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Engineered microbes for the biotransformation of plastic waste into value-added chemicals.

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Introduction

Plastic pollution has emerged as a formidable environmental challenge, with over 400 million metric tons of plastic produced annually and a significant portion accumulating in landfills and marine environments. Traditional recycling methods, both mechanical and chemical, face limitations due to high energy costs, material degradation, and limited feedstock compatibility. In recent years, biotechnological approaches, particularly the use of engineered microbes, have gained attention for their ability to biotransform plastic waste into value-added chemicals. This emerging field combines synthetic biology, metabolic engineering, and environmental microbiology to offer a sustainable solution to the global plastic crisis [1].

Most conventional plastics—such as polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET)—are derived from fossil fuels and are resistant to microbial degradation. These polymers accumulate in the environment, taking hundreds of years to decompose naturally. While biodegradable alternatives are in development, legacy plastic waste continues to pose significant risks to ecosystems and human health. Addressing this issue requires innovative, scalable, and eco-friendly technologies for plastic upcycling [2].

Biotransformation refers to the microbial conversion of complex molecules into simpler or more useful products through enzymatic processes. In the context of plastic waste, certain microbes have been discovered that can degrade plastic polymers into monomers or oligomers. By genetically engineering these microbes, scientists are now enhancing their ability not only to break down plastics but also to convert the resulting compounds into valuable industrial chemicals such as biofuels, bioplastics, and platform chemicals [3].

The cornerstone of microbial plastic degradation lies in plastic-degrading enzymes such as PETase, MHETase, and cutinases, which hydrolyze plastic polymers into smaller, digestible molecules. For example, *Ideonella sakaiensis*, a bacterium discovered in 2016, can degrade PET into its monomers—terephthalic acid (TPA) and ethylene glycol (EG). Genetic engineering has enabled the optimization of these enzymes for enhanced stability, specificity, and efficiency under industrial conditions [4].

Once the plastic polymers are depolymerized into monomers, engineered microbial strains such as *Escherichia coli*, *Pseudomonas putida*, or *Corynebacterium glutamicum* are employed to funnel these intermediates into desired biosynthetic pathways. Through metabolic engineering, researchers have developed pathways for converting TPA into muconic acid, a precursor to nylon and PET, or into vanillin, a high-value flavoring compound. Similarly, EG can be transformed into glycolic acid, ethanol, or polyhydroxyalkanoates (PHAs)—a class of biodegradable bioplastics [5].

Conclusion

Engineered microbes represent a cutting-edge solution to the global plastic pollution crisis by enabling the biotransformation of persistent waste into valuable, sustainable products. Although the field is still in its early stages, advancements in synthetic biology, metabolic engineering, and bioprocess design are paving the way for real-world applications. With continued research and interdisciplinary collaboration, microbial plastic upcycling could become a cornerstone of future circular bioeconomies—where waste is not discarded but reinvented as a resource.

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