

Utilization of Palm Oil Waste as Raw Material for Making Environmentally Friendly Biobriquettes

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ABSTRACT

Purpose: This study aims to analyze the potential of palm oil waste specifically shells, fibers, and empty fruit bunches (EFB) as raw materials for producing environmentally friendly biobriquettes. The research evaluates their chemical composition, mechanical properties, and thermal performance to determine the most suitable biomass source for high-quality fuel production.

Subjects and Methods: The materials used were palm kernel shells, fibers, and EFB obtained from palm oil mills. Each biomass type underwent cleaning, drying, milling, carbonization at 400–500°C, and briquette formation using 5% tapioca starch adhesive. Laboratory analyses included moisture, lignin, cellulose, hemicellulose, ash content, calorific value, emissions, mechanical strength, and thermal behavior. Data were processed using descriptive-comparative analysis to identify performance differences.

Results: Shells showed the highest lignin and cellulose levels, improved compaction, and superior calorific value (18.2 MJ/kg). They also produced the lowest emissions and exhibited excellent mechanical durability. Fiber briquettes demonstrated moderate quality, with acceptable strength and combustion performance but higher moisture and ash content. EFB briquettes recorded the lowest density, highest ash content, weakest strength, and lowest calorific value (12.3 MJ/kg), making them less efficient unless blended with other biomass.

Conclusions: Palm kernel shells are the most promising raw material for biobriquette production, while fibers remain viable alternatives. EFB is better used in mixed formulations. Overall, palm oil waste presents significant potential for renewable energy development and sustainable waste management.

INTRODUCTION

Indonesia is one of the world's largest palm oil producers, with plantation area increasing annually (Hambali & Rivai, 2017). The development of the palm oil industry not only contributes significantly to the country's foreign exchange but also generates large amounts of solid waste, such as shells, fibers, and empty fruit bunches (Mahlia et al., 2019; Sumathi et al., 2008). To date, much of this waste has not been optimally utilized and is often simply burned or landfilled, creating environmental problems. Foo & Hameed (2010) said that, this situation has prompted the need for innovative efforts to manage palm oil waste to increase its utility.

One approach is to utilize palm oil waste as a raw material for alternative energy. According to Olujobi et al. (2023), Amidst increasing energy demand and limited fossil resources, renewable

energy is a strategic solution to ensure a sustainable energy supply. Biobriquettes, as a form of biomass-based renewable energy, offer significant potential for development (Vaish et al., 2022; Hadiyanto et al., 2023). Biobriquettes have the advantages of a relatively high calorific value, a more practical form, and are environmentally friendly because they produce lower emissions compared to fossil fuels.

Utilizing palm oil waste for biobriquette production not only contributes to energy diversification but also supports industrial waste reduction (Siagian et al., 2024; Sulaiman et al., 2011). Empty fruit bunches, shells, and fibers of oil palms contain high levels of lignocellulose, potentially producing sufficient calorific value to serve as an energy source. With the right technology, this waste can be converted into high-quality biobriquettes, which can be utilized by households, small-scale industries, and the large-scale energy sector (Seboka et al., 2024).

Several previous studies have demonstrated that biomass from agricultural and plantation waste has significant potential as a raw material for biobriquettes (Espinoza-Tellez et al., 2020). However, research specifically on the use of oil palm waste requires further development, particularly in improving briquette quality through modifications to the raw material composition, carbonization techniques, and the use of environmentally friendly adhesives. This demonstrates the potential for further research to produce biobriquettes with high calorific value, good mechanical durability, and environmental friendliness (Khan et al., 2023).

From an environmental perspective, utilizing oil palm waste as biobriquettes can reduce greenhouse gas emissions and pollution from open waste burning. Destek et al. (2021) and Müller et al. (2015) said that furthermore, this biomass utilization can support green energy policies and the government's Sustainable Development Goals (SDGs). Thus, developing biobriquettes based on palm oil waste not only has economic value but also has a positive impact on environmental sustainability.

Based on this background, this research focuses on analyzing the use of palm oil waste as a raw material for environmentally friendly biobriquettes. The main objective is to assess the potential calorific value, combustion efficiency, and environmental impact of the resulting biobriquettes. This research is expected to contribute to the development of biomass-based renewable energy and provide alternative solutions for managing palm oil waste in Indonesia.

