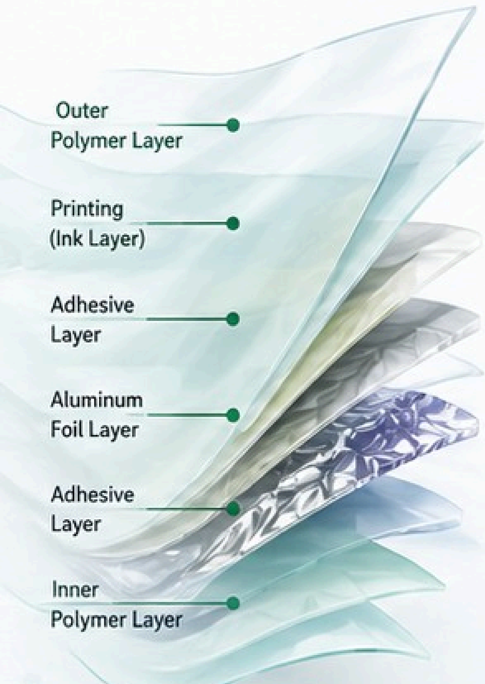


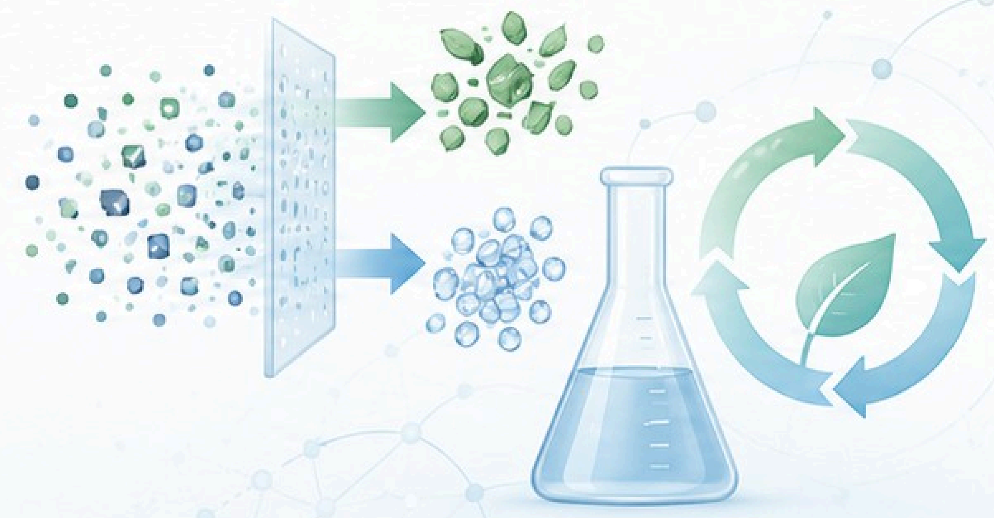
Solvent-Based Separation of Composite Multilayer Packaging Waste for High-Purity Resource Recovery

T. Mumladze[1], Kh. Kharazishvili[1], G. Denafas[2], I. Bochoidze[1], Ts. Turkadze[1], M. Gabidzashvili[1], N. Guleishvili[1]

[1] Department of Chemical and Environmental Technologies, Akaki Tsereteli State University, Kutaisi, Imereti, 4600, Georgia

[2] Department of Environmental Technology, Kaunas University of Technology, Kaunas, LT-50254, Lithuania

