



## A Review: Utilization of By-Products from Areca Nut and Coconut Processing as Environmentally Friendly Biobriquettes

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**Abstract.** Large quantities of by-products from areca nut and coconut processing generated annually have significant potential as solid fuel feedstocks due to their high lignocellulosic content. Optimal utilization of these residues can increase their added value and reduce the environmental impacts associated with organic waste. This study aimed to explore the manufacturing process and characteristics of biobriquettes made from biomass waste in the form of areca nut husk, coconut husk, and coconut shell. These raw materials were processed through the stages of cleaning, drying, carbonation, refining, mixing with adhesives, molding, and drying. The use of adhesives such as tapioca flour, sago, or palm oil liquid waste affects the quality of biobriquettes, including their moisture content, ash content, calorific value, density, and combustion rate. The results of the study revealed that biomass-based biobriquettes have several advantages, such as being cost-effective, environmentally friendly, and producing a high calorific value. This study provides scientific and practical benefits to the processing of biomass waste into renewable energy with high economic value. The utilization of this waste not only enhances renewable energy production but also reduces agricultural waste and environmental pollution.

**Keywords:** areca nut husk; coconut husk; coconut shell; biobriquette.

**Type of the Paper:** Article Review.



### 1. Introduction

Coconut and areca nut plants belong to the palm tree family, which grows widely throughout Indonesia. Indonesia is the second-largest coconut producer after the Philippines. In 2023, the area of coconut plantations in Indonesia was 3.33 million hectares, with a production of 2.89 million tons [1]. The area of areca nut plantations in Indonesia is estimated to reach 163,327 hectares in 2024, with a production of 83,246 tons [2]. Coconuts in Indonesia are harvested for their flesh, which is mostly processed into copra and coconut milk. Areca nuts are processed into dried areca nuts. The processed copra and dried areca nuts produce by-products in the form of coconut husks, coconut shells, and areca nut husks. Coconut fiber, shells, and areca nut husks offer unique advantages over many other types of biomass due to their high lignin content, high energy content, superior durability, low carbon emissions, and versatile applications beyond simple energy generation; furthermore, these materials are abundant, renewable, and eco-friendly resources [3–5].

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The weight of a coconut husk reaches 35%, the coconut shell weighs 12%, while the coconut's moisture content is 25% of the total composition of the coconut fruit [6]. If the processing of coconut flesh is optimized to make copra, approximately 1,014,756.75 tons of husks and 347,916.6 tons of shells will be produced annually. The weight of the areca nut husk reaches 60–80% of the total areca nut [7], resulting in 66,608 tons of areca nut husks annually.

The utilization of areca nut husks and coconut husks remains suboptimal. They are primarily used as simple planting media, yard covers, or left unused. When dry, they are often burned. Coconut shells are sometimes converted into charcoal, but many are discarded. Coconut husks and shells take a long time to decompose, around 8–12 years [8]. Saputro [9] asserts that the accumulation of coconut husk waste has negative impacts, including unpleasant odors and environmental pollution. Accumulated waste in residential areas can become breeding grounds for rats, snakes, and mosquitoes, potentially causing diseases [10]. Yuan et al. [11] noted that in many areca nut processing factories, areca nut husks are directly burned or buried as waste, leading to the loss of biomass energy with potential application value. Moreover, decomposing areca nut husks produce unpleasant odors and environmental pollution.

As a type of plantation waste, areca nut and coconut processing by-products represent biomass that can be further processed. To reduce the volume of areca nut husk, coconut husk, and coconut shell waste, these materials can be utilized as renewable energy in the form of biobriquettes [12–18].

Biobriquettes are made from the remaining organic materials that have undergone a compression process, resulting in a solid fuel form [19]. The raw material for biobriquettes is charcoal, which is produced by controlling the combustion process and can be molded to serve as a substitute fuel. Biobriquettes can be utilized for both household and industrial applications. Biobriquettes made from coconut shells possess an attractive shape, are cleaner, more practical, environmentally friendly, and produce higher and more consistent energy output [20]. The use of biomass-based biobriquettes offers several advantages, including: (a) cost-effectiveness; (b) renewability; (c) being sulfur-free, thus environmentally friendly; (d) higher calorific value than other solid fuels; (e) lower ash content (2–10%) compared to coal (20–40%); (f) uniform combustion compared to coal; (g) local production close to consumers, reducing dependence on long-distance transportation; and (h) higher boiling efficiency due to lower moisture content and higher density compared to firewood or biomass waste [21,22].

