Advances: Jurnal Ekonomi & Bisnis

OPEN ACCESS

Volume 4, Issue 2 (2026). 379-391

e-ISSN: 2985-9859

DOI: https://doi.org/10.60079/ajeb.v4i2.762

Technical and Financial Feasibility Study of A 10 MW Waste-Power Plant Construction Project

Swempri Agung Prasetyo [1*]

[1] Institut Teknologi PLN, Jakarta, Indonesia. Email: swempri.agung@gmail.com

ARTICLE HISTORY

Submitted	:	April 15, 2026
Reviewed	:	April 21, 2026
Revised	:	April 29, 2026
Accepted	:	May 04, 2026
Published	:	May 06, 2026

Conflict of Interest Statement:
The author(s) declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

ABSTRACT

Purpose: This study evaluates the technical and financial feasibility of developing a 10 MW Waste-to-Energy Power Plant (PLTSa) in Tembilahan City as an integrated response to urban waste management problems and increasing electricity demand.

Research Method: A quantitative techno-economic feasibility approach was employed. Waste generation was measured in accordance with SNI 19-3964-1994, yielding 0.376 kg/person/day. Energy potential was analyzed using an assumed Lower Heating Value of 3,674 kcal/kg under three technology scenarios: pyrolysis, incineration with combined heat and power, and gasification. Financial feasibility was assessed using Net Present Value, Benefit-Cost Ratio, Internal Rate of Return, and Payback Period at a 10% discount rate.

Results and Discussion: Gasification demonstrated the highest feasibility, with an NPV of IDR 83.03 billion, a B/C ratio of 1.86, an IRR of 15%, and a payback period of 12.8 years. Pyrolysis and incineration were less feasible due to lower conversion efficiency. However, project viability remains sensitive to assumptions about waste calorific value and cost.

Implications: WTE planning should consider local waste characteristics, technology-specific costs, and operational risks to support realistic policy decisions.

Originality: This study provides a context-specific techno-economic assessment of PLTSa development in a non-metropolitan city in Indonesia.

Keywords: financial feasibility; municipal solid waste; technical feasibility; techno-economic analysis; energy waste.

1. Introduction

Indonesia stands at a strategic crossroads, facing two fundamental, interrelated challenges: the urgent need to transition away from fossil fuel dependence and a worsening urban waste management crisis. National reliance on fossil fuels not only creates vulnerability to global price volatility but also places Indonesia as a significant contributor to greenhouse gas emissions in Southeast Asia, with far-reaching environmental impacts (Yasmeen & Shah, 2024). In line with global commitments, the government has set an ambitious target for a new and renewable energy mix in the National Energy General Plan (RUEN). However, achieving it still faces various systemic obstacles.

In parallel, population growth and rapid urbanization have increased the volume of municipal solid waste (MSW), exceeding the capacity of existing management infrastructure (Voukkali *et al.*, 2024). Many cities in Indonesia face challenges in managing waste effectively, often due to a lack of coordination, fragmented systems, and limited landfill space (Mukhlis, 2024; Punta *et al.*, 2024). Poorly

Volume 4, Issue 2 (2026). 379-391
e-ISSN: 2985-9859
DOI: https://doi.org/10.60079/ajeb.v4i2.762

managed waste is a source of soil, water, and air pollution, and contributes to methane emissions, a greenhouse gas far more potent than carbon dioxide (Fayyazbakhsh *et al.*, 2022). This situation demands innovative solutions that can address both problems simultaneously.

Waste-to-Energy (WTE) technology, known in Indonesia as Waste-to-Energy Generation (PLTSa), has emerged as a strategic intervention offering integrated solutions. By transforming waste, previously an environmental liability, into an energy asset, WTE fundamentally shifts the waste management paradigm from a linear "collect, transport, dispose" model to a more sustainable, circular model (Ram *et al.*, 2021; Oktavilia *et al.*, 2024). This technology not only reduces the volume of waste sent to landfills by up to 90% but also generates electrical and/or thermal energy, contributing to the diversification of the national energy mix (Beyene *et al.*, 2018).

Several developed countries, such as Japan, Germany, and South Korea, have successfully implemented WTE on a large scale, making it an integral component of their waste and energy management systems (Alao *et al.*, 2022; Purnomo, 2024). This international success demonstrates the technical maturity of various WTE platforms, such as incineration, gasification, and pyrolysis. However, WTE implementation in Indonesia still faces significant challenges. Existing projects, such as the Sumur Batu Waste-to-Energy Plant (WTE) in Bekasi, often operate below optimal capacity and face complex technical and financial constraints, including very high initial investment costs and dependence on external funding (Thio *et al.*, 2021; Tjendra & Ismelina, 2024).

While most of the WTE discourse in Indonesia centers on metropolitan cities, the challenges of waste and energy management are also acutely felt in non-metropolitan cities. Tembilahan City, the administrative and economic center of Indragiri Hilir Regency in Riau Province, serves as a relevant case study for exploring the feasibility of WTE outside major urban centers. Data from the National Waste Management Information System (SIPSN) indicates a significant volume of waste in this regency, with a clear upward trend from 299.93 tons/day in 2020 to 460.62 tons/day in 2021.

