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Utilization of Solid Fuel in Environmentally Friendly Alternative Energy Learning

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Abstract
The target for the development of New and Renewable Energy (NRE) in the National Energy General Plan continues to increase toward 2050. The limited availability of fossil energy resources and the growing environmental impacts of their use encourage the development of sustainable and environmentally friendly alternative energy sources that can also be integrated into learning activities. One potential renewable energy source that can be utilized in educational contexts is Solid Clumped Fuel (SCF). SCF is a solid fuel produced through the densification of biomass waste using a clumping method, resulting in a product with higher density, easier handling, and favorable combustion characteristics. This study aims to examine the potential of SCF as an environmentally friendly alternative energy source and as a learning medium for renewable energy education. The analysis focuses on the production process, physical characteristics, and energy properties of SCF. The raw materials used consist of biomass waste, namely rice husk and sawdust, which are processed through drying, grinding, mixing, compaction, and final drying stages. The parameters analyzed include moisture content, calorific value, and particle size analysis. The results indicate that SCF has a competitive calorific value compared to conventional solid fuels and produces relatively lower emissions. Therefore, SCF has strong potential as an environmentally friendly alternative energy source and as a contextual learning medium to enhance students' understanding of renewable energy concepts and sustainable biomass waste utilization.

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1. BACKGROUND OF THE PROBLEM

The ever-increasing demand for energy, coupled with population growth, industrialization, and economic development, presents a major challenge to energy supply, both nationally and globally. Fossil fuels such as coal, oil, and natural gas still dominate the energy mix. However, the availability of fossil fuels is increasingly limited, and their use creates various environmental problems, including greenhouse gas emissions, air pollution, and a contribution to climate change. This situation drives the need to develop and utilize sustainable and environmentally friendly alternative energy sources, while simultaneously supporting energy transition efforts.

Biomass is one renewable energy source with significant potential in Indonesia. As an agricultural country, Indonesia produces abundant biomass waste, such as rice husks, sawdust, bagasse, coconut shells, and various other agricultural waste. However, the utilization of this biomass waste is still suboptimal and, in some cases, can even cause environmental problems if not managed properly. Therefore, utilizing biomass as an alternative fuel is a strategic solution that not only contributes to energy supply but also supports sustainable waste management.

One form of biomass utilization that is beginning to be developed is Solid Bunch Fuel (BBJP). BBJP is a solid fuel produced through a biomass compaction process using the bunching method, resulting in a product with higher density, relatively uniform size, and more stable combustion characteristics than bulk biomass. This compaction process aims to increase the utility value of biomass, simplify handling, storage, and transportation, and improve combustion efficiency.

From an environmental perspective, BBJP has the advantage of being a more environmentally friendly fuel compared to fossil fuels. Biomass is relatively carbon-neutral, meaning the carbon dioxide emissions produced during combustion are comparable to the carbon absorbed during plant growth. Furthermore, biomass generally contains lower sulfur and nitrogen, potentially resulting in lower SO_2 and NO_x emissions. These characteristics make BBJP a potential alternative fuel for use in households, small- and medium-sized industries, and certain applications in the energy sector.

Beyond energy and environmental aspects, BBJP also holds significant potential for use in learning about environmentally friendly alternative energy. The relatively simple manufacturing process, readily available raw materials, and concepts relevant to sustainable energy issues make BBJP a contextual learning medium. Through BBJP-based learning, students can directly understand the concepts of renewable energy, biomass waste utilization, and the importance of environmentally friendly energy innovation in addressing global challenges.

However, the development and utilization of BBJP still face various challenges, including variations in raw material quality, the impact of the production process on physical and energy characteristics, and limited studies integrating technical and educational aspects. Therefore, further research is needed on the manufacturing process, characteristics, and utilization of BBJP as an environmentally friendly alternative energy source and as an effective learning medium in renewable energy education.

Problem Formulation

Based on the background that has been described, the problem formulation in this research is as follows:

1. What are the physical and energy characteristics of the resulting Solid Jumputan Fuel (BBJP), including water content (total moisture), calorific value, and particle fraction size?
2. What is the relationship between total moisture and fraction size, **as well as** the relationship between total moisture and calorific value on BBJP products?
3. Does the Solid Jumputan Fuel (BBJP) produced meet the criteria as a viable and environmentally friendly alternative fuel to be used in renewable energy learning?

