AGILE TECHNO-ECONOMIC ANALYSIS AND LIFE CYCLE ASSESSMENT TO ADVANCE THE 'POLY-CRUDE' PRODUCTION FROM PLASTIC WASTE

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Abstract

The increasing plastic waste accumulation in landfills and the environment has emerged as a critical global challenge. Among various strategies to address this issue, chemical recycling has gained attention for its ability to convert plastic waste into high-quality products. However, the development and adoption of any recycling technology depends on its long-term economic viability. Given that these processes compete with fossil-based products, achieving feasibility often requires large-scale operations and a multiproduct approach, both of which demand significant capital investment. This project addresses these challenges by integrating plastic waste into the petrochemical supply chain, leveraging energy efficiency and the infrastructure of established petroleum processes to achieve significant cost savings. Our conceptual model targets an energy-dense liquid, termed 'poly-crude' as a refinery feedstock, using catalytic hydrocracking. Hydrocracking yields high paraffinic hydrocarbons, aligning with conventional refinery inputs. To evaluate the economic and environmental feasibility of poly-crude production, we conduct a techno-economic analysis (TEA) and life cycle assessment (LCA). We assess two hydrogen-handling scenarios: (1) hydrogen purchase and storage, and (2) on-site hydrogen production. The minimum selling price (MSP) of poly-crude is estimated at \$3.27/gal for the hydrogen purchase scenario and \$2.68/gal for on-site hydrogen production, with capital costs being the primary economic driver. The first scenario incurs higher costs due to hydrogen storage, while the second benefits from a 37% reduction in capital expenses. In terms of environmental performance, the GHG emissions for the on-site hydrogen production scenario are significantly lower due to the shift from steam-reformed hydrogen to green hydrogen derived from PEM electrolysis. This study provides valuable insights into the economic and environmental potential of poly-crude production, highlighting the benefits of integrating plastic waste into the existing petrochemical infrastructure.

Introduction and Motivation

Plastic versatility and outstanding properties have made plastic an indispensable material across a wide range of applications, driving a global production of 413.8 million metric tons in 2023[1]. This widespread use has resulted in substantial waste generation, with an estimated 300 to 400 million tons of plastic discarded every year[2]. The majority of this plastic waste is landfilled (40%), while a substantial portion (32%) ends up in the environment, followed by smaller portions managed through incineration and/or energy recovery methods (14%) and recycling (14%)[3]. The mismanagement of plastic has severely impacted ecosystems and exacerbated global warming, as in incinerating one ton of plastic releases three times its mass in CO_2[2]. Furthermore, plastic production currently accounts for 3.5% of global greenhouse gas emissions[4] and consumes 6% of the global oil supplies[3], numbers that are expected to rise with the exponential increasing in plastic demand. Many global initiatives are advocating for the valorization of plastic waste leveraging the high calorific value embodied in plastic waste and promoting initiatives towards circularity of plastic. Aligned with these efforts, chemical recycling has emerged as a promising solution, enabling the production of plastics and other chemical products from plastic waste with a quality comparable to those derived from virgin materials. Many chemical recycling methods have been investigated to produce monomers, chemical compounds and fuels[5,6]. However, the necessity for extensive separation and upgrading processes reduces both the economic feasibility and environmental advantages of using plastic waste as feedstock[7]. To address this, initiatives focused on producing intermediates products are being explored, aiming to leverage existing petrochemical infrastructure for refining processes[8]. The refinery integration approach seeks to utilize intermediate products from plastic recycling as feedstocks for steam crackers, enabling the production of base chemicals, including plastics. The goal is to support circular economic efforts, reduce the consumption of non-renewable resources and develop economically viable and environmentally sustainable recycling alternatives. Building on this, we aim to model and evaluate a hydrocracking process with the potential to produce a high energy-dense intermediate, which we refer as “poly-crude”. Poly-crude describes a product containing long hydrocarbon chains in the range of C_{18}-C_{50}, with a high paraffinic content. This composition makes poly-crude suitable for direct integration into existing refinery operations. Our study will perform a techno-economic analysis and life cycle assessment at the early stages of technology development to guide research strategies and support decision-making processes.

