

The State of the Art in Recycling Waste Thermoplastics

Introduction

Thermoplastics, a class of polymers that can be repeatedly softened and reshaped through heating, dominate global plastic production due to their versatility and durability. However, their widespread use has led to significant environmental challenges, with only a fraction of waste being effectively recycled. The "state of the art" in thermoplastic recycling now emphasizes advanced chemical and depolymerization methods, alongside mechanical recycling, to address the escalating plastics crisis. This report synthesizes recent advancements, challenges, and applications highlighted in technical studies, market analyses, and industry case studies.

Advanced Recycling Technologies: Chemical and Depolymerization Methods

The **Global Advanced Plastics Recycling Market 2025-2040** report (Future Markets Inc., 2024) identifies depolymerization, pyrolysis, and enzymolysis as leading technologies for advanced recycling. These methods break down polymers into monomers or hydrocarbons, enabling the creation of virgin-like materials.

Depolymerization

Depolymerization is highlighted as a commercially viable process for specific thermoplastics like PET and polycarbonate. For instance, **Eastman's Carbon Renewal Technology** (U.S. Plastics Pact, 2024) uses depolymerization to convert waste plastics into raw materials, with a facility processing over **110,000 metric tons annually**. The report's Table 50 (Future Markets Inc., 2024) lists companies like **Nexus Circular** and **Novolooop** as pioneers in depolymerization, with commercial-scale operations underway.

Pyrolysis and Gasification

Pyrolysis, which thermally decomposes plastics into oil, gas, and char, is widely studied but faces criticism for low yields and high greenhouse gas (GHG) emissions. A study cited by **Richmond Containers** (2024) notes that pyrolysis for "plastic-to-plastic" recycling achieves only **30-40% material yield**, with a GHG footprint exceeding virgin plastic production. However, **plasma pyrolysis** and **hydrothermal cracking** (Table 54 and 51, Future Markets Inc., 2024) show promise in improving efficiency and reducing emissions.

Enzymolysis and Solvent-Based Methods

Enzymolysis uses biological catalysts to break down polymers, particularly PLA. The report's Table 46 (Future Markets Inc., 2024) lists **NatureWorks** as a developer of enzymatic recycling for PLA, though commercial adoption remains limited. Solvent-based purification, another chemical method, separates contaminants from polymers, enhancing recyclate quality.

Mechanical vs. Chemical Recycling: Trade-offs and Complementarity

While mechanical recycling remains dominant due to its lower energy intensity and maturity, chemical recycling is critical for handling mixed or contaminated plastics. **Paramount Global** (2024) emphasizes that a combined approach is necessary for a circular economy.

Advantages of Chemical Recycling

- **Wider feedstock flexibility:** Handles multilayer composites and post-consumer waste (Paramount Global, 2024).
- **Monomer recovery:** Enables infinite recycling loops for materials like PET (Eastman case study, 2024).

Limitations of Chemical Recycling

- **High energy consumption:** Processes like pyrolysis require significant thermal input (Richmond Containers, 2024).
- **Immature infrastructure:** Scaling depolymerization facilities faces capital and technical barriers (Future Markets Inc., 2024).

Mechanical recycling, despite its efficiency for clean, single-stream plastics, struggles with colored or multilayered materials. For example, reprocessing mixed PET colors reduces recycle quality (Nature Sustainability, 2024).

Applications in Construction and Material Science

The integration of recycled thermoplastics into construction materials represents a cutting-edge application. A **Springer study** (2025) explores using recycled HDPE in wattle-and-daub walls, demonstrating improved thermal and acoustic performance. The optimal soil composition for such applications includes **50% sand, 30% silt, and 20% clay** (Springer, 2025).

Another study (Academia.edu, 2023) evaluates thermoplastic composites in construction, noting that additives like hydrated lime prevent mold growth in plant-fiber mixes. However, mechanical properties like tensile strength remain inconsistent, requiring further research.

Challenges and Limitations

Despite advancements, several barriers hinder progress:

1. **Technical hurdles:** Pyrolysis yields and GHG emissions remain problematic (Richmond Containers, 2024).
 2. **Global waste trade:** Developing nations bear disproportionate pollution burdens due to waste imports (Nature Sustainability, 2024).
 3. **Policy gaps:** The **Global Plastics Treaty** aims to address EPR schemes and chemical additives but faces implementation challenges (Nature Sustainability, 2024).
-

Market Drivers and Policy Impacts

The **Future Markets Inc. report** (2024) projects significant growth in advanced recycling capacities, driven by corporate commitments and regulatory pressures. For instance, **\$50 billion in investments** by 2030 could scale up chemical recycling (NES Fircroft, 2024). The U.S. Plastics Pact's collaboration with over 25 brands underscores industry alignment with sustainability goals.

Future Outlook

The next decade will focus on:

- **Technological optimization:** Improving pyrolysis yields and depolymerization scalability.
 - **Policy enforcement:** Implementing the Global Plastics Treaty to curb virgin plastic use.
 - **Cross-sector innovation:** Expanding construction applications and biobased feedstocks.
-

Conclusion

The state of the art in thermoplastic recycling combines mature mechanical methods with emerging chemical technologies. While depolymerization and plasma-based processes show promise, challenges like energy use and global equity must be addressed. A holistic approach—integrating recycling with design-for-recyclability and policy reforms—is essential to achieve a circular economy by 2040.

Sources

- **The Global Advanced Plastics Recycling Market 2025-2040**, [Future Markets Inc. \(2024\)](#).
- **Eastman: Molecular Recycling Technology**, [U.S. Plastics Pact \(2024\)](#).

- **Mechanical vs Chemical Post Consumer Recycled Resin**, [Paramount Global \(2024\)](#).
- **Mechanical Vs Chemical Recycling**, [Richmond Containers \(2024\)](#).
- **Application of recycled high-density polyethylene for construction**, [Springer \(2025\)](#).
- **Plastic recycling: A panacea or environmental pollution problem**, [Nature Sustainability \(2024\)](#).
- **State of the art in recycling waste thermoplastics**, [Academia.edu \(2023\)](#).
- **An Insight into Mechanical Recycling vs Chemical Recycling**, [NES Fircroft \(2024\)](#).