The data gap for Indragiri Hilir Regency in 2022 and 2023 underscores a fundamental challenge in regional infrastructure planning: the lack of a consistent, reliable data collection system. However, the available data is sufficient to indicate that without effective intervention, waste volumes will continue to pose a serious environmental burden. The development of a waste-to-energy plant (PLTSa) in a location like Tembilahan has the potential to not only address local waste issues but also improve regional energy security and support national renewable energy targets (Santosa *et al.*, 2023).

This study aims to fill several important gaps in the WTE literature in Indonesia and offers significant new contributions. By focusing on Tembilahan City, this study provides an empirical analysis for the context of a non-metropolitan city, which is often overlooked in feasibility studies that tend to concentrate on large cities such as Jakarta or Surabaya. Rather than relying on secondary data, this study uses primary data for the most crucial parameter, the per capita waste generation rate, obtained through direct field measurements in accordance with Indonesian National Standard (SNI) 19-3964-1994. This approach ensures more accurate and locally relevant baseline data, thereby increasing the validity of technical and financial projections. Furthermore, this study conducts a systematic techno-economic analysis of three different WTE technology scenarios—pyrolysis, incineration with combined heat and power (CHP), and gasification—each of which has distinct technical characteristics and performance implications (Al Arni, 2018; De Greef *et al.*, 2018; Dong *et al.*, 2019). This multi-scenario analysis provides a more comprehensive decision-making framework for stakeholders, clearly highlighting the trade-offs between efficiency, reliability, and financial viability. The most significant contribution of this study lies

e-ISSN: 2985-9859

in its critical perspective on financial modeling assumptions, particularly by identifying key limitations such as the assumption of uniform costs across technologies and the exclusion of tipping fee revenue streams, which are crucial under Indonesia's regulatory framework.

The remainder of this paper is organized as follows. Section 2 provides a literature review and hypothesis development. Section 3 presents the research method and design. Section 4 provides a discussion. Section 5 is Concluding Remarks and Recommendations.

2. Literature Review and Hypothesis Development

2.1 Conceptual Framework of Waste-to-Energy (WTE) in Sustainable Development

Waste-to-Energy (WTE) represents an integrated approach that connects the domains of waste management and energy production within the broader framework of sustainable development. From the perspective of circular economy theory, WTE transforms municipal solid waste (MSW) from an environmental burden into a valuable resource, thereby reducing dependence on landfills while generating energy (Ram *et al.*, 2021; Oktavilia *et al.*, 2024). This paradigm shift aligns with the principles of resource efficiency and environmental sustainability, particularly in rapidly urbanizing countries such as Indonesia.

In addition, WTE contributes to climate change mitigation by reducing methane emissions from landfills, which are significantly more potent than carbon dioxide in terms of global warming potential (Fayyazbakhsh *et al.*, 2022). From an energy policy standpoint, the diversification of energy sources through WTE supports national targets for renewable energy mix and enhances energy security (Yasmeen & Shah, 2024; Santosa *et al.*, 2023). Therefore, WTE can be theoretically positioned at the intersection of environmental sustainability, energy transition, and economic efficiency.

2.2 Technical Feasibility of WTE Technologies

Technical feasibility is a critical dimension in determining the success of WTE projects, particularly in developing countries where waste characteristics and infrastructure readiness vary significantly. The main WTE technologies include incineration, gasification, and pyrolysis, each with distinct operational mechanisms and performance outcomes. Incineration is the most mature and widely implemented technology globally, capable of reducing waste volume by up to 90% while generating stable energy output. When integrated with combined heat and power (CHP) systems, incineration achieves higher energy efficiency by simultaneously producing electricity and heat (De Greef *et al.*, 2018). However, this technology requires strict emission control systems and high-calorific-value waste to operate optimally (Sebastian *et al.*, 2024).

Gasification converts waste into syngas through partial oxidation at high temperatures. This technology offers higher energy efficiency and lower emissions compared to conventional incineration but is highly dependent on feedstock quality and pre-treatment processes (Liang *et al.*, 2024). Pyrolysis involves thermal decomposition of waste in the absence of oxygen, producing bio-oil, syngas, and char. This technology is considered more environmentally friendly and flexible in handling different waste compositions, although it is less commercially mature and faces scalability challenges (Al Arni, 2018; Nguyen & Khuong, 2022; Zhao *et al.*, 2022). The performance of these technologies is strongly influenced by key technical parameters, including waste composition, moisture content, and Lower Heating Value (LHV), which determine the efficiency of energy conversion (Nufus *et al.*, 2025). Thus,

Volume 4, Issue 2 (2026). 379-391
DOI: https://doi.org/10.60079/ajeb.v4i2.762
e-ISSN: 2985-9859

accurate characterization of local waste is essential for assessing the technical feasibility of WTE projects, especially in non-metropolitan contexts such as Tembilahan City.

2.3 Financial Feasibility and Economic Constraints

Beyond technical considerations, financial feasibility plays a decisive role in WTE project implementation. WTE projects are characterized by high capital expenditure (CAPEX), complex financing structures, and long payback periods. Initial investment costs for WTE facilities, particularly those utilizing advanced technologies, can be prohibitively high, often requiring government support or public-private partnerships (Thio *et al.*, 2021).

