MIPLACE

Microbial **I**ntegration of **Pla**stics in the **C**ircular **E**conomy

Upcycling plastic waste

MIPLACE: a multidisciplinary project funded within the framework of the
ERA-CoBioTech programme of the European Union

ERA CoBioTech

Plastic waste: A global crisis

- 400 million tonnes of plastic produced globally each year
- Estimated 25% is incinerated and 56% going to landfill
- Global average recycling rates are 14-18%
- Plastic pollution poses environmental and health risks
- Use of fossil fuels for virgin plastics contributes to climate crisis

**Source: Plastics, the Circular Economy and Global Trade. World Economic Forum (2020)*

Plastic recycling technologies

Mechanical recycling

- Plastic is sorted, washed and ground and the materials are recovered by remelting and regranulating.
- If the material is of good quality, the recycled materials can be converted into the same or similar type plastic products.
- However, the recycling process can result in ‘downcycling’ as high temperatures and shear forces can reduce the quality of the recycled material.
- There is a limit on how many times plastic can be recycled by this method.

Chemical recycling

- For recycling plastics that are mixed with other materials or different types of plastics.
- There are different types of chemical recycling processes such as glycolysis and hydrolysis.
- Plastic is broken down by chemical transformation into its building blocks and used to form new plastics or upcycled to higher value chemicals.
- Generally, no limit to the number of times plastic can be recycled.

Sources: European Bioplastics: Mechanical recycling (July 2020); Zhu et al *(2021) Enzyme discovery and engineering for sustainable plastic recycling. Trends in Biotechnology; Plastics, the Circular Economy and Global Trade. World Economic Forum (2020); Plastic pollution: how chemical recycling technology could help fix it. The Conversation (2021); Chemical Recycling Europe (2019); EEA Report No. 18/2020*

The MIPLACE approach for upcycling PET and PU plastic waste

- MIPLACE **aims** to develop an efficient **bio-based process** that converts plastic waste (PET and PU) into molecules of value that can be **upcycled** into new products thus contributing to a **circular economy**.
- **Microbial communities** will **enzymatically** degrade PET and PU into their constituent monomers and transform them into building blocks for the synthesis of Bio-PU, a more environmentally-friendly construction and insulation material.
- Microbial degradation and transformation offers an additional approach alongside current plastic recycling technologies.
- Operating at lower temperatures, biodegradation methods may have lower energy inputs/costs and a reduced carbon footprint.

How to create microbial communities to transform PET and PU waste into building blocks for Bio-PU?

Screening of microorganisms from the environment for plastic degrading activity

Designing microbial strains for greater efficiency by applying synthetic biology techniques

Selecting for plastic degraders by adapted laboratory evolution (ALE)

PET: polyethylene terephthalate commonly used for single-use plastics especially in the beverage industry
PU: polyurethane (foams) used in insulation panels, carpet underlay, furniture and bedding, footwear

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Techniques in a nutshell

- **Synthetic biology:** employing engineering techniques to redesign organisms for beneficial applications such as solving problems within agriculture and the environment.
- Pieces of DNA from an organism, or novel DNA, are inserted into another organism's genome thus changing the genetic code and the activities of the recipient organism.

- **Adapted laboratory evolution (ALE):** the continuous culturing of individual strains or communities on PET or PU as the sole carbon source.
- As a result of such selection pressures, better plastic degraders will emerge.

Adapted laboratory evolution (ALE): From left to right: increasing turbidity as a strain of *Pseudomonas putida* adapts to grow on terephthalic acid (TA). *Source: Dr. Alice Banks (ICL)*

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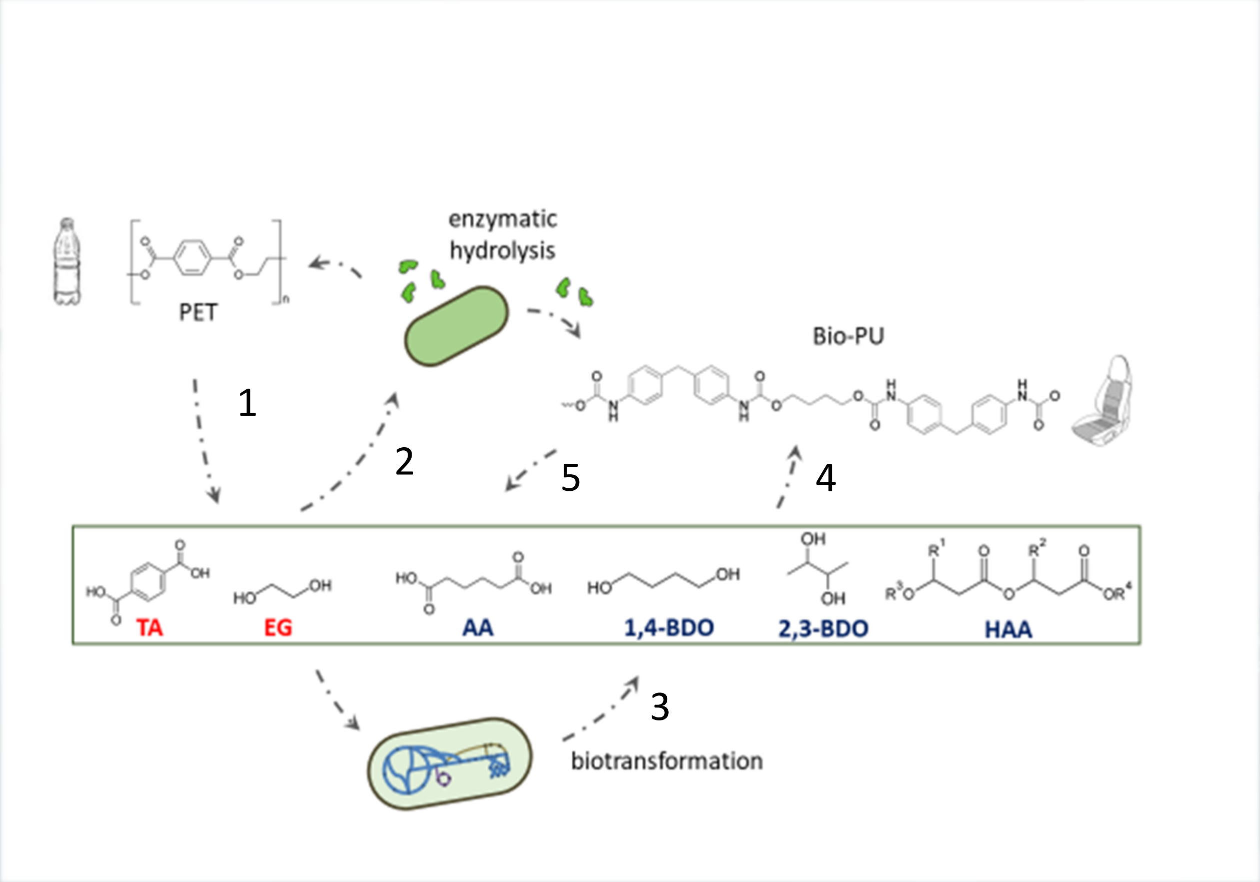
Upcycling PET and PU plastic waste: a more detailed look



