Biomass Resources in Nigeria and the Conversion Pathways

Collins O. Ugwu, Paul A. Ozor, Chigbogu G. Ozoegwu, Agwu Ndukwe, Charles Mbohwa
Department of Mechanical Engineering, University of Nigeria, Nsukka, 410001, Nigeria
Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
Africa Centre of Excellence for Sustainable Power and Energy Development (ACE-SPED), University of Nigeria, Nsukka
Onyinyechukwu.ugwu@unn.edu.ng, pozor@uj.ac.za, chigbogu.ozoegwu@unn.edu.ng, agwu.ndukwe@unn.edu.ng, cmbohwa@uj.ac.za

Abstract

In order to improve the socio-economic development of any nation, such factors as the amount and type of energy resources available, conversion and extraction pathways employed, the rate of utilization and sustainability must be addressed appropriately. Nigeria is one of the developing countries that is lagging in that regard because of poor and disrupted investment in the energy sector irrespective of its enormous energy resources. Nigeria has enormous potential in both fossil fuels and renewable energy sources. Some of these renewable sources include hydropower, solar energy, wind power, biomass and geothermal energy. In this paper, the focus is on biomass energy because it is one of the sustainable renewable energy sources with high extraction potentials, due to the vast arable land and favourable climatic conditions in Nigeria. The biomass resources found in Nigeria include agricultural resources, forest resources, aquatic biomass, and waste. These resources are capable of generating about 2.33 EJ of energy and about 144 million tonnes in mass, yearly, which can be harnessed through some pathways such as thermochemical, physio-chemical, and biochemical, for heating or cooling, electricity generation, and as fuel for transportation. Some authors argued that the utilization of the available landmass for the production of biomass resources poses a great threat to food security in Nigeria. However, this challenge can be offset by enhancing the existing agricultural practices to improve the quality of yield without tampering with the quantity of food produced. Biomass is reliable, cost-effective, sustainable, and has the capacity to create both direct and indirect jobs.

Keywords
Nigeria Biomass Resources, Nigeria Biomass Potential, Biomass Conversion Technologies, Prospects and Challenges of Biomass, Renewable Energy

1. Introduction
Despite the enormous natural and renewable energy resources scattered in all the regions in Nigeria, it is one of the nations that is greatly lagging with respect to meeting its energy demand. This observation is supported by a revelation from Oyedepo (2012) that about 60-70% of Nigerians do not have access to electrical power. And there can be no remarkable socio-economic and technological improvement in any nation without sufficient sustainable energy supply. Nigeria as a nation utilize more of natural gas, oil and coal in the production of power and transportation fuels for both domestic and industrial uses. However, it is established that the combustion of these fossil fuels releases enormous greenhouse gases (GHG) that are generating a lot of global concerns (Ben-Iwo et al. 2016). Some of these poisonous gases include carbon dioxide, sulphur dioxide and nitrogen oxides. When released into the atmosphere, GHGs become so detrimental to the ozone layer that protects the surface of the earth from direct exposure to radiations from the sun, especially the ultra violet rays that are both harmful to plants and humans as well. Some of these GHGs, especially the sulphur dioxide and nitrogen oxides can produce acid rain when in contact with water, oxygen and other chemicals. This product is so poisonous to both humans and animals. Consequently, there is the need to harness other low carbon alternatives such as biomass fuel so as to minimize these emissions during power generations (Ben-Iwo et al. 2016).

Biomass is an organic material that is derived from both plants and animals (Ben-Iwo et al. 2016), (EIA). It is a source of energy that is limitless in supply thus, it is renewable (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. According to

Carneiro and Ferreira (2012), biomass can be applied or utilized greatly in three major ways, viz; for heating or cooling, electricity generation and as transportation fuel. As a means of reducing GHG emissions from the use of fossil fuels, many developed countries have increased the use of biomass fuels for transportation and electricity generation (EIA). One of the key factors that has greatly influenced the viability of any energy resource is sustainability. Hence, in a bid to drop the use of the dwindling fossil fuel reserves, it then comes as no surprise to why sustainability is at the forefront of this global campaign (Akorede et al. 2017). The transformation of biomass into power, fuels and other bio-products has great impact on the global policy and economy as well as the rural development because it leads to the diversification of energy supply, reduction on the dependence on fossil fuels and other natural gases for energy generation and most importantly, the creation of both direct and indirect jobs at the local/rural levels hence, can lead to the development of the rural areas (Carneiro and Ferreira 2012). And the creation of job opportunities at such rural level can pave way for the decongesting of urban areas thereby reducing the environmental and socio-economic implications that can be created due to over population. Summarily, biomass as an alternative source of energy is a sustainable, reliable, cost-efficient, environmentally-friendly type of energy system that can employ local resources and networks for its production (Oyedepo 2019). However, it is noteworthy that biomass has its own issues and challenges, for instance, there is the possibility that it affects the biodiversity, quality of the soil, air and water. In addition, the production of biomass from primary sources like forest or agricultural sources is affected by external conditions of climate and pest attacks. Furthermore, at the point of installation of the conversion technologies, it involves high investment costs.

1.1 Objectives

Irrespective of some of these challenges, the prospects and advantages of harnessing these biomass potentials for energy generation, transportation, cooking and heating over other sources is more important. Hence, the major aim of this review work is to x-ray the potentials, conversion techniques, prospects, advantages and challenges of employing biomass resources as source of energy with the view to encouraging both private and public investors to look keenly in the direction of biomass as a reliable alternative for sustainable energy generation in Nigeria.