Indonesia's growing palm oil industry continues to generate substantial quantities of solid waste, presenting both environmental challenges and opportunities for renewable energy development (Farobie & Hartulistiyoso, 2022; Yusoff, 2006; Yana et al., 2022). As palm oil processing plants expand their production capacities, the volume of biomass waste particularly shells, fibers, and empty fruit bunches escalates proportionally. This accumulation highlights the urgent need for effective waste management strategies that not only address environmental concerns but also create added value through alternative uses.

Mignogna et al. (2024) said that, in recent years, biomass-based energy has gained prominence as a promising solution for addressing energy shortages while reducing dependency on fossil fuels. The large biomass reserves from oil palm plantations offer a strategic advantage for energy diversification. However, the conversion of palm oil waste into energy remains underutilized, primarily due to technological constraints and limited awareness regarding its potential as a sustainable resource. Improving this utilization requires systematic research to optimize processing methods and product quality (Groten & Gallego-García, 2021; Goswami & Daultani, 2023).

Biobriquette production has emerged as one of the most feasible approaches to transforming palm oil waste into an environmentally friendly solid fuel. Unlike raw biomass, biobriquettes possess enhanced density, improved calorific value, and consistent combustion characteristics, making them more suitable for domestic and industrial applications. Their compact form also simplifies transportation and storage, offering practical benefits for large-scale distribution. With proper treatment, palm oil waste can be processed into briquettes that compete with conventional fuels in terms of performance and efficiency.

The adoption of biobriquettes from palm oil waste aligns with global efforts to transition toward cleaner energy sources (Hansen & Nygaard, 2014). As countries work to reduce carbon emissions and mitigate climate change, converting agricultural waste into biomass fuel can support national energy policies and contribute to international sustainability commitments. Integrating waste-to-energy initiatives within the palm oil sector therefore represents a strategic step toward achieving environmentally responsible industrial operations.

Furthermore, the success of biobriquette development hinges on understanding the physicochemical properties of palm oil waste and how these factors influence briquette performance (Seetapong et al., 2024). Each type of waste shells, fibers, and empty fruit bunches possesses distinct characteristics that affect its suitability as a fuel source. Comprehensive scientific evaluation is needed to determine the most effective combinations of raw materials, carbonization methods, and binding agents in order to produce high-quality biobriquettes that meet energy standards.

Given these considerations, the present research aims to examine the feasibility of utilizing palm oil waste in the production of environmentally friendly biobriquettes (Jagaba et al. 2021). By analyzing chemical composition, mechanical behavior, and thermal performance, this study provides an evidence-based foundation for optimizing biobriquette manufacturing processes. Ultimately, the findings are expected to support the advancement of renewable energy technologies while offering practical solutions for sustainable waste management within Indonesia's palm oil industry.

METHODOLOGY

Research Materials

This study utilized solid palm oil waste consisting of shells, fibers, and empty fruit bunches (EFB), all sourced from operational palm oil mills. These three types of biomass were chosen due to their abundant availability and distinct chemical compositions, which allow for comparative evaluation in briquette production. Tapioca starch was used as the adhesive, added at 5% of the biomass dry weight to ensure proper binding during briquette formation. All materials were initially sorted manually to remove impurities such as soil, stones, and residual oil before undergoing further treatment. The selection of materials followed criteria related to cleanliness, dryness, and intact fiber structure to ensure uniformity during processing and testing.

Sample Preparation

The preparation phase began with cleaning each type of biomass shells, fibers, and EFB—to remove contaminants that could affect combustion and chemical test results. After cleaning, the samples were dried in an oven at 105°C until reaching a moisture content of less than 10%, ensuring consistency in the subsequent processing stages. Once dried, the biomass samples were milled to reduce particle size and then sieved using a 60-mesh sieve to obtain finely sized particles suitable for briquette formation. This uniform particle size was essential to achieve even mixing with the adhesive and to promote optimal densification during molding. The prepared samples were stored in airtight containers to prevent reabsorption of moisture before carbonization.

Carbonization Process

The carbonization process was carried out to enhance the fixed carbon content of the biomass and to improve its thermal properties. Each type of biomass was heated in a controlled furnace at a temperature range of 400–500°C. This temperature was selected to allow slow pyrolysis, during which volatile compounds are removed and the material is converted into a more stable carbon-rich product. The carbonization process was closely monitored to maintain a consistent heating rate, ensuring uniform carbonization across all samples. After carbonization, the resulting charcoal-like material was cooled at room temperature in a sealed container to prevent oxidation. The carbonized samples were then lightly re-milled to break down any aggregated chunks and ensure uniformity for subsequent mixing.

