic, or using materials other than plastic whose functionality and/or LCA is not as good. See https://www.biodeg.org/subjects-of-interest/life-cycle-assessments/ and https://www.symphonyenvironmental.com/wp-content/uploads/2019/11/Denkstatt-report.pdf Further, the energy required to convert this by-product into PE or PP is less than the energy required to collect, sort, wash, and reprocess post-consumer plastic.

For many years the oil companies and plastic manufacturers have been warned by governments and NGOs that their business is under threat because plastic creates microplastics and is very persistent in the environment. The only way to respond to this is to accept that it will not be possible in the foreseeable future to collect all the postconsumer plastic for recycling even in the developed world, and therefore to support and use biodegradable masterbatch technology. This can be put into PE and PP products at little or no extra cost, so that they will no longer persist and accumulate in the open environment.

D2w is used to make biodegradable PE and PP products, which look and perform during their useful life just the same as ordinary PE or PP products. D2w plastic has been available for 25 years and much of it has been recycled, but when waste-management fails and it gets into the open environment it will degrade and then biodegrade much more quickly than ordinary plastic, without leaving microplastics or other harmful residues. It does not contain heavy metals, and is proved to be non-toxic according to the OECD Standards.

There have been many scientific studies of this technology, and the latest and most important was a four-year research programme sponsored by the French Government, at l'Observatoire Oceanologique de Banyul Sur Mer. It was known as **Oxomar,** and concluded in March 2021 that plastic made with Symphony's d_2w technology will biodegrade even in the marine environment significantly more efficiently than conventional plastic. The Report can be found in English and French at https://www.biodeg.org/wp-content/uploads/2021/07/Final-report-OXOMAR-10032021.pdf

Following this study, the Oxomar scientists allowed bacteria commonly found in the open environment access to d_2w plastic film containing Carbon 13. They found Carbon 13 in the CO_2 exhaled by the bacteria, proving beyond doubt that the plastic had been bio-assimilated by the bacteria.

Despite the obvious environmental benefit, there are some in the recycling industry who are reluctant to accept this type of plastic, claiming that it could adversely affect the new plastic product made with their recyclate. It is necessary therefore to consider whether this is true, and whether recyclers are justified in preferring the continued use of ordinary plastic, which can be recycled if collected but will not biodegrade for many decades if it gets into the open environment.

The Association of Plastic Recyclers (APR) in the US has been advising recyclers not to accept plastic for recycling which does or might contain pro-oxidant masterbatch, but for the reasons explained in this paper their advice should not be followed.

The short answer is that PE and PP products containing masterbatches such as d2w can be safely recycled into short-life and long-life products without separation from ordinary PE and PP. The extent of degradation already induced in the material by sunlight and weathering before recycling, needs to be considered whether the plastic contains a pro-oxidant masterbatch or not.

DEFINITIONS

"d2w" is a polymer masterbatch supplied by Symphony Environmental Ltd., which contains a catalyst and stabilizers in a PE or PP carrier.

"d2w product" means a product made from PE or PP which contains a d2w PE or PP biodegradable masterbatch respectively, at the level prescribed by Symphony.

"ordinary" or "conventional" plastic product means a petroleum-based PE or PP product which is exactly the same as a d2w product, except that the d2w masterbatch is absent.#

“Recyclate” means flakes or granules of polymer made by reprocessing existing polymer products, and which are then used to make new polymer products.

Recyclers sometimes say that they are opposed to “biodegradable” plastic, but what exactly do they mean? If they mean the type of bio-based plastic marketed as “compostable” then they are certainly justified in rejecting it, because it has a fundamentally different chemistry to ordinary (petroleum-based) plastic. If even a small proportion of this bio-based material gets into a post-consumer recycling stream it will compromise the resulting recyclate and the new product. It is not in any event tested to biodegrade in the open environment or to convert into compost. It converts into CO_2 in a composting facility https://www.biodeg.org/subjects-of-interest/composting/

The US Association of Plastic Recyclers says: “Degradable additives” refers to those additives, catalytic and non-catalytic, that are intended to reduce the molecular weight of polyolefins, fragment the polymer and/or convert the carbon of the polymer to carbon dioxide or methane.”

