

# The Potential of Bio-Coal Briquettes in Nigeria

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## ABSTRACT

Energy demand has become a critical challenge as population continues to grow and this calls for sustainable energy production and supply. Presently in Nigeria, energy supply is not sustainable which negatively affects all facets of national life. Lack of access to reliable and cheap energy sources has been a major factor contributing to the stunted national development. Many Nigerians still rely heavily on traditional sources of energy, especially fuel wood for cooking and heating which has environmental and health implications. Studies have revealed that a cleaner, affordable fuel source which can substitute fuel wood can be produced by blending biomass with coal. Nigeria has large coal deposits which has remained untapped, following the discovery of petroleum in the country coupled with its huge agro wastes. This paper reviews bio-coal briquetting potential with the aim of creating awareness of its replacement as alternative energy source. It explores the extent to which the establishment of bio-coal briquette plants would provide a reliable and affordable fuel steering Nigerian's energy system towards sustainability, and the benefits, drawbacks, concluding that the establishment of bio-coal briquette plants would be a strategic direction to sustainable energy development.

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## Introduction

Energy is a basic requirement for economic development. Every sector of Nigerian economy (agriculture, industry, transport, commercial and domestic) needs inputs of energy. This makes energy one of the most important necessities of life. Due to growths in population and industry, energy demand has increased, which resulted in the requirement to use available fuels more efficiently and to find alternative energy sources. The Nigerian energy industry is probably one of the most inefficient in meeting the needs of its customers. The use of kerosene and gas for cooking and domestic heating has become very expensive and thus making it almost unaffordable by common Nigerians. Though Nigeria is said to be endowed with many natural resources, there is problem of energy scarcity. More than 70% of the populace have no access to the national grid and those that have face the problem of low and epileptic supply coupled with high cost of tariffs (Tokan *et al.*, 2014).

Most Nigerians living in the rural areas have depended solely on fuel wood for their energy needs for the past decades. Continual exploitation of fuel wood used for domestic heating applications has led to deforestation, which has environmental implications. Energy availability in the rural as well as urban areas of Nigeria is fast becoming a great challenge with the high cost of cooking gas and kerosene and environmental problems associated with fuelwood (Oladeji, 2011). This has drawn attention to the need for urgent transition to more sustainable energy systems that would be affordable and ecologically friendly.

In this respect, biomass is of great interest because of its miscellaneous advantages such as easy availability, low price, and CO<sub>2</sub> neutral feature. However, direct combustion of biomass is not preferable because of the negative aspects coming from its intrinsic properties such as low density, low calorific value per unit volume, high moisture, and storage, handling and transportation problems. From this point of view, it is important to develop strategies by which biomass is converted to secondary fuels which have better characteristics in comparison to the parent material (Haykiri-Acma and Yaman, 2010).

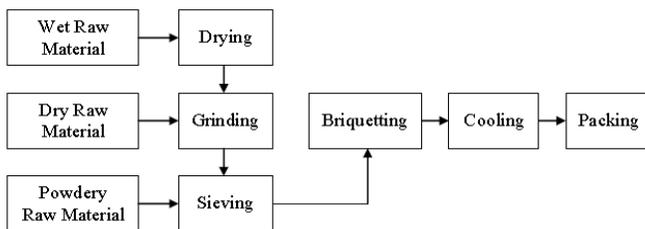
Nigeria is endowed with large reserves of coal, and coal combustion is known to release high levels of pollutants. Fears about environmental implications of continuous burning of coal have being raised. Increased use of coal will worsen global environmental problems unless cleaner and more efficient coal combustion technologies are deployed. For this reason, it is imperative to find alternatives for coal and fuel wood which will ensure that the issue of pollution from coal combustion and excessive use of fuel wood are minimized

The quest by nations to produce efficient and reliable energy for manufacturing and domestic uses has reawakened interest in coal and how it can be used without its accompanying harmful environmental impact and health hazards Adekunle *et al.*, (2015a). Studies reveal that blending coal with biomass gives bio-coal briquettes which have better fuel properties and less harmful emissions compared to raw coal briquettes and fuelwood. Nigerian coal deposits have not been maximally

utilized due to availability of other sources of energy such as petroleum and natural gas. Attention should be shifted to some of these deposits for investigation and conversion into bio-coal briquettes, in order to reduce dependence on fuel wood and petroleum products.

