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Pyrolysis for plastic waste: Environmental goals vs business interests, which is more realistic?

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Abstract

Global plastic production exceeds 390 million tons annually, yet only about 9% is recycled, leaving severe environmental impacts. Pyrolysis is emerging as a promising solution, converting plastic waste into fuels and chemicals. However, popular claims on mass media and commercial technology publications, that 1 kg of plastic yields 1 liter of fuel are misleading, as they ignore differences in mass, volume, and fuel density. Pyrolysis oil can indeed serve as fuel but often needs further refining to meet engine standards. Economically, it holds potential, with oil prices ranging from USD 600–900 per ton and syngas generating up to 800 kWh per ton. Nonetheless, high capital and operational costs challenge its feasibility, particularly for small-scale operations. Environmentally, pyrolysis aligns with sustainability and circular economy goals, potentially reducing emissions by up to 3.5 tons of CO_2-equivalent per ton of plastic processed. This paper examines pyrolysis critically, addressing misconceptions and evaluating its realistic prospects as both an environmental solution and a business venture.

Keywords: Plastic pyrolysis; Conversion efficiency; Circular economy; Economic viability

1. Introduction

Global plastic production has continued to rise since the mid-20th century, reaching over 390 million tons in 2021. Unfortunately, only around 9% of plastic waste is successfully recycled [1], while the rest accumulates in the environment [2]. To address this issue, technologies such as pyrolysis are gaining significant attention due to their ability to convert plastic waste into valuable products, including pyrolysis oil that can be used as fuel or as a feedstock for the petrochemical industry [3], [4]. However, numerous claims require critical scrutiny, one of which is the popular assertion, frequently appearing in media reports, commercial technology publications, and public discussions, that 1 kg of plastic can yield 1 liter of fuel oil [5], [6]. From an economic perspective, pyrolysis offers attractive business opportunities, with pyrolysis oil prices ranging around USD 600–900 per ton [7]. Nonetheless, equipment investment costs, high energy consumption, and operational expenses pose significant challenges, especially at smaller scales, which are often less competitive. Moreover, the success of this technology is determined not only by technical aspects but also by business strategies capable of integrating sustainability with profitability [8], [9]. Life Cycle Assessment (LCA) studies indicate that pyrolysis has a lower carbon footprint compared to landfill or incineration [10], however, the energy required remains substantial and can result in additional emissions if still derived from fossil fuels [11].

The fundamental question is whether pyrolysis technology is intended for environmental missions or business purposes, and whether these goals can work in synergy (**Figure 1**). This opinion is written to give readers a more objective perspective on the role of pyrolysis technology in the context of sustainability and future industries, while also correcting misconceptions about the efficiency of converting plastic into oil.

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2. Technical and Economic Analysis

2.1. Technical Aspect

The claim that plastic pyrolysis yields a 1:1 conversion efficiency needs to be clarified because there is a fundamental difference between units of mass (kilograms) and volume (liters), which cannot be equated without considering the physical properties of the material, particularly its den-

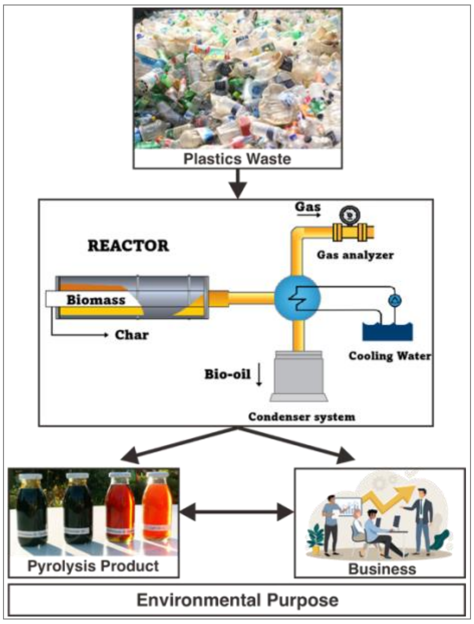

Figure 1. Pyrolysis technology for environmental missions or business purposes?

sity. Diesel fuel produced from pyrolysis has a specific gravity of around 0.78–0.82 kg/liter [12], [13], while pyrolysis oil comparable to gasoline has a lower density of about 0.75 kg/liter [14]. This means that 1 liter of diesel weighs approximately 0.78 to 0.82 kilograms, so the claim that 1 kg of plastic can directly become 1 liter of diesel or gasoline is inaccurate. Mass-to-volume conversion is not a 1:1 relationship, because apart from density factors, the pyrolysis process itself does not entirely produce oil. A portion of the plastic mass breaks down into gas (syngas), which has high calorific value, or into solid residue in the form of char [15].