Review of related work

Due to the large scale operations of industrial crackers, it is likely that liquid feedstocks of plastic waste will be blended with fossil-based feedstocks[8]. Therefore, refinery integration requires a liquid feedstock that is compatible with the composition requirements of steam crackers. Among the various chemical recycling technologies, pyrolysis is one of the most extensively studied and has been proposed as a method to produce an intermediate product, known as pyrolysis oil. One of the key advantages of pyrolysis is its ability to process complex mixtures of plastics, thereby increasing the utilization of plastic waste[9]. However, the composition of pyrolysis oil often exceeds the maximum impurity limits acceptable for cracker feedstocks[8], necessitating additional treatment steps to meet the desired composition. Without extensive pretreatment, only 5% of substitution of fossil feedstocks with pyrolysis oil is feasible. While increasing the substitution to 20% is possible with additional hydrotreatment, the associated greenhouse gas (GHG) emissions benefits decline significantly, from an approximately 23% reduction to just 4% improvement compared to the production of virgin polyolefins from fossil feedstocks[10].

Alternative processes such as hydrothermal liquefaction (HTL) have been investigated for plastic waste conversion using sub- or supercritical water. While HTL can produce liquid hydrocarbons, its low selectivity towards paraffinic products (up to 50%)[11] makes it unsuitable for refinery integration. Hydrogenolysis, another alternative, preferentially cracks long hydrocarbon chains, maximizing the yield of high-quality liquid while suppressing the formation of light hydrocarbons[12]. However, hydrogenolysis typically requires reaction times exceeding 24 hours[6], limiting its commercial viability. In contrast, hydrocracking occurs on bifunctional catalysts, where cracking reactions take place at Brønsted acidic sites in a hydrogen-rich atmosphere[13,14]. This catalytic mechanism enables significantly shorter reaction times (1-6 hours) while achieving high liquid yields (> 70%) and minimal char formation[15–17]. Similar to hydrogenolysis, hydrocracking produces paraffin-rich liquid products, but its faster conversion and high selectivity make it a promising process for producing feedstocks suitable for steam crackers.

While numerous studies have examined the reaction mechanisms and performance of plastic waste hydrocracking, few have investigated its economic and environmental implications, and no studies have been found that evaluate the feasibility of producing intermediate products through hydrocracking. Hydrocracking of polyolefins typically occurs at 250-300 °C and 30-60 bar of H_2 pressure[16,17]. Preliminary techno-economic analysis indicate that the significant capital expenses associated with pressure operations and H_2 requirements are present challenges to the economic feasibility of hydrocracking[5,18]. Our study aims to address these challenges by: (1) developing a model that target an intermediate product or ‘poly-crude’, which reduces the need for extensive refining and, consequently, capital investment; and (2) generating long-chain hydrocarbons that reduce cracking events[14] and, in turn, H_2 requirements.

Technology Approach

Process description

The modeled process converts 250 ton/day of low-density polyethylene (LDPE) plastic waste into poly-crude (main product) and light hydrocarbons (co-product) via hydrocracking. LDPE was selected as the feedstock due to its extensive research on plastic waste hydrocracking[16,17,19], its widespread presence in plastic waste and potential availability, as well as its lower cost compared to HDPE, which is primarily used in mechanical recycling[20]. The 250 ton/day capacity was chosen based on studies suggesting it as the minimum scale for economic feasibility[21,22]. We used Microsoft Excel to incorporate data, design formulas, and external models for building the poly-crude manufacturing model. Process and equipment designs were based on process design methodologies[23,24] and literature models[7,25],[26–28]. External tools, including Python (v3.12.5) and ASPEN, were employed to model liquid-vapor separations. Figure 1.a shows the conceptual design of poly-crude manufacturing and Figure 1.b provides a more detailed representation.

a)

b)

