ROYAL SOCIETY OF CHEMISTRY

SUSTAINABILITY

Additives for degradable plastics

Plastic products are designed to be durable, and while this characteristic delivers many benefits, it also has made them a persistent threat when they are discarded in the environment.

Some polymers are designed from the beginning to be compostable or biodegradable in the environment of release, for instance polyglycolide (PGA) which is used for oil drilling and poly(lactic acid-co-glycolic acid) (PLGA) which is used for medical devices and sutures, and breaks down naturally in the body.

Another way to induce the breakdown of a plastic product at the end of its useful lifetime may be to include certain additives within a mixture of 'traditional' non-degradable polymers, such as polyethylene (PE).

This type of additive-induced degradable plastic is designed to be durable in its normal use, but is proposed to break down completely and disappear once it is released into the environment. The additives are intended to act as a 'trigger' to initiate the breakdown process.

New, innovative, environmentally degradable plastics could help to reduce the environmental impact of plastic pollution. Their use, however, must be informed by transparent research into their potential for complete degradation in all relevant environments, and the long-term consequences of environmental degradation, along with comprehensive safety testing of any additives used.

What are additives?

Plastics often contain additives: chemicals which improve particular properties, such as colour, flexibility, and making plastics flame retardant. These chemicals are often sourced from fossil resources, and are added to polymers during the formulation of a plastic product.

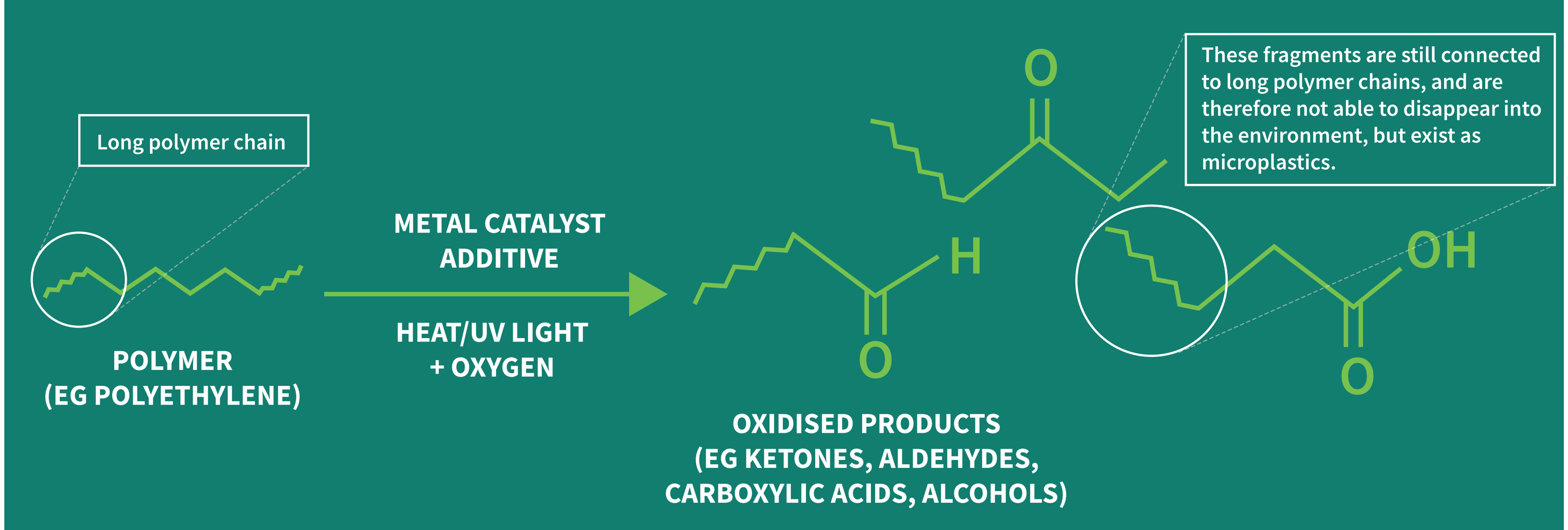
Some additives can be a cause for concern if they have hazardous properties, and are used in applications which result in exposure, such as for example in food packaging. Research is currently being undertaken to find safer alternatives for these additives.

