ADVANCING SOLVENT-BASED RECYCLING OF COMPLEX POST-CONSUMER PLASTICS

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Abstract

Several advanced recycling technologies are being developed to address the limitations that mechanical recycling has with complex waste streams. Amongst those is Solvent Targeted Recovery and Precipitation (STRAP), a solvent-based recycling technique aiming to recycle complex plastic mixtures from mixed waste streams. STRAP can separate polymers from waste streams through selective dissolution. The target polymer is dissolved by a solvent capable of only dissolving the target polymer and not the other polymers present in the mixture. The dissolved solution is separated from the undissolved particles through filtration. The polymer is then precipitated out of solution through a temperature decrease. We have been successful in applying the process to various feedstocks including multi-layer plastic films, monolayer films with paper and adhesives, single use coffee cups, supersack containers, and municipal solid waste (MSW). These feedstocks have been characterized to determine polymer composition, polymer content, and impurities present. We have optimized the process conditions including solvent, temperature, dissolution time, and process sequence, if needed, to achieve the highest yield of purified polymer produced. In the case of monolayer polyethylene films, we have successfully removed paper labels, adhesives, and inks to produce a high-quality polyethylene (PE) comparable to virgin polyethylene. The STRAP PE cast film has total volatile organic content below 4 ppm and color similar to virgin PE. Techno-economic analysis and life-cycle assessment of the STRAP process with mono-layer PE films show economic viability on 56 kton/yr scale and lower global warming potential than virgin PE production. We have been able to produce a blend of polypropylene (PP) and PE from MSW with minimal ash and contaminants. This blend of PP and PE was blended with virgin PE to achieve comparable mechanical and rheological properties to purely virgin PE. Our current efforts are performed at lab scale, producing 1-5 kg per material. Next efforts will focus on the scaleup of this process, recycling these feedstocks at a 25 kg/hr pilot-scale unit.

1. Introduction and Motivation

U.S. Environmental Protection Agency (USEPA) estimates that more than 35.6 million tons of plastic wastes were generated, within which, only 8.7% was recycled, while about 75% was disposed of in landfills.[1] The majority of post-consumer plastics—particularly flexible films, composite structures, and mixed polymer streams—remain incompatible with mechanical recycling due to their heterogeneous compositions, multilayer architectures, and incorporation of additives, inks, and paper substrates.[2-5] Mechanical reprocessing of these materials typically results in downgraded products with diminished performance, accumulation of impurities, and limited application value. As a result, complex plastic packaging and multilayer films are frequently landfilled or incinerated, contributing to environmental burdens and resource loss.

Advanced mechanical recycling techniques, including solvent-based recycling, have been shown to be a promising avenue to recycle plastics and retain their value in the supply chain. Several solvent-based recycling technologies are in pilot stages and are being scaling up to commercial from CreaSolv, PureCycle, APK AG, Dow, and Flexloop. Each of these technologies targets different plastics and various feedstock streams while using unique solvents for solutions. CreaSolv has demonstrated their solvents to be effective on PE, polystyrene (PS), and polyvinyl chloride (PVC). [6] PureCycle has been successful at using supercritical butane to recycle various PP waste streams. [6] STRAP differs from these techniques in the feedstocks, solvent, and operating conditions that it uses. Several dissolutions in the STRAP process allow for recycling of multilayer packaging.

In this paper, we explore several complex feedstocks including shrink films, coffee cups, supersacks, and municipal solid waste to gain better understanding of the challenges with these materials and how to process them through solvent-based recycling.

2. Review of Related Work

Solvent-based recycling technologies have emerged as a promising complement to mechanical approaches, offering the ability to selectively dissolve and recover high-purity polymers while removing incompatible components. Among these, the Solvent-Targeted Recovery and Precipitation (STRAP) process represents a computationally guided dissolution–fractionation platform capable of separating polyolefins, polyesters, polyamides, and other engineered polymers from realistic waste matrices.[7-10] In contrast to mechanical recycling, STRAP avoids resin degradation, and compared with chemical recycling, it is far less energy- and capital-intensive.[11, 12] The schematic of the STRAP process is shown in Figure 1 (A). The dissolution and filtration vessel is shown in Figure 1 (B). Prior work has demonstrated STRAP's capacity to deconstruct multilayer flexible packaging containing polyethylene (PE), ethylene vinyl alcohol (EVOH), polyethylene terephthalate (PET), tie layers, and inks with recovery efficiencies exceeding 95%. Further studies have shown its applicability to printed post-industrial films, disposable face masks, and mixed plastic waste streams containing up to ten polymer types. These investigations collectively establish STRAP as a versatile method for producing purified resins with thermal, rheological, and mechanical properties comparable to virgin materials.

