FOAMtastic: Polystyrene Repurposing to Reduce Landfill Waste

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University of Waterloo Chemical Engineering Capstone 2025

References:

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FOAMtastic

Polystyrene Repurposing to Reduce Landfill Waste

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Introduction

Problem Statement

Polystyrene (PS) is a durable and versatile plastic that can take over 500 years to degrade, which presents environmental risks due to its limited recyclability and potential to release harmful toxins [1]. With less than 10% being recycled, the majority accumulates in landfills. This project addresses these challenges by developing a pyrolysis process to convert PS waste into feedstock.

Context

PS is classified as #6 on the plastic resin identification scale, making it one of the most difficult plastics to recycle despite its common use in takeout containers and packaging.

Using pyrolysis, a method that thermally degrades plastic anaerobically, this recycling process will:

1. Divert municipal PS waste from entering landfills

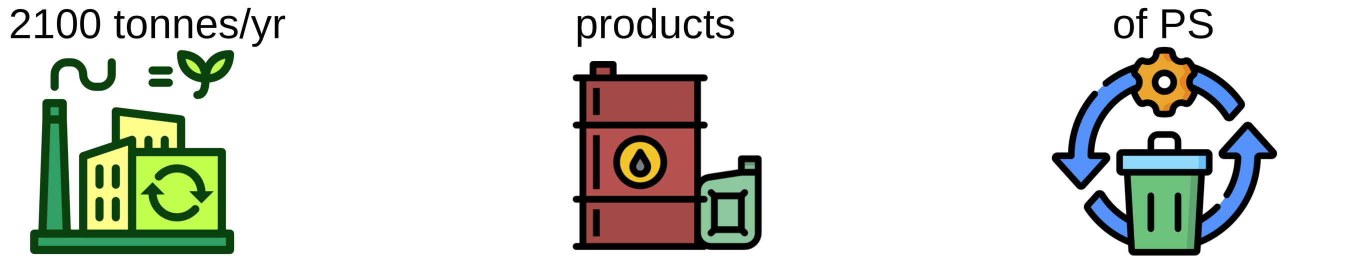
Table 1: 2013 City of Markham PS Densifier project [2]

Polystyrene Collected	Revenue ($)	Profit/Loss ($)
2100 tonnes/year	3,029.61	(53,036)

2. Develop a novel solution that can operationally repurpose PS waste into valuable products

Constraints

Process capacity of 2100 tonnes/yr	Yield 98% purity of all products	Improve circularity of PS



Sustainable Development Goals

SDG 12: Responsible Consumption and Production
- Reducing virgin material use
- Addresses single use nature and low recyclability
- Improve waste management

SDG 13: Climate Action
- Diversion of waste from landfills and incineration
- Reduce greenhouse gas emissions
- Minimize energy use and emissions

