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Financial feasibility of converting plastic waste as an alternative energy source

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ABSTRACT

The increasing accumulation of non-degradable plastic waste is threatening our environment. Transforming plastic waste into fuel via pyrolysis is a promising approach. This research aims to evaluate the economic viability of a project that converts plastic waste into gasoline, diesel, and kerosene through the pyrolysis process. The profit and loss projection, Net Present Value (NPV), Internal Rate of Return (IRR), Return on Investment (ROI), Break-Even Point (BEP), and Contribution Margin (CM) were calculated over 10 years to conduct the analysis. The analysis indicates that the project demonstrates significant financial viability, featuring an NPV of IDR 550.75 billion, an estimated IRR exceeding 1000%, an ROI of 1,610.7%, a BEP of around 23 working days, and a CM of IDR 7,040 per liter or 86.9%. However, this research has some limitations, including the quality of the generated products, the environmental implications of the pyrolysis process, and the reliable supply of raw materials. This research provides a more comprehensive understanding of the feasibility of the plastic waste-to-fuel conversion project from a technical and financial perspective by incorporating a comprehensive technical and financial analysis. It also supports the concepts of a circular economy and sustainable waste management by turning waste into a valuable resource.

Contribution/ Originality: This study contributes to global research and lies in the integration of local parameters in the economic feasibility analysis of pyrolysis, which can be used as an adaptive model to be applied in other developing cities in the world. This research outlines the process and market parameters that affect the cost of producing oil from plastic waste and how these parameters affect the financial viability if the Makassar City Government considers waste management, taking into account the transportation costs of feedstock and waste generated, taxes, feedstock costs, volume of feedstock available, wages, and disposal costs.

1. INTRODUCTION

Plastics play a very important role in various industrial sectors such as food, beverages, textiles, healthcare, automotive, aerospace, construction, and agriculture (Bhamu & Sangwan, 2014; Mastos & Gotzamani, 2022; Moshood et al., 2021). The lightweight, waterproof, and moldable characteristics render it a crucial packaging material for ensuring food safety, storage, and distribution (Ncube, Ude, Ogunmuyiwa, Zulkifli, & Beas, 2021; Pongrácz, 2007). Plastic polymers play a crucial role in the production of insulating layers for electrical cables (Nakiri et al., 2007; Pleşa, Noţingher, Stancu, Wiesbrock, & Schlögl, 2018; Zhao, Siew, & Given, 2013). Furthermore, polymer membranes find applications in water desalination processes, fuel cell technology, and blood purification processes (Abid, Wahab, Salam, Moujdin, & Gzara, 2023; Alentiev, Bermeshev, Volkov, Petrova, & Yaroslavtsev, 2025; Wang et al., 2024; Xu, Yang, Liu, & Chu, 2022). Within the healthcare sector, plastics are utilized in various applications such as drug carriers, implants, dental repairs, hip implants, blood bags, and medical devices (Czuba, 2014; Moshkbid, Cree, Bradford, & Zhang, 2024; Trucillo, 2024). The presence of plastics has become increasingly important due to their extensive application as personal protective equipment during the coronavirus pandemic (Cubas et al., 2023; Ganguly & Chakraborty, 2024; Mahmoudnia, Mehrdadi, Kootenaei, Deiranloei, & Al-e-Ahmad, 2022). Analysis indicates that between 1950 and 2017, around 8.3 billion metric tons of plastic were generated worldwide, with merely 9% undergoing recycling, 12% being incinerated, and the vast majority, 79%, either discarded or deposited in landfills within the environment (Rhodes, 2018; Zaman & Newman, 2021). Predictions suggest that by 2050, the amount of plastic waste could reach 26 billion tons, which could cause serious harm to the environment if new recycling methods are not quickly developed. While certain plastics, including polyethylene terephthalate (PET) and high-density polyethylene (HDPE), have experienced a rise in mechanical recycling in recent times, others like low-density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS) continue to exhibit low recycling rates.

Waste generation throughout Indonesia reached 19,562,664.13 tons/year, consisting of 40.9% household waste, 18% plastic waste, 12.5% wood/leaf/plant waste, 10.3% paper and cardboard, 3.4% metal, 2.6% cloth, 2.5% glass, 2.3% rubber/leather, and 7.1% other waste (Hidayat, Kiranamahsa, & Zamal, 2019). Furthermore, in 2023, the Nusantara River Affairs Research Agency [BRUIN] conducted a census at 64 locations across 28 districts and cities in 13 provinces, revealing a total of 25,733 tons of plastic waste, predominantly from sachet packaging. Additionally, data from the Tamangapa landfill in 2022 indicates that Makassar generates approximately 274,912.3 tons of waste, with around 38.56%, or 106,006.2 tons, classified as plastic waste. Of this, only 30% is recycled, while 5% is reused, 33% is sent to landfills, and 32% is disposed of through burning (Rusni, 2024). The incineration of plastic waste results in the emission of harmful dioxins, which are highly toxic chemicals. These substances can be inhaled by both humans and animals, deposited into soil and surface water, and subsequently accumulated in plants (Pathak, Nichter, Hardon, & Moyer, 2024; Pilapitiya & Ratnayake, 2024; Siddiqua, Hahladakis, & Al-Attiya, 2022). This process leads to landfilling or practices that harm the environment, stemming from insufficient capacity or infrastructure for recycling this type of waste. In addition, material recovery facilities (MRFs) in Indonesia face significant challenges in effectively sorting MPW (Lubongo, Congdon, McWhinnie, & Alexandridis, 2022).