1.2 Potentials of Biomass in Nigeria

With respect to the huge biomass resource potentials in Nigeria, it is possible to successfully deploy its use in the remote and rural areas. Figure 1 below illustrates the major biomass sources in Nigeria with their individual contributions. This is in accordance with the observation by Agbro and Ogie (2012) who stated that given the enormous magnitude of various biomass resources in Nigeria, the country could be one of the major players in the biofuel industry. As supported by Ben-Iwo et al. (2016), Agbro and Ogie (2012) further noted that bioenergy feedstock is greatly distributed in enormous quantities in all parts of the country due to the favourable climatic conditions which are well suited to growing biomass. With respect to capacity, in quantity, Nigeria can stand as one of the leading exporters of bioenergy products globally. Internally, biofuel production can ease, to a significant extent, the great burden placed on fossil fuels if adopted. For instance, it can reduce the financial implications associated with the importation of refined crude oil products otherwise known as subsidy. In addition, the adoption of biofuels can improve or enhance local human development through job creation, both directly and indirectly, through the installation and the entire production chains (Agbro and Ogie 2012). These stated prospects are possible because Nigeria can boast of about 11 million hectares in forest and woodland reserves, about 245 million in animal livestock and about 28.2 million hectares in arable lands (Carneiro and Ferreira 2012), (Chilakpu 2015). These figures represent about 30% of the total land mass of the entire nation and which can lead to the production of over 1.2 million tonnes of biomass resources daily (Carneiro and Ferreira 2012). About three decades ago, it was estimated that approximately 1.2 PJ of biomass resources, made up of wood residues, agricultural and animal wastes was produced in Nigeria (Carneiro and Ferreira 2012), (Agbro and Ogie 2012). Furthermore, a research conducted in 2005 revealed that the bioenergy potential of the country was about 83 million tonnes in crop residues, 13 million hectares in wood resources and 61 million tonnes in animal waste yearly (Carneiro and Ferreira 2012). In addition, Vincent-Akpu (2012) revealed that Nigeria produces an estimated 227,500 tons of animal wastes per day. In its conversion, it found that Nigeria can potentially produce about 6.8 million m^3 of biogas from animal waste daily since 1 kg of animal waste produces about 0.03 m^3 of biogas. In a 2014 research by Shaaban and Petinrin (2017), it revealed that Nigeria can boast of about 144 million tonnes in biomass potential yearly. However, in a recent study by Jekayinfa et al. (2020), it stated that a significant portion of the entire Nigeria's land mass of about 77.8% is available for biomass energy production. It went further to note that based on these technical potential estimates, the energy derivable from biomass resources is approximately 2.33 EJ. In 2015, the U.S. Energy Information Administration (2015), revealed that biomass resources accounts for approximately 80% of the entire primary energy that is used in the country with natural gas, oil and hydro sources accounting for as low as (13%), (6%) and (1%) respectively. This remarkable high percentage was achieved due to the employment of biomass resources in the cooking and heating purposes especially in the remote and rural settlements. In other words, in the present day Nigeria, it is mostly the rural dwellers utilize biomass to meet their energy needs in Nigeria. It is reported that countries like Brazil and Nigeria have enormous natural resources, in the form of biomass that can be harnessed into biofuels for automotive transportation, bio-power for electricity generation and other valuable bio-products (figure 1).

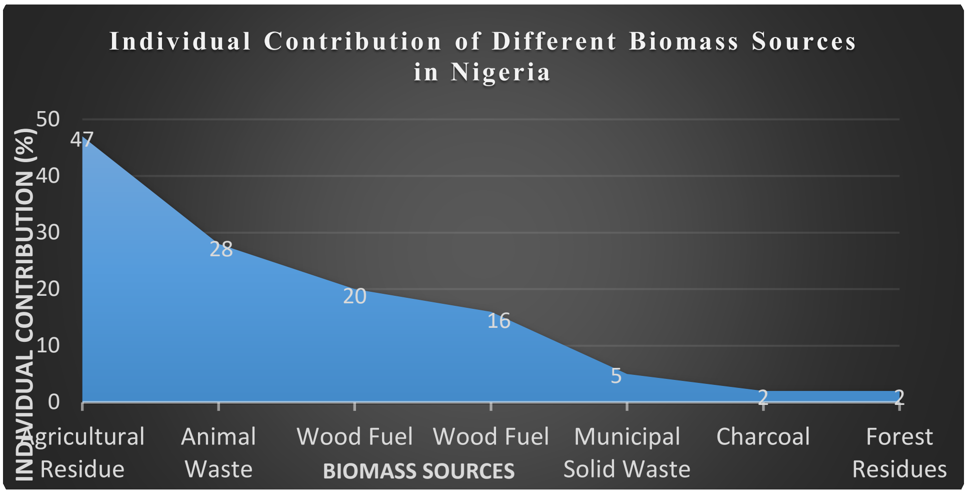

Figure 1. Contributions of Biomass Sources in Nigeria (Jekayinfa et al. 2020)

2. Sources of Biomass in Nigeria

The distribution and type of bioenergy resources in Nigeria is dependent on the climatic condition prevalent in that region. For instance, mostly woody biomass are found in the rain forest zone while crop residues are more prevalent the in savannah zones. Due to lesser rainfall in the north, mostly millet, wheat, sorghum and short season cereals are found in the north as opposed to the south with increased rainfall that produces yams, cassava and rice. Table 1 below contains these crops with their production capacities in different states in Nigeria. In the same vein, in the drier part of the north, crops such as groundnuts, cotton and tobacco which are also known as cash crops are grown while in the wet zones of the south, crops grown include coffee, oil palm, cocoa, ginger, sugar and rubber (Ben-Iwo et al. 2016). According to Carneiro and Ferreira (2012), fuel wood, animal wastes, energy crops and agricultural residues are the major forms of biomass resources available in Nigeria.