Process Development & Tools

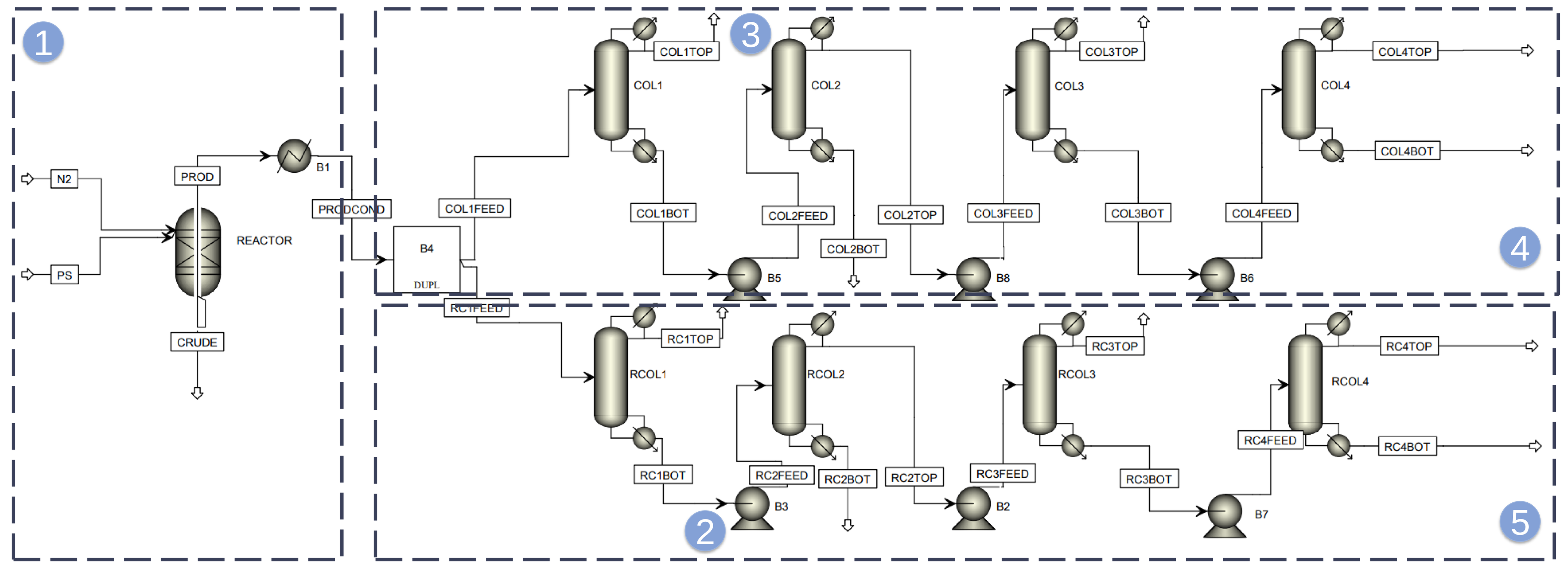
Process Development

Literature review on PS/plastic pyrolysis → Develop process flow diagram → Preliminary calc. & Analysis → Simulate in Aspen Plus → Validate model with literature

Engineering Tools

- Aspen Plus v14 for process simulation of shortcut and rigorous design of the process
- Microsoft Excel for cost analysis and general calculation
- Python for model validation using Matplotlib, NumPy, SciPy, and pandas

Process Flow Diagram & Analysis



Feed:
- 100 kg/hr N2
- 257 kg/hr PS

Assumptions:
- Feed contamination is negligible
- Fixed conversion reactor
- NRTL thermodynamic model
- Steady-state

1 Reactor
N2 and PS are the feed of the reactor for the pyrolysis process. B1 (heat exchanger) cools the reactor output and ensures the input of the distillation columns are at the set temperature.

2 Pumps

3 Distillation Columns
Sieve tray columns used to separate the products of the process. Separations in each column:
1. Toluene
2. Alpha Methylstyrene
3. Ethylbenzene
4. Cumene and Styrene

4 Shortcut Method
Uses a simplified distillation model (DSTWU) for quick estimates of the process using minimal information. Model provides estimates of key parameters such as reflux ratios and feed tray location.

5 Rigorous Method
Uses a more complex distillation model (RadFrac), and the results of key parameters from the shortcut method as starting values to fine-tune column operating conditions for a more accurate process.

Table 2: Key Analysis Results based on shortcut method design

Product	Toluene	Alpha Methylstyrene	Ethylbenzene	Cumene	Styrene
Production Location	COL 1	COL 2	COL 3	COL 4	COL 4
Mass (tonnes/year)	158	281	387	82	1343
Product Purity	99.71%	99.97%	99.61%	98.02%	99.97%
Uses	Paint solvent, rubber	Paint, resins, coatings, synthetic rubbers	Inks, dyes, perfume, new PS	Phenol, acetone	New PS, rubbers

Thermodynamic Model Validation

NRTL (Non-Random Two-Liquid)

Thermodynamic model chosen for modelling vapor-liquid equilibrium (VLE) of the process:
- Effective at modelling non-ideal interactions between hydrocarbons like styrene/toluene [3]
- VLE data obtained from NIST ThermoData Engine [4] and NRTL Aspen Plus Simulation [5]
- Simulated temperatures very closely reflect literature values

