BIOMASS AVAILABILITY AND ITS POTENTIAL FOR SUSTAINABLE GREEN ENERGY PRODUCTION AND UTILIZATION IN NIGER STATE, NIGERIA

Aminu, A., Aliyu, M., Mohammed, I. S., Daniel, P. Shehu, A., Umar, S.
E-mail – abdulkarimbo22@gmail.com; +2347033179380

ABSTRACT

Biomass has gained an essential role in the last decades as renewable energy feedstock due to energy, economic and environmental concerns. Sources of biomass can be from primary and secondary sources. Primary sources include plant materials, such as wood and crops, while the secondary sources comprised waste materials; these include plant or animal residues. The biomass materials available mostly in abundance in Niger State are rice husk and groundnut shell, to the extent they are being left or dump, sometimes in heap format, in some places they are subjected to burning, which has environmental impact. Also, fossil fuels reserves are finite and non-renewable. Depending on the method of conversion used, the available residues can be utilized for production of environmentally friendly energy that is sustainable in nature. This paper focused on determining the quantity of rice husk and groundnut shell available for utilization for energy production in Niger State, the amount of energy that can be obtained from the available rice husk and groundnut shell, various techniques or technological processes for converting these resources, as well as the cost of conversion process. The projected quantity of rice husk and groundnut shell in Niger State is 7172.41 and 3575.495 tons/annum respectively. The projected amount of energy that can be obtained from the available biomass is 128370724.1 MJ/annum. The various technological processes feasible for converting these residues are combustion, torrefaction, pyrolysis, gasification and hydrothermal carbonization. The estimated cost for installing a mini pyrolysis reactor is seven hundred and fifty-five thousand naira (N755,000).

Keywords: *Biomass, availability, potential, green energy, production, utilization*

1.0 INTRODUCTION

Biomass has gained an essential role in the last decades as renewable energy feedstock due to energy, economic and environmental concerns (Lucio et al., 2022). Nowadays, biomasses have a leading role in the definition of sustainable consumption strategies since they can be used in a wide range of applications involving energy production, carbon sequestration, and environmental remediation (Elena et al., 2022). Biomass has great potential to reduce carbon emissions due to its ability to absorb CO_2 in the atmosphere through photosynthesis. (Elena et al., 2022).

Sources of biomass can be from primary and secondary sources. Primary sources include plant materials, such as wood, crops, fruits, maize, sugar cane, etc., while the secondary sources comprised waste materials, these include plant residues (agricultural and forestry residues), fish and animal waste (manure, fish heads and abattoir waste etc.), industrial waste (waste from the beer-brewing industry, waste from food processing industry, paper mill sludge etc.) and sewage (CRSES, 2018). Among the various sources of biomass, biomass from crop residue is the most readily available globally, for utilization for energy production, as shown in table 1 from Salem, 2022. Nigeria has substantial biomass potential of about 144 million tons per year. Most Nigerians, especially rural dwellers, use biomass and waste from wood, charcoal, and animal dung, to meet their energy needs. Biomass (comprising crop residues, manure, charcoal, and wood) accounts for about 80% of the total primary energy consumed in Nigeria (Juliet, 2016).

Table 1: Major Agricultural Residue Available Globally

Agric Wastes	Quantity (Million Tons)
Wheat straw	354.34
Rice straw	731.3
Corn Stover	128.02
Sugarcane bagasse	180.73

Source: Salem (2022).

Agricultural residues are organic materials produced as by product in the course of harvesting and processing agricultural crops. They are classified into two categories: crop residues (materials left or burnt on farms after the harvest of desired crops), and agricultural industrial by-product (materials produced after crop processing). Crop residues produced during harvest are primary or field-based residues while those produced alongside the product at time of processing are secondary or process-based residues (Juliet et al., 2016). The Table 2 below shows the available crop residues available in Nigeria. From which Niger state has reasonable percentage of these residues produced in Nigeria. Fossil fuel reserves are non-renewable and finite. Several researchers report clear indications of depleting fossil fuel resources. According to estimates, the global recoverable oil reserves are diminishing at a rate of 4 billion tons per annum (Salem, 2022). Also, disposal of crop residues is thing of concern in Nigeria, particularly in Niger State. These problems can be greatly reduced if the residues can be utilized as a source of an environmentally friendly energy (solid fuel and biogas).