Revenue streams in WTE projects typically include electricity sales, tipping fees, and by-product utilization. However, many feasibility studies tend to underestimate the importance of tipping fees, which are critical in ensuring project viability, especially in regions where electricity tariffs alone are insufficient to cover operational costs (Tjendra & Ismelina, 2024). From an institutional perspective, ineffective waste management systems, lack of policy integration, and limited stakeholder coordination further exacerbate financial risks (Mukhlis, 2024; Punta *et al.*, 2024). These constraints highlight the importance of adopting a comprehensive techno-economic analysis framework that incorporates both cost structures and regulatory factors.

2.5 Empirical Gaps in Non-Metropolitan Contexts

Existing literature on WTE in Indonesia predominantly focuses on large metropolitan areas, where waste volumes, infrastructure, and financial capacity are relatively well established. However, non-metropolitan cities such as Tembilahan face distinct challenges, including limited data availability, lower waste generation rates, and constrained fiscal capacity. The lack of empirical studies in such contexts creates a significant research gap, particularly regarding how technical and financial variables interact across different regional conditions. Moreover, the absence of reliable waste data systems complicates infrastructure planning and investment decision-making. Therefore, an empirical study focusing on Tembilahan City is essential to provide context-specific insights and enhance the generalizability of WTE feasibility models in Indonesia.

2.6 Hypothesis Development

Based on the theoretical and empirical literature discussed above, this study formulates the following hypotheses:

H1: *Technical parameters of municipal solid waste (composition, moisture content, and calorific value) have a significant effect on the technical feasibility of a 10 MW Waste-to-Energy power plant in Tembilahan City.*

H2: *The choice of WTE technology (incineration, gasification, and pyrolysis) significantly influences energy efficiency and operational reliability in the proposed project.*

H3: *High capital investment and operational costs negatively affect the financial feasibility of the WTE project if not supported by adequate revenue streams.*

H4: *The inclusion of tipping fee mechanisms and supportive policy frameworks positively influences the financial viability of the WTE project.*

H5: *Integrated techno-economic analysis provides a more accurate and reliable assessment of WTE project feasibility compared to single-dimensional (technical or financial only) approaches.*

Advances: Jurnal Ekonomi & Bisnis
Volume 4, Issue 2 (2026). 379-391
DOI: https://doi.org/10.60079/ajeb.v4i2.762
OPEN ACCESS e-ISSN: 2985-9859

This study positions itself within the intersection of technical feasibility and financial viability, emphasizing the need for a holistic evaluation framework to support evidence-based decision-making in WTE project development, particularly in non-metropolitan regions.

3. Research Method

3.1 Research Design

This study adopts a quantitative, comparative techno-economic feasibility analysis to evaluate the development of a 10 MW Waste-to-Energy (WTE) power plant in Tembilahan City. The research integrates two interrelated analytical dimensions: technical feasibility, which examines waste characteristics and the capability of selected technologies to generate energy efficiently, and financial feasibility, which evaluates the project's economic viability over its lifecycle. This dual approach is consistent with prior studies emphasizing the importance of integrating engineering performance and economic analysis in WTE assessments (Ram *et al.*, 2021; Alao *et al.*, 2022). Furthermore, the comparative design allows systematic evaluation across multiple technology scenarios, namely pyrolysis, incineration with combined heat and power (CHP), and gasification, each of which has distinct performance characteristics (Dong *et al.*, 2019).

3.2 Sample and Sampling Technique

The study employs a primary sampling approach to estimate municipal solid waste (MSW) generation, in accordance with the Indonesian National Standard SNI 19-3964-1994. The sample size is determined using a standardized formula:

$$S = C_d\sqrt{P_s}$$

Where S represents the number of sampled individuals, C_d is the coefficient for medium/small cities (0.5), and P_S is the total population. Based on a 2024 population of 84,608, the required sample size is 145 individuals, equivalent to 29 households (KK). This sampling technique ensures representativeness in estimating per capita waste generation, a critical parameter that influences WTE system design and performance (Nufus *et al.*, 2025). The use of standardized sampling methods also aligns with best practices in waste characterization studies, ensuring reliability and comparability of results.

3.3 Data and Instrumentation

This study utilizes both primary and secondary data. Primary data consist of direct measurements of household waste generation collected over seven consecutive days, providing empirical estimates of per capita waste generation. Secondary data include population statistics, electricity tariffs, financial assumptions, and technical parameters obtained from institutional reports and literature.

Key technical variables include waste composition and Low Heating Value (LHV), which determines the energy potential of waste. The assumed LHV of 3,674 kcal/kg is based on typical waste composition patterns reported in previous studies (Nufus *et al.*, 2025). Additionally, technological parameters such as conversion efficiency (η) are derived from established literature on pyrolysis, incineration, and gasification systems (Al Arni, 2018; De Greef *et al.*, 2018). Financial data instrumentation includes structured parameters such as discount rate, capital expenditure (CAPEX),

Volume 4, Issue 2 (2026). 379-391
e-ISSN: 2985-9859
DOI: https://doi.org/10.60079/ajeb.v4i2.762

operational expenditure (OPEX), and electricity tariffs, which are essential for modeling long-term project feasibility (Thio *et al.*, 2021).

