FOAMtastic: Polystyrene Repurposing to Reduce Landfill Waste

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University of Waterloo Chemical Engineering Capstone 2025

References:

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[4] aspentech, “Aspen Plus | Leading Process Simulation Software | AspenTech,” *www.aspentech.com*. https://www.aspentech.com/en/products/engineering/aspen-plus

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 PS landfill waste from municipalities

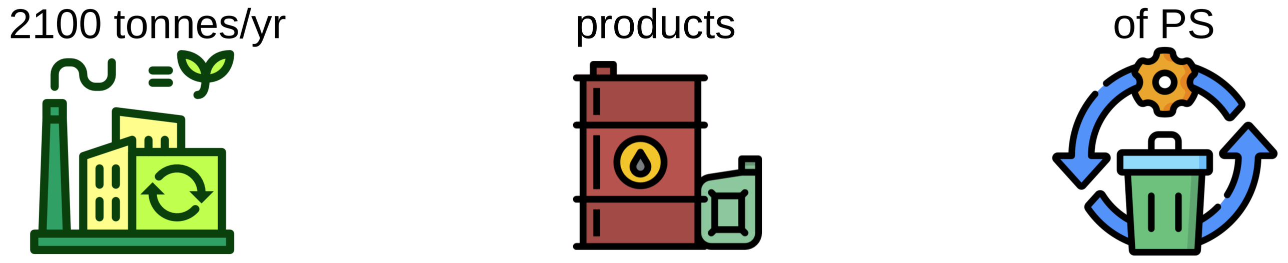
Table 1: 2013 Town of Markham PS Densifier project [2]