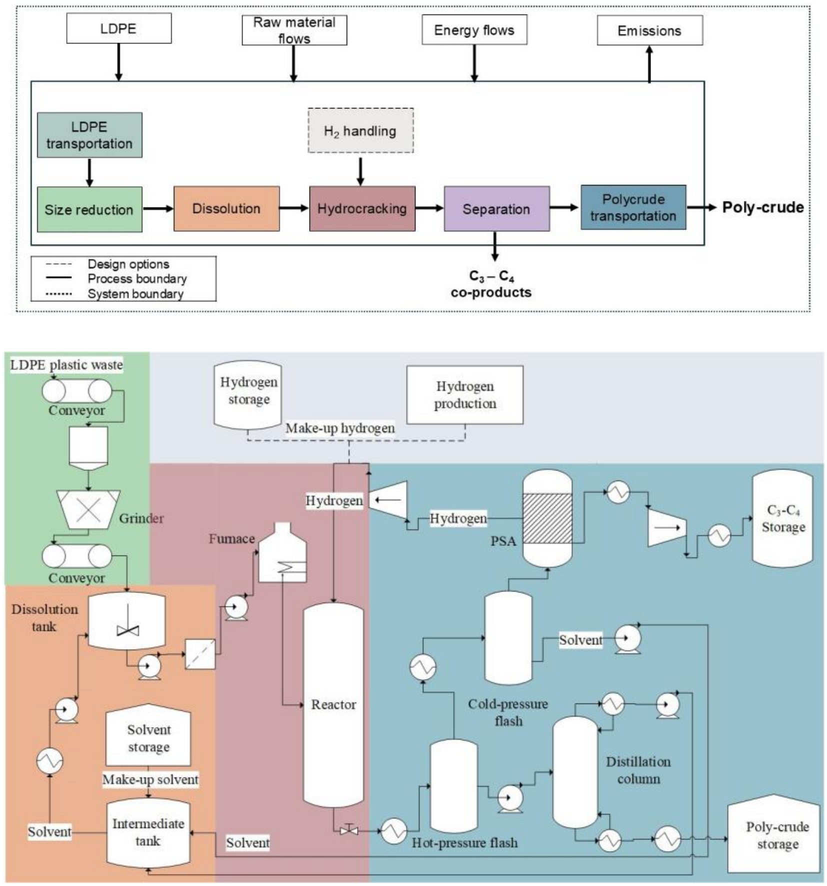

Figure 1. Poly-crude manufacturing process: a) Block diagram illustrating the system boundary for the cradle-to-gate LCA. b) Detailed process diagram highlighting the processing sections: size reduction (green), dissolution (orange), reaction (pink), separation (blue), and hydrogen handling (gray).

Size reduction and Dissolution sections: The modeled process starts with the transportation of LDPE plastic waste in bales from the material recycling facility (MRF) to the recycling plant. Then, the feedstock size is reduced in a grinder to smaller pieces or flakes. LDPE flakes are dissolved in dodecane (solvent) to decrease the polymer melt viscosity, enhance mass transfer, and as a result, increase the low reaction rates observed in hydrocracking reactions[12,16]. The dissolution is conducted in an agitated tank at 120 °C, using a LDPE: solvent ratio of 1:10 to achieve complete dissolution[29]. In this base case scenario, the solvent is not produced within the system. Instead, the model considers the recycling of the recovered solvent. The dissolution of plastic waste before entering the reactor has also been explored for thermal pyrolysis, where polyethylene is dissolved in wax (recycled from the system) to produce pyrolysis oil[31–33]. These studies suggest that a liquid feed enhances heat transfer within the reactor, improves flow properties and provides better control over residence time.

Hydrocracking and separation sections: The reactor operates at 300 °C and 11.7 H_2-bar, achieving 100% conversion and a poly-crude yield (poly-crude mass rate/LDPE mass rate) of 90%[12,17]. Before entering the reactor, the LDPE dissolution is preheated from 120 °C to 300 °C using a furnace, while hydrogen is pressurized to 11.7 H_2-bar. The reaction output consists of a mixture of poly-crude, a light mix of hydrocarbons (C_3-C_4), hydrogen, and solvent (C_{12}), which are separated into a series of flash vessels (Figure 1.b). Since the catalytic conversion of polyolefins results in a narrow product distribution, we use $C_{34}H_{70}$ as a representative hydrocarbon to characterize the properties of poly-crude[12]. The poly-crude and solvent are recovered through a hot, low-pressure flash and further separated into a distillation column. Meanwhile, the lighter components are separated from the residual solvent using a cold, low-pressure flash. The recovered solvent, with 99.98% recovery, is mixed with make-up solvent to compensate for process losses, heated to 120 °C, and recycled back into the dissolution tank. Finally, the hydrogen is separated from the light hydrocarbon mixture via pressure swing adsorption, which operates at 68 °C and achieves an 85% hydrogen recovery rate[34]. The light hydrocarbon mix is liquified before storage. Both poly-crude and the light hydrocarbon mix are stored for an average of 2 weeks[23] before being sold[18,35].

