Potential Renewable Energy from Landfill Waste and Refuse-Derived Fuel at Bantargebang

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Received: 15 January 2025 | Revised: 15 February 2025 | Accepted: 6 March 2025

ABSTRACT

The Waste-to-Energy (WtE) and co-firing technologies are used for waste management in Indonesia. The Bantargebang Integrated Waste Management Site (IWMS) is a landfill that has already implemented WtE and industrial co-firing facilities in the form of Refuse Derived Fuel (RDF). The potential of Bantargebang IWMS for WtE and industrial co-firing materials is enabled due to the availability of raw materials in the form of Municipal Solid Waste (MSW) and Landfill Mining (LM), and facilities, such as the Waste Power Plant and RDF plant. Therefore, it is essential to study the chemical quality potential of raw waste materials and RDF products. This study aims to analyze the possible use of RDF for WtE in the industrial sector based on the chemical quality of RDF produced in Bantargebang IWMS. The results show that the Bantargebang IWMS via the Waste Power Plant offers WtE with a capacity of approximately 100 tons per day and an electricity output of around 750 kWh. The chemical quality analysis of MSW and LM raw materials indicated calorific values of approximately 1,943 kcal/kg and 2,415.98 kcal/kg, respectively, with 59% and 29% moisture content. This suggests that the raw waste materials processed in the Bantargebang IWMS meet the SNI 8966:2021 Class III quality standards for power plants. The Bantargebang RDF Plant has a processing capacity of 2,000 tons/day and produces approximately 700 tons/day of RDF. The processed waste was sourced from 1,000 tons of MSW and 1,000 tons of LM waste. The chemical quality analysis of RDF showed that it had calorific values of 2,962 and 4,289.6 kcal/kg. This indicates that the produced RDF is suitable for co-firing in the cement industry. PT Indocement Tunggal Prakarsa and PT Solusi Bangun Indonesia are the main off-takers of RDF produced from the Bantargebang IWMS.

Keywords-refuse derived fuel; waste to energy; municipal solid waste; landfill; Bantargebang

I. INTRODUCTION

MSW from households, commercial establishments, and institutions requires sustainable management to mitigate its environmental impacts [1-3]. Conventional disposal methods, like open dumping, contribute to pollution and greenhouse gas emissions, rendering advanced waste management strategies essential. Among these, sanitary landfills with engineered systems for leachate control and gas recovery provide a sustainable alternative [4, 5].

WtE technologies offer the dual benefit of reducing MSW volume while generating electricity and heat. Biomass from MSW, primarily composed of organic materials, such as food waste and paper, plays a key role in renewable energy production. The WtE capacity in Southeast Asia in 2020 was over 323 MW and was expected to double by 2022 [6]. Globally, WtE growth was projected to reach 24.5 million USD in 2024, a 10 times increase compared to 2010. The Asia-Pacific WtE market was anticipated to grow at an annual rate exceeding 15%, reaching a market size of 13.66 billion USD by 2023 [6]. The global MSW production is expected to have grown from 2 billion metric tons in 2016 to 3.4 billion metric tons by 2050 [7]. Consequently, the WtE industry in Asia has the potential for technological transfer and investment opportunities [8, 9].

MSW processing presents a valuable opportunity for energy recovery, reducing the reliance on fossil fuels in industrial sectors [10]. One key application is co-firing, where processed MSW is converted into RDF for energy-intensive industries, like cement manufacturing. In 2020, the European cement industry replaced 45% of the thermal energy with RDF [11], contributing to industrial decarbonization [12] and this percentage can increase by more than 74% [13].

To ensure efficiency and safety, the RDF quality is standardized based on its calorific value, moisture content, and contaminant levels. Studies indicate that RDF with a calorific value above 15 MJ/kg and chlorine content below 0.7% is optimal for cement kilns [14, 15]. MSW is a key feedstock for RDF production, with 34% of the generated MSW being suitable for conversion. In Europe, RDF has been widely adopted, particularly in cement kilns, replacing up to 52% of the thermal energy demand. WtE technologies further contribute to reducing landfill dependency and fossil fuel consumption [13, 16].

The Bantargebang IWMS, also known as the TPST, is the largest MSW processing facility in Indonesia, operating with a sanitary landfill system. The waste composition, comprising 49.87% biodegradable waste and 17.24% paper, has significant potential for RDF and WtE applications. Given Indonesia's projected energy crisis by 2086, optimizing Bantargebang's resources through WtE technologies is crucial.