Biomass with a high calorific value can be utilized as a mixing material in the production of biobriquettes, while the primary ingredients are typically obtained from biomass waste that has a lower calorific value but is available in abundant supply. Calorific value is one of the critical properties of fuel. The quality of biobriquettes can be determined based on their physical,

chemical, and mechanical properties, such as ash content, volatile matter content, fixed carbon content, moisture content, specific gravity, and calorific value [23]. Coconut shells have a calorific value of 7,283.5 cal/g [24], coconut husks have 3,942.751 cal/g [25], and biobriquettes made from areca nut husks with 5% tapioca adhesive have 5,966.00 cal/g [15]. According to Frida et al. [26], biobriquettes made from areca nut husks and coconut shells in a 50:50 ratio with 7% tapioca adhesive have a moisture content of 6.9% and a carbon content of 60.9%. Meanwhile, Vegetama [27] reported that biobriquettes from coconut husks and coconut shells in a ratio of 50 : 50 have a calorific value of 3708,34 cal/g. Research by Satria et al. [28] found that biobriquettes made from corn husks and areca nut husks in a 90:10 ratio produced a density of 0.66 g/cm<sup>3</sup>, moisture content of 4.23%, volatile matter content of 15.01%, ash content of 3.68%, and calorific value of 6,528.73 cal/g.

Several studies on biobriquettes have focused on production, methodology, technology, results, market potential, and economic feasibility. This study aimed to explore the manufacturing process and characteristics of biobriquettes made from areca nut husk, coconut husk, and coconut shell. The biobriquettes are expected to increase the utility and economic value of areca nut husks, coconut husks, and coconut shells.

## 2. Materials and Methods

The biomass raw materials used are coconut shell, coconut fiber, and areca nut husk, as well as other biomass as a blending material. These raw materials were processed through the stages of cleaning, drying, carbonation, refining, mixing with adhesives, molding, and drying. The use of adhesives such as tapioca flour, sago, or palm oil liquid waste can affect the quality of biobriquettes, including their moisture content, ash content, calorific value, density, and combustion rate.

## 3. Result and Discussion

### 3.1. Biobriquette Processing

#### 3.1.1. Raw Materials

The raw materials used for biobriquettes are biomass waste, such as areca nut husks, coconut shells, and coconut husks. The areca nut husks used are by-products of areca nut processing, which are characterized by their yellow or orange color. Meanwhile, the coconut husks and shells used are by-products of copra processing. The coconuts used for making copra are typically 11–13 months old and are identified by their brownish husks. Areca husks are shown in Fig. 1. Coconut shells are shown in Fig. 2, and coconut husks are shown in Fig. 3.

Areca nut husk contains the same compounds as coconut shells and coconut husks, which are lignin and cellulose. The cellulose content in areca nut husk is 40%, while lignin content is 18% [29]. According to Djatmiko et al. [30], coconut shells contain 27.31% cellulose and 33.30%

lignin. Meanwhile, research conducted by Iskandar and Rofiatin [31] showed that coconut shells have a cellulose content of 29.6% and lignin content of 36.51%. The lignin content in the raw materials functions as a natural binder during the biobriquette processing [32]. Additionally, cellulose influences the biobriquette combustion process, where a higher cellulose content results in a faster combustion process [33]. Lignin is the most suitable compound for bio-briquettes, and among the raw materials mentioned, coconut shell is the most ideal, followed by areca nut husk, while coconut fiber is more suitable as a blending material. Hemisocellulose, Lignin and Cellulose found in Areca Nut Husk, Coconut Shell and Coconut Husk are shown in Table 1.

**Table 1.** Composition of Hemisocellulose, Lignin and Cellulose found in Areca Nut Husk, Coconut Shell, and Coconut Husk

Material	References	Hemisocellulose (%)	Lignin (%)	Cellulose (%)
Areca Nut Husk	Kumar et.al (2011) [29]	32.98	7.20	53.20
	Chandra et.al (2016) [38]	20.83	31.6	34.18
	Muliyanti et.al (2023) [39]	12.66	21.21	46.94
Coconut Shell	Iskandar and Rofiatin (2017) [31]	19.27	36.51	29.6
	Rahmawati et.al (2024) [40]		29	26
	Tamado, et.al (2013)[41]	21	27	34
Coconut Husk	Joseph and Kindagen (1993)[42]	8.5	29.23	21.07
	Anuchi, Campbell, & Hallett (2022) [43]	15-30	50	20-30