Waste recycling is an economical option (Kopsidas & Giakoumatos, 2021; Roleders et al., 2024), and it is optimal for recycling one type of plastic at a time. However, it becomes less effective when dealing with mixed plastic waste, coated plastics, and those that are heavily contaminated (Alaghemandi, 2024; Haba et al., 2025; Kassab, Al Nabhani, Mohanty, Pannier, & Ayoub, 2023; Lahl & Zeschmar-Lahl, 2024). Furthermore, items produced through mechanical recycling frequently possess diminished value as a result of the degradation of polymer quality throughout the recycling process (Alaghemandi, 2024; Baechler, DeVuono, & Pearce, 2013; Ragaert, Delva, & Van Geem, 2017; Shafik, 2025). Consequently, there is a need for a technology that can efficiently process mixed and multilayered plastics. The conversion of plastics through pyrolysis into valuable products presents a viable approach to address the challenges associated with municipal solid waste management (Alaghemandi, 2024; Uthpalani, Premachandra, De Silva, & Weerasinghe, 2023). The pyrolysis process involves breaking down materials at high temperatures without oxygen, which breaks polymers into smaller parts called monomers or short-chain hydrocarbons, and also produces oil, fuel gas, and other by-products (Al-Haj Ibrahim, 2020). Devi, Rawat, and Sharma (2021). Pyrolysis represents one of the various methodologies employed in the realm of chemical recycling. Other methods include gasification, where plastics are mixed with agents like steam, oxygen, and air at high temperatures between 500 and 1300°C to produce fuel gas. Chemolysis, a process that transforms plastics like PET into monomers, is discussed in the works of Kumar et al. (2021), Quicker, Seitz, and Vogel (2022), and Rickert, Cerdas, and Herrmann (2020) alongside combustion and deposition methods. Pyrolysis demonstrates advantages in the recycling of food-contaminated plastics by removing the necessity for extensive washing and sorting prior to the recycling process, thereby lowering pre-treatment expenses. The return on investment for pyrolysis is known to be higher than for gasification or chemolysis (Antelava et al., 2021; Glushkov, Nyashina, Shvets, Pereira, & Ramanathan, 2021; Lubongo et al., 2022). Furthermore, pyrolysis is considered more environmentally friendly compared to waste incineration and landfilling (Akinbomi et al., 2025; Dennison et al., 2025; Dharmaraj et al., 2021; Wróblewska-Krepsztul & Rydzkowski, 2020).

Pyrolysis processes can be categorized into three types: (1) conventional or slow pyrolysis, (2) fast pyrolysis, and (3) ultra-fast or flash pyrolysis. Traditional or slow pyrolysis occurs at temperatures ranging from 400 to 500°C, with a retention time of 5 to 30 minutes and a gradual heating rate of approximately 10°C/s. Fast pyrolysis occurs at temperatures ranging from 400 to 500°C, with a residence time of 0.5 to 2 seconds and a rapid heating rate of approximately 100°C/s, resulting in the production of oil, gas, and charcoal. Ultra-fast or flash pyrolysis occurs at temperatures between 700 and 1000°C, with a holding time of under 0.5 seconds and an exceptionally high heating rate of approximately 500°C/s to generate oil and gas (Brownsort, 2009; Jerzak, Acha, & Li, 2024; Pahnila, Koskela, Sulasalmi, & Fabritius, 2023; Zaman & Newman, 2021). It is important to recognize that pyrolysis oil generated from fossil-fuel plastics exhibits distinct characteristics compared to pyrolysis oil obtained from biomass. Biomass-derived oil exhibits a significant water content of 20-30% and an oxygen content ranging from 35-50%, leading to a high acidity level with a pH around 2. On the other hand, pyrolysis oil from fossil-fuel plastics has less water and oxygen, making it less acidic, except for the pyrolysis oil made from PET plastic.

Although turning plastics into fuel using pyrolysis has been shown to help with waste management issues faced by the Ministry of Public Works (Jadhao & Seethamraju, 2020; Onwudili, Insura, & Williams, 2009), especially with multi-layer plastics, there is still a significant lack of research on whether it is financially practical. Zabaniotou and Vaskalis (2023) conducted an economic evaluation of a pyrolysis plant for mixed plastic waste in Belgium, designed to process 40,000 tons annually. The internal rate of return was calculated at 20%, indicating that the plant maintains a positive net present value (NPV) up to a 20% discount rate. Revenues were estimated at €210/t, despite the oil price assumptions applied in the calculations being the lowest observed in the past 15 years. The analysis emphasizes that financial sustainability is significantly influenced by the quantity and quality of plastic waste, feedstock expenses, capital and operational costs, income generated from the sale of produced oil, disposal expenses, and the potential location of the plant at the same site as a plastic waste sorting facility.

The viability of turning waste plastic into gasoline at 1,000, 10,000, and 100,000 kg/h production scales was examined by Fivga and Dimitriou (2018). In the case of production scales of 1,000 and 100,000 kg/h, the costs of pyrolysis fuel production were calculated to vary between 0.87 and 0.03 British pounds per kilogram (£/kg). Evaluations focusing on the technical and economic aspects of plastic-to-fuel conversion plants, as presented by Fivga and Dimitriou (2018); Riedewald, Patel, Wilson, Santos, and Sousa-Gallagher (2021), and Larrain et al. (2020), indicate that the profitability of such conversions is often constrained by factors such as the market price of the produced oil, the cost of feedstock, and both capital and operating expenses, in addition to competition from traditional oil refineries (Qureshi, Kirkerud, Theresa, & Ahsan, 2020). Additional challenges related to pyrolysis involve ambiguity regarding the amount and variable quality of the feedstock, as well as the absence of recognized market standards for pyrolysis oil (Qureshi et al., 2020).

This research aims to evaluate the financial feasibility of converting plastic waste into fuel via the pyrolysis process in Indonesia. The declining recycling rate for plastic waste in Indonesia has exacerbated the recycling landscape in the country, underscoring the necessity to assess possible recycling alternatives (U.S. Environmental Protection Agency (EPA), 2019, 2021; Vedantam et al., 2022). Moreover, studies examining the financial viability of transforming plastics into oil or fuel through pyrolysis in Indonesia are scarce (Doherty, Madigan, Nevill, Warrington, & Ellis, 2021; Fivga & Dimitriou, 2018). This study examines the financial viability of transforming waste plastics into fuel, with a focus on the context of Indonesia.

There are two main questions that can be summarized as the main objective of this research. First, does the project of converting plastic waste into oil or fuel through pyrolysis have economic value in Indonesia? And second, if so, how can this project be funded? First, the project is valued as if it is fully owned and funded by the company's resources, a method known as the entity basis, which is evaluated using the unlevered Net Present Value (NPV) or entity NPV that forms the basis for investment decisions (Crundwell, 2008). Secondly, the project evaluation is conducted by considering the discount rate, a method known as the equity basis (Crundwell, 2008), which is the main method used to evaluate the project feasibility in this research. We assessed the economic viability of transforming plastic waste into fuel by analyzing the technical and market conditions essential for the effective implementation of pyrolysis technology. Thirdly, the project was evaluated in terms of the break-even point, indicating the status at which the project neither generates profit nor incurs a loss. Finally, the benefit-cost ratio, often referred to as the B/C ratio, evaluates the relationship between the costs incurred in production and the advantages gained from a business initiative. The assessment of whether turning plastic waste into oil or fuel is financially feasible includes checking the materials needed, planning the process, changing the processing capacity, estimating the initial costs (CapEx), ongoing costs (OpEx), cash flow from operations, analyzing how changes affect outcomes, and evaluating risks. The CapEx and OpEx results are used to calculate the entity NPV and equity NPV, or simply the NPV of the pyrolysis plant with capacities of 30, 60, and 100 tons per day (TPD).

