

Trash to Treasure: An Innovative, Sustainable Transformation of Plastic Waste into CO₂-Capturing Materials

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Plastic Waste Valorization for the CO₂-Capturing Technology

Polyethylene terephthalate (PET) is among the most extensively manufactured polymers worldwide, with an annual production of ~70 million metric tons and accounting for nearly 18% of global plastic output.^{1–4} Nevertheless, PET recovery is limited by inadequate collection infrastructure, the complexity of post-consumer sorting, and the unfavorable cost comparison between recycled and virgin PET. Consequently, most discarded PET (approximately 85–90%) is either landfilled or incinerated, thereby increasing its environmental footprint.^{5–7} Thus, only about 10–15% of PET waste is recycled mainly through mechanical methods, highlighting the need for more efficient and economically viable recycling technologies to manage the increasing quantities of plastic waste.

Chemical upcycling offers an attractive alternative by converting PET waste into high-value functional materials while addressing both plastic pollution and carbon-management challenges. The transformation of PET into carbon dioxide (CO₂) sorbents, in particular, could help meet projected CO₂ removal requirements, which may reach 1.5–2.6 billion metric tons annually by 2050 to achieve carbon neutrality. Meeting this scale of deployment will require sorbents that can be manufactured at million-ton production rates using inexpensive, readily available feedstocks. Earlier studies have investigated PET conversion through energy-intensive pyrolysis to produce activated carbon, as well as the preparation of organic ligands from PET-derived intermediates for subsequent metal–organic framework (MOF) synthesis.

Building on our prior demonstration of nanosheet morphology of α -Al₂O₃ catalyzing aminolysis depolymerization of polyesters, we propose aminolysis as a scalable, operationally simple, and cost-effective route to the production of CO₂ sorbents from PET waste.¹ Here, we developed sustainable catalytic strategies for the atom-economic aminolysis of post-consumer PET waste, providing a cost-effective solution for plastic waste recycling. α -Al₂O₃ stands out as a practical choice because of its low cost and wide availability, along with its tunable, mild acid-base properties. The optimized α -Al₂O₃ catalyst exhibited excellent activity in PET aminolysis with ethylenediamine (EDA), affording 92% isolated yield of bis(2-aminoethyl) terephthalamide (BAET) as solid-state CO₂-capture materials.

Sustainable Catalysis Research at SP HeteroCat Lab, IIT Hyderabad

Dr. Sudarsanam's research group (SP HeteroCat Lab) at IIT Hyderabad is dedicated to developing practical catalytic technologies to valorize plastic waste into value-added monomers, fuels, and chemicals. One of the central focuses of the SP HeteroCat Lab is the production of monomers from PET plastic waste for CO₂-capturing technology (Fig. 1). To achieve efficient PET depolymerization, a heterogeneous catalyst with an optimal density of acid sites is essential.

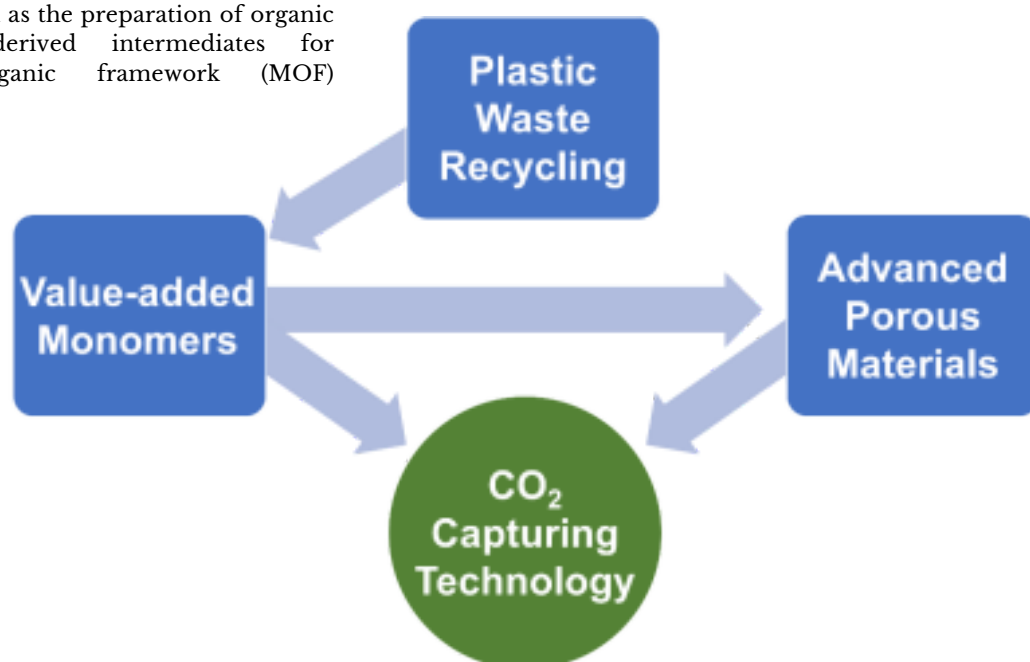


Figure 1. Overview of Dr. Sudarsanam's group research on the PET plastic waste recycling into value-added monomers and their conversion into advanced porous materials for efficient CO₂-capturing technologies.

In this direction, Mr. Arun Kumar Mudavath, a PhD student in Dr. Sudarsanam's group, has developed a novel catalytic strategy for PET aminolysis using EDA as the amine source to produce BAET over a cost-effective 2D α -Al₂O₃ nanosheet catalyst. The catalyst possesses a porous, accessible surface that exposes a high concentration of catalytically active sites with tailored acidity. This combination of nanoscale architecture and controlled acid-site distribution promotes the depolymerization of PET under mild, near-ambient conditions. The synthesized BAET monomer has enormous potential for CO₂ capture, offering an economical and sustainable way to reduce atmospheric CO₂ levels.

Challenges and Prospects

Although our group has established an economically attractive and environmentally benign catalytic process for converting PET into value-added monomers via aminolysis, its practical industrial implementation will require further advances in process scale-up, catalyst recovery, and product separation. In this direction, Dr. Sudarsanam Putla and Mr. Arun Kumar Mudavath are investigating reaction enlargement and catalyst reusability using a range of post-consumer plastic feedstocks.

Concurrently, we are exploring the conversion of plastic-derived monomers into covalent organic frameworks (COFs) and metal-organic frameworks (MOFs) for CO₂ capture, with particular emphasis on preserving their adsorption performance under mild operating conditions. Together, these efforts aim to develop an integrated, sustainable platform for producing useful monomers and porous functional materials from plastic waste, while supporting greenhouse gas mitigation and broader environmental applications.

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