The aim of this paper is to review briquetting studies with a view of awakening interest in Nigeria to it's the potential of bio-coal briquette as an alternative ecofriendly energy source capable of reducing dependence on fuel wood and petroleum derivatives. This study will instigate direct deliberate action in implementing the utilization of bio-coal briquettes in the country by the creation of the synergic interaction of stakeholders including the target end users.

Briquetting is a mechanical compaction process for increasing the density of bulky materials. It is a process utilized for forming fine or granular materials into a desired shape (Wilaipon, 2008). Briquetting is simply a densification process with the application of pressure to fuel materials in order to obtain a compact, durable, and high quality fuel (Altun *et al*, 2003). Briquetting process consists of drying, grinding, sieving, compacting, cooling, and packing stages. During these stages, the moisture content of the raw material is eliminated and the dried material is ground, passed through a screen, and briquetted. The obtained briquettes are cooled and then packed (Gonen, 2010). The flow diagram is shown in Figure 1. During this process, fine material is compacted into a regular shape and size which does not separate during transportation, storage or combustion. In some briquetting techniques, the materials are simply compressed without addition of adhesive (binderless briquettes) (Mangena and Cann, 2007) while in some, an adhesive material is added to assist in holding the particles of the material together. It can be regarded as a waste control measure in the case of production of briquettes from agricultural wastes. Briquetting is one of the promising methods for manufacturing a uniform, stable and durable fuel with the standard quality. By briquetting process, the costs of handling, transportation, and storage can be reduced, and volumetric calorific value can be increased owing to increase in bulk density and decrease in moisture content (Tabares *et al.*, 2006).



**Fig. 1: Flow diagram of briquette production process (Gonen, 2010)**

A briquette is a block of combustible matter which is used to start and maintain fire (Tokan *et al.*, 2014). Bio-coal briquette represents a type of solid fuel produced from coal and biomass with the application of pressure. It is prepared by compacting pulverized coal, biomass, binder, and Sulphur fixation agent (Lu and Wang, 2000). The presence of Sulphur fixation agent known as desulfurizing agent ensures that most of the Sulphur content of the coal is fixed into the ash instead of being liberated into the atmosphere as Sulphur (iv)oxide (Oyelaran and Tudunwada, 2015). The high pressure involved in the process ensures that the coal and the biomass particles are sandwiched and adhere together, as a result do not separate during transportation, storage and combustion (Adekunle *et al.*, 2015a; Wilaipon, 2008)

Bio-coal briquettes have favorable ignition, better thermal efficiency, and emit less dust and soot. The mechanism behind this is that, since the biomass component of the briquette ignites at low temperature compared to the coal, this ensures that the volatile matter in the coal which would have otherwise been liberated as smoke at low combustion temperature combusts completely. The complete combustion of the volatiles reduces smoke and contributes to the total heat released by the fuel as well (Onuegbu *et al.*, 2010b).

There are various biomass resources available in Nigeria for production of bio-coal briquettes. Some of them are saw dust, sugar bagasse, corn stalk, groundnut shell, wheat straw, palm husk, rice husks, corn cobs, forest wastes, and other agricultural wastes. Several researches on bio-coal briquette have been carried out using some of these biomass resources. However, selection of the biomass material should be carried out carefully considering limitations associated with the utilization of biomass energy. Some of the biomass properties preferred for briquetting are given below (Amanor, 2014):

- i. Moisture content should be in the range of 10–15% in order to prevent requirement of more energy consumption for drying, and problems that appear during grinding. Moreover, high moisture content causes decrease in combustion temperature;
- ii. Low ash content, since slagging behavior of the fuel is influenced from ash content, together with furnace temperature and mineral composition of the ash; and
- iii. The material should be granular and uniform so that it can flow easily in bunkers and storage silos.