It appears that they are confusing two different technologies here – (a) catalytic additives which accelerate the reduction of molecular-weight by oxidation in aerobic conditions, so that the material becomes biodegradable, and is then converted by micro-organisms into CO_2, water, and humus, and (b) non-catalytic additives which are intended to reduce molecular weight under anaerobic conditions and generate methane. It is not clear precisely what technology APR are referring to here – perhaps “enzymatic” additives which will probably damage their recyclate and have questionable efficacy, but they need to be more specific. In this paper we are concerned with type (a).

d2w biodegradable plastic is in type (a) and is made as to 99.9% from the same petroleum-based material as ordinary plastic. In this paper we will consider:

1. Whether it is likely to be recycled at all
2. If so, into what type of new product
3. Whether it is likely to have any adverse effect on the new product.

NOT LIKELY TO BE RECYLED

d2w is used in PE and PP only, and is used for packaging and other low-value products, which at the end of their useful life are often contaminated with chemical or biological contaminants, and mixed with other household waste.

Whilst almost all pre-consumer waste PE and PP (eg factory offcuts, the provenance of which is known) is recycled, most of the post-consumer PE and PP is not.

See the video at https://youtu.be/NLkfpjJoNkA which explains why recycling of post-consumer plastic makes very little sense in economic or environmental terms.

A report by Kinnaman et al (68 Journal of Environmental Economics and Management (2014) 54-70), evaluated the cost of recycling each material, the energy and emissions involved in recycling, and various benefits (including simply feeling good about doing something believed to have an environmental or social benefit). They came to the conclusion that an optimal recycling rate in most countries would be around 10% of goods. "To get the most benefit with the least cost, we should be recycling more of some items and less — or even none — of others. The composition of that 10% should contain primarily aluminium, other metals and some forms of paper, notably cardboard and other source[s] of fibre, while optimal rates of recycling plastic might be zero."

Plastic bottles made of PET are worth recycling, but d2w is not an issue here because d2w is not used in PET.

The UK recycling charity RECOUP says ("Recyclability by Design") that "where plastic products are particularly lightweight and contaminated with other materials, the energy and resources used in a recycling process may be more than those required for producing new plastics. In such cases recycling may not be the most environmentally sound option." These are the very products for which d2w is used.

Another reason why postconsumer plastic is not popular with recyclers is that it has to be separated from other household waste and from other types of plastic, and then washed. A great deal of water is needed to wash contaminated plastic, so the amount of waste-water generated is enormous, and in many countries water is a scarce resource in part or all of the year. Moreover, this process leaves large quantities of dirty waste, including biological and chemical waste that is hazardous and highly undesirable.

At the end of its useful life, plastic which has been collected but is not suitable for recycling, should not be wasted by being dumped or sent to landfill or composting https://www.biodeg.org/subjects-of-interest/composting/ it should revert to being a fuel, and be sent to modern incinerators to be used for generating heat and electricity instead of importing more oil and gas. Modern incinerators like the one in Zurich, do not cause harmful emissions.

WHAT TYPE OF NEW PRODUCT?

The physical properties (tensile strength, resistance to chemicals, etc.) of all recycled plastics are less reliable as a result of the recycling process, and neither post-consumer nor post-industrial recycled polymers can ever achieve 100% of the mechanical properties of virgin materials.

The use of recycled plastic is not normally permitted for food-packaging, or pressure-piping, and is strictly limited in the case of building films.

Recyclate from PE or PP would not be mixed with recyclate from PET, and would not be used to make synthetic fibres for carpets, geotextiles, or clothing. As already noted PET bottles and trays would not contain d2w.

NO ADVERSE EFFECT

The PE and PP plastic for which d2w technology is used, is likely to be recycled (if recycled at all) into packaging and similar low-value items which often get into the environment as litter. For these products biodegradability is desirable, and d2w should actually be added to the new product.