Research purposes

The objectives to be achieved in this research are:

1. Analyze the characteristics of BBJP, including water content, calorific value, and size.
2. Knowing and describing BBJP as an alternative energy potential
3. Assessing the potential of BBJP as an environmentally friendly alternative energy source.

Benefits of research

This research can provide benefits, including:

1. Adding scientific references and developing knowledge in the field of renewable energy, especially the use of biomass as a solid fuel.

2. To be a reference material for further research related to the development and optimization of Solid Jumputan Fuel.
3. Supporting the use of biomass waste as an alternative energy source with economic value.
4. Support renewable energy development programs and reduce dependence on fossil fuels.

2. Literature Review and Theoretical Framework

Solid biomass derived from agricultural waste, such as rice husks, coconut shells, straw, corn cobs, and organic waste, has great potential as an alternative energy source due to its abundant availability and ability to reduce dependence on fossil fuels. Utilizing biomass in the form of solid fuels, such as briquettes or Solid Jumputan Fuel (BBJP), can convert waste into an energy source with a relatively high calorific value and more stable combustion characteristics than bulk biomass (Qistina et al., 2016).

BBJP is a solid fuel produced through a biomass compaction process using the pickling method. In general, the BBJP manufacturing process includes drying, chopping or grinding the raw materials, mixing with natural adhesives (such as tapioca), compaction, and final drying to produce a homogeneous product. Previous research has shown that variations in raw material type, mixture composition, adhesive use, and production methods significantly affect the physical and energy characteristics of BBJP, such as moisture content, ash content, calorific value, and mechanical strength (Kurniawan, 2012).

In the development of a waste-based and mixed biomass fuel (BBJP), Arta (2024) explained that solid fuel can be produced through the process of sorting and homogenizing organic waste into small particles or pellets as a substitute for fossil fuels. The BBJP production process for cofiring tests at a Steam Power Plant (PLTU) involves several stages, namely:

1. Determination and characterization of the composition of waste to be processed with a maximum requirement of 20% non-organic content and a minimum of 80% organic.
2. Sorting waste that cannot be used or that still has economic value (glass, iron, aluminum, diapers, etc.).
3. Weighing and mixing the sorted waste according to the required variations (differences in composition result in differences in the quality of BBJP biomass). Then, the waste is placed into the beds using heavy equipment (bobcat, excavator, etc.).
4. Water the bio activator as needed (a rule of thumb is to dilute the bio activator with 40-80 L of water, and water it every 20 cm of waste in the bed). Once the bed is full, cover it with a tarp or burlap sack.
5. The fermentation process will occur approximately 3 days after the beds are covered. After fermentation, allow 3-5 days to reduce the total moisture content of the potential BBJP product. During the process, periodically measure the temperature and pH.
6. Harvesting the fermented product (BBJP) and airing the BBJP to reduce the water content and make the machine work easier.
7. Coarsely chop the BBJP (mesh 1) and finely chop it (mesh 5). The BBJP can then be packed and loaded onto a means of transportation.

Research that combines organic waste with other biomass (e.g., castor bean meal) can increase the combustion rate and reduce the water content and increase the calorific value of the biomass, making it an ideal composition as a raw material for BBJP production. J. M. Nganko (2025)

One of the main objectives of utilizing BBJP is to reduce greenhouse gas and pollutant emissions. Solid biomass can produce lower SO_2 and NO_x emissions than burning coal or other fossil fuels due to its lower hazardous element content and near-neutral carbon content. The CO_2 released during combustion can be reabsorbed through plant photosynthesis. Wu (2025).

However, several studies have also noted that particulate emissions from biomass combustion (e.g., briquettes) can have significant impacts if not properly controlled, making it important to optimize production processes and fuel composition to minimize health and environmental impacts. J. M. Nganko (2025).

The application of BBJP is not only for household or small industrial use but also for co-firing in Steam Power Plants (PLTU), where it is mixed with coal. Research shows that the use of BBJP at a certain percentage in a co-firing system can reduce coal consumption, lower carbon emissions, and change combustion characteristics in pulverizers and boilers without substantially reducing performance. Arta (2024).

