# Chemical recycling of PET waste with pressurized solvents

## Brief description

Polyethylene terephthalate (PET) is a copolymer formed of terephthalic acid and ethylene glycol. It is one of the most commonly used polyesters in the manufacture of plastic beverage bottles, packaging, and textiles. The life cycle of PET products is generally short, leading to rapid waste generation which, if not properly disposed of, can accumulate in the environment and cause serious environmental problems such as the accumulation of macro- and microplastics in marine ecosystems.

The technologies developed for the chemical recycling process use a protic solvent (water, methanol, ethylene glycol, ammonia, or amine), but this solvolysis usually requires high temperatures to achieve optimal performance. Alternatives have been tested to overcome this drawback, such as using catalysts or high concentrations of strong acids or bases.

The proposal is to carry out PET solvolysis under inert gas pressure, without using catalysts or strong acids or bases.

***Figure 1.*** *Post-consumer PET wastes.*

## How does it work?

In the proposed process, PET comes from post-consumer transparent plastic bottles. Once washed and dried, they are cut into fragments and placed together with a protic solvent in a pressure reactor equipped with a stirring system. An inert gas is also added and the mixture is heated. Once the reaction is complete, the reactor is cooled down to room temperature and a crystalline solid is recovered.

The reaction was carried out using a methanol/PET ratio ranging from 24:1 to 3.6:1, $N_2$ is added up to a pressure of 50-60 bar, and the mixture was heated to moderate temperatures (140-160 °C). The conversion of PET was 100% and the product was high-purity dimethyl terephthalate (DMT) crystals with a yield close to 90%. Using water as solvent a 100% conversion was also achieved and the yield to terephthalic acid was close to 60% in terephthalic acid. By comparison, when the process is carried out under CO2 pressure, the yield under the same conditions was lower.

This procedure has also been applied to colored bottles with equally satisfactory results. The DMT crystals obtained maintain the same appearance as when starting with transparent plastic. Only the supernatant solution was slightly colored.

***Figure 2.*** *Green PET flakes from a colored plastic bottle and white DMT after depolymerization*


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## What problem does it solve?

Physical recycling methods—such as shredding, melting, and extrusion—require feedstock with high purity and specific properties. As a result, a significant portion of plastic waste is unsuitable for this approach. Moreover, the quality of recycled materials tends to degrade with each cycle.

In contrast, chemical recycling enables the recovery of monomers for repolymerization, thereby allowing for potentially infinite recycling while maintaining material quality equivalent to that of virgin polymers.

The developed technology enhances the efficiency of the depolymerization reaction by lowering the required operating temperature, improving both the economic viability and overall competitiveness of the process. Additionally, it reduces the input purity requirements and allows for a significant simplification of the purification stage.

## What future products will it develop?

High-purity dimethyl terephthalate (DMT) can be obtained from hard-to-recycle PET waste. The use of lower reaction temperatures compared to conventional methanolysis methods reduces the formation of by-products, resulting in higher DMT purity at a significantly lower cost. Additionally, ethylene glycol can be recovered from the supernatant solution.

Once fully developed, the technology is also expected to enable the production of terephthalic acid through PET hydrolysis, with potentially high yield and purity. Moreover, the approach may be extended to other condensation polymers, such as polyurethanes, to recover the monomers, likely in the form of dicarbamates.

## **Competitive advantages** compared to other research

The developed recycling method offers a clear advantage over existing technologies: it requires no acids, bases, or catalysts, making the process simpler and more cost-effective by eliminating the need for catalyst recovery or regeneration. Operating temperatures are relatively low (140–180 °C), and the monomer yield is significantly higher than that achieved with conventional methods.

The use of inert gases provides additional benefits compared to $CO_2$. For instance, nitrogen is less expensive, more environmentally friendly—since it does not contribute to the greenhouse effect—and allows for higher operating pressures. Under certain conditions, $CO_2$ and methanol become fully miscible, which can limit the range of process conditions.

Furthermore, the new process was developed using actual PET waste (not commercial PET), ensuring that the starting material reflects real-world industrial conditions. The process is the subject of a patent application submitted through our university's technology transfer office (OTC), and it is currently under evaluation.

## Where has it been developed?

The technique has been developed by the research group Separation Processes and Material Preparation in Sustainable Chemistry Using Supercritical Fluids, based at the Faculty of Chemistry at Complutense University. The group focuses on the use of supercritical fluids as a cleaner alternative to conventional solvents in material synthesis and is composed of a highly multidisciplinary team.

The group has extensive experience in conducting research projects funded by national and European public agencies, as well as by private foundations and companies.


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Additionally, it is an active member of the Green Chemistry Group of the Royal Spanish Society of Chemistry (RSEQ), the Spanish Association of Chemists and Chemical Engineers (ANQUE), the Spanish Association for Compressed Fluids (FLUCOMP), and the International Society for the Advancement of Supercritical Fluids (ISASF).

## And furthermore...

The process can be applied to specific materials involving mixtures or compounds of PET and other polymers, such as multilayer packaging or PET-based textiles. This opens the possibility of selective depolymerization-based separation; for example, if a PET bottle neck with the tamper-evident ring made of PE is treated, only the PET undergoes depolymerization, leaving the ring as a PE pellet.

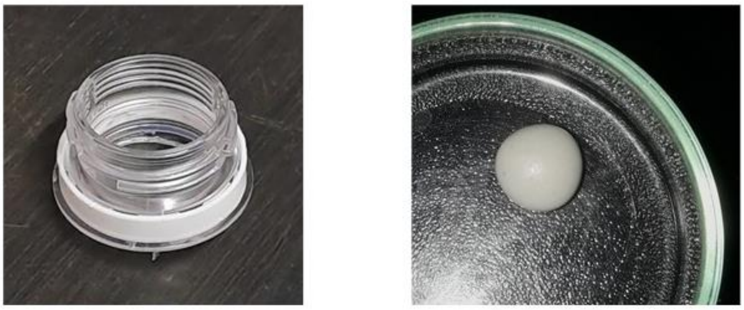

***Figure 3.*** *PET bottle neck with tamper-evident ring made of PE and ring converted into a PE pellet.*

The group is open to collaborations with companies and/or other research groups to apply this technique in scenarios where conventional methods yield unsatisfactory results, aiming to produce high-value-added products. The group has access to reactors and high-pressure equipment to conduct solvolysis experiments at the laboratory scale, as well as instrumentation for material characterization.

## Researcher in charge

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