The production process of bio-coal briquette is very simple. The raw materials; coal and biomass, are pulverized and then dried. It has been shown that 0-5mm is the optimum particle size of the raw materials for a briquette (Gonen, 2010). The dried pulverized materials, a desulphurizing agent and binder are mixed together in appropriate proportions and are compressed with a briquetting machine into a designed shape. The type of briquetting machine determines the shape and size

of the briquette. Some briquette machines have small moulds while some have relatively larger ones. For a large mould, there is always a facility which creates holes in the briquettes when formed. These holes are necessary for efficient combustion of the briquette. It allows for proper flow of air needed to maintain the combustion. In this production process, high temperature is not required. The process is simple, safe and does not require skilled operating technique. Hence, the process can easily be adopted and sustained in Nigeria.

The following are some of the advantages of bio-coal briquettes:

- i. They have much lower ash content;
- ii. Compared to fire wood or loose biomass, they give much higher boiler efficiency due to low moisture and higher calorific density;
- iii. They are easy to store, pack and hygienic to handle;
- iv. They have a consistent quality, high burning efficiency, and are ideally sized for complete combustion;
- v. They emit less Sulphur (IV) oxide and contain desulphurizing agent, and the high pressure involved in the process enables the coal particles to adhere strongly to the desulphurizing agent. During combustion, the desulphurizing agent effectively reacts with the Sulphur content of the coal to form a solid compound instead of being released as oxides of Sulphur to the atmosphere (Wilaipon, 2008); and
- vi. They have a significantly shorter ignition time when compared with coal.

Coal occurs in several areas in Nigeria and ranges in grade from lignite to bituminous as shown in Table 1, being one of the abundant fossil fuel resource (Adekunle, 2015). Nigeria's large coal deposits have remained untapped since the 1950's, following the discovery of petroleum in the country. Also, huge agricultural wastes are generated in Nigeria annually as shown in Tables 2 and 3. But it is unfortunate that farmers still practice "slash-and-burn" agriculture. These agricultural wastes they encounter during clearing of land for farming or during processing of agricultural produce are usually burnt off. This practice not only wastes the useful raw materials but further pollutes the environment and reduces soil fertility (Oji and Monday, 2017).

### Bio-Coal Briquetting Studies Carried out in Nigeria

Several bio-coal briquetting studies have been carried out in the country. These studies involved the use of different biomass and Nigerian coal samples to produce bio-coal briquettes as well as producing different bio-coal briquettes through variations of process/briquetting equipment parameters such as briquetting pressure, dwell time, particle size, biomass composition etc. Some of these studies are presented in this section. Onuegbu *et*

*al.*, (2010a) studied the effects of elephant grass on coal briquette. Briquettes of various compositions were produced and the physical, mechanical and combustion properties of the briquettes were analyzed. Results showed that ignition, smoke emission, cooking efficiency, boiling time, burning rate and specific fuel consumption were enhanced. The optimum biomass concentration for improving calorific value was between 20-30%.