The use of BBJP can be part of a circular economy strategy, where previously unused organic and agricultural waste can be processed into value-added energy sources. This can also help reduce the environmental burden from waste disposal while creating economic opportunities in the provision of local fuel. Nugraha (2023)

Although BBJP has high potential as an alternative energy fuel, several technical and environmental challenges need to be overcome, including:

1. Optimization of raw material composition to reduce ash content and harmful emission resistance; Guo (2023)
2. Development of BBJP processing technology to increase the calorific value and stability of fuel; Wu (2025)
3. BBJP quality standardization according to national/international standards for industrial and household applications.

Solid biomass, such as BBJP, can be used as an environmentally friendly and sustainable energy alternative compared to fossil fuels. Recent scientific studies demonstrate the importance of technical aspects of production, fuel characterization, emission impacts, and application in modern energy systems such as co-firing coal-fired power plants. Research and development should focus on improving BBJP quality, mitigating emissions, and integrating technology to support large-scale utilization that is economic and ecological.

Co-firing is the simultaneous combustion of two (or more) different fuel categories integrated in a specific ratio with more economical renewable alternative fuels to reduce coal utilization and lower the basic cost of electricity generation (Xu et al., 2020). There are three different technological approaches for co-firing biomass and coal in power plants. These methodologies vary in boiler system configuration and biomass ratio. The three methods or techniques are direct co-firing (direct co-firing) and direct co-firing (direct co-firing). firing), indirect co-firing and parallel co-firing. Al-Mansour (2020)

From an economic and sustainability perspective, the use of BBJP aligns with the concept of a circular economy, where previously worthless organic and agricultural waste can be processed into value-added energy sources. This approach not only reduces the environmental burden caused by waste disposal but also opens up new economic opportunities by providing local fuel based on renewable resources (Nugraha, 2023).

Despite its great potential, the development of BBJP still faces several challenges, including optimizing the composition of raw materials to reduce ash content and harmful emissions (Guo, 2023), developing processing technology to increase the calorific value and stability of the fuel (Wu, 2025), and the need for standardization of BBJP quality in accordance with national and international standards so that it can be widely applied in the household, industrial, and power generation sectors.

3. RESEARCH RESULT

Based on research conducted on several BBJP samples sent from the factory by truck for co-firing purposes, the energy content was sufficient to meet combustion requirements. The samples were then prepared for analysis. The parameters tested used the ASTM method. The analysis of three samples yielded the following results:

Table 1. BBJP sample testing

Sample		A1			B2			C3		
Parameter	Unit	WITH	ADB	DB	WITH	ADB	DB	WITH	ADB	DB
Total Moisture	%	22,69			13,41			29,61		
Moisture in the Analysis Sample	%		9,44			3,65			5,62	
Gross Calorific Value	Kcal/Kg	3359	3935	4345	3687	4103	4258	3432	4602	4876
Size Test	Size Fraction	+5mm	+2,36 mm	-2,36mm	+5mm	+2,36 mm	-2,36mm	+5mm	+2,36 mm	-2,36mm
	%	4,80	43,22	51,79	36,80	26,08	36,95	11,25	40,43	48,14

Discussion

The test results, as per Table 1, show that there is a significant variation in moisture content between samples. Total Moisture (As Received/AR) ranged from 13.41% to 29.61%. Sample B2 had the lowest Total Moisture (13.41%), while Sample C3 showed the highest value (29.61%). Moisture in the Analysis Sample (ADB) ranged from 3.65%–9.44%, reflecting differences in the inherent moisture content of BBJP. High Total Moisture values have the potential to reduce the actual calorific value and affect combustion efficiency and transportation costs related to the net weight of the vehicle used.

Table 1 shows the Gross Calorific Value (GCV) obtained based on AR, ADB, and DB with the following results:

1. GCV AR ranged from 3359–3687 Kcal/Kg, with the highest value in Sample B2.
2. GCV ADB is in the range of 3935–4602 Kcal/Kg.
3. GCV DB showed a range of 4258–4876 Kcal/Kg, with the highest value in Sample C3.

