



MANUSCRIPT ID: BTS0826009

Medicines from Waste: Pioneering the Path from Plastics to Paracetamol Review

Hanumanthu Mounika Aditya ¹, Gandikota Jnana Prasanna ², Dr.Kiran Manda ³, Kanuri Srivallika*

Shri Vishnu College of Pharmacy, Bhimavaram, West Godavari, Andhra Pradesh, India.

Corresponding Author Mail Id: srivallakikanuri@gmail.com

Received:15 July 2025 | **Revised & Accepted:**09 December 2025

Keywords: Paracetamol, PET upcycling, Synthetic biology, Lossen rearrangement, *E. coli*, Green chemistry, Circular economy, Biotransformation.

ABSTRACT

Made from a variety of organic compounds, including ethylene, vinyl chloride, vinyl acetate, vinyl alcohol, and others, plastic is a synthetic polymeric material with a high molecular weight. Petroleum, coal, and natural gas are the primary raw materials used to make plastics. The materials used to make plastics have a variety of drawbacks despite their many positive effects on human society. Di-(2-ethylhexyl) phthalate (DEHP), bisphenol A (BPA), polyhalogenated compounds, and heavy metals are just a few of the harmful additives found in plastics that may be harmful to human health (Boyu Jiang, 2020). In addition to the pharmaceutical industry's continued heavy reliance on fossil fuels for the production of active pharmaceutical ingredients, plastic waste presents a serious environmental threat. According to the researchers, who are from AstraZeneca and the University of Edinburgh in the United Kingdom, their work shows an integrated chemical and biological approach for upcycling and sustainable plastic remediation (Robinson, 2025). The recent discovery uses *Escherichia coli* to produce paracetamol in less than 24 hours, addressing the pressing need to recycle polyethylene terephthalate (PET), a common plastic that eventually ends up in landfills or pollutes oceans. (ed.ac.uk, 2025) (wired, 2025). On an industrial scale, the yields are modest, but each one-litre soft drink bottle would yield about nine standard 500 mg tablets (ralls, 2025). This review highlights the sustainability potential of this process, discusses its implications for circular economy strategies in pharmaceutical manufacturing, and summarises the new biotechnological and synthetic advancements that underlie it.

INTRODUCTION

Plastic is a material that is widely used and has many social advantages. As the global economy grows, so does the amount of garbage produced worldwide, particularly due to the growing use of plastic products, of which disposable plastic is the most widely used. Although disposable plastic products have made people's lives and production more convenient, "white

pollution" has gotten worse because of how difficult it is for plastic products to decompose. The soil and marine environments are severely polluted as a result of the high volume of single-use plastic products and the low recycling rate. Plastic waste is to blame for the global environmental crisis. Nowadays, "limiting plastic" is widely accepted, and numerous



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nations and areas have started taking steps to restrict and outlaw plastic. (Boyu Jiang, 2020).

Plastic is a high molecular weight synthetic polymeric substance (RB, 1989), composed of a variety of organic substances, including vinyl alcohol, vinyl chloride, vinyl acetate, and ethylene. When plastic is soft, it can be moulded into a variety of shapes; when it hardens, it becomes rigid or slightly elastic. The main raw materials used to make plastics are coal, natural gas, and petroleum. Despite plastics' numerous benefits to human society, the materials used to make them have a number of disadvantages (Bupe GM, 2017).

Among the dangerous additives present in plastics that could be detrimental to human health are heavy metals, bisphenol A (BPA), di-(2-ethylhexyl) phthalate (DEHP), and polyhalogenated compounds (RU, 2010). It has been demonstrated that the majority of these additives are readily immobilised in the environment, which can have detrimental effects on human health, such as endocrine system disruption (Robinson, 2025). Plastics are extremely stable in the ambient environment and do not break down easily, so disposing of them in the environment has resulted in a significant pollution issue. Plastic waste management is currently a significant environmental concern. Recycling, landfilling, incineration, microbial degradation, and conversion into useful materials are some of the methods used to handle plastic waste (Ilyas, 2018)

The majority of single-use water and soft drink bottles are made of PET, or polyethylene terephthalate. Only a small portion of the more than 350 million tonnes of material produced worldwide each year is recycled. Even when PET is collected, it is usually "down-cycled" into fibres and lower-value plastics that will ultimately end up as waste. The medication paracetamol

has both analgesic and antipyretic properties. Despite being one of the most widely used medications in the world, paracetamol tablets are usually made using dwindling fossil fuels (ralls, 2025).

