**Sustainable Production of Alternative Aviation Fuel via Thermolytic Conversion of Plastic Waste: Techno-economic Analysis and Life Cycle Assessment**

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**ABSTRACT**

Conversion of plastic waste into transportation fuels via pyrolysis has been garnered significant research interest. However, developing scalable process alongside comprehensive techno-economic and environmental assessments remains underexplored. This study presents a viable scalable process for producing alternative aviation fuel from plastic waste, particularly high-density polyethylene (HDPE), through pyrolysis. Prior to process design, HDPE pyrolysis experiments at 500, 600, and 700°C were conducted to investigate the influence of temperature on aviation fuel yield, revealing that pyrolysis at 500 and 600°C was most effective. Based on these findings, two aviation fuel production processes (AFP-500 and AFP-600) were developed, integrating pyrolysis at 500 and 600 ˚C with catalytic cracking. Notably, catalytic cracking was employed to convert wax produced during pyrolysis into aviation fuel. Simulation results showed that a HDPE feed rate of 5,000 kg h-1 yielded 1,523 and 1,159 kg h-1 of aviation fuel in AFP-500 and AFP-600, respectively. Techno-economic analysis (TEA) revealed that the levelized cost of production (LCOP) for AFP-500 and AFP-600 were 2.8 and 5.4 USD gal-1, respectively, indicating that 500°C is the optimal pyrolysis temperature. Additionally, the aviation fuel cost from AFP-500 is 25–81% lower than that of sustainable aviation fuels (SAFs). A life cycle assessment (LCA) of AFP-500 evaluated its global warming potential (GWP) against landfill and incineration used as reference scenarios. Although landfill disposal exhibited the lowest GWP, it is not viable due to HDPE’s non-biodegradability. AFP-500 demonstrated a lower GWP than incineration, highlighting its potential as a more environmentally sustainable approach to plastic waste disposal.

**KEYWORDS:** *Aviation fuel; Plastic waste; Pyrolysis; Circular economy; Waste valorization*

# **1. INTRODUCTION**

Plastics have become indispensable materials in modern society [1]. They are widely used in various sectors, including packaging, medical, construction, electrical, and electronics, due to their advantageous properties, such as lightweight [2], mechanical and chemical durability [3], and low production cost [4], compared to conventional materials like wood, concrete, and metals. These functional benefits have driven an increase in plastic demand, leading to a surge in global plastic production from 2 million metric tons (Mt) in 1950 to 460 Mt in 2019 [5]. However, this rapid growth has raised environmental concerns, particularly regarding the accumulation of plastic waste. Specifically, when exposed to environmental conditions, plastic waste undergoes weathering [6] and breaks down into smaller particles (less than 5 mm), known as microplastics (MPs) and nanoplastics (NPs) [7]. Due to their hydrophobic nature, MPs and NPs have an affinity for organic and inorganic toxicants [8]. Because these small plastic fragments are easily ingested by living organisms [9], toxicant-contaminated MPs and NPs can enter the food web, posing risks to human health [10]. Therefore, reducing plastic waste discharge into the environment is crucial for mitigating these environmental concerns.

Landfilling is a common and cost-effective method for plastic waste disposal [11] and prevents its discharge into the environment. However, because of plastics’ extremely low biodegradability, landfill disposal does not directly reduce waste volume [12]. Additionally, leachates from landfills can contaminate surrounding soil and groundwater [13]. Alternatively, incineration is an effective waste management approach that significantly reduces waste volume. Given that plastics are manufactured using petroleum, their heating value is comparable to that of commercial fuels such as coal, diesel, gasoline, and natural gas [14], making heat recovery during incineration favorable. However, complete combustion of plastic waste is challenging due to difficulties in precisely controlling the fuel-to-oxidant ratio [15]. Consequently, incomplete combustion leads to the emission of air pollutants, including particulate matter (PM), polyaromatic hydrocarbons (PAHs), dioxins, and carbon monoxide (CO) [16]. Furthermore, the release of carbon dioxide (CO2), a major greenhouse gas, during incineration exacerbates global warming concerns [17]. In this context, developing environmentally friendly methods for plastic waste valorization has gained significant interest.