This study analyzed the chemical quality of MSW and RDF produced at Bantargebang IWMS and evaluated their potential as alternative energy sources for industrial applications. By leveraging the international best practices, this study aims to support Indonesia's transition toward sustainable waste management and energy diversification.

II. RESEARCH METHOD

The research was conducted between December 2023 and March 2024 at the Bantargebang IWMS. The research samples included waste from various observation points, such as the active disposal zone (for acquiring MSW), LM, RDF from MSW, and RDF from LM. Sampling was carried out using the grab method with an auger tool. The sampling points in the active and landfill zones consisted of five points each, with depths of 2.5 m and five m, respectively. Sampling was conducted three times at two-day intervals. The locations and sampling station points are shown in Figure 1. RDF was sampled from the RDF hangar. The samples obtained were analyzed in the laboratory using the methods listed in Table I [17, 18].

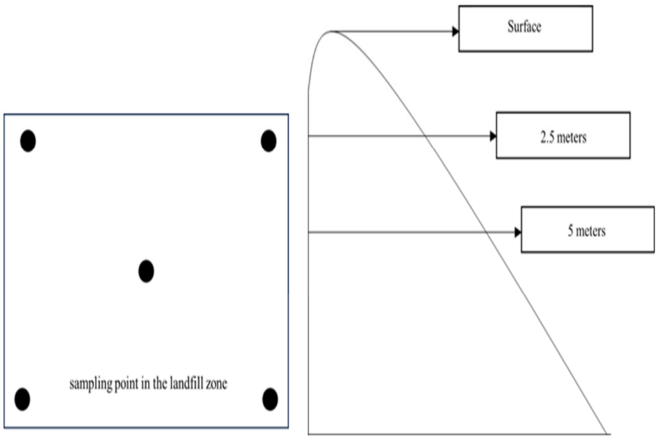

Fig. 1. Sampling points and depths.

TABLE I. OVERVIEW OF RDF ABSORPTION POTENTIAL IN THE INDUSTRY SECTOR

Parameters	Units	Analysis method
Water content	%	SNI 03-1971-1990
Ash content	%	ASTM E (830)-87
Volatile	%	ASTM E (897). -88
Total carbon	%	ASTM D 3172
Total organic	%	ASTM D 4427
Total sulfur	%	ASTM 4239
Chlorine	%	ASTM D 4929
Mercury	mg/L	ASTM 6350
Potassium	%	ASTM D 4628
Melting point of ash	%	ASTM D 1857
Caloric value	kcal/kg	ASTM D240 (2009)

The SNI 8966:2021 is the reference quality standard for using RDF and other solid waste fuels in Indonesia for electricity generation. In this work, secondary data on the average daily amount of waste transported to Bantargebang IWMS from 2019-2023, the chemical analysis results of RDF from Upst IWMS Bantargebang, and the users of RDF products (off-takers) were collected.

A purposive sampling method was employed to ensure that the collected waste samples accurately represented the composition of MSW in the Bantargebang IWMS. Purposive sampling was chosen because this research focused on evaluating the chemical quality of RDF and its potential as an alternative energy source in industrial applications. Given the heterogeneous nature of MSW, selecting representative samples based on specific criteria, such as biodegradable content, moisture levels, and calorific value, is essential for obtaining reliable results. The followed sampling process established guidelines for RDF quality assessment, ensuring consistency with international standards [19, 20]. Additionally, this method allowed targeted sampling from different waste processing zones at the Bantargebang IWMS, including fresh waste deposits, pre-sorted waste, and partially decomposed waste. This approach ensured a comprehensive analysis of RDF feedstock potential across various waste stages [21]. The rationale behind this selection was to identify the most viable waste fractions for RDF production while minimizing contaminants such as chlorine and heavy metals. The sampling procedure is aligned with previous studies on RDF characterization in Indonesia, reinforcing the study's scientific validity and practical applicability in the local context [22].

The flow chart in this research represents the systematic methodology used to analyze the potential of WtE and RDF at the Bantargebang IWMS. It outlines the key steps involved, ensuring a structured approach to data collection, analysis, and interpretation. The main stages include:

1. Data Collection: This involves gathering information on the composition and quantity of MSW and LM at Bantargebang. It also includes sampling procedures for chemical quality analysis.