Briquette Production

The carbonized biomass samples were mixed thoroughly with 5% tapioca starch adhesive, calculated based on the dry weight of the carbonized material. The mixing process was conducted manually and assisted with mechanical stirring to ensure homogeneous distribution of the adhesive throughout the biomass particles. The mixture was then poured into a hydraulic mold and compacted under a pressure of 100 kg/cm² to form solid briquettes. Hydraulic pressing ensured high density and structural stability. After molding, the briquettes were carefully removed and dried again in an oven at 105°C for 24 hours to eliminate residual moisture and enhance durability. The dried briquettes were labeled based on the type of biomass used for easy identification during testing.

Laboratory Testing Procedures

Laboratory tests were performed to evaluate both the chemical composition and combustion performance of the briquettes. Chemical composition analyses included measurements of moisture content, lignin, cellulose, hemicellulose, and ash content, all conducted according to ASTM standard procedures to maintain data accuracy and comparability. The calorific value of each briquette type was measured using a bomb calorimeter, which provided precise data on the energy content of the samples. Combustion performance tests included observations of burning time, flame color, and flame stability to assess usability and efficiency during practical applications. Exhaust gas emissions were analyzed using a calibrated gas analyzer to measure CO, CO₂, and SO₂ concentrations, while particulate emissions were assessed using a dust sampler. All instruments were calibrated prior to use to ensure measurement reliability.

Data Analysis Techniques

The collected data were analyzed using descriptive-comparative methods. Each parameter—chemical composition, calorific value, combustion performance, and emission levels—was compared across briquettes made from shells, fibers, and EFB. This comparison allowed identification of the biomass type that produced the highest quality biobriquette based on established biomass briquette standards. The analysis included evaluation of compliance with national and international briquette quality standards, enabling a comprehensive assessment of the feasibility of each biomass source. All findings were interpreted systematically to provide insights into the strengths and limitations of each type of palm oil waste when processed into biobriquettes.

RESULTS AND DISCUSSION

Chemical composition analysis of solid palm oil waste was conducted to determine the basic characteristics of the raw materials to be used in biobriquette production. Parameters tested included moisture content, lignin, cellulose, hemicellulose, and ash content, as each has a direct impact on combustion quality, briquette density, and the resulting calorific value. Differences in the chemical composition of shells, fibers, and empty fruit bunches (EFB) provide an overview of the potential of each type of waste as a biomass energy source. This information is crucial for determining the most optimal raw materials for producing high-quality biobriquettes. The following table presents the results of the chemical component analysis of the three types of palm oil waste tested.

Table 1. Chemical Composition of Palm Oil Waste

Type of Waste	Moisture Content (%)	Lignin (%)	Cellulose (%)	Hemicellulose (%)	Ash (%)
Shell	8.5	38.2	32.5	18.0	2.8
Fiber	10.2	34.5	30.8	20.5	3.1
Empty Fruit Bunch (EFB)	12.8	28.7	29.5	23.6	5.4

Based on Table 1, it can be seen that palm kernel shells have the highest lignin content compared to fiber and empty fruit bunches. High lignin content significantly impacts calorific value, as lignin serves as the most combustible component in biomass. This makes shells the most potential raw material for producing biobriquettes with high energy quality. Meanwhile, palm kernel shells

have a relatively high cellulose content, so they can still produce adequate calorific value. However, the fibers have a higher moisture content than the shells, requiring a more optimal drying process before being used as raw material for biobriquettes. Unlike the other two types of waste, empty fruit bunches (EFB) have a relatively high ash content. This high ash content can potentially produce more combustion residue, reducing the energy efficiency of biobriquettes. Nevertheless, EFB remains strategically valuable due to its abundant availability in oil palm plantations.