Pyrolysis is a viable option for valorizing plastic waste. This thermal decomposition process breaks down long-chain molecules into smaller ones in the absence of oxygen, producing liquid, gaseous, and solid products [18]. Additionally, product yields can be easily controlled by adjusting operational parameters such as temperature and heating rate [19]. Typically, pyrolysis of plastic waste is primarily performed to produce liquid hydrocarbons (HCs), commonly referred to as pyrolysis oil [20]. However, pyrolysis oil obtained from plastic waste consists of hydrocarbons with a wide range of carbon chain lengths [21]. Given that commercial fuels, such as gasoline, diesel, and aviation fuels, are specified within certain carbon ranges, controlling the HCs in pyrolysis oil to meet these specifications offers an opportunity for the practical application of pyrolysis oil. As a result, extensive research has focused on optimizing pyrolysis conditions for producing transportation fuels from plastic waste.

Lee et al. [22] investigated the conversion of high-density polyethylene (HDPE) into aviation fuel using two-stage pyrolysis, which consisted of a dynamic heating zone followed by an isothermal heating zone set at 500, 600, 700, or 800°C. The feasibility of the resulting HDPE-derived pyrolysis oil was evaluated using thermodynamic modeling in an ideal turbojet cycle. Their findings indicated that an isothermal temperature of 600°C in the second heating zone was optimal, producing HDPE-derived oil with compositional properties comparable to commercial aviation fuels, such as Jet-A, JP-8, and JP-5. Park et al. [23] conducted a two-stage pyrolysis of polystyrene (PS) to produce transportation fuels such as gasoline and diesel. Their system included an auger reactor followed by a fluidized bed reactor. The auger reactor was set at 300°C, whereas the fluidized bed reactor temperature varied from 500 to 780°C. They found that an optimal temperature of 780°C in the fluidized bed reactor yielded pyrolysis oil that met the standard properties of gasoline and diesel. Nugroho et al. [24] converted polypropylene (PP) into liquid fuels via vacuum pyrolysis under varying temperatures, heating rates, residence times, and flow rates. The maximum pyrolysis oil yield (28.5 wt.%) was achieved at 425°C with a heating rate of 15 ˚C min-1, a residence time of 6 h, and a flow rate of 0.1 L min-1. The resulting fuel exhibited properties similar to diesel. These studies demonstrated the potential for converting plastic waste into transportation fuels. However, they primarily focused on yield and product properties without addressing the economic viability of pyrolysis oil derived from plastic waste. This indicates the need for further analysis to validate the feasibility of this method.

Therefore, this study evaluates the feasibility of producing aviation fuel from plastic waste pyrolysis. Polyethylene (PE), which constitutes a significant portion of global plastic waste, was selected as a model compound to produce pyrolysis oil within the aviation fuel carbon range (C8–C16) [25]. To achieve this, two-stage pyrolysis with dynamic and isothermal heating of PE was conducted. The isothermal heating stage was maintained at either 500°C or 600°C. The resulting pyrolysis oils were qualitatively analyzed using gas chromatography/mass spectrometry (GC/MS), and their chemical composition was quantified using gas chromatography/flame ionization detection (GC/FID). Subsequently, the feasibility of HDPE pyrolysis for aviation fuel production was assessed through process simulations. Additionally, the environmental benefits of the proposed process were compared with those of conventional disposal methods (landfilling and incineration) using life cycle assessment (LCA).

The key novel contributions of this study are as follows:

1. This study provides experimental findings demonstrating the potential of pyrolysis for producing alternative aviation fuels from HDPE-based waste.
2. A full-scale process for aviation fuel production via HDPE pyrolysis was developed under optimal conditions identified through techno-economic analysis (TEA).
3. The environmental benefits of the proposed process were rigorously evaluated through LCA, highlighting its advantages over conventional disposal methods such as landfilling and incineration.

# **2. METHODOLOGY**

This section presents an overview of the methodology for designing a pyrolysis-based process to convert HDPE into aviation fuels. Specifically, Sec. 2.1 outlines the methodology for the pyrolysis experiment, which provided foundational data for process design. Sec. 2.2 describes the proposed process, which was developed based on experimental results. Sec. 2.3 and 2.4 explain the methodologies used for the TEA and LCA of the proposed process.