2. Waste Characterization: The collected samples are analyzed based on key parameters, such as moisture content, calorific value, and chemical composition, to determine their suitability for RDF production and WtE applications.

3. Processing and RDF Production: MSW and LM undergo pre-processing techniques, such as sorting, drying, and shredding to produce RDF with optimal energy content for industrial use.

4. Quality Analysis and Standard Comparison: The produced RDF is tested according to national and international standards (e.g., SNI 8966:2021) to evaluate its compliance with industrial requirements.

5. Industrial Application Assessment: The potential use of RDF in energy-intensive industries (e.g., cement production) is assessed by comparing its properties with conventional fossil fuels.

6. Findings and Recommendations: The final stage includes the interpretation of the results, discussion on the feasibility of RDF implementation, and suggestions for optimizing waste-derived energy solutions at Bantargebang.

III. RESULTS AND DISCUSSION

A. *Overview of the Bantargebang Integrated Waste Management Site*

The Bantargebang IWMS is a waste processing site that includes a Waste Power Plant, Composting, Solid Waste Fuel (RDF) Processing, and Landfill gas utilization facilities. These facilities are integrated with the daily waste transportation system that enters Bantargebang. The Bantargebang IWMS area covers approximately 132.5 hectares, and comprises six processing and landfill zones and 23.3 facilities and infrastructure. The average amount of waste transported to the Bantargebang IWMS between 2019 and 2023 is displayed in Figure 2.

The waste composition at the Bantargebang IWMS consists of 49.87% organic waste, 17.24% paper, 3.18% wood, 1.48% glass, 1.08% metal, 0.90% fabric, 0.78% masks, 0.70% leather, and 0.42% hazardous household waste [23]. This diverse waste composition poses challenges and opportunities for WtE systems. Organic waste, which forms nearly half of the total waste, presents substantial potential for biogas production through anaerobic digestion [24]. Moreover, a significant portion of paper and wood provide opportunities for WtE technologies that convert these materials into heat and electricity through combustion or gasification [25, 26]. With proper sorting, the metals and plastics found in the waste can be recycled, while non-recyclable plastics could be processed into RDF, contributing to energy recovery and reducing landfill dependency [27, 28].

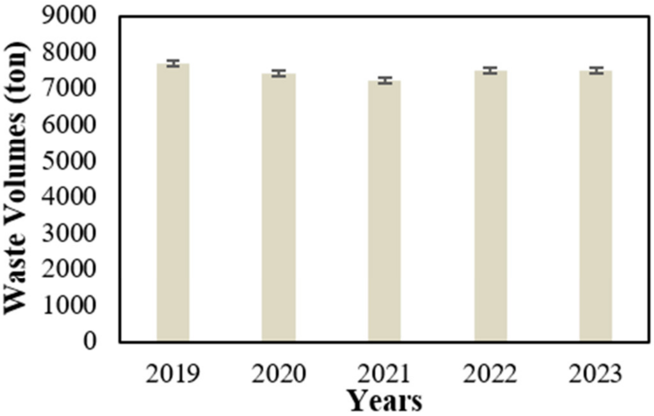

Fig. 2. Average amount of waste transported to the Bantargebang IWMS.

Furthermore, hazardous waste, such as masks and household waste, presents a challenge in waste management. Improper handling and disposal of such waste can lead to environmental contamination and pose health risks [29]. As waste management technologies evolve, it becomes imperative to implement more effective sorting and treatment processes to ensure that hazardous materials do not compromise the safety of energy recovery systems [30]. Additionally, the development of advanced WtE technologies, such as pyrolysis and advanced thermal treatment, can help address the challenges posed by mixed waste streams and improve the overall efficiency of energy recovery [31].

Indonesia's increasing demand for renewable energy underscores the importance of integrating WtE solutions into the national energy mix. According to the Ministry of Energy and Mineral Resources (2021), Indonesia will have faced an energy crisis by 2086 due to the depletion of fossil fuels. Thus, exploring WtE potential as a sustainable energy source is essential for reducing reliance on fossil fuels and mitigating greenhouse gas emissions.

Through further research and development of optimal waste processing technologies, including RDF production, Indonesia can move towards a more sustainable and circular waste management system that contributes to energy security and environmental sustainability.