Depending on the method of conversion used, these residues can be utilized for production of environmentally friendly energy that is sustainable in nature. This paper focused on determining the available biomass for utilization for energy production in Niger State, the amount of energy that can be obtain from the available biomass in the state, various techniques or technological process of converting these residues, as well as the expected cost of the conversion process.

Table 2: Estimated Agricultural Crop Residues for Major Crops Grown in Nigeria

Crop	Production (x103t)	Residue type	Total residue (Million tons)
Rice	3368.24	Straw	7.86
		Husk	1.19
Maize	7676.85	Stalk	15.35
		Cob	2.1
		Husk	1.54
Cassava	42533.17	Stalks	85.07
		Peelings	127.6
Groundnut	3799.25	Shells	1.81
		Straw	8.74
Soybean	365.06	Straw	0.91
		Pods	0.37
Sugarcane	481.51	Bagasse	0.14
		Tops/leaves	0.14
Cotton	602.44	Stalks	2.25
Millet	5170.45	Straw	9.05
Sorghum	7140.96	Straw	8.93
Cowpea	3368.24	Shell	9.77

Source: Juliet et al. (2016).

2.0 BIOMASS AVAILABILITY IN NIGER STATE

Figure 1: Nigerian Map Showing the Various States of the Country

Figure 2: Map of Niger State

Niger State is located between latitude 8°201 and 11°, 31 and longitude 3°,301 and 7°,201. It has 25 Local Governments, and agricultural activities form the major occupation of the people because about 80% of the population engaged in farming either directly or indirectly. The State experiences two distinct seasons, rainy season which spans between May and November and the dry season between December and April. The annual rainfall is about 1600mm with highest temperature hovering over 340°C. Three major soil types can be found in the state, ferruginous tropical soil, hydromorphic soil and ferrosol. The most predominant soil type is the ferruginous tropical types which are ideal for the cultivation of guinea corn, maize, millet, rice and groundnut (Adeoye et al., 2011). This is a clear indication that Niger state has abundance quantity of crop residue. However, the paper will be limited to two crop residues, (i.e., rice husk and groundnut shell) reason being that these residues is being left or dumb, sometimes in heap format, as shown in plate 1, 2 and 3 below. According to Adeoye et al. (2011) in some places, they are subjected to burning. Burning, apart from its bad environmental effect of depleting oxone layer, is also harmful for soil micro- organisms. It may also pose health hazard to the nearby villagers that inhale the smoke from this combustion process.

Plate 1 and 2: Groundnut Shell Heap in Mariga and Mokwa Towns

Plate 3: Rice Husk Heap in Doko Village

2.1 Rice Husk Availability in Niger State

Niger state has over the years, remained a leading contributor to agricultural productivity in the country at the regional, and state levels, being a major hub with vast production acreage make it the third among rice producing states of the nation (Merem et al., 2017). This indicates the availability of abundance rice husk in the state. As reported by Wakatuntu et al. (2023), rice husk is potential bio-oil precursor, they can also be used to improve soil fertility after being charred, and it can also be used for production of ethanol, biogas, fuel briquettes as well as direct combustion.

The projected quantity of rice husk in Niger State can be achieved with the aid of data obtained from Adeoye et al. (2011) shown in the Table 3 below. The projected quantity of the rice husk for each of the three zones (zones A, B and C) that constitute Niger State was determined first, then later added together to arrive at the projected quantity of rice husk in the state.

This was done by finding the average of the calculated quantity of rice husk from the four treated Local Government Areas in the research work, then multiplying by the number of the LGAs in the zone. Thus, the projected quantity of rice husk in Niger State can be as 3943.28, 1873.89 and 1355.24 tons for zones A, B and C respectively, which leads to the total project quantity of rice husk to be equals to 7172.41 tons/annum, as shown in Table 3 below.