The author of the Roediger Report 21st May 2012 https://www.biodeg.org/wp-content/uploads/2020/12/ROEDIGER-REPORT-21-May-2012.pdf says "If the new product, to be made from recyclate containing a pro-oxidant additive, is intended for short-life uses such as garbage-sacks, bin-liners, shopping bags, bread-wrappers etc. the effect of any pro-oxidant formulation is unlikely to manifest itself before the end of the intended service-life. Biodegradability for such items is in any event desirable, because a proportion of them will find their way into the land or sea environments, where they could otherwise subsist for decades after being discarded."

It is however possible that some PE or PP recyclate might be used to make durable PE or PP products such as blow-moulded components for the automotive industry, or drainage pipes. Here, it is important to note that chemical stabilisation is the key to durability of all plastics.

A March 2020 Report by the Institute of Environmental Engineering, Zurich, for the Swiss Federal Office for the Environment found that: "Conventional plastics may contain pro-oxidant additives that were added to produce different intended functionalities. For example, Moura et al. (1997) showed that colorants in general can act as pro-oxidants. If they partake in the creation of radicals or reactive oxygen species, such as singlet oxygen ($1\Delta g$), they can trigger photo-degradation of the polymer matrix."

"Conventional plastic products were found to regularly contain Fe, Ba, Ti, Zn, Cu and V. Some individual conventional plastic bag samples also contained Cr and Pb" "Thus, a potentially much higher number of plastics on the market may match the current legal definition of degradable plastics without being advertised or intended as such."

The point of this is that it cannot be assumed by manufacturers of polymer products that any recyclate is free from pro-oxidants, whether it contains d2w plastic or not. It is therefore always necessary to add stabilisers when making long-life plastic products.

STABILISERS

The Roediger report says "With regard to long-life products, since polymers lose stabilisation each time they are reprocessed, it is good practice when making long-life products from recycled polymer to add stabilisers, whether the feedstock contains plastic with pro-oxidant or not."

The TCKT Report of 27th July 2016 https://www.biodeg.org/wp-content/uploads/2020/12/Report_20160727_final_corr-9-8-16-1.pdf says "… the UV stabiliser inhibits the propagation of free-radicals which are responsible for polymer degradation. Both stabilised samples therefore exhibit a smooth, un-cracked and uninfluenced surface."

The Roediger report adds "The stabilisers will neutralise any pro-oxidant which may be present. As the recycler does not usually determine the final use of the recyclate, the stabilisers would be added by the next processor in the chain - the manufacturer of the new finished product."

Roediger continues "The specification in some countries for long-life building films requires the use of a virgin polyolefin, and recyclate is not therefore used at all. In the case of lower-grade building films, where no guarantee is given, these are sometimes made from recyclate whose origin is not known, but the manufacturer of the film would always add stabilisers, whether the feedstock is known to contain a pro-oxidant formulation or not."

It is important to note that it is not necessary to use stabilisers which are any different to the ones which would normally be used for conventional PE or PP, nor to add a different quantity of the stabilisers. Nor is it necessary to estimate the proportion of stabilisers already added.

The extent of degradation already induced in the material must be assessed before reprocessing, whether the feedstock contains d2w or not, as any plastic which has been exposed to sunlight for an extended period may not be suitable for recycling).

A Report by Aldas et al is cited by APR in support of the proposition that degraded oxo-biodegradable plastic will have an adverse effect on products made with recyclate. This is not a useful proposition, because degraded plastic should not be used for recycling whether it is oxo-biodegradable plastic or not.

Also the Aldas authors were incorrect in adding Symphony's d2w @5wt.%. This is five times the amount specified by Symphony.

The Aldas report shows at 2.2.4 that degraded oxo-biodegradable plastic was incorporated into the neat (ie non-oxo) LDPE. They predicted an adverse effect on the new product made with this recyclate, but they did not examine the effect of incorporating degraded plastic which is not oxo-biodegradable, on new products made with recyclate. Had they done so they would have found a similar adverse effect on the new product.

The same fallacy is evident in footnote 15 of the 2019 Ellen MacArthur Report, that "both the heat and UV ageing tests were performed on samples that were 'recycled' (blown into film and then re-pelletised) in-house from primary materials rather than from recovered post-consumer waste material. Therefore, this does not demonstrate the effects of any oxidation as a result of UV ageing that has occurred during use, and/or between disposal and being recycled as in real world environments." If oxidation has occurred in *any* plastic it should not be recycled.