**Table 1: Existing/Potential Coal Mine Site with Estimated/Proven Reserves in Nigeria**

| Mine Location         | State       | Coal Type      | Estimated Reserves (Million tons) | Proven Reserves (Million tons) | Mining Method        |
|-----------------------|-------------|----------------|-----------------------------------|--------------------------------|----------------------|
| Okpara                | Enugu       | Sub-Bituminous | 100                               | 24                             | U/ground             |
| Onyeama               | Enugu       | Sub-Bituminous | 150                               | 40                             | U/ground             |
| Ezinmo                | Enugu       | Sub-Bituminous | 156                               | 56                             | Open Cast & U/ground |
| Amasiodo Inyi         | Enugu       | Bituminous     | 1000                              | NA                             | U/ground             |
|                       | Enugu       | Sub-Bituminous | 50                                | 20                             | Open Cast & U/ground |
| Ogugu/Augu            | Enugu       | Sub-Bituminous | NA                                | NA                             | U/ground             |
| Ihioma                | Imo         | Lignite        | 40                                | NA                             | Open Cast            |
| Afikpo/Osigwe         | Ebonyi /Imo | Sub-Bituminous | 50                                | NA                             | U/ground             |
| Ogboyaga              | Kogi        | Sub-Bituminous | 427                               | 107                            | Open Cast & U/ground |
| Okaba                 | Kogi        | Sub-Bituminous | 250                               | 3                              | Open Cast & U/ground |
| Ogwasi/Azagba/Obankpa | Delta       | Lignite        | 250                               | 63                             | Open Cast & U/ground |
| Oba/Nnewi             | Anambra     | Lignite        | 30                                | NA                             | U/ground             |
| Lafia/Obi             | Nasarawa    | Sub-Bituminous | 156                               | 21.42                          | U/ground             |
| Owukpa                | Benue       | Sub-Bituminous | 75                                | 57                             | Open Cast            |
| Afuyi                 | Edo         | Sub-Bituminous | NA                                | NA                             | U/ground             |
| Ute                   | Ondo        | Sub-Bituminous | NA                                | NA                             | U/ground             |
| Doho                  | Gombe       | Sub-Bituminous | NA                                | NA                             | U/ground             |
| Kammu                 | Gombe       | Sub-Bituminous | NA                                | NA                             | U/ground             |
| Lamja                 | Adama       | Sub-Bituminous | NA                                | NA                             | U/ground             |
| Garin-Maigungu        | Bauchi      | Sub-Bituminous | NA                                | NA                             | U/ground             |
| Gindi                 | Plateau     | Sub-Bituminous | NA                                | NA                             | U/ground             |
| Akwati                |             | Bituminous     |                                   |                                |                      |
| Jamoto                | Kwara       | Sub-Bituminous | NA                                | NA                             | U/ground             |
| Koji                  |             | Bituminous     |                                   |                                |                      |

Source: (Olugbemi *et al.*, 2012)

**Table 2: Residue Estimate from Agricultural Crops in 2010**

| Crop         | Production (000 tons) | Residue     | Moisture Content (%) | Total amount of residue available (Million tons) | Lower Heating Value (kJ/kg) |
|--------------|-----------------------|-------------|----------------------|--|-----------------------------|
| Rice         | 3368.24               | Straw       | 12.71                | 7.86   | 16.02                       |
|              |                       | Husk        | 2.37                 | 1.19   | 19.33                       |
| Maize        | 7676.85               | Stalk       | 15.0                 | 10.75  | 19.66                       |
|              |                       | Cob         | 7.53                 | 2.10   | 16.28                       |
| Cassava      | 42533.17              | Husk        | 11.11                | 0.92   | 15.56                       |
|              |                       | Stalk       | 15.0                 | 17.01  | 17.50                       |
| Groundnut    | 3799.25               | Peelings    | 5.0                  | 76.56  | 10.61                       |
|              |                       | Shells      | 8.2                  | 1.81   | 15.66                       |
| Soybeans     | 365.06                | Straw       | 15.0                 | 4.37   | 17.58                       |
|              |                       | Pods        | 15.0                 | 0.91   | 12.38                       |
| Sugar cane   | 481.51                | Bagasse     | 5.0                  | 0.37   | 12.38                       |
|              |                       | Tops/leaves | 10.0                 | 0.11   | 18.10                       |
| Cotton       | 602.44                | Stalk       | 12.0                 | 0.14   | 15.81                       |
| Millet       | 5170.96               | Stalk       | 15.0                 | 2.25   | 18.81                       |
| Sorghum      | 7140.96               | Stalk       | 15.0                 | 7.24   | 12.38                       |
| Cowpea       | 3368.24               | Shell       | 15.0                 | 7.14   | 12.38                       |
|              |                       |             |                      | 4.89   | 19.44                       |
| <b>Total</b> |                       |             |                      | <b>145.62</b>                                    |                             |

Source: Simonyan and Fasina (2013)

