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Research Article

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Bio-Sourced Feedstocks for Biofuel Production: Nigeria as a Case Study

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Abstract Energy crisis is a global concern and Nigeria has a fair share of this crisis. Series of crises witnessed so far are attributed to the increasing energy demand which does not commensurate with its depleting energy supply due to over-dependence on fossil fuel. However, industrialized nations have broken this monopoly and have diversified by tapping into an unceasing energy source from bio-economy. This paper reviews the biomass resources available in Nigeria and the potential for biofuel production from bio-sourced feedstocks. It has been found that there has been an upscale of activities by government towards increasing the energy mix within the country as several biofuel production projects have been developed. However, most of the emerging biofuels projects in Nigeria utilize first generation biomass feedstock for biofuel production. These feedstocks are mostly food crops and thus in competition with food which in an attempt to address energy crisis could plunge into a crisis that threaten human existence, food crisis. This is the dilemma confronting the utilization of these bio-sourced feedstocks. Exploiting the avalanche residue and wastes generated per day in the country for biofuel production would address the potential food versus fuel conflict challenging biofuel production in Nigeria.

Keywords Biomass, Bio-sourced feedstock, Biofuel, Energy crisis, Food crisis, Renewable Energy

Introduction

Energy crisis is presently the biggest headache in Nigeria and lack of energy is the worst tragedy that can befall any 21st century society since life itself revolves around energy [1-2]. Although energy crisis is a global concern, the adverse impact of this crisis on both urban and rural populations in Nigeria is severe [3-4]. Energy is the power required for transportation, heat, light and even in manufacture of products. In science, energy is simply a quantitative property that must be transferred to an object in order to perform work, heat an object or the power derived from the utilization of physical or chemical resources to provide light, heat or work machines. It comes in various forms as seen in light, mechanical, chemical, electrical, heat, sound, gravitational, nuclear and atomic energy. Each form can be converted into the other. The demand for each of these forms of energy varies from place to place and it is related to advances in technology and population of the place [5]. However, identifying the available sources of energy and technology required to converting these sources into the most needed form to meet the societal demand are the basic challenges confronting the sector which if not properly tackled culminate into energy crisis [6]. Nevertheless, energy is significant in achieving economic growth and the state at which energy is exploited is a veritable indicator of the level of development of a nation [7-8]. Thus, conversion of available energy sources into thermal energy to meet the domestic and industrial requirements for direct heat, mechanical energy for direct use to drive machines and into electricity which is the most versatile form of energy should be treated bereft of levity.

The world generally needs energy to sustain the economy and make life worth living. Prior to industrial revolution era, sources of energy were mostly animals (beast of burden) and humans (slaves). As a veritable indicator of the level of development, these energy sources were linked with wealth and attributed to the number of slaves and animals one possesses [9]. The situation is similar today as the richest nations such as USA, China, Japan and others are ranked high in energy consumption. They constitute the developed nations, first world countries or world/super powers. On the contrary, the poor nations recognized as developing nations or third world countries are challenged with population explosion which equally translates to exponential increase in energy consumption. Generally, every nation irrespective of its status needs energy [10]. The influx of technological products coupled with population explosion is responsible to high energy demand seen recently [3, 11]. This worsens when there is no corresponding increase in exploitation and utilization of energy resources to meet the demand. A significant bottleneck in the supply of energy resources to the economy lead to energy crisis. Research shows that series of energy crises witnessed so far are linked to overdependence on fossil fuels [12-13]. Moreover, the continuous depletion of these fossil fuels and their adverse environmental impacts prompt the quest for clean and reliable alternatives for the fossil fuels. This paper reviews sources of energy to be exploited in order to meet the ever-increasing demand for energy in Nigeria.

In view of this development, researchers are focusing on exploiting the bio-economy for energy generation. Industrialized nations such as USA, China, Brazil, Malaysia and others have broken the monopoly of energy generation from hydrocarbon (fossil fuels) and have diversified by tapping into an unceasing energy source from bio-economy. Although traces of bio-related projects exist, Nigeria is yet to exploit her bio-economy for energy generation. Currently, energy crisis bedeviled the Nigerian society as the sector supplies only 4000MWto about six million customers amidst hundreds of million Nigerians who are yet to be linked to the national grid (USAID, 2020). Consequently, businesses and individuals run generators several hours per day at operating costs which vary from four to six times the tariff per kilowatt-hour on the public grid while biomass accounted for over 85% of total energy consumption to meet off-grid heating and cooking [6]. However, it is not appealing to exploit the bio-economy to curtail energy crisis as food and feed make up the largest sectors of the bio-economy constituting 12% and 49% of biomass demand respectively amidst food crisis [14].