Oxo-biodegradable plastic products are stabilised to allow for a storage and service-life, and to allow time for re-use and recycling. The TCKT study found that plastics made with recyclate with and without pro-oxidant masterbatch, both failed rapidly during sunlight exposure; but conventional stabilisers, routinely used in the manufacture of outdoor products, were successful in preserving the products with and without the additive. These would include blow-moulded parts used in automotive and agricultural equipment applications.

The authors of the Aldas report are not correct in saying that "for these types of plastics to be considered as biodegradable, their biodegradation must be no less than 90% after the assimilation time limits have elapsed according to the European standard EN13432." This standard does not apply to oxo-biodegradable plastics - which are designed to degrade if they become litter in the open environment. EN13432 itself says in para 1 that it "makes provision for obtaining information on the processing of packaging in controlled waste treatment plants, but does not take into account packaging waste which may end up in the environment through uncontrolled means, ie as litter."

The authors of the TCKT Report (March 2016) https://www.biodeg.org/wp-content/uploads/2020/06/TCKT-Report-17.3.161.pdf say "In our opinion it is unlikely that recyclate from short life films would be used for long-lasting films used in the building industry. These long-life films should be made with virgin polymer and be stabilized to deal with loss of properties caused by the melt-processing and the recycling process, whether or not any pro-oxidant additive is present. Such stabilization would effectively neutralize the effect of any pro-oxidant additive. Also, recyclate from shopping bags tends to contain high levels of fillers like calcium carbonate, and is not suitable for producing long-life films."

ASSOCIATION OF PLASTIC RECYCLERS

This US Association is advising recyclers not to accept for recycling any plastic which does or might contain pro-oxidant masterbatches, but for the reasons explained in this paper their advice should not be followed.

It is important for APR to compare the performance of PE and PP containing pro-oxidant masterbatch, with the conventional PE and PP found in a post-consumer recycling stream, and not with some hypothetical material which does not degrade. It is also important not to confuse these polymers with PET.

It is essential that products made wholly or partly from recyclate containing pro-oxidant masterbatch are not expected to pass tests which products made from conventional plastic recyclate would fail under the same conditions. As already noted, the recycling process is known to have a significant effect on the performance of *all* polymer products, and is a concern even for non-degradable post-consumer recyclate.

In April 2022 APR said in their FAQ on Degradable Additives [since withdrawn]:

“Consider this scenario: A bottle with degradable additives makes it through the recycling collection stream and ends up in a bale of crushed PET bottles. The bale sits outside for several weeks exposed to sun and weather, and then goes through the normal grinding, washing, and pelletizing process of recycling. The recycled PET plastic is then made into strapping that holds bricks on a pallet. The pallet is stored outside for many months because bricks are insensitive to weather. Then the pallet is placed on the back of a truck heading down the highway. That's a lot of time, weather, and heat that could potentially trigger the degradable qualities of the plastic with additives present and cause that strapping to fail. The consequences could be very serious.”

Indeed they could, but APR have made three fundamental mistakes here:

1. Pro-oxidant masterbatches such as d2w are not used in the manufacture of PET bottles.
2. The exposure to sun and weather before recycling described in this scenario is likely to impact adversely on the suitability of the plastic for recycling whether it contained a pro-oxidant masterbatch or not.
3. The conditions of use described in this scenario would make it essential to have included stabilisers to protect the plastic strapping against time, weather, and heat, whether the recyclate contained a pro-oxidant masterbatch or not.

On 7th April 2022 the President & CEO of APR, Mr. Steve Alexander, made a statement that: “Claims regarding the recyclability of degradable additives are unfounded, untested and possibly misleading …. as no third-party testing data has confirmed these recyclability claims.” And in their FAQ “APR is not aware of any companies marketing degradable additives that have put together convincing test data to show that their products will not interfere with the quality and performance of demanding, long-lived applications for recycled plastics.”