Table 1. Major Crops for Bioenergy Production in Nigeria (Simonyan and Fasina 2013) and (NASS 2012)

Bioenergy Resources	Production Area (10^6 ha)	Total Production (10^6 MT)	State with Highest Production	Production Capacity (10^3 MT)
Cowpea	2.860	3.368	Benue	0.428
Cassava	3.482	4.2533	Benue	3.792
Maize	4.149	7.677	Kaduna	0.436
Cotton	0.399	0.602	Zamfara	0.155
Soybeans	0.291	0.356	Benue	0.079
Groundnut	2.785	3.799	Niger	0.547
Sorghum	4.960	7.141	Kano	0.746
Millet	4.364	5.171	Sokoto	0.714
Rice	2.433	4.473	Kaduna	0.732

2.1 Agricultural Resources- Crops and Residues

The crop resources include the energy crops from which these abundant residues are derived from. Such energy crops like cocoa pods, rice, maize, sorghum, corn, millet, palm oil, palm kernels, groundnuts, sugarcanes, plantain, cassava stalk/peelings, cashew, potato, coffee, cocoyam, etc., that are generated by farmers in the farmlands and other feed stocks, utilized for the production of bioenergy/biofuels are found in almost every part of the country (Ben-Iwo et al. 2016), (Akorede et al. 2017), (Agbro and Ogie 2012), (Jekayinfa et al. 2020), (Simonyan and Fasina 2013), (Osaghae 2009). According to the report by National agricultural sample survey (NASS 2012) that was done between 2010 and 2011, there are about twelve major crops for bioenergy production in Nigeria such as maize, cowpea, cotton, cassava, cocoyam, groundnut, melon, soya beans, millet, rice, yam and guinea corn.

During the harvesting and processing of agricultural crops, the organic materials produced as by-products are known as agricultural residues. Due to the fact that about 94% and 68% of the Nigerian families are involved in agricultural activities, viz; crop and livestock farming respectively, there is enormous production of agricultural biomass annually (Akorede et al. 2017). Such residues produced in Nigeria include straw leaves and stalks of cereal, cocoa pods, cassava peelings, cocoa husk, rice husk, coconut shell and husk, etc. However, such crops as sorghum, sugarcane, cassava, maize and rice have sustainable potential for biofuel production. While the ones famous for biodiesel production include such crops as jatropha, oil palm, groundnut, sunflower, soyabeans, sesame and castor oil (Akorede et al. 2017), (Mohammed 2013). Depending on the age, mode of handling, stage of harvest, harvesting practices and length of storage, these residues are fibrous, heterogeneous, low in nitrogen, moisture content, particle size and distribution with varying bulk density (Ben-Iwo et al. 2016), (Simonyan and Fasina 2013), (Atta Krah and Reyholds 1987).

Generally, both the crops and residues are generally useful as food for livestock, fertilizer for soil conditioning, source of erosion control and most importantly, they present great potential as energy source (Ben-Iwo et al. 2016), (Simonyan and Fasina 2013), (Cooper and Laing 2007).

2.2 Forest Resources and Residues

Forest has a substantial biomass resource potential that can contribute significantly to the nation's energy demands. According to Simonyan and Fasina (2013), it is estimated that the forest reserves in Nigeria is about 10million hectares which is approximately 11.3% of the nation's entire land mass. This was supported by some studies which also revealed that Nigeria can boast of about 1,160 forest reserves, which is covering 10,752,702 hectares of the total land area and this figure represents approximately 10 % of the country's land area (Ben-Iwo et al. 2016), (Agbro and Ogie 2012), (Sokan-Adeaga and Ana 2015). Nigeria is made up of eight major forest classifications located in 28 states, viz; mangrove forest, savanna woodland forest, riparian forest, lowland rain forest, freshwater swamp forest, montane forest, plantain agriculture and plantain forest. Though this classification excluded the eight dry/arid Northern states, viz; Sokoto, Zamfara, Katsina, Jigawa, Yobe, Borno, Gombe and Bauchi (Simonyan and Fasina 2013). This wealth of forest reserves in the nation can be utilized appropriately to stir development, create jobs, produce energy products, create reliable fibre supply, reduce GHG emissions, improve domestic economies and create resources for industrial purposes (Ben-Iwo et al. 2016), (Zhang et al. 2012).