Presenting author: tamari.mumladze@atsu.edu.ge

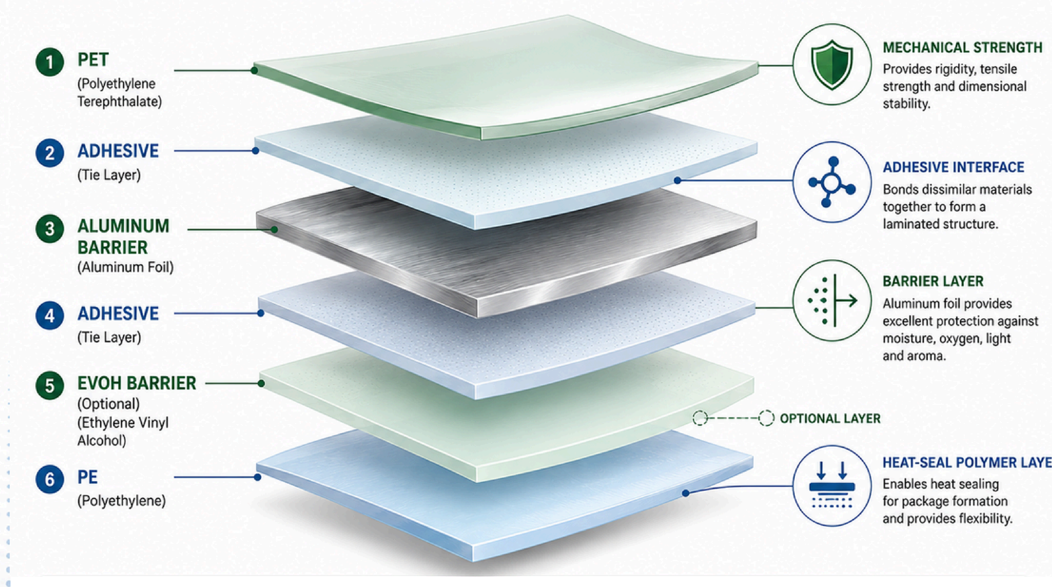


Background / Problem Statement

Composite multilayer packaging is widely used in food, beverage, and pharmaceutical applications because it provides excellent barrier properties, mechanical stability, and shelf-life extension. However, the same multilayer design creates serious end-of-life challenges.

Key problem points:

- Multilayer packaging commonly combines PE, PET, PA, EVOH, aluminum, adhesives, inks, or paperboard.
- Conventional mechanical recycling is limited by polymer incompatibility and complex layer structures.
- Adhesives, barrier layers, and inks reduce recyclate quality and increase downcycling.
- Large quantities of composite packaging are still directed to landfilling, incineration, or low-value recovery.
- Advanced separation technologies are needed to recover high-purity materials and support closed-loop recycling.



Aim

To evaluate solvent-based separation as an advanced recycling pathway for recovering high-purity polymers and valuable materials from composite multilayer packaging waste.

Specific Objectives

1. Compare key solvent-based separation approaches used for multilayer packaging waste.
2. Summarize reported recovery performance for STRAP, switchable solvents, and deep eutectic solvents.
3. Assess the relevance of solvent-based separation for resource recovery, circular economy, and sustainable packaging systems.
4. Identify technical, environmental, economic, and regulatory barriers to wider implementation.

Materials and Methods

Because the uploaded document is a literature-based synthesis, the methods are presented as a review and comparative assessment workflow.

Methodological Workflow

1. **Waste Stream Identification**
   Composite multilayer packaging from food, beverage, and pharmaceutical applications.
2. **Material Composition Review**
   Typical layers: PE, PET, PA, EVOH, aluminum, paperboard, adhesives, inks.
3. **Technology Screening**
   Comparison of solvent-based separation routes:
   - STRAP process
   - Switchable hydrophilicity solvents
   - Deep eutectic solvents
   - Green solvent screening approaches
4. **Separation Principle**
   Selective dissolution of polymer layers based on differences in solubility, followed by controlled precipitation and material recovery.
5. **Evaluation Criteria**
   - Recovery efficiency
   - Recovered material purity
   - Polymer quality retention
   - Solvent recovery potential
   - Environmental impact
   - Economic feasibility
   - Scale-up barriers

Results and Key Findings

Finding 1 — Solvent-based separation enables high recovery

Reported recovery efficiencies for solvent-based processes typically exceed 95%, outperforming conventional mechanical recycling of multilayer materials.

>95% recovery potential for selected solvent-based separation systems

Finding 2 — STRAP shows strong closed-loop potential

The STRAP process enables selective recovery of polymers such as PE, EVOH, and PET, with reported recovery efficiencies of >95–99%.