Hydrogen handling section: The recovered hydrogen is mixed with make-up hydrogen to compensate for the H_2 consumed during the reaction and the unrecovered H_2. Two scenarios are considered for supplying the make-up hydrogen: the "Hydrogen purchase & storage" scenario and the "On-site hydrogen production" scenario. In the first scenario, hydrogen is purchased and stored as pressurized gas at the plant. In this scenario, we assume H_2 is produced off-site via steam methane reforming. In the second scenario, green hydrogen is produced on-site through polymer electrolyte membrane (PEM) electrolysis. We incorporated the PEM model developed by NREL[36].

Techno-economic analysis

The TEA of poly-crude production was conducted to calculate its minimum selling price (MSP), following established cost analysis methodologies based on nth-plant project costing and financing[26]. DCF incorporates the total capital investment (TCI) and operating cost. The TCI is based on the equipment cost, which were estimated using cost equations based on size factors[23,24]. When no cost equation was available, values from the literature were escalated to the required capacity using 6-tenths rule. All equipment costs were updated to 2023 U.S dollars using the Chemical Engineering Plant Cost Index (CEPCI). Operating costs compromise variable costs, such as those for the inputs listed in Table 1, and fixed costs, which include labor-related expenses. From the DCF, the minimum selling price (MSP) was calculated by setting the net present value (NPV) to zero. The MSP serves as the economic indicator, representing the potential market price of poly-crude and enabling comparison with alternative products or target price benchmarks.

The baseline TEA was conducted under the conditions outlined in Table 1. To assess the variability of the model inputs, an uncertainty analysis was performed using Monte Carlo simulation with 3000 iterations in Oracle Crystal Ball. The analysis accounted for fluctuations in raw material prices, DCF parameters and key design variables, including reaction performance metrics. Specifically, for the H_2 purchase and storage scenario, we considered a price range of $1.25 to $5 per kg, reflecting different hydrogen sourcing methods (e.g., steam methane reforming, renewable hydrogen).

Table 1. Summary of the inputs and outputs to produce 1 kg of poly-crude.

		H_2 purchase & storage	On-site H_2 production	Price
Input	LDPE plastic waste, kg	1.170	1.17	0.231 $/kg[30]
	Makeup solvent, kg	0.007	0.007	5.68 $/kg[41]
	Replacement rate of Pt/zeolite catalyst†, kg	5.057E-05	5.057E-05	326.5 $/kg[7]
	Heat utility (natural gas), kg	0.260	0.260	0.235 $/kg[42]
	Electricity, kWh	0.492	0.455	0.081 $/kWh[43]
	Cooling water, kg	238.77	196.41	0.065 $/m^3 [40]
	Makeup hydrogen, kg	0.006	0.006	2.05 $/kg[44]
Output	Mix light hydrocarbons, kg	0.039	0.039	0.49 $/kg[45]

†The catalyst replacement rate was calculated based on full replacement every 3 years over a plant lifespan of 20 years.

Life cycle assessment

The LCA of poly-crude production was conducted to evaluate the greenhouse gas (GHG) emissions per 1 gallon of poly-crude and identify the primary contributors to these emissions. The results will facilitate a comparison of the environmental impact of poly-crude with other potential alternatives such as pyrolysis oil (for plastic-based alternatives) and crude naphtha (for fossil-based alternatives), respectively[37]. The LCA was performed in R&D GREET

2024. NET (Greenhouse gases, Regulated Emissions, and Energy in Technologies model) software[38]. In GREET, the poly-crude manufacturing design was created using the existing Post-Use Plastic (PUP) conversion inventory data and pathways as a reference. Table 1 summarizes the material and energy inputs to produce 1 kg of poly-crude.