Mr. Alexander ought to have been aware that extensive third party testing has been done, and the reports have been published.

Both of the TCKT studies from Austria, and the Report by Roediger Laboratories in South Africa have been available to recyclers for years on the websites of Symphony Environmental (www.d2w.net) and the Biodegradable Plastics Association (www.biodeg.org). All of these studies demonstrate that recycling of d2w plastics can be safely achieved up to 100%, but in the new products the proportion of d2w-type plastics would in real-life be much lower.

In March 2016 Transfercenter für Kunststofftechnik (TCKT) of Austria https://www.biodeg.org/wp-content/uploads/2020/06/TCKT-Report-17.3.161.pdf recycled a sample of LDPE film containing d2w, and found that “not only did the film made from the recyclate retain thermal stability after reprocessing, but the impact of the stabiliser in the d2w masterbatch was greater than the effect of the pro-oxidant in the masterbatch - resulting in stability which actually increased with the proportion of recyclate containing d2w masterbatch.”

They continued “The presence of pro-oxidant additives in polyethylene shopping bags is most unlikely to prevent compliance of the bags with EN 13430-2004 "Packaging - Requirements for packaging recoverable by material recycling."

In a follow-up to their report mentioned above, TCKT reported in July 2016 https://www.biodeg.org/wp-content/uploads/2020/12/Report_20160727_final_corr-9-8-16-1.pdf on the potential for recyclate containing d2w plastic to be used in long-term outdoor applications in thick cross-section products such as garden furniture or plastic lumber. They observed that “as degradation is dependent upon oxygen, the thickness of the material limits the penetration of oxygen into the body of the plastic. Therefore, the thicker the material, the less susceptible to degradation it will be. Evaluation of the FTIR-spectra confirms that inside the sample, where oxygen is not available, no significant oxidation has been found in any of the samples.”

They added “an important point to remember is that thick cross-section plastic products intended for use outdoors should always contain a UV stabiliser whether or not they contain any recyclate with a pro-oxidant masterbatch. The stabiliser is there to protect the products from the damaging effects of sunlight and more general weathering influences, and they would not otherwise be fit for purpose.”

“The UV stabiliser inhibits the propagation of free-radicals which are responsible for polymer degradation. Both stabilised samples (with and without pro-oxidant) exhibited a smooth, un-cracked and uninfluenced surface.”

“We have chosen the worst-case scenario by using samples made entirely from recycled polymer material, which is very unlikely in practice. In reality it is likely that recyclate would be mixed with virgin polymer, and the material containing a pro-oxidant masterbatch is likely to contribute part only of the overall recycled material.”

The catalytic activity of stearates is not linear to their concentration. It is an asymptotic curve so, due to dilution with polymers which do not contain the catalyst, the stearates stop catalysing the degradation reaction due to an insufficient concentration.

The author of the Roediger Report said “We are able to confirm that plastic products made with Symphony’s d2w biodegradable technology may be recycled without any significant detriment to the newly formed recycled product.”

APR says that “testing of just tensile properties is useful but incomplete, and the two more important tests are flexural properties and impact properties. Materials with surface defects are prone to failure when loaded in flexure, and embrittled materials are prone to fail in impact testing.”

These three tests may be used if desired to assess the quality of products containing conventional and/or or d2w recyclate, but verification of polymer stability is best done by measuring oxidation of the polymer directly, as a proxy for molecular weight reduction – which is the root cause of loss of mechanical properties.

These plastics are tested for thermo-oxidation, which will detect changes long before changes occur in their appearance or mechanical properties.

APR also says that testing properly recognizes ageing of the final product, but in recycling there is also the ageing of the initial product.   However, as already noted, polymers exposed to sunlight and air for extended periods are likely to experience oxidation, whether or not they contain a pro-oxidant masterbatch, and in both cases there will be a point in time when they are no longer suitable for recycling. In fact, real-time outdoor ageing of d2w plastics and a conventional plastic control, identified that the onset of oxidative degradation (representing the point at which the plastic is no longer suitable for recycling) occurred *on the same day* as the conventional plastic (Bandol 2015, 2016).