3.4 Data Collection Procedure

Data collection was conducted through field-based measurements and document analysis. Primary data were collected by measuring daily household waste generation from 29 sampled households over seven days, ensuring temporal consistency and minimizing daily variability. This approach follows standardized waste measurement protocols to enhance data accuracy. Secondary data were obtained from official reports, including electricity tariff data and macroeconomic indicators, as well as from relevant literature on WTE technologies and waste management systems. The integration of primary and secondary data enables a comprehensive evaluation of both local conditions and broader technological benchmarks (Mukhlis, 2024; Punta *et al.*, 2024).

3.5 Data Analysis

Data analysis is conducted using a techno-economic modeling framework. From the technical perspective, waste generation is projected over a 35-year project lifespan using a geometric growth model:

$$\boldsymbol{W_t = W_0(1+g)^t}$$

The potential electrical energy generated is estimated using the energy conversion model:

$$E_{PLTSa} = W_t \times \eta \times LHV$$

Where η represents the conversion efficiency, a key differentiating factor among technologies. The importance of LHV and conversion efficiency in determining WTE performance has been widely emphasized in previous studies (Beyene *et al.*, 2018). From a financial perspective, a discounted cash flow (DCF) analysis is applied to evaluate project feasibility over 35 years. The analysis incorporates capital inflows (electricity sales) and outflows (CAPEX and OPEX). Four standard financial indicators are used:

- Net Present Value (NPV)
- Benefit-Cost Ratio (B/C Ratio)
- Internal Rate of Return (IRR)
- Payback Period (PP)

These metrics are widely recognized in infrastructure project evaluation and provide a comprehensive assessment of investment viability (Thio *et al.*, 2021). A comparative scenario analysis is conducted across three technologies: pyrolysis (15% efficiency), incineration with CHP (20%), and gasification (30%), based on literature benchmarks (Al Arni, 2018; De Greef *et al.*, 2018). However, the model assumes uniform cost and revenue structures across scenarios, implying that financial outcomes are primarily driven by conversion efficiency. This simplification highlights a critical limitation of techno-economic models, as real-world feasibility is also influenced by policy instruments, operational risks, and market dynamics (Dong *et al.*, 2019). Overall, this analytical approach provides a systematic and empirical basis for evaluating the feasibility of WTE development in non-metropolitan contexts such as Tembilahan City.

Volume 4, Issue 2 (2026). 379-391
e-ISSN: 2985-9859
DOI: https://doi.org/10.60079/ajeb.v4i2.762

4. Results and Discussion

4.1 Analysis Results

The technical analysis begins with quantifying the available raw materials. Primary field measurements yielded a baseline parameter: the per capita waste generation rate in Tembilahan City was set at 0.376 kg/person/day. Based on this rate and population projections, the total annual waste volume available as raw material for the waste-to-energy plant (PLTSa) in 2024 is projected to be 11,616.5 tons.

Using this raw material volume and assuming a lower heating value (LHV) of 3,674 kcal/kg, the potential annual gross electrical energy for each technology scenario in 2024 is shown in Table 1.

Table 1. Annual Gross for Electrical Energy

Scenario	η	Energy
1	15%	27.045 MWh/year
2	20%	36.060 MWh/year
3	30%	54.090 MWh/year

The linear relationship between technology efficiency and potential energy output over time is visually illustrated in Figure 1.

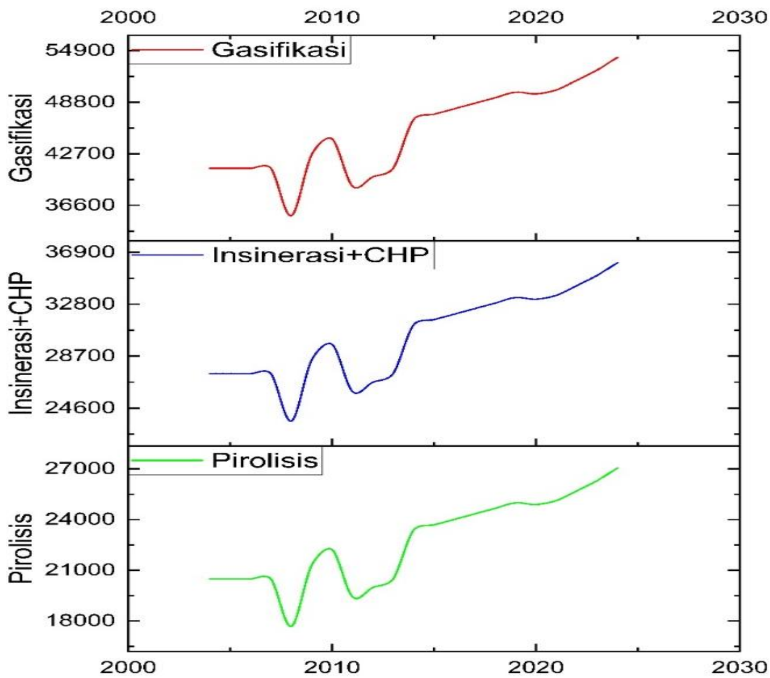

Figure 1. Electrical Output Results Graph in Three Scenarios

The results of the financial analysis, which includes a 35-year cash flow evaluation at a 10% discount rate, are summarized in Table 2. This table consolidates the key feasibility indicators for the three scenarios to facilitate direct comparison.