Forest residues, on the other hand, consist of wastes or wood residue that are generated from wood-processing and logging activities (Agbro and Ogie 2012). There are two major categories of residues, viz; logging and industrial by-products. The logging residues include branches, stumps, leaves, off-cuts and sawdust generated during logging activities while the industrial by-products includes the wood processing wastes generated by firms as a result of the manufacture of such products as sawn wood, plywood, particleboard, etc. (Oyedepo 2019), (FAO 2009). The Nigeria's forest residue can generate an estimated energy potential of about 8.68 Mtoe (363 PJ). This figure can be obtained from a biomass resources of approximately 19 million tonnes in weight (Olanrewaju 2019). Due to the fact that many people, especially the rural inhabitants, cannot afford cooking fuels such as kerosene and gas, over 70% of the population utilize woods as the main source cooking especially (Akorede et al. 2017).

2.3 Aquatic Biomass

Nigeria has a great potential in aquatic biomass that is fast growing because about eight of its states is bounded by large coastal regions (Simonyan and Fasina 2013), (Ezealigo 2021). Aquatic weeds includes algae and emerging plants (Jekayinfa et al. 2020). These emerging plants have the potential of being converted to biogas through bio-digestion (Ezealigo 2021). Examples of such aquatic weeds include seaweed, kelp, lake-weed, water hyacinth and lettuce, and bracken fern (Ezealigo 2021). Also with great potential in the production of biodiesel, vegetable oil, bioethanol, biomethanol, biogasoline, biobutanol and other biofuels through the same conversion pathways, is algae which is the microforms of aquatic weeds (Simonyan and Fasina 2013), (Ezealigo 2021). They are of different forms such as freshwater or marine algae, macroalgae or micro algae (Jekayinfa et al. 2020), (Simonyan and Fasina 2013). However, the three fast-growing aquatic weeds that are common in Nigeria include water lettuce, water hyacinth and brackenfern (Jekayinfa et al. 2020), (Simonyan and Fasina 2013), (Ezealigo 2021). According Kaur et al. (2018), the reproduction rates of these aquatic weeds are exceptionally high. It further noted that they are efficient as biofuel crops because they are rich in cellulose and hemicellulose with a lignin content that is very low. For instance, water hyacinth has wide tolerance range, great competitive ability and high productivity; water lettuce has succulent leaves and it is a free growing aquatic herb; and brackenfern is a terrestrial weed which can be bio-digested for biogas production (Simonyan and Fasina 2013). These aquatic weeds have been observed to have an increased biogas production especially when combined in varying proportions (Simonyan and Fasina 2013). In addition, algae farming, in recent times, has gained significant attention because of competing demands between foods and other biofuel sources, high oil prices, food crisis and the availability of lands not suitable for agriculture (Simonyan and Fasina 2013). In general, aquatic biomass has the advantage of producing larger amounts of resources when compared to land crops per hectare (Jekayinfa et al. 2020).

2.4 Waste

According to Ben-Iwo et al. (2016), the Nigerian environment is highly littered with wastes such as municipal solid waste (MSW), industrial, animal and food wastes. These wastes can be utilized as feed stocks for biofuel production.

2.4.1 Municipal Solid Waste

Municipal solid wastes consists mostly discarded materials that make up the items being disposed by the general public. Such materials include wood, organic, polythene, textiles/leather, glass/bottle, rubber, sanitary, e-waste, polystyrene food pack, medical and metal wastes (Ugwu et al. 2020). These wastes are mostly generated from academic environment, households, commercial and industrial sectors. Nigeria generates approximately 74,428.85 tons of MSW per day which is about 27,166,530.25 tons on annual basis (Oyedepo 2019), (Giwa 2017). These values have the potential to generate biogas of about 2.04 million m^3 daily (Giwa 2017). In addition, Ben-Iwo et al. (2016), revealed that in every 1 ton of MSW that is deposited in a landfill, about 160-250 m^3 of biogas is produced. Nonetheless, most of these wastes are currently disposed indiscriminately into the sea, unsanitary landfills or burnt in open dumps hence, polluting the environment and also leading to under-utilization. Consequently, there is the need to recover these useful wastes through appropriate techniques such as natural anaerobic digestion in the landfill or by direct combustion (Agbro and Ogie 2012), (Jekayinfa et al. 2020). This assertion was also supported by Ugwu et al. (2021) which further stated that MSW can be treated by composting and all other waste-to-energy technologies though depending on the individual waste composition.

2.4.2 Food Industry Waste/Wastewater

The food industries deliver all kinds of food, both fresh and processed foods, to consumers thereby leading to the generation of wastes which can take different forms like solid, liquid and gaseous forms (Oladepo 2014). The quantity of these wastes generated on daily basis have been on the increase due to the increase on the number of food processing industries in Nigeria (Oladepo 2014). Such industries as dairy factories, sugar mills, fruits, meat, fish, wine, vegetable processing plants and the Nigeria bottling company are examples of the food processing industries (Ben-Iwo et al. 2016), (Simonyan and Fasina 2013), (Shulin 2007). In addition, Ben-Iwo et al. (2016) noted that hotels and restaurants contribute greatly in the generation of these wastes. For instance, such wastes as remnants and peelings from crops, vegetables, fruits and leftover or expired foods (Ben-Iwo et al. 2016).