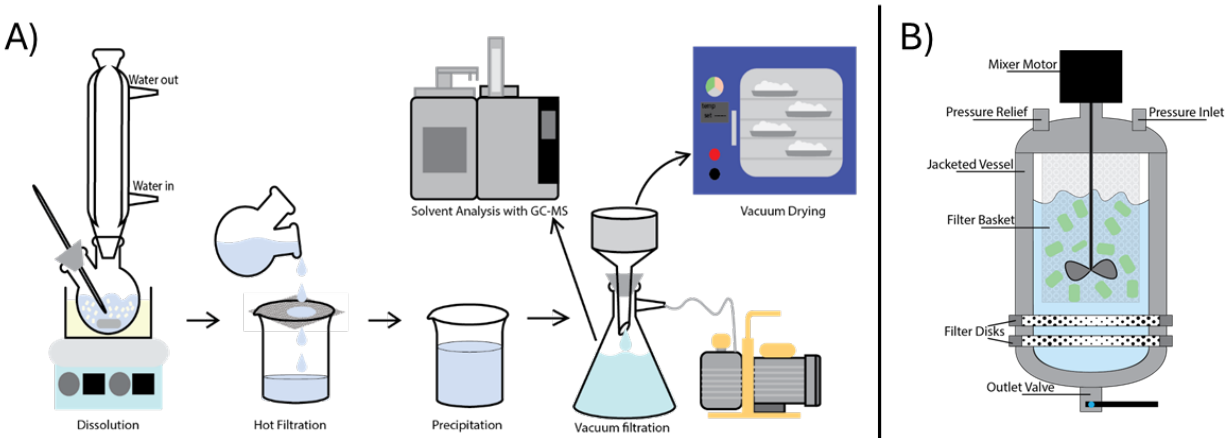

Figure 1. Schematic of the (A) STRAP process; (B) Dissolution and Filtration vessel. Adapted from Radkevich et.al. (2026), Waste Management; Copyright 2026 Elsevier [13].

However, the majority of STRAP demonstrations to date have focused on post-industrial feedstocks with relatively predictable compositions. Significant technical barriers remain for post-consumer waste (PCW) streams, which are often heavily contaminated, degraded, or structurally complex, and which contain unpredictable mixtures of polymers, fillers, and organic residues. Advancing solvent-based recycling into the PCW domain is essential to address the largest and most landfilled portion of the plastics waste landscape.

In alignment with this need, the present work extends STRAP to four challenging PCW feedstocks: (i) shrink-wrap films containing paper labels, adhesives, and inks; (ii) single-use coffee pods composed of layered or co-mingled PS and PP; (iii) woven supersack PP textiles with stitching fibers and particulate impurities; and (iv) municipal solid waste (MSW). Across these diverse materials, we demonstrate selective dissolution, hot filtration, and precipitation conditions that allow recovery of high-quality PE and PP resins with minimal impurities. The resulting polymers exhibit optical and mechanical characteristics suitable for reprocessing into cast films or blended products. These results corroborate the versatility and robustness of STRAP for upgrading PCW streams and reinforce its potential role in enabling circularity for otherwise non-recyclable plastic materials. Moreover, the techno-economic and life-cycle analyses presented in this work highlight the potential for STRAP-derived resins to achieve both cost competitiveness and reduced environmental burdens relative to virgin polymer production.

3. Technology Approach

We have identified several feedstocks that are different in nature to understand their behavior in solvent-based recycling. The main steps of our process are outlined in Figure 1. We note dissolution characteristics and challenges with each feedstock. The dissolved target polymer is separated from insoluble particles in the hot filtration step. The dissolved polymer is then precipitated through a temperature decrease. Once precipitated, the solids are separated from liquids in vacuum filtration (mechanical) and drying (thermal). The differences between feedstocks may have noticeably different behavior in the dissolution and precipitation steps depending on the polymer and solvent used. The polymer recovered is then further analyzed for its properties and composition through Fourier-transform infrared (FTIR) and differential scanning calorimetry (DSC). Solvent contents may be analyzed through gas chromatography with flame ionization detector (GC-FID) or mass spectrometry (GC-MS).