This research outlines the process and market parameters that affect the cost of producing oil from plastic waste and how these parameters influence the financial viability if the Makassar City Government considers waste management, taking into account the transportation costs of feedstock and waste generated, taxes, feedstock costs, volume of feedstock available, wages, and disposal costs. This study aims to offer valuable insights to decision-makers about the financial viability of converting plastic to fuel or oil in Indonesia. The main contribution of this research to global studies lies in the integration of local parameters in the economic feasibility analysis of pyrolysis, which can be used as an adaptive model to be applied in other developing cities worldwide. In conclusion, the viability of transforming plastic waste into oil via pyrolysis as a business venture in Indonesia has been assessed. Recommendations are provided concerning essential factors to consider and actions necessary to enhance the decision-making process moving forward.

2. LITERATURE REVIEW

2.1. Plastic Waste

The issue of plastic waste stands as one of the most pressing environmental challenges globally. Plastic is a resilient material that resists natural decomposition, leading to a significant buildup of plastic waste both on land and in marine environments (Kibria, Masuk, Safayet, Nguyen, & Mourshed, 2023; Kumar et al., 2021). Moreover, plastic waste can lead to detrimental effects, including environmental pollution. Plastic waste contaminates natural environments, including rivers, lakes, seas, and soil (Bhadarka et al., 2024; Kehinde, Ramonu, Babaremu, & Justin, 2020). There is a risk to the lives of marine animals and fauna that may consume or become entangled in plastics. The decomposition of plastic in landfills has the potential to release detrimental substances into both soil and water sources (Ajaj, Abu Jadayil, Anver, & Aqil, 2022; Oxford Analytica, 2022; Wojnowska-Baryła, Bernat, & Zaborowska, 2022). Furthermore, microplastics that have degraded from plastic waste can infiltrate the human food chain via fish and marine animals, posing potential risks to human health (Alberghini, Truant, Santonicola, Colavita, & Giaccone, 2023; Cverenkárová, Valachovičová, Mackuľak, Žemlička, & Bírošová, 2021; Witczak, Przedpełska, Pokorska-Niewiada, & Cybulski, 2024; Ziani et al., 2023). Moreover, the buildup of plastic waste poses a threat to delicate ecosystems, including coral reefs and mangrove forests. A decline in biodiversity and economic losses for communities reliant on these ecosystems may result from this situation (John, Nandhini, Velayudhaperumal Chellam, & Sillanpää, 2022;

Walther & Bergmann, 2022). The creation and disposal of plastics result in greenhouse gas emissions that contribute to global warming and climate change. Solving the issue of plastic waste requires collaborative actions from multiple parties, such as government bodies, industry leaders, community groups, and individual citizens.

Several strategies can be implemented, including 1) minimizing reliance on single-use plastics like plastic bags, straws, and water bottles. 2) Enhancing recycling initiatives to minimize the volume of plastic waste entering landfills. 3) Informing the community about the risks associated with plastic waste and the importance of minimizing, recycling, and correctly disposing of plastic materials. 4) Developing advanced technologies aimed at improving the efficiency and sustainability of plastic recycling processes. 5) Creating rules and guidelines to reduce single-use plastics, enhance waste management systems, and provide rewards for businesses that use eco-friendly materials. With committed efforts, there is hope that we can reduce the negative impacts of plastic waste and maintain environmental sustainability for future generations.

Plastic waste can be categorized according to its type, which typically hinges on its physical and chemical characteristics. Below are several prevalent categories of plastic waste: 1. Polyethylene (PE): a) High-density polyethylene (HDPE): Commonly utilized for detergent containers, milk containers, drinking water containers, and water piping. Low-Density Polyethylene (LDPE): Employed in the production of plastic bags, wrapping films, and food packaging materials. Low Linear Polyethylene (LLDPE): Commonly utilized in the production of shopping bags, plastic bags, and wrapping films. 2 Polypropylene (PP): This material is utilized in the production of syrup bottles, yogurt containers, food packaging, and various other plastic items. 3. Polyvinyl Chloride (PVC): This material is used in plumbing, food packaging, toys, and various other plastic products. Nonetheless, PVC is composed of hazardous substances and poses challenges in the recycling process. 4. Polyethylene Terephthalate (PET): This material is commonly used in the production of drinking water bottles, soft drink bottles, and food containers. 5. Polystyrene (PS): This material is used in the production of Styrofoam, food containers, and packaging for electronic products. 6. Polycarbonate (PC): This material is frequently utilized in the production of drinking water bottles, baby bottles, toys, and items that demand both durability and transparency. 7 Biodegradable Polyethylene (PBAT): These are types of plastics made from natural materials that can break down on their own after a certain time. Additionally, sorting and recycling various types of plastic waste is crucial for reusing materials and mitigating their adverse effects on the environment. Furthermore, efforts focused on minimizing single-use plastics and shifting toward sustainable alternatives are essential to addressing the challenge of plastic waste.