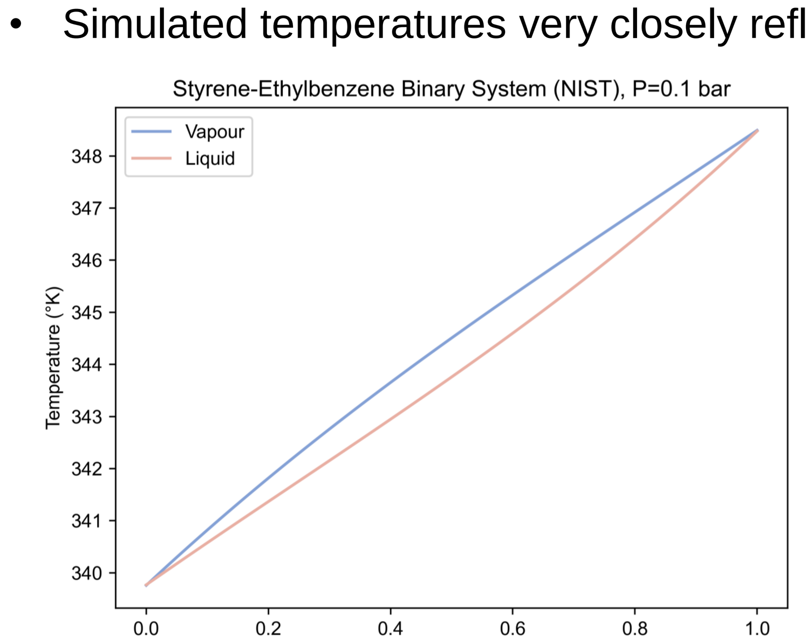


Figure 1: NIST ThermoData Engine Dataset

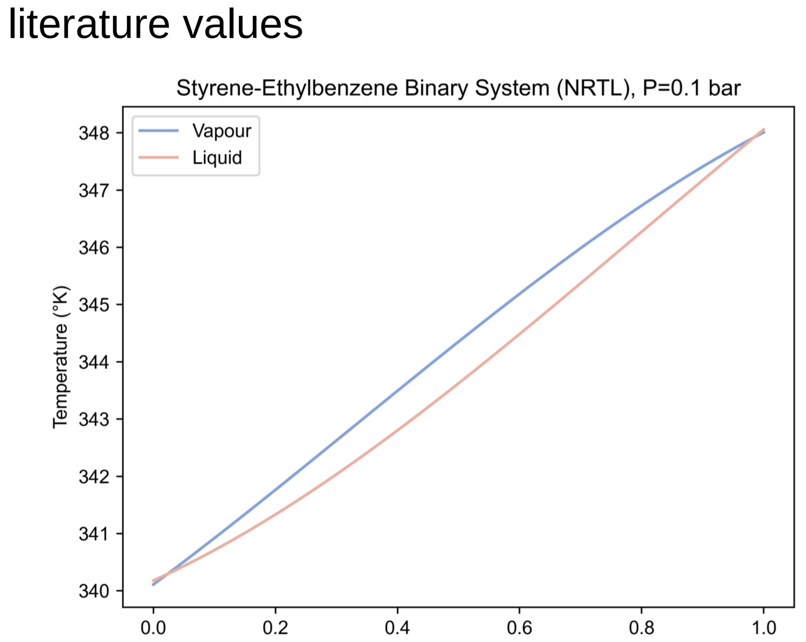


Figure 2: NRTL Thermodynamic Model Dataset

0.13% Max. error across vapor/liquid composition for both datasets

R^2 >= .995 Fitted coefficients of VLE data used in temperature simulation

Cost Analysis

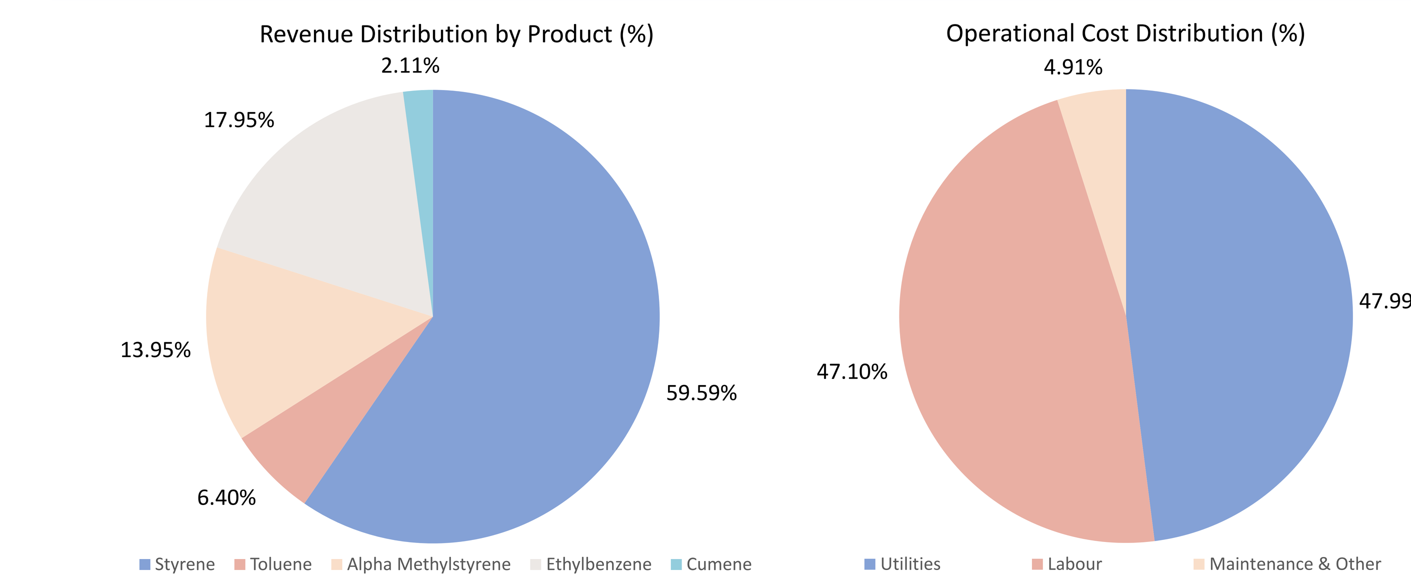


Table 3: Cost Analysis Summary

Cost Analysis ($/year)			
Total Equipment Cost ($)	7,390,000	Revenue	8,533,000
Total Operational Cost	6,420,000	**Profit**	**2,113,000**
Payback Period: 4.1 years			