4. Discussion

4.1. Post-Consumer Shrink-Wrap Films

Post-consumer (PCW) shrink-wrap films represent a high-volume waste stream characterized by paper labels, adhesives, inks, and residual contaminants that significantly hinder mechanical recycling. Feedstock characterization revealed substantial paper fiber agglomerates embedded within the polyethylene (PE) matrix, consistent with prior reports of multilayer and paper-contaminated films. Applying the STRAP process enabled selective dissolution of PE using xylene (solvent) at 95°C (temperature). Non-polymeric contaminants—including paper, inks, and mineral fillers—remained insoluble and were removed through hot filtration.

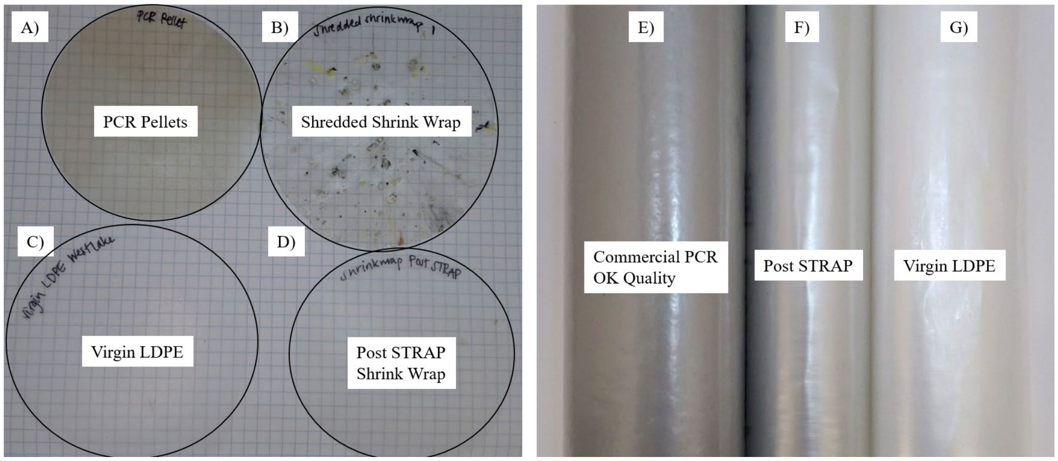

Figure 2. A) Pressed PCR PE pellets from Amcor, B) Shredded shrink wrap material (STRAP feed), C) virgin LDPE used at Amcor, D) Post-STRAP recovered PE, E)100% Commercial PCR Ok Quality Cast film roll, F) Post-STRAP Cast Film roll, G) Virgin LDPE Cast Film roll and single layer. Paper impurities present in the shrink wrap feed sample while the post STRAP PE has no visible paper content. The image is on a white background. Adapted from Radkevich et.al. (2026), Waste Management; Copyright 2026 Elsevier [13].

The recovered PE exhibited a marked reduction in visible impurities compared with the as-received PCW shrink film, as confirmed by optical imaging of both pelletized and compressed-film samples shown in Figure 2 (A-D). Cast films fabricated from STRAP recovered PE demonstrated optical clarity and color comparable to virgin LDPE used in commercial packaging applications, as shown in Figure 2 (E-G). These results are consistent with observations from prior STRAP studies showing that dissolution-based separation effectively removes paper fibers and adhesive residues that cannot be eliminated through mechanical reprocessing. The high quality of the recovered PE suggests suitability for incorporation into high-value film products, overcoming the historical downgraded end-use pathways associated with post-consumer films.

4.2. Single-use Coffee Cups

Single-use coffee pods (K-cups) present a complex waste stream composed primarily of polystyrene (PS), polypropylene (PP), ethylvinyl alcohol (EVOH), paper filters, aluminum foils, and residual organic matter. Mechanical processing of such components is infeasible due to the presence of multiple incompatible polymers. In this study, STRAP was applied as a sequential dissolution strategy to fractionate PS and PP from the K-cup assemblies.