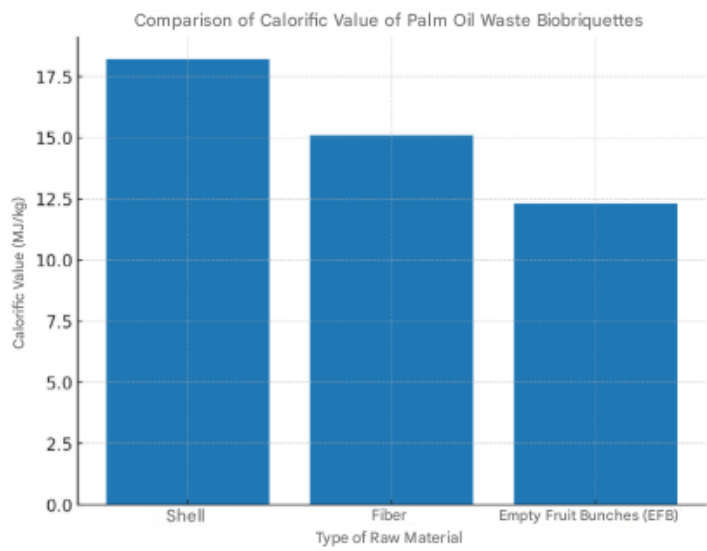


Figure 1. Comparison of the Calorific Value of Biobriquettes from Shells, Fibers, and Empty Fruit Bunches (EFB).

The calorific value test results showed that palm kernel shell biobriquettes had the highest calorific value, at 18.2 MJ/kg. This value is comparable to the quality of several types of lignite, making it suitable as an alternative fuel. Furthermore, the resulting flame is bright yellow, indicating more stable and efficient combustion. Fiber-based biobriquettes have a lower calorific value (15.1 MJ/kg), with a burning time of approximately 78 minutes. The reddish flame color indicates a relatively high carbon content, although the flame stability is not as good as that of shell-based biobriquettes. This still makes palm kernel shell biobriquettes a potential raw material, especially for household and small-scale industrial use. Meanwhile, empty fruit bunch (EFB) biobriquettes have the lowest calorific value, at 12.3 MJ/kg. The burning time is also relatively short, only 65 minutes. The dim flame color indicates the low energy efficiency of this raw material. However, even in its abundant supply, EFB remains useful when mixed with other biomass materials to improve the quality of the biobriquettes.

Table 2. Exhaust Gas Emissions from Palm Oil Waste Biobriquettes

Type of Biobriquette	CO (ppm)	CO ₂ (%)	SO ₂ (ppm)	Particulates (mg/Nm ³)
Shell	115	12.4	12	65
Fiber	130	11.8	15	72
Empty Fruit Bunch (EFB)	145	10.9	18	88

Table 2 shows that shell-based biobriquettes produce the lowest exhaust emissions. Their carbon monoxide (CO) content is only 115 ppm, while particulate matter reaches 65 mg/Nm³. This value is still below the emission threshold for biomass combustion, making shells more environmentally friendly than other palm oil waste. Fiber biobriquettes exhibit higher CO emissions, at 130 ppm, with a SO₂ content of 15 ppm. This is influenced by their higher moisture and ash content compared to shells. However, these emission levels are still considered safe for use on a household and small industrial scale. Empty fruit bunch (EFB) biobriquettes, on the other hand, produce the highest emissions, particularly particulate matter, at 88 mg/Nm³. The high ash content of EFB contributes to increased solid emissions during combustion. However,

emission control technologies such as filters or cyclones can help mitigate the negative impacts of burning EFB-based biobriquettes.

The evaluation of palm oil waste as a raw material for biobriquettes was carried out comprehensively to observe its physicochemical characteristics, thermal behavior, and operational performance during combustion. Prior to briquette testing, each material shell, fiber, and empty fruit bunches (EFB) underwent preliminary characterization to understand its physical properties, particularly bulk density, particle size distribution, and carbonization yield. These parameters are essential because they influence the compaction strength, burning stability, and ash formation during combustion.

Additionally, the structural integrity of the briquettes was assessed through mechanical durability tests. The durability and impact resistance of the briquettes are important in real field conditions, especially for storage, transportation, and handling. Briquettes with poor mechanical strength tend to crumble, increasing material losses and reducing user acceptance. Finally, thermal performance tests, including ignition time, burning rate, and heat retention capacity, were conducted to determine how effectively each briquette type performs as a household and industrial fuel alternative.

The combination of physicochemical, mechanical, and thermal analyses provides a more holistic understanding of the feasibility of using palm oil waste as a renewable energy source. The results not only highlight the advantages of each material but also reveal potential limitations that must be addressed to achieve optimal biobriquette performance. The following tables summarize the additional research findings obtained from field and laboratory evaluations.