2.4.3 Animal Wastes

Animal wastes are mostly manures from livestock (Ben-Iwo et al. 2016), (Simonyan and Fasina 2013), (Gerba and Ian 2009). Animal wastes are of great concern to both the public and to regulatory bodies because they contaminate both ground and surface water (Gerba and Ian 2009). They are made of organic materials, moisture and ash. Hence, when decomposed under aerobic conditions, they produce CO_2 and stabilized organic materials while CH_4, CO_2 and stabilized organic materials are produced in anaerobic decomposition. According to Simonyan and Fasina (2013), Nigeria is estimated to produce about 15.76 million tonnes of dry animal waste and approximately 4.19 billion m^3 of biogas in 2010. However, Olanrewaju et al. (2019), in a latter study estimated a higher value. It stated that a total of 18 million tonnes of dry dung was estimated in 2013 from which would yield 4.76 billion $m^3$of biogas per year.

3. Thermo-Chemical and Bio-Chemical Conversion Pathways for Biomass

The type of energy released from biomass when converted is dependent on the conversion route, temperature and the type of resource converted as seen in figure 2 (Biomass Technology). During the treatment process, the chemical energy in biomass is converted and released in form of heat energy. Most times, this heat is used to produce steam which is applied to drive turbines so as to generate electricity for household or industrial consumption. In addition, the heat energy could be applied directly in homes and small scale commercial activities like cooking and baking. Hence, biomass as an energy resource, can be utilized in different forms, either as solid fuel, liquid or gaseous forms after being transformed through a variety of pathways (Oyedepo 2019).

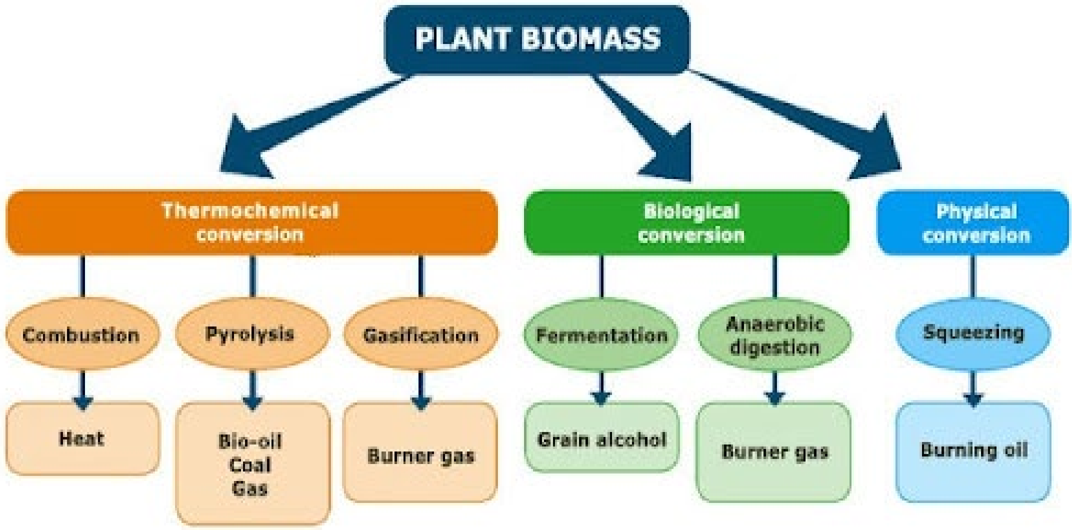

Figure 2. Some Conversion Pathways for Biomass Feedstock (Biomass Technology)

3.1 Combustion

This is involved in the processing of over 97% of the world bioenergy production hence, reported as the commonest way of producing energy from biomass (Ben-Iwo et al. 2016). Mankind has applied this technology in varieties of ways for thousands of years for instance; to generate warmth environment, to forge tools and weapons and to cook food. In general, combustion can be employed to produce heat for direct application, influence the temperature of a given environment or to drive turbines so as to generate electricity. The combustion of biomass is more prevalent in the rural and remote parts of Nigeria to generate energy for cooking and heating purposes. In the recent times, the application of combustion for heating, cooking and small scale industrial heating processes are carried out by inefficient three-stone stoves, charcoal stoves and sawdust stoves with remarkably poor performance and high specific fuel consumption (Jekayinfa et al. 2020). Jekayinfa et al. (2020) revealed that in Nigeria, this form of energy conversion has a relatively low efficiency resulting into waste of energy. Bello et al. (2015) obtained efficiencies of 34.56%, 52.64% and 64.38% for the three-stone stove, sawdust stove and charcoal stove respectively. Combustion technologies can be conveniently applied to all the biomass resources available in Nigeria (Ben-Iwo et al. 2016), (Ullah et al 2015).

3. 2 Gasification

This involves the thermochemical conversion of carbon-based substances such as feedstock and other organic materials, in solid or liquid forms into gaseous products or combustible gas in the presence of gasification agents (Ugwu et al. 2021). It also involves the partial oxidation of materials at temperatures between 800-900°C with a controlled amount of oxygen (Simonyan and Fasina 2013). The combustible gas, which is also referred to as synthesis or syngas, is made up of the following gases with the ranges of their proportions indicated, viz; CO (18 to 20%), CO_2 (8 to 10%), H_2 (18 to 20%), CH_4 (2 to 3%), with trace amounts of H_2O, N_2 and other hydrocarbons (Simonyan and Fasina 2013), (Ugwu et al. 2021), (Ezealigo 2021). The gas so produced has a low calorific value of about 4-6 MJ/Nm^2 (Simonyan and Fasina 2013), (McKendry 2002). It can be burnt directly or employed as fuel for electricity generation in gas engines and turbines (McKendry 2002). It can also be utilized as a feedstock for chemical productions (Simonyan and Fasina 2013), (McKendry 2002).

