Plastic Pyrolysis: From Waste to Fuel

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Introduction

Overview: Consider a society in which plastic trash is no longer an issue but rather a rich resource. Our cutting-edge technology converts plastic trash into clean, long-lasting fuels. Reducing our dependence on fossil fuels and paving the road for a greener future.

Objective: Our objective is to develop an efficient, profitable and sustainable processing plant for upcycling plastic waste into valuable fuels, such as diesel and gasoline, to address environmental concerns and contribute to the circular economy. Throughout the design, we targeted and where limited by the following specifications and constraints.

Specifications

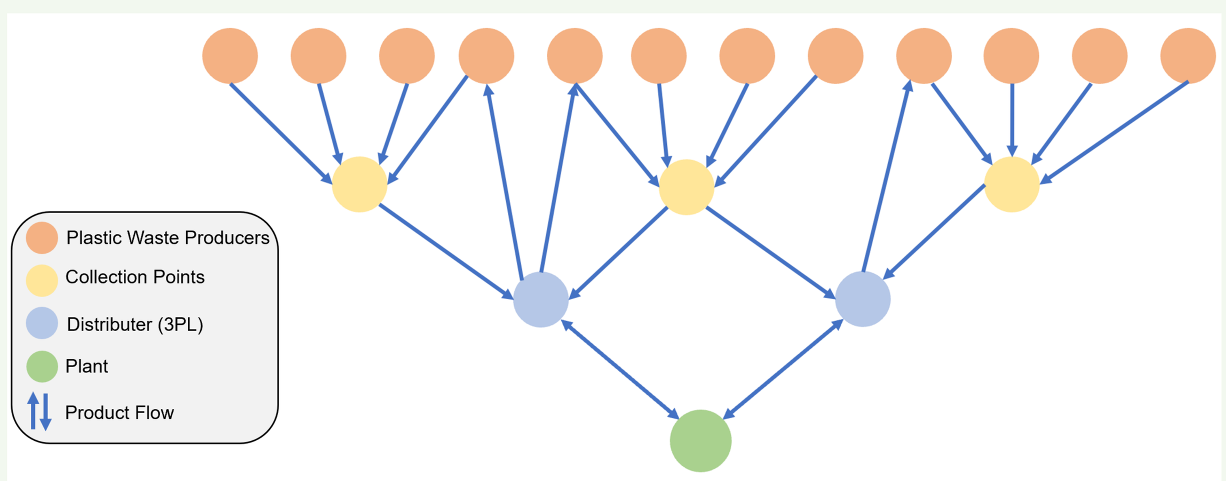
Octane Number
(87 ~ 93) RON
Cetane Number **> 40**
Reliability **> 98%**
Sulfur Content
< 14 ppm

Constraints

Waste Compostion:
Different types of plastic waste compostions.
Budget
Resource Availibilty

Methodology and Results

Supply Chain Netowrk design:
First, we started with the strategic decision related to designing the supply chain network we will determine the lifeline of how products get from the beginning to the end, ensuring everything happens smoothly and with the minimum possible cost. Our supply chain network is illustrated in the Figure below.



Methodology and Results

Analytical Hirechary Process:
Second, the AHP was implemented, a helpful tool for deciding the best location for our facility. It breaks down complex decisions into an organized structure, making it easier to compare factors like cost and accessibility. Factors that we took into consideration are: Proximity to Plastic Waste, Cost of Land, Governmental Support, Market Access and Future Expansion Opportunity, Results are shown in the table

Criteria\Location	Weights	Riyadh	Dammam	Jeddah	King Abdullah Economical City
Cost of Land	49%	3.450	0.493	2.465	1.479
Proximity to Plastic waste	28%	1.479	2.465	3.450	1.479
Governmental Support	14%	1.479	1.479	2.465	4.436
Market Access	5%	3.450	2.465	2.465	1.479
Future Expansion Opportunity	5%	4.436	3.450	1.479	2.465
Sum	100%	14.294	10.351	12.323	11.337
Rank		1	4	2	3

