Towards a Circular Economy for PET bottles in the US

Plastic Parallel Pathways Platform

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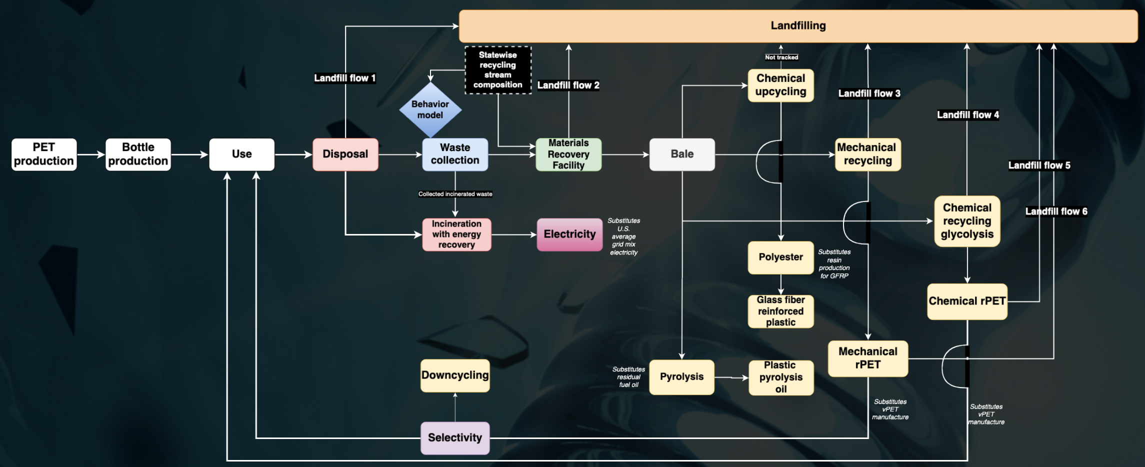
Develop a framework capable of quantitatively comparing the plastic end-of-life strategies that generate different products.

Ghosh, Tapajyoti, et al. "Comparing Parallel Plastic-to-X Pathways and Their Role in a Circular Economy for PET Bottles." *Advanced Sustainable Systems* (2023): 2300068.

- Tracking the flow of plastics in the economy within single and multiple life cycles.
- Implementing metrics for measuring circularity for complex systems.
- Process-based life cycle assessment to compare circular solutions' environmental impacts.
- Techno-economic analysis of end-of-life pathways.



Material flow model

- Model all the stages of the life cycle with detailed mass flow models
- Model technological and market constraints mathematically
- Model substitution of virgin with recycled resin, electricity from incineration, residual fuel oil and reinforced polymer resin
- Model novel recycling pathways
- Improve regional resolution
- Calculate circularity and LCA indicators

Circularity index

- **Linear Flow Index**
- The Linear Flow Index (LFI) measures the proportion of material flowing in a linear fashion, sourced from virgin materials and ending up as unrecoverable waste

$$LFI = \frac{\text{Linear flow}}{\text{Total Flow}}$$

- **Utility Factor**
- A utility factor (X) considers both the product lifetime (L) and product utility, or the extent to which a product is used to its full capacity (U)

$$X = \left(\frac{L}{L_{av}}\right)\left(\frac{U}{U_{av}}\right)$$

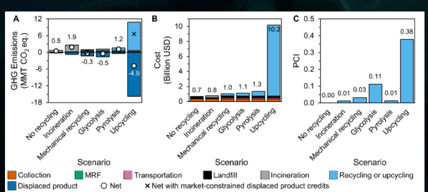
- Where L_{av} is the industry average product lifetime and U_{av} is the industry average product utility
- **Plastic Circularity Index** is defined by considering the Linear Flow Index of the product and a factor F(X), built as a function of utility X. The product's utility is captured using the X
- $PCI = 1 - \left(LFI \times \left(\frac{0.9}{X}\right)\right)$
- PCI is calculated for the entire system for every time step in the model

Life cycle assessment

- PyLCIA* – Python based Rapid LCA (Prospective LCA performing 1000s of calculations with evolving inventory – background as well as foreground changes with time)
- Foreground system – Activities in the material flow model
- Background system – US life cycle inventory
- Electricity provider –Dynamic grid mix (from ReEDS – Regional Electricity Deployment System) utilized for foreground system electricity consumption
- TRACI 2.1 LCIA methodology adopted
- This python module integrable with any attributional or systems model can build foreground models from user data and perform LCA rapidly.