3.3 Pyrolysis

This is a thermal conversion process that involves the decomposition of biomass materials under pressure in the absence of oxygen and at temperatures ranging from 350 to 550 °C (Ben-Iwo et al. 2016), (Ugwu et al. 2021), (Simonyan and Fasina 2013). There are three major fractions produced from this process, viz; solid fraction in the form of ash, liquid fraction in the form of bio-oil and gaseous fractions (Ben-Iwo et al. 2016). In addition, it aids in the recovery of chemicals with higher value through the transformation of low-energy density resources into bio-fuels of high-energy density (Ugwu et al. 2021). Pyrolysis has had wide application since many ago especially in charcoal production but it is gaining more attention in the recent times characteristic of its short residence time and moderate temperature (Ben-Iwo et al. 2016). The process is both technologically and economically viable because it presents great application in co-processing of petroleum with renewable feedstock. In this opportunity, little capital investment is required while using existing infrastructure and configuration (Ben-Iwo et al. 2016). However, this incorporation of a pyrolysis plant into a refinery is dependent on a number of factors such as the value of the off-gases, the cost of hydrogen and the availability of land. The fast pyrolysis, i.e. the transformation of biomass materials into bio-crude and subsequently into refined bio-diesel and other drop-in fuels, of biomass feedstock is estimated to have the lowest capital cost. For instance, a plant with annual capacity of 289 ML is estimated to have about USD 1/litre/year production capacity (IRENA 2013). Consequent upon these valuable prospects and opportunities, several authors have proposed that pyrolysis technologies be greatly developed to solve the rural electrification problems in Nigeria (Jekayinfa et al. 2020).

3.4 Torrefaction

Torrefaction involves the thermal processing of biomass materials in an engineered reactor known as torrefier to produce a "charred" product. This product can be utilized for soil amendment or as a fuel (Barskov et al 2019), (Anukam et al 2017). It also involves the addition of heat from an external fuel source to the material under conversion into a torrefied product. These torrefied products are commonly known as bio-coal or green coal when used as fuel (Anukam et al 2017). However, when used for soil amendment it is often called bio-char (Anukam et al 2017). In the torrefier, a sweep inert gas, often nitrogen is used to control the oxidizing conditions of the internal reactor so as to prevent full combustion. The temperature of the reactor ranges between 200-300 ^{o}C, under a residence time that is often less than 30 min and under ambient pressure (Anukam et al 2017), (Kumar et al 2017). There are three key transformations that take place during a torrefaction process, namely; volatilization, polymerization and carbonization (Anukam et al 2017), (Kumar et al 2017). The resulting torrefied product often has similar physical and chemical characteristics with charcoal.

3.5 Physicochemical Conversion

Physicochemical conversion involves an oil extraction process from oil crops such as rapeseed, soybean, Jatropha, etc. followed by a transesterification process. The liquid fuels usually produced by this process are biodiesel and vegetable oil. It also involves the conversion or synthesis of products by employing physical and chemical processes at or very close to ambient pressures and temperatures. Some of the primary feedstock utilized in this sort of transformation technology include animal fats, greases, tallow and fresh or used vegetable oils. After these materials are converted into useful chemicals and liquid fuels such as biodiesel, a transesterification process is used to displace alcohol in the presence of a base or an acid catalyst.

3.6 Fermentation

Fermentation process involves the conversion of carbohydrates such as starch and sugar, into ethanol (Jekayinfa et al. 2020). It is also a process that utilizes microorganisms/enzymes in the conversion of substrates that are fermentable into products that are recoverable using alcohols or organic acids. The process materials undergo two major processes before the fermentation, viz; pre-treatment and hydrolysis processes. It is during the pre-treatment stage that the surface area of the biomass material is increase, the cellulose crystallinity is decreased, the hemicellulose eliminated, and the lignin seal broken. During the hydrolysis, the enzymes convert the cellulose components into glucose and the hemicellulose into hexoses and pentose. It is after this stage that the selected microorganisms ferment the glucose into ethanol. This conversion process has been widely applied in the treatment of organic wastes and also in the production of ethanol from sugar (Ben-Iwo et al. 2016), (Ugwu et al. 2021). It is revealed that in 2011, Brazil produced approximately 5.6 billion gallons of ethanol fuel which accounted for about 24.9% of the world's total ethanol fuel. It was also revealed that Nigeria boasts of a favourable climatic condition that is greatly similar to that of Brazil which produces enormous sugarcane materials hence, Nigeria can be adjudged to produce large quantities of ethanol fuel as well (Ben-Iwo et al. 2016), (Simonyan and Fasina 2013). Ben-Iwo et al. (2016), stated that biofuel projects, focusing on ethanol and other chemical compounds such as methanol, hydrogen and succinic acid, production has become the subject of most development and research programmes in Nigeria presently (Ben-Iwo et al. 2016).