The characteristic of the plastic containing the pro-oxidant masterbatch was not that it became unsuitable for recycling earlier, but that subsequent degradation progressed more rapidly, even in the absence of sunlight or heat, until the plastic became biodegradable.

Products made with d2w from aged material are evaluated for thermo-oxidation due to ageing, in order to ensure that the product is fit for initial use (shelf/service life/ reuse) and to allow sufficient time for collection for proper disposal, including recycling. All such validated products show adequate stability, which is predicted using very conservative factors and modelled for extreme storage conditions. This is expected to substantially underestimate the actual shelf and service life of the products.

In fact, as already noted, the stabilisers in the masterbatch can result in *increased* stability during shelf and service-life, as compared with the same PE or PP product made without d2w masterbatch.

Again, the TCKT (July 2016) study found that photo-induced oxidation of both conventional and d2w products was eliminated by the use in each case of the UV stabilisers which would always be used for products intended for long-term use.

APR also say “The nature of plastics-recycling is that initial products are not exclusively directed to specific end-uses. Films do go back into films and do also go into thick-sectioned items such as plastic lumber. Some recycled milk bottle material is used to make films for its next use. This means that test protocols need to call for the most challenging use comparison, not the least.” This is well understood, and it is the manufacturer of the new product, not the recycler, who decides what recyclate to use, and what stabilisation is required.

The TCKT studies (March and July 2016) examined recycling of inherently low-stability LDPE films (as a worst-case scenario) into both short-life film and durable thick-cross section products – demonstrating that satisfactory products can be produced and that in both cases the contribution of stabilisers in the masterbatch has a more significant impact than the pro-oxidant catalyst carried through the process.

APR also say “Accelerated ageing for complex systems is relatively easy to conduct, but not so easy to interpret. For actions that are described by first order kinetics, a linear log(time) relationship is well known.

When there are multiple steps involved with the limiting steps changing over time, converting hours in a weather-o-meter to actual exposure time is rather uncertain. And, when the next use of the recycled plastic can be for years of service, the accelerated aging must be validated to assure the testing on accelerated aged specimens have useful meaning."

However, most ordinary waste plastics will have been exposed to UV radiation, in particular agricultural film, and may have oxidised to some extent, but not enough to become biodegradable. Recyclers of mixed plastic wastes have no way of knowing which have been exposed and for how long, and it is also known that printing inks, and other chemicals will affect the recycling process. Therefore, the industry already has the problem of identification when dealing with post-consumer plastic films, and deals with it by using those materials for low-value/short-life applications such as carrier bags and garbage sacks.

It is true that photo-oxidation in the environment is difficult to model, and lifetime prediction should be approached with caution; however, since it is well known that sunlight causes damage which is likely to harm the recyclability of the plastic, it should not be collected for recycling and stored in sunlight for extended periods. For so long as it remains suitable for recycling, and if the next use of the recycled plastic is for durable products, it should of course be stabilised as already mentioned.

Stability to thermo-oxidation is the critical parameter for processing and long-term storage of polymer recyclate; and is much better understood and simpler to model. Therefore shelf-life and service-life prediction for polymers via well-understood principles, (including those included in ASTM F1980-16), is typically done with conservative factors in order to provide a substantial margin for error.

There is also the question of dilution. Pro-oxidant catalysts are incorporated at trace levels and dilution is likely to result in a degradation response which is indistinguishable from the degradation behaviour of conventional polymers. Pro-oxidant masterbatches do not themselves cause degradation, they are designed to augment the behaviour of conventional plastics which are already vulnerable to degradation by a combination of photo-oxidation and thermo-oxidation. We have already noted that conventional PE and PP contain compositional and structural impurities. Pro-oxidant masterbatches are there to extend the degradation response with or without sunlight so that it can reach completion, resulting in biodegradability.

APR say "In the practical world the recyclers have no reasonable means of knowing if a pro-oxidant is present. The variety and concentration levels are not helpful to detection and the economics of such a sorting would not be trivial." Again, this is well understood, but separation of different types of polymer is a problem with all types of plastic film, and is one reason why post-consumer plastic film is not attractive to recyclers. However, as we have explained in this paper, sorting of PE and PP products containing pro-oxidant masterbatch from PE and PP products without such masterbatch, is not necessary.