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

2. Develop a novel solution that can operationally repurpose 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

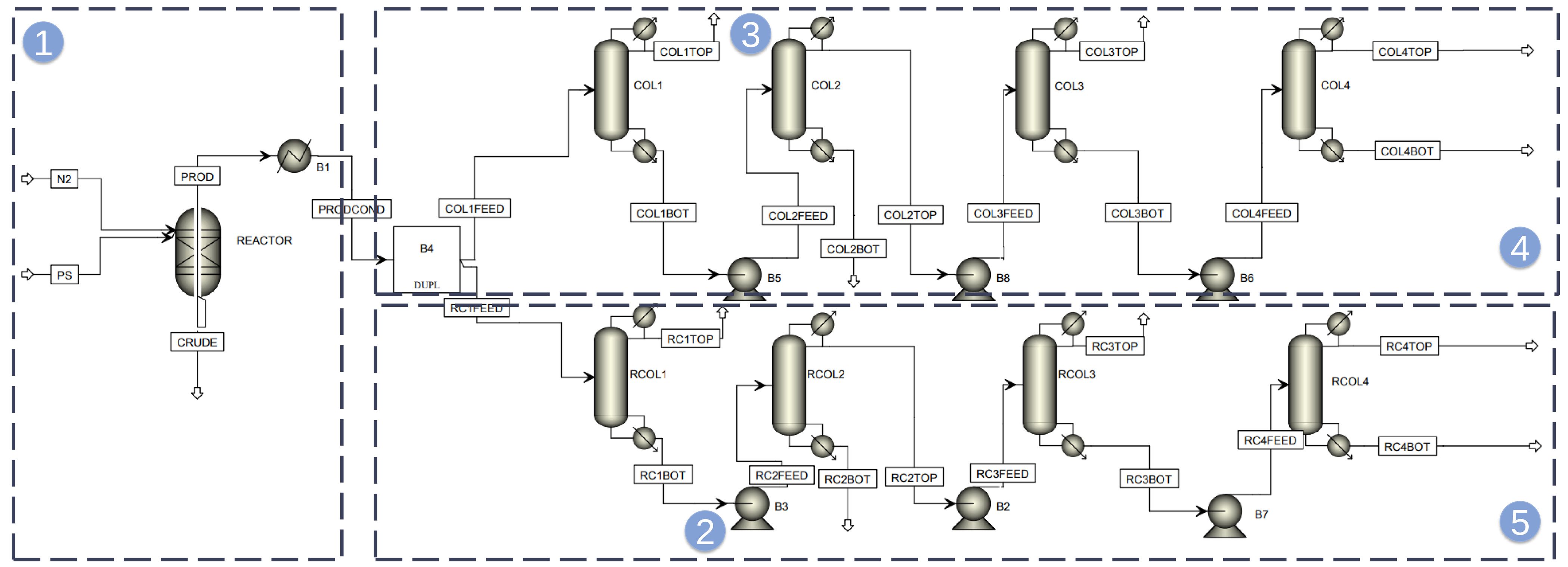
Process Development

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) 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 methyl styrene
3. Ethylbenzene
4. Cumene and Styrene

4 Shortcut Method
Modelling of the process using "simple" distillation columns. There are fewer parameters that can be changed:
- Specifications
- Calculation Options
- Convergence

5 Rigorous Method
The shortcut method provides inputs for the rigorous distillation. More parameters can be changed:
- Configuration
- Streams
- Pressure
- Condenser

Table 2: Key Analysis Results based on shortcut method design

Product	Toluene	Alpha Methyl Styrene	Ethylbenzene	Cumene	Styrene
Production Location	COL 1	COL 2	COL 3	COL 4	COL 4
Mass (tonne/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 Verification

NRTL (Non-Random Two-Liquid)

Thermodynamic model chosen for modelling vapor-liquid equilibrium:
- Effective at modelling non-ideal interactions between hydrocarbons (i.e., styrene/toluene)
- VLE data obtained from NIST ThermoData Engine [3] and NRTL Aspen Plus Simulation [4]
- Simulated temperatures closely reflect literature