**Fig.1.** Areca Husk



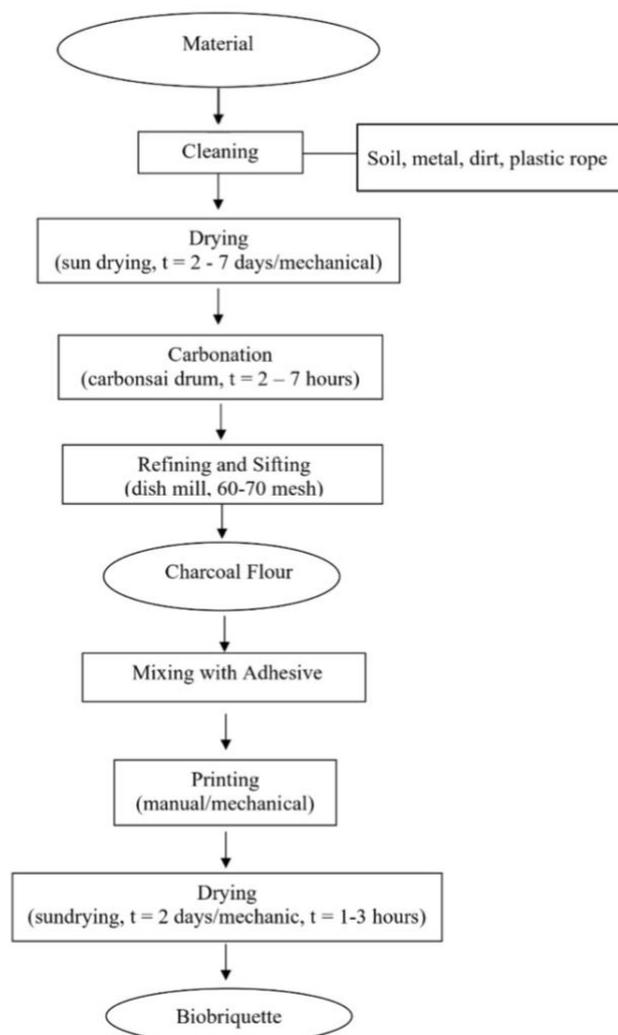
**Fig.2.** Coconut Shell



**Fig.3.** Coconut Husk

### 3.1.2. Cleaning Process

The materials used are areca nut husks obtained from the processing of dried areca nuts, with the criterion that the husks must be yellow. Coconut husks and shells are sourced from mature coconuts, characterized by their perfectly brownish color and harvested from fallen coconuts no older than five days. The coconut husks and shells are first sorted to separate any attached husks and shells. The areca nut husks are obtained from peeling areca nuts [34]. The materials are then cleaned and sorted to remove foreign substances, such as metal, plastic ropes, dirt, soil, and other debris, through filtration or by using filtering equipment and magnetic conveyors. Foreign materials can affect machine performance during processing and the quality of the final product [35–37].



**Fig.4.** Flowchart of Biobriquette Processing Process

Coconut husks and shells are obtained from mature coconuts, characterized by dried fruit with a perfect brownish color, and from coconuts that have fallen from the tree for no more than five days. The husks and shells are first sorted to separate any husks and shells that are still attached to each other. Areca nut husks, on the other hand, are obtained from peeling areca nuts [34].

The materials then undergo a cleaning and sorting process to remove contaminants, such as metal, plastic ropes, dirt, soil, and other debris. This is done through filtration or by using filtering equipment and magnetic conveyors. The presence of foreign materials can affect machine performance during processing as well as the quality of the final product [38–43]. The flowchart of biobriquette processing process is shown in Fig. 4.

### 3.2. *Drying of Raw Materials*

The drying of raw materials can be carried out using sunlight or mechanical dryers. Sun drying (natural drying) is simpler and cheaper but highly dependent on weather conditions, unlike mechanical drying (forced drying) [44]. According to Yulia et al. [18], the moisture content of coconut husk and coconut shells used should be between 10–20%.

Research conducted by Pranowo et al. [16] indicates that coconut shells must be dried under sunlight until the moisture content reaches 10%, which takes approximately seven days. Anom and Lombok [45] reported that coconut shells can be dried under sunlight for two days, while Sabo et al. [17] dried coconut shells in the sun for three days. Similarly, Tun et al. [13] dried coconut husks for one week. Reducing the moisture content of the material is essential to facilitate the carbonation process.

### 3.3. *Carbonation*

According to Yulia et al. [18], the coconut husk and shell, after weighing and meeting processing requirements, are placed into a kiln for burning until they turn into charcoal. The burning duration for coconut shells and husks using a carbonation drum is approximately four hours. Ali et al [46]. reported that the carbonation of coconut shells was conducted using pyrolysis in a drum for 5–7 hours. The carbonation drum was also used by Mardawati et al. [47], for coconut shell carbonization, which was carried out for two hours at a temperature of 450°C. Meanwhile, Rusnadi's study showed that the optimal carbonization temperature for coconut shell was 400 °C for 135 minutes using 4 kg of feedstock and a cylindrical retort kiln method. Afrianah et al. [48] performed coconut shell carbonization at 500 °C for two hours. According to Camarta et al. [14], carbonization of areca nut husk at 300 °C for 60 minutes resulted in the most optimal calorific value. Anggita [49] reported that coconut husk and coconut shell were carbonized at 300 °C for 60 minutes using a furnace.

These studies indicate that the optimal carbonization temperature for coconut shell ranges between 400 and 500 °C, while coconut husk and areca nut husk exhibit optimal carbonization at 300 °C for 60 minutes. The higher the carbonization temperature, the lower the moisture and ash content, as well as volatile matter, resulting in a higher calorific value.

