UNIVERSITY OF MARYLAND

Recycling Plastic Waste to Petrochemical Feedstocks

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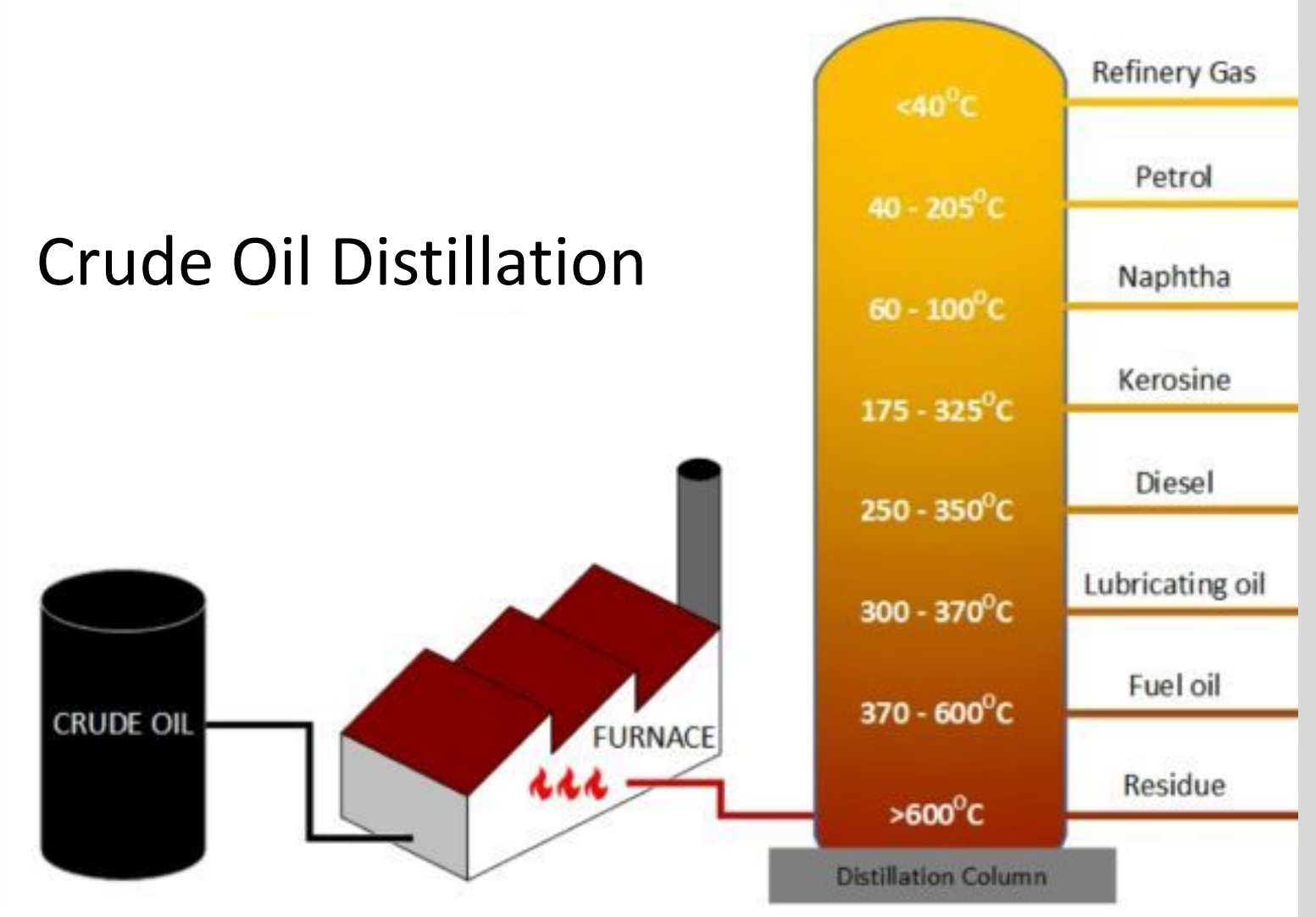
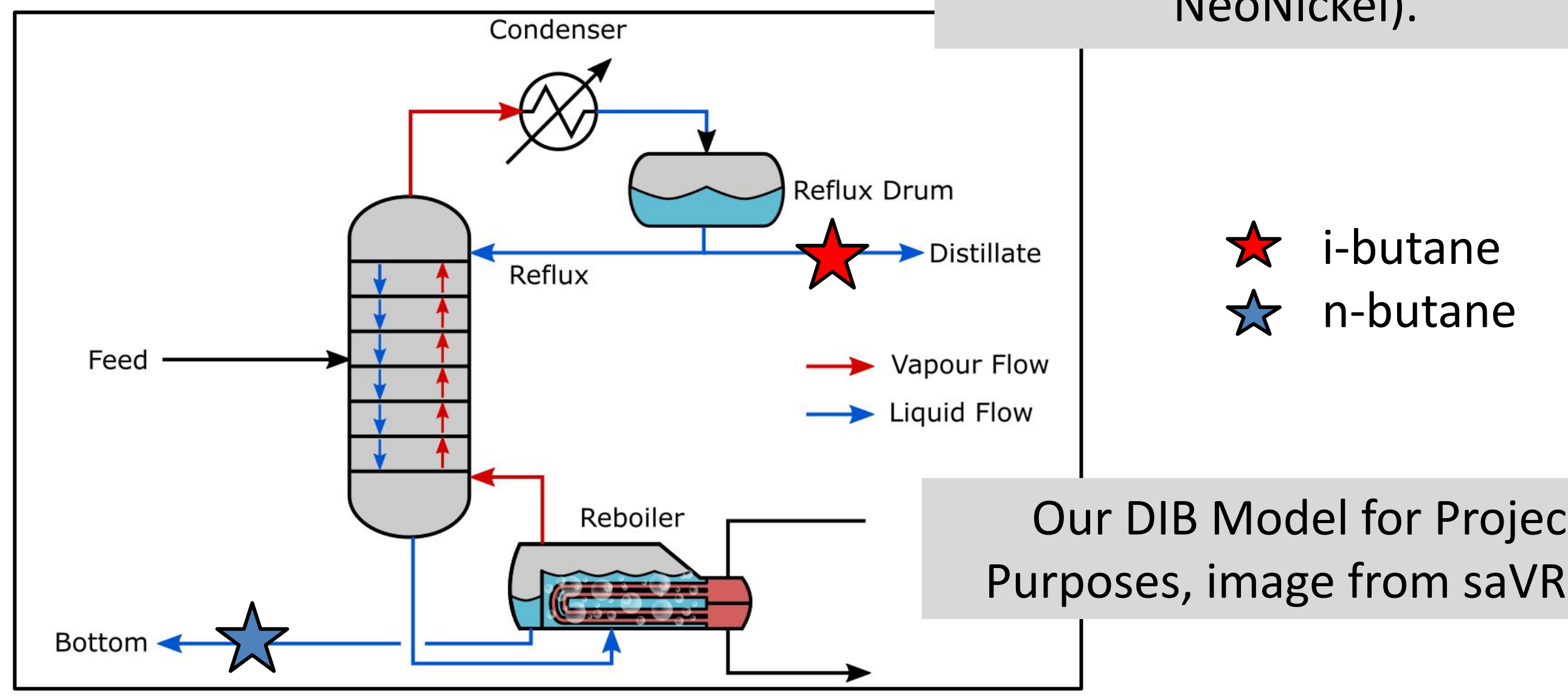
Project 1: DIB Tower Electrification

