The scale **Journal Website:** https://thescalejournal.com.ng/
An Interdisciplinary Journal of
The ACADEMIC STAFF UNION OF POLYTECHNICS - ZONE D
ISSN: 2992-3727 Published 25th May, 2025

PRODUCTION OF ZERO EMISSION ENERGY USING PYROLYSED BIOMASS BRIQUETTE

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Abstract

The increasing global demand for energy, coupled with rising concerns about climate change, necessitates the development of sustainable and zero-emission energy solutions. This project investigates the production of zero-emission energy using pyrolysed biomass briquettes. This project utilized agricultural residues as a potential renewable energy system by converting them into a useful clean solid fuel. The thermo-chemical conversion of the biomass (agricultural residue) under oxygen-controlled conditions to produce bio char has been seen to be one major way of managing these residues. Using a locally designed pyrolysis system, four different bio char samples were produced from the agricultural residues, namely palm nut shells, bagasse, corn cobs and sawdust. From the analysis conducted on these different agricultural waste samples, they were found to contain appreciable amounts of soil nutrients such as phosphorus, potassium, magnesium, calcium and sodium in the form of ash, which are very essential for plant growth. However, a large percentage of the agro waste was given off in the process as volatiles. These volatiles could be collected for other purposes and studies. The project evaluates the char yield, volatile yield, ash content, porosity, pH level and cost-effectiveness of the pyrolysed biomass briquettes. Results indicate that the residue can be pyrolysed into a bio char with significantly reduced greenhouse gas emissions, making it a promising zero-emission energy solution, potential energy source for boilers and electricity generation.

Keywords: zero-emission energy, pyrolysis, biomass, briquettes, climate change.

1. Introduction

Non-renewable energy sources based on fossil fuels such as petroleum, natural gas, coal, etc. presently remain the most widely used sources of electricity generation. Study on the reserves of the world fossil fuel has revealed a probable decrease and eventual total depletion of hydrocarbon production (Cavallo, 2004; Agbontalor, 2007; Funahashi & Urata, 2008). Despite the global call for a switch to greener and sustainable energy sources, fossil fuels still provide over 80 % of the world energy usage (Pike, 2016). The high cost of fossil fuels and their attendant environmental effects such as global climate changes, environmental pollution and the emissions of greenhouse gases have resulted in research and development of alternative energy sources (Oladeji, 2012; Jarman, Khalil and Khalaf, 2013; Ben-Iwo *et al*. 2016; Energy, 2017). These alternative energy sources include solar power (photovoltaic), wind power, biofuels (biomass), geothermal, nuclear power and thermoelectrics. Biomass amongst these promising renewable energy sources have received significant attention.

Biomass is a renewable organic material derived from both plants and animals (Ben-Iwo et al. 2016; Ugwu *et al*. 2020). It is reliable, sustainable and less harmful to the environment when compared to some other sources like coal and crude oil (Oladeji, 2015). Biomass resources include various natural and derived materials, such as woody and herbaceous species, wood wastes, bagasse, agricultural and industrial residues (Agbro & Ogie, 2012). Biomass can be applied or utilized greatly in three major ways, viz; for heating or cooling, electricity generation and as a transportation fuel (Carneiro & Ferreira 2012).

ISSN: 2992-3727 Published 25th May, 2025

1.1. Agro waste sources

The fertility of Nigerian soil has given hope for the availability and affordability of agricultural wastes required for the production of energy to serve as alternatives to fossil fuels. Agricultural residues have been reported to be a large and an underexploited energy resource, almost always underestimated (Rosillo-Calle, 2007). Therefore, agricultural and forestry residues offer much potential for renewable energy sources in form of biomass. With advances in biotechnology and bioengineering, some resources, which could have been classified as waste, now form the basis for energy production.

Jekayinfa et al. (2020), noted that a significant portion of the entire Nigeria's land mass of about 77.8% is available for biomass energy production. Thus, Nigeria can boast of about 144 million tons in biomass potential annually (Shaaban & Petinrin, 2017). These large quantities of agricultural residues produced in Nigeria can play a significant role in meeting her energy demand. Regrettably, these wastes are underutilized and poorly managed. Agricultural residues have lower density, higher moisture content and lower energy density. Moreover, the low bulk density and dusty characteristics of the biomass can cause problems in transportation, handling and storage (Husan, *et al*., 2002). Therefore, there is the need to transform residues into forms that will make their combustion easy and more efficient. Table 1 shows the most common agro waste sources in Nigeria.