Table 3: Estimated Crop Waste Produced based on Calculation for Rice

Local Govt.	Grain-Straw-Husk-ratio	Total Crop Output (Ton)	Total Crop Waste (Ton)
Zone A			
Edati	1.34:1	613	457.46
Bida	1.34:1	710	529.85
Gbaiko	1.34:1	654	488.06
Lavun	1.34:1	665	496.27
Average Waste			492.91
Total Waste			492.91 X 8 = 3943.28
Zone B			
Bosso	1.34:1	239	178.36
Munyan	1.34:1	278	207.46
Shiroro	1.34:1	298	222.39
Paiko	1.34:1	301	224.63
Average Waste			208.21
Total Waste			208.21 X 9 = 1873.89
Zone C			
Kontagora	1.34:1	187	139.55
Kagara	1.34:1	202	150.75
Magama	1.34:1	215	160.45
Wushishi	1.34:1	304	226.87
Average Waste			169.405
Total Waste			169.405 X 8 = 1355.24
Grand Total			7172.41tons/annum

Source: Adeoye et al. (2011).

2.2 Availability of Groundnut Shell in Niger State

Groundnuts are widely grown in West Africa but the crop thrives best in the thickly populated area of Savannah zone. In Nigeria the crop is grown mainly in Kano State, but also cultivate in Sokoto, Borno, Kaduna, Katsina and Niger States (Ndanitsa et al., 2013). Being Niger State one of the leading states in groundnut production, indicates the availability of groundnut shell in abundance, in the state.

Groundnut shells account for approximately 20% of the dried peanut pod by weight, meaning there is a significant amount of shell residual left after groundnut processing. Increased groundnut production leads to the accumulation of these groundnut shells which is not utilized, thus either burnt or buried. As groundnut shells are rich in many functional compounds and composed of cellulose, hemicelluloses and lignin, it can be utilized in multiple ways. Groundnut shells can be converted in various bio-products such as biodiesel, bioethanol, solid fuels etc. (FAO, 2019).

The projected quantity of available groundnut shell in the Niger State was obtained using data obtained from Adeoye et al. (2011) shown in the Table 4 shown below. After following same procedure as above, the quantity of groundnut shells in the various zones of Niger has been found to be 999.32, 814.275 and 1761.9 tons for zone A, B and C respectively. This leads to the obtaining of total amount of groundnut shells in Niger State to be equals to 3575.495tons/annum.

Table 4: Estimated Crop Waste Produced based on Calculation for Groundnut

Local Govt.	Grain-Straw-Husk-ratio	Total Crop Output (Ton)	Total Crop Waste (Ton)
Zone A			
Edati	2.94:1	349	118.71
Bida	2.94:1	332	112.93
Gbaiko	2.94:1	387	131.63
Lavun	2.94:1	401	136.39
Average Waste			124.915
Total Waste			124.915 x 8 = 999.32
Zone B			
Bosso	2.94:1	236	80.27
Munyan	2.94:1	218	74.15
Shiroro	2.94:1	312	106.12
Paiko	2.94:1	298	101.36
Average Waste			90.475
Total Waste			90.475 x 9 = 814.275
Zone C			
Kontagora	2.94:1	736	250.34
Kagara	2.94:1	675	229.59
Magama	2.94:1	612	208.16
Wushishi	2.94:1	567	192.86
Average Waste			220.2375
Total Waste			220.2375 x 8 = 1761.9
Grand Total			3575.495tons/annum

Source: Adeoye et al. (2011)

3.0 BIOMASS CONVERSION TO BIOFUELS

Biomass conversion is the key step to produce biofuels form biomass. Biomass conversion is often accomplished either through biochemical or thermochemical methods, the Figure 3 below shows the typical flow diagram of biomass conversion.