A two-step temperature-programmed dissolution using xylene was employed, as shown in Figure 3. The first dissolution stage at approximately 35 °C selectively solubilized PS, enabling its separation from PP, paper, and metal components. After filtration and PS recovery, the remaining solids underwent a second dissolution stage at 130 °C, selectively dissolving PP. The insoluble residue—consisting of EVOH, paper filter materials and inorganic particulates—was easily removed. From feedstock analysis, EVOH is coupled with PP most likely in a multilayer composition.

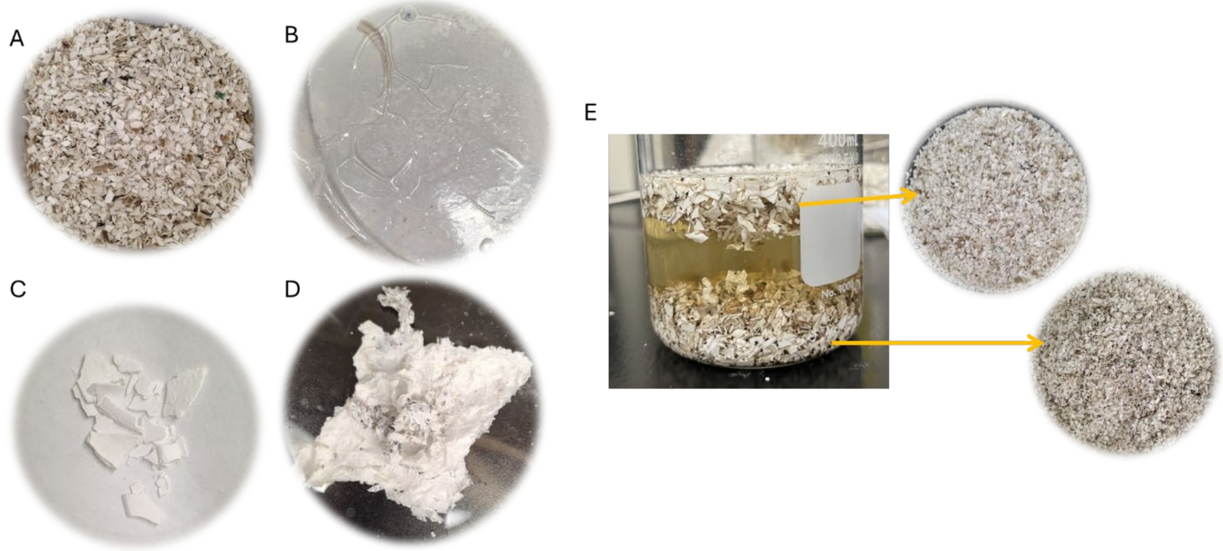

Figure 3. A) Coffee cup (Kcup) material as received, B) Polystyrene recovered from first dissolution of STRAP process using xylene at 35°C, C) Polypropylene recovered from second dissolution with xylene at 130 °C, D) residue remaining after the second dissolution, E) Separation of PP and PS using density, 25-34% in top float (PP) and 64-72% in bottom sink (PS)

Based on solvent recovery techniques and dissolution dynamics during scale-up from 20g to 100g+, pretreatment separation of organics (coffee grounds) for polymer color purity will be required. A water washing step is sufficient. PS separation from PP via mechanical separation will simplify PS recovery. A water density-based separation of the K-cups allows for cleaning of the feedstock and separation of PS and PP fraction, with the PS fraction forming a higher-density sink phase and PP (with EVOH) forming a low-density float phase. This demonstrates that pretreatment with STRAP can yield two high-purity polymer streams from a single PCW product with minor stream of EVOH. The recovered polymers showed morphology and purity consistent with prior STRAP extractions from multilayer films, highlighting the method's robustness for multi-polymer consumer packaging.

4.3. Supersack Woven

Woven polypropylene (PP) supersacks are widely used for bulk material transport but are difficult to recycle mechanically due to stitching ropes, mineral particulates, and additives used in weaving. Feedstock imaging revealed significant levels of contamination, including dense stitching materials and fines embedded within the textile structure, as shown in Figure 4 (A-B).