B. *Utilization of Waste to Energy (Waste Power Plant)*

WtE utilization is widely practiced, particularly in power generation. Waste power plants, or IWMS, are used for this purpose. The technology deployed to produce electrical energy from waste has been extensively developed. Waste is typically converted into electrical energy through direct or indirect combustion. Several waste-to-energy conversion methods exist, including thermochemical, physicochemical, and biochemical methods [32].

The Bantargebang IWMS is a waste processing facility that utilizes incineration technology in a thermal system. It has a capacity of approximately 100 tons per day, and the raw material waste has a calorific value of approximately 1,943-2,415 kcal/kg. The combustion temperature in the furnace exceeds 850 °C without additional fuel, resulting in an output of approximately 750 kWh. The electricity generated is used for the Bantargebang IWMS operations, with an output of approximately 350 kWh. Raw material measurements were conducted on MSW and LM waste, with the results being depicted Table II.

TABLE II. THE RESULTS OF WASTE RAW MATERIALS AT BANTARGEBANG IWMS

Parameters	Units	MSW Waste	LM Waste
Water content	%	56	29
Ash content	%	38	21
Volatile	%	42.5	45
Total carbon	%	28.4	24.5
Total organic	%	69.2	82.1
Total sulfur	%	0.39	0.11
Chlorine	%	0.018	0.014
Mercury	mg/L	< 0.0005	< 0.0005
Potassium	%	9.5	6.4
Melting point of ash	%	1.22	1.04
Calorific value	kcal/kg	1,943.96	2,415.98

The results indicate that the calorific values of MSW and LM waste are influenced by the water content of the waste. The relationship between these two parameters is inversely proportional. Specifically, MSW with 56% moisture content has a calorific value of 1943 kcal/kg, whereas LM waste with 29% moisture content has a calorific value of 2,415 kcal/kg. This finding is consistent with the results of [33], where it was demonstrated that the moisture content affects the calorific value. The calorific value increases as the moisture content decreases.

The production process flowchart for the Waste Power Plant in Bantargebang is presented in Figure 3. The waste requirement for start-up is approximately 7 tons after which the daily waste input process can be initiated. According to the flow chart, the residue produced consists of bottom ash and fly ash. The bottom ash produced is approximately 86 tons and the fly ash contained 49 bags. Off-takers of agricultural needs will reuse the residue produced by this incineration process.

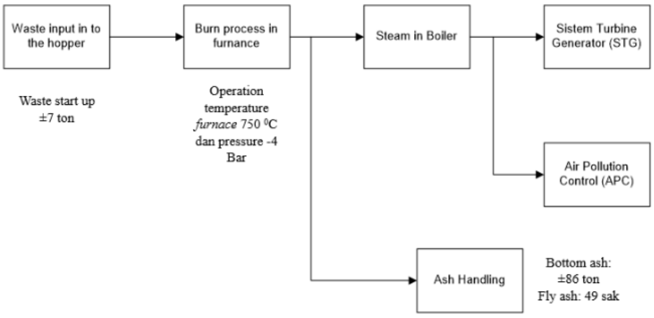

Fig. 3. Flow diagram production of the waste power plant.

C. Refuse Derived Fuel

The Bantargebang RDF Plant is a waste processing facility that produces RDF products. It has been operating since 2023 and processes two types of waste sources: new MSW and old waste collected from LM. The plant uses mechanical treatment, which includes a shredder, trommel screen, magnetic separator, wind shifter, sun dry bay, kiln dryer, and drying conveyor. The processes for treating new waste (MSW) and old waste (LM) are portrayed in Figures 4 and 5, respectively.