Multilayer film → selective dissolution → precipitation → recovered PE / EVOH / PET

Finding 3 — Green solvent systems improve sustainability

Switchable hydrophilicity solvents and deep eutectic solvents are promising alternatives because they may reduce solvent loss, enable solvent recovery, and support safer recycling system design.

Green solvent design = lower chemical loss + improved circularity potential

Finding 4 — Recovered polymers can retain useful properties

The uploaded document reports that recovered polymers can retain molecular weight, thermal stability, and mechanical properties comparable to virgin resins, supporting possible reuse in higher-value applications.

[Insert polymer quality comparison chart: recovered polymer vs virgin polymer]

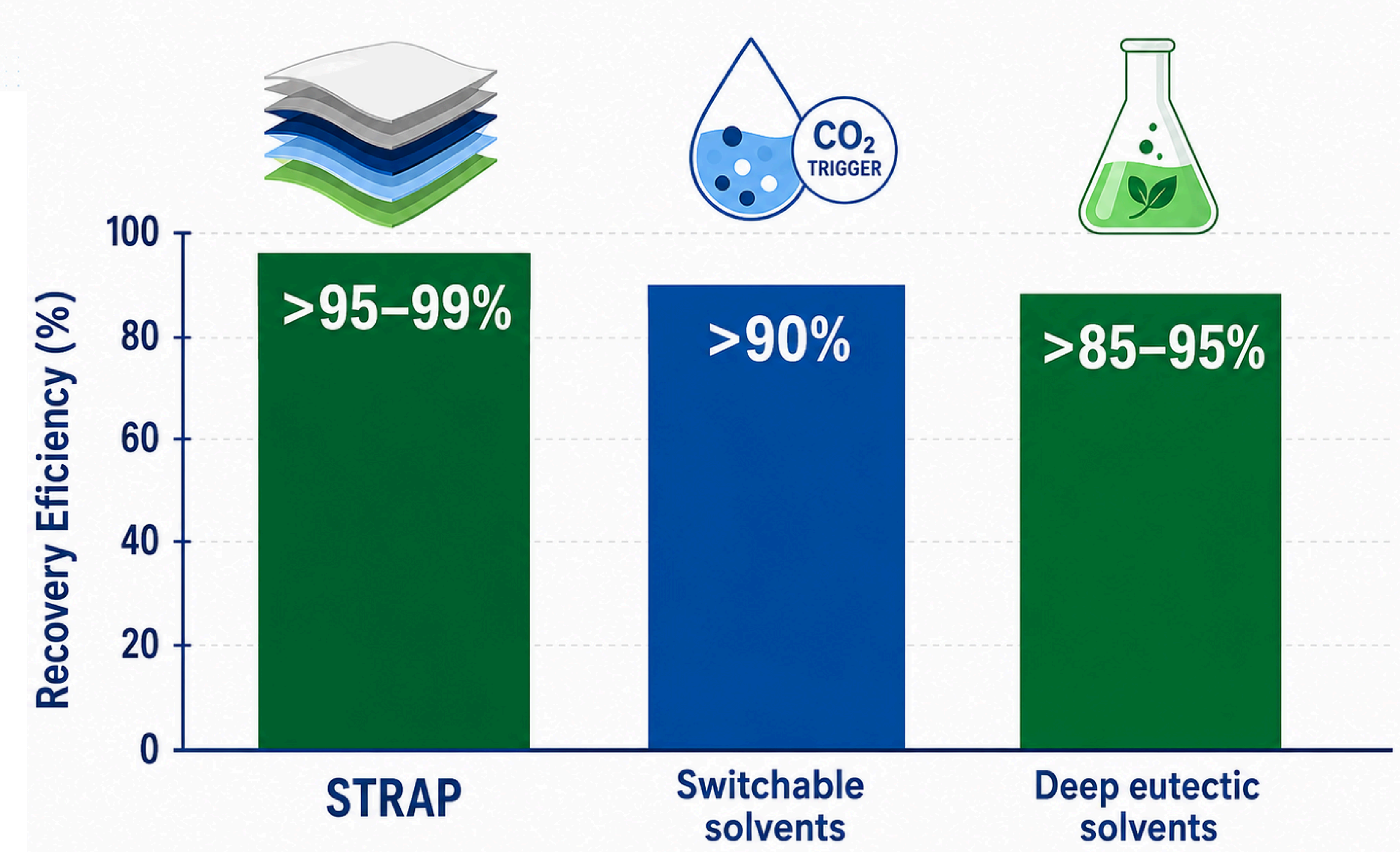
Finding 5 — Environmental benefits depend on process optimization