**Table 3: Residue Estimate from Perennial Plantation Crops in 2010**

| Crop     | Area (hectares) | Production (kg) | Residue       | Total amount residue available (Million tons) | Lower heating Value (MJ/kg) |
|----------|-----------------|-----------------|---------------|---|-----------------------------|
| Oil palm | 3,200,000       | 8,500,000       | Fibre         | 1.020   | 11.34                       |
|          |                 |                 | Empty bunches | 1.955   | 8.16                        |
|          |                 | 1,170,000       | Palm kernel   | 0.878   | 18.83                       |
| Cocoa    | 1,341,500       | 360,000,000     | Pods          | 0.181   | 15.12                       |
| Coconut  | 36,200          | 170,000         | Husk          | 0.072   | 18.63                       |
|          |                 |                 | Shell         | 0.028   | 18.09                       |
| Rubber   | 345,000         | 143,500,000     | Leaves        | 0.338   | 17.63                       |

Source: Simonyan and Fasina, (2013)

Also, Onuegbu *et al* (2010b), enhanced the properties of coal briquette using spear grass. Briquettes of different concentrations were produced using starch as binder and Calcium Hydroxide as desulphurization agent. It was found that the ignition time, burning rate and reduction in smoke emission showed improvement with increase in biomass concentration. Onuegbu *et al*, (2012) produced an environmental friendly bio-coal briquette from groundnut shell and maize comb biomass waste of different concentrations of biomass and coal using calcium hydroxide desulphurization agent. Proximate, and ultimate analysis, ignition time and boiling studies were carried out. Results show that briquettes blended with maize were better

than groundnut shell and the biomass increased burning efficiency of the briquettes, ignites faster and produces fewer pollutants.

Ikelle and Ogah, (2014) produced briquettes of coal and corn cobs of various compositions of coal and corn cob using bitumen as binder and calcium hydroxide as desulphurization agent. The briquettes were produced using a manual briquetting machine with pressure maintained at 5 MPa. Results showed that all briquettes produced had reasonable calorific value but the 60% coal 40% corncob briquette exhibited optimum combustible qualities compared to the rest.

Adekunle *et al.*, (2015a) produced and analyzed bio-coal briquettes to ascertain the optimum biomass composition for use as composite fuel. Coal samples from Ogboyaga and Okaba in Kogi State, Nigeria and sawdust were blended at different biomass-coal compositions using starch as binder and calcium hydroxide as desulphurizing agent. The study revealed that bio-coal briquettes from both coal samples were suitable for domestic heating applications. It further showed that briquettes of 50% biomass composition of the two coal samples had better characteristics than the other blends but the 10% biomass composition of Ogboyaga bio-coal briquette exhibited the highest calorific value of 29.55 kJ/kg. Adekunle *et al.*, (2015b) investigated the properties of Okpara and Onyeamabio-coal briquette using sawdust biomass for use as domestic fuel. The bio-coal briquettes produced from Okpara and Onyeama coal mines in Enugu State, Nigeria were evaluated with the view to ascertain the optimum biomass composition for use as domestic fuel using cassava starch as binder and calcium hydroxide. The coals were blended with sawdust at different mixing proportions and experimental tests were carried out. Results shows that all the briquettes produced are suitable for domestic heating applications and the 50/50 blends had better characteristics than others while the 90/10 Onyeama bio-coal briquette exhibited the best quality and the highest calorific value of 33.25 MJ/kg and 70.68% carbon content. Adekunle (2015) investigated bio-coal briquettes as composite domestic fuel by blending sawdust and 12 different species of Nigerian coal samples with varying biomass: coal concentrations in order to ascertain the optimum biomass composition by evaluating their combustion characteristics.

Oyelaran and Tudunwada (2015) investigated the properties of bio-coal briquette of Okaba coal in Nigeria using melon shell and corn cob biomass with view to find out their effects on coal briquette. The bio-coal briquette were produced at different ratios using cassava starch as binder and calcium hydroxide as desulphurization agent using a manual briquetting machine with pressure maintained at 5 MPa. It was found that the sulphur content, burning rate and reduction in smoke emission revealed improvement with increase in biomass concentration. The

biomass sample with 40% corn cob gave the best combustible values but for industrial heating bio-coal briquette containing 10% corn cob may be preferred due to the high calorific value.