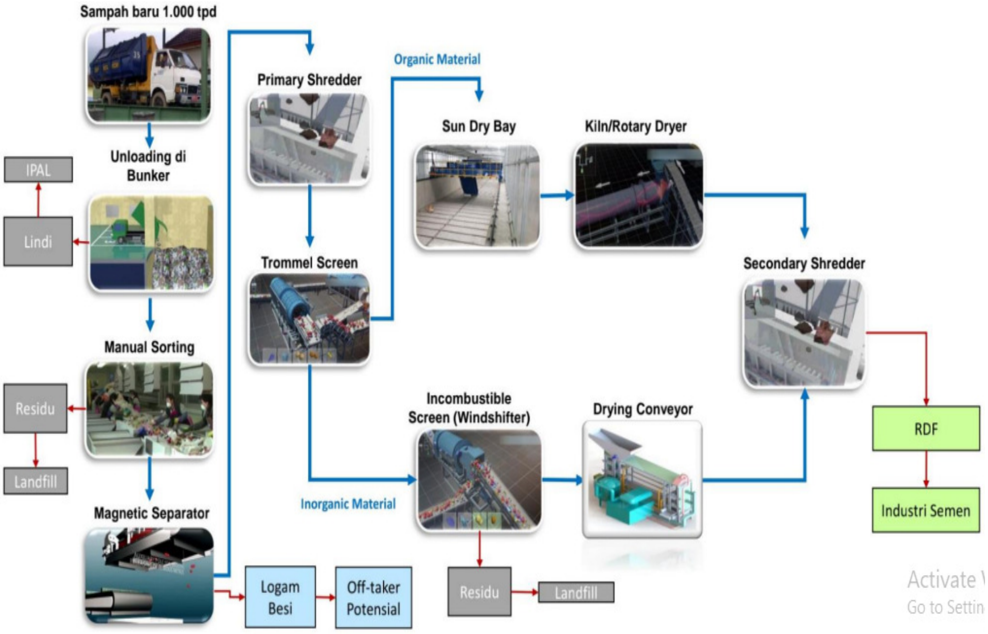

Fig. 4. RDF processing of MSW.

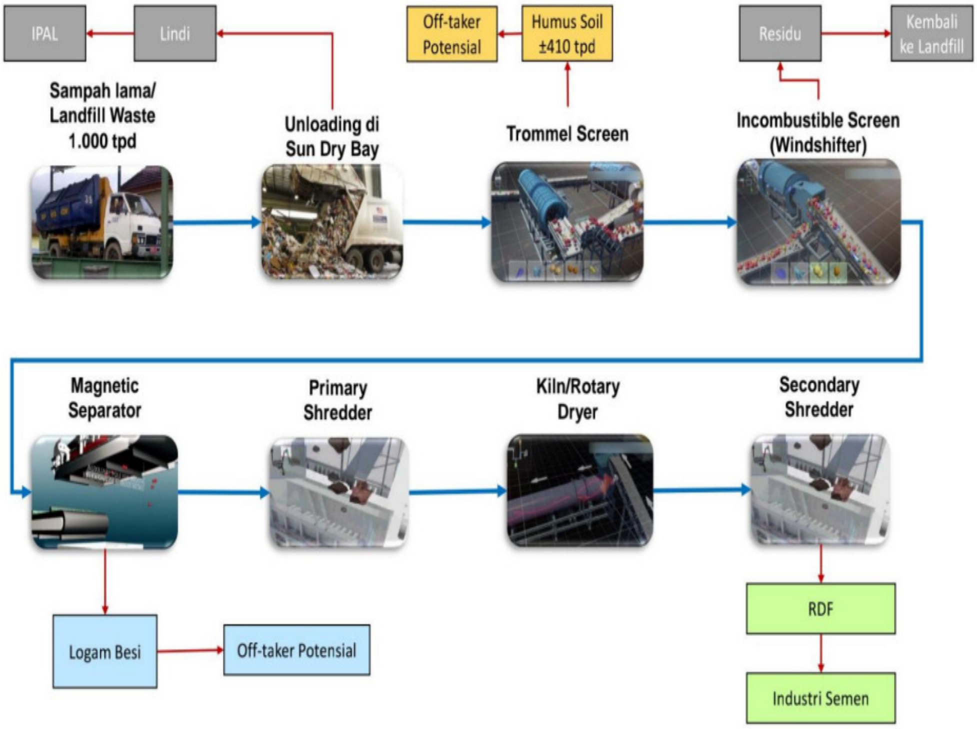

Fig. 5. RDF processing of LM.

The processing capacity for new MSW and old waste LM at the facility is 1000 tons daily, ensuring a steady supply of waste materials for further processing. The daily production of RDF yields at least 700 tons, with an RDF particle size of 50 mm, which is crucial for optimizing combustion processes in energy recovery systems. This size allows for better handling and combustion efficiency when used as an alternative fuel in industries, such as cement manufacturing and power plants. The RDF produced from MSW and LM undergoes rigorous analysis to ensure that it meets the required standards for energy production.