## **2.1. Pyrolysis experiment**

HDPE was converted into aviation fuel via pyrolysis using a multistage pyrolysis setup, as shown in Fig. 1. The primary reactor was a cylindrical quartz tube, with two ultra-Torr fittings connected to both ends to provide an inlet and outlet system. A tubular furnace with two heating zones served as the heat source. HDPE (5 ± 0.01 g) was placed at the center of the first heating zone in the quartz tube. The temperature of the first heating zone was increased from 100°C to 600°C at a heating rate of 10 ˚C min-1, whereas the second heating zone was maintained at 500°C, 600°C, or 700°C. The evolved pyrolysis products were passed through two cold traps maintained at 20°C and -40°C, respectively. The condensable products collected in both cold traps were diluted with 200 mL of dichloromethane (DCM ≥99.8%). The resulting solution was qualitatively and quantitatively analyzed using GC/MS and GC/FID. For calibration, standard solutions containing C8-40 alkanes (each at a concentration of 2000 mg L-1) and a mixture of benzene, ethylbenzene, and xylene isomers (BTEXs) were used. Chemical species not present in the standard solutions were quantified using the effective carbon number (ECN) method, which estimates the relative response factor based on the relative contribution of functional linkages in the chemical species [26].

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**Figure 1.** Schematic of the experimental setup for the multi-stage pyrolysis of HDPE

## **2.2. Process overview**

Fig. 2. illustrates the block diagram of the overall process for converting HDPE into aviation fuels, which consists of three main steps. First, HDPE undergoes pyrolysis (at 500 or 600 ˚C) to produce gas, oil, and wax. Second, a wax cracking process converts the heavy wax fractions (C>16) into shorter-chain HCs. The resulting oil and wax products from Steps 1 and 2 are then distilled to obtain aviation fuel-range HCs (C8-16). Finally, byproducts from Steps 1 and 2 are combusted to generate heat, which is used to produce low-pressure (LP) steam. Additionally, a CO2 capture process is implemented to manage CO2 emissions from combustion. Notably, entire processes involving pyrolysis at 500 and 600 ˚C denoted as AFP-500 and AFP-600, respectively. A detailed description of each process is provided in Sec. 2.2.1-3.

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**Figure 2**. Block diagram of the overall process for valorizing HDPE into aviation fuel

The overall process was simulated for two cases based on experimental results from HDPE pyrolysis at 500°C and 600°C. The experimental data were scaled up and adjusted for an HDPE feed rate of 5,000 kg hr-1. The Peng–Robinson (P-R) equation of state was employed as the thermodynamic model, as the process primarily involves HCs. The P-R method is widely used for predicting the thermodynamic behavior of HCs, particularly their vapor-liquid equilibrium (VLE) and thermodynamic properties under moderate pressure and temperature conditions [27].

### **2.2.1. Pyrolysis process**

Pyrolysis experiments were conducted using a furnace with two consecutive heating zones, which initially suggested the use of two reactors in the process model. However, in this study, the pyrolysis process was simulated based on experimentally determined product yields. It was assumed that HDPE conversion into gas, oil, and wax occurred within a single reactor operating at the temperature of the second heating zone (500°C or 600°C) under atmospheric pressure. Fig. S1. provides a schematic of the pyrolysis process. In the pyrolysis reactor, HDPE is converted into gas, oil, and wax. The resulting products are cooled to 20°C through a three-stage cooling system (HX-1, HX-2, and COOL-1). HX-1 uses deionized water (Stream No. 110) as the cooling medium, generating LP steam (LP steam-1). HX-2 employs air as the cooling fluid, which is subsequently introduced into COMB-1. COOL-1 relies on electricity for cooling. After cooling, the products are separated into gas, oil, and wax mixtures using a flash drum. The gaseous products (Stream No. 115) are combusted in COMB-1, with a combustion efficiency set at 70% to reflect realistic energy recovery potential [28]. The heat generated is supplied to the pyrolysis reactor to maintain its operating temperature, as the pyrolysis reaction is endothermic [29]. The oil and wax mixture (Stream No. 109) is then introduced into distillation columns, where aviation fuel-range HCs are separated and purified (Fig. S2.). The specifications of the distillation columns are summarized in Table S1.

### **2.2.2. Catalytic cracking process**

The wax generated from pyrolysis undergoes further conversion into aviation fuel through a catalytic cracking process. A schematic of this process is shown in Fig. S4. The waxes are cracked further, and the resulting products (Stream No. 202) are fed into the distillation process, which separates them into wax (C>16), aviation fuel (C8-16), naphtha (C<8), LPG (C3-4), and other products. Byproducts, primarily unreacted wax and dry gas are combusted in COMB-2 and COMB-3, with combustion efficiency set at 70%. The operating conditions for the catalytic cracking process are based on a previous study [30] that examined the cracking of HDPE wax under various fluid catalytic cracking (FCC) conditions (temperatures: 500°C, 530°C, and 560°C; catalyst-to-oil (C/O) ratios: 3, 5, and 7 g g-1). The resulting products included dry gas (C1-C2), liquefied petroleum gas (LPG, C3-C4), naphtha (C5-C12), light-cycle oil (LCO, C13-C20), heavy-cycle oil (HCO, C20+), and coke. The highest conversion rate was achieved at 560°C with a C/O ratio of 7 g g-1. Notably, the compositional properties of the waxes in the previous study and this study were similar (Table S3).