Meanwhile, electricity which is one of the most versatile forms of energy is critical to national growth. The epileptic power supply currently experienced in the country is one of the major constraints to national development and several attempts have been made towards exploiting bio-sourced feedstock for bio-energy (electrical energy) generation. The available studies in this direction have been chronicled in this paper to assess the potential of using bio-sourced feedstock not just for bio-energy generation but also for blending/upgrading with/to transportation fuel. There is a growing interest in biomass conversion processes and many of them are exploited at varying stages of development. These processes can lead to the production of biofuels, biochemical and other related bioproducts. The biofuels can be bio-solid (wood), bio-liquid (biodiesel, bioethanol) and biogas (biomethane). However, the production of ethanol from sugar canein Brazil [15] has reached commercial level while others such as biofuel production from algae are currently at research and development level [16]. Similarly, in Nigeria, exploitation of bio-economy is advancing and biomass conversion processes abound at various stages of development. The conversion processes can be grouped into: bio-sourced feedstock for biofuels production and bio-sourced feedstock for bio-chemical production. However, more research interest is focused on the later with the aim of generating power from the bio-economy. More can be achieved if the technology is expanded beyond power generation to transportation fuel as currently limited information exist on the state of biomass conversion technologies for transportation fuels production in Nigeria [17]. Therefore the development of alternative fuels particularly biomass-derived fuels from locally available biomass require substantial research focus. Consequently, the potential to produce biofuel especially transportation fuels, notably biomass resources available from first, second, third and fourth generation feedstocks in Nigeria is reviewed based on availability. However, considerable attentions and laudable projects were earmarked to advance this course. Hence, this paper reviews the emerging biofuel production projects in the country. This would enable the authors to assess the journey so far in exploiting bio-sourced feedstock to solve the double-headed problems of energy crisis and environmental pollution.

2. Bio-Fuel: An Alternative to Fossil Fuel

Fuel is simply an energy source and can generally be any material that reacts with oxidizer or other substances to release energy as heat or to be used for work. They are grouped into two main sources: the renewable energy and non-renewable energy. Nonrenewable energy source comprises of the fossil fuels (coal, crude oil and natural gas) and nuclear fuel which are available in limited amount and take a long time to replenish [17]. The renewable counterpart comprises of wind, biomass, solar, geothermal and hydropower are constantly replenishing. However, the nonrenewable energy sources are regarded as dirty due to their impact on the environment as they were formed from fossilized (buried remains of plants and animals subjected to several geological processes) sources [5]. Biomass and fossil materials are both carbonaceous material and rich in energy contents. In this case, they are regarded as fuels: biofuel and fossil fuel respectively. Fossil fuel has been extensively exploited for many centuries while biofuel has been neglected perhaps rarely exploited conventionally [17]. Meanwhile, biofuel is a renewable energy source as its energy content is captured through natural processes and it is potentially renewable indefinitely. It is currently the largest renewable energy source with wider geographical spread while fossil fuel is a non-renewable energy source as its energy content is captured through geological processes which take a long time to replenish hence continuously depleted [4]. Fossil fuel is found in specific parts of the world making them more plentiful in some nations than others [2]. Biomass is organic material that comes from plants and animals, and includes crops, waste wood and trees. When biomass is burned, the chemical energy is released as heat and can generate electricity with a steam turbine. Biomass is often described as a clean renewable fuel and a greener alternative to fossil fuel for generating electricity.

Globally, bio-fuel is becoming more attractive as suitable substitute for fossil fuels due to the increasing demand for clean energy, declining fuel reserves and its contribution towards reducing dependence on fossil fuel [3]. The processing of biomass for bio-fuel, bio-power and other bio-products has important effects on the economy and on national development [18]. It reduces the over-dependence on oil and gas, eliminates environmental pollution associated with gas flaring and supports rural economies by creating jobs and providing additional income. Nigeria is yet to significantly exploit her resources and utilize them efficiently to meet her energy demand. This is seen as the country imports over 19 billion litres of gasoline among others into the country annually while the refineries produced less than 5% of these products [11, 13]. Currently, Nigeria is challenged with energy crisis and environmental pollution due to the low capacity utilization of existing refineries coupled with flared natural gas [13]. To reduce the nation's dependence on imported fuel, it is important to improve refinery utilization and diversify to other energy resources. Obviously, fossil fuel is not keeping pace with the increasing demand for environmentally friendly fuel, it is anticipated that biofuel will significantly impact on the country's petroleum products quality. With biofuel, the potential of replacing toxic octane enhancers in gasoline, and thus, reduces particulate emission, tailpipe emissions and ozone pollution is high [2]. Moreover, other benefits of biofuels are increased economic development, job opportunities, rural community empowerment, improved farming techniques, agricultural research and crop yield. Therefore the development of bio-fuels as a substitute from locally available bio-sourced feedstock should be given considerable attention. In the following sections, classification and availability of bio-sourced feedstock in Nigeria are presented.