3.7 Anaerobic Digestion

This is a conversion technology that involves the decomposition of wastes in the absence of oxygen. Anaerobic digestion gives rise the production of gases such as carbon dioxide, methane, ammonia and trace amounts of other gases such as hydrogen sulphide (Ben-Iwo et al. 2016), (Simonyan and Fasina 2013), (McKendry 2002), (Ugwu et al. 2021), (Dutta et al. 2014). Biomass with high-moisture content of about 85–90% is very suitable for the type of technology. The high moisture content aids the microorganisms present in the system to be more active. The by-product or nutrient rich digestate, also known as compost, can be utilized as fertilizer for soil conditioning. The energy content of the biogas produced from anaerobic digestion is about 20–40% of the lower heating value of the feedstock (Ben-Iwo et al. 2016). Anaerobic digestion is multi-beneficial and also a flexible technology that is appropriate for extracting energy from biodegradable waste materials and agricultural residues. In support of this statement, Ben-Iwo et al. (2016) and Dutta et al. 2014 noted that anaerobic digestion is very suitable for biomass feedstock and algae thus, has the capacity to produce biogas and recycle nutrients. Methane, carbon dioxide, with traces of hydrogen, hydrogen sulphide and nitrogen are the constituents of a biogas (Jekayinfa et al. 2020). However, a raw biogas contains impurities such as dust, hydrogen sulphide and water halogenate hydrocarbons that can cause corrosion problems during the processing, handling and also in the storage facilities and equipment. Therefore, a raw biogas has to be cleaned and upgraded before it can be efficient in engines or heaters (Simonyan and Fasina 2013), (McKendry 2002).

3.8 Transesterification

This is a biochemical conversion process that takes place in the presence of an acid or a base catalyst and it involves the displacement of alcohol from an ester by another one. It is suitable for the production of biodiesel from fatty acid methyl esters (Ben-Iwo et al. 2016), (Jekayinfa et al. 2020). Vegetable oils and valuable chemicals are contained in wood extractives thus, making this process suitable for conversion to biodiesel with methanol (Ben-Iwo et al. 2016), (FAO 2010). Biodiesel is produced in the presence of an enzyme, acid or alkali catalyst, through the alcohol transesterification of large branched triglycerides into smaller straight-chain molecules (Ben-Iwo et al. 2016). The resulting fatty acid methyl esters (FAME) are easily mixed with fossil diesel.

4. Prospects and Advantages of Biomass in Nigeria

According to Sa'ad and Bugaje (2016), the use of biomass in the household sector, commercial outlets and small scale rural industries has continued to increase over the years in Nigeria. It further noted that its employment in those areas has remained the most dominant energy source in the country (Sa'ad and Bugaje 2016). Hence, Nigerians are keenly observing to know if biofuels can chart the much anticipated path of change owing to the enormous potentials in the country. The drivers of biofuel development emanates from the search for an alternative to fossil fuels, due to the mounting evidence with respect to global warming, through research and development activities. These necessary activities were not only to reduce the high dependence on oil but also stimulated by the quest to improve on the associated by-products and reduce environmental issues. The global decline in crude oil reserves and the high cost of exploring crude oil are also important factors driving the shift in attention to biomass resources. These drivers increase the attractiveness of renewable energy and environmental goals of GHG emissions that were set by national governments and international agreements such as the 1997 Kyoto Protocol and the 2009 Copenhagen Summit (Onuoha 2010). Owing to the high level of water availability, vast fertile and arable land, coupled with a very favourable climatic conditions, the full scale employment of bioenergy in Nigeria is possible. With respect to human development, investment in biomass development will create both direct and indirect job opportunities. There are great benefits derivable from the development of the enormous biomass resources scattered in all parts of Nigeria.

5. Challenges of Biomass in Nigeria

Onuoha (2010) stated that although biofuels are renewable and made from plant materials, they may not be as green as they seem. The production of biofuels require large amount of land for feedstock cultivation. Almost all the activities involved in the production of biomass resources, such as irrigation, fertilizer application, transportation of products and materials, conversion and refinery processes, require energy for the operation thus, emitting carbon dioxide (Onuoha 2010). Some studies on lifecycle analysis on biofuels production indicate that there are still the emission of GHGs posing serious threat on the environment (Onuoha 2010). In addition, the utilization of the available land mass for the production of biomass resources poses great threat to food security in Nigeria. Therefore, there is an urgent need to enhance the existing agricultural practices so as to improve on quality and yield without tampering the quantity of food produced. There is also the need to enhance the infrastructures, such as power, roads and water to boost production capacity and efficiency.

In line with the challenges discussed above, Nwofe (2014) listed some factors militating against full scale development of biomass as a source of renewable energy in Nigeria to include lack of manpower, long payback times, high cost of initial investment, lack of awareness, illiteracy, lack of establishment/investment in waste management research lack of infrastructure for bottling biogas for cooking and its use for generation of electricity, and lack of proper Government policies/implementation on renewable resources.

Furthermore, Ezealigo (2021) noted some pertinent factors militating against full scale bioenergy production from biomass irrespective of its high potential in the country to include poor investment climate, poor regulatory framework, poor access to technology, inadequate research and development, poor policy formulation and implementation and poor information on feedstock.