Therefore, the aim of this research is to blend biomass briquette with paraffin wax to obtain a higher energy solid fuel suitable for electricity and heat steams generation for both home and industrial use. Paraffin wax (or simply paraffin) is a white or colorless, odorless, and tasteless solid wax derived from petroleum. It is a complex mixture of hydrocarbons primarily consisting or saturated hydrocarbons and naphthenic hydrocarbons (Speight, 2019). Paraffin is characterized by its relative low melting temperature (45 – 65 ^{o}C), a typical viscosity of 3-5 mm^2/S at 100 ^{o}C, a density range of 0.9 – 0.92 g/cm^2, insoluble in water and soluble in organic solvents such as ether and benzene.

Table 1: Some agricultural products and estimated wastes generated in Nigeria in 2001 (Adebayor et al, 2002).

CROP	AGRICULTURAL PRODUCTION (MILLION TONS)	AGRICULTURAL WASTE GENERATED (%)	AGRICULTURAL WASTE GENERATED (MILLION TONS)
Maize	6.69	15.8	1.06
Rice	3.99	30.0	1.20
Groundnut	2.40	30.2	0.72
Sugarcane	0.73	15.0	0.11

ISSN: 2992-3727 Published 25th May, 2025

1.2. Biomass Briquettes and Pyrolysis

Briquettes are generally 50-80 mm diameter and 150 mm length sawdust cylinders compacted at a high heat, with a moisture content ranging between 10 to 20% (Ichu, 2020). According to Ichu (2020) briquette is a densified biofuel made with or without additives, having a cubic, prismatic or cylindrical shape, with a 25 mm diameter, produced from woody biomass compression or crushed herb. Biomass briquettes as a renewable energy source are made from agricultural waste and are a potential replacement for fossil fuels such as oil or coal, and can be used to heat boilers in manufacturing plants.

The thermal conversion process that leads to the decomposition of biomass materials is known as pyrolysis. It involves the application of pressure at a temperature range of 350 to 550 °C in the absence of oxygen (Ugwu *et al*, 2021). Generally, Pyrolysis is a thermo-chemical process employed in the breakdown of organic materials into chemical and energy products (Demirbas, 2009).

Therefore, pyrolysis of biomass produces three basic fractions or products, namely; solid fraction in the form of ash, liquid fraction in the form of bio-oil and the gaseous fraction (Ben-Iwo *et al*., 2016; Girard, *et al*., 2005; Pro-Natural International, 2004). According to Bridgewater (2003), pyrolysis can be classified into three categories, viz; slow, fast and flash pyrolysis.

2. Materials and Methods

2.1. Equipment

The equipment used were suitably sized waste bag for waste collection, waterproof materials with wide surface areas (for sun-drying of waste), Barnstead International Furnace (Model: FD1530M), a crushing device, char storage bin, thermometer, digital electronic balance, pH meter, oven, timer, beaker and stirrer.

2.2. Materials

The following Agro waste samples were used: bagasse*,* corn cobs*,* palm nut shells *and* saw dust.

2.3. Methods

It involves production and characterization of the char; and the production of briquette.

2.3.1. Procedure for Char Production

i. Biomass collection and preparation

The agro waste samples were collected from different locations at appropriate time ensuring a steady supply of the raw materials to the pyrolysis unit. The collected samples were dried in the sun for three days in order to remove adsorbed moisture. After the sun drying, the samples were crushed and properly mixed to obtain a homogeneous mix.

ii. Biomass carbonization

It involves the thermal conversion process known as pyrolysis. Here, two methods of pyrolysis, namely; slow and fast pyrolysis were utilized.

The slow pyrolysis is a traditional method of pyrolysis and it involves applying heat across a surface into a bed containing the material to be pyrolyzed. The major product of interest is the char; therefore, no design was made in the incineration vessel to trap the gaseous products while the operating temperature was maintained at 360 ^{o}C for an hour.