The residual heat generated in the proposed process was utilized to form the LP steam. In the pyrolysis process, excess heat during cooling process was recovered in HX-1 by converting the DI water into LP steam. In the catalytic cracking process, heat generated from combustion in COMB-2 and COMB-3 was utilized to form LP steam. The generated LP steam was then used to supply heat for operating monoethanolamin (MEA)-based CO2 capture system.

### **2.2.3. CO2 capture process**

Fig. S5. shows a schematic of the MEA-based CO2 adsorption process. Flue gas, cooled to 40°C in HX-6, is introduced into the absorber, where CO2 is captured using a 30 wt% MEA solvent. The CO₂ capture efficiency is reported to be 80% [31]. The CO2-rich MEA solvent (Stream No. 303) is pressurized in PUMP-3, heated in HEAT-1, and then directed to the regeneration tower, which is driven by heat. The key reactions involved in CO2 capture using MEA are as follows [32]:

|  |  |
| --- | --- |
|  | (2) |
|  | (3) |
|  | (4) |
|  | (5) |
|  | (6) |

## **2.3. Techno-economic analysis (TEA)**

The levelized cost of production (*LCOP*) is a key indicator for evaluating the economic feasibility of a product [32, 33]. It is calculated using the annualized capital cost (*CAPEX*), total operating cost (*OPEX*), carbon tax (*Ccarbon tax*), revenue (*Rrevenue*), and total production volume, in this case, of aviation fuel (*Paviation fuel*), as expressed in the following equation:

|  |  |
| --- | --- |
|  | (7) |

Here, represents the total capital cost distributed over the lifespan of the process, expressed as a uniform annual cost; *OPEX* includes all operational expenses, such as raw materials, energy, and labor; *Ccarbon tax* denotes the government-imposed charge on carbon emissions, set at 40 USD per ton of CO₂; and accounts for the profit generated from the sale of byproducts, including naphtha, LPG, and LP steam. The detailed calculation procedure for each variable is provided in Sec. B of the Supporting Information.

## **2.4. Life cycle assessment (LCA)**

LCA is a method used to quantify the overall environmental impact of a product. It consists of four main stages: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and life cycle interpretation [34]. In this study, an LCA was conducted to evaluate the environmental impact of the proposed process. The goal was to assess the environmental benefits of the proposed process compared to conventional disposal methods. A cradle-to-gate system boundary was adopted, as illustrated in Fig. 3. This boundary includes raw material inputs, utilities, and product production stages. The functional unit was defined as 1 kg of HDPE. A life cycle inventory analysis was conducted to collect the data required for the LCA, quantifying all inputs (materials and energy resources) and outputs (such as waste) based on 1 kg of HDPE. The life cycle impact assessment (LCIA) was performed using the Intergovernmental Panel on Climate Change (IPCC) methodology, which calculate the 100-year Global Warming Potential (GWP100) index based on greenhouse gas (GHG) emissions within the assessment boundary. The analysis considers fossil, biogenic, and land-use-related CO₂ emissions. Finally, the LCIA results were compared with those of conventional disposal methods, such as landfill and incineration.

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**Figure 3.** System boundary of the proposed process

# **3. RESULTS AND DISCUSSIONS**

## **3.1. HDPE pyrolysis experiment**

HDPE consists of repeating ethylene units. During pyrolysis, C–C bonds in HDPE are cleaved by thermal energy, producing a wide range of HC chain lengths [35]. This suggests that the distribution of HC chain lengths can be controlled by adjusting the pyrolysis temperature. To investigate this, HDPE was pyrolyzed using a multi-stage pyrolysis process with two heating zones. In the first heating zone, HDPE was thermally degraded into volatile matter (VM). This VM was further decomposed in a second heating zone, maintained at 500, 600, or 700°C. The condensable products, such as oil and wax, generated from multi-stage pyrolysis at these temperatures were qualitatively and quantitatively analyzed using GC/MS and GC/FID.

