Turning Trash into Treasure: Recycling PET Waste with Catalysts from PET Labels

Dr Mojtaba Enayati

Center for Materials and Manufacturing Sciences, Troy University

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Plastic pollution has become a critical environmental problem, with polyethylene terephthalate (PET) plastic widely used in food and beverage packaging being a major contributor. Dr Mojtaba Enayati from Troy University's Center for Materials and Manufacturing Sciences (CMMS) is leading innovative research aimed at utilising the labels from PET water bottles as an environmentally friendly and cost-effective catalyst for chemically recycling PET waste into valuable monomers and other value-added materials. This innovative work provides an elegant solution for recycling PET by sourcing key components from the PET bottles themselves.

The Pervasive Problem of Plastic Pollution

Plastic waste, especially from single-use packaging, has rapidly accumulated in the environment, threatening ecosystems and human health. Polyethylene terephthalate, or PET, is one of the most widely used plastics, particularly for food and beverage packaging. In fact, PET accounts for 44.7% of single-use beverage containers in the US and 12% of global solid waste.

PET's popularity stems from its excellent properties – it's lightweight, strong, transparent and inexpensive. However, PET is not biodegradable, so it persists in the environment for hundreds of years before it degrades. Persistent microplastics from PET breakdown increasingly contaminate soil, water and the food chain. There is an urgent need to develop efficient, sustainable methods to recycle the ever-growing amounts of PET waste.

Current Recycling Methods Fall Short

The two main approaches for recycling PET are mechanical and chemical recycling. Mechanical recycling, which involves melting and re-extruding the plastic, is widely used as it's economical. However, the high temperatures needed degrade the PET, resulting in recycled plastic with reduced mechanical properties unsuitable for the same applications, so it's basically a 'downcycling'.

Chemical recycling, on the other hand, breaks down PET into its chemical building blocks which can then make new, virgin-grade PET. This maintains the material's properties, but current methods are energy-intensive, requiring expensive catalysts and solvents. Dr Enayati recognised the need for more efficient, sustainable chemical recycling processes.

Catalytic Inspiration from PET Labels

Dr Mojtaba Enayati from Troy University had a creative idea – what if the ingredients in labels on PET bottles themselves could catalyse PET chemical recycling? Calcium carbonate ($CaCO_3$) and titanium dioxide (TiO_2) are common fillers used in making plastic packaging, including water bottle labels. Previous studies showed these compounds could catalyse glycolysis to break down PET into its monomers. According to Dr Enayati, considering the catalytic activity of calcium carbonate, calcium oxide (CaO), and titanium dioxide, and the fact that calcium carbonate and titanium dioxide are used in label manufacturing inspired them to examine PET bottle labels as the source of catalysts for PET depolymerisation via glycolysis.

Preparing an Eco-Friendly Catalyst from Waste

To test their hypothesis, the researchers first recovered the solid fillers from the labels. They cut the labels into small strips and heated them in a furnace at high temperatures to decompose the plastic and other organic components.

The team used furnace temperatures of 600, 800, and 1000°C for catalyst preparation, resulting in solid catalyst recoveries of 13.5, 12.0, and 10.4 wt%, respectively. Dr Enayati designated these catalysts as Cat-600, Cat-800, and Cat-1000 based on preparation temperature. Characterisation by Fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM-EDX) confirmed the white powders obtained were rich in $CaCO_3$, CaO and TiO_2 – typical fillers and pigments used in plastics. No expensive or toxic metals were present.

Unlocking Sustainable PET Recycling with Glycolysis

With catalysts in hand, Dr Enayati's team tested their performance in PET glycolysis. In this process, PET is heated with excess ethylene glycol, causing the polymer chains to be cleaved by the ethylene glycol molecules. This 'unzips' the PET into its monomers, mainly bis(2-hydroxyethyl) terephthalate (BHET).

The researchers shredded PET bottles into small flakes and combined them with ethylene glycol and each catalyst in a high-pressure reactor. After heating to 200°C for up to 1.5 h, various analytical techniques determined how much PET was broken down and pure BHET monomer obtained.

Promising Results Validate Waste-to-Catalyst Approach

The results were extremely promising, especially for Cat-800, the catalyst prepared at 800°C. Using just 1.0 wt% of Cat-800, an impressive 95.8% yield of pure BHET monomer was achieved after 1.5 h – on par with the best literature catalysts. Almost all the PET was converted, leaving no solid waste.

In comparison, Cat-600 and Cat-1000 were less effective, providing 70.3% and 81.9% BHET yields, respectively, at higher loadings. Control experiments with pure commercial $CaCO_3$ and TiO_2 at 1.0 wt% gave even poorer results, showing the synergistic effect of the mixed-oxide catalyst derived from PET labels.

Cat-800's superior performance is attributed to its high surface area and optimal composition of $CaCO_3$, CaO and TiO_2, as some $CaCO_3$ converts to CaO at 800°C. The high surface area means more active sites are available on the catalyst to facilitate glycolysis.