Mathematical Model

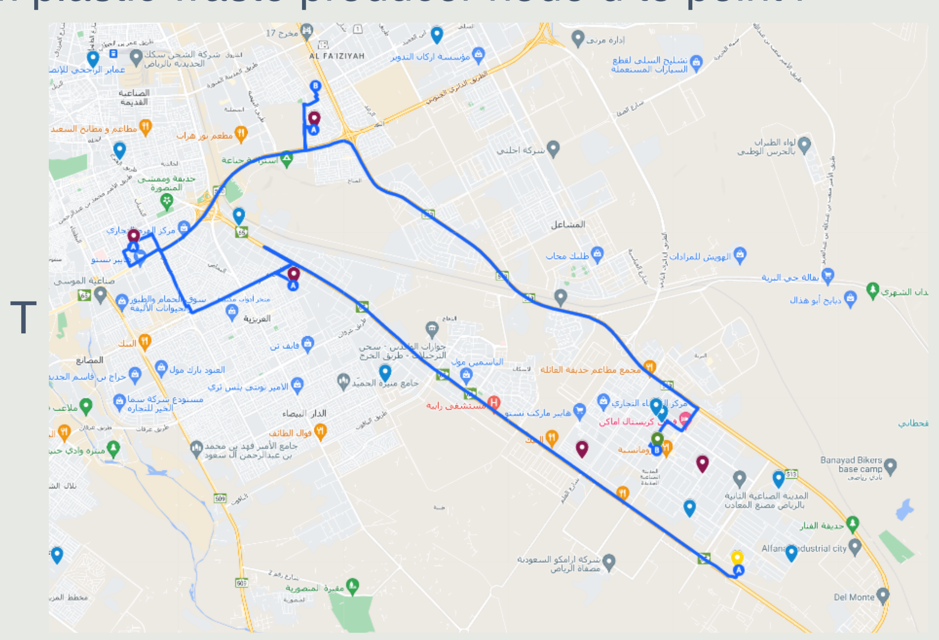
Sets:
WP: set of demand nodes (plastic waste producers) **PL:** set of potential points for the installation of a collection point
Q: set containing points of set PL, 0 (point of origin or parking of trucks), and n (endpoint of the vehicle's route)
T: set of collection vehicles **U**: all combinations of points on a given sub-route with |U| points.

Decision Variables:
x_{ijt}: 1 if collection truck t moves from point i to point j, 0 otherwise w_i: Estimated amount of plastic waste to be collected (in kg) at collection point i
$w_i = \sum_{t \in T} y_{it} * w_{it}$, for all $i \in PL$. w_{it}: Estimated amount of plastic waste to be collected (in kg) at collection point i by truck t
y_{it}: auxiliary variable, 1 if truck t visits point i, 0 otherwise. $y_{it} = \sum_{j \in PL} x_{ijt}$, for all $i \in PL$, $t \in T$
z_i: auxiliary decision variable, 1 if there is a collection point at point i, 0 otherwise. $= \min(1, \sum_{t \in T} y_{it})$, for all $i \in PL$

Parameters:
FI: average cost of installing a collection point 600 SAR. **CO:** cost of opportunity (per kg) of plastic waste 8.4225 SAR
CTt: capacity of vehicle t load (in kg) 20000. **TA:** total amount (in kg) of plastic waste generated at all waste producer points; (4500)
CPi: maximum capacity of collection point i (in kg) (20000). **Sid:** cost of distance from plastic waste producer node d to point i
Tijt: transport cost of truck t between i and j