### 3.4. Refining and Sifting

Coconut shell charcoal and coconut husk obtained from the carbonization process are ground into small particles. The ground coconut shell charcoal and husk are then sieved using a 60-mesh sieve [49–50]. Lawal et al. [51] reduced the size of coconut husks by grinding and sieving them with a 2 mm mesh sieve. Similarly, areca nut husks are reduced in size and sieved using a 60-mesh sieve [15,28]. According to Jaswella et al. [52], a particle size of 70 mesh for coconut shell charcoal meets the criteria for the best quality briquettes, producing minimal smoke, less ash, and no unpleasant odor.

The smaller the particle size of the charcoal powder, the longer the briquette burns. Particle size also affects the compressive strength of biobriquettes. Smaller particle sizes result in higher compressive- strength [53,54].

Equipment used to reduce the size of raw materials includes hammer mills, knife mills, linear knife grids, and disc attrition. The most effective equipment is the hammer mill [55].

### 3.5. Adhesive Mixing

The compaction of biobriquettes into various shapes can be performed using a cylindrical or box-shaped mold with an adhesive. The type and amount of adhesive used significantly affect the quality of the biobriquettes produced [55–58]. Adhesives can be categorized into organic, inorganic, and composite types [59].

Examples of organic adhesives include starch, asphalt, tar, paraffin, molasses, and natural gums, while inorganic adhesives include clay, cement, and sodium silicate [60]. Natural adhesives are preferred over synthetic alternatives due to their biodegradability and environmental sustainability.

Adhesives commonly used for biobriquette production include tapioca, sago flour, hibiscus extract, and crude palm oil (CPO) liquid waste. Shobar et al. [15] reported that biobriquettes made with 5% tapioca adhesive and 5% sago flour produced the best results, meeting Indonesian National Standards (SNI) for biobriquettes from areca nut husk. Yulia et al. [18] indicated that biobriquettes made from coconut shells and husks can use 10% CPO waste as an adhesive. Santoso [61] demonstrated that the optimal ratio of coconut shell charcoal to tapioca flour for producing high-quality briquettes is 5:1.

Rodiah et al. [62] also found that biobriquettes made from rice husks and coconut shells could use 2.5 grams of mango sap as adhesive for every 60 grams of material. Tapioca flour adhesive is prepared by mixing 1 gram of tapioca flour with 10 ml of water, then heating the mixture until it forms a gel [61].

### 3.6. *Printing*

Producing biobriquettes in specific sizes and shapes requires a molding tool or machine. According to Ikhsan et al. [63], molding machines come in various types and shapes. The common types include manual molding machines powered by human effort, semi-automatic molding machines such as hydraulic systems [64,65] and biobriquette molding machines with electro-pneumatic systems [63,66].

There are five types of biobriquette densification technologies and equipment: piston press densification, screw press densification, roller press densification, pelletizing, and low-pressure manual briquette pressing [67]. Okwu [68] designed and developed densification technology using a piston press. Similarly, Obi et al. [69] created a simple compression plate, while Fadeyibi and Adebayo [70] developed a briquette pressing tool using a screw press system. Wahyudi et al. [71] designed a coconut shell charcoal biobriquette pressing machine using the screw method, and Santosa and Yuliati [72] created a screw extruder machine for briquette molding.

The shape and size of biobriquettes vary depending on the molding tool used. Biobriquettes can take cylindrical (tube) shapes with or without cavities, as well as cube, oval, square, hexagonal, or block shapes [73–76]. These differences in shape can affect the combustion quality of the resulting biobriquettes.

### 3.7. *Drying*

The drying of molded biobriquettes can be conducted using two methods: sunlight drying and machine drying, such as in an oven.

#### A. *Sunlight Drying*

Sunlight drying is a traditional and natural method to reduce moisture from biomass products. This method is especially effective in areas with abundant sunlight where oven or drying equipment is unavailable. The process involves spreading the biobriquettes on a dry surface in an open area or using racks. Regular turning ensures even drying, and the duration depends on weather conditions, briquette size, and initial moisture content. Sun drying is cost-effective, natural, and environmentally friendly. Karamoy et al. [77] reported that drying biobriquettes made from sago bark and coconut shell waste for 2 days using sunlight achieved satisfactory results.

#### B. *Oven Drying*

Oven drying is a common and effective method for controlled and uniform heating. Biobriquettes are placed on trays or racks to ensure proper air circulation during drying. The temperature and drying duration are maintained consistently, depending on the desired level of moisture reduction. Oven drying provides a controlled environment, efficient and uniform drying, and flexibility in handling different sizes and quantities of biobriquettes.

Drying molded coconut husk and shell biobriquettes using an oven at 105°C for 1 hour reduces moisture content, resulting in higher calorific value and less cracking [18]. Setiawan et al. [76] found that drying coconut shell biobriquettes in an oven at 75°C, 100°C, and 125°C for 3 hours effectively reduced the moisture content to 1.88–3.44% while maintaining acceptable levels of cracking, particularly at 75°C and 100°C. The drying of areca nut husk biobriquettes was carried out using an oven at a temperature of 120 °C for 4 hours [14].