Volume 4, Issue 2 (2026). 379-391
e-ISSN: 2985-9859
DOI: https://doi.org/10.60079/ajeb.v4i2.762

Table 2. Comparative Summary of Financial Viability Indicators

Indicator	Scenario 1	Scenario 2	Scenario 3	Eligibility Threshold
NPV	-Rp 49.95 Billion	Rp 9.06 Billion	Rp 83.03 Billion	> 0
B/C Ratio	0.56	1.10	1,86	> 1
IRR	1%	1%	15%	> 10%
Payback Period	> 36 Years	26.9 Years	12.8 Years	< Project Age

4.2 Discussion

Scenario 1 (Pyrolysis) is clearly not financially viable. The NPV is negative, the B/C ratio is well below 1, the IRR is significantly lower than the discount rate, and the payback period exceeds the project's lifespan. Scenario 2 (Incineration + CHP) is marginally feasible. Although the NPV is positive and the B/C ratio is slightly above 1, the IRR of 1% is still well below the acceptable threshold, and the very long payback period of almost 27 years indicates a high-risk profile. Scenario 3 (Gasification) is the only scenario demonstrating strong financial feasibility within this model framework. All indicators significantly exceed the feasibility threshold, with a substantial positive NPV, an attractive IRR, and the fastest payback period. However, these differences are largely driven by the higher assumed energy conversion efficiency of gasification compared with pyrolysis and incineration technologies (Panepinto *et al.*, 2015; Al Arni, 2018; De Greef *et al.*, 2018).

This study determined the per capita waste generation rate in Tembilahan City to be 0.376 kg/person/day, based on field sampling conducted in accordance with the Indonesian National Standard SNI 19-3964-1994 for collecting and measuring urban waste generation and composition samples. The use of this national standard provides strong procedural validity to the waste generation data collection method. However, the obtained value requires comparative analysis. Various studies in other regions in Indonesia indicate a tendency toward higher waste generation rates. For example, a comprehensive study conducted by the Ministry of National Development Planning (Bappenas) across several Indonesian cities found that waste generation ranged from 0.38 to 0.55 kg/person/day. In comparison, case studies in Gunung Kidul Regency and Bojonegoro Regency recorded values of 0.48 kg/person/day and 0.4 kg/person/day, respectively (Faradina *et al.*, 2020).

The discrepancy between this study's findings and those of previous studies suggests that the value of 0.376 kg/person/day used here is conservative. While the socio-economic profile of Tembilahan City may justify a lower figure, using this value as the basis for projections over a 20-year project life carries inherent risks. If the actual waste generation rate turns out to be higher and approaches the national average, a waste-to-energy facility designed based on this projection risks being undersized. Consequently, the proposed waste-to-energy plant will be unable to process the full volume of municipal waste, thereby undermining the project’s primary objective of comprehensive urban waste management (Mukhlis, 2024; Punta *et al.*, 2024).

Even more crucial is the assumption regarding waste quality, specifically the Lower Heating Value (LHV). This study used an LHV of 3,674 kcal/kg, calculated from assumed waste compositions from the literature: 40% paper, 30% plastic, 20% organic material, and 10% other waste. This value is significantly higher than the typical characteristics of municipal solid waste in Indonesia. Various studies and technical reports consistently show that Indonesian municipal waste has a much lower LHV, often around 2,396.8 kcal/kg, due to the dominance of organic waste with high moisture content (Nufus *et* *al.*, 2025). In comparison, incineration technology generally requires a minimum LHV of 1,500 kcal/kg to operate autogenously, without additional fuel input (Sebastian *et al.*, 2024).

This disparity arises because the assumed waste composition does not adequately represent local conditions. National studies indicate that municipal waste in Indonesia is dominated by food waste and other organic fractions, which often exceed 50%, rather than by paper and plastic. Organic waste with a moisture content as high as 70% drastically reduces the LHV because much of the combustion energy is first consumed in evaporating water before useful heat can be generated (Nufus *et al.*, 2025). Consequently, the reliance on overly optimistic LHV assumptions becomes the most fundamental technical limitation of this study. Higher LHV assumptions yield higher projected energy outputs, which in turn increase projected revenues and make the project appear more financially feasible than it likely would under actual operating conditions.

Based on the assumed waste generation and LHV, this study projects the potential electrical energy generated under three technology scenarios with different conversion efficiencies: pyrolysis (15%), incineration with CHP (20%), and gasification (30%). For 2024, the projected energy output is 27,044.97 MWh/year for pyrolysis, 36,059.97 MWh/year for incineration + CHP, and 54,089.95 MWh/year for gasification. These efficiency assumptions are consistent with previous literature on the relative performance of each technology (Al Arni, 2018; De Greef *et al.*, 2018; Panepinto *et al.*, 2015).