The system boundary for the LCA, shown in Figure 1.a, includes the processing sections, transportation of LDPE to the plant and poly-crude to the refinery, as well as the upstream emissions from raw materials, and energy production, making it a cradle-to-gate assessment. For the plastic waste LDPE, the upstream emissions are attributed to waste collection, transportation to the MRF, and sorting[39], with zero burden assigned to LDPE itself[40]. The co-product treatment in GREET was conducted using both energy allocation and co-product displacement, the latter applying the system expansion approach. In this approach, we assumed that the light hydrocarbons displaced an equivalent amount of light petroleum gas (LPG) produced from crude oil. To maintain consistency with the methodology used in LCA of hydrocracking[7,39], the GHG emissions presented are based on the displacement method unless otherwise stated. Finally, we further explore the impact of transportation distance and electricity source in a local sensitivity analysis.

Discussion

Techno-economic and Life cycle assessment

The minimum selling price of poly-crude is calculated at 3.27$/gal poly-crude and 2.68$/gal poly-crude for the H_2 purchase & storage scenario and On-site H_2 production scenario, respectively. The higher MSP in the first scenario is primarily attributed to the elevated capital cost contribution of 1.23$/gal poly-crude (Figure 2.a), driven by the substantial expense of hydrogen storage tanks (534 $/kg H_2 store). Additionally, H_2 purchase contributes an extra 0.10 $/gal poly-crude to the MSP. In contrast, the On-site H_2 production scenario benefits from a 37% reduction in capital costs, which offsets the 9% increase in utility and electricity expenses associated with green hydrogen production. The largest variable cost contribution is from LDPE plastic waste, accounting for 0.8 $/gal, followed by smaller contribution (less than 0.2 $/gal each) from utilities, raw materials and other costs. Additionally, the production of light hydrocarbons provides a credit of 0.07 $/gal to the MSP of poly-crude.

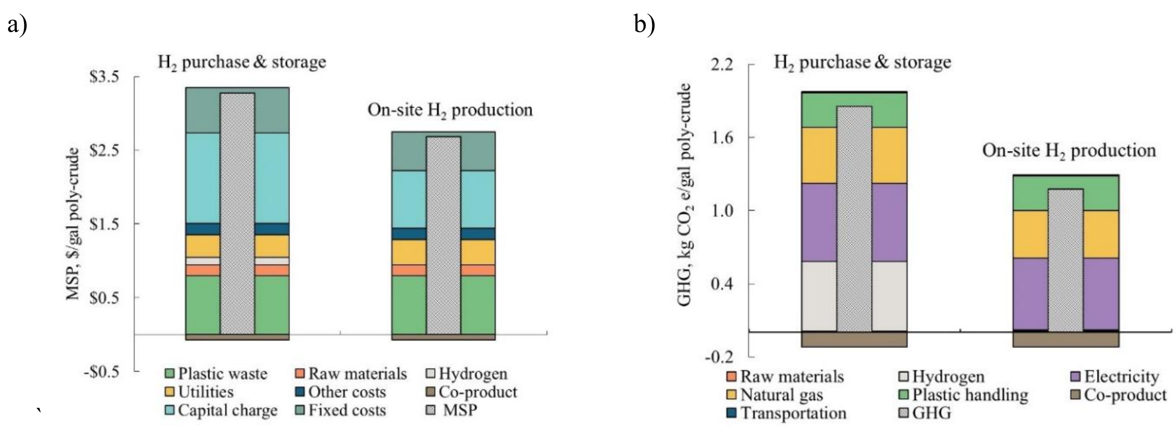

Figure 2. a) MSP of poly-crude and b) GHG emissions across the two scenarios. "Raw materials" include solvent and catalyst replacement. In the MSP, "other costs" encompass solid disposal and transportation. In the GHG "plastic handling" accounts for collection, sorting and transportation, while "transportation" refers to poly-crude.