Oji and Monday (2017) produced and analyzed bio-coal briquettes from Onyema coal and groundnut shell. The bio-coal briquettes were produced at various biomass composition using clay/rice starch as binders and calcium oxide desulphurization agent and a manual briquetting machine. Results show that all the briquette samples had reasonable calorific values but 60% coal 40% groundnut shell bio-coal briquette exhibited optimum combustion quality.

Results of some briquetting studies carried out in the country have been summarized in Table 4 above. It can be seen that bio-coal briquette has lower moisture content, less smoke emission and higher calorific value when compared to biomass briquettes. The calorific value of bio-coal briquettes ranged from 14.29 – 30.53 MJ/kg which is comparable with that of fuel wood (16.93 – 18.68 MJ/kg), carbonized wood at 25 MJ/kg, and with the net calorific value of kerosene at 37 MJ/kg used for domestic heating application (Adekunle, 2015) and thus can be a suitable substitute. Briquetting technology is yet to get a strong foothold in Nigeria, because of the technical constraint involved and the lack of knowledge to adapt the technology to suit local conditions.

### Prospect of Bio coal briquette in the Nigerian Energy Industry

Thus, with the present energy crisis, there is a high potential of bio-coal briquette becoming a preferred substitute fuel for nearly all energy type used for cooking and commercial process heat. Setting up briquetting production requires considerable financial outlay as well as good technical know-how. The basic requirements for setting up/promotion of briquetting in Nigeria are briquetting technologies, technological capability, raw material base, electric power source, awareness/promotional programs and policies (Sesan, 2008).

Several briquette production machines have been developed in the country by energy research centers. The research centers shoulder most of the responsibility for development and dissemination of briquette technology. Design, marketing, training, operation and maintenance of this technology are all handled by the research centers, without a central implementing body to coordinate their activities. There is no system in place for monitoring the quality and degree of briquette demand and supply, or for examining how the end users engage the technology. There is only one functioning small-scale sawdust Briquetting Company in Nigeria, located in Ogun State (Sesan, 2008).

Nigeria has suffered from policy decay which is a reason why briquetting technology is not even common. However, a summary of some briquettes machines that have been developed using local technologies according to Danjuma *et al.*, (2013) include

**Table 4: Comparison of Coal, Biomass, Bio-coal Briquettes and Fuel wood**

| Samples                    | MC (%)                           | AC (%) | SC (%) | CV (MJ/kg) | Source |                                 |
|----------------------------|----------------------------------|--------|--------|------------|--------|---------------------------------|
| <b>Coal</b>                | Okaba coal                       | 5.99   | 3.32   | 0.6        | 32.93  |                                 |
|                            | Onyema coal                      | 5.87   | 1.25   | 0.6        | 33.33  |                                 |
|                            | Ogboyaga coal                    | 6.93   | 8.63   | 0.6        | 32.51  | (Adekunle, 2015)                |
|                            | Okpara coal                      | 6.14   | 4.87   | 0.5        | 33.69  |                                 |
| <b>Biomass</b>             | Elephant grass                   | 8.00   | 4.35   | -          | 15.98  | (Onuegbu <i>et al</i> 2012)     |
|                            | Spear grass                      | 7.90   | 6.09   | -          | 16.13  |                                 |
|                            | Melon shell                      | 9.51   | 6.93   | 0.34       | 20.30  | (Oyelaran & Tudunwada, 2015)    |
|                            | Corn cob                         | 9.19   | 3.12   | 0.82       | 21.90  |                                 |
| <b>Bio-coal Briquettes</b> | Groundnut shell                  | 8.50   | 36.12  | -          | 8.14   | (Oji & Monday, 2017)            |
|                            | Rice husk                        | 6.95   | 16.82  | 3.45       | 9.02   | (Ikelle <i>et al.</i> , 2014)   |
|                            | Sawdust                          | 8.26   | 1.68   | 0.00       | 17.68  | (Adekunle, 2015)                |
|                            | Elephant grass                   | 7.50   | 12.22  | -          | 18.53  | (Onuegbu <i>et al.</i> , 2010a) |
| <b>Bio-coal Briquettes</b> | Spear grass                      | 7.80   | 13.40  | -          | 18.09  |                                 |
|                            | Melon shell                      | 6.50   | 13.51  | 0.52       | 21.70  | (Oyelaran & Tudunwada, 2015)    |
|                            | Corn cob                         | 1.50   | 12.97  | 0.80       | 22.00  |                                 |
|                            | Groundnut shell                  | 7.00   | 32.50  | -          | 12.10  | (Oji & Monday, 2017)            |
| <b>Bio-coal Briquettes</b> | Rice Husk                        | 4.42   | 20.26  | 4.69       | 14.29  | (Ikelle <i>et al.</i> , 2014)   |
|                            | Sawdust                          | 8.50   | 12.72  | 0.2        | 30.53  | (Adekunle, 2015)                |
|                            | Iroko (Ceiba pentandra)          | -      | -      | -          | 16.93  |                                 |
|                            | White Afara (Terminalia superba) | -      | -      | -          | 18.22  | Onuegbu <i>et al.</i> , 2012    |
| <b>Fuel wood</b>           | Silk Cotton (Cholophora exelsa)  | -      | -      | -          | 18.56  |                                 |
|                            | Gmelina                          | -      | -      | -          | 18.60  |                                 |
|                            | Arhorea                          | -      | -      | -          | 18.24  |                                 |
|                            | Danta Mahogany (Khaya ivorensis) | -      | -      | -          | 18.24  |                                 |
| <b>Fuel wood</b>           | Iron wood (Prosopis Africana)    | 5.63   | 6.79   | 0.03       | 18.68  |                                 |
|                            | Copal tree                       | 4.35   | 14.79  | 0.05       | 16.44  | (Kwaghger)                      |