It is also important to remember that once that plastic has degraded, everything contained within it will be released to the environment. Therefore any environmentally harmful additives could impact the environment of release.

What are oxo-degradable plastics?

Oxo-degradable plastics are 'plastic materials that include additives which, through oxidation, lead to the fragmentation of the plastic material into micro-fragments or to chemical decomposition.'[1]

In these materials, additives are incorporated into conventional plastic mixes while they are being converted into final products. The most effective pro-oxidant additives use transition metal salts or oxides – often with cobalt, manganese or iron, for example iron(II) carbonate (Fe_2CO_3). Metals can also be added to plastic as organic ligand complexes. Metal salts, oxides and complexes cause fragmentation of the plastic as a result of the oxidation of the polymer chains triggered by exposure to UV radiation or heat.[2,3,4]



The heat- or light-induced oxidation (and therefore fragmentation) of the polymer chain could happen naturally to a plastic degrading in the open environment, but the presence of the pro-oxidant additive greatly speeds up the process.

Researchers have been debating the use of degradation additives for some time and oxo-degradable plastics have now been shown to be harmful, as they do not truly disappear in the environment and instead produce microplastics.[5] These plastics are banned by the EU, with other nations also considering legislation.

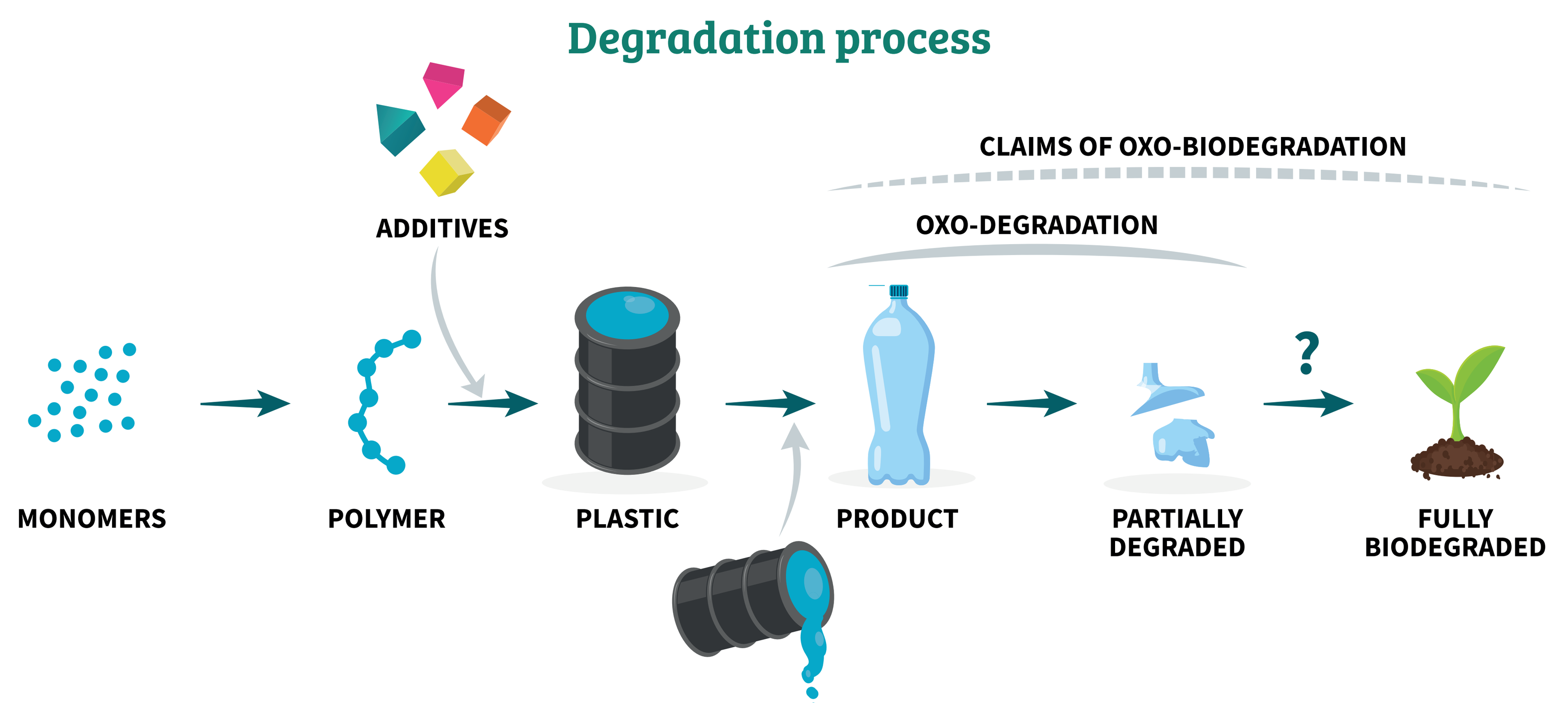
What are oxo-biodegradable plastics?