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**Figure 4.** (a) Compositions of three HCs groups in the condensed products from multi-stage pyrolysis of HDPE at second stage temperatures of 500, 600, and 700 ˚C. (b) Mass distribution of two phases produced at 500, 600, and 700 ˚C

Fig. 4(a). presents the mass fractions of three HC groups in the condensed products at 500, 600, and 700°C, categorized as: C<8 HCs, C8-16 HCs, and C>16 HCs. The pyrolysis temperature plays a crucial role in determining the carbon number distribution in the condensable product. Specifically, at 500 and 600°C, the process predominantly produces wax-like products (C>16 HCs), which account for over 50 wt.%. Conversely, at 700°C, a larger proportion of HCs with carbon numbers below 16 is observed. These results indicate that higher temperatures enhance C–C bond cleavage in HDPE, leading to the formation of shorter HC chains. The aviation fuel fraction (C8-16 HCs) in the condensable product was highest at 700°C, reaching 46.0 wt.%, suggesting that this temperature is optimal for aviation fuel production from HDPE pyrolysis. However, pyrolysis at 700°C resulted in a total condensable product yield of only 6.6 wt.%, meaning that the yield of aviation fuel-range HCs at this temperature was just 3.0 wt.% (Fig. 4(b).). Given both the C8-16 content and the overall condensable product yield, the aviation fuel-range HC yield at 700°C was lower than at 500 and 600°C. Therefore, pyrolysis temperatures should be limited to 500–600°C. Among these, 500°C exhibited the most favorable conditions for aviation fuel production, as it yielded a higher fraction of C8-16 compared to 600°C. However, the actual production process involves multiple unit operations, including separation, purification, combustion, and CO2 capture, all of which influence overall process efficiency. This implies that experimentally determined optimal conditions may not directly translate to large-scale production. To determine the optimal temperature for aviation fuel production from HDPE pyrolysis, a comprehensive techno-economic assessment of the entire process is required. To this end, reliable process designs for HDPE pyrolysis at 500 and 600°C were first developed. Subsequently, techno-economic assessments of these designs were conducted and compared.

## **3.2. Process simulation results**

### **3.2.1. HDPE pyrolysis process**

Simulations were conducted for two cases, particularly AFP-500 and AFP-600: one where the pyrolysis process operates at 500°C and another at 600°C in the overall aviation fuel production processes. Except for temperature, simulation of pyrolysis at 500 and 600 ˚C were performed under identical conditions, including pressure (1.013 bar) and the mass flow rate of HDPE (5,000 kg-1). Additionally, N2 purge gas (33 kg h1) was introduced to maintain an inert atmosphere in the pyrolysis reactor. Fig. 5. presents the production rates of aviation fuel, wax, naphtha, gases, and LP steam for both pyrolysis temperatures. The corresponding heat demand and the heat generated from combustion within these processes are also shown. Detailed stream conditions for pyrolysis at 500 and 600°C are provided in Table S2.

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**Figure 5.** Production rates of (a) aviation fuel, wax, naphtha, gases, and (b) LP steam from pyrolysis at 500°C and 600°C in AFP-500 and AFP-600

As illustrated in Fig. 5, pyrolysis at 500°C produced an effluent comprising aviation fuel (1,202 kg h-1), heavy wax (2,963 kg h-1), naphtha (60 kg h-1), and gases (808 kg h-1). This effluent was subsequently cooled to facilitate the separation of oil/wax and gases in a flash drum. During this process, heat was recovered, generating 630 kg h-1 of LP steam (135°C and 3.0 bar). The oil and wax separated in the flash drum were further processed in distillation columns to yield aviation fuel, wax, and naphtha. The overall heat duty of the pyrolysis process at 500°C was 16,822 kW, comprising 16,578 kW for the pyrolysis reactor and 244 kW for the distillation column. To compensate for this heat demand, gases separated in the flash drum were used as fuel, generating 6,969 kW of heat. The remaining energy requirement (9,609 kW) was met through the combustion of byproducts from the catalytic cracking process (Sec. 3.2.2).