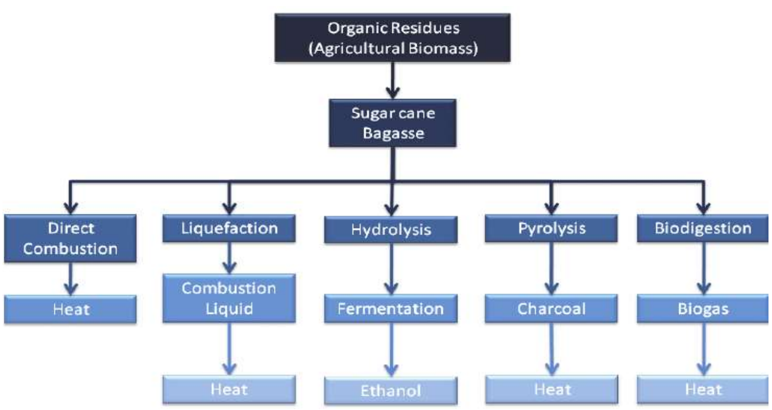


Figure 3: Flow diagram of biomass conversion to biofuels.

3.1 Various Technologies for Conversion of the Available to Biofuels

Popular available biomass conversion technologies are defined in terms of the use of resources, reduced environmental impacts, climate change and economic feasibility (Salem, 2022). Currently, several techniques are available for the production of biochar; however, depending upon the type of feedstock (wet or dry) and the desired properties of biochar for its different applications, the choice of pretreatment method(s) is very limited. As per definition, under all the thermal pre-treatments, biochar is generally produced by heating biomass at high temperature in the absence or limited supply of oxygen (Kombo and Dutta, 2015). The available technologies for converting biomass to biofuels include thermochemical processes (such as combustion, torrefaction, pyrolysis, liquefaction, gasification and hydrothermal carbonization processes) and non-thermal process (such as anaerobic digestion).

Combustion process

Agriculture biomass is directly combustible in the presence of air, and produces heat and light. It is reported that more than 96% of the global energy is generated via direct combustion of biomass. Energy produced from the direct combustion of biomass is mainly used in domestic cooking and heating (Salem, 2022). In small-scale applications, such as domestic cooking appliances, it can be very inefficient, with heat transfer losses of 30 - 90%. This problem can be addressed through the use of more efficient stove technology (Lohri et al., 2015). Suriya et al. (2019) conduct an experimental combustion work using rice husk as a fuel in a rectangular fluidized-bed combustor, the percent excess air of 40 – 70% was obtained. Also, the Figure 4 below indicates how biomass can be utilized by direct combustion to generate electricity.

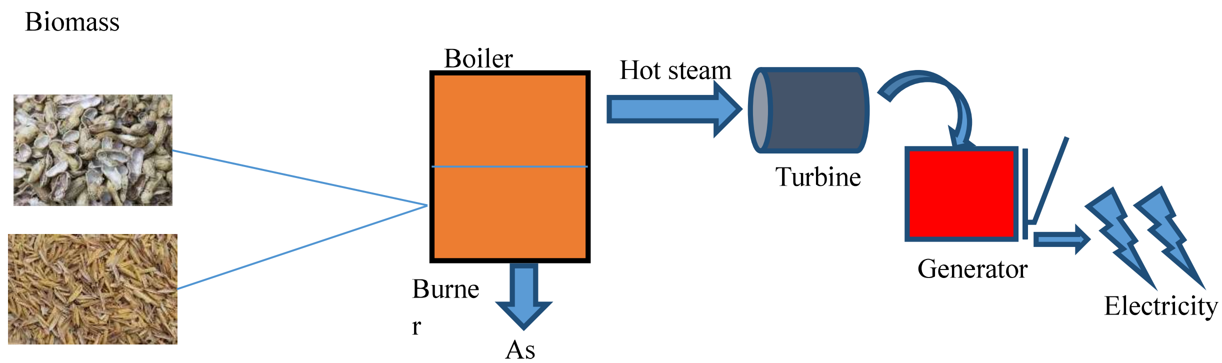
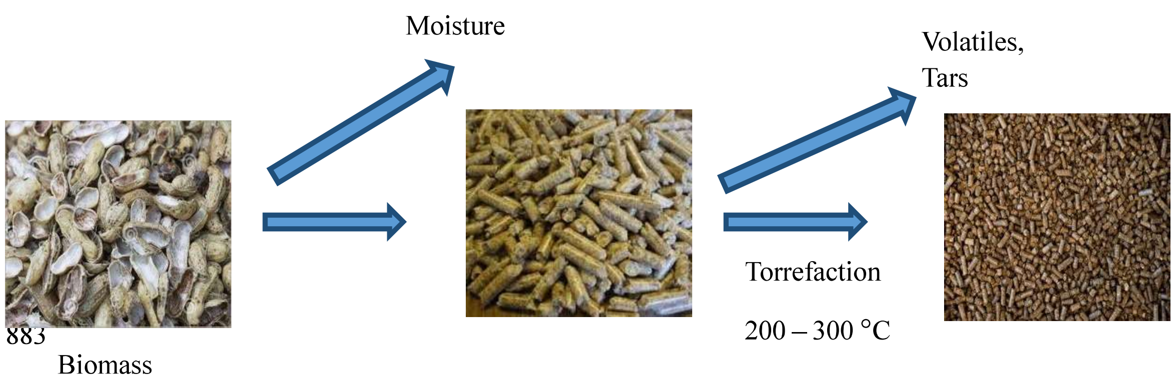