The analysis results of the RDF samples, sourced from MSW and LM, provide valuable insights into the chemical and physical properties of the fuel. These include the calorific value, moisture content, ash content, and the proportion of non-combustible materials, all of which play an essential role in determining the energy output and efficiency of the RDF when utilized in combustion or co-firing processes [34]. RDF quality can vary depending on the waste composition, with higher proportions of organic waste leading to better calorific values and lower ash content [35]. For instance, the RDF produced from MSW typically has a higher energy content owing to the increased proportion of paper, plastics, and biodegradable materials [36]. However, LM may contain more non-combustible materials, affecting combustion efficiency [37].

Table III indicates that the RDF produced from MSW at the Bantargebang IWMS meets the class 3 quality standards. In contrast, the RDF produced from LM meets class 2 quality standards for electricity generation. This classification is based on the chemical and physical properties of the RDF, including its calorific value, moisture content, ash content, and heavy metal concentrations. The difference in quality between MSW and LM RDF highlights variations in waste composition, with MSW typically containing more biodegradable and combustible materials. This improves its energy content compared to LM, which may have a higher proportion of non-combustible materials or older waste with lower energy potential [37].

TABLE III. RESULTS OF RDF FROM MSW AND LANDFILL WASTE

Parameters	Unit	Class 1*	Class 2*	Class 3*	RDF MSW	RDF LM
Water content	%	15	20	25	20	16
Ash content	%	15	20	25	95	10.2
Volatile	%	65	70	75	46.5	43.6
Total carbon	%	15	10	5	12.2	28.8
Total organic	%	95	87.5	80	89.4	89.5
Total sulfur	%	1.5	2	1.5	1.2	0.55
Chlorine	%	0.2	1	1.0	0.8	0.03
Mercury	mg/L	0.02	0.03	0.08	0.0002	< 0.0005
Potassium	%	5	10	15	2.6	5.3
Melting point of ash	%	1,200	1,180	1,180	1.5	1.09
Calorific value	kcal/kg	4,765.7	3,574.27	2,382.85	2,962	4,289.6

RDF utilization in the cement industry has been successful, with the Bantargebang RDF plant currently supplying two off-takers: PT Indocement Tunggal Prakarsa and PT Solusi Bangun Indonesia. PT Indocement has an absorption capacity of 625 tons/day, whereas PT Solusi Bangun Indonesia has an absorption capacity of 75 tons/day. RDF employment in cement plants helps replace conventional fuels, like coal, contributing to a reduction in carbon emissions and improving sustainability in the cement production process [38]. The high-temperature requirements in cement kilns make them ideal for utilizing the energy content of RDF, as the combustion process in these facilities can effectively use the calorific value of RDF while reducing dependence on fossil fuels [38].

Between June and November of 2023, the Bantargebang RDF plant processed 40,705 tons of waste and produced 13,785 tons of RDF products, demonstrating its substantial capacity and efficiency. This production ratio (approximately 33.9% RDF yield from waste) aligns with typical RDF production efficiencies, where the final RDF product is commonly around 30-40% of the input waste weight, depending on the waste composition and the processing methods [38].

This RDF production is particularly valuable given Indonesia's growing demand for renewable energy sources. The use of waste as a resource for energy generation aligns with global trends toward a circular economy, where waste is viewed not as a burden, but as a potential source of energy and raw materials. The successful implementation of RDF technologies at Bantargebang can serve as a model for other regions and countries looking to enhance their waste management systems and transition towards more sustainable energy sources.

Figure 6 illustrates the increase in waste input processed at the Bantargebang RDF plant. In November, the waste input peaked at 12,411 tons, resulting in a product yield of 4,344 tons. In contrast, the lowest waste input was in June, with only 1,460 tons processed and a product yield of 534 tons. This can be attributed to the fact that June marked the first production process after the initial commissioning of the Bantargebang plant.

The chemical quality of RDF production from June to September was tested for moisture content and heating value by off-takers in PT Indocement Tunggal Prakarsa and PT Solusi Bangun Indonesia. The test results for the RDF chemical quality are listed in Table IV.