|  |      |      |      |       |                      |
|--|------|------|------|-------|----------------------|
| (Copaiba Oliveri)                      |      |      |      |       | <i>et al., 2017)</i> |
| Shea butter tree (Vittellana Paradoxa) | 4.74 | 7.77 | 0.04 | 18.42 |                      |

- i. Single cylinder extrusion machine that transform rice, millet husk and sawdust to briquettes developed by Sokoto Energy Research Centre.
- ii. Screw press machine for sawdust briquetting developed at Obafemi Awolowo University, Ile-Ife.
- iii. Simple table-top close-end piston process fitted with both pressure and dial gauge has been developed at University of Ibadan for briquetting using rattan furniture waste.
- iv. A manual hydraulic briquetting machine fabricated at Federal University of Technology, Akure.
- v. The latest development is the briquetting machine developed by the Centre for Industrial Studies of the ATBU, Bauchi in collaboration Raw Material Research and Development Council, Abuja. This machine has four pistons and cylinders, a hopper with four feed holes, cover and locking device and a crank arrangement as the major operating parts.

Currently there are manual hydraulic briquetting machines in hydraulic equipment development institute Kano and National Center for Energy Research and Development, University of Nigeria, Nsukka. Also, there is a vibratory block mould briquetting machine at the National Cereal Research Institute Badegi, Bida, Niger State. (Onuegbu *et al.*, 2010; Efomah and Gbabo, 2015; Oyelaran and Tudunwada, 2015)

According to Sesan (2008) the implementation of bio-coal briquette projects in Nigeria may be hindered by the following factors

- i. **Policy and regulatory factors** - Well-formed policies are essential for the successful implementation of any technology in the country.
- ii. **Financial and market factors** - Financing is the main barrier for most energy projects due to heavy initial capital demand. Alternative energy technologies typically have higher initial costs than conventional sources of energy. However, renewable energy systems have long life spans and low maintenance costs, leading to much lower life cycle costs than conventional systems. The problem with this is that people do not care much about life cycle costs. They are more concerned with how much the technology costs up front. There is a need for private sector participation in the energy sector so that a sustainable, realistic energy market will be created, as opposed to

the distorted market that is so often created by purely government and international aid-driven programmes.