Intro - A deisobutanizer (DIB) tower is a distillation column used to separate isobutane from n-butane based on differences in volatility. This separation is important because isobutane is a more valuable product used in fuel blending and petrochemical applications.



Distillation columns are a key unit in chemical engineering, separating components based on volatility. Higher temperatures at the base drive separation, allowing more volatile compounds to rise and exit at the top. They are widely used in industries such as oil refining (image source: NeoNickel).



Our DIB Model for Project Purposes, image from saVRee.

Base Case Design - A deisobutanizer column separates isobutane from n-butane using 57 trays, achieving ~95% isobutane purity. However, the process is highly energy-intensive, requiring significant reboiler and condenser duties (~28.5 MW each).

Heat Pump Design - The heat pump recovers energy from the distillation column and reuses it to supply the reboiler. It delivers more heat than required, allowing it to fully replace conventional steam heating while operating efficiently at ~57% of the Carnot limit.

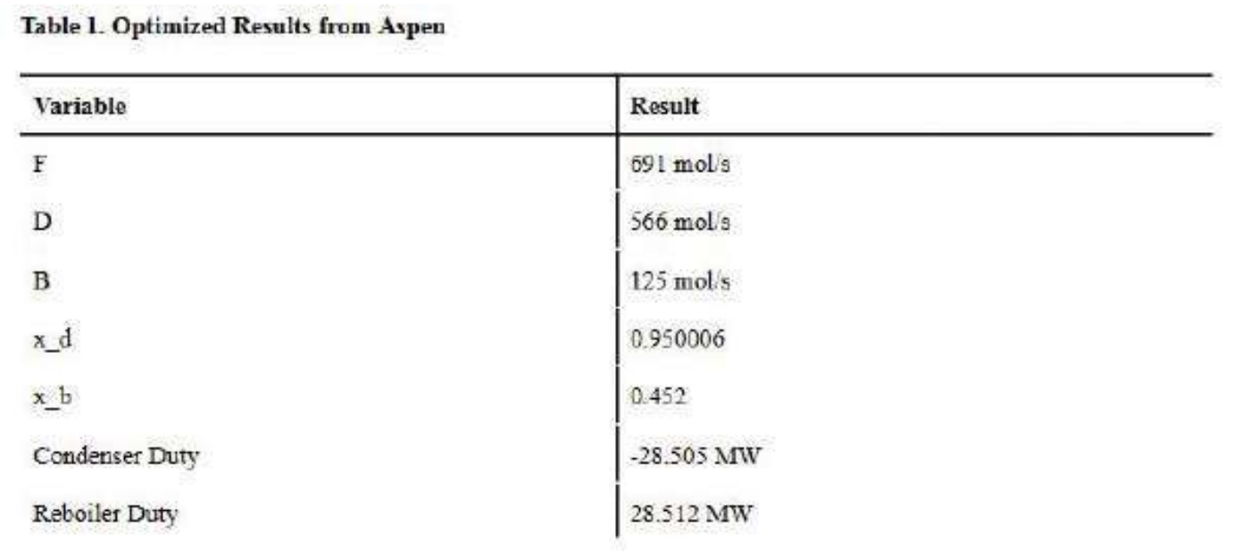
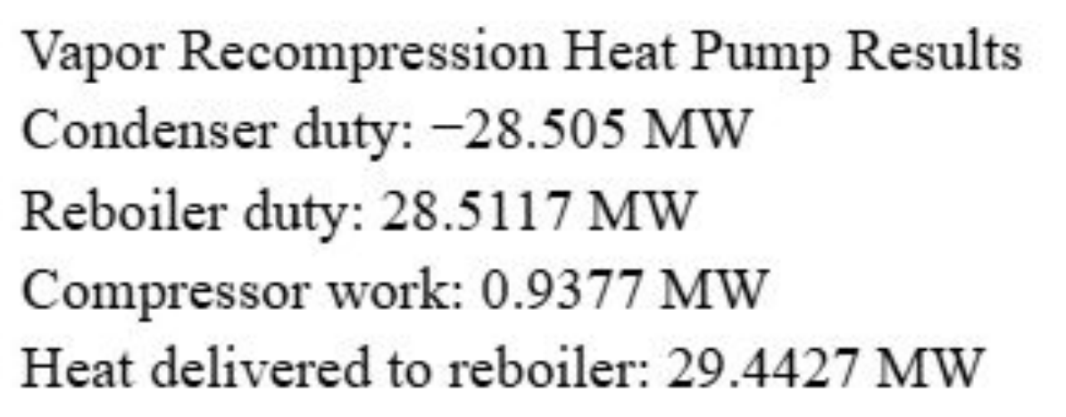