Mathematically, these results demonstrate a linear relationship: higher conversion efficiency yields greater energy output. However, a deeper discussion must go beyond this theoretical conclusion and consider real-world trade-offs. Gasification technology, while offering the highest efficiency, is technically more complex and highly sensitive to feedstock quality, including homogeneity, composition, and moisture content. In contrast, incineration is the most mature WTE technology and has demonstrated operational reliability worldwide (Dong *et al.*, 2019). Gasification's primary advantage lies in its ability to process heterogeneous and poorly sorted waste, which is likely to characterize municipal waste in Tembilahan (Liang *et al.*, 2024). Therefore, there is a critical trade-off between theoretical efficiency and operational reliability. Selecting the technology with the highest efficiency without considering its compatibility with low-quality local feedstock represents a substantial operational risk.

Furthermore, it should be emphasized that the energy calculations in this study represent gross energy output. WTE facilities consume a portion of their own generated energy for auxiliary needs, including pumps, fans, control systems, and emission treatment units. Moreover, if the actual LHV of Tembilahan waste is as low as indicated by previous Indonesian studies, the facility may require co-firing with fossil fuels such as coal to maintain stable combustion temperatures and system efficiency. Such a practice would reduce the net energy exported to the electricity grid, weaken the project's status as a renewable energy initiative, and increase greenhouse gas emissions (Fayyazbakhsh *et al.*, 2022).

Pyrolysis is the thermochemical decomposition of organic material at temperatures typically ranging from 300°C to 650°C under oxygen-free or very limited oxygen conditions. The absence of oxygen fundamentally distinguishes pyrolysis from combustion or incineration (Dong *et al.*, 2019). Rather than burning the waste, pyrolysis decomposes complex organic molecules into simpler compounds in solid, liquid, and gaseous forms. This process produces three product fractions, each with potential economic value, thereby supporting the concept of waste valorization (Simanjuntak *et al.*, 2024).

Volume 4, Issue 2 (2026). 379-391
e-ISSN: 2985-9859
DOI: https://doi.org/10.60079/ajeb.v4i2.762

The main products generated from pyrolysis are bio-oil, syngas, and biochar. The liquid fraction consists of a complex mixture of water, alcohols, hydrocarbons, aldehydes, ketones, and carboxylic acids. The gaseous fraction is non-condensable and flammable, mainly composed of hydrogen, carbon monoxide, methane, and other light hydrocarbons (Al Arni, 2018). This gas can be used internally to supply heat for the pyrolysis process itself or in gas engines to generate electricity. Meanwhile, the solid residue, biochar, is carbon-rich and chemically stable, making it suitable for use as a fuel, activated carbon, or soil amendment in agriculture (Nguyen & Khuong, 2022).

Pyrolysis offers several advantages but also faces significant technical limitations, particularly when applied to mixed municipal waste. One of its key advantages is product valorization. Unlike incineration, in which the primary output is energy, and the by-product is ash, pyrolysis generates three potentially marketable products—bio-oil, syngas, and biochar—thereby diversifying the project's revenue stream (Simanjuntak *et al.*, 2024). Another advantage is the potential for lower emissions. Because pyrolysis occurs without direct combustion, the volume of flue gas requiring treatment is much lower, theoretically reducing the formation of pollutants such as dioxins and furans. However, precursor compounds may still form and require treatment (Dong *et al.*, 2019).

Pyrolysis is highly sensitive to feedstock composition and physical characteristics. The process achieves its highest efficiency with relatively homogeneous, dry feedstock of uniform particle size, such as plastic waste, woody biomass, or used tires. For highly heterogeneous municipal solid waste containing mixed plastic, paper, food waste, glass, and metal, with correspondingly high moisture content, the efficiency and performance of pyrolysis decline substantially. Although the concept of pyrolysis is well established, its commercial application at a large scale for mixed municipal waste remains limited compared with incineration, which has been proven globally for decades. This indicates a significantly higher level of operational and technical risk (Al Arni, 2018; Zhao *et al.*, 2022).

The financial feasibility analysis presented in this study initially appears highly positive, particularly for the gasification scenario. However, these results are the product of a mathematical model based on several simplifying assumptions that become problematic when confronted with real implementation conditions and the Indonesian regulatory framework. Based on the detailed calculations, scenario 1 (Pyrolysis) is financially infeasible, with an IRR of only 1%, far below the required discount rate of 10%, and an NPV of –Rp4.99 billion. Scenario 2 (Incineration + CHP) is only marginally feasible, with a B/C ratio of 1.10 and an IRR still below the required threshold, producing a slightly positive NPV of Rp9.06 billion. Scenario 3 (Gasification) appears strongly feasible, with an IRR of 15%, significantly above the discount rate, and an NPV of Rp83.02 billion (Al Arni, 2018; De Greef *et al.*, 2018; Panepinto *et al.*, 2015). However, these results do not necessarily indicate that gasification is the most economically superior technology in practice. Rather, the apparent superiority of gasification stems from the assumption that it has the highest conversion efficiency. At the same time, all other cost and revenue parameters are treated as identical across scenarios. Such an assumption ignores the fact that each technology has fundamentally different capital and operational cost structures. Technologies such as gasification are more complex and generally require higher capital costs, more sophisticated maintenance, and stricter feedstock preparation than incineration or pyrolysis (Dong *et al.*, 2019). Therefore, the resulting NPV and IRR values may overstate the actual attractiveness of gasification.