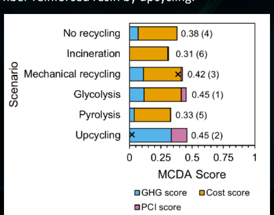
Agent-based modelling

- **Objective:** model household recycling behaviors under different intervention scenarios (e.g., increased access to curbside recycling programs or car-tagging campaigns)
- **Scope**: trash, recycling, and "wish-cycling" of PET with up to Census Block Group geographic resolution
- **Methodology**: Model the habitual nature of disposal behaviors and agents have a chance to "ponder" their action based on factors from a meta-analysis on recycling behavior
- Modeling the collection phase with a detailed human behavior prediction model was important as this phase involves the largest loss of plastics from the supply chain.

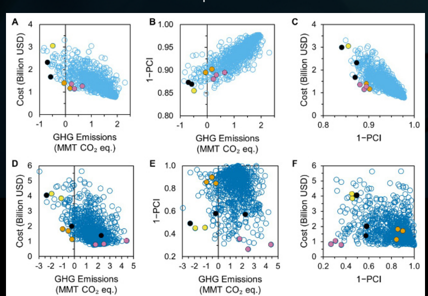


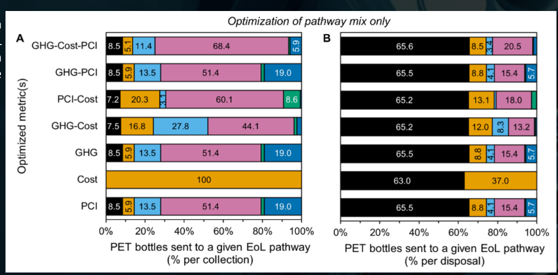
Predicted optimal EoL pathway mixes in 2020 when only the ratio of PET waste sent to a given EoL pathway is varied and when all model uncertain parameters are varied under the brute-force algorithm

Comparison of the **(A)** GHG emissions, **(B)** cost, and **(C)** PCI if all PET bottles collected for recycling in the United States in 2020 were used to produce lower-quality PET resin by mechanical recycling, food-grade PET resin by glycolysis, electricity from incineration, fuel oil from pyrolysis, or fiber-reinforced resin by upcycling.

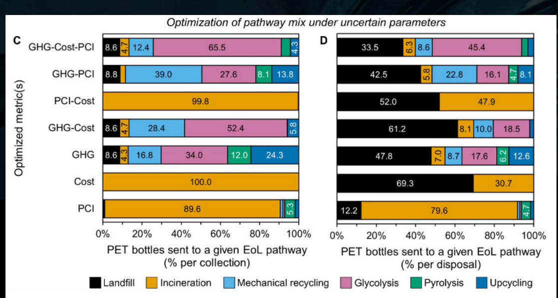


MCDA comparing PET EoL pathways for equal weighting of GHG emissions, cost, and PCI.





Brute force algorithm results for **(A-C)** optimization of EoL pathway mix only, and **(D-F)** optimization of EoL pathway mix and all uncertain parameters.



The MCDA results suggested that glycolysis, mechanical recycling, and PET upcycling to GFRP would be the most advantageous. Furthermore, a brute force algorithm was used to identify optimal combinations of EoL pathways that minimize cost and GHG emissions and maximize circularity, both without and with consideration of the uncertainty of key parameters such as transportation distances, MRF efficiencies, and recycling yields. 4P offers a powerful platform for identifying tradeoffs and synergies across plastic-to-*x* technologies that are not typically directly comparable, enabling the transformation of a complex PET EoL system through actionable insights for both researchers and decision-makers.

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