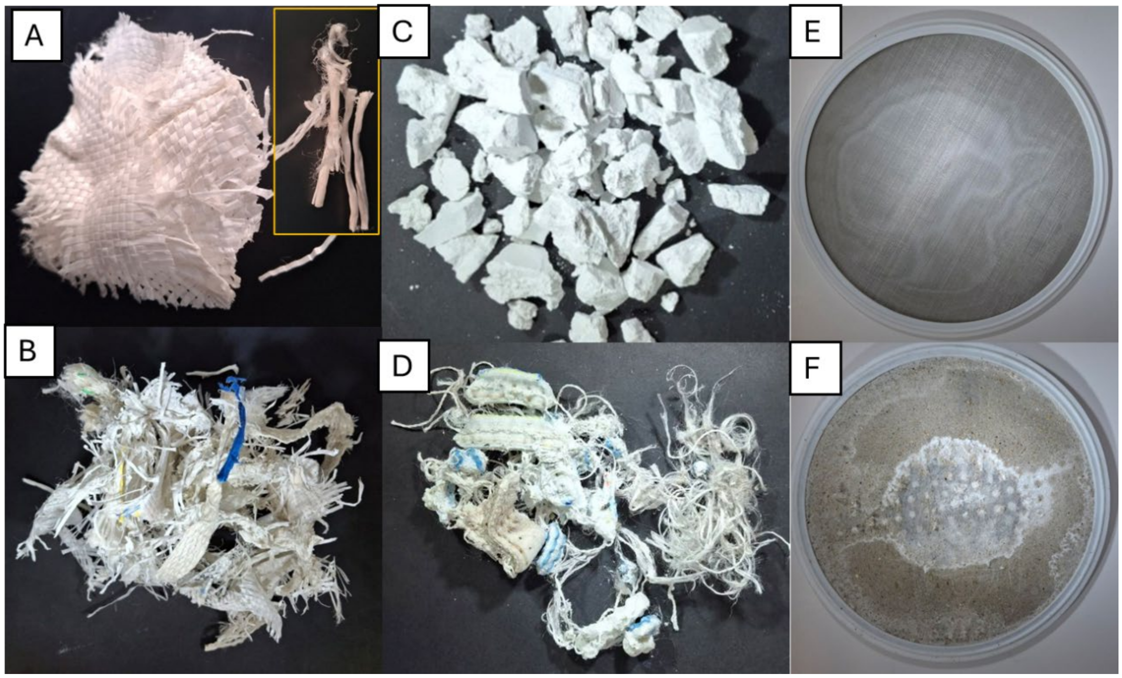

Figure 4. A) Appearance of supersack fabric (main body, shredded); B) Presence of impurities including ropes used for stitching; C) PP produced from supersack dissolution; D) Remains after dissolution; E) New 100 µm filer; F) 100 µm filer after use in dissolution.

STRAP processing was conducted using xylene at 110°C. The woven PP matrix dissolved efficiently and recovered, as shown in Figure 4C, while stitching fibers—typically polyester or nylon—remained insoluble and were removed by filtration, as shown in Figure 4D. Use of a 100 µm stainless-steel filter was essential to control the passage of fines and ensure resin purity. Figure 4 (E-F) show the filter images before and after the filtration.

Recovered PP exhibited uniform melt behavior, and impurity analyses indicated suitability for melt reprocessing. These results demonstrate that STRAP can serve as an effective pathway to reclaim high-quality PP from textile-grade industrial packaging that currently has no viable closed-loop recycling route.

4.4. Municipal Solid Waste (MSW)

Municipal solid waste (MSW) represents one of the most challenging feedstocks for high-quality resin recovery, due to degraded polymers, fillers, organic residues. The polymer fraction in MSW contains a vast untapped reservoir of polyolefins – 47-94% PE and PP – the two highest-volume commodity plastics essential for packaging, consumer goods, and industrial applications.[14-16] Due to the similar solubility characteristics, PE and PP are co-recovered using xylene in this study. The mechanical properties of the STRAP-recycled polyolefins (PE and PP) are limited by the immiscibility of PE/PP blends. To tailor the mechanical property, we blended at 10 wt% with virgin HDPE and evaluate mechanical performance.

As shown in Figure 5 (A-C), tensile testing revealed that blends of 10 wt% STRAP-polyolefins exhibited mechanical properties approaching those of virgin HDPE. Stress–strain curves showed minimal loss in modulus and yield strength. Optical microscopy confirmed substantial impurity reduction following STRAP processing; STRAP-polyolefin compressed films displayed fewer dark inclusions and particulate clusters than the raw MSW polymer fraction, as shown in Figure 5 (D-G).