New terms such as 'oxo-biodegradable' plastics, or 'triggered degradation' plastics have been used to describe materials which claim to offer the benefits of additive-induced degradation, whilst avoiding the harm of oxo-degradation.

Upon exposure to the degradation environment, these new materials are said to follow the pattern of initial heat or UV induced break down, followed by biodegradation to natural products which are harmless to the natural environment. However as the first part of this process follows the definition of oxo-degradable above, more independent testing is needed to determine whether these newer materials overcome the clear problems identified in oxo-degradable plastics before they are permitted for use.

The additives used are designed to degrade the plastic structure when exposed to certain conditions. This property, however, could mean that oxo-biodegradable type plastics contaminate recycling streams, although some of these new materials are marketed as safe for recycling as the primary end of life option. Again, more impartial assessment is necessary to determine their impact on the waste management system.

Degradation process



The legacy of oxo-degradable plastics has meant that there is understandable hesitancy around introducing plastics with other additives to trigger degradation using the same mechanism. How much do we know about newly proposed materials and how do they compare to those deemed unsafe for the environment?

OXO-DEGRADABLE TYPE PLASTICS	'OXO-BIODEGRADABLE' TYPE PLASTICS
Contains additive to trigger breakdown of the plastic when exposed to certain conditions (usually light/UV and oxygen).	Contains additive to trigger breakdown of the plastic when exposed to certain conditions (usually light/UV and oxygen) in the same way as oxo-degradable plastic, may contain further additives to promote subsequent biodegradation of the material.
Additives tend to contain contaminants such as metals which may negatively impact upon the environment on release.	Little information is currently available about what is used in the additives, and therefore the impacts of these additions are unknown.
As only fragmentation of the product occurs, this process does not fully degrade the plastic, and in fact forms microplastics.	Little information is currently available on how effective the transformation is, and whether the initial destabilisation phase moves quickly enough to biodegradation in a range of natural environments without release of microplastics.
Oxo-degradable plastics have been shown to persist in ocean environments, an environment with possibly the least chance of recovering plastic.	Little information is currently available on the persistence of these materials prior to break down and biodegradation.

To prevent the unintended consequences seen in the use of oxo-degradable plastics, thorough independent assessment is needed of oxo-biodegradable plastics, and any other plastics with additives to promote degradation.

This should include a better understanding of the process and products of degradation, the safety of additives used, and any impacts on the waste management system. Only once these outstanding questions about their lifetime impacts have been answered satisfactorily should these products be used.

In the RSC's recent report 'A chemicals strategy for a sustainable chemicals revolution'[6], the pillar on Innovation makes clear that potential environmental impacts of chemical or product innovations need to be considered upfront, and assessed with appropriate tools early in the design phase. With support from a regulatory system that is balanced, proportionate and based on risk assessment, chemical science innovators have the power to create solutions to some of society's biggest challenges.