Pyrolysis oil indeed has potential as an alternative fuel, but it is not automatically compatible with all types of engines. The chemical composition of pyrolysis oil differs from that of conventional fuels such as pure diesel, making it necessary to test its physical and chemical properties, including density, viscosity, calorific value, and sulfur content. Such testing is typically performed in accordance with international standards like ASTM. Therefore, although pyrolysis oil can be utilized as a fuel, further treatment such as advanced purification through hydrotreating [11] is required to ensure that the fuel quality meets engine specifications optimally and can be safely used. With proper technical understanding, pyrolysis remains a promising technology, even though simplistic efficiency claims need to be examined more critically.

2.2. Business Aspect

Plastic pyrolysis is technically feasible, but from a business perspective, it is not as simple as it may seem. Plastic must be purchased, sorted, cleaned, and dried, and the process requires high energy input (300–700 °C), significantly exceeding theoretical values due to heat losses in real systems [16]. All these factors increase production costs and contribute to the carbon footprint [17]. The initial investment is also substantial. Costs include the price of equipment (which varies depending on capacity and technology), labor, and supporting systems such as cooling units, oil purification systems, and exhaust gas treatment. The main challenge arises at small scales, as the smaller the processing capacity, the higher the production cost per ton [9], [18]. After calculating all investment and operational costs, the next crucial step is to analyze financial feasibility using indicators such as the Benefit to Cost Ratio (BCR), which ideally should be greater than 1, Net Present Value (NPV), to assess the present value of future profits, and the Internal Rate of Return (IRR), which reflects the rate of return on capital [9], [19]. For example, with a bank interest rate of 10% per year and a pyrolysis machine lifespan of five years, it is necessary to calculate depreciation and salvage value. Without detailed financial calculations, a pyrolysis business carries a high risk of incurring losses, even though it may be technically viable. Furthermore, a positive NPV or an IRR higher than the bank interest rate does not guarantee definite profits, as this business still faces risks such as tax burdens, maintenance costs, sustainable plastic supply, oil price fluctuations, market certainty, and environmental regulations. Comprehensive risk analysis is key to ensuring that potential profits can truly be realized in practice.

3. Environmental Goals vs Business Interests

3.1. Environmental Goals

Pyrolysis is a promising solution to environmental challenges, especially in reducing plastic pollution and supporting sustainability. It transforms plastic waste into valuable products like liquid fuels and chemicals, which can substitute fossil-based fuels and lower greenhouse gas emissions up to 3.5 tons of CO_2-equivalent per ton of plastic processed [16], [17]. The technology also supports a circular economy by converting non-recyclable plastics into chemical feedstocks, enabling the production of virgin-quality polymers and reducing dependence on fossil resources [20], [21]. This aligns with the UN's Sustainable Development Goals and global efforts to curb plastic pollution [17], [21]. However, pyrolysis is not without challenges. While life cycle assessments show lower climate impact than landfilling or incineration, the process still requires high energy input and further development of efficient catalysts to improve yield and minimize environmental impact [16], [22]. Continued research and innovation are essential to unlock its full environmental potential.