By integrating external evidence on technology costs, waste characteristics, and the Indonesian policy context, it becomes clear that technology selection is not merely a matter of choosing the most efficient option. Existing models assume that efficiency is the sole determinant of financial performance.

Volume 4, Issue 2 (2026). 379-391
DOI: https://doi.org/10.60079/ajeb.v4i2.762
e-ISSN: 2985-9859

Because electricity revenue is directly proportional to energy conversion efficiency, the technology with the highest efficiency automatically becomes the most financially attractive. However, this approach ignores critical considerations such as technology maturity, operational reliability, and cost structure. As shown in previous studies, gasification is theoretically efficient but highly sensitive to heterogeneous feedstocks, thereby increasing operational uncertainty and investor risk (Dong *et al.*, 2019; Liang *et al.*, 2024). Therefore, the most appropriate technology is not necessarily the most efficient on paper, but rather the one that is most reliable, suitable, and sustainable under the specific conditions of Tembilahan City.

The Indonesian government, through the National Energy General Plan (RUEN), has set an ambitious target to achieve a 23% renewable energy mix by 2025. However, progress toward this target remains slow, reflecting persistent structural barriers to renewable energy development (Santosa *et al.*, 2023). In this context, the proposed Tembilahan WTE project is strategically important because it addresses two policy priorities simultaneously: reducing urban waste and increasing renewable energy production. Such projects are further supported by Presidential Regulation No. 35 of 2018, which was specifically enacted to accelerate the development of WTE facilities in Indonesia. The Tembilahan WTE project also illustrates the broader dilemma of Indonesia's energy transition. The same challenges identified in this study—uncertain feedstock quality, high technology costs, and substantial financial risk—mirror the challenges that have hindered national renewable energy development. Consequently, the successful implementation of the Tembilahan WTE project would provide an important proof of concept for Indonesia's WTE strategy. Conversely, failure would reinforce the need for more realistic assumptions and more comprehensive solutions to the technical, financial, and institutional barriers that renewable energy projects face.

5. Concluding Remarks and Recommendation

In terms of quantity, the volume of waste generated in Tembilahan City is projected to be sufficient to supply raw materials for a 10 MW waste-to-energy plant (PLTSa). The potential energy growth of the three technology scenarios (Pyrolysis 6.5%, Incineration + CHP 8.7%, and Gasification 13.1%) exceeds the energy growth target in the Riau Province RUPTL (6.1%), indicating technical feasibility in terms of energy contribution. However, the overall operational technical feasibility is highly conditional and uncertain, as it relies critically on the assumption of a lower calorific value (LHV) of 3,674 kcal/kg that has not been empirically verified and is likely overly optimistic for local waste conditions. Within the presented model framework, the Gasification Scenario demonstrates strong financial feasibility (NPV of IDR 83.03 billion; IRR of 15%; PP of 12.8 years), making it the theoretically superior option. The Incineration+CHP Scenario demonstrates marginal feasibility, while the Pyrolysis Scenario is clearly infeasible. However, these conclusions are artifacts of the model's simplification of reality, particularly its ignoring of cost differences between technologies and its omission of the crucial revenue stream from tipping fees.

Statement of Use of Generative AI

During the preparation of this work, the author used ChatGPT to assist in improving the clarity and readability of the text. The author reviewed and edited the output and takes full responsibility for the content of the publication.

Advances: Jurnal Ekonomi & Bisnis
OPEN ACCESS
Volume 4, Issue 2 (2026). 379-391
e-ISSN: 2985-9859
DOI: https://doi.org/10.60079/ajeb.v4i2.762

References

Al Arni, S. (2018). Comparison of slow and fast pyrolysis for converting biomass into fuel. Renewable Energy, 124, 197–201. https://doi.org/10.1016/j.renene.2017.04.060

Alao, M. A., Popoola, O. M., & Ayodele, T. R. (2022). Waste-to-energy nexus: An overview of technologies and implementation for sustainable development. Cleaner Energy Systems, 3, 100034. https://doi.org/10.1016/j.cles.2022.100034

Beyene, H. D., Werkneh, A. A., & Ambaye, T. G. (2018). Current updates on waste to energy (WtE) technologies: A review. Renewable Energy Focus, 24, 1–11. https://doi.org/10.1016/j.ref.2017.11.001

De Greef, J., Verbinnen, B., & Van Caneghem, J. (2018). Waste-to-energy: Coupling waste treatment to highly efficient CHP. International Journal of Chemical Reactor Engineering, 16(10), Article 20170248. https://doi.org/10.1515/ijcre-2017-0248

Dewi, L. S., Haris, A., Ambarita, N. P., & Hanafi, M. H. (2024). Public perception of circular economy implementation in household waste management. Oikonomia: Journal of Management Economics and Accounting, 2(1), 11–21. https://doi.org/10.61942/oikonomia.v1i1.270

Dong, J., Tang, Y., Nzihou, A., & Chi, Y. (2019). Key factors influencing the environmental performance of pyrolysis, gasification, and incineration waste-to-energy technologies. Energy Conversion and Management, 196, 497–512. https://doi.org/10.1016/j.enconman.2019.06.016