### 3.8. Biobriquette Quality

#### 3.9. Biobriquette Quality Standards

The biobriquettes produced must meet quality standards to ensure high quality, efficiency, and environmental friendliness. Adherence to these standards builds consumer confidence, enhances global market competitiveness, supports sustainable trade practices, and minimizes environmental impact. Some recognized quality standards include the Indonesian Quality Standard (SNI), Japan, the U.S., the U.K., and ASTM International. These standards assess parameters such as moisture content, ash content, volatile matter content, calorific value, and density. Table 2 provides an overview of these quality standards.

**Table 2.** Biobriquette Quality Standards

Quality Parameters	SNI 01-6235- 2000	Japan	American	English	ASTM International
Moisture content (%)	Max 8	6-8	6.2	3.6	< 20
Ash content (%)	Max 8	3-6	8.3	5.9	14-20
Volatile matter content (%)	Max 5				
Calorific value (Cal/gram)	Min 5000	6000-7000	6230	7289	>4000
Density (grams/cm <sup>3</sup> )	0.44	1-2	1	0.46	

Indonesia's coconut shell briquette charcoal exports are primarily directed to South Korea, Saudi Arabia (for shisha), Japan, China, Australia, Turkey, Malaysia, and the UAE. Export volumes increased from 325,409 tons in 2022 to 343,500 tons in 2023 [78].

#### 3.10. Moisture Content

Biobriquettes have a natural tendency to absorb moisture, making moisture content a critical parameter for determining their quality. Lower moisture content indicates better quality biobriquettes [31,15,79].

Factors influencing moisture content include the type and amount of adhesive and the raw materials used [18,28,47,80]. Higher adhesive amounts increase moisture content, making ignition more difficult and lowering combustion temperature [81]. Additionally, high moisture content can result in excessive smoke during combustion [82]. The characteristics of biobriquettes made from coconut shell with various mixtures are shown in Table 3.

**Table 3.** Characteristics of biobriquettes made from coconut shell with various mixtures.

Raw Material	Mixture	Adhesive	Composition	Particle size (mesh)	Quality		Reference
					Parameter	Value	
Cassava Peel	Tapioca		Material 80 : 20 75 : 25 70 : 30	35 mesh	Moisture content	6.71 to 7.75%	[79]
					Ash content	4.16 to 4.64%	
					Volatile matter	2.01 to 2.18%	
					Calorific Value	6709.29 to 8142.82%	
					Density	0.56 to 0.76 g/cm <sup>3</sup>	
Areca nut stem	Tapioca		Comparison of Materials 100%:0%; 100%:0%; 80%:20%; 60%:40%; 50%:50%; 40%:60%; 20%:80% 0%:100% Adhesive 10%	60 mesh	Moisture content	2.43 to 6.73%	[80]
					Ash content	3.3 to 24%	
					Calorific value	5067.59 to 7261.39	
					Density	1 – 1.26 g/cm <sup>3</sup>	
					Burning Rate	0.0335 to 0.0416 grams/minute	

Raw materials also significantly affect moisture content. Materials with higher initial moisture content yield biobriquettes with elevated moisture levels. For example, Satria et al. [28] observed that biobriquettes made from corn cobs and areca nut husks had higher moisture content when more corn cobs were used due to their higher cellulose levels.

Coconut shells and husks are noted for their low initial moisture content, which enhances the resulting biobriquettes' calorific value and burn efficiency [18]. Arifin et al. [80] reported that increasing coconut shell charcoal content decreases moisture levels, further improving calorific value. The characteristics of biobriquettes made from coconut shell with various mixtures are shown in Table 4.

### 3.11. Ash Content

Ash content significantly affects biobriquette quality. Lower ash content is preferable, as it results in higher carbon content and calorific value, making the fuel more efficient and producing less smoke [88].

Ash content is influenced by raw materials and adhesives. For example, Yulia et al. [18] found that biobriquettes using 10% crude palm oil adhesive had ash content as low as 15.66%. Similarly, Satria et al. [28] reported that biobriquettes made from areca nut husk and corn cobs, with a 90:10 ratio using tapioca adhesive, had an ash content of 3.68%.