3. Bio-Sourced Feedstock in Nigeria: Classification and Availability

Biomass refers to biological (plant and animal) material. It extends beyond the remains/residue of animal/plant to their waste especially agricultural waste products which are principally used as a source of fuel. The advances in technological development and science reveal that these biological materials are highly valuable feedstock for industrial production of chemicals, fuel and other related products hence they are bio-sourced feedstocks. The classification of these bio-sourced feedstocks is discussed in Section 3.1 and their availability in Nigeria is presented in Section 3.2.

3.1. Classification of Bio-Sourced Feedstocks

Bio-sourced feedstocks are materials derived from recently living biological material. They are generally called biomass which indicates that they are biological materials. These materials include mostly resources derived from plant and algae-based material that includes crop wastes, forest residues, purpose-grown grasses, woody energy crops, algae, industrial wastes, sorted municipal solid waste, urban wood waste, and food waste. Generally, Bio-Sourced feedstocks are classified by categories of plants or residues, by the products they produce, etc [17, 19].

3.1.1: Bio-Sourced Feedstocks Based on Residue

In this category, there are primary, secondary and tertiary residues [19]. Figure 1 indicates the sources and the products derived from these feedstocks.

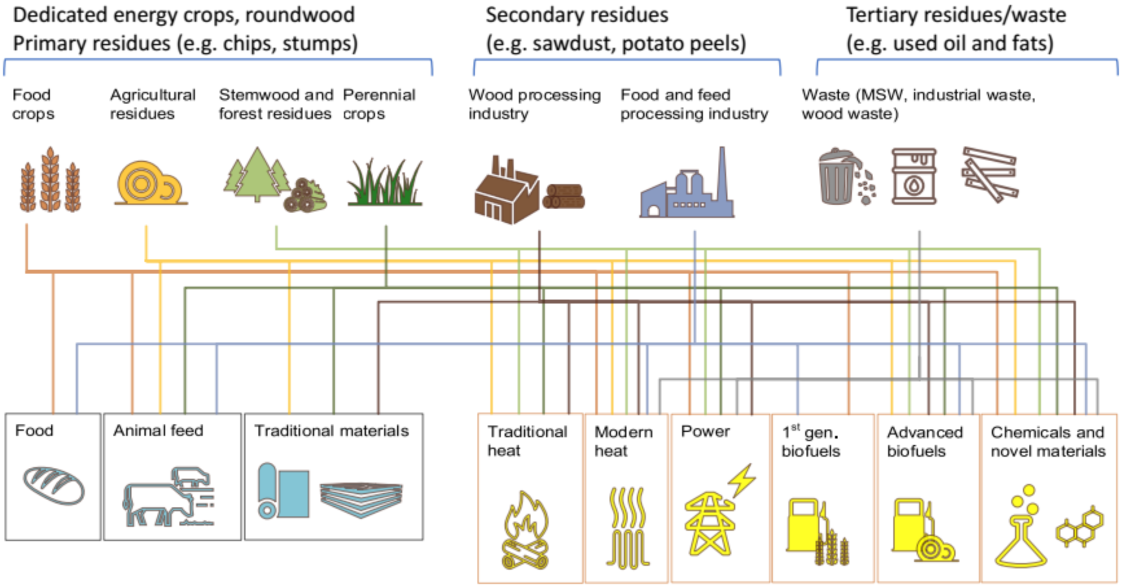

Figure 1: Classes of Biomass [19]

Primary Residues: These include chips, stumps and other residues from food crops, agricultural wastes and forest tree residues. Biomass from this category can be harnessed to produce mostly animal feed and other traditional materials.

Secondary Residues: These constitute industrial wastes from wood, feed and food processing industries. They include sawdust, potato peels and others exploited for animal feed, heating and power generation.

Tertiary Residues: These are mainly wastes from sewage and industries such as: used oil and fats that are converted to biofuels and bio-chemicals.

Bio-Sourced Feedstocks Based on Products

In terms of the products, biological materials are classified into four generations: first generation, second generation, third generation and fourth generation.

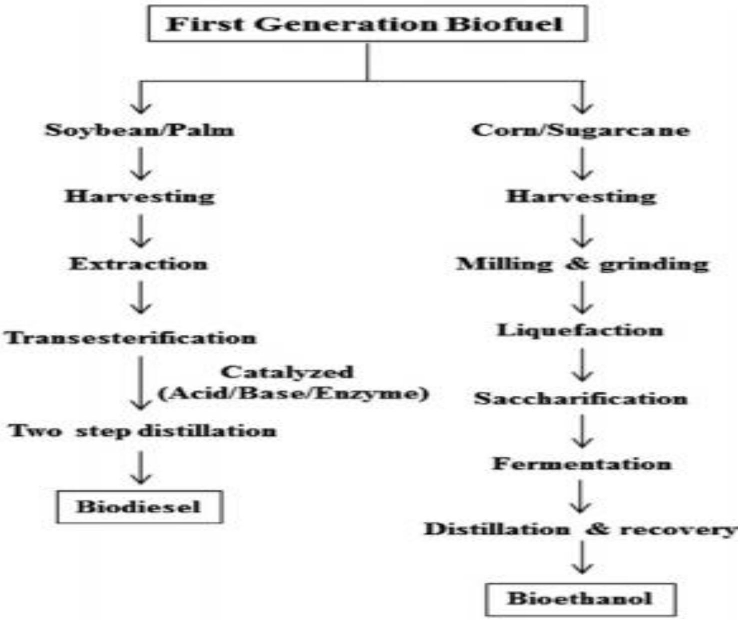

Figure 2: First generation bio-sourced feedstocks [20]