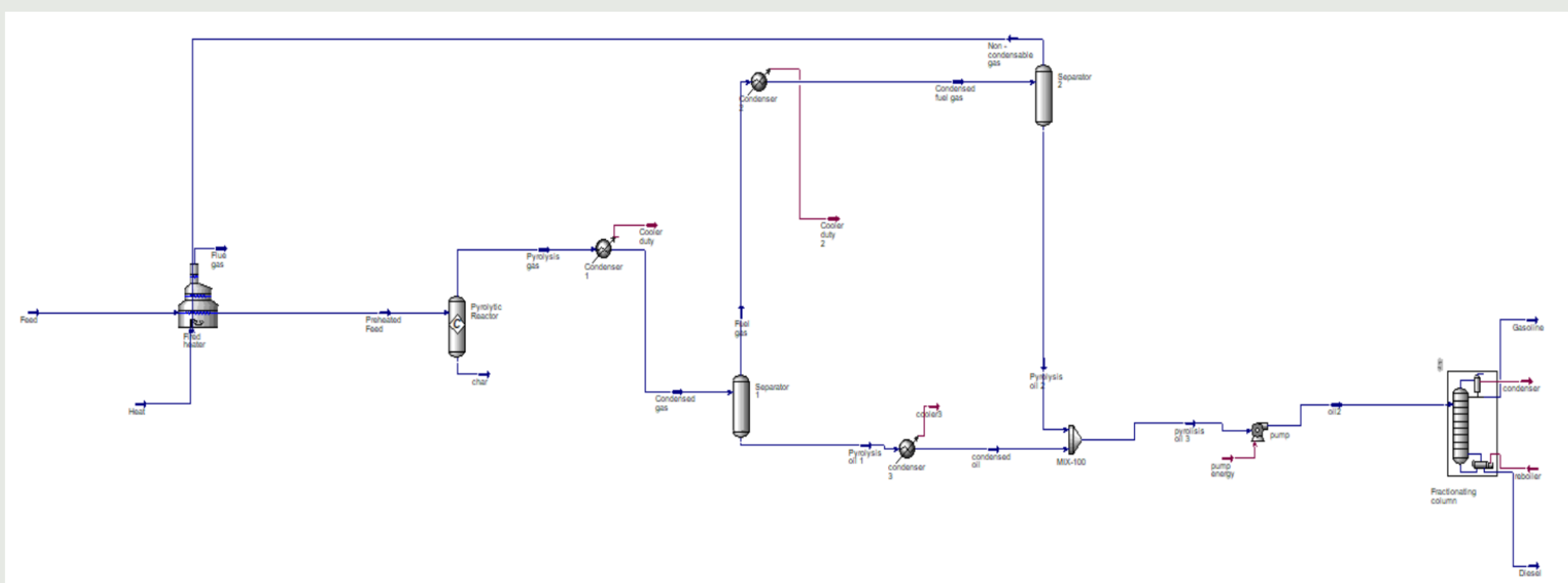
Objective:
$$\text{Minimize } Z = \sum_{i \in Q} \sum_{j \in Q} \sum_{t \in T} x_{ijt} * T_{ijt} + CO(TA - \sum_{i \in PL} w_i) + FI \sum_{i \in PL} z_i + \sum_{i \in PL} \sum_{d \in WP} z_i * S_{id}$$

Constraints:
1- $\sum_{j \in Q} x_{jit} = \sum_{j \in Q} x_{ijt}$, for all $i \in PL$, $t \in T$ **2-** $\sum_{j \in Q} x_{ijt} \leq 1$, for all $i \in Q : i \neq n$, $t \in T$
3- $\sum_{j \in Q} \sum_{t \in T} x_{0jt} \geq 1$ **4-** $\sum_{i \in Q} \sum_{t \in T} x_{int} \geq 1$ **5-** $\sum_{i \in PL} w_i \leq TA$
6- $\sum_{i \in PL} w_{it} y_{it} \leq CT_t$, for all $t \in T$. **7-** $\sum_{t \in T} w_{it} y_{it} \leq CP_i$, for all $i \in PL$.
8- $\sum_{i,j \in U} x_{ijt} \leq |U| - 1$, for all $t \in T$, $U \subset Q$. **9-** $\sum_{i \in Q} x_{i0t} = 0$, for all $t \in T$
10- $\sum_{j \in Q} x_{njt} = 0$, for all $t \in T$. **11-** $x_{ijt} \in \{0, 1\}$, for all $i, j \in Q$, $t \in T$.
12- $y_{it} \in \{0, 1\}$, for all $i \in PL$, $t \in T$ **13-** $z_i \in \{0, 1\}$, for all $i \in PL$ **14-** $w_i \geq 0$, for all $i \in PL$