Some key outstanding questions

Plastics which safely disappear in the open environment could provide one solution to further plastic pollution, which creates a massive problem in oceans and on land. Many scientists believe there should be further exploration into the development of truly environmentally degradable plastic as a means to tackle plastic leakage.

However, when it comes to plastics with additives for degradation, more evidence is needed to establish whether they are a good and safe option – and whether this is the case across all the environments they could end up in.

IMPORTANT OUTSTANDING QUESTIONS ABOUT PLASTICS WITH ADDITIVES FOR DEGRADATION:
Do these products truly biodegrade completely in the environment, under a variety of conditions depending on where they may end up and within a timeframe that does not cause environmental harm during breakdown?
How do these products influence the rest of the waste management system? Can they be properly identified and separated in collection systems if needed?
Will making these products available influence consumer behaviour in a negative way eg through increased littering?
How do currently used additives impact human health and the environment? Where harmful, can they be substituted for options that are safer for humans and the environment, and sourced from more sustainable materials?

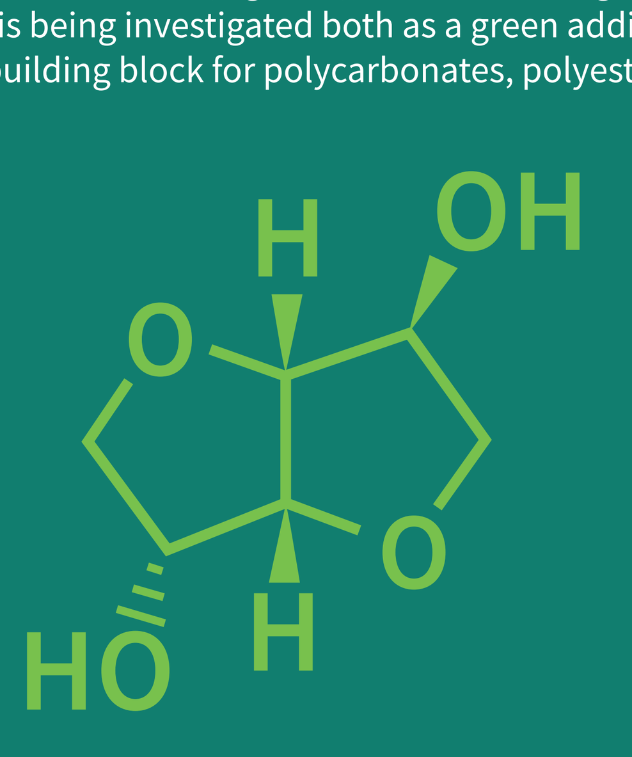
CASE STUDY

Additives are really important for plastics to be able to perform a wide range of functions in their day to day use.

However additives can also be a cause for concern in both the sustainability, and safety of plastic products if they have hazardous properties for human health and the environment. Chemists are currently researching safe and sustainable additives for the future.

One target for scientific interest is isosorbide (Figure 1), a derivative of glucose that is sourced from natural starches. This molecule is being investigated both as a green additive to replace phthalate plasticisers, and as a potential building block for polycarbonates, polyesters and polyurethanes.

Figure 1: Isosorbide



Researchers at the Korea Research Institute of Chemical Technology demonstrated that transparent polycarbonate sheets made with isosorbide outperform those made with the traditional, fossil fuel based, bisphenol A molecule in strength tests.[7]

> *We are excited about the possibility of using isosorbide in plastics, as a safe, sustainable, and outstanding alternative.*
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> DR JEYOUNG PARK, RESEARCH TEAM

1 DIRECTIVE (EU) 2019/904 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 June 2019 'on the reduction of the impact of certain plastic products on the environment'
2 https://docs.european-bioplastics.org/2016/publications/bp/EUBP_bp_additive-mediated_plastics.pdf
3 https://www.sciencedirect.com/science/article/pii/S030438941730763X#bib0905
4 https://onlinelibrary.wiley.com/doi/10.1002/app.40750
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