GHG emissions are calculated at 1.856 kg CO_2-e/gal poly-crude in the H_2 purchase & storage scenario and 1.175 kg CO_2-e/gal poly-crude in the on-site H_2 production scenario. Two key differences in the inputs between the scenarios contribute to this variation. First, additional emissions arise in the H_2 purchase & storage scenario due to hydrogen transportation and compression prior storage. Second, while the quantity of H_2 input remains the same in both scenarios (as shown in Table 1), the source differs: purchased hydrogen is derived from steam reforming, whereas on-site hydrogen is produced via PEM electrolysis. This change in the hydrogen source results in a significant reduction in hydrogen-related emissions, as illustrated in Figure 2.b. Hydrogen-related emissions drop from 0.568 kg CO_2-e/gal poly-crude for steam-reformed H_2 (first scenario) to negligible levels for green H_2 (second scenario).

Another significant source of GHG emissions is electricity, contributing between 0.592 to 0.640 kg CO_2-e/gal poly-crude, depending on the scenario assessed. The largest consumers of electricity are the size reduction and separation sections, collectively accounting for 89% to 96% of the total electricity-related emissions. In the separation section, in particular, the emissions are driven by the energy requirement of compressors to reach the H_2 pressure. The third-largest GHG emission is natural gas, contributing 0.381 to 0.460 kg CO_2-e/gal poly-crude (Figure 2.b). Natural gas is utilized for heating the plastic dissolution in the reaction section and for steam generation to support cooling processes in the separation section. Plastic handling contributes an additional 0.286 kg CO_2-e/gal poly-crude, with emissions distributed as follows: transportation to MRF (26%), sorting (32%), and transportation to the plant (42%). The contributions from raw materials and poly-crude transportation are minimal, each accounting for less than 1% of the total emissions. Finally, Figure 2.b shows the co-product credit of 0.118 kg CO_2-e/gal poly-crude, applied due to the displacement approach used in the analysis.

Comparison of MSP and GHG emissions from poly-crude and alternative products

To assess the economic viability of poly-crude manufacturing, the minimum selling price (MSP) of poly-crude is compared against a target MSP of 2.38 \$/gal (Figure 3.a), which reflects the input from potential end-users in the petroleum industry. For additional context, Figure 3.a also shows the pyrolysis oil price set at 3.20 \$/gal[38] as a benchmark. The MSP results for poly-crude are presented for the base line case with uncertainty analysis depicted by the 5th (lower bound) and 95th (upper bound) percentiles. In the scenario involving H_2 purchase and storage, the MSP exceeds the target MSP across all simulations. On the other hand, the on-site H_2 production scenario demonstrates improved economic performance, with approximately 25% of the simulated cases achieving an MSP below the target. Furthermore, when compared to the pyrolysis oil price, the on-site hydrogen production scenario offers a more cost-effective alternative, highlighting its potential for enhanced economic feasibility.

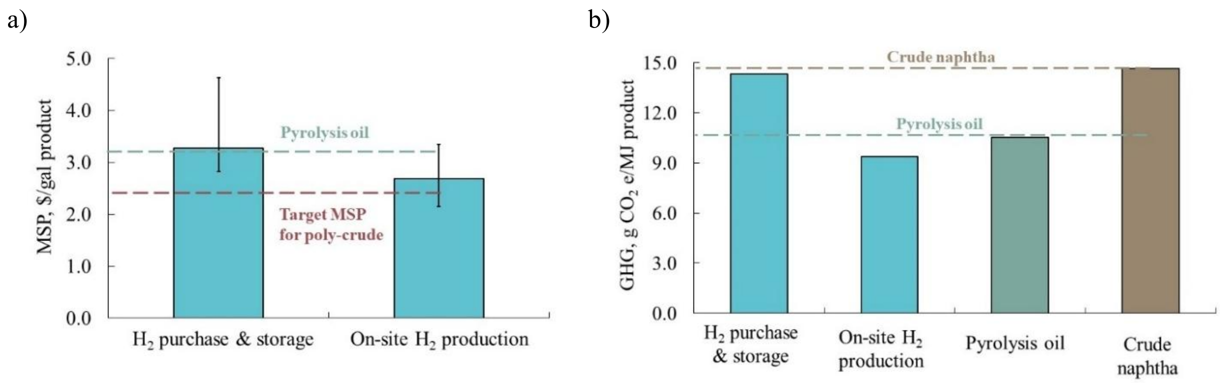

Figure 3. a) MSP of poly-crude compared to pyrolysis oil and the target MSP for poly-crude and b) Net GHG emissions of poly-crude compared to pyrolysis oil and crude naphtha alternatives.