Figure 4: Power Plant Set-up Utilizing Agricultural Biomass

Torrefaction process

Torrefaction, also referred to as mild pyrolysis, is a process during which biomass is heated in an inert atmosphere at temperatures of about 200 – 300 °C for residence times of 30min to a couple of hours (Kambo and Dutta, 2015). Biomass torrefaction has been recognized as a technically feasible method for converting raw biomass into high-energy-density, hydrophobic, compactable, grindable, and lower oxygen-to-carbon (O/C) ratio solid that is suitable for commercial and residential combustion and gasification applications (Tumuluru et al., 2011). Besides improving physical attributes, torrefaction also results in significant change in proximate and ultimate composition of the biomass and makes it more suitable for fuel applications (Tumuluru et al., 2011).



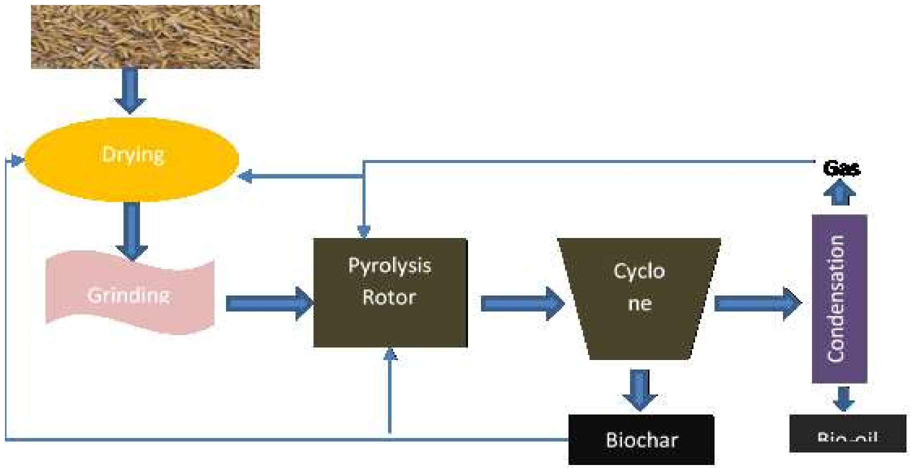


Figure 5: Typical Process Diagram of Torrefaction

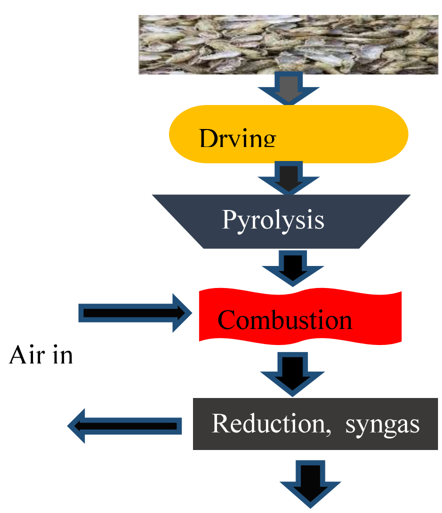
Pyrolysis

Pyrolysis is a thermochemical decomposition process during which biomass is heated at elevated temperature (300–650 °C) in the absence of oxygen. The process results in the formation of three main products: carbon-rich solid product (biochar), a volatile matter which can further be partially condensed to liquid phase (bio-oil), and the remaining so-called "non-condensable" gases, like CO, CO_2, CH_4, and H_2 (Kambo and Dutta, 2015). Depending on the operating conditions, pyrolysis processes can be further divided into two main subclasses: slow (or conventional) pyrolysis and fast (also including flash) pyrolysis (Lohri et al., 2015). Figure 6 below shows the process diagram of pyrolysis as thermochemical process.

Figure 6: Process diagram of Pyrolysis

Gasification process

Gasification was found to be a robust process, which converts biomass into a combustible gaseous mixture mainly containing hydrogen, carbon monoxide, carbon dioxide and methane (Salem, 2022). Gasification is a process of partial combustion of biomass at a very high temperature range (600 – 1200