6. Conclusion

Biomass is a source of energy that is limitless in supply thus, it is renewable. It can be applied or utilized greatly in three major ways, viz; for heating or cooling, electricity generation and as transportation fuel. About 77.8% of Nigeria's land mass is available for biomass energy production. It went further to note that based on these technical potential estimates, the energy derivable from biomass resources is approximately 2.33 EJ. The bioenergy resources in Nigeria is dependent on the climatic condition prevalent in that region. For instance, mostly woody biomass are found in the rain forest zone while crop residues are more prevalent in the savannah zones. The major forms of biomass available in Nigeria are agricultural residues, aquatic biomass, fuel wood, wastes and energy crops. As an energy resource, biomass may be utilized in solid form or transformed through different technologies into liquid or gaseous forms for direct heating in homes or small scale industrial applications, production of electric power, steam or fuel for powering automotive engines. Such varieties of conversion technologies include thermo-chemical, physiochemical and bio-chemical technologies. The employment of bioenergy as a source of energy in Nigeria will not only reduce the high dependence on oil but also stimulate the quest to improve on the associated by-products and reduce the accompanying environmental issues with oil explorations.

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Engr. Collins O. Ugwu is with the department of Mechanical engineering, University of Nigeria Nsukka as a lecturer. He obtained both bachelors and Masters Degrees from the Department of Mechanical Engineering, University of Nigeria, Nsukka. He specializes in Industrial Engineering and Management. He is currently undergoing his Ph.D studies in the same area of specialization, department and university. His major research interests includes Municipal Solid Waste, Renewable Energy, Energy Management, Route Optimization, and Siting of Suitable Landfills for Solid Wastes (SW) by employing Multi-Criteria Decision Analysis (MCDA) and Geographic Information System (GIS).

Paul A. Ozor is the West African Sub-Regional Coordinator of Industrial Engineering and Operations Management Society International. He holds a bachelor's degree in Mechanical/Production Engineering from the Enugu State University of Science and Technology as well as Masters and PhD in Industrial Engineering and Management from the University of Nigeria, Nsukka. Dr Ozor had been a Project Manager in a reputable Engineering company in Nigeria for many years. He had been a faculty member of University of Nigeria Nsukka since 2009, and has served the Department of Mechanical Engineering and Faculty of Engineering in various capacities prior to his appointment as the head of Department of Mechanical Engineering in August 2021. Dr Ozor is a Scholar of the Association of Commonwealth Universities (ACU), and a fellow of The World Academy of Science. He is a fellow of the global excellence stature (GES) of the University of Johannesburg. He is currently serving as a Senior Research Associate of the University. As a speaker and participant in international conferences, seminars and workshops, he has visited several countries on research grounds. Dr Ozor has published research articles in many peer reviewed local and international Journals and conference proceedings. He has supervised significant local and international postgraduate students to successful study completion. He is an external examiner to University of the Witwatersrand, South Africa. He is a member of the Nigeria Society of Engineers (NSE) and registered with the Council for the Regulation of Engineering in Nigeria (COREN). His research interest is not limited to Asset Management, Quality, Operations Management, Reliability Engineering, Environmental Influence, Sustainable materials, lean six sigma, smart manufacturing.

Dr. Chigbogu G. Ozoegwu is currently an experienced Humboldt Fellow at the Institute of Engineering and Computational Mechanics, University of Stuttgart, Germany. He bagged a B.Eng degree from the Mechanical Engineering Department, University of Nigeria, Nsukka (UNN), where he is also a member of academic staff. Dr Ozoegwu obtained both Masters and PhD in Mechanical Engineering from the Nnamdi Azikiwe University Awka, Anambra State Nigeria. He is into Computational and Data Science/Engineering research with interests not limited to the Mechanics of Materials, Structures, Machines and Industrial/Energy/Environmental/Biological systems. He seeks out how analytical skills promote sustainability. Dr. Ozoegwu has over 100 publications in both local and international journals/conference proceedings. He has also successfully supervised many postgraduate students in both PhD and Masters levels.

Ndukwe Agwu is a master's student of materials and mechanics major at the University of Nigeria, Nsukka. He received a barchelor's degree in Mechanical Engineering from Michael Okpara University, Nigeria. He is currently a graduate assistant in the University of Nigeria, Nsukka.

Professor Charles Mbohwa is the Pro Vice Chancellor of the University of Zimbabwe, Harare, Zimbabwe. He obtained B. Sc. Honours in Mechanical Engineering in 1986 from Department of Mechanical Engineering of the same University. He later bagged M. Sc. in Operations Management and Manufacturing Systems with a distinction in 1992, from Department of Manufacturing Systems Engineering, University of Nottingham, UK. He obtained PhD in Engineering (Production Systems focusing on Energy and life cycle assessment) from Tokyo Metropolitan Institute of Technology, Tokyo, Japan in 2004. Professor Mbohwa is an NRF-rated established researcher. In January 2012 he was confirmed as an established researcher making significant contribution to the developing fields of sustainability and life cycle assessment. In addition, he has produced high quality body of research work on Southern Africa. He is an active member of the United Nations Environment Programme/Society of Environmental, Toxicology and Chemistry Life Cycle Initiative, where he has served on many taskforce teams. He has published over 600 research articles in leading international Journals and Conference Proceedings. Prof Mbohwa had been keynote speaker in many international conferences and has supervised many local and international postgraduate students while playing host to several international postdoctoral fellows. He is a visiting Professor to the University of Johannesburg, South Africa, where he had served in various capacities, including Dean of Postgraduate Studies and Executive Dean of Faculty of Engineering and the Built Environment.