The economic performance of poly-crude manufacturing is primarily influenced by capital expenses and the costs of LDPE feedstock (Figure 2.a). Further improvements in reaction performance would not only decrease the LDPE requirement per unit of poly-crude produced but also reduce the size of equipment needed, ultimately lowering capital costs. Our previous study (unpublished) further supports this, showing that poly-crude yield and reaction time are critical economic drivers of the process. Optimizing the reaction conditions could enhance the competitiveness of poly-crude, particularly in the on-site hydrogen production scenario, which already demonstrates a better economic feasibility. Figure 3.b presents the net GHG emissions (with energy allocation) of poly-crude compared to crude naphtha (a fossil-based alternative) and pyrolysis oil (a plastic-based alternative). Naphtha is an ideal benchmark due to its widespread use as a feedstock in existing steam crackers and refinery processes[8], in which poly-crude could potentially be blended. The cradle-to-gate emissions for alternative products were leveraged from the GREET 2024 model[38], using the energy allocation approach. The results reveal that poly-crude from plastic waste can achieve GHG reductions of 2% to 36% compared to crude naphtha, depending on the scenario assessed. In addition, only poly-crude produced with green hydrogen (on-site production) demonstrates comparable environmental performance when compared to pyrolysis oil.

Both crude naphtha refining and pyrolysis oil production benefit from internal utilization of co-products for heating purposes, reducing their overall energy demands and environmental burdens. For crude naphtha refining, 0.08 MJ of still gas is co-produced per 1 MJ of crude naphtha[38]. This still gas is internally utilized for heating, reducing external energy demand, but its burning accounts for 32.14% of total process GHG emissions[38]. Similarly, pyrolysis oil production yields a higher amount of co-product fuel gas, generating 0.2 MJ of fuel gas per 1 MJ of pyrolysis oil[10,38], supplying about 77% of the total energy required for this process[38]. In contrast, hydrocracking of plastic waste yields lower light-hydrocarbon content as co-products[14,17]. In this study, there is a production of 0.05 MJ of light hydrocarbon mixture (mainly C_3 and C_4) per 1 MJ of poly-crude. However, this preliminary analysis does not account for potential heat integration of these co-products, meaning the avoided burden of utilizing them for internal heating and the additional emission from their combustion are not reflected in Figure 3.b. Additionally, even though higher GHG emissions benefits could be expected from hydrocracking because it operates at lower temperatures than pyrolysis (300°C compared to 450°C- 700°C[37]), particularly with on-site H_2 production, this benefit seems to be offset by lower co-product yields in hydrocracking. Future work should explore the impact of reaction performance and heating integration strategies in the hydrocracking process. This analysis could provide a more comprehensive understanding of the GHG emission reductions achievable with poly-crude production and identify potential areas for process optimization to improve environmental performance further.

Any strategy aimed at improving either the MSP or GHG emissions must account for inherent trade-offs, requiring careful consideration of both environmental and economic impacts. For instance, the significant contribution of natural gas to GHG emissions highlights the potential for implementing heat integration strategies to achieve further emission reductions. As discussed earlier, increasing the production of light hydrocarbons could amplify these benefits. Nevertheless, this approach may introduce trade-offs, such as increased LDPE feedstock requirements per unit of poly-crude produced, larger equipment sizes, and higher utilities consumption, all of which negatively impact both the MSP and GHG emissions. Conversely, strategies to reduce the production of short hydrocarbon chains (increasing poly-crude yield) can lower H_2 consumption during hydrocracking, thereby reducing make-up H_2 requirements. This reduction is particularly impactful in the H_2 purchase & storage scenario, where H_2-related capital costs and H_2 emissions are main components of the MSP and GHG emissions, respectively.