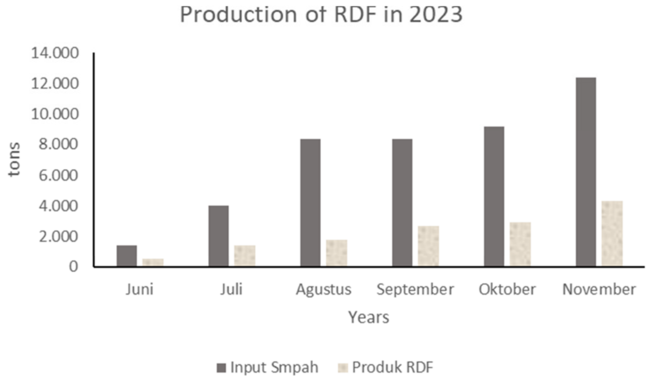

Fig. 6. Production of RDF in 2023.

Table IV shows that the moisture content of the RDF produced in Bantargebang did not meet the quality standards set by off-takers. However, the heating value parameter satisfied the required specifications. The moisture content in RDF is an important parameter affecting combustion performance, because higher moisture content results in more energy being lost during the evaporation of water in combustion. Therefore, a higher moisture content can reduce the energy efficiency generated from RDF combustion.

TABLE IV. THE QUALITY OF RDF PRODUCTS BASED ON THE TAKER

Month	Parameters	
	Water content (%)	**Calorific value (kcal/kg)**
	Maks 20%*	**Min. 3,400***
June	24.57	4,908.61
July	26.40	4,171.05
August	34.19	3,615.45
September	29.08	3,734.95
October	31.60	3,822.96
November	34.93	4,156.83

While the moisture content does not meet the off-takers' standards, the heating value still meets the energy requirements for industrial applications, such as cement production. The heating value is a key indicator of fuel efficiency in generating energy. RDF with a high heating value can contribute to replacing conventional fossil fuels, such as coal. This shows that although RDF moisture content needs improvement to meet quality standards, its ability to provide energy can still be effectively utilized by industries requiring renewable and environmentally friendly energy sources.

It is important to note that although moisture content is a parameter that requires attention, some studies have shown that drying technologies and further processing can reduce moisture content in RDF without affecting the energy quality produced. Processes, such as thermal drying, compaction, or further sorting can improve RDF quality, making it more suitable for use in sensitive combustion processes, such as biomass power plants [19]. With sufficient heating value and proper processing technology, RDF can be a sustainable solution that effectively reduces reliance on fossil fuels and minimizes the environmental impact of burning conventional fuels.

IV. CONCLUSIONS

The results indicate that the Waste-to-Energy (WtE) facility at the Bantargebang Integrated Waste Management Site (IWMS) has great potential for converting waste into energy. The Waste Power Plant (PLTSa) at this site has a processing capacity of 100 tons/day, generating 750 kWh of electricity. The chemical quality analysis showed that the calorific values of MSW and LM meet industrial specifications, although RDF moisture content exceeds the standards set by off-takers.

Although RDF high moisture content needs to be reduced to improve combustion efficiency, its calorific value is sufficient for industrial applications, such as cement production, as a substitute for fossil fuels. The Bantargebang RDF Plant has a processing capacity of 2,000 tons/day, producing approximately 700 tons/day of RDF, which has already been utilized by the cement industry in Indonesia. Optimizing the drying and compaction processes can further enhance RDF quality, rendering it more efficient for combustion and contributing to the transition toward sustainable energy.

The novelty of this research lies in its comprehensive analysis of the potential of WtE and RDF in the Bantargebang IWMS, specifically focusing on its chemical quality and suitability for industrial applications. Unlike previous studies, this research provides:

1. Site-Specific analysis: A detailed assessment of Bantargebang's waste composition, energy potential, and RDF quality, offering localized insights that have not been extensively explored.
2. Industrial application focus: An evaluation of RDF's feasibility as an alternative fuel in Indonesia's cement industry, highlighting its heating value and limitations due to moisture content.
3. Comparative benchmarking: A comparison between RDF from Bantargebang and international standards, including European RDF specifications, to assess its competitiveness and improvement potential.
4. Sustainability implications: An exploration of the RDF and WtE role in reducing Indonesia's reliance on fossil fuels, supporting the transition toward a circular economy and sustainable energy solutions.

This study contributes to the ongoing discourse on waste management and renewable energy by offering practical recommendations for enhancing RDF quality and integrating waste-based energy into industrial sectors.

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