°C) for short residence time (10– 20s) The primary product of gasification is a mixture of gases (CO, H2, and CO_2), also referred to as Syngas (Synthetic gas) or producer gas and is itself a fuel (Kambo and Dutta, 2015). The Figure 7 below indicates how typical gasifier operate.

.Syngas

Ash

Figure 7: Down-draft style Gasifier

Hydrothermal carbonization

Hydrothermal carbonization (HTC), also referred to as wet torrefaction, is a thermochemical process of converting organic feedstock in to a high carbon rich solid product. Hydrothermal carbonization (HTC) is an attractive method for the conversion of lignocellulosic biomass (e.g., wood, straw and rice husk) into valuable carbon materials (hydrochar) in water at elevated temperatures and pressures (generally subcritical water). Biomass derived hydrochar can be applied in many fields, such as catalysis, adsorption, and energy storage (Shijie Yu et al., 2022). HTC is performed at the temperature range of 180 – 260 °C during which biomass is submerged in water and is heated in a confined system under pressure (2–6 MPa) for 5–240 min (Kambo and Dutta, 2015). The Figure 8 below shows the material obtained when biomass subjected to hydrothermal carbonization.

Figure 8: Hydrothermal Carbonization Process

Anaerobic digestion process

In anaerobic digestion process, microorganisms decompose biomass in an oxygen deficient environment. Studies reported the feasibility of this process, technically as well as economically, which reduces the dependency on costly chemicals, special enzymes and expensive equipment. Biogas production was demonstrated at a pilot scale digester utilizing agriculture crop residues. It was found that digestion was stable below 11 °C. Maximum net energy was produced at 30 °C, while keeping a loading rate of 3.3 kg VS/m^3 day. The process was found to be cost economical and produced an optimal quantity of methane (Salem, 2022). The Figure 9 below shows the process diagram of anaerobic digestion.