The product distribution from pyrolysis at 600°C differed significantly from that at 500°C. Specifically, production rates of aviation fuel (1,039 kg h-1) and heavy wax (1,308 kg h-1) were lower at 600°C than at 500°C. However, naphtha (154 kg h-1) and gas (2,533 kg h-1) production was higher at 600 ˚C. These trends align with experimental results, confirming that higher temperatures enhance C–C bond dissociation, leading to the formation of shorter-chain HCs. Due to the higher effluent temperature at 600°C, LP steam production increased to 1,050 kg h-1, compared to 630 kg h-1 at 500 ˚C. Additionally, the heat generated from combustion during pyrolysis at 600°C reached 22,772 kW, surpassing that at 500°C. This increase is attributed to the higher gas production rate at 600°C. Despite the higher heat duty at 600°C (17,782 kW for the reactor and 237 kW for the distillation system), the energy from combustion was sufficient to fully meet the process requirements. The excess heat was used to produce additional LP steam, leading to a total LP steam production rate of 7,381 kg h-1 at 600°C—significantly higher than the 630 kg h-1 generated at 500°C (Fig. 5(b).).

### **3.2.2. HDPE-based wax catalytic cracking process**

Wax generation from HDPE pyrolysis at 500°C and 600°C reached 2,963 and 1,308 kg h-1, respectively. Notably, long-chain HCs have the potential to be converted into aviation fuel-range HCs by adjusting their chain lengths, suggesting that additional conversion of wax into aviation fuel is desirable. To maximize aviation fuel production from HDPE, a catalytic cracking process was incorporated. Catalytic cracking was performed under FCC conditions (temperature: 560°C, pressure: 1.013 bar, and C/O ratio: 7). The major products yield from catalytic cracking in AFP-500 and AFP-600 are illustrated in Fig. 6. The overall heat demand of the catalytic cracking processes, along with the heat produced through combustion, is also shown.

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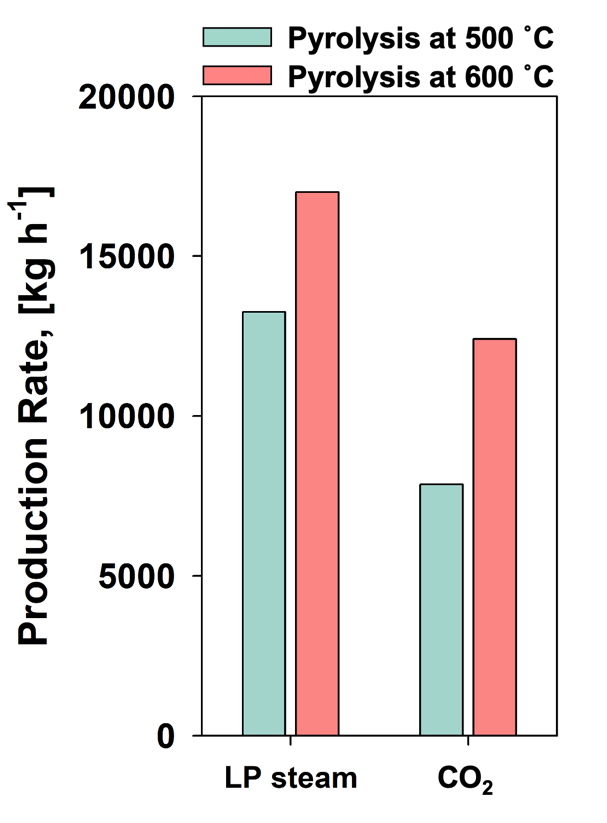
**Figure 6.** Production rates of (a) aviation fuel, wax, naphtha, LPG, other gases, and (b) LP steam from catalytic cracking processes in AFP-500 and AFP-600

As depicted, integrating catalytic cracking in AFP-500 resulted in an effluent consisting of aviation fuel (321 kg h-1), wax (1,055 kg h-1), naphtha (637 kg h-1), LPG (407 kg h-1), and other gases (543 kg h-1). These products were introduced into distillation systems and separated. The total heat demand for catalytic cracking of wax from pyrolysis at 500°C was 1,734 kW. However, 11,041 kW of energy was produced through the combustion of wax and other gases. This heat was used to meet the energy requirements of both the catalytic cracking and pyrolysis processes (as discussed in the previous section), leaving no residual heat. Consequently, LP steam was not produced in this process.

When catalytic cracking was integrated with pyrolysis at 600°C (AFP-600), the production rates of all products from catalytic cracking decreased. This reduction is attributed to the lower wax feed rate from pyrolysis at 600°C compared to that at 500°C. However, LP steam was only generated when catalytic cracking was linked to pyrolysis at 600°C. As noted, the heat from combustion during pyrolysis at 500°C was insufficient to fully sustain the process, requiring additional energy from combustion in the catalytic cracking process. In contrast, the combustion system in pyrolysis at 600°C fully met its total heat duty. Therefore, the excess heat from combustion of by-product from the catalytic cracking of wax in AFP-600 was used for LP steam production, leading to a steam generation rate of 5,929 kg h-1.