Microbes will perform enzymatic hydrolysis of PET and PU plastic waste to produce monomers (1). These monomers (red) support microbial growth (2) but also undergo biotransformation (3) into other monomers (blue) that may be used to synthesize Bio-PU (4) so achieving the upcycling of plastic waste.

Bio-PU is used as a construction and insulation material and can be recycled (5) at the end of its life demonstrating a **circular approach for tackling PET and PU waste.**

PET = polyethylene terephthalate; PU = polyurethane; EG = ethylene glycol; TA = terephthalic acid;
AA = adipic acid; 1,4-BDO = 1,4-butanediol; 2,3-BDO = 2,3-butanediol; HAA = hydroxyalkanoyloxy-alkanoic acid

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MIPLACE: Some technical details

MIPLACE: Technology readiness levels (TRLs)

Aim: microbial hydrolysis of PET and PU, production of monomers and synthesis of Bio-PU from plastic waste operating at industrial scales (TRL 5 or above)

Current situation

- Enzymatic hydrolysis of PET (TRL 4)
- Enzymatic hydrolysis of PU (TRL 3)
- Synthesis of Bio-PU from monomers (TRL 4)

Technology readiness levels (TRLs)

TRL 3: experimental proof of concept

TRL 4: technology validated in lab

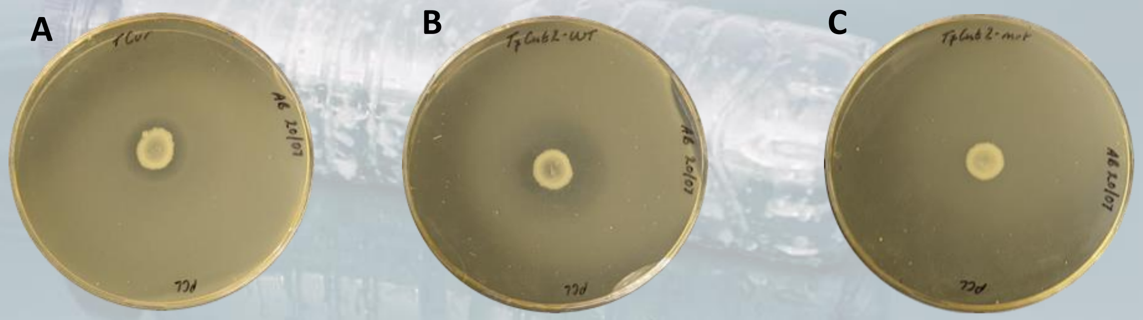
TRL 5: technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 6: technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

Source: Tournier et al (2020) An engineered PET depolymerase to break down and recycle plastic bottles. Nature, 580, 216-219.
Sonnendecker et al (2021) Low carbon footprint recycling of post-consumer PET plastic with a metagenomic polyester hydrolase. ChemSusChem 10.1002/cssc.202101062
Carbios press release 29 September 2021

Examples of enzyme activities

- **PET hydrolase**: a minimum of 90% PET depolymerization into monomers over a 10-hour period. Mean productivity of 16.7g terephthalate per litre per hour (Tournier *et al*, 2020).
- **Polyester hydrolase, PHL7**: completely hydrolysed amorphous PET films, releasing 91 mg of terephthalic acid per hour and mg of enzyme (Sonnendecker *et al*, 2021)
- French company, **Carbios**, launched a demonstration plant for its enzymatic recycling technology in September 2021.



Plates showing degradation of the polymer, polycaprolactone (PCL), a model substrate for plastic degradation. Plates A and B show ‘halos’ surrounding microbial growth where the polymer has been degraded by enzyme activity. In Plate C, the halo is absent as the enzyme responsible for degradation is inactive. *Source: Dr. Alice Banks (ICL)*

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Microbial Integration of Plastics in the Circular Economy

Website: www.miplacebio.com
Twitter: @miplacebio

UNIVERSITÄT LEIPZIG
Imperial College London
RWTH AACHEN UNIVERSITY
VNIVERSITAT DE VALÈNCIA
SOPREMA GROUP
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