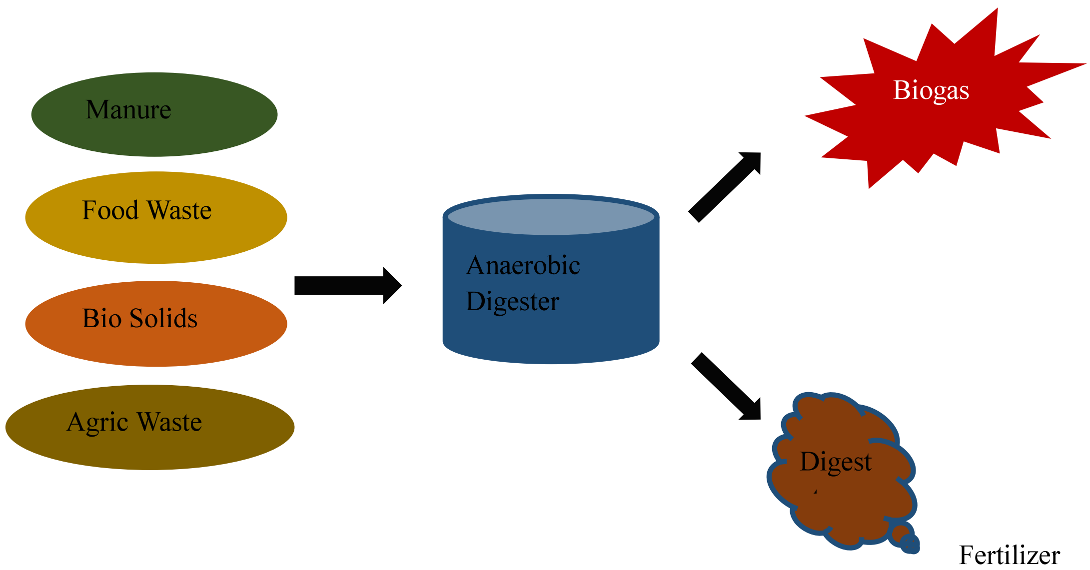


Figure 9: Process Diagram of Anaerobic Digestion

4.0 TECH-ECONOMIC PERSPECTIVE OF THE AVAILABLE BIOMASS FOR CONVERSION TO BIOFUELS

The techno-economic evaluation of agriculture biomass for conversion to biofuels is primarily based on the technical traits and the viability of the thermo-chemical procedures utilized for the production of biofuels from agriculture biomass.

4.1 Viability of Available Biomass (Rice husk and Groundnut shell) for Conversion to Biofuels

Lignocellulose materials, present in agriculture biomass in abundant amounts, are the key component in biofuels production (Salem, 2022). The typical composition of rice husk and groundnut shell weight percentage of dry matter basis is presented in the table 5 below

Table 5: Composition of Rice Husk and Groundnut Shell

Crop Waste Types	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Rice Husk	33.47	21.03	18.80
Groundnut Shell	40.5	14.7	26.4

Source: (Salem, 2022).

Since Cellulose, hemicellulose and lignin content have a high influence on the quantity and yield of hydrochar, (Sharma et al., 2019), and with the data in table 5 above, qualifies the available biomass (rice husk and groundnut) more for conversion into biofuels.

4.2 Energy Content of the Available Biomass (Rice husk and Groundnut shell) When Converted to Biochar or Hydrochar.

Sharma et al., (2019), reported in the table 6 below, the amount of energy obtained from rice husk when converted to hydrochar, using hydrothermal carbonization (HTC), subjected to certain level of temperature under a given duration.

Table 6: Optimum Physio-chemical Conditions for Maximum Yield of Hydrochar

Source	Temperature (0C)		Time (h)	HHV (MJ/kg)		Yield (%)	
	Tmin	Tmax		Tmin	Tmax	Tmin	Tmax
Rice husk	300	300	6	17.8	17.8	66	66

Source: Sharma et al. (2019).

Also, Cheng et al. (2021), reported the fuel characteristics of hydrochar from groundnut shells shown in the Table 7 below;

Table 7: Fuel Characteristics of Hydrochar from Groundnut Shells

Materials	HHV (MJ/kg)	Mass yield (%)	Energy Yield (%)
HTC150	19.2	72.45	81.10
HTC210	22.22	55.52	71.45
HTC270	25.98	44.28	66.90
HTC300	26.97	41.88	65.68

Source: Cheng et al. (2021).

From the fast pyrolysis experiment conducted by Joel et al. (2023) using rice husk indicate that at temperature, holding time and heating rate in the ranges 400 – 650 °C, 600 – 1800s, 6000 – 10000 °C/h respectively resulted in bio-oil yields of 16 – 42%. The quality characteristics of bio-oil were higher heating value (18.5 – 24.95 MJ/kg).

Also, from the component analysis study conducted by Nhan et al. (2022) indicated that rice husks are potential biomaterial for syngas production. With 5kg of dry rice husk, 4.63kg of syngas with an energy value of 44.42MJ was obtained.