2.2. Methods to Convert Plastic Waste into Alternative Energy

Transforming plastic waste into alternative energy presents a viable solution to mitigate the influx of plastic waste in landfills, while simultaneously producing energy for practical use (Alaghemandi, 2024; Banurea et al., 2024). Presented below are various techniques for transforming plastic waste into alternative energy sources: 1. Thermal Processing: a) Pyrolysis: This technique involves the application of heat to plastic waste in an oxygen-deprived environment, resulting in the breakdown of the plastic waste into gas, oil, and charcoal. The generated gas and oil can be used as fuel or refined into liquid fuels such as diesel or gasoline. b) Gasification: This process involves the application of heat to plastic waste within an oxygen-limited environment, producing synthesis gas. This gas can then be harnessed as fuel for power generation or for a range of industrial applications (Cuevas, Leiva-Candia, & Dorado, 2024; Surapati, Puspawan, & Handayani, 2023; Tulashie, Boadu, & Dapaah, 2019; Wijianto & Hayatullah, 2024). 2 Anaerobic Composting: Organic plastic waste can be processed in conjunction with other organic waste using an anaerobic composting approach. Throughout this process, microorganisms decompose organic matter, leading to the generation of methane gas and carbon dioxide. Methane gas functions as an effective fuel source for power generation or heating (Ayilara, Olanrewaju, Babalola, & Odeyemi, 2020; Molino, Nanna, Ding, Bikson, & Braccio, 2013; Syafrudin, Samadikun, Wardhana, & Rizaldianto, 2020). 3 Chemical processing: A range of chemical processes, such as thermal depolymerization and catalysis, can efficiently break down waste plastic molecules into more basic compounds. These compounds can subsequently be refined into fuels or other chemicals (Alaghemandi, 2024; Damayanti et al., 2022; Harasymchuk, Kočí, & Vitvarová, 2024; Tang, Xiao, Wang, Zhao, & Su, 2024). 4. Integrated Waste-to-Energy (WtE) Combustion: Plastic waste can be incinerated alongside other waste materials to produce heat, which is subsequently utilized to generate steam. This steam drives a turbine, ultimately leading to electricity generation (Dadario et al., 2023; Leckner, 2015; Papamichael et al., 2024). It is crucial to recognize that transforming plastic waste into alternative energy presents a potentially beneficial approach, but it also raises several issues related to greenhouse gas emissions, air pollution, and the presence of hazardous residues. Therefore, the efficient management and monitoring of emissions and waste produced during this conversion process are essential for the successful application of this technology. Moreover, it is crucial to focus on reducing dependence on single-use plastics and improving plastic recycling initiatives to lower the amount of plastic waste generated.

An extensively used method for converting plastic waste into alternative energy is the pyrolysis process. The procedure involves subjecting plastic waste to high temperatures, generally ranging from 300°C to 900°C, in an oxygen-free environment (Dennison et al., 2025; Dinesh, 2020; Nanda, Sarker, Kang, Li, & Dalai, 2023). The pyrolysis process leads to the decomposition of plastic waste molecules into gas, oil, and charcoal (Manickavelan et al., 2022). The subsequent stages of the pyrolysis method are outlined as follows: 1) Heating: Plastic waste is introduced into a reactor or furnace that is heated from the outside. The temperature within the reactor is elevated until it attains the necessary operating temperature for the pyrolysis process. 2) Thermal degradation: Under elevated temperatures and in an oxygen-free environment, the chemical bonds within the plastic molecules start to disintegrate. This procedure yields gas, oil, and charcoal. 3) Product separation involves the separation of the pyrolysis products, which include gas, oil, and charcoal. The gases generated primarily include light hydrocarbons like methane, ethane, propane, and hydrogen. The oil extracted typically consists of a blend of liquid hydrocarbons that can be processed into liquid fuels like gasoline or diesel. The produced charcoal serves as a solid fuel or can undergo additional processing to become activated carbon. 4) Gas purification: It is essential to treat pyrolysis gases that contain vapors and contaminants, including light organic pollutants, prior to their application. This procedure may entail cooling, filtration, and the elimination of impurities through scrubbers or adsorption methods. 5) The gases and oils produced through pyrolysis have potential applications as fuel for power generation, heating, or as feedstock in the chemical industry. Charcoal serves as a viable alternative fuel and finds utility in various applications, including the treatment of water and soil. The pyrolysis method offers numerous benefits, such as transforming plastic waste into usable energy, minimizing the amount of plastic waste requiring landfill disposal, and facilitating the recycling of challenging plastics. It is important to recognize that this process demands substantial financial resources and necessitates meticulous waste management to regulate the emissions and residues produced.

2.3. Financial Feasibility of Plastic Waste Conversion

The pyrolysis method can result in a variety of costs during the plastic conversion process (Dennison et al., 2025; Putra, Rozali, Patah, & Idris, 2022; Wijianto & Hayatullah, 2024). Below are various categories of expenses that could arise: 1) Initial capital investment: The expense associated with constructing or acquiring the pyrolysis facility, which encompasses the pyrolysis machinery, reactor, ancillary equipment, and additional infrastructure (Aryanfar et al., 2024; Oliveira Neto et al., 2019). 2) Raw material cost: This includes the expenses for obtaining plastic waste for processing, specifically the costs related to its collection, transportation, and sorting (Groot, Van Der Meer, Smit, & Bakker, 2023; Kim, Kim, Baek, & Phae, 2023). 3) Operational costs: The daily operational expenses encompass energy expenditures for reactor heating, fees associated with machine maintenance and upkeep, labor expenses, and administrative costs (Kabeyi & Olanrewaju, 2023). 4) Waste Management Cost: This cost encompasses the expenses associated with handling the waste produced during the pyrolysis process. It includes solid wastes like charcoal and residue, as well as liquid and gaseous wastes that require treatment and purification prior to their release into the environment (Dong et al., 2018; Li et al., 2025). 5) Gas purification and processing costs: The cost of cleaning the pyrolysis gases from harmful substances such as particulates, light organic pollutants, and toxic gases using scrubber technology, adsorption, or other processes (Li, 2024; Singh & Shukla, 2014). 6) Product processing costs: The cost of refining and processing pyrolysis products such as oil into usable or saleable fuels, as well as charcoal processing to improve its quality (Cuevas et al., 2024; Jerzak et al., 2024; Lachos-Perez et al., 2023). 7) Regulatory compliance costs: The cost of complying with environmental rules and regulations related to the plastic frying process, including monitoring of gas emissions and waste, and reporting to the competent authorities (Javed et al., 2025; Pan, Zhang, Wang, & Shang, 2024). 8) Product marketing and distribution costs: The cost of marketing and distributing the products, such as liquid fuels or charcoal, to consumers or industries in need (Andrejić, Pajić, & Kilibarda, 2023; Sun & Yoon, 2022). 9) Research and development costs: The long-term costs of research and development for more efficient, eco-friendly, and economical pyrolysis technology (Jerzak et al., 2024; Velmurugan, 2022). 10) Cost of maintaining compliance and certification: The cost of maintaining the company's quality, safety, and compliance standards with environmental and industry regulations, as well as the cost of obtaining necessary certifications (Akang, 2024). Depending on the local conditions, the technology employed, and the scope of the operation, these types of costs may fluctuate.