**Table 4.** Characteristics of biobriquettes made from coconut shell with various mixtures.

Raw Material	Mixture	Adhesive	Composition	Particle size (mesh)	Quality		Reference
					Parameter	Value	
Coconut shell		Cassava flour and corn flour	5%, 10% 15%	40 60	Moisture content	5.20 to 6.36%	[83]
					Volatile matter	19.85 to 31.25%	
					Calorific value	26,790.76 to 31,509.58 kJ/kg	
	Tapioca Cassava flour Mocaf	25% adhesive 5% moisture	40	Ash content	1.71 to 2.23%	[84]	
				Volatile matter	17.25 to 21.78%		
				Density	0.9 to 1.010 g/cm <sup>3</sup>		
Rice Husk	Tapioca	30% adhesive 40% 50%	Powder size: 20 mesh 40 mesh 60 mesh	Moisture content	3.2 to 6%	[85]	
				Volatile matter	83.07 to 84.13%.		
				Density	0.4082 to 0.6396 g/cm <sup>3</sup>		
				Burning Rate	0.1238 to 0.2364 grams/minute		
Water hyacinth	Tapioca	The composition of water hyacinth and coconut shell was varied at ratios of 1:1, 1:2, 1:3, and 1:4	10 mesh 42 mesh 60 mesh	Moisture content	1,0140 to 2,4936%	[86]	
				Burning Time	0,0028 – 0,0043 gram/second		
				Calorific Value	5.102,9025 - 6.851,3311 cal/gram		
Palm Kernel	Tapioca	Material 100 : 0 75 : 25 50 : 50 25 : 75 0:100 Adhesive 6%		Moisture content	2.26 to 4.20%	[87]	
				Ash content	5.31 to 5.98%		
				Volatile matter	1.39 to 4.37%		
				Calorific Value	6869 to 6985 cal/g		

Anis et al. [84] found that the type of adhesive affects ash content; mocaf flour resulted in the highest ash content (2.23%), followed by tapioca (1.93%), and cassava flour (1.71%).

Research by Shobar et al. [15] showed that the type and amount of adhesive affect the ash content of areca nut shell biobriquettes. In this study, tapioca and sago flour adhesives were used, and it was observed that the greater the amount of sago flour adhesive added, the higher the ash content produced.

### 3.12. Calorific Value

The calorific value greatly determines the quality of briquettes and is an important factor in determining their efficiency as fuel [83,89,90]. The higher the calorific value, the better the quality of the briquettes produced [36]. The calorific value indicates the energy contained in the briquettes [21].

The high or low calorific value of a briquette depends on the moisture content, volatile matter, ash content, and carbon content [15,89,91,92]. High moisture content, volatile matter, and ash content in biobriquettes will reduce the calorific value, while a higher carbon content will increase the calorific value.

**Table 5.** Characteristics of biobriquettes made from coconut Husk with various mixtures.

Raw Material	Mixture	Adhesive	Composition	Particle size (mesh)	Quality		References
					Parameter	Value	
Coconut Husk	Shell	Crude palm oil liquid waste	Ingredients composition 50% : 50% Adhesive 10% 20% 30% 40%	60 mesh	Moisture content	3.16 to 7.29%	[18]
					Ash content	15.66 to 19.25%	
					Volatile matter	23.97 to 37.44%	
					Calorific Value	5491 to 5951 cl/gr	
					Burning Rate	0.1079 to 0.1744 g/min	
Male Flowers of guineensis	Tapioca Elaeis	50:50 60:40 40:60 Adhesive 20 25 30		60 mesh	Ash content	6.733 to 9.8333%	[51]
					Volatile matter content	58.9933 to 74.6667%	
					Calorific Value	21.6467 to 25.5667 Mj/kg	
Teak Wood Powder	Tapioca	Ingredients composition 50 : 50 60 : 40 70 : 30 Adhesive 20%		60 mesh	Moisture content	5.84 to 6.686%	[82]
					Calorific Value	5,182 to 7,607 cal/gr	
					Burning Rate	1,436 to 1,858 gr/mi	
Bitaghol Sibat (Calophyllum soulattri Burm. f.)	Tapioca stem	Ingredients Composition 100 : 0 90 : 10 80 : 20 70 : 30 0 : 100 12 gram adhesive		60 mesh	Moisture content	1.4 to 14.54%	[91]
					Ash content	13.52 to 16.53%	
					Volatile matter content	29.7 to 40.87%	
					Calorific Value	4,721 to 5,168 cal/gr	

The calorific value of biobriquettes is influenced by the ratio of raw materials used. The higher the calorific value of the raw materials, the higher the calorific value of the resulting biobriquettes. According to Mustafa and Ibrahim [93], the calorific value of biobriquettes produced from a mixture of coconut shells and cocoa shells is lower than that of biobriquettes made solely from coconut shells. Coconut shells have a calorific value of 18.30 MJ/kg, while cocoa shells have a calorific value of 17.40 MJ/kg, resulting in a calorific value of 15.92 MJ/kg for the mixture. Quaicoe, et al. [92] reported that sawdust briquettes produced the highest calorific value of 5085 kcal/kg, followed by fine charcoal particle briquettes with 4047 kcal/kg, while coconut husk biobriquettes had the lowest calorific value at 3531 kcal/kg.

The differences in calorific value can be attributed to variations in briquette properties, including residual moisture, volatile matter, fixed carbon content, and ash content. The primary factors contributing to these variations in briquette properties are the differences in the raw material/biomass characteristics and the formulation of binders, including both type and quantity. The characteristics of biobriquettes made from coconut husk with various mixtures are shown in Table 5.

The calorific value of biobriquettes is also influenced by the type and amount of adhesive used. According to Shobar et al. [15], biobriquettes made from areca nut shells using 5% tapioca adhesive and no sago adhesive have the highest calorific value. Research by Rudiyanto et al. [89] shows that the calorific value of biobriquettes made from coconut shells decreases as the concentration of cassava husk adhesive increases.