Life cycle assessment studies indicate potential reductions in greenhouse gas emissions, fossil resource depletion, and overall environmental impacts compared with landfilling and incineration. However, energy demand for heating and solvent recovery remains a key hotspot.

Critical optimization needs:
Heat integration | High solvent recovery | Low-carbon energy | Feedstock quality control

Recovery Efficiency Comparison

Reported efficiencies of solvent-based separation technologies for multilayer packaging waste



Efficiencies reflect reported values from literature; ranges indicate variability across studies and conditions.

DISCUSSION / SCIENTIFIC INTERPRETATION

Solvent-based separation addresses the central limitation of multilayer packaging recycling: the inability of mechanical recycling to separate incompatible polymers and barrier materials without quality loss. By selectively dissolving and precipitating individual polymer layers, these technologies can recover cleaner fractions suitable for higher-value applications.

The strongest advantage of this approach is its potential to preserve polymer quality while recovering multiple materials from complex packaging structures. This makes solvent-based separation particularly relevant for barrier packaging containing EVOH, PET, PE, and aluminum, where conventional recycling often leads to downcycling.

However, industrial implementation depends on solving several practical barriers. These include feedstock heterogeneity, contamination, solvent recovery at scale, energy consumption, solvent handling regulations, and food-contact approval for recycled materials.

Conclusions

1. Composite multilayer packaging requires advanced recycling because conventional mechanical recycling is limited by complex layer structures.
2. Solvent-based separation can recover high-purity polymers and valuable materials from multilayer packaging waste.
3. STRAP, switchable solvents, and deep eutectic solvents show strong recovery potential, with reported efficiencies ranging from >85% to >99% depending on the system.
4. Environmental performance depends strongly on solvent recovery, energy demand, feedstock quality, and process integration.
5. Further research should focus on green solvent selection, scale-up, heat integration, regulatory compliance, and industrial application.

Acknowledgements / Funding

This work was supported by the Shota Rustaveli National Science Foundation of Georgia — SRNSFG under grant number:

FR-24-2116 —
'Recycling of Combined Aluminum-Polymer Packaging Waste APPW Using Circular Economy and Green Chemistry Approaches.'

REFERENCES

1. Walker, T. W. et al. 2020. Recycling of multilayer plastic packaging materials by solvent-targeted recovery and precipitation. *Science Advances*, 6, eaba7599.
2. Sánchez-Rivera, K. L. et al. 2021. Reducing antisolvent use in the STRAP process. *ChemSusChem*, 14, 4317–4329.
3. Mumladze, T. et al. 2018. Sustainable approach to recycling multilayer flexible packaging using switchable hydrophilicity solvents. *Green Chemistry*, 20, 3604–3618.
4. Kaiser, K. et al. 2017. Recycling of polymer-based multilayer packaging: A review. *Recycling*, 3, 1.
5. Li, H. et al. 2024. Progress in solvent-based recycling of polymers from multilayer packaging. *Polymers*, 16, 1670.
6. Loukodimou, E. E. et al. 2024. Delamination of PE/Al/PET packaging waste using hydrophobic deep eutectic solvent. *Polymers*, 16, 2718.
7. Munguía-López, A. C. et al. 2023. Environmental benefits of solvent-based separation for multilayer plastic films. *Green Chemistry*, 25, 1611–1625.
8. Jasiński, D. et al. 2025. Sustainability assessment of chemical recycling technologies for multilayer packaging waste. *Sustainability*, 17, 556.