Table 3. Physical Characteristics of Carbonized Palm Oil Waste

Type of Waste	Bulk Density (g/cm ³)	Carbonization Yield (%)	Average Particle Size (mm)
Shell	0.72	31.4	0.45
Fiber	0.54	27.8	0.62
EFB	0.47	24.6	0.71

The data in Table 3 indicates that palm kernel shells possess the highest bulk density and carbonization yield compared to fiber and EFB. Higher density enhances briquette compaction, resulting in improved burning duration and thermal efficiency. Fiber, with moderate density, still forms structurally stable briquettes but requires consistent particle size control during processing. EFB shows the lowest density and yield, which impacts both compaction efficiency and material consumption during carbonization.

Table 4. Mechanical Properties of Biobriquettes

Type of Briquette	Compressive Strength (kg/cm ²)	Durability Index (%)	Impact Resistance (Drops Before Failure)
Shell	92	94.6	11
Fiber	76	88.3	8
EFB	61	79.5	5

As shown in Table 4, shell-based briquettes demonstrate the highest compressive strength and durability index, indicating excellent mechanical stability suitable for storage and distribution. Fiber briquettes remain acceptable for practical usage but show moderate resistance to cracking when subjected to impact. EFB briquettes have the lowest durability, often requiring reinforcement such as higher adhesive concentration or blending with shell or fiber—to meet industrial-quality standards.

Table 5. Thermal Performance of Biobriquettes

Type of Briquette	Ignition Time (seconds)	Burning Rate (g/min)	Heat Retention (minutes)
Shell	48	1.62	94
Fiber	41	1.83	79
EFB	28	2.05	63

Thermal performance results in Table 5 show that shell-based briquettes take longer to ignite but maintain heat for the longest duration due to their compact structure and high fixed carbon content. Fiber briquettes ignite faster but exhibit a slightly higher burning rate, causing them to deplete fuel more quickly. EFB briquettes ignite the fastest due to their porous structure but retain heat for the shortest duration, reinforcing their classification as lower-quality fuel unless blended with denser biomass.

Overall, the combined results demonstrate that palm kernel shells consistently outperform fiber and EFB across physical, mechanical, and thermal parameters. Fiber-based briquettes remain a viable intermediate-quality option, balancing availability and performance. Meanwhile, EFB briquettes, although naturally abundant and easy to carbonize, require formulation improvements to reach industrial-grade standards. These findings support the strategic use of mixed-biomass formulations to optimize both performance and resource utilization in palm oil waste biobriquette production.

Discussion

Evaluation of Chemical Characteristics of Palm Oil Waste

The chemical properties of palm oil waste materials reflect the intrinsic quality of each biomass type before conversion into biobriquettes. The variation in lignin, cellulose, and ash content indicates the different roles each component plays during combustion. Materials with higher lignin and lower ash typically demonstrate better thermal efficiency, as lignin contributes to higher fixed carbon while low ash minimizes residue formation. The differences in chemical structure also influence how efficiently each material undergoes thermal decomposition, which further affects the energy yield produced during controlled burning tests.

Distinct moisture levels among the three waste types also affect processing efficiency. Higher moisture content generally slows down carbonization, requiring longer drying durations to achieve optimal quality. This parameter has practical implications because excessive moisture often leads to incomplete combustion and unstable flame patterns. Therefore, the chemical profile not only determines combustion efficiency but also dictates the necessary pretreatment steps to maximize briquette performance.

Overall, the analysis of chemical components provides foundational insights into how each biomass type behaves under thermal conversion. These chemical indicators serve as a predictive measure of performance before mechanical and thermal testing is conducted, allowing researchers to anticipate which materials are likely to produce superior briquettes.

Implications of Physical and Structural Characteristics

The physical parameters of carbonized biomass influence its ability to form dense and durable briquettes. Higher bulk density facilitates a more compact arrangement of particles during molding, ultimately resulting in stronger briquettes with increased resistance to impact and wear. Conversely, lower density materials tend to form briquettes with higher porosity, which may ignite more easily but sacrifice durability and burning duration. Thus, optimizing particle compactness becomes essential for enhancing product performance.