### 3.13. Volatile Matter

Volatile matter content refers to the compounds that can evaporate at high temperatures. It significantly impacts combustion properties: higher volatile matter content typically improves combustion efficiency, but it can also affect emissions. Factors influencing the volatile matter content of biobriquettes include the type of raw material, moisture content, type and amount of adhesive added, and ash content [92,94]. The characteristics of biobriquettes made from areca nut husk with various mixtures are shown in Table 6.

Yirijor et al. [83] found that the type of adhesive used, such as cornstarch or cassava flour, affects the volatile matter content in coconut shell biobriquettes. Biobriquettes made with cassava flour adhesive tend to have higher volatile content compared to those made with cornstarch adhesive. The study also indicated that increasing the amount of adhesive resulted in higher volatile matter content. Similarly, research by Anis et al. [84] revealed that different adhesives, such as tapioca, cassava flour, and mocaf flour, produce varying levels of volatile matter in coconut shell biobriquettes.

**Table 6.** Characteristics of biobriquettes made from areca nut husk with various mixtures.

Raw Material	Mixture	Adhesive	Composition	Particle size (mesh)	Quality		Reference
					Parameter	Value	
Areca Nut Husk		Tapioca glue and sago glue	Concentration Tapioca + Sago 5% + 0% 0% + 5% 3% + 2% 2.5% + 2.5% 2% + 3%	60 mesh	Moisture content	3 to 4%	[15]
					Ash content	7.90 to 13.70%	
					Volatile matter	14.20 to 23.50%	
					Calorific Value	5146.60 to 5966 cal/gr	
					Density	0.68 to 0.70 gr/cm <sup>3</sup>	
Corn Cob	Tapioca	Ingredients: 10 : 90 20 : 80 30 : 70 40 : 50 50 : 50	60 mesh	Moisture content	3.88 to 4.23%	[23]	
				Ash content	3.68 to 4.65%		
				Volatile	15.01 to 17.57%		
				Calorific Value	5,578.31 to 6,528.73 cal/gr		
				Density	0.66 to 0.72 gr/cm <sup>3</sup>		
Tofu Dregs Lemongrass	Tapioca	Ingredients Composition Tofu dregs : Areca nut husk : Lemongrass 10/90/30, 40/60/30, 50/50/30, 60/40/30, 10/90/30	100, 150, and 500µm	Moisture content	48 to 56%.	[95]	
				Density	1.10 to 1.38 g/cm <sup>3</sup>		
				Burning rate	0.55 to 0.78 g/min		
Simarouba seed shell	Black Liquor	Composition: The best treatment ingredients 60:40:00,		Moisture content	5.75%	[96]	
				Ash content	2.48%		
				Volatile matter	73.71%		
				Calorific Value	18.81 MJ/kg		

Lawal et al. [51] demonstrated that the volatile content in biobriquettes made from coconut husk and *Elaeis guineensis* male flowers increased as the concentration of coconut husk and cassava starch adhesive increased. The volatile content in these biobriquettes ranged from 58.99% to 74.66%. A similar trend was observed by Mendoza et al. [91], where the composition of coconut husk and bitanghol-sibat stems influenced the volatile content of biobriquettes, with ash content ranging from 29.7% to 40.87%. Shobar et al. [15] reported that biobriquettes made from areca nut

husk showed lower volatile content when more tapioca adhesive was added and less sago adhesive was used, likely due to differences in adhesive type and concentration. Quaicoea et al. [92] stated that higher volatile content makes biobriquettes easier to ignite. However, increased volatile content also leads to greater smoke production.

#### 3.14. Density

Density is one of the primary indicators of how compact a biomass-derived briquette fuel is. The type of raw material, the adhesive used, the pressure applied during manufacturing, and the moisture content of the material all affect the density of biobriquettes. Biobriquettes with higher densities are typically more compact, which often results in a higher calorific value. The combustion quality is also influenced by density; specifically, the higher the density of the material, the longer the combustion time. However, increased density can also make the material more difficult to burn [97].

One of the most important factors in determining the quality of biobriquettes is their density. Briquettes with higher density are more durable, less likely to break, and generally produce better heat and fire when ignited [85]. Higher-density briquettes are also less likely to separate during transportation, storage, and combustion [98]

Anis et al. [84] reported that the type of adhesive used in making biobriquettes from coconut shells, such as tapioca, cassava flour, and mocaf, affects the density. Among these, cassava flour adhesive results in the highest density, at 1.010 g/cm<sup>3</sup>. The addition of adhesive is intended to improve the physical properties of the briquettes, including increasing their density, making them denser and easier to handle.

Research by Satria et al. [28] shows that the type of raw material used in making biobriquettes also influences density. The density increases as the amount of corn cob charcoal decreases and the amount of areca nut charcoal increases. This is because corn cob briquettes have lower density compared to areca nut shell charcoal briquettes. Arifin et al. [80] also noted that the more coconut shell charcoal is added to a mixture of coconut shells and nipah fronds, the higher the density of the resulting briquettes.