3.2. Business Interests

Pyrolysis offers strong economic potential through its valuable outputs. Pyrolysis oil can sell for USD 600–900 per ton, while syngas can generate up to 800 kWh of electricity per ton of plastic processed [16]. These products present promising revenue streams. However, the technology faces significant economic barriers, including high capital and operational costs due to its energy-intensive nature and the need for catalysts and ongoing maintenance [16], [17]. Its feasibility is also shaped by market conditions, such as fossil fuel prices and demand for sustainable products. In regions with favorable policies, like subsidies, tax incentives, or recycled content mandates, and high energy costs, pyrolysis can be more competitive [16], [23]. From an industrial perspective, major companies like Plastic Energy, SABIC, and Unilever have begun investing in pyrolysis, signaling growing interest in its integration within existing value chains [17]. Yet, as an emerging technology, broader adoption hinges on overcoming technical barriers and navigating regulatory complexities [23].

4. Conclusion

While pyrolysis indeed offers economic opportunities through valuable outputs like pyrolysis oil and syngas, its primary mission must remain environmental. The ultimate goal of plastic pyrolysis should not be profit, but rather the urgent need to reduce plastic pollution and mitigate ecological harm. A truly successful waste management industry would ideally face the “problem” of lacking plastic feedstock because society has effectively reduced plastic consumption and waste generation. Therefore, business interests in pyrolysis should be carefully balanced with environmental objectives, ensuring that economic gains do not overshadow the core purpose of protecting the planet.

References

[1] L. Parker, “A whopping 91% of plastic isn’t recycled,” *National Geograohic*, Dec. 20, 2018. [Online]. Available: https://www.nationalgeographic.com/science/article/plastic-produced-recycling-waste-ocean-trash-debris-environment

[2] R. Geyer, J. R. Jambeck, and K. L. Law, “Production, use, and fate of all plastics ever made,” *Science Advances*, vol. 3, no. 7, p. e1700782, Jul. 2017, doi: 10.1126/sciadv.1700782.

[3] R. Miandad, M. A. Barakat, M. Rehan, A. S. Aburiazaiza, I. M. I. Ismail, and A. S. Nizami, “Plastic waste to liquid oil through catalytic pyrolysis using natural and synthetic zeolite catalysts,” *Waste Management*, vol. 69, pp. 66–78, 2017, doi: 10.1016/j.wasman.2017.08.032.

[4] S. Sunaryo, S. Sutoyo, S. Suyitno, Z. Arifin, T. Kivevele, and A. I. Petrov, “Characteristics of briquettes from plastic pyrolysis by-products,” *Mechanical Engineering for Society and Industry*, vol. 3, no. 2, pp. 57–65, Jun. 2023, doi: 10.31603/mesi.9114.

[5] G. Plastic, “Get plastic foundation - no plastic goes to waste,” Jul. 2025. [Online]. Available: https://getplastic.id/

[6] Kementerian ESDM Republik Indonesia, “Premium dari limbah plastik,” Jul. 2025. [Online]. Available: https://www.esdm.go.id/id/media-center/arsip-berita/premium-dari-limbah-plastik

[7] Mordor Intelligence, “Pyrolysis Oil market - price, companies & manufacturers.” [Online]. Available: https://www.mordorintelligence.com/industry-reports/pyrolysis-oil-market

[8] W. Fong-Silva, R. Pitre-Redondo, and J. Chiquillo-Rodelo, “Business competitiveness and its association with exogenous factors in plastic recycling companies of the Colombian Caribbean coast,” *Contemporary Engineering Sciences*, vol. 11, no. 2, pp. 71–79, 2018, doi: 10.12988/ces.2018.711190.

[9] A. Fivga and I. Dimitriou, “Pyrolysis of plastic waste for production of heavy fuel substitute: A techno-economic assessment,” *Energy*, vol. 149, pp. 865–874, 2018, doi: 10.1016/j.energy.2018.02.094.

[10] T. Xayachak, N. Haque, D. Lau, R. Parthasarathy, and B. K. Pramanik, "Assessing the environmental footprint of plastic pyrolysis and gasification: A life cycle inventory study," *Process Safety and Environmental Protection*, vol. 173, pp. 592–603, 2023, doi: 10.1016/j.psep.2023.03.061.

[11] L. Pires Costa, D. M. Vaz de Miranda, and J. C. Pinto, "Critical Evaluation of Life Cycle Assessment Analyses of Plastic Waste Pyrolysis," *ACS Sustainable Chemistry & Engineering*, vol. 10, no. 12, pp. 3799–3807, Mar. 2022, doi: 10.1021/acssuschemeng.2c00265.