Table 1. Optimized Results from Aspen

Variable	Result
F	691 mol/s
D	566 mol/s
B	125 mol/s
x_d	0.950006
x_b	0.452
Condenser Duty	-28.505 MW
Reboiler Duty	28.512 MW

Base Case Results



Vapor Recompression Heat Pump Results
Condenser duty: −28.505 MW
Reboiler duty: 28.5117 MW
Compressor work: 0.9377 MW
Heat delivered to reboiler: 29.4427 MW

Heat Pump Results

Findings

- ★ **Same separation, lower energy demand** - Both designs achieve ~95% purity, but the heat pump reduces external energy needs.
- ★ **Heat recovery replaces utilities** - Heat pump supplies full reboiler duty, eliminating the need for steam.
- ★ **More efficient and sustainable design** - Lower energy input (~0.94 MW) makes the heat pump the better option.

Project 2: Catalytic Conversion of Plastic Waste to Valuable Hydrocarbon Products

Introduction - This project designs a chemical recycling process that converts mixed plastic waste into valuable hydrocarbon products using catalytic pyrolysis. Common plastics such as polyethylene, polypropylene, and polystyrene are transformed into liquid fuels and petrochemical feedstocks. The goal is to reduce plastic waste while creating useful, high-value products in a more sustainable way.

Problem - Plastic waste is rapidly accumulating in landfills and waterways, especially in regions like the Chesapeake Bay. Current recycling systems struggle to process mixed plastics, leading to environmental pollution and inefficient use of resources. This process provides an alternative to landfilling plastic waste by turning it into valuable products. It helps reduce environmental pollution while creating economic value and supporting a circular economy.