In fast pyrolysis, the intention is to expose larger surface area of the biomass from the start of the carbonization over a shorter period of time, to higher values of temperature than slow pyrolysis, typically around 500 ^{o}C. Thus, a relatively flat and wide metal plate was as the heat transfer surface. The biomass was placed in the carbonization chamber as a relatively thin layer of material on the heat transfer surface and charred for a about 10-15 minutes at the fixed temperature. After charring, the products (char, syngas and

ISSN: 2992-3727 Published 25th May, 2025

liquids) were air cooled and measurements were taken before storage. The operating conditions for the fast pyrolysis include a furnace temperature (500 °C), a plate thickness (0.35 cm), a layer thickness (0.30 cm) and a particle size of 0.03 cm.

2.3.2. Characterization of Char

i. pH Measurement

2.5 g of sample produced was weighed out and dissolved in 50 ml of distilled water. The resulted mixture was heated and stirred adequately for some minutes to ensure proper dilution of the sample. The clear solution was filtered and its pH was determined using the digital pH meter.

ii. Particle Size Determination

The char sample was weighed and placed on top of a set of sieves with different aperture sizes stacked in a mechanical sieve shaker. It was shaken with a sieve shaker for 2 minutes, after which the weight percent of the activated carbon retained on the sieve was determined

iii. Bulk Density Test

The bulk density of the sample was determined using Archimedes method.
10 g of sample was measured and weighed using a digital electronic balance. It was then transferred into a 50 ml of distilled water using a measuring cylinder. The volume of the water displaced was recorded and the bulk density was calculated by dividing the mass of the sample by the volume of water displaced (Aneke & Okafor, 2005).

iv. Moisture Content

2.0 g of sample A was dried in an oven for four hours at 150 °C, until its weight became constant and the moisture content was determined using the following equation:

$$x = 10 - \frac{w_1 - w_2}{w_1} * 100$$

where, x is the moisture content on weight percentage basis, w_1(g) is the initial weight of sample before drying, and w_2 (g) is the final weight of sample after drying.

v. Ash Content Measurement

2.0 g of sample A was ignited in a Bunsen flame and cooled in a desiccator. It was transferred into a crucible of constant weight and heated to 900°C for 3 hours in a muffle furnace and cooled to room temperature. The weight of the cooled sample A was recorded. The ash content for this sample was determined by dividing the weight difference by the initial mass of sample A used.

vi. Pore Volume and Porosity Test

2.0 g sample A was weighed and transferred into a measuring cylinder in order to get the total volume of the particle. This sample was further poured into a beaker containing 20 ml of distilled water and was boiled for 5 mins (to displace air in the sample). The content in this beaker was filtered, superficially dried, and weighed. The increase in weight of the sample divided by the density of water gave the pore volume for sample A. The porosity was calculated by dividing the pore volume of the particle with total volume of the particle.

2.3.3. Determination of Heats of Combustion of the Char Material

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In order to predict the final heating value of the briquette, the heats of combustion of all the individual components starting with the char as the major component was determined. The following summarized steps were utilized:

- The calorimeter was turned on, followed by accurate weighing of three pellets of benzoic acid not exceeding 1 g.
- One of the pellets was placed in the stainless-steel cup and attached was one strand of cotton string to the wire connecting the electrodes. It was ascertained that the string touches the sample while the ignition wire was attached firmly to the electrodes.
- The bomb was filled with oxygen, allowing the pressure to build up slowly to 25 atm. The bomb was purged twice with pure oxygen. The ignition head was connected to the top of the bomb while it was closed via tighten down the cap by the use of hand only. Thereafter, the bomb was then put into the calorimeter and centered.
- The calorimeter was filled with tap water and temperature readings were taken every 30 seconds for 2 minutes before igniting the bomb. Upon igniting the bomb, a delay of about 10-15 seconds was observed before a temperature rise began. Hence, a temperature of the calorimeter was measured every 15 seconds for 3 minutes.
- When the temperature began to level off, temperature readings were taken every 30 seconds for another 2 minutes.
- Thereafter, the lid was opened, the water drained, and the bomb was removed. The pressure in the bomb was released and opened to ensure that no sample was left. Consequently, it was washed and dried.
- Three samples of the benzoic acid standard, two char samples, and two wax samples were combusted. For each combustion carried out, the temperature changes were measured.