The First generation Bio-sourced Feedstocks: These are generally agricultural products for biofuels production. They are mostly energy crops (sugar or starch-based crops) and oilseeds as shown in Figure 2. This category of bio-sourced feedstocks is harnessed through fermentation and tranesterification for production of first generation biofuels. However, these feedstocks are mostly food for consumption and exploiting them for biofuel production has adverse effect on food price globally. The competition for food attracted research interest into the use of non-food biological materials [9].

Second Generation Bio-sourced Feedstocks: These are generally non-food (non-edible) biological materials and energy crops dedicated for biofuel production. They are lignocellulosic because they are composed of lignin and cellulose, found in woody tissues of plants. These include: crop residues, wood residues and dedicated energy crops cultivated mainly for biofuel production as shown in Figure 3. Studies show that there is a growing interest in exploiting second generation bio-sourced feedstocks since they are not in competition with food [19, 21]. However, cultivation of energy food crops requires land and other agricultural inputs thereby incurring costs. Hence, a cheaper and non-edible biological material was sought.

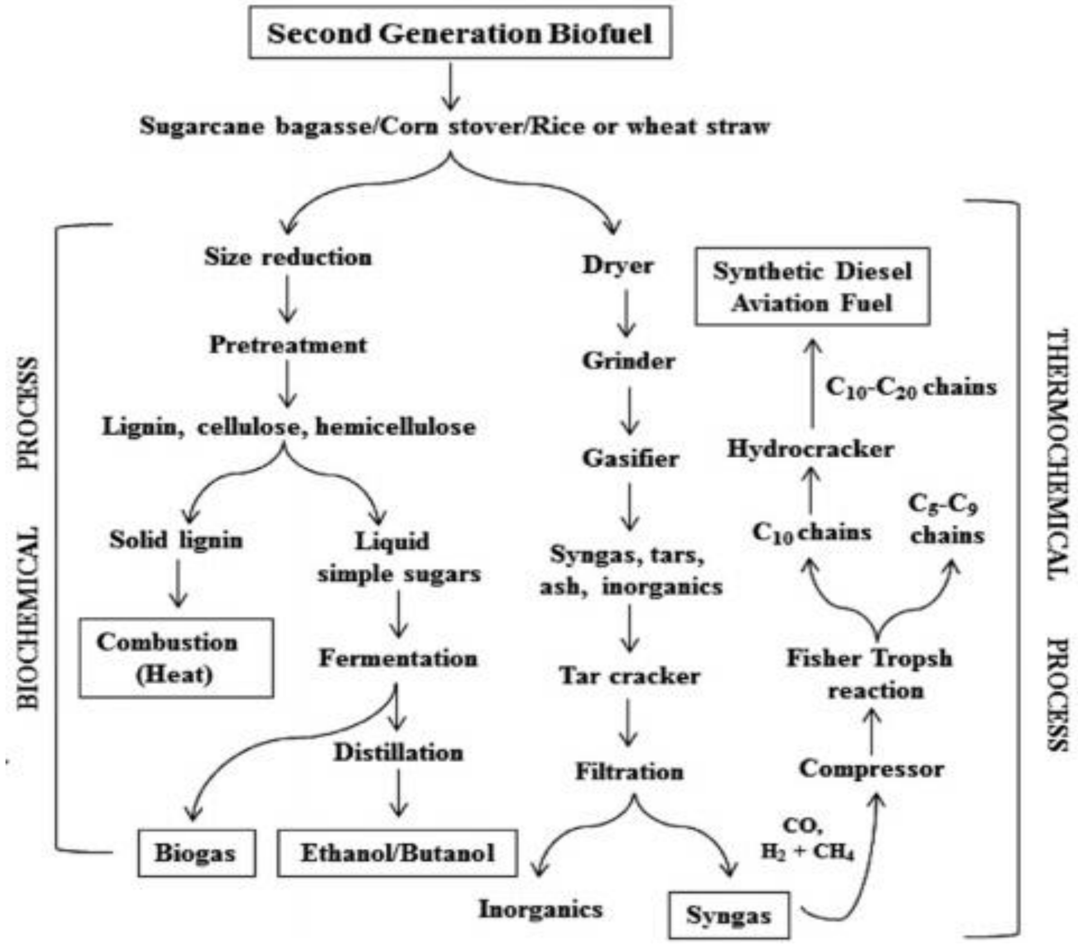

Figure 3: Second generation bio-sourced feedstocks [20]