- iii. **Technological factors** - This encompasses a whole range of issues, including insufficient resource data, substandard product quality, inadequate research and development activity, limited human and manufacturing capacities. Lack of local skilled labour to operate and maintain briquetting equipment is another major deterrent to their widespread adoption, especially in rural Nigeria. Also, inadequate research and development into briquetting studies is another hindering factor. There are two main centers for energy research affiliated to the Energy Commission of Nigeria. They are the National Centre for Energy Research and Development, Nsukka and the Sokoto Energy Research Centre. These establishments are responsible for manpower development, dissemination and promotion of renewable and alternative energy technologies in Nigeria (Sesan, 2008). Some remarkable results have been recorded in these centers. However, a lot of work still needs to be done in creating a sustainable framework for transferring energy solutions from the laboratories to the market place.
  - iv. **Socio-cultural factors** - This has to do with the awareness, perception and attitudes of people to energy sources. There is a general lack of awareness about what options are available and what benefits can be obtained from each of these options. This is a foundational issue, as there is no way any energy systems can be optimally operational in the country if the prospective end users are ignorant of their potential.
  - v. **Institutional factors** - Until recently, governments at all levels in Nigeria, almost without exception have not addressed the cooking energy challenges faced by poor families (Danjuma *et al.*, 2013). Other than renewed efforts by donors, no institution of the state has clear vision and resources to provide access to energy technologies such as briquettes.
- The following are the features of investing and development of bio-coal briquette project in Nigeria
- i. Provision an alternative eco-friendly energy source for domestic heating or cooking applications;
  - ii. Reduction in the demand and dependence on fuel wood and petroleum derivatives thereby conserving forest reserves and reducing environmental pollution;
  - iii. The production of bio-coal briquette utilizes agricultural wastes thereby eliminating waste disposal

problem by converting waste to wealth and also taps into the abundant coal reserves in the country;

- iv. Prevention of health risks associated with use of traditional energy sources;
- v. High profitability (high demand as a result of rising cost of fossil fuel);
- vi. Excellent growth potentiality with a ready market;
- vii. Wide variety and easy availability of agro-waste from various crops;
- viii. Tax benefits and incentives;
- ix. Short gestation and quick returns;
- x. Creation of job opportunities; and
- xi. Less market competition

Industries such as ceramic and refractory industries, chemical industries, food processing industries, leather industries, brick making units and any other industries having thermal applications can utilize bio-coal briquettes to fill its energy needs as several research studies have been carried out indicating optimal parameters for producing high quality bio-coal briquette with different application (Sharma *et al.*, 2015). The need for private sector participation in implementation of bio-coal briquette project cannot be overemphasized. The Nigerian Government can provide series of incentives to motivate the private sector to invest in the bio-coal briquette project. According to Sharma *et al* (2015) some of these can be

- i. Offering sales tax exemption in rural areas.
- ii. The whole industry of non-conventional ecofriendly energy sources can be exempted for obtaining any license.
- iii. Income tax exemption for first five years.
- iv. Subsidies from Government.
- v. Low rate of interest from Government financial institutions.

### Conclusion

Bio-coal briquette as an alternative energy source, which can be used for heating and cooking applications in Nigeria, will be a strategic direction to sustainable energy development. This paper explored the extent to which the establishment of bio-coal briquette plants in Nigeria would mitigate problems associated with the use of fuelwood and high cost of petroleum products.

Nigeria is highly endowed with large reserves of coal and biomass which can be converted to bio-coal briquettes to fill energy needs of the masses. The following are some recommendations towards the proper harnessing and development of bio-coal briquette energy potential in Nigeria

- i. Proper enlightenment and advocacy by relevant agencies of the government on usage of bio-coal briquettes to alleviate domestic energy usage problems

and also provide employment opportunities, if firms for its production are established.

- ii. Local available briquetting technology should be deployed to rural areas for production of briquette since they solely depend on fuelwood
- iii. Development of well-equipped Research and development Centers for technical man power development and further investigation into briquetting studies.
- iv. Government should motivate the private sector participation in the energy sector.
- v. Establishment of briquette promotional institutions.
- vi. An enabling policy should be developed for the regulation of briquette tapping and development.

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