Similarly, Ropiudin and Syska [79] found that both the concentration of adhesive and the type of raw material affect the density of biobriquettes made from coconut shells and cassava husk. Ali et al. [46] showed similar results, where the type and concentration of adhesives, specifically tapioca and sago starch, affected the density of coconut shell biobriquettes. The highest density (0.856 g/cm<sup>3</sup>) was achieved with 8% tapioca adhesive.

A higher density value makes biobriquettes harder to ignite, while a lower density value can cause them to burn more easily. This is because low-density briquettes contain larger air cavities,

allowing more oxygen to reach the combustion process. However, low-density briquettes tend to burn out faster due to excessive air cavities [99].

### 3.15. *Burning Rate*

The burning rate refers to the speed or length of time a biobriquette burns when ignited. Testing is done by weighing the biobriquette before and after burning to determine the mass burned per unit time. Variables that affect the burning rate include moisture content, calorific value, and density [81,95].

Sirun et al. [50] reported that the burning rate is influenced by the material's structure, bound carbon content, and hardness. Theoretically, if the volatile compound content is high, the briquette will ignite more easily and combust more rapidly.

Nandianto et al. [95] stated that high-quality biobriquettes tend to have a low burning rate, which is influenced by particle size. The finer the particle size of the biobriquette, such as those made from a mixture of areca nut husk, tofu dregs, and lemongrass, the lower the resulting burning rate, and vice versa. A low burning rate means the biobriquette will take longer to turn into ash, thus extending the combustion time. Jaswella et al. [52] reported similar findings, where the burning time was influenced by the size of the biobriquette made from coconut shells.

Research by Sirajuddin [100] showed that density affects the combustion rate of coconut shell biobriquettes. Specifically, the lower the density, the faster the combustion rate, making the biobriquettes easier to burn. This was also highlighted by Iriani et al. [86], who demonstrated that biobriquettes made from a mixture of coconut shells and water hyacinth, with varying particle sizes, exhibited combustion rates influenced by briquette density. Higher-density biobriquettes exhibited lower combustion rates, resulting in longer burning times. This is because the smaller air cavities within the briquettes restrict the flow of oxygen during combustion. Biobriquettes with a 1:4 ratio of water hyacinth to coconut shells, processed at a 60 mesh particle size, demonstrated the lowest combustion rate, measured at 0.0029 g/second.

Yulia et al. [18] reported that biobriquettes made from a mixture of coconut shells and coconut husk, using crude palm oil liquid waste as an adhesive, produced combustion rates ranging from 0.1079 to 0.174 g/minute. The lowest combustion rate occurred at a ratio of 10% adhesive and 90% material, while the highest combustion rate was observed at a ratio of 40% adhesive and 60% material. The combustion rate of biobriquettes is directly proportional to the percentage of adhesive used. This is in line with the findings of Ramdani et al. [97] who demonstrated that a higher adhesive composition increases the moisture content of the briquettes. As a result, more moisture evaporates during combustion, causing the briquettes to lose mass quickly and burn faster.

#### 4. Conclusions

This review demonstrated that by-products from areca nut and coconut processing, particularly coconut shell, coconut husk, and areca nut husk, have considerable potential to be utilized as environmentally friendly biobriquettes. These biomasses are abundant, renewable, and characterized by high lignocellulosic content, especially lignin, which plays a crucial role in enhancing calorific value, mechanical strength, and combustion performance. Among the reviewed materials, coconut shell exhibits the most favorable properties for biobriquette production, followed by areca nut husk, while coconut husk is more suitable as a blending material. The literature indicates that optimal carbonization conditions are generally achieved at 400–500 °C for coconut shell and around 300 °C for coconut husk and areca nut husk, resulting in biochar with reduced moisture, ash, and volatile matter contents and, consequently, improved energy characteristics.

Future research should be directed toward experimental optimization of biomass composition, including blending ratios, binder selection, and compaction parameters, to further enhance biobriquette quality and performance. In addition, comprehensive studies on combustion behavior, emission characteristics, and thermal efficiency in domestic and industrial applications are required. Techno-economic analysis and life cycle assessment are also essential to evaluate the feasibility and environmental impacts of large-scale implementation. Ongoing and future experimental work may further explore the integration of areca nut and coconut-based biobriquettes into sustainable local energy systems as viable alternatives to conventional fossil fuels.

#### Abbreviations

Not applicable.

#### Data availability Statement

Data will be shared upon request by the readers.

#### CRedit Authorship Contribution Statement

**Ade Yulia:** Conceptualization, Methodology, Resources, Formal analysis, Investigation, Data curation, Funding acquisition, Writing – review & editing. **Dompak MT Napitupulu, Sahrial,** and **Addion Nizori:** Conceptualization, Supervision, Data curation, Writing – original draft, and Formal analysis.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Declaration of Use of AI in the Writing Process

Nothing to disclose.

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