In the search for carbon-neutral waste-to-resource processing routes: coupling plastic waste pyrolysis and CO_2 capture towards Circular Economy

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Introduction

The circular economy paradigm offers an attractive path toward sustainability since it creates value and growth in ways that benefit customers, businesses, society, and the environment. It is a systems solution framework based on three principles: eliminate waste and pollution, keep products and materials in use, and compensate for natural systems exploitation. In this direction, in the last decades, there has been a vast development towards the treatment and recovery of plastic materials. Among all these emerging alternatives, pyrolysis has proven to be very promising from several points of view for the upcycling of plastic waste (Pacheco-López et al., 2022). Despite its economic and environmental benefits, pyrolysis is an energy-demanding process (above 2MJ per kg of plastic waste), and combustion is one of the most economical energy-supply alternatives due to the higher cost of other energy sources (such as electric power). In consequence, even though the entire process might be environmentally favorable, there is still a considerable amount of carbon dioxide emissions (around 150g of CO_2 per kg of plastic waste). To promote a carbon neutral, or even carbon negative, process, the coupling of carbon capture technologies and pyrolysis arises as a suitable solution to improve the process from the environmental perspective. Currently, several alternatives are available for CO_2 separation including capture from post-combustion, pre-combustion, oxy-combustion, chemical looping combustion, as well as ambient air capture. The most commercially available and mature post-combustion capture process is chemical absorption, usually with aqueous amine solutions. Among them, monoethanolamine (MEA) has good CO_2 transfer rates, has a low price, and is biodegradable. However, it may suffer from toxicity and solvent losses due to evaporation and degradation; additionally, at higher concentrations, the MEA solution is highly corrosive to the equipment. Therefore finding alternative CO_2 absorbents is an arising challenge (Wang and Song, 2020). The captured CO_2 is usually stored, but it can be utilized to synthesize valuable chemicals (i.e., CCU or carbon capture and utilization) such as carbon monoxide, formic acid, methane, methanol, ethanol, or ethylene via electroreduction. However, these technologies are currently underdeveloped, and it is hard to predict their performance at an industrial scale (Somoza-Tornos et al., 2021).

Methodology

In this contribution, the pyrolysis of Mixed Plastic Waste (MPW) at 500ºC has been chosen for plastic waste upcycling, as it has proven to be a very promising alternative according to several objectives, as shown by the synthesis and assessment framework developed by Pacheco-López et al., (2022): further specifications are also presented in that contribution. The required energy to carry out the pyrolysis was obtained with a fired heater, using as fuel the hard-to-separate mixture of heavy compounds from the pyrolytic liquid with an 80% efficiency and a stoichiometric amount of air, therefore avoiding the need to use any other fuel. This process was coupled with a Carbon Capture (CC) Unit, using chemical absorption with 30 wt.% MEA to separate the CO_2 from the flue gases (assuming a typical 4 wt.% CO_2 composition). The entire process was simulated and designed with Aspen Plus® (see Figure 1) and its economic performance was evaluated using the Aspen Plus Economic Analyzer®. The obtained capital cost was annualized accounting for a 10-year depreciation scheme with a 15% fixed interest rate, including other costs, such as ISBL equipment installation, OSBL construction, engineering, and contingencies, finally, it was converted to an hourly rate considering 8000 operational hours per year. The same procedure was applied to the CC Unit and their economic performances were compared to assess the impact of integrating them (Table 1).

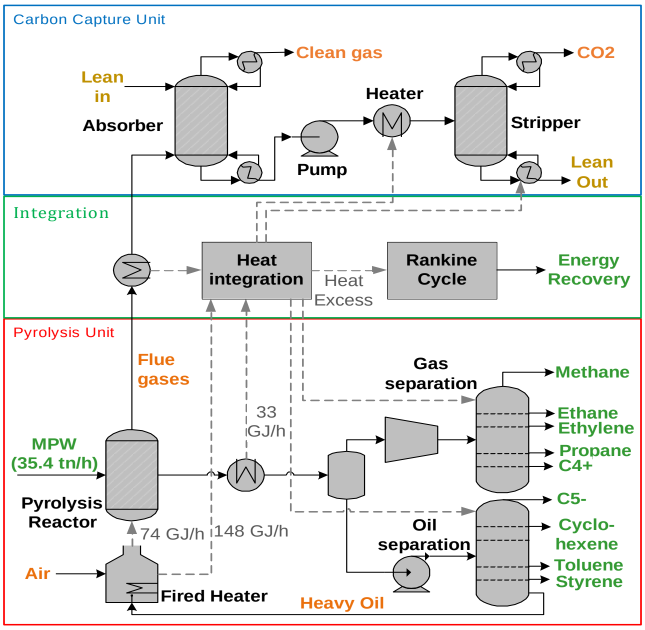

Figure 1. Simplified process flow diagram of the coupled pyrolysis and carbon capture units.

Table 1. Techno-economic assessment summary.

Concept	Units	Amount
Pyrolysis Unit (Capital cost: 70.75 MM$)		
MPW feedstock	kg/h	35,420
Operative cost	$/h	15,258
Product revenues	$/h	22,277
Total produced CO_2	kg/h	5,161
CC Unit (Capital cost: 6.23 MM$)		
Flue gas design capacity	kg/h	200,000
Operative cost	$/h	1,187
Total		
Total operative cost	$/h	15,575
Profit excluding CC Unit	$/h	7,019
Profit including CC Unit	$/h	6,702

Concluding remarks

A preliminary economic assessment has been performed on the proposed coupled plastic waste pyrolysis and CC process. The results show that including this new unit in the pyrolysis has a relatively low impact on its overall cost (8.5% cost increase) and thanks to the heat integration, a lower impact on the tentative profit (4.5% profit decrease). The integration of both processes offers a symbiotic effect and provides a more environmentally favorable process, leading to zero carbon emissions, the upcycling of waste, and the production of valuable chemicals. It is important to remark that the profit could be increased with the addition of CO_2 electrolytic technologies. As a future work, it is expected to continue exploiting the symbiotic potential of the proposed integration by coupling CC with *in situ* conversion steps, which should offer further significant improvements in terms of compensation of previous environmental impacts (circularity), overall energy efficiency and cost-effectiveness, as well as the synthesis of a variety of carbon-based chemicals. This fact could in turn increase the economic performance even more if carbon emissions trading is considered.

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