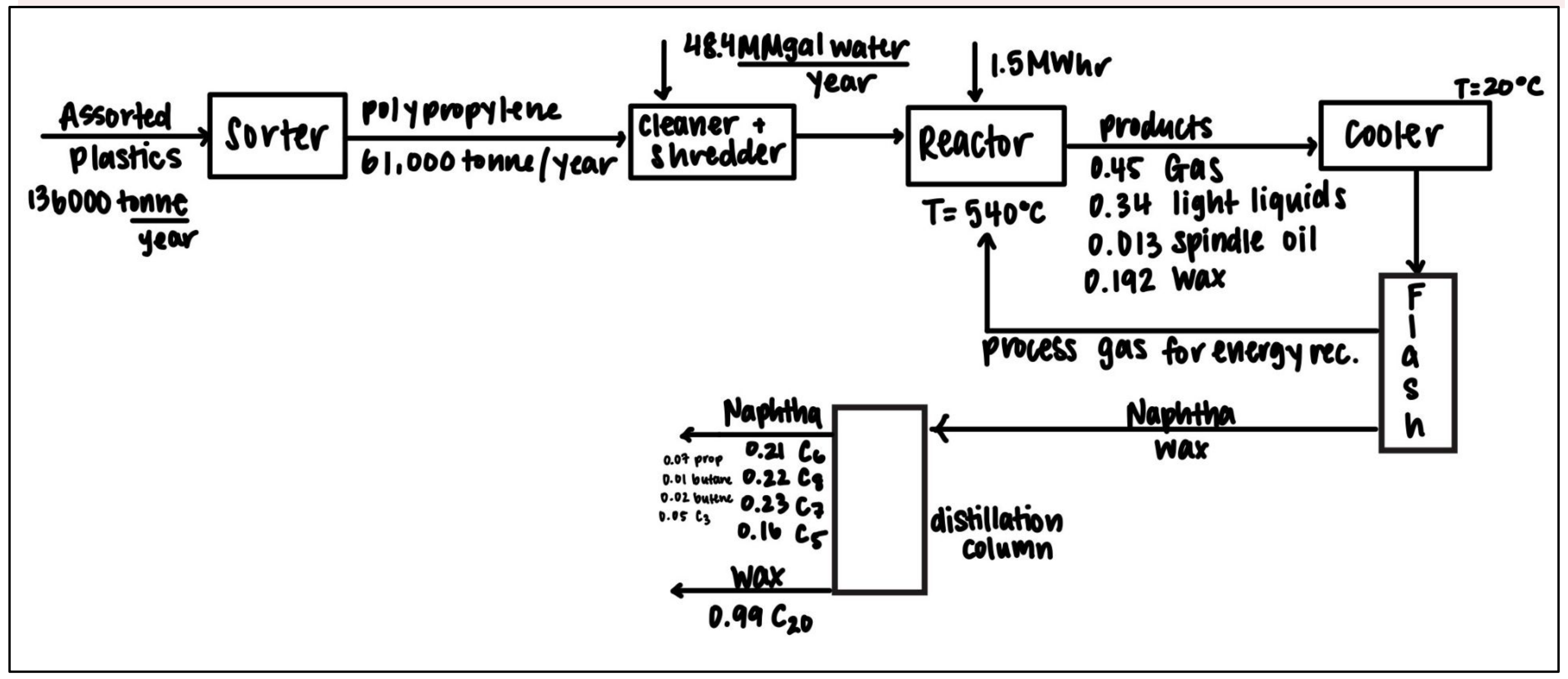
Key Challenges

- Limited ability of existing recycling methods to handle mixed plastics
- Low conversion of waste into high-value products
- Lack of infrastructure for chemical recycling
- Difficulty removing contaminants (e.g., PVC)
- Limited integration of renewable energy

Baltimore Harbor - Taken by Britannica, Maryland Clipart by Pngtree

Proposed Solution - Mixed plastic waste is first sorted to remove contaminants, then processed in a fluidized bed reactor using catalytic pyrolysis. This breaks down long polymer chains into smaller hydrocarbon molecules. The products are then separated and refined into usable fuels and chemical feedstocks. To improve sustainability, the process incorporates:

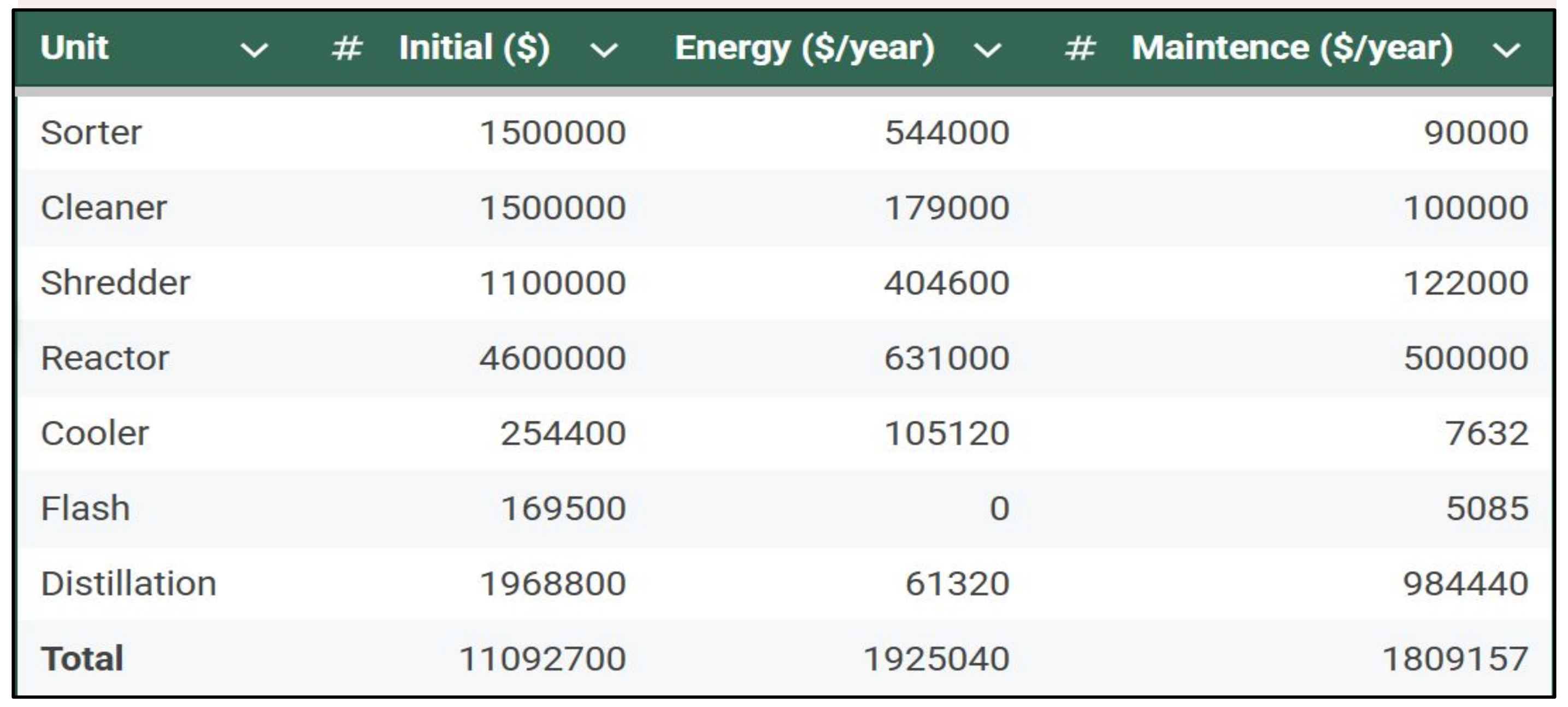
- Heat integration to reduce energy demand
- Recovery and reuse of process byproducts



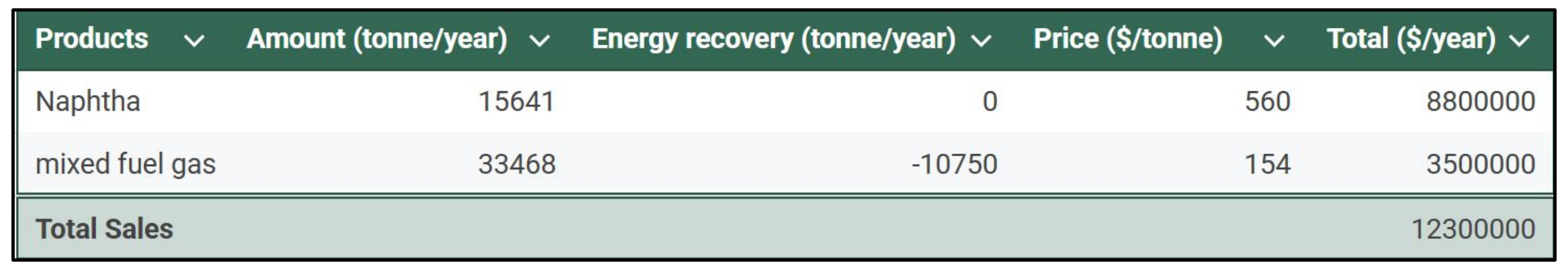
Our Proposed Model

We use catalytic pyrolysis to burn polypropylene in a fluidized bed reactor at a temperature of 540 C. The reactor hydrocarbon products range from methane up to eichosane, which are later separated by their boiling points. The reactor was modeled using lumped kinetic parameters[1] in Python. We then used Aspen to model the separation. Gas out of the flash drum was primarily composed of methane, ethane, ethylene, propane and polypropylene. This gas was used as a fuel source for the reactor and provided 95% of the required energy. The remaining gas was sold as mixed fuel gas. The remaining liquid from the flash drum was sent to the distillation column, which produced a vapor containing a majority pentane through octane. This naphtha had an average molecular weight of 86.6 g/mol and essentially no contamination from heavy hydrocarbons such as eichosane.