Sustainability Linearity Analysis

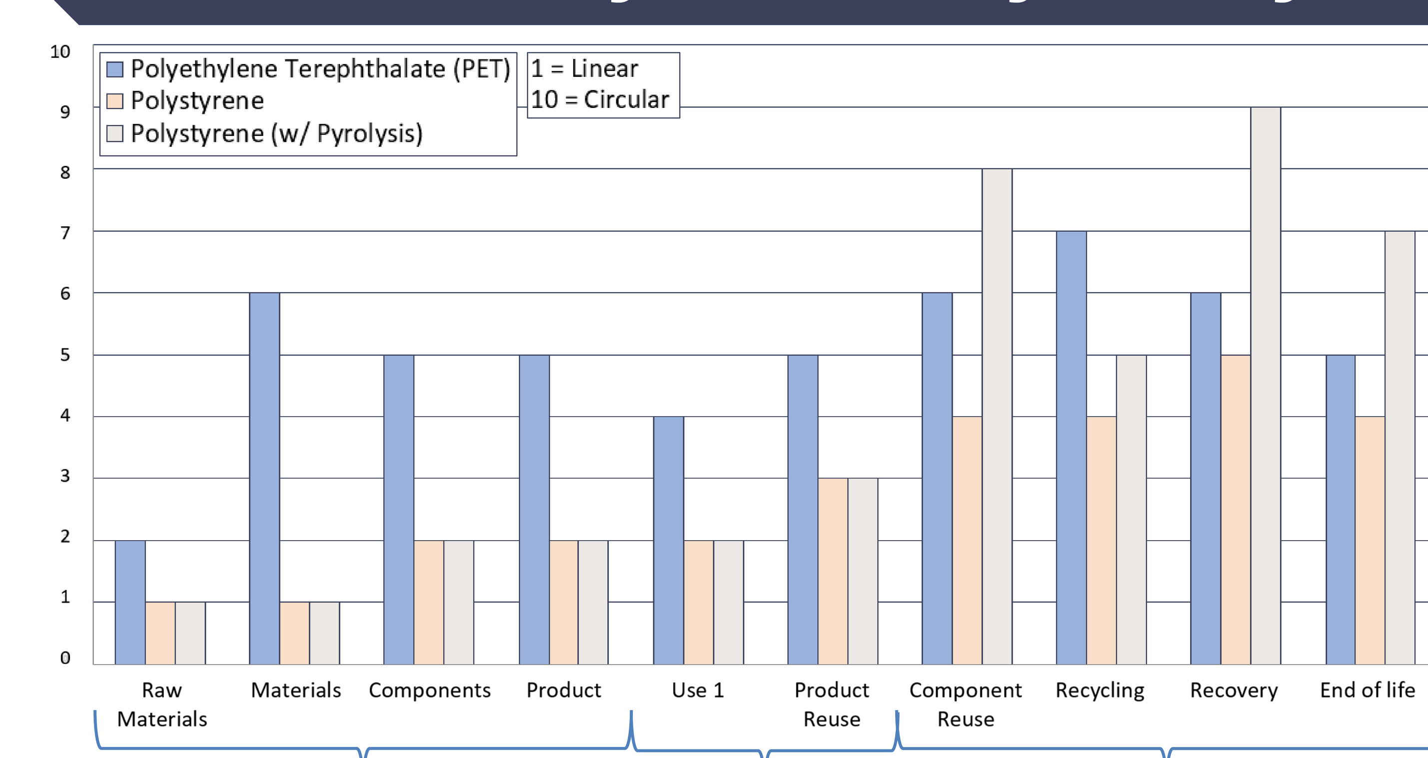


Figure 3: Sustainability Linearity Analysis

A linearity analysis was performed to evaluate a product's lifecycle from raw material to end of life. The developed pyrolysis process, improved all aspects of the recovery chain

Conclusion

- The process effectively processes 100% of annual polystyrene waste collected by the City of Markham with a payback period of 4.1 years
- The process yields 98% purity of all products with profit of $2,113,000/yr
- The process improves the material circularity by improving its recyclability using sustainability linearity analysis

Future Direction

- Analysis on impact of CaO catalysts to reduce energy expenditure
- Operational cost reduction through distillation column parameter optimization

Acknowledgments & References

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