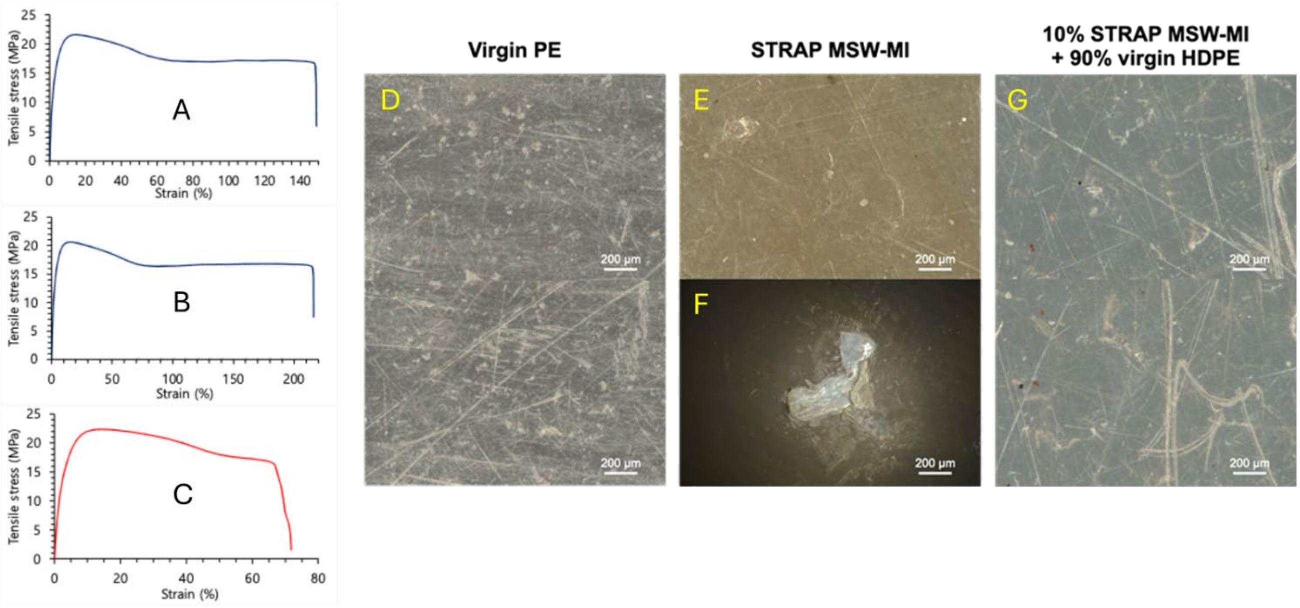

Figure 5. (A, B) Representative tensile stress-strain curves of polymer samples with blended samples containing 10wt% STRAP-recovered polymer and 90wt% virgin HDPE. (C) Virgin HDPE. (D) Optical microscopy image of virgin PE compressed film and (E, F) STRAP-MSW polymer compressed film with impurity and (G)10% STRAP-MSW polymer with 90% virgin HDPE compressed film.

4.5. Techno-Economic Analysis (TEA) and Life-Cycle Assessment (LCA)

A Techno-economic analysis (TEA) was conducted for the post-consumer shrink wrap films case study using process models adapted from previously published STRAP studies on multilayer PE films. [11, 12] The model accounts for the dissolution yield, solvent cleaning and recycling, and feedstock price. For a commercial-scale 56 kton yr^{-1} STRAP facility, Monte-Carlo simulations indicate a minimum selling price (MSP) for STRAP-derived PE that is competitive with virgin resin markets at a 15% internal rate of return, as shown in Figure 6A. Sensitivity analyses, in figure 6B, identify solvent recovery efficiency, energy consumption for dissolution heating, and labor costs as key economic drivers. Solvent recovery is estimated a for a pilot process, since the recovery process differs between manual solvent removal and drying in lab experiments, compared to automated sealed units in the pilot process. We assume that 0.1% of solvent is lost as the base case. The sensitivity analysis reveals that solvent loss can be tolerated to 1% to maintain a competitive MSP. Solvent is not a key economic driver, yet remains important.