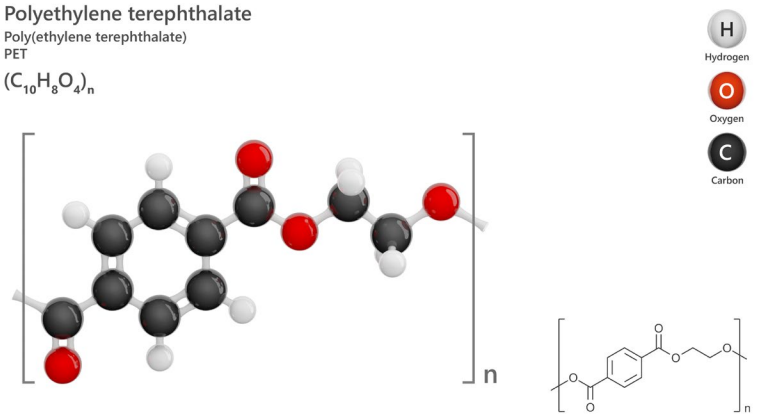
Notably, the catalyst is safe enough to be left in the reaction mixture without separation or purification. Unreacted ethylene glycol and BHET monomers can be easily recovered by cooling the mixture, filtering off the solid BHET, and recrystallising to obtain pure monomer feedstock for synthesising new PET.

Harnessing the Circular Economy Potential

This pioneering work by Dr Enayati and colleagues elegantly exemplifies a circular economy approach to plastic recycling. Their process demonstrates the potential to use waste – the labels from PET bottles – for chemically recycling the PET bottles themselves, as Dr Enayati points out. The catalyst is not only sourced from the same waste stream, but also makes the glycolysis reaction more energy-efficient, enabling high monomer yields under milder conditions than other processes, without exotic metals or toxic solvents.

While the catalyst cannot be reused as its active sites become blocked by products, Dr Enayati does not see this as a drawback. As he explains, calcium carbonate and titanium dioxide are non-toxic, environmentally benign, and widely used as plastic additives. The catalyst loading is so low it can be left in the reaction mixture without separation, simplifying the process. In fact, it may even nucleate and reinforce new PET synthesised from the recovered BHET monomer.

> Establishing effective collection and sorting infrastructure for PET labels will be key to realising the full potential of this technology.



Next Steps on the Path to Impact

Further optimisation and scale-up are the next steps toward potential commercialisation. Dr Enayati is also exploring using other waste materials, like agricultural waste biomass, as additional catalytic components. Gaining molecular-level mechanistic understanding could guide the design of even more effective catalysts.

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Dr Enayati envisions this as part of an integrated biorefinery model for plastic waste. Catalytic glycolysis can work in tandem with other recycling streams, like the mechanical recycling of PET bottles and pyrolysis of caps to make fuels. BHET monomer can make new PET or other value-added products. Ultimately, Dr Enayati and his team aim to create a closed-loop system preventing environmental distribution of the plastics and recycling as much material as possible using waste-derived catalysts.

While there is still a long way to go in solving plastic pollution, Dr Enayati's research represents an important step forward. By finding treasure in our trash, he is lighting the way to a more sustainable future. No doubt, further creative approaches combining remediation with a circular economy mindset will be needed to tackle this global environmental challenge. Fundamental scientific research, as exemplified by Dr Enayati's work, will continue to play a vital role in this mission.

MEET THE RESEARCHER

Dr Mojtaba Enayati
Center for Materials and Manufacturing Sciences (CMMS), Department of Chemistry and Physics, Troy University, Troy, AL, USA

Dr Mojtaba Enayati was born in Birjand, Iran in 1979. He received his Ph.D. from the University of Tehran in 2011 in Polymer Chemistry, where he studied the microstructure of polyolefins. From 2011 to 2015, he served as an assistant professor at the University of Qom, Iran. Dr Enayati then undertook postdoctoral research at the University of Pennsylvania (2015–2017) and Cornell University (2017–2020). In January 2021, he joined Troy University's Center for Materials and Manufacturing Sciences (CMMS) as an assistant professor. His current research focuses on the chemical recycling of polyethylene terephthalate (PET) into monomers, the development of new catalysts for the chemical recycling of polymers, and simultaneous depolymerisation and polymerisation of post-consumer PET.

CONTACT

menayati@troy.edu

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KEY COLLABORATORS

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FURTHER READING

M Enayati, S Mohammadi, M Bouldo, Sustainable PET Waste Recycling: Labels from PET Water Bottles Used as a Catalyst for the Chemical Recycling of the Same Bottles, *ACS Sustainable Chemistry & Engineering*, 2023, 11, 16618-16626. DOI: https://doi.org/10.1021/acssuschemeng.3c02966

S Mohammadi, M Bouldo, M Enayati, Controlled Glycolysis of Poly(ethylene terephthalate) to Oligomers under Microwave Irradiation Using Antimony(III) Oxide, *ACS Applied Polymer Materials*, 2023, 5, 6574-6584. DOI: https://doi.org/10.1021/acsapm.3c01071

M Enayati, M Karmi Abdolmaleki, A Abbaspourrad, Synthesis of Cross-Linked Spherical Polycationic Adsorbents for Enhanced Heparin Recovery, *ACS Biomaterials Science and Engineering*, 2020, 6, 2822–2831. DOI: https://doi.org/10.1021/acsbiomaterials.0c00168

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