The difference in GCV values between bases indicates a significant influence of moisture content on the actual calorific value. Inherently (DB), Sample C3 had the highest BBJP quality, while under acceptance conditions (AR), Sample B2 showed the best energy performance.

Distribution of Size (Size Test) in Table 1, the results of the grain size test show the following characteristics:

1. Sample A1 was dominated by fine fraction (−2.36 mm) at 51.79%, which has the potential to increase the risk of dusting, segregation, and loss during handling.
2. Sample B2 has the most balanced size distribution, with a +5 mm fraction of 36.80%, making it more stable in the handling and transportation process.
3. Sample C3 also showed a dominance of fine fractions (48.14%), although it was still better than Sample 1.

Size distribution with high fines content can impact the stability of the load, especially if shipping by sea transportation.

Based on the data, the following is the correlation between Total Moisture and Fraction Size, and the correlation between Total Moisture and Caloric Value of 3 BBJP samples.

1. Relationship of Total Moisture to Fraction Size (Fine Fraction −2.36 mm)

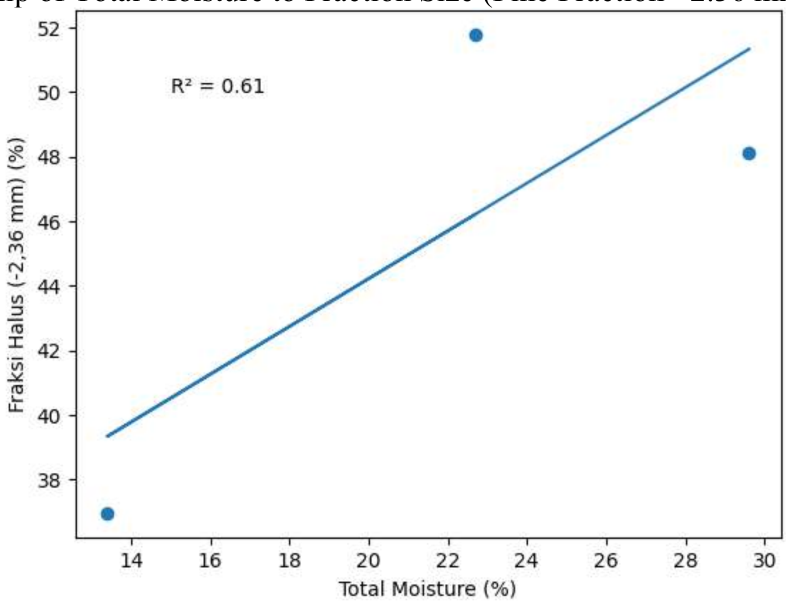

Figure 1. Graph of the Relationship between Total Moisture and Size (Fine Fraction −2.36 mm)

The graph shows the relationship between Total Moisture (%) and the percentage of fine fraction (−2.36 mm) of three BBJP samples, accompanied by a linear trend line and a coefficient of determination value ($R^2 = 0.61$). This value indicates a moderate correlation between the increase in Total Moisture and the increase in the fine fraction of BBJP products. Technically, this can be interpreted as follows:

a. The analysis results show that BBJP products with higher total moisture tend to have larger fine fraction sizes. This indicates that moisture content plays a role in the degradation of BBJP product fraction sizes during manufacturing, handling, and storage.
b. Increasing the fine fraction size can have an impact on:
    1) Fleet load stability during transportation,
    2) Increased potential for dusting and segregation of fines,
    3) There is a risk of handling problems, especially in bulk shipments using sea transportation.

Although it shows a clear trend, this relationship can still be influenced by other factors such as manufacturing process methods, handling, stockpile conditions, and BBJP product characteristics.