Re-engineering the gut bacterium *Escherichia coli* has now been shown to be an alternative by a research team headed by the University of Edinburgh. It can turn the components of used bottles into the medication's active ingredient in less than a day. (ralls, 2025).

The University of Edinburgh research team transformed polyethylene terephthalate (PET), a plastic used in bottles and food packaging, into a new substance.

This was subsequently transformed into a solid known as Para-Aminobenzoic Acid (PABA), most likely through a Lossen rearrangement, a chemical reaction that typically only takes place in extreme laboratory settings. However, the scientists discovered that when they incubated the material with a strain of *E. coli*, the conversion occurred on its own. After that, the PABA was converted to acetaminophen, or paracetamol. (Mitchell, 2025).

MAIN

Researchers have discovered that bacteria can convert plastic waste into painkillers, which could lead to a more environmentally friendly method of making the medications. Chemists have found that *E. coli* can be used to make paracetamol, also called acetaminophen, from a substance made in a lab using plastic bottles. (Guardian, 2025).

1. PET-to-Paracetamol Conversion

1.1 Chemical Depolymerization of PET

Terephthalic acid (TPA) is produced by the alkaline hydrolysis of PET. P-xylene, a petroleum product, is usually oxidised to produce terephthalic acid, a white, crystalline powder. PET plastic bottles and packaging are commonly made with it. It is



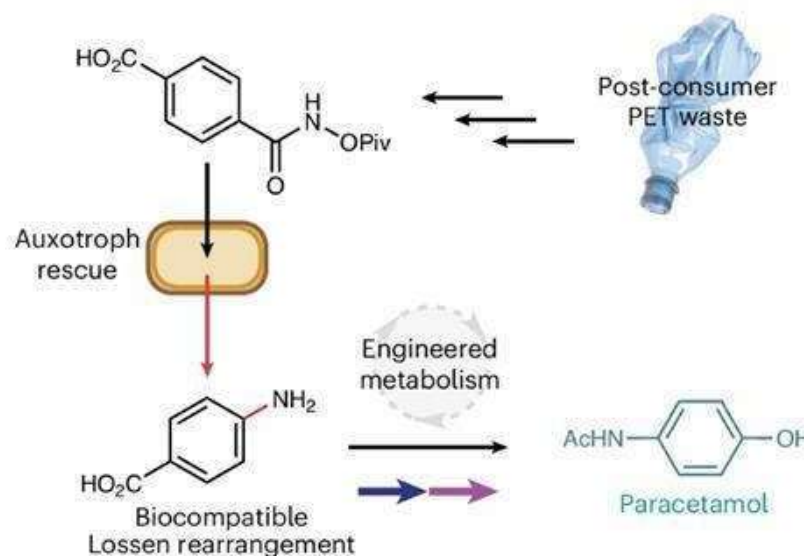
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suitable for a variety of industrial uses, including medicine, due to its chemical structure, which consists of two carboxyl conditions, producing high-purity TPA appropriate for additional biotransformation. (Orchard, 2025).

1.2 Biocompatible Lossen Rearrangement

Using phosphate as a catalyst, Lossen rearrangement can occur in living cells under benign, non-toxic circumstances. Hydroxamate esters are usually converted into isocyanates and amines by this non-enzymatic process. To produce para-aminobenzoic acid (PABA), a nutrient necessary for *Escherichia coli* growth, the researchers devised a biocompatible Lossen rearrangement that began with an acyl hydroxamate substrate. By manipulating the bacteria through synthetic biology, the researchers were able to change their present when they looked at synthesizing acyl hydroxamate esters from PET, specifically the PET monomer terephthalic acid (Robinson, 2025).

1.1 Engineered *E. coli* for Paracetamol Biosynthesis



By inserting two genes into the *E. coli*, one from a fungus and one from

groups on a benzene ring. Using hydrolytic or enzymatic systems, this degradation is catalysed in mild

internal chemistry and turn terephthalic acid, a molecule derived from PET, into the active component of acetaminophen. They employed a fermentation method that is comparable to making beer. (wired, 2025). They discovered that a strain of *E. coli* lacking PABA continued to grow when it was cultured with different O-acyl substituted hydroxamate esters without the use of extra catalysts, suggesting that Lossen rearrangement had taken place in the culture. They later discovered that the growth medium's phosphate had catalysed the reaction. The PABA-deficient *E. coli* then grew just as well with the plastic-derived esters as they did with PABA

another bacterium, researchers discovered (Robinson, 2025).