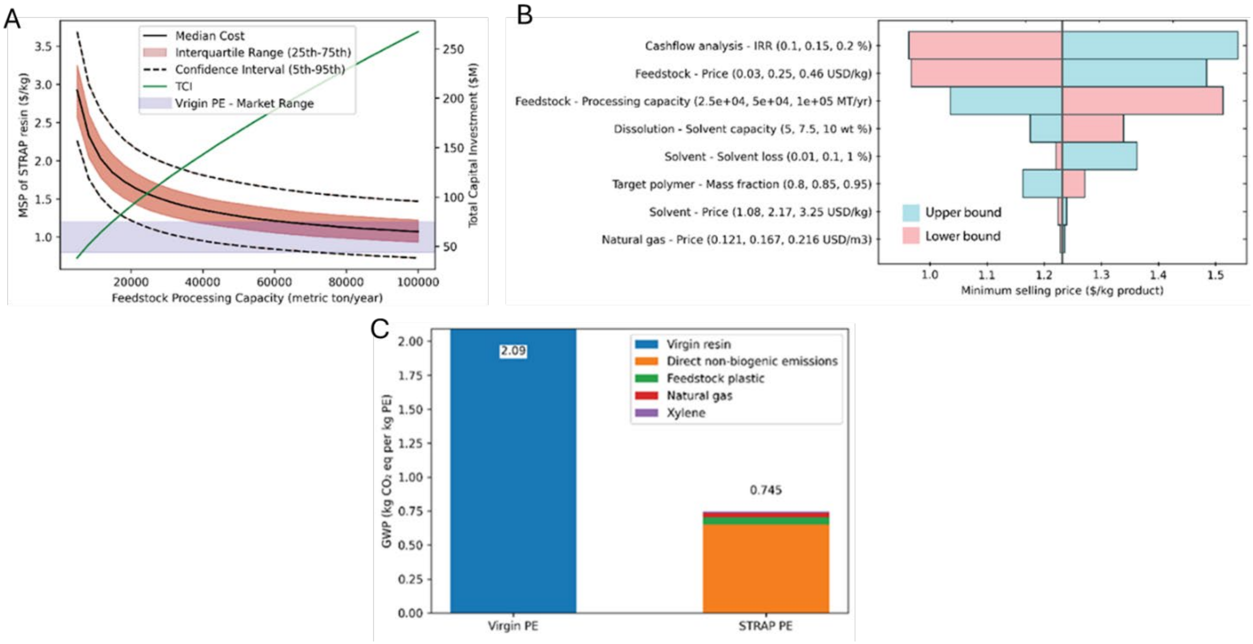

Figure 6. A) Monte Carlo result of minimum selling price of STRAP rPE to return 15% IRR B) Sensitivity analysis of most impactful variables in STRAP process on the minimum selling price C) Comparison of global warming potential for STRAP and virgin resin production. Adapted from Radkevich et.al. (2026), Waste Management; Copyright 2026 Elsevier [13].

Life-cycle assessment (LCA) shows that STRAP processing can provide significant greenhouse gas (GHG) reductions relative to virgin polymer production.[12,17]Avoided extraction, monomer synthesis, and polymerization steps contribute to these reductions, while solvent recycling minimizes additional environmental burdens. For shrink-wrap films in particular, LCA results indicate substantial decreases in global warming potential, as much as 64% reduction, compared with virgin LDPE, consistent with findings from the broader STRAP literature.

Together, the TEA and LCA results highlight STRAP's viability as both an economically competitive and environmentally favorable recycling pathway for PCW plastic streams.

5. Conclusions

This study demonstrates the broad applicability of the STRAP process for upgrading multiple categories of post-consumer plastic waste. Across shrink-wrap films, single-use coffee pod components, woven supersack textiles, and MSW-derived polymer blends, STRAP enables selective dissolution, impurity removal, and recovery of high-purity PE and PP resins. Recovered polymers exhibit optical, morphological, and mechanical properties comparable to virgin materials, supporting their suitability for high-value applications.

Combined with TEA and LCA results indicating economic competitiveness and reduced environmental burdens, these findings establish STRAP as a promising platform for advancing circularity in complex PCW plastic systems. Future efforts will focus on translating these laboratory-scale demonstrations to continuous operation at a 25 kg hr^{-1} pilot scale and integrating enhanced color-removal and solvent-recovery strategies.

6. Acknowledgements

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