[12] Ł. Grabowski, M. Gliniak, M. Wołosiewicz-Głąb, and K. Dziedzic, "Possibilities of Using the Hydrocarbon Fraction from the Depolymerization Process for Combined Heat and Power Systems," *Energy & Fuels*, vol. 31, no. 3, pp. 2914–2918, Mar. 2017, doi: 10.1021/acs.energyfuels.6b03024.

[13] S. McIntosh, M. N. Nabi, L. Moghaddam, P. Brooks, P. S. Ghandehari, and D. Erler, "Combined pyrolysis and sulphided NiMo/Al2O3 catalysed hydroprocessing in a multistage strategy for the production of biofuels from milk processing waste," *Fuel*, vol. 295, p. 120602, Jul. 2021, doi: 10.1016/j.fuel.2021.120602.

[14] S. H. Masakhoh *et al.*, "Pyrofuel extraction from polyethylene terephthalate (PET) plastic waste," in *International Symposium on Advanced Materials and Processing 2021 (ISAMP 2021)*, 2022, p. 040001. doi: 10.1063/5.0090704.

[15] G. Lopez, M. Artetxe, M. Amutio, J. Alvarez, J. Bilbao, and M. Olazar, "Recent advances in the gasification of waste plastics. A critical overview," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 576–596, 2018, doi: 10.1016/j.rser.2017.09.032.

[16] M. M. Hasan, R. Haque, M. I. Jahirul, and M. G. Rasul, "Pyrolysis of plastic waste for sustainable energy Recovery: Technological advancements and environmental impacts," *Energy Conversion and Management*, vol. 326, p. 119511, Feb. 2025, doi: 10.1016/j.enconman.2025.119511.

[17] S. Saxena, "Pyrolysis and beyond: Sustainable valorization of plastic waste," *Applications in Energy and Combustion Science*, vol. 21, p. 100311, Mar. 2025, doi: 10.1016/j.jaecs.2024.100311.

[18] S. R. Khan, M. Zeeshan, S. Fatima, D. Ciolkosz, I. Dimitriou, and H. Jin, "A comparative techno-economic analysis of combined oil and power production from pyrolysis and co-pyrolysis plants utilizing rice straw and scrap rubber tires," *Fuel*, vol. 348, p. 128639, Sep. 2023, doi: 10.1016/j.fuel.2023.128639.

[19] B. Biakhmetov, Y. Li, Q. Zhao, A. Dostiyarov, D. Flynn, and S. You, "Transportation and process modelling-assisted techno-economic assessment of resource recovery from non-recycled municipal plastic waste," *Energy Conversion and Management*, vol. 324, p. 119273, Jan. 2025, doi: 10.1016/j.enconman.2024.119273.

[20] S. Das, C. Liang, and J. B. Dunn, "Plastics to fuel or plastics: Life cycle assessment-based evaluation of different options for pyrolysis at end-of-life," *Waste Management*, vol. 153, pp. 81–88, Nov. 2022, doi: 10.1016/j.wasman.2022.08.015.

[21] H. Jeswani *et al.*, "Life cycle environmental impacts of chemical recycling via pyrolysis of mixed plastic waste in comparison with mechanical recycling and energy recovery," *Science of The Total Environment*, vol. 769, p. 144483, May 2021, doi: 10.1016/j.scitotenv.2020.144483.

[22] X. Li *et al.*, "Review of Co-Pyrolysis Technologies of Typical Plastic and Biomass Waste for Value-Added Products," *Research of Environmental Sciences*, vol. 36, no. 9, pp. 1765–1778, 2023, doi: 10.13198/j.issn.1001-6929.2023.08.01.

[23] C. Stallkamp *et al.*, "Economic and environmental assessment of automotive plastic waste end-of-life options: Energy recovery versus chemical recycling," *Journal of Industrial Ecology*, vol. 27, no. 5, pp. 1319–1334, Oct. 2023, doi: 10.1111/jiec.13416.