Local sensitivity analysis in GHG emissions

Improving the environmental performance of poly-crude manufacturing can also be achieved by transitioning to greener sources of electricity, as electricity accounts for approximately 30% of the total GHG emissions in the process (Figure 2.b). To evaluate this potential, we conducted a sensitivity analysis on the impact of the electricity source on GHG emission. Additionally, we analyzed the sensitivity of the transportation distances for LDPE and poly-crude, given the high uncertainty associated with these values. Figure 4 shows the results for the on-site H_2 purchase scenario, which has been identified as the most promising option. The analysis highlights that the electricity source has the most substantial impact on emissions. In the base case, we assume the USA grid mix, which has 60% of fossil fuels and 40% of renewable energy sources[38]. In comparison, the California (CA) mix, with 54% renewables[38], reduces 16.5% of the GHG emissions, while the Midwest mix (MRO), with 68% fossil fuel content[38], yields higher emissions. Leveraging energy mixes with greater renewable content could reduce emissions by 53% compared to crude naphtha, underscoring the importance of cleaner energy sources in improving environmental performance.

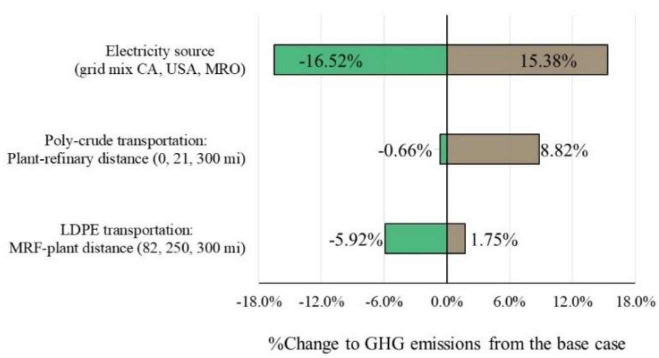

Figure 4. Local sensitivity analysis for the On-site H_2 production scenario.

The transportation distances for feedstock and poly-crude are based on survey data from pyrolysis plants[37] and optimal distances identified in studies of the plastic waste supply chain[46]. The base case assumes the recycling plant is situated closer to the refinery (21 miles) and relatively further from the MRF (250 mi), consistent with prior research findings[20,21]. The local sensitivity analysis explores scenarios where the plant-refinery distance ranges from 0 (co-located at the refinery) to 300 miles (Figure 4). Locating the plant at the refinery results in a 9% reduction in emissions compared to the 300-mile scenario. Similarly, variations in the transportation distance for LDPE to the plant lead to comparable changes in GHG emissions. Even at the maximum LDPE and poly-crude distance, the emissions for poly-crude in the on-site H_2 production scenario (10.02 g CO_2e/MJ poly-crude) remain lower than those of the fossil-based alternative, reinforcing the environmental advantage of the proposed process.

Conclusions & Recommendations

This study presents the TEA and LCA of producing poly-crude from LDPE plastic waste via hydrocracking. The results demonstrated that on-site H_2 production via electrolysis is a promising pathway for plastic conversion, balancing environmental sustainability with economic feasibility. On-site hydrogen production reduced the baseline MSP by 18% and the GHG by 37% compared to the H_2 purchase & storage scenario. The system analysis identified capital costs and LDPE feedstock price as the primary contributors to the MSP, while H_2 source, electricity, natural gas and LDPE handling were the largest contributors to GHG emissions. TEA findings suggest that poly-crude production has the potential to become economically competitive with pyrolysis oil production. Furthermore, the LCA results show that poly-crude production achieves comparable environmental performance to pyrolysis oil production while significantly reducing GHG emissions compared to crude naphtha (from 14.66 g CO_2/MJ naphtha to 9.39 g CO_2/MJ poly-crude).

This study provides a preliminary discussion of the trade-offs between environmental and economic performance, with a focus hydrogen handling. Future work will explore the alternative scenarios on heat integration and identify the most environmental and economic options. In particular, understanding how product distribution impacts these indicators, especially the potential production of medium-chain hydrocarbons for use as internally recycled solvent, will be critical. These insights will provide valuable guidance for catalyst design optimization. Overall, the results underscore the potential of poly-crude as a sustainable alternative to refinery-compatible feedstocks, offering a new pathway to reduce fossil fuel dependence, increase plastic waste valorization and advance the circular economy for plastics.

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