### **3.2.3 CO2 capture in flue gases**

During aviation fuel production, pyrolysis and catalytic cracking processes involve combustion systems that generate CO2-rich flue gases. To enhance sustainability, a CO2 capture system was incorporated. Before capture, the flue gases were cooled to 40°C, a common temperature specification for absorption towers in CO2 capture systems. During this cooling process, heat was recovered from LP steam production (135°C and 3 bar), which was then mixed with LP steam generated from combustion during the catalytic cracking and pyrolysis processes.



**Figure 7.** Production rates of LP steam and CO2 from the CO2 capture system treating flue gases generated from catalytic cracking and pyrolysis in AFP-500 and AFP-600

Fig. 7. shows the production rates of LP steam and CO2 during the treatment of flue gases from the catalytic cracking and pyrolysis in AFP-500 and AFP-600. When pyrolysis was conducted at 500°C, LP steam production from flue gas reached 13,250 kg h-1, whereas CO2 production was 7,589 kg h-1. In comparison, pyrolysis at 600°C resulted in higher LP steam and CO2 production rates, reaching 17,000 and 12,413 kg h-1, respectively. This increase is attributed to the greater generation of flue gases, which correlated with the higher amount of byproducts available for combustion. Specifically, the total amount of combusted byproducts in the combined processes was 3,233 kg h-1 for pyrolysis at 600°C and 2,406 kg h-1 for pyrolysis at 500°C. Due to the increased flue gas generation, the heat duty for CO2 capture in the combined process involving pyrolysis at 600°C (18,400 kW) was higher than that at 500°C (11,400 kW). The required heat was supplied by LP steam produced during the pyrolysis, catalytic cracking, and CO2 capture processes. As a result, the net LP steam generation AFP-500 and AFP-600 were -1,383 and 5,826 kg h-1, respectively.

Table 1 summarizes the production rates of various products from AFP-500 and AFP-600. The production rate of aviation fuel in AFP-500 was 1.3 times higher than in AFP-600, indicating that a pyrolysis temperature of 500°C is more effective for aviation fuel production. Additionally, the production rates of naphtha and LPG were higher in AFP-500 than in AFP-600. In contrast, CO2 production was lower in AFP-500, which is attributed to the higher combustion capacity of AFP-600. However, the overall energy yield in AFP-500 was insufficient to fully meet its process requirements, resulting in an LP steam deficit of 1,383 kg h-1. This suggests that while AFP-500 is more favorable for producing valuable products such as aviation fuel, it is less efficient in generating heat, potentially impacting aviation fuel production costs. To assess this, a TEA was performed for AFP-500 and AFP-600.

**Table 1.** Production rates of all products (aviation fuel, naphtha, LPG, LP steam, and CO2) from AFP-500 and AFP-600

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | **Aviation fuel** | **Naphtha** | **LPG** | **CO2** | **LP steam** |
|  | [kg h-1] | | | | |
| AFP-500 | 1,523 | 697 | 407 | 7,589 | -1,383 |
| AFP-600 | 1,159 | 418 | 225 | 12,413 | 5,926 |

## **3.3. Economic feasibility analysis**

A TEA was conducted to evaluate the economic feasibility of AFP-500 and AFP-600. In this analysis, theCAPEX, OPEX, and revenues for both processes were determined. The LCOP was calculated based on these results. The findings are summarized in Table 2.

**Table 2.** CAPEX, OPEX, and revenue for AFP-500 and AFP-600

|  |  |  |
| --- | --- | --- |
|  | **AFP-500** | **AFP-600** |
| CAPEX [USD yr-1] | 3,233,755 | 3,531,447 |
| OPEX [USD yr-1] | 14,896,189 | 16,258,673 |
| Revenue [USD yr-1] | 8,115,029 | 5,390,337 |
| LCOP [USD gal-1] | 2.8 | 5.4 |