The lower lignin component of the groundnut biomass compared with other Lignocellulose waste makes it an attractive feedstock for bio-oil production. The chemical composition of the derived bio-oil of the biomass confirmed the suitability of the waste (groundnut shell) for the production of bio-based chemicals that can find use in the production of wood preservative.

Considering the amount of the concerned biomass (rice husk and groundnut shells) available in the state and the calorific value of the biomass when converted to biofuels obtained from the literature, which shows the state potentials in terms of bio-energy production.

4.3 Obtainable Energy from the Available Biomass (Rice husk and groundnut Shell) in Niger State

Sharma et al. (2019), obtained 66% yield and high heating value (HHV) of 17.8 MJ/kg of hydrochar, when converting rice husk to hydrochar using hydrothermal carbonization. Going by this, the projected amount of energy that can be obtain from the available rice husk (7172.41 tons/annum) can be obtained as;

0.66 X 7172.41

= 4733790.6 kg X 17.8 MJ/kg

=84261472.68 MJ/annum

Also, Cheng et al. (2021), reported the yield of 55.52% and high heating value (HHV) of 22.22 MJ/kg obtained from groundnut shell when converted to hydrochar. Going by this, the projected amount of energy that can be obtained from the available groundnut shell (3575.495 tons/annum) can be estimated as;

0.5552 X 3575.495

=1985114.825 kg X 22.22 MJ/kg

=44109251.39 MJ/annum

Total projected energy equals to;

84261472.68 + 44109251.39

= 128370724.1 MJ/annum.

4.4 Cost Analysis

In order to elaborate more on the need to explore the available biomass in Niger State (rice husk and groundnut shell), cost analysis on setting mini biomass conversion plant (Mini pyrolysis reactor) will be helpful. Pyrolysis plant was considered because it is the most common method among the various techniques of biomass conversion. The cost analysis presented in the table 8 below is the proposed expenditure of setting mini pyrolysis reactor, as well as the proposed cost of running the plant on a monthly basis.

Machine type: Pyrolysis Reactor

Capacity: 300kg/d

Table 8: Proposed Cost Analysis for Installing Mini Pyrolysis Reactor

Items	Cost (N)
Cost of Materials	N/A
Cost of Equipment (Reactor)	500000
Labour cost (3 Operators)	90000
Rent Charges	50000
Light bill	15000
Fuel	40000
Transportation	40000
Installation cost	10000
Tax	10000
Total	755000

All of the costs mention in the table 8 above is proposed to be expend monthly for the running of the mini carbonization plant, except the cost of the equipment. The most commendable item in the cost analysis above is the cost of material that non applicable. This is due to the availability of the biomass in abundance, in the state (almost 7172.41 and 3575.495 tons/annum for rice husk and groundnut shell respectively).

5.0 CONCLUSION AND RECOMMENDATIONS

The quantity of rice husk and groundnut shell in Niger State was projected to be 7172.41 and 3575.495tons/annum respectively. This is a clear indication that these biomass materials are readily available in the state at commercial quantity waiting to be utilized.

The amount of energy that can obtain from rice husk and groundnut shell available in Niger State was projected to be, 1283707254.1 MJ/annum. This indicates the potential for sustainable green energy production and utilization in Niger State, Nigeria.

There are various technological methods (such as direct combustion, torrefaction, pyrolysis, gasification, hydrothermal carbonization etc.) available for the conversion of the available biomass in the state.

And also based on findings from the literature, the chemical composition of the biomass (Rice husk and groundnut shell) and the abundance of the material is clear indication of the viability of the material for biofuels production. Thus, the following recommendations were made

As there is available biomass in the state, the concern authorities are here by urge to explore these biomass materials, by coming up with the optimum solution to convert these materials to biofuels utilizing the most economical and realistic route.

Among the various method of converting biomass materials discussed, direct combustion, pyrolysis and hydrothermal seems to be more feasible, therefore are here by recommended. Though, there is need to carry out some experimental research using hydrothermal carbonization process, for further understanding of the process.

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