Two heterogeneous genes were added to the metabolite pathway.:

- Agaricus bisporus's **AbPAT**, which codes for PABA N-acetyltransferase.
- Pseudomonas aeruginosa's **PhnP**, which codes for a PABA deaminase.
- In a two-step process, these enzymes catalyse the conversion of PABA to paracetamol. Within 24 to 48 hours, the modified *E. Coli* strains produced paracetamol yields of up to 92% in a lab-scale bioreactor. (Soon, 2025).

Although the yields are modest on an industrial scale, roughly nine standard 500 mg tablets would be produced from each one-litre soft drink bottle (ralls, 2025)

2.Sustainability and Circular Economy Implications

By turning a pollutant (PET) into a medicinal product (paracetamol), this procedure provides an efficient example of upcycling. It exemplifies the fundamental principles of the circular economy and green chemistry by:

waste would need FDA approval through an Abbreviated New Drug Application (ANDA) (Orchard, 2025).

- Economic unknowns: A new techno-economic analysis is necessary because it is uncertain whether producing paracetamol from plastic will be less expensive than using conventional techniques (Orchard, 2025).
- Scalability: Significant investments in infrastructure and process enhancement are required

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- lowering plastic waste in landfills and the ocean.
- Steer clear of fossil fuels.
- Reducing harmful byproducts.
- Facilitating dispersed pharmaceutical production close to waste collection locations

These developments could simultaneously lessen the environmental impact and vulnerabilities in the pharmaceutical chain.

3.Challenges and Future Prospects

1.1 Challenges

Despite its potential, a number of barriers keep terephthalic acid-based pharmaceutical production from being widely used.:

- PET Waste Quality: Strict quality control is required because variations in recycled PET's composition may reduce the purity of terephthalic acid (Orchard, 2025)
- Regulatory Restrictions: To incorporate the novel biotech method into the drug manufacturing process, a generic version of paracetamol made from recycled PET when transitioning from lab-scale to industrial production (Orchard, 2025).
- Hundreds of thousands of litres can be stored in industrial bioreactors. Researchers need to show that the bacteria act consistently at that scale. (ralls, 2025)
- Adding an enzyme-based step to convert mixed PET into clean TPA without the need for expensive purification presents



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another difficulty. (ralls, 2025)

- There are also regulatory concerns. Microbe-produced medications must adhere to strict purity requirements (ralls, 2025).
- To verify that the approach is actually more cost-effective and environmentally friendly on a large scale, researchers must carry out a comprehensive life-cycle analysis. (ralls, 2025)

Future Prospects

One step towards a circular economy in pharmaceuticals is the use of terephthalic acid made from recycled plastics. Among the upcoming trends are:

- Biotechnological Developments: Increasing microbial fermentation to produce additional medications (Orchard, 2025).
- Regulatory Support: Green chemistry incentives may be

CONCLUSION

Thousands of tonnes of fossil fuels, particularly petroleum, are currently used in the manufacturing of medications like paracetamol, which has a major impact on climate change. PET, in turn, seriously harms the environment by producing over 350 million tonnes of waste annually. Despite the fact that this material can be recycled, current processes frequently produce goods that contribute to the global plastic pollution problem. The fact that microorganisms can turn PET plastic into useful new products, including ones with therapeutic potential, shows that it is not simply a waste product or a material that will only become more plastic. In

established by governments.

- Industry Adoption: Pharmaceutical companies will look for eco-friendly ways to increase their competitiveness in the market as investor and consumer demand for sustainability grows (Orchard, 2025)
- Circular Economy Integration: Reducing reliance on virgin petrochemicals and environmental footprints by scaling up recycling and bioconversion processes to meet industry demands and enabling pharmaceutical manufacturing to use plastic waste streams as regular feedstocks (Orchard, 2025)

Together, these advancements point to a time when pharmaceuticals will be produced in a more sustainable manner, promoting environmental conservation and global health goals (Orchard, 2025).

addition to being a scientific breakthrough, the use of engineered *E. coli* to convert PET into paracetamol represents a scalable, resource-efficient, low-carbon, and circular approach to medicine production in the future (Orchard, 2025). The PET get depolymerized to get terephthalic acid by alkaline hydrolysis method and then by using *E. coli* it undergoes microbial fermentation to produce PABA which is then converted to yield paracetamol.

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