The CAPEX and OPEX of AFP-500 were 3,233,755 and 14,896,189 USD yr-1, respectively. Additionally, revenue from the sale of naphtha, LPG, and LP steam generated by this process was 8,115,029 USD yr-1. In comparison, AFP-600 exhibited a 9.2% higher CAPEX and a 9.1% higher OPEX. These discrepancies can be attributed to variations in product distribution between AFP-500 and AFP-600. Notably, the yield of valuable products is a critical factor influencing both CAPEX and OPEX. Detailed CAPEX and OPEX values for both conditions are provided in Tables S8 and S9. Unlike CAPEX and OPEX, revenue was higher for AFP-500 than AFP-600, primarily due to the greater production of profitable products such as naphtha and LPG, rather than CO2 and LP steam. Due to its lower CAPEX and OPEX, as well as higher revenue, AFP-500 achieved a lower aviation fuel price of 2.8 USD gal-1 compared to 5.4 USD gal-1 for AFP-600. This finding suggests that a pyrolysis temperature of 500°C is optimal for producing aviation fuel from HDPE.

As illustrated in Fig. 8., the aviation fuel produced via AFP-500 is more expensive than conventional fossil-based aviation fuel but significantly cheaper than other sustainable aviation fuels (SAFs) produced through pathways such as hydroprocessed esters and fatty acids (HEFA), alcohol-to-jet (AtJ), Fischer-Tropsch (FT), and power-to-liquid (PtL). This result indicates that aviation fuel production from HDPE via AFP-500 is an economically viable approach compared to other SAF production methods.

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**Figure 8.** Comparison of LCOP between fossil-based aviation fuel, aviation fuel from AFP-500, and SAFs produced via HEFA, AtJ, FT, and PtL [36]

## **3.4. LCA results**

Traditionally, plastic waste has been disposed of through incineration or landfill, both of which pose environmental concerns. In contrast, the proposed process offers a more environmentally sustainable alternative by utilizing HDPE waste as a feedstock for aviation fuel production. To quantitatively assess the environmental impact of AFP-500, an LCA was performed. As a reference, LCAs of conventional disposal methods (incineration and landfill) were also conducted.

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**Figure 9.** GWP100 values for landfilling, incineration, and AFP-500

Fig. 9. compared the global warming potential (GWP) of the proposed process (AFP-500) and traditional disposal methods. Among the evaluated methods, landfill disposal exhibited the lowest GWP100 at 0.8 kg CO2-eq, reflecting the minimal CO2 emissions due to the non-biodegradable nature of HDPE. However, this finding suggests that landfilling is not an effective disposal method for HDPE-based waste. In contrast, incineration had the highest GWP (4.0 kg CO2-eq) due to the inherent oxidation reactions involved. Notably, AFP-500 achieved a GWP of only 1.7 kg CO2-eq, demonstrating that the proposed process is more environmentally favorable than both incineration and landfill disposal.

# **4. CONCLUSION**

This study presents an aviation fuel production process from HDPE using pyrolysis. The pyrolysis experiments confirmed that temperature plays a crucial role in product distribution. Specifically, pyrolysis at 500°C and 600°C resulted in higher aviation fuel yields than at 700°C. Based on these experimental results, the entire aviation fuel production process using pyrolysis of HDPE at 500°C and 600°C (AFP-500 and AFP-600) was designed. The production rates of aviation fuel for AFP-500 and AFP-600 were 1,524 and 1,159 kg h-1, respectively. According to the TEA, the LCOP for aviation fuel from AFP-500 and AFP-600 was 2.8 and 5.4 USD gal-1, respectively. These results indicate that AFP-500 is more cost-effective than AFP-600. Additionally, the price of aviation fuel from HDPE via AFP-500 is significantly lower than that of SAFs produced through various processes, suggesting that the proposed method is economically viable. Furthermore, the LCA results demonstrated that AFP-500 is a more environmentally sustainable alternative than conventional disposal methods such as incineration and landfilling.

**AUTHOR CONTRIBUTIONS**

Junyoung Park: Data curation, Formal analysis, Methodology, Writing–original draft

Dongho Choi: Formal analysis, Visualization, Writing–original draft

Hyukwon Kwon: Investigation

Taewoo Lee: Investigation, Resources

Eilhann E. Kwon: Investigation

Jaewon Lee: Supervision, Validation, Funding acquisition, Writing-review and editing

Hyungtae Cho: Supervision, Validation, Writing-review and editing

# **ACKNOWLEDGEMENTS**

This work was supported by the Industrial Technology Innovation Program (RS-024-00507471, “Development and Demonstration of an Operations Optimization Platform for AI Driven Autonomous Manufacturing in Refinery and Petrochemical Processes”) funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea)

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