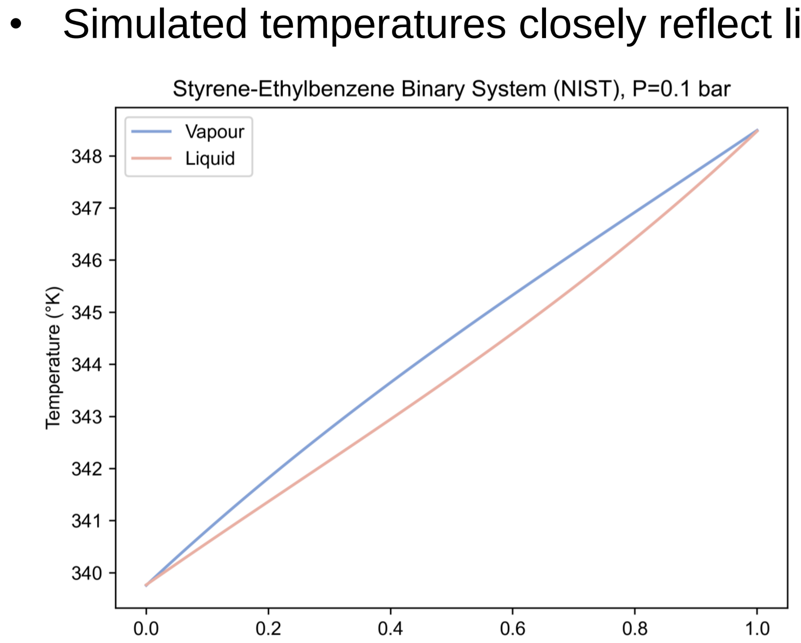


Figure 1: NIST ThermoData Engine Dataset

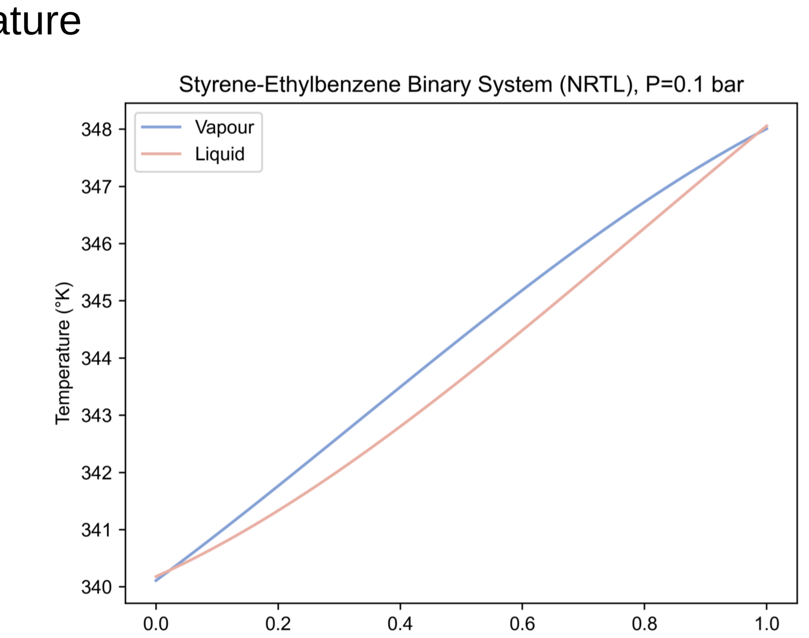


Figure 2: NRTL Thermodynamic Model Dataset

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

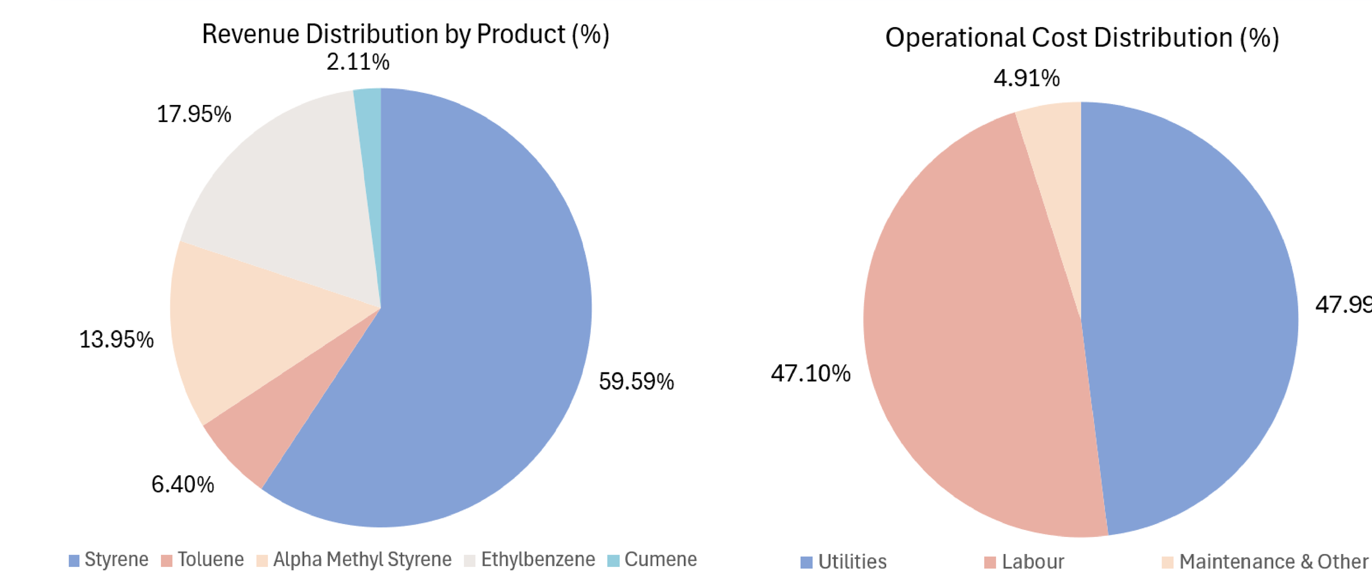


Table 3: Cost Analysis Summary

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

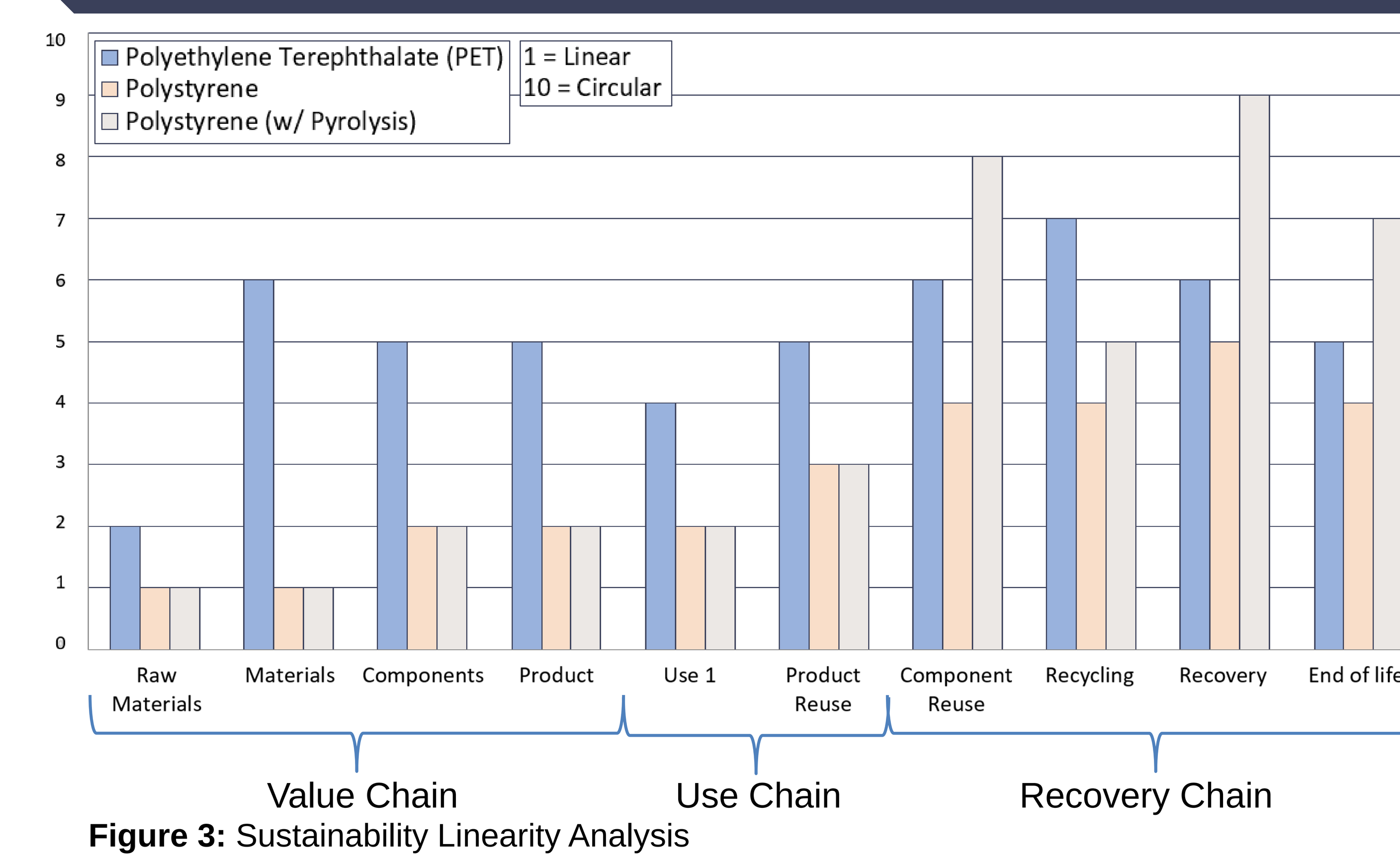


Figure 3: Sustainability Linearity Analysis

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 Town of Markham.
- The process yields 98% purity of all products.
- The process improves the material circularity by improving its recyclability.

Future Direction

Addition of Catalyst
- Using a decision matrix to compare the capital/operational costs, efficiency, and product quality found in literature, the recommended catalyst was found to be calcium oxide (CaO).

Acknowledgements & References

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