Plastic waste to sustainable solutions: accelerating the biodegradation of synthetic plastics

The manufacture of synthetic polymers from crude oil was a breakthrough in the last century. These materials show a great combination of properties: flexibility, strength, lightweight and low-cost production. However, their massive production (up to 320 million tons per year) and inert nature (extremely durable, with most considered non-biodegradable materials) have led to a significant challenge: plastic pollution.

Emerging bioplastics: a promising solution to combat plastic pollution

Plastics and microplastics are pervasive in every environmental compartment, such as soil, marine or freshwater. Some scientists even recognise a new environmental compartment named 'plastisphere', referring to ecosystems that have evolved to live in human-made plastic environments.

For this reason, biodegradable and bio-based plastics have emerged as viable alternatives to traditional non-biodegradable fossil-based plastics. Biodegradable and bio-based plastics have experienced an increase in production in recent years. European Bioplastics reports a notable increase, reaching 2.2 million tons in 2022 (European Bioplastics, n.d.). They also showed the potential market for bioplastics for the next five years, showing a huge increase in the production of PLA and PHA, expected to reach 6.3 million tons of bioplastics produced in 2027. Different actions have been taken to manage the actual issue of plastic pollution. One example of these actions is the Bio Innovation of Circular Economy for Plastics (BioICEP) project.

BioICEP: pioneering a circular economy for plastic waste

BioICEP is a pan-European-Chinese collaboration formed to reduce the burden of plastic waste in the environment. Different mixed plastic pollution environments are represented, with partners selected specifically for their expertise and facilities necessary to carry out the technical innovation.

BioICEP started in February 2020 and is funded by the EU's Horizon 2020 programme. The project aims to develop environmentally sustainable alternatives to petroleum-based plastics, transforming these fossil-based materials into high-value bio-based products, such as PHB and rhamnolipids.

The project employed an innovative cascade process, applying and combining novel chemical and biological methods to turn fossil-based plastic waste into feedstocks usable by enzymes and microorganisms, producing biodegradable substitute materials for the packaging and pharma industries. A number of innovative booster technologies are at the core of this solution, accentuating, expediting, and augmenting mixed plastic degradation and transformation to other bioproducts to levels far in excess of those currently achievable.

The approach to reach these goals is a triple-action depolymerisation system where plastic waste is broken down into three consecutive processes. Firstly, mechano-biochemical disintegration pretreatment processes, including a new proprietary sonic-green-chemical technology, reduce polymer molecular weight and modify their properties. This enhances their amenability to biotransformation. Secondly, polymers undergo biocatalytic digestion with modified enzymes, employing innovative techniques such as accelerated screening by novel fluorescent sensor technology and directed evolution to enhance enzyme activity. Finally, microbial consortia, developed from the best single microbial strains, are used to obtain a highly efficient degradation of mixed plastic waste streams. The output products serve as building blocks for new polymers or other bioproducts, enabling a new plastic waste-based circular economy.

AIMPLAS delivers breakthroughs in plastic pretreatment for enhanced biodegradation

AIMPLAS' role in the project involved the development of the novel pretreatment of plastics through different physico-chemical techniques. Therefore, AIMPLAS performed pretreatments to accelerate the biodegradation of synthetic plastics. Their Plastics Technological Centre uses methods based on microwaves and reactive extrusion. The centre provided 'promising' results through the new microwave technology, turning non-biodegradable plastic waste (such as low-density PE) into a wax that then resulted in a readily biodegradable material, which reached total biodegradation in less than 28 days using a specific strain.

Reactive extrusion has also been used to change the properties of LDPE to make it more amenable to biotransformation using enzymes and microorganisms. AIMPLAS, in collaboration with TUS and IMGGE (partners of BioICEP project), set up the optimisation of reactive extrusion for further biodegradation of LDPE. This set of experiments showed that LDPE was efficiently converted into bio-amenable LDPE using an energy-favourable, industrially scalable reactive extrusion process (Ferrero *et al.*, 2022). Best conditions were found using low screw speed (50 rpm), an operating temperature of 380°C, and catalytic and non-catalytic conditions. This resulted in a significant increase in the LDPE carbonyl index from 0 to 1.04 and a decrease of LDPE crystallinity index from 29 to 18. The molecular weight decreased to 81 per cent compared to the virgin LDPE, confirming that polymer chains break down during the reactive extrusion process. Furthermore, pretreated samples were incubated with microorganisms, showing that biofilms were successfully formed on pretreatment LDPE samples after 14 days of incubation, indicating their potential for biodegradation.

Another technique used involved depolymerising various fossil-based polymers like polyamides or PET to obtain the monomers constituting these polymers. After the depolymerisation process of those polymers, monomers are used as substrates for bioplastic production by utilising microorganisms capable of using those monomers as feedstock to produce some bioproducts such as PHA or bacterial nanocellulose. For example, the monomers obtained from PET hydrolysis are terephthalic acid and ethylene glycol. It was then demonstrated that these monomers can be used to produce bacterial cellulose using *Komagataeibacter xylinus* DSM 2004 and DSM46604 (Esmail *et al.*, 2022). The bacterial cellulose produced in all tested media had identical chemical structure and thermal behaviour, but their crystallinity and nanostructure were different depending on the bacterial strain used and the medium composition. Thus, these findings pave the way for the upcycling of PET degradation monomers into a high-value biopolymer.

In conclusion, the BioICEP project is developing novel techniques combining different technological areas to promote plastic recycling alternatives and the production of biopolymers from fossil-based polymers. The results have shown promising advances in the different fields where the project is working to close the loop and enhance the circular bioeconomy in the plastic sector.

References

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PROJECT NAME

BioICEP – Bio Innovation of a Circular Economy for Plastics

PROJECT SUMMARY

BioICEP combines chemical and biological methods to turn fossil-based plastic waste into natural, biodegradable substitutes for the packaging and pharma industries. It combines three technologies that enhance, accelerate and increase the degradation of plastics to levels far beyond what is currently possible. A triple-action depolymerization system breaks down plastic waste through chemical disintegration processes, biocatalytic digestion and microbial consortia.

PROJECT PARTNERS

Acteco, Avecom, Technische Universitat Clausthal, Institut Za MoleKularnu Genetiku I Geneticko Inzenjerstvo, Instituto De Biologia Experimental E Tecnológica, Logoplaste Innovation Lab LDA, Technological University of the Shannon, The Provost, Fellows, Foundation Scholars and Other Members of Board of the College of the Holy and Undivided Trinity of Queen Elizabeth near Dublin, Microlife Solutions BV, National Technical University of Athens – NTUA, Beijng Institute of Technology, Institute of Microbiology – Chinese Academy of Sciences and Shandong University.

PROJECT LEAD PROFILE

Dr Pablo Ferrero holds a PhD in Chemical Environmental and Process Engineering from the Universitat de València (Spain). He has been working as a researcher at the Chemical Recycling department of AIMPLAS since 2019. His expertise is focused on the anaerobic biodegradation of solvents from flexographic industries and on the enzymatic and microbial degradation of plastics for the obtention of biochemical products of interest to the plastic industry. Among his main research activities, we find recycling/recovery and biodegradation of materials. He has been a speaker at several seminars and conferences and the author of technical articles for scientific journals and magazines.

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