2. Relationship between Total Moisture and Gross Calorific Value (AR)

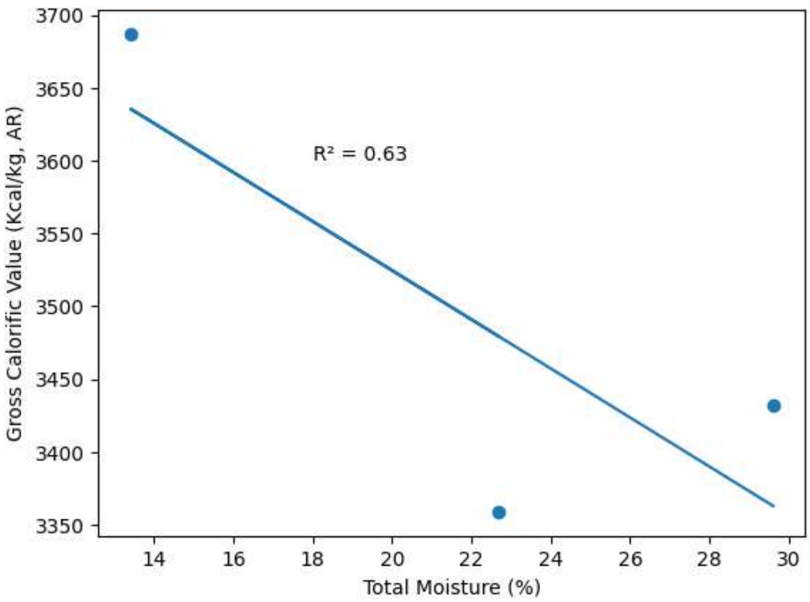

Figure 2. Graph of the Relationship between Total Moisture and Gross Calorific Value (AR)

The graph shows a negative relationship between Total Moisture and Gross Calorific Value (AR), where an increase in moisture content is followed by a decrease in the actual calorific value of BBJP products. This indicates a strong correlation, indicating that Total Moisture has a significant effect on GCV in the As Received condition. Technically, this can be interpreted as follows:

1. The analysis results show that BBJP products with low Total Moisture (±13–14%) have the highest GCV AR. This may reflect better energy efficiency. Increasing moisture content causes some of the combustion energy to be used for water evaporation, thus reducing the effective calorific value. Differences in GCV values between samples on an AR basis are primarily influenced by variations in moisture content, not solely the quality of the BBJP product.
2. Total Moisture is a critical parameter in evaluating the quality of BBJP products for transportation and commercial transactions. A lower GCV AR value can potentially impact:
   a. Decreased combustion efficiency,
   b. Price adjustment (penalty),
   c. Blending considerations before shipping.

Based on the results of the tests that have been carried out, the following is an evaluation of the quality and feasibility for use as an environmentally friendly alternative energy, so that it can increase efficiency and produce lower emissions per kWh.

1. **Sample B2 is considered** the most stable for shipping and direct use, in terms of low Total Moisture and relatively balanced size distribution.
2. **Sample C3**has inherently good BBJP product quality, but requires attention to water content and fines content.
3. **Sample A1**requires further management regarding fines and water content to minimize potential problems during handling and transportation.

Table 2. Technical Feasibility of BBJP Products

Sample	Technical Feasibility	Information
Sample A1	Conditionally Eligible	Medium–high moisture and high fines; blending recommended

Sample B2	Worth Using	Low moisture, best GCV AR, relatively stable size
Sample B3	Conditionally Eligible	Inherently good quality, but high moisture and fines

4. CONCLUSION AND SUGGESTIONS

1. Conclusion
   a. Based on laboratory analysis results, the quality of the tested BBJP products showed variations in their characteristics. Test results indicated that total moisture was a critical parameter influencing the characteristics of the resulting BBJP products.
   b. Based on the correlation graph, controlling water content and size distribution are important factors in maintaining quality, transportation safety, and the suitability of BBJP product specifications to the needs of end users.
   c. In general, the use of BBJP products is still suitable for trading and use according to the required specifications, with the note that it is necessary to control the water content and size of the fine fraction to maintain quality and safety during the shipping process.
2. Suggestion
   a. For co-firing, a study can be conducted on mixing coal with BBJP:
      1) Reducing net CO_2 emissions,
      2) Utilizing organic waste,
      3) Increase combustion efficiency.
   b. Study of medium-calorie coal processing based on BBJP biomass mixture:
      1) Reduces effective moisture,
      2) Reduce dusting and losses,
      3) Improves combustion stability.
   c. Studies on the use of clean technologies, ESP, FGD, and high-efficiency burners strengthen the position of BBJP-Coal cofiring as a transitional energy with a more controlled environmental impact.

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