Economic Analysis

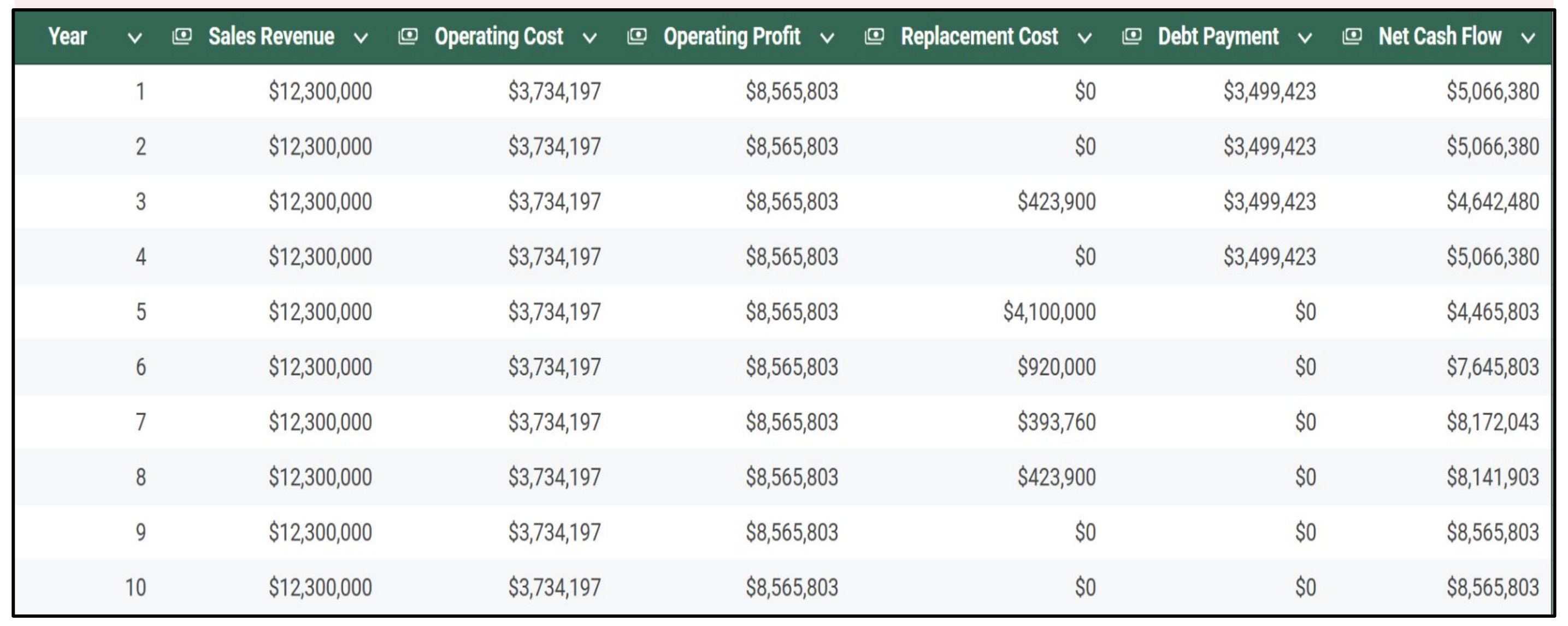


Unit	Initial ($)	Energy ($/year)	Maintence ($/year)
Sorter	1500000	544000	90000
Cleaner	1500000	179000	100000
Shredder	1100000	404600	122000
Reactor	4600000	631000	500000
Cooler	254400	105120	7632
Flash	169500	0	5085
Distillation	1968800	61320	984440
Total	11092700	1925040	1809157