Third Generation Bio-sourced Feedstock: These are bacteria and algae exploited for biofuel production because of their high carbohydrate or lipid/ oil contents as shown in Figure 4. Dutta *et al*. [20] discusses the role of bacteria and algae as biocatalysts in a wide variety of photosynthetic and fermentative processes leading to biofuel production. The use of these microbial cells (bacteria and algae) as bio-sourced feedstocks is more attractive as neither arable lands nor farming inputs such as: pesticides, fertilizers are required for cultivation. In addition, these microbial feedstocks are not edible as such are not in competition with food. However, their reliance on sunlight, ecological footprint, economic performance and geographical location are some of the challenges confronted this generation of bio-sourced feedstocks [20]. Hence, more advanced biological material was sought.

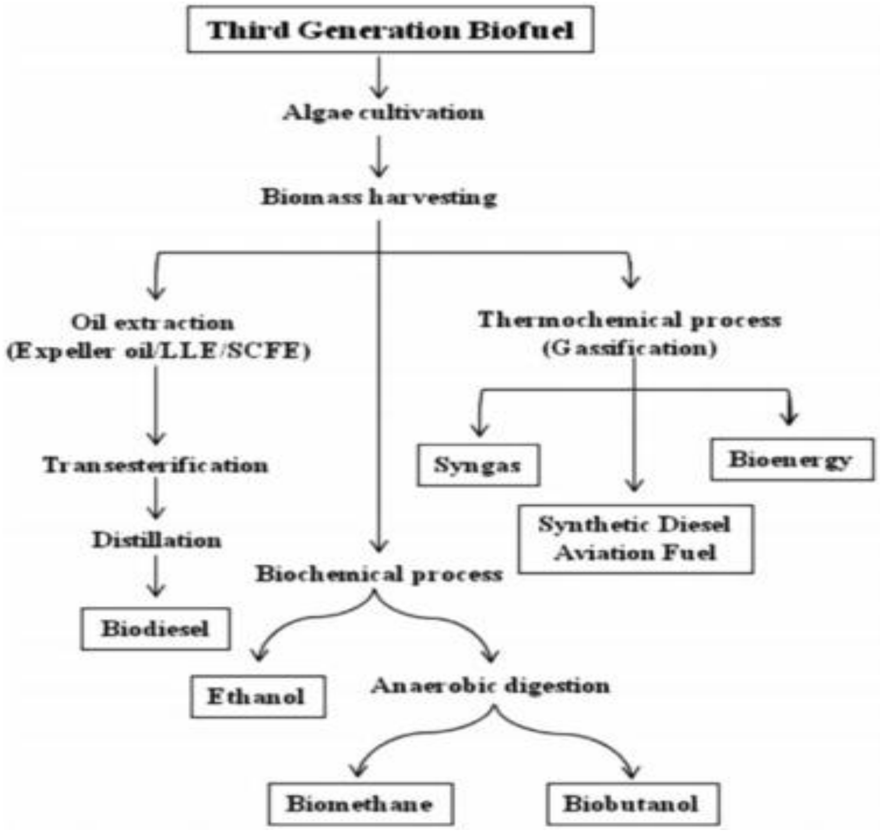

Figure 4: Third generation bio-sourced feedstocks [20]