Faradina, D., Maryono, M., & Warsito, B. (2020). The role of waste banks in reducing waste in Gunung Kidul Regency. In E3S Web of Conferences (Vol. 202, Article 06038). https://doi.org/10.1051/e3sconf/202020206038

Fayyazbakhsh, A., Bell, M. L., Zhu, X., Mei, X., Koutný, M., Hajinajaf, N., & Zhang, Y. (2022). Engine emissions with air pollutants and greenhouse gases and their control technologies. Journal of Cleaner Production, 376, 134260. https://doi.org/10.1016/j.jclepro.2022.134260

Liang, R., Chen, C., Ge, Y., Tao, J., Yan, B., Wang, H., Wang, K., Bu, Q., & Chen, G. (2024). A conceptual sorting strategy of municipal solid waste towards efficient gasification. Energy Conversion and Management, 304, 118209. https://doi.org/10.1016/j.enconman.2024.118209

Nguyen, H. N., & Khuong, D. A. (2022). New trends in pyrolysis methods: Opportunities, limitations, and advantages. In S. Ramola, D. Mohan, O. Masek, A. Méndez, & T. Tsubota (Eds.), Engineered biochar. Springer. https://doi.org/10.1007/978-981-19-2488-0_7

Nufus, T. H., Hidayati, N., Ekayuliana, A., & Saputra, D. (2025). Analyzing the lower heating value (LHV) in urban waste management: Optimizing energy efficiency in urban areas. *In IOP Conference Series: Earth and Environmental Science 1504*(1), 012015. https://doi.org/10.1088/1755-1315/1504/1/012015

Oktavilia, S., Putri, P. I., Wahyuningrum, I. F. S., & Kistanti, N. R. (2024). Potensi ekonomi sampah. Penerbit NEM.

Panepinto, D., Tedesco, V., Brizio, E., & Genon, G. (2015). Environmental performances and energy efficiency for MSW gasification treatment. Waste and Biomass Valorization, 6(1), 123–135. https://doi.org/10.1007/s12649-014-9322-7

Punta, B. A. D., Sajiddah, D. M., Ahmadi, D. A. P., Kalisha, F. A., Keliat, R. A., Prasetiyo, T., & Rozamuri, A. M. (2024). Edukasi sampah anorganik dan pelatihan pemanfaatan kreasi limbah anorganik. *ABDI MOESTOPO: Jurnal Pengabdian Pada Masyarakat, 7*(2), 237–244. https://doi.org/10.32509/abdimoestopo.v7i2.4181

Purnomo, C. W. (2024). Solusi pengelolaan sampah kota (Edisi ke-2). UGM Press.

Ram, C., Kumar, A., & Rani, P. (2021). Municipal solid waste management: A review of waste to energy (WtE) approaches. *BioResources, 16*(2), 4275. https://doi.org/10.15376/biores.16.2.Ram

Santosa, J., Kuncoro, A. H., Dwijatmiko, A., Hesty, N. W., & Darmawan, A. (2023). The role of nuclear power plants in Indonesia towards net zero emissions (NZE) in 2060 with a multi regions approach. https://doi.org/10.5109/7151715

Sebastian, R. M., Kumar, D., & Alappat, B. J. (2024). A graphical method to determine the incinerability of municipal solid waste. International Journal of Environmental Waste Management, 34(2), 228–248. https://doi.org/10.1504/IJEWM.2024.139248

Volume 4, Issue 2 (2026). 379-391
e-ISSN: 2985-9859
DOI: https://doi.org/10.60079/ajeb.v4i2.762

Thio, M. D. F., Romadhoni, A. F., Nisya, D. A., Maheswari, H., & Rozamuri, A. M. (2021). Empowerment of semi formal and informal sector in realizing a cheap and environmentally friendly alternative energy of PLTSa Sumur Batu business process. *Journal of Management and Energy Business, 1*(1). https://doi.org/10.54595/jmeb.v1i1.14

Tjendra, V., & Ismelina, M. (2024). Analisis permasalahan pengelolaan sampah di DKI Jakarta berdasarkan Peraturan Daerah Nomor 4 Tahun 2019 tentang perubahan atas Peraturan Daerah Nomor 3 Tahun 2013. *Jurnal Ilmu Hukum, Humaniora dan Politik, 5*(1). https://www.elibrary.ru/defaultx.asp?rpage=https://www.elibrary.ru/item.asp?id=80013982

Yasmeen, R., & Shah, W. U. H. (2024). Energy uncertainty, geopolitical conflict, and militarization matters for renewable and non-renewable energy development: Perspectives from G7 economies. Energy, 306, 132480. https://doi.org/10.1016/j.energy.2024.132480

Zhao, Y., Yuan, J., Zhao, S., Chang, H., Li, R., Lin, G., & Li, X. (2022). Is pyrolysis technology an advisable choice for municipal solid waste treatment from a low carbon perspective? *Chemical Engineering Journal, 449*, 137785. https://doi.org/10.1016/j.cej.2022.137785

Corresponding author

Swempri Agung Prasetyo can be contacted at: swempri.agung@gmail.com