Products	Amount (tonne/year)	Energy recovery (tonne/year)	Price ($/tonne)	Total ($/year)
Naphtha	15641	0	560	8800000
mixed fuel gas	33468	-10750	154	3500000
Total Sales				12300000

Our annual sales are approximately $12.3 million, while our yearly operating costs total about $3.7 million, resulting in an annual net revenue of $8.6 million. This annual revenue is lower than the initial capital investment of approximately $11.1 million, so we plan to establish a 4-year payback period with an assumed 10% interest rate. To meet this target, we would allocate $3.5 million per year toward repayment during the first three years, with the remaining balance paid in the fourth year.



Year	Sales Revenue	Operating Cost	Operating Profit	Replacement Cost	Debt Payment	Net Cash Flow
1	$12,300,000	$3,734,197	$8,565,803	$0	$3,499,423	$5,066,380
2	$12,300,000	$3,734,197	$8,565,803	$0	$3,499,423	$5,066,380
3	$12,300,000	$3,734,197	$8,565,803	$423,900	$3,499,423	$4,642,480
4	$12,300,000	$3,734,197	$8,565,803	$0	$3,499,423	$5,066,380
5	$12,300,000	$3,734,197	$8,565,803	$4,100,000	$0	$4,465,803
6	$12,300,000	$3,734,197	$8,565,803	$920,000	$0	$7,645,803
7	$12,300,000	$3,734,197	$8,565,803	$393,760	$0	$8,172,043
8	$12,300,000	$3,734,197	$8,565,803	$423,900	$0	$8,141,903
9	$12,300,000	$3,734,197	$8,565,803	$0	$0	$8,565,803
10	$12,300,000	$3,734,197	$8,565,803	$0	$0	$8,565,803

Over the 10-year lifespan, the process is expected to generate approximately $123 million in total sales revenue. After subtracting about $37.34 million in operating costs, the process would produce roughly $85.66 million in operating profit before replacement and debt payments. With an estimated $6.26 million in equipment replacement and overhaul costs and $14.00 million in total debt repayment at 10% interest, the final projected net cash flow over 10 years is approximately $65.40 million.

Sustainability

Our process generates 7,883 kg CO_2/hr corresponding to an overall carbon intensity of 1.12 kg CO_2/kg product. Emissions are almost entirely from the gas stream 7,863 kg CO_2/hr which is a carbon intensity of 2.06 kg CO_2/kg product, while naphtha and C20 are minimal. The gas is reused to supply 95% of reactor energy, this demonstrates effective energy integration, with emissions arising from internally recovered energy rather than external utility consumption. In-house water treatment enables process water reuse, decreasing freshwater withdrawal and improving water intensity (water used per unit product).

References

1. Lechleitner, A. E., Schubert, T., Hofer, W., & Lehner, M. (2021). Lumped Kinetic Modeling of Polypropylene and Polyethylene Co-Pyrolysis in Tubular Reactors. Processes, 9(1), 34. https://doi.org/10.3390/pr9010034
2. Jiantai Machine. (n.d.). 11 types of plastic recycling machines compared by cost and output. https://jiantaimachine.com/11-types-of-plastic-recycling-machines-compared-by-cost-and-output/
3. World Scientific Publishing. (n.d.). Article abstract (DOI: 10.1142/S2382624X22500047).https://www.worldscientific.com/doi/abs/10.1142/S2382624X22500047?srsltid=AfmBOopO7bkFYF5BFZywSaDo6YLF12Dj4
4. Towler, G., & Sinnott, R. (2022). *CHEMICAL ENGINEERING DESIGN PRINCIPLES, PRACTICE AND ECONOMICS OF PLANT AND PROCESS DESIGN THIRD EDITION*. https://elmoukrie.com/wp-content/uploads/2022/06/chemical-engineering-design-principles-practice-and-economics-of-plant-and-process-design-gavin-towler-ray-sinnott-3edition.pdf