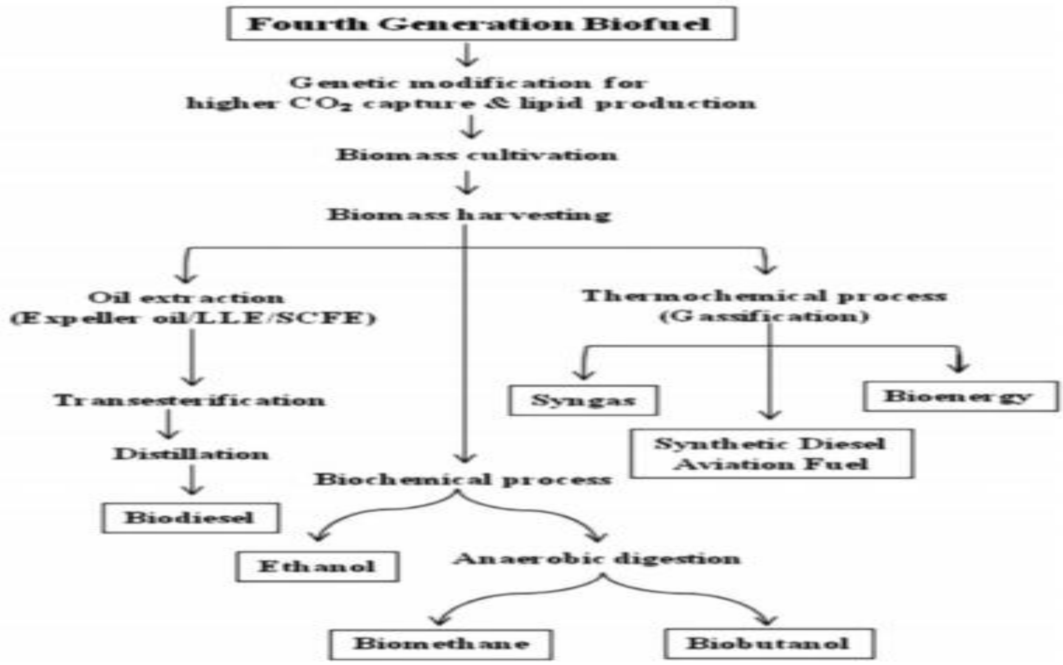

Figure 5: Fourth generation bio-sourced feedstocks [20]

Fourth Generation Bio-sourced Feedstock: These are genetically modified biomaterials harnessed for biofuel production. This requires application of metabolic engineering science in biosynthesis processes resulting to improve productivity. Most of the challenges confronting the previous classes of bio-sourced feedstocks are conveniently handled by the fourth generation feedstocks. Genetically modified energy crops such as wheat and barley require less farm inputs (fertilizers, pesticides and water) and are generally fast growing crops with high yield. This process can be exploited to increase CO_2 capture and lipid production [20, 22]. Genetically modified feedstocks are more hydrolysable biomass with improve alcohol productivity as shown in Figure 5. The growing interest recently in the production of advanced biofuels with desired properties high energy density, low hygroscopic and less corrosive nature is attributed to the emergence of these genetically modified bio-sourced feedstocks [17].

3.2. Availability of Bio-sourced Feedstock in Nigeria

Globally, bio-sourced feedstock is becoming more attractive as suitable substitute for fossil fuels due to quest for clean and environmental friendly energy. Nigeria is blessed with these resources due to availability of arable lands and water coupled with diverse agro-friendly climatic conditions as the rain forest zones in the southern part on Nigeria generate the highest quantity of woody biomass while savannah zones in the northern counterpart generate more crop residues [23-25]. These resources can be conveniently harnessed as biofuel, bio-power, and bio-products for the betterment of economy. However, prior to her independence and beyond, agriculture was the mainstay of Nigerian's economy and account for more than 50% of the GDP and 75% of export revenue [26]. Agricultural sector which produces starch-based crops and oilseeds in Nigeria is mainly influenced by land tenured system and the traditional smallholders are subsistence farmers despite chunk of arable land for cultivation. In this section, the availability of these bio-sourced feedstocks is presented. Bio-sourced feedstocks can be obtained generally from two different categories: conventional agricultural products such as: starch-based crops, and oilseeds; and lignocellulosic products and residues which fall into first three generation bio-sourced feedstocks [27]. Generally, the biological materials available in Nigeria are mostly the first three generation bio-sourced feedstocks. These are: starch-based crops and oilseeds (first generation), residue/lignocellulosic (second generation) and the algae (third generation).

3.2.1. Starch-based Crops and Oilseeds in Nigeria

Starch-based crops and oil seeds such as sugarcane, cassava, corn, sweet sorghum, oil palm, soybean, coconut and others constitute the first generation bio-sourced feedstock available in Nigeria. Specifically, sugarcane, cassava, sweet sorghum and maize are plants with high energy contents hence they are called energy crops. With approximately 92,376000 ha land area of which 37.3% of the agricultural are is arable land as shown in Figure 6, the potential for energy crop cultivation in Nigeria is huge [28]. Moreover, availability of different sources of water and suitable climatic conditions are favorable for energy crops cultivation. This is attributed to the availability of several dedicated energy crops grown on marginal or degraded agricultural land for biofuel production in Nigeria [29-30].

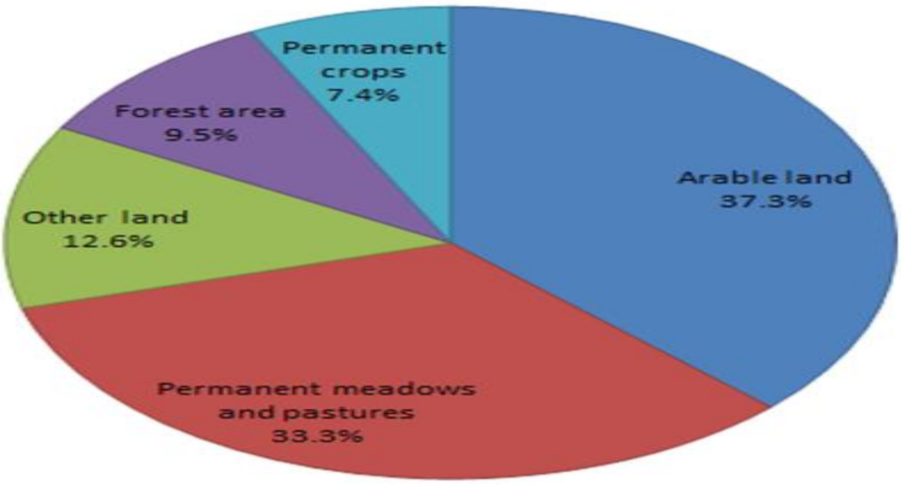

Figure 6: Nigeria land use in 2011 (latest update: 2015) [31]