Carbonization yield also plays an important role in determining material efficiency. A higher yield indicates that the biomass retains more mass after carbon conversion, making it more economical for briquette production. Materials with low yield require larger quantities of raw material, thereby increasing operational costs. Additionally, particle size uniformity influences how well each material can be compressed; irregular or oversized particles often reduce binding strength and promote cracking during drying and handling.

These physical characteristics collectively shape the structural integrity of biobriquettes. A material's ability to produce briquettes with consistent texture and minimal surface defects is critical for large-scale distribution. Hence, monitoring physical attributes is essential for predicting field performance, particularly in demanding environments where briquettes may be subjected to repeated handling or transportation stress.

Assessment of Mechanical Performance in Practical Use

Mechanical strength determines whether biobriquettes can withstand operational stresses encountered during storage and transportation. Briquettes with high compressive strength maintain their shape even under significant pressure, ensuring minimal product loss. Durability index further reflects the reliability of briquettes during repeated handling, with higher values indicating resilience against crumbling or structural degradation. These parameters are particularly important when briquettes are intended for commercial markets.

Impact resistance provides additional insights into how well briquettes survive accidental drops or shocks. Materials with low impact resistance often break more easily, reducing their suitability for long-distance distribution. These mechanical factors not only affect user convenience but also influence overall economic feasibility, as low-strength briquettes may incur higher material loss during packaging or delivery.

Collectively, the mechanical findings suggest that selecting an appropriate raw material is essential for producing briquettes that meet industrial and household standards. Enhancing mechanical performance either through material selection or formulation improvements—remains a key strategy in optimizing product reliability.

Analysis of Thermal Behavior and Combustion Efficiency

Thermal performance indicators such as ignition time, burning rate, and heat retention offer a direct measurement of how effective each briquette type is as a fuel source. Materials that ignite more slowly often possess higher density and fixed carbon, contributing to longer-lasting combustion. In contrast, materials that ignite quickly may be beneficial for initiating fire but typically burn out faster due to lower mass concentration and higher porosity.

Burning rate also influences the practicality of briquettes for different applications. A slower burning rate is generally preferred for cooking or industrial heating, as it allows heat to be distributed more evenly over time. Faster burning rates may be ideal for short-term heating but reduce total energy output per unit mass. Thus, balancing ignition ease with burning duration is important in determining product suitability for specific user needs.

Heat retention reflects the briquettes' ability to maintain a stable temperature throughout the combustion cycle. High heat retention is typically associated with materials rich in fixed carbon and low in volatile matter, which provide a more controlled and uniform burn. These thermal findings reinforce the need to match raw materials to intended usage scenarios, ensuring optimal fuel performance.

Integration of Overall Performance and Practical Implications

When all analytical parameters chemical, physical, mechanical, and thermal are considered together, a clearer understanding emerges regarding the relative strengths of each biomass type. Some materials may exhibit strong chemical or thermal characteristics but fall short in mechanical strength, making them less suitable for transport-intensive applications. Others may be mechanically reliable but require further enhancement to improve combustion efficiency.

These results also highlight valuable opportunities for material blending. Combining biomass types with complementary properties can produce briquettes with balanced performance, especially when abundant materials such as EFB fall short in critical areas. This approach aligns with sustainable waste utilization strategies and supports the development of cost-effective renewable energy solutions.

Ultimately, the integrated evaluation underscores the importance of adopting a multi-parameter assessment framework when developing biomass briquettes. Such a holistic approach ensures that selected materials not only burn efficiently but also meet practical field requirements, contributing to the advancement of biomass-based energy alternatives.

CONCLUSION

Based on the overall findings, it can be concluded that palm kernel shells are the most superior raw material for biobriquette production, as they consistently demonstrate the best chemical composition, highest mechanical strength, and strongest thermal performance compared to fibers

and empty fruit bunches (EFB). Shells contain the highest lignin and cellulose levels, resulting in high calorific value, stable combustion, low emissions, and excellent heat retention. Fiber-based briquettes show moderate performance and remain viable due to acceptable mechanical durability and thermal characteristics, although they require improved moisture control. Meanwhile, EFB, despite its abundance, exhibits the lowest quality in terms of density, carbonization yield, mechanical strength, and emission levels, making it less suitable for standalone use but still valuable when blended with higher-quality biomass. Overall, the integrated analysis shows that palm oil waste holds significant potential as a renewable energy source, with mixed-biomass formulations offering an effective strategy to enhance performance, improve resource efficiency, and support sustainable energy development.

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