2.3.4. Production of Briquette

The production of solid briquettes involved using a version of the ram and piston method. A starch solution was prepared using a hot water and was used as a binder. The starch solution and the melted wax were mixed in the hot water solution. Consequently, the char was added to the starch-wax solution and mixed vigorously to form a homogeneous phase (briquette). A deflocculant or accelerant (sodium nitrate) was added to the mix to facilitate the ability of the briquette to combust itself.

The molten briquette mix was then poured into a prepared mould (Figure 1) and compacted. It was later removed and allowed to dry in the sun.

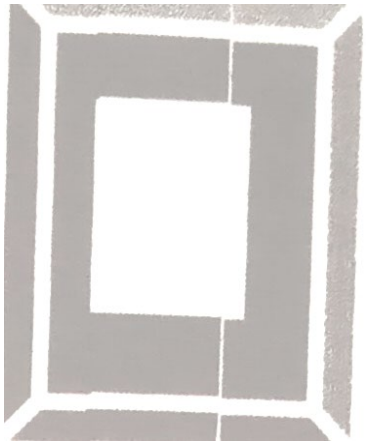


Figure 1. The Briquette mould

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3. Results and Discussion

3.1. Result of Agro Waste Collection and Preparation

Table 2 shows the results of the four Agro waste samples used in the research.

Table 2. Results of the collected and prepared Agro waste samples

Agro waste	Mass (Kg)		Moisture content (%)
	Wet basis	Dry basis	
Bagasse	10	9.25	7.5
Corn cobs	10	9.47	5.3
Palm nut shell	10	9.83	1.7
Saw dust	10	9.79	2.1

3.2. Characterization of Char from Agro samples

The characteristics (char yield, volatile yield, ash content, porosity. pH) of the Char made from the slow and fast pyrolysis of the four Agro samples are presented in Tables 3 and 4. The results from the combustion of the char from the two methods of pyrolysis used in this study are given in Table 5.

Table 3. Characterization of products of Slow Pyrolysis

Agro Waste Samples	Char Yield (%)	Volatile Yield (%)	Ash Content (%)	Porosity	pH
Bagasse	28	64	7.5	0.327	7.1
Palm Nut Shell	33	54	12	0.33	7.2
Corn Cob	26	66	8	0.319	6.8
Saw Dust	29	67	4	0.325	6.8

Table 4. Characterization of products of Fast Pyrolysis

Agro Waste Samples	Char Yield (%)	Volatile Yield (%)	Ash Content (%)	Porosity	pH
Bagasse	15	77	8	0.33	6.91
Palm Nut Shell	27	66	7	0.3308	6.98
Corn Cob	13	79	8	0.320	9.97
Saw Dust	17	79	7	0.3305	6.9

As shown in Table 3, slow pyrolysis results in a higher amount of Char thereby producing Char with higher heating value. Also, greater bulk of the products of any type of pyrolysis, be it slow or fast are in the volatile phase as evidenced in Tables 3 and 4.

Table 5. Heat of Combustion of Char

Process Type	Average Char Yield%	HHV (m)/kg) of Char
Slow	29	33.8
Fast	19	32.79

The heats of combustion of Char are dependent on the method used in its production (Table 5). The higher the carbonization temperature, the higher the amount of carbon present in the char and therefore, less of other less combustible components.

4. Conclusion

Investigation into the production of zero-emission energy using pyrolysed biomass briquettes was carried out. The project utilized agricultural residues as a potential renewable energy system by converting them into a useful clean solid fuel. The following major deductions were made from the study:

1. Slow pyrolysis results in a higher amount of Char (Table 3) thereby producing Char with higher heating value
2. High temperature carbonization produces the highest quality of Char for fuel needs
3. The greater bulk of the products of any type of pyrolysis are in the volatile phase as evidenced in Tables 3 and 4. Therefore, a further research into collection and separation methods of these volatiles is required.
4. The heat content of briquettes can be easily altered by changing the ratio of Char to paraffin wax in the mould in order to yield better results.

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