Meanwhile, in more than a decade ago, there has been continuous increase in the areas of land harvested and tonnes of energy crops produced in Nigeria. The Food and Agriculture Organization of the United Nations (FAO) reported that substantial cultivation of energy crops was witness in Nigeria as shown in Table 1. These energy crops are the major feedstocks for emerging biofuel projects in Nigeria. However, these agricultural resources which are candidates for biofuel production are currently harness for food. On the other hand, there are crops or trees such as: oil palm, coconuts whose seeds produce 15% to 50%+ oil. Oil can be extracted by crushing the seed and squeezing to get the oil [17]. Thus, energy crops and oilseeds can easily be converted via fermentation and tranesterification to bioethanol and biodiesel respectively. Some of these feedstocks available in Nigeria are presented next.

Table 1: Energy crops cultivation in Nigeria 2004–2013 [28]

Energy crop	Element	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Sugar cane	Area harvested (Ha)	43,000	44,000	47,000	63,000	71,890	73,060	73,060	74,000	74,000	74,000
	Yield (Hg/Ha)	198,605	207,727	210,000	239,048	196,421	191,853	191,623	195,946	195,946	195,946
	Production (tonnes)	854,000	914,000	987,000	1,506,000	1,412,070	1,401,680	1,400,000	1,450,000	1,450,000	1,450,000
Cassava	Area harvested (Ha)	3,531,000	3,782,000	3,810,000	3,875,000	3,778,000	3,129,030	3,481,900	3,737,090	3,850,000	3,850,000
	Yield (Hg/Ha)	110,011	109,902	120,003	112,026	118,004	117,679	122,155	140,225	140,260	140260
	Production (tonnes)	38,845,000	41,565,000	45,721,000	43,410,000	44,582,000	36,822,250	42,533,180	52,403,455	54,000,000	54,000,000
Sorghum	Area harvested (Ha)	7,031,000	7,284,000	7,308,000	7,812,000	7,617,000	4,736,830	4,960,130	4,891,150	5,500,000	5,500,000
	Yield (Hg/Ha)	12,200	12,600	13,500	11,595	12,233	11,145	14,397	14,101	12,545	12,182
	Production (tonnes)	8,578,000	9,178,000	9,866,000	9,058,000	9,318,000	5,279,170	7140,970	6,897,060	6,900,000	6,700,000
Maize	Area harvested (Ha)	3,479,000	3,589,000	3,905,000	3,944,000	3,845,000	3,350,560	4,149,310	6,008,470	5,200,000	5,200,000
	Yield (Hg/Ha)	16,002	16,598	181,82	17,049	19,571	21,961	18,502	15,279	18,096	20,000
	Production (tonnes)	5,567,000	5,957,000	7,100,000	672,4000	7,525,000	7,358,260	7,676,850	9,180,270	9,410,000	1,0400,000
Oil, palm	Production (tonnes)	1,094,000	1,170,000	1,287,000	1,309,000	1,330,000	1,233,050	970,820	930,000	940,000	960,000
Soybeans	Area harvested (Ha)	587,000	601,000	630,000	638,000	609,000	592,000	281,890	608,650	570,000	600,000
	Yield (Hg/Ha)	8995	9401	9603	9091	9704	7206	10,112	9263	10,175	10,000
	Production (tonnes)	528,000	565,000	605,000	580,000	591,000	426,590	285,050	563,810	580,000	600,000
Millet	Area harvested (Ha)	4620000	4685000	4,971,000	5,056,000	4,904,000	3,787,730	4,364,140	2,889,020	3,800,000	3,800,000
	Yield (Hg/Ha)	14,500	15,300	155,00	16,001	18,483	13,016	11,848	4400	13,158	13,158
	Production (tonnes)	6,699,000	7,168,000	7,705,000	8,090,000	9,064,000	4,929,950	5,170,430	1,271,100	5,000,000	5,000,000
Cocoa, beans	Area harvested (Ha)	1,062,000	1,088,698	1,104,000	1,359,550	1,349,130	1,354,340	1,272,430	1,240,000	1,196,000	
	Yield (Hg/Ha)	3879	4051	4393	2652	2720	2684	3137	3153	3202	
	Production (tonnes)	412,000	441,000	485,000	360,570	367,020	363,510	399,200	391,000	383,000	
Coffee, green	Area harvested (Ha)	3580	3670	3710	2000	2100	1800	2000	2100	2200	
	Yield (Hg/Ha)	13,017	13,597	14,394	12,600	14,286	11,333	12,000	12,381	12,727	
	Production (tonnes)	4660	4990	5340	2520	3000	2040	2400	2600	2800	
Groundnuts, with shell	Area harvested (Ha)	2,097,000	2,187,000	2,224,000	2,202,638	2336,400	2,643,330	2,789,180	2,342,810	2,420,000	2,360,000
	Yield (Hg/Ha)	15,498	15,903	17,199	12,927	12,296	11,265	13,621	12,646	12,690	12,712
	Production (tonnes)	3,250,000	3,478,000	3,825,000	2,847,373	2,872,740	2,977,620	3,799,240	2,962,761	3,071,000	3,000,000
Rice, paddy	Area harvested (Ha)	2,348,000	2,494,000	2,725,000	2451,000	2,382,000	1,836,880	2,432,630	2,579,540	2,685,000	2,600,000
	Yield (Hg/Ha)	14199	14302	14833	12,999	17,544	19,306	18,386	17,706	18,000	18,077
	Production (tonnes)	3334000	3567000	4042000	3,186,000	4,179,000	3,546,250	4,472,520	4567,320	4,833,000	4,700,000
Cotton lint	Production (tonnes)	171,000	190,000	208,000	165,000	180,000	130,000	220,000	103,000	111,500	
Cottonseed	Production (tonnes)	302,000	323,000	350,000	280,000	305,000	225,000	370,000	175,000	189,000	130,000
Taro (cocoyam)	Area harvested (Ha)	640,000	667,000	712,000	739,000	728,000	482,460	520,130	455,301	500,000	500,000
	Yield (Hg/Ha)	74,000	75,982	76,868	67,605	73,997	62,872	56,853	71,727	69,000	69,000
	Production (tonnes)	4,736,000	5,068,000	5,473,000	4,996,000	5,387,000	3,033,340	2,957,090	3,265,740	3,450,000	3,450,000