Nor in the practical world do the recyclers know to what conditions and for how long the conventional polymer feedstock coming to their facility for recycling has been exposed. Moreover, as we have seen, any conventional PE or PP received for recycling is likely contain an unknown quantity of compositional (catalyst residues, mineral pigments, etc) or structural (carbonyl and peroxide groups, vinyl content, etc.) impurities that act in the same way as pro-oxidant masterbatches to cause degradation to occur (Yousif 2013). One cannot therefore accept the idea that conventional plastic can be safely recycled and that d2w plastic cannot.

The processing of plastics which may contain pro-oxidant masterbatch must therefore be managed in the same way as any other post-consumer plastics, and it is not necessary to determine the presence or level of pro-oxidant catalyst. Instead, if long term stability of new products is critical, the manufacturer of the new products will make a performance-based evaluation for the type of product he wishes to make eg. analysis by OIT and determination of oxidation and mechanical properties, with or without accelerated ageing – this is critical as much for conventional recyclate, as for recyclate which contains or might contain pro-oxidant masterbatch.

The APR FAQ also said “Won’t degradable additives in plastics help the environment? It is hard to see how that can be. Fragmenting plastics such as created by oxo-degradable additives has few if any benefits and many potential problems. Degrading plastics to methane may sound good, but the capture rate of methane in landfills is such that the biodegradable additives may increase greenhouse gas emissions.”

APR was again mistaken here. Plastics containing pro-oxidant masterbatches such as d2w do not simply cause the plastic to fragment (this is what happens to ordinary plastic under the influence of sunlight). They rapidly reduce the molecular weight after the stabiliser is exhausted at the end of the designed life of the product, so that it becomes a waxy material which is no longer a plastic and is biodegradable.

Further, plastics containing pro-oxidant masterbatches are reliant upon access to oxygen, so they will not degrade under anaerobic conditions in landfill and create methane, which is a dangerous greenhouse gas. (This is what “compostable” plastics do).

The benefits of degradation are obvious, because conventional plastics, of which APR approve, will accumulate in the environment for decades – do APR think that all the plastic litter gets collected? If so, why is there so much public concern about plastic in the environment?

Their FAQ also said “A degraded plastic material is an opportunity lost to reuse a valuable resource through recycling which provides tangible benefits in reducing greenhouse gases and energy use compared to use of virgin plastics.” As noted above, it is questionable whether recycling of plastics reduces greenhouse gases and energy use compared to the use of virgin plastics.

In any event, d2w is intended for plastic which cannot be recycled because it has escaped into the open environment from which it cannot realistically be collected. The opportunity has therefore been lost, not because the plastic is biodegradable, but because waste-management has failed and the material has not been collected in time or at all.

APR said that "due to the emerging nature of the degradable additive technologies, these materials are not currently part of the APR recognition program." However, d2w is not emerging – it has been commercially available for more than twenty years, and in fact this type of plastic has been mandatory in some parts of the world – eg in the UAE since 2009, and Saudi Arabia since 2018.

APR said that the addition of antioxidants to test-materials is not permitted. This makes no sense, because plastic products (including conventional plastic products) which are exposed outdoors, notably plastic lumber, garden furniture, and pipes, conduits, and automotive plastics, must have antioxidants for stabilisation against sunlight and heat, and would not otherwise be fit for purpose. As noted above, such stabilisation would neutralise the effect of any d2w plastic in the recyclate.

CONCLUSION

Polyethylene and polypropylene products containing masterbatches such as d2w can be safely recycled at no extra cost into short-life and long-life products without separation from ordinary PE and PP.

In the last 15 years, enough masterbatch has been sold by Symphony Environmental alone to make more than 2.1 million tonnes of biodegradable products from polyethylene and polypropylene. We know that d2w products have been successfully recycled around the world, and in those 15 years we have heard no reports of any difficulty encountered. Our experience is entirely consistent with the specialist reports mentioned above, that d2w plastic can be safely recycled without separation from conventional plastic.