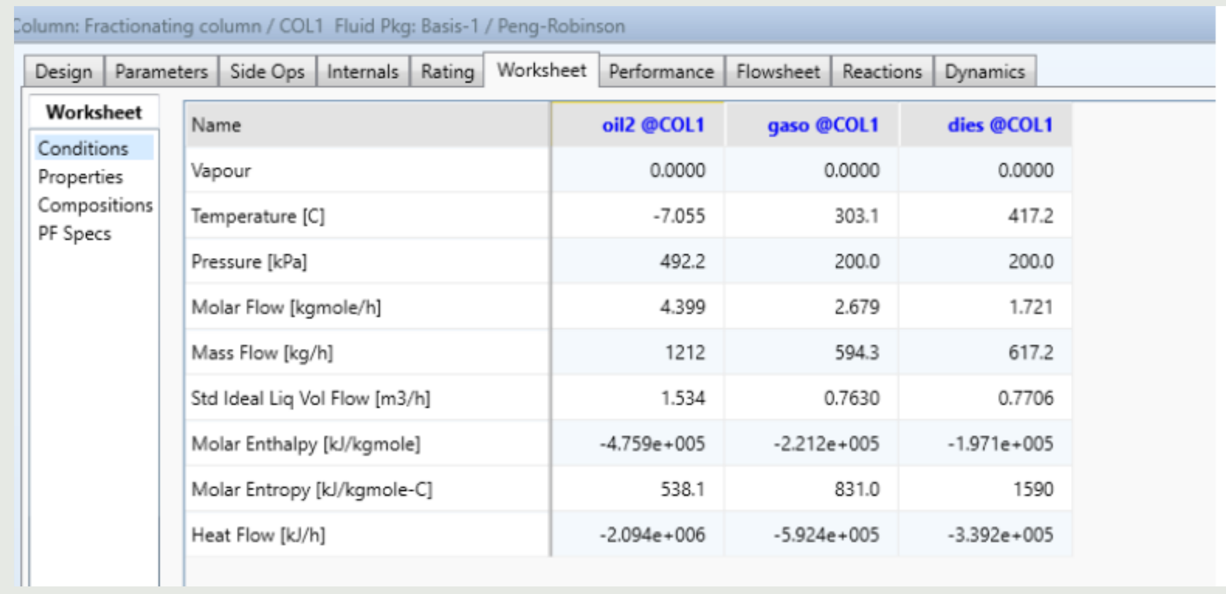
Prototype Design and Testing

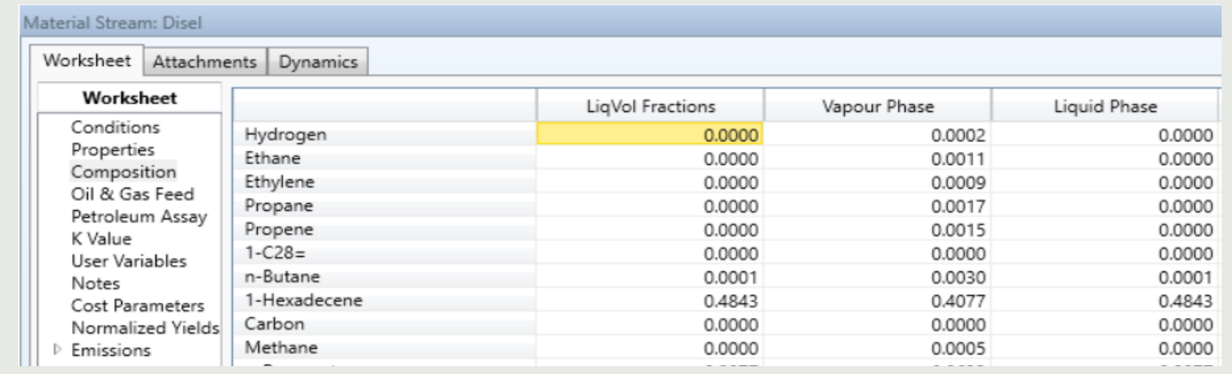
The process used for the conversion is Pyrolysis which is an oxygen-free process to convert complicated carbon chains in plastic into useful fuel. Our prototype is computer-based prototype using Aspen Hysys v11 as our designing software. We have used couple of assumptions in our process.
• Plastic particles in our feed to be within the range of 0.1 to 0.5 mm.
• The process is under steady state.
• The feed is pure HDPE.
We used 2000 kg/h of HDPE as basis



Methodology and Results

Results and Specifications are illustrated in the two figures below extracted from the simulation software:





Pyrolysis oils from both separators is mixed in a mixer unit and we obtained pyrolysis oil with 1212 kg/h with 60.6% conversion. Also, to separate pyrolysis oil to diesel and gasoline, we used a fractionating column and we obtained 594.3 kg/h of gasoline and 617.2 kg/h of diesel. Cetane number and sulfur content of diesel fuel have met our specification successfully. However, gasoline fuel fails to meet specification. Furthermore, overall cost of the plant was calculated using Aspen Hysys v11 economic analysis tool and total CAPEX obtained was 4,191,630 $.

Conclusion and Acknowledgments

In conclusion, this project studies the feasibility of plastic waste upcycling facility that transforms plastic waste from industrial facilities into renewable sources of energy that meets the market's specifications with the minimum possible cost. A contribution of Industrial and Chemical Engineering tools were utilized in this project such as AHP, mathematical modeling and process simulation.

First and foremost, all the thanks and gratitude are due to Allah the one who allowed this project to be accomplished. Then all the sincere gratitude to the esteemed professor Dr. Wasif Farroq for his invaluable guidance and continuous support.