Sugarcane: It is widely known and exploited for its high energy content. As the name implies, sugarcane contains free sugars (sugar crop). It is mostly used in bioethanol production and many industrialized nations have achieved sustainable biofuel production from sugarcane [32-33]. Sugar beet and the bagasse are raw materials for bioethanol production [34]. In Nigeria, sugarcane is cultivated at subsistence level for consumption and as feed for livestock in all parts of the country as favored by Nigerian weather [33]. However, due to high demand for biofuel production from sugarcane, there are dedicated sugarcane commercial farm by Nigerian National Petroleum Corporation (NNPC) and other investors for bioethanol production for its Automotive Biofuel Program [35]. This is follow up with the construction of 10,000 units of mini refineries and 19 ethanol bio-refineries for the annual production of 2.66 billion litres of fuel grade ethanol [17, 36].

Cassava: It is a starch-based root crop with energy/carbohydrate content second to sugarcane. Cassava is typically used as food staples throughout the world. As energy crop, it can easily be converted, via traditional fermentation methods, to bioethanol. Nigeria is leading the world in cassava production [15, 37-38] and it is grown on a commercial scale mostly in the humid tropical zones of the southern Nigeria. The crop attracted farmers and researchers interest when it graduated from being famine reserve crop initially, then to being a rural staple food crop, then a cash crop for urban consumption, and finally to being an industrial raw material for biofuel production [39]. Thus, cassava has high potential as industrial raw material for ethanol production in Nigeria [36]. There are several ethanol bio-refineries in Nigeria for ethanol production using cassava [35].

Corn: It is produced in greater weight each year than any other grain around the world which makes it suitable for cultivation as a fuel source. Corn also referred to as maize is a biological material used as feedstock for the production of bioethanol in Nigeria. Cultivation of corn utilizes C_4 carbon fixation, as opposed to the C_3 carbon fixation process of plants like soybeans and smaller grains and as such corn is a more effective carbon source. Research shows that ethanol obtained from corn is estimated to accounts for 40% greenhouse gas emission savings [40-41]. In Nigeria, cultivation of maize is favored mainly by temperate climates and its water consumption is low. However, the crop uses large amounts of fertilizers and pesticides, and thus consumes fossil fuel energy [17].

Sweet Sorghum: It is one of the energy crop cultivated primarily in Nigeria for food/beverages and roofing in local communities. The high sugar contents in sorghum readily available within the hollow stem of the plant gives the crop an economic advantage over starch-based crops as enzymatic conversion of starch to sugar is not necessary for biofuel production. The crops is commercially grown in Nigeria as the country is second to US in the world as top producer of sorghum [42]. However, apart from competition with food, the use of sorghum as bio-sourced feedstock is constrained because of its seasonality.

Soybean: It is one of the oil crops grown for consumption and biodiesel production worldwide. The oil is transesterified to make biodiesel. The crop is favorable grown in Nigeria as the climate is suitable for large