Assessing the financial viability of converting plastic waste through the pyrolysis method requires a thorough examination of multiple elements, such as the initial investment, operational expenses, income generated from the resulting products, and possible profit margins (Chotiratanasak, Vitidsant, & Khemkhao, 2023; Zabaniotou & Vaskalis, 2023). To evaluate the financial viability of converting plastic waste through the pyrolysis method, it is essential to first calculate all expenses related to the establishment and functioning of a plastic fryer facility. This includes the initial capital investment, daily operational expenses, waste management fees, gas purification costs, and any additional expenditures (Koumpakis, Vlachokostas, Tsakirakis, & Petridis, 2025). Subsequently, assess the potential revenue that could be generated from the sale of pyrolysis products, including oil, gas, or charcoal. Next, determine the volume of plastic waste that requires processing and the products that must be marketed to achieve the break-even point, at which revenue matches costs. This assists in identifying the least quantity of products required for the investment to be recouped. Third, compute the rate of return on investment (ROI) to assess the speed at which the initial investment can be recouped. This entails an analysis of the anticipated net income generated by the investment in relation to the initial capital outlay. Fourth, conduct a sensitivity analysis to consider variations in critical elements like raw material costs, product pricing, or operational expenses. This aids in understanding the project's sensitivity to fluctuations in market conditions. Additionally, following an extensive financial feasibility assessment, the organization or investor is positioned to determine whether to proceed with a waste plastic conversion initiative utilizing the pyrolysis technique, informed by the analysis that has been performed.

3. RESEARCH METHOD AND DATA

This research employs an explanatory mixed-method approach, beginning with a quantitative analysis to assess the financial feasibility of pyrolysis technology in converting plastic waste into fuel in Makassar City. The quantitative phase involves simulation calculations of investment costs, operational expenses, transportation of raw materials, taxes, and projected income based on secondary data and estimated volumes of available plastic waste. Subsequently, the research proceeds with a qualitative approach to deepen the analysis through semi-structured interviews and focus group discussions (FGDs) with stakeholders, including local government officials, recycling industry representatives, and community leaders. The interviews explore perceptions, regulatory challenges, infrastructure readiness, and social support for implementing this technology. Data analysis utilizes financial techniques such as NPV, IRR, ROI, payback period, and sensitivity analysis for the quantitative data, while thematic analysis is applied to interpret qualitative data.

3.1. Preparation of Pyrolysis Raw Materials

The materials employed include LDPE-type plastic waste, particularly plastic bags and packaging, PP-type plastic, and 100 tons of activated natural zeolite. The plastic waste underwent an initial washing process with clean water to eliminate impurities, followed by a drying phase under sunlight. The plastic waste was then cut using a plastic cutter into 1-2 cm^2 pieces. The plastic waste was tested for moisture content before being pyrolyzed using an oven at 100°C for 1 hour. Plastic is said to be suitable for pyrolysis if the water content is less than 10%.

3.2. Plastic Waste Pyrolysis Process

This study employs the ultra-fast, or flash pyrolysis technique. A 100-ton blend of LDPE and PP plastics was introduced into a stationary reactor tube and sealed off from oxygen exposure. The control panel or temperature controller is activated, and the heating flame is calibrated until the operating temperature is attained. The gas produced from the combustion of LDPE and PP plastics is subsequently directed to the condenser for the condensation process. The end result achieved is a liquid product presented as oil. The pyrolysis process is completed in a span of 4 hours, utilizing 100 tons of plastic waste and yielding a total of 1,040,800 ml.

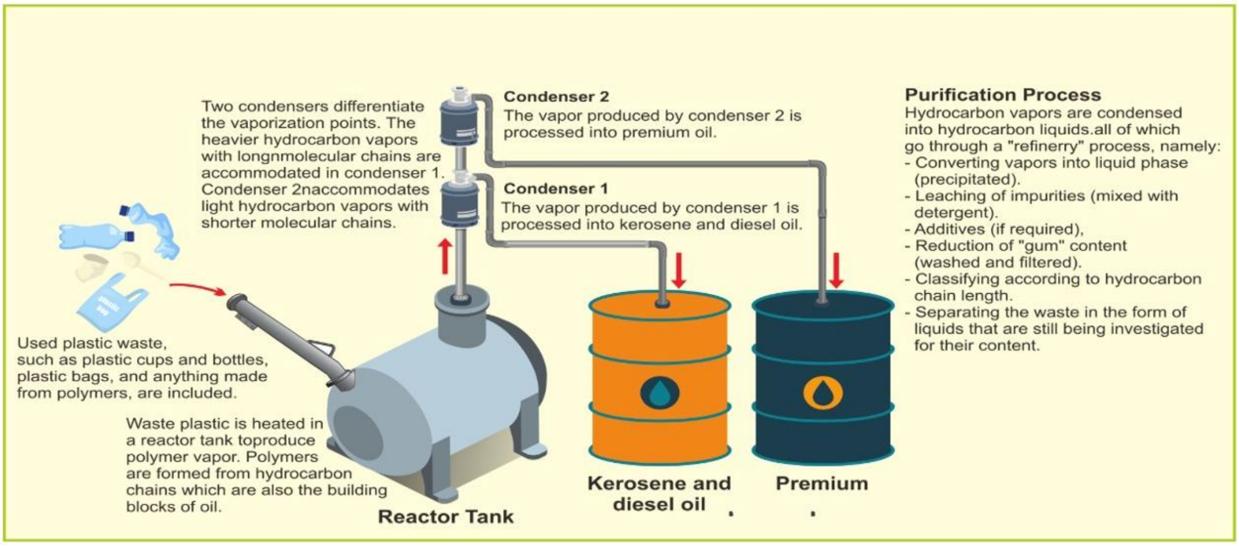

Figure 1. Plastic waste to fuel oil processing tool.

Figure 1 illustrates the process of converting plastic waste into fuel oil through pyrolysis and condensation. The process begins in the reactor tank, where plastic waste, such as bottles and bags, is heated. The heating breaks the hydrocarbon chains in the polymers into hydrocarbon vapors. The tool has two condensers that differentiate the boiling points of the produced vapors. Condenser 1 captures the heavier hydrocarbon vapors and converts them into kerosene and diesel oil. Condenser 2 captures light hydrocarbon vapors with shorter molecular chains, producing premium oil. Next, the condensed vapor undergoes a refining process to remove impurities, reduce moisture content, and adjust the fuel content to meet standards. This process includes settling, separating the oil layer, filtering, and separating the waste liquid, which is still being analyzed for its composition. Overall, this figure illustrates how plastic waste is converted into valuable fuel through the utilization of the boiling point differences of hydrocarbons. This technology reduces plastic waste while producing alternative energy in the form of premium kerosene and diesel. Thus, it has the potential to support the concepts of a circular economy and sustainable waste management.

3.3. Financial Feasibility Measurement

The Return on Investment (ROI) for the method of converting plastic waste to energy through pyrolysis can be determined by evaluating the revenue from product sales against the expenses associated with the research and development of the technology. The anticipated revenue is derived from the sale of pyrolysis products, including oil, gas, or charcoal. This estimate may be based on the market price of comparable products or on the anticipated demand within the local market. Subsequently, all expenses related to the research and development of the pyrolysis technology should be assessed, encompassing the costs of laboratory equipment, raw materials, labor, and additional expenditures. It is essential to consider overhead expenses and unforeseen costs. The next step involves calculating ROI using the formula provided below.

$$ROI = \left(\frac{Net\ Income - Total\ Cost}{Total\ Cost}\right) x\ 100\% \qquad (1)$$

Where net income represents the overall earnings after accounting for variable expenses like raw materials and operational costs, while total costs encompass all expenditures related to research and development, including both fixed and variable costs.

Net Present Value (NPV) serves as a method for evaluating investments by considering the time value of future cash flows. In the realm of investigating the conversion of waste plastic to energy through the pyrolysis method, NPV serves as a tool to evaluate the financial advantages of the research and development initiative. All cash flows related to the research and development project were identified, encompassing cash inflows (revenue generated from the sale of pyrolysis products) and cash outflows (costs associated with research, development, operations, etc.) over a specified timeframe. Subsequently, the discount factor for all future cash flows is calculated to convert them into present value by utilizing a suitable discount rate. The discount rate typically represents the cost of capital or the lowest rate of return anticipated from comparable investments. To determine the NPV, sum all future cash flows that have been discounted to their present value, and then subtract the initial investment cost using the formula provided.

$$\text{NPV} = \sum_{t=0}^{T} \frac{CFt}{(1+r)2} - Co \qquad (2)$$

Where CFt represents the net cash flow during a specific time period. In this context, r represents the discount rate, t denotes the time period, T indicates the total time period, and Co refers to the initial cost of the investment. A positive NPV signifies that the project possesses a favorable present value, suggesting it can be regarded as a lucrative investment opportunity. A greater NPV value indicates superior investment performance. Nevertheless, if the NPV is negative, it indicates that the project may not yield profitability within a specified timeframe or requires enhancements. Utilizing the NPV method allows companies or investors to make more informed decisions regarding the viability of investing in the development of pyrolysis technology for converting plastic waste into energy.

The Internal Rate of Return (IRR) represents the rate at which the present value of cash inflows equals the present value of cash outflows associated with an investment. In the context of investigating the conversion of plastic waste to energy through the pyrolysis method, IRR serves to assess the financial viability of the project by determining the rate of return on investment based on anticipated future cash flows. All cash flows related to the research and development project were identified, encompassing cash inflows (revenue generated from the sale of pyrolysis products) and cash outflows (costs associated with research, development, operations, etc.) over a specified timeframe. We use the manual IRR calculation method, so we estimate the discount rate to be used. This may rely on the weighted average cost of capital or the anticipated rate of return from comparable investments. Subsequently, we determine the internal rate of return by utilizing the IRR calculation function available in spreadsheet or financial software to derive the IRR from the cash flows collected. Alternatively, we employ the trial-and-error approach to determine the discount rate that equates the present value of cash inflows with the present value of cash outflows. The equation is presented below:

$$\text{IRR} = P1 - \text{C}2\,\frac{P2-P1}{C2-C1} \qquad (3)$$

Where P1 is the first interest rate prevailing at the time of investment, P2 is the second interest rate (the interest rate at the time of negative NPV), C1 is the first NPV value, and C2 is the second NPV. Moreover, it is economically viable as it produces a return rate that exceeds the discount rate. Nonetheless, if the internal rate of return falls below the discount rate, it suggests that the project may lack profitability or require further evaluation. Utilizing the IRR method allows companies or investors to enhance their decision-making regarding the viability of investing in the development of pyrolysis technology aimed at converting plastic waste into energy.

The Benefit-Cost Ratio (BCR) serves as a method for evaluating investments by comparing the present value of benefits to the costs linked to a project. In the context of pyrolysis waste-to-energy conversion studies, the BCR is utilized to assess the financial viability of the project by comparing the present value of benefits (revenue from the sale of pyrolysis products) with the related investment and operating expenses. We outline all advantages linked to the project, including income from the sale of pyrolysis products (oil, gas, or charcoal), and apply a suitable discount rate to convert them to present value. Next, identify all costs associated with the project, including initial investment costs, operating costs, maintenance costs, overhead costs, and other expenses. Apply the same discount rate used for the benefits to bring these costs to their present value. To determine the BCR, divide the present value of the benefits by the present value of the costs. The equation is presented below:

$$BCR = \frac{Present\ Value\ of\ Benefits}{Present\ Value\ of\ Costs} \quad (4)$$

The present value of benefits represents the cumulative present value of all advantages gained from the project. The present value of costs represents the cumulative present value of all expenses related to the project. The findings are open to interpretation. A BCR greater than 1 signifies that the project's benefits surpass its costs, indicating financial viability. A higher BCR value indicates greater profitability for the project. However, if the BCR is less than 1, it indicates that the costs of the project exceed its benefits, and the project may not be financially viable. Utilizing the BCR method enables companies or investors to make more informed decisions regarding the viability of investing in the development of pyrolysis technology for converting plastic waste into energy.

The break-even point, within the framework of examining the conversion of plastic waste to energy through the pyrolysis method, denotes the level of production or sales necessary for total revenue to match total costs. In other words, the break-even point is the point at which a project or investment makes no profit or loss but only covers its operational costs. We identify fixed costs and variable costs, separating project costs into fixed costs (costs that remain independent of production volume, such as initial investment costs and other fixed costs) and variable costs (costs that vary in line with production volume, such as raw materials, operating costs, etc.). Finally, determine the contribution margin, defined as the difference between the unit selling price of the product and the variable cost per unit. This illustrates how each unit of sales contributes to covering fixed costs and generating profits.

$$Contribution\ Margin = Selling\ Price\ per\ Unit - Variable\ Cost\ per\ Unit \quad (5)$$

Furthermore, calculating the margin contribution ratio, the margin contribution ratio is the percentage of margin contribution from the selling price per unit.

$$Margin\ Contribution\ Ratio = \left(\frac{Margin\ Contribution}{Selling\ Price\ per\ Unit}\right) x\ 100\% \quad (6)$$

When the margin contribution ratio has been established, proceed to calculate the break-even point. The break-even point is determined by dividing the total fixed costs by the contribution margin ratio. This indicates the quantity of product units that need to be sold for revenue to meet fixed costs.

$$\text{BEP} = \frac{Fixed\ Costs}{Margin\ Contribution\ Ratio} \quad (7)$$

After determining the break-even point, we ascertain the number of product units that need to be sold for the project to neither generate profit nor incur a loss. If production or sales are below the break-even point, the project will incur a loss. However, if production or sales exceed the break-even point, the project will generate a profit. The break-even point is an important tool in project planning and management because it helps to understand the minimum production or sales volume required to achieve a balance between revenue and costs.

4. RESULTS AND DISCUSSION

4.1. Investment Needs

For the conversion of waste into gasoline, kerosene, and diesel, some investment is needed in the procurement of waste processing machines, specifically designed to convert plastic waste into alternative fuels. For example, a machine with a capacity of 30 tons can produce 60% diesel, 25% premium equivalent gasoline, and 15% kerosene, or 22,086 liters of diesel, 9,203 liters of premium equivalent gasoline, and 5,522 liters of kerosene. This process requires equipment such as 1) a frame, 2) a reactor tube, 3) a condenser tube, 4) a water reservoir, 5) a liquefied petroleum gas (LPG) tube, 6) a pump, and 7) a heating furnace.

Table 1. Investment costs with a lifetime of 10 years.

No.	Equipment name	Investment costs (IDR)
1.	Reactor tank	IDR 500,000,000
2.	Heating furnace	IDR 230,000,000
3.	Valve	IDR 1,650,000,000
4.	Plastic shredder	IDR 500,000,000
5.	Liquefied petroleum gas (LPG) cylinders	IDR 1,000,000,000
6.	Thermometer	IDR 100,000,000
7.	Condenser	IDR 200,000,000
8.	Water pump	IDR 500,000,000
9.	Premium and diesel reservoirs	IDR 200,000,000
	Total	**IDR 4,880,000,000**

Table 1 details the investment cost components required to establish a waste plastic-to-fuel processing facility with a project lifetime of 10 years. The total investment cost amounts to IDR 4,880,000,000.

In addition to equipment investment costs, supporting infrastructure costs are also required, such as building construction, work floors, warehouses, ventilation, etc.

Table 2. Building construction, work floor, warehouse, ventilation.

No.	Infrastructure name	Supporting infrastructure costs
1.	Building/Work floor	IDR 250,000,000
2.	Warehouse	IDR 350,000,000
3.	Environmental and legality licensing costs	IDR 150,000,000
	Total	IDR **750,000,000**

Table 2 illustrates the detailed costs required for supporting infrastructure in the plastic waste-to-fuel conversion project. The total investment for this infrastructure is IDR 750,000,000. This table emphasizes the importance of non-machine infrastructure support in ensuring smooth production processes and regulatory compliance.

4.2. Operational Costs

The operational costs associated with the conversion of plastic waste into petroleum, kerosene, and diesel are comprised of several critical components:

Table 3. Cost of plastic waste raw materials.

No.	Raw materials	Unit	Price per ton	Amount of cost per day
1.	Coarse salt	2 ton	IDR 400,000	IDR 8,000,000
2.	Block ice	1 ton	IDR 100,000	IDR 1,000,000
3.	Polyethylene (PE)	7 ton	IDR 100,000	IDR 7,000,000
4.	Polypropylene (PP)	10 ton	IDR 100,000	IDR 10,000,000
5.	Polyethylene terephthalate (PET)	5 ton	IDR 100,000	IDR 5,000,000
6.	Polystyrene (PS)	7 ton	IDR 100,000	IDR 7,000,000
7.	Polyvinyl chloride (PVC)	1 ton	IDR 100,000	IDR 1,000,000
	Total Cost per day			IDR **39,000,000**

Table 3 shows the estimated daily raw material requirements for the waste plastic to fuel conversion process, complete with the type of material, quantity required, price per ton, and total daily cost. The total cost of raw material requirements per day is IDR 39,000,000. This indicates that the production process requires a combination of recycled plastic materials and auxiliary materials, with a significant operational cost of raw materials per day. This information is important for calculating the total operational cost and projected profit of the project.

4.3. Utility Costs

Utility costs are routine expenses required to support the daily operations of a facility or industry, especially those related to the use of basic services.

Table 4. Utility costs per month.

No.	Description	Quantity	Cost Per month
1.	Water	1000 m^2	IDR 2,000,000
2.	Electricity	1000 kWh	IDR 1,500,000
	Total		**IDR 3,500,000**

Table 4 details the monthly routine expenses required to maintain the operation of the facility, specifically related to water and electricity consumption. The total cost of utilities per month is IDR 3,500,000. This cost reflects the relatively economical efficiency of energy and water consumption for a small- to medium-scale production facility.

Table 5. Other support costs consist of employee salaries.

No.	Description	Quantity	Cost per month	Total cost/Year
1.	Employee salary	4 people	IDR 2,000,000	IDR 24,000,000
	Total			IDR **24,000,000**

Table 5 shows the labor cost of 4 employees, each receiving a salary of IDR 2,000,000 per month. Thus, the total salary cost per month is IDR 8,000,000, and the total cost per year is IDR 96,000,000. This reflects the standard operating wage, possibly for production or technical employees.

4.4. Production and Income Projections

Production and revenue projections are estimates of how much product will be produced (production) and how much income (revenue) can be obtained from the sale of these products in a certain period, usually per year. In the context of the waste plastic to fuel conversion project, the following table provides relevant insights.

Table 6. Production and Income Projections.

No.	Product	Volume/Day	Unit	Selling price/Liter	Sales per year (350 days)
1.	Gasoline	±9.203	Liter	IDR 9,000	IDR 28,989,450,000
2.	Solar	±22.086	Liter	IDR 8,000	IDR 61,840,800,000
3.	Kerosene	±5.522	Liter	IDR 7,000	IDR 13,528,900,000
Total income per year					IDR 104,359,150,000

Table 6 displays the estimated daily production volume and annual revenue generated from the sale of three types of pyrolysis fuel products for 350 operational days per year. The projected total annual revenue reaches IDR 104,359,150,000.

4.5. Annual Profit and Loss Projection

The annual profit and loss projection is an estimate of revenues and costs within a year that is used to determine whether a business will make a profit or a loss. This projection is important in business planning or feasibility studies to assess how profitable a business is within a year.

Table 7. Annual profit and loss projection.

No.	Description	Amount (IDR)	Total (IDR)
1	Income:		
	Gasoline:	IDR 28,989,450,000	
	Solar:	IDR 61,840,800,000	
	Kerosene:	IDR 13,528,900,000	
Total income			IDR 104,359,150,000
2	Operating costs:		
	Raw materials:	IDR 13,650,000,000	
	Utilities:	IDR 42,000,000	
	Employee salaries:	IDR 24,000,000	
Total operating costs:			IDR 13,716,000,000
Annual net income (Before tax & depreciation)			IDR 90,643,150,000

Table 7 presents a comparison between total income and operating costs in one year to obtain an estimate of annual net profit before tax and depreciation. This shows a very high profit potential, with an unusually high ratio of profit to operating costs. This projection is important to support the argument for the economic viability of the business.

Table 8. The investment feasibility criteria.

Criteria	Unit	Value
Break-even point (BEP)	Year	0.062
Return on investment (ROI)	Percent	1.61%
Net present value (NPV)	Rupiah	IDR. 550,750,000
Internal rate of return (IRR)	Percent	**1000%**
Benefit-cost ratio (BCR)		6.2
Contribution margin (CM)	Percent	8.60%

4.6. Financial Feasibility

The findings from the financial analysis of the plastic waste to fuel conversion (gasoline, diesel, and kerosene) presented in Table 8 indicate that the project holds significant promise and is economically viable. This analysis is based on several key indicators of financial viability calculated over a 10-year projection period. First, the ROI figure of 1,610.7% indicates that the project generates a return on investment of more than 16 times the initial capital within just 1 year. This is a very high profitability indicator and is rarely observed in similar industrial-scale projects. The substantial ROI demonstrates that the project is highly efficient in generating profits from relatively small capital, with low investment risk and rapid returns (aligned with BEP results of approximately 23 days). The potential to attract investors or business partners is significant due to profit levels that surpass market standards. Second, the annual profit and loss projection shows that the project can generate a net profit of IDR 90,643,150,000 per year after deducting all operational costs, including raw materials, utilities, and employee salaries. The primary revenue is derived from the sale of three categories of fuels produced through pyrolysis: gasoline (approximately 9,203 liters per day), diesel (approximately 22,086 liters per day), and kerosene (approximately 5,522 liters per day), resulting in total income exceeding IDR 104 billion annually. Third, regarding financial feasibility, the Net Present Value (NPV) over a 10-year period with a 10% discount rate is approximately IDR 550.75 billion. This high NPV reflects the excess of economic benefits over costs and indicates that the project will deliver returns well above investor expectations. Additionally, the estimated Internal Rate of Return (IRR) exceeds 1000%, given the relatively small initial investment of IDR 5.63 billion compared to the large annual cash flows. This suggests an exceptionally high rate of return, making it a highly profitable investment. Furthermore, the benefit-cost ratio (BCR) of 6.2 confirms that the financial benefits significantly outweigh the total project costs. Since the BCR is greater than 1, it indicates that each IDR 1 invested can generate benefits of more than IDR 6. Most notably, the break-even point (BEP) is approximately 0.06 years, or about 23 working days, meaning the project can break even in less than one month from the start of operations. This is rare for large industrial projects and highlights the high efficiency and profitability of pyrolysis technology in this context. The contribution margin of IDR 7,040 per liter indicates that each liter of product sold substantially contributes to covering fixed costs and generating profits. The high margin contribution ratio of 86.9% suggests that most revenue is gross profit rather than raw material costs, indicating variable cost efficiency and supporting earlier feasibility findings (ROI, NPV, and BEP). It is important to note that these findings are heavily influenced by consistent product selling prices, the availability of plastic raw materials, and the efficiency of production equipment. These estimates may change due to supply disruptions or significant fluctuations in fuel prices. Therefore, risk management and operational efficiency are critical factors in project implementation.

5. CONCLUSION, LIMITATIONS AND FUTURE RESEARCH AGENDA

The financial feasibility analysis of the plastic waste-to-fuel conversion project through the pyrolysis method showed very positive results. With an initial investment of IDR 5.63 billion, the project is projected to generate an annual net profit of IDR 90.64 billion. Key financial indicators such as NPV of IDR 550.75 billion, IRR estimated at more than 1000%, ROI of 1,610.7%, and the BEP achieved in approximately 23 working days suggest that the project demonstrates significant profitability and economic viability. The project not only offers financial advantages but also plays a significant role in minimizing plastic waste and providing alternative energy sources, aligning with the objectives of environmental sustainability. Nonetheless, the achievement of this project is significantly influenced by the consistency of product selling prices, the accessibility of plastic raw materials, and the efficiency of production equipment.

Although the analysis shows promising prospects, there are some limitations that need to be considered: a. Product Quality: Current pyrolysis fuel products still face challenges in terms of quality, such as low octane value and high sulfur content, which may affect engine performance and environmental emissions. b. Environmental Impact: The pyrolysis process can generate air pollution and other wastes if not managed properly, which may conflict with the purpose of plastic waste treatment itself. c. The scalability of technology presents significant hurdles for the large-scale implementation of pyrolysis technology, particularly concerning cost efficiency and the necessity for sufficient facilities. d. Raw Material Availability: The success of the project is heavily dependent on the consistent availability and supply of suitable plastic waste for the pyrolysis process.

In order to address current limitations and improve future outcomes of the project, several proposed research agendas include: 1. Catalyst Technology Development: Additional investigation is required to enhance catalysts that can boost the efficiency of the pyrolysis process and elevate the quality of the resulting fuel products. 2. Environmental Impact Analysis: A comprehensive examination of the environmental consequences of the pyrolysis process, focusing on gas emissions and other byproducts, along with the formulation of effective mitigation strategies. 3. Production Process Optimization: Investigation to determine the ideal parameters in the pyrolysis process, including temperature, residence time, and type of plastic utilized, to enhance efficiency and product quality. 4. Economic Study and Business Model: Formulation of a sustainable business model accompanied by an in-depth economic analysis to guarantee the project's long-term viability. 5. Integration with Renewable Energy Systems: Investigate the potential for combining pyrolysis technology with various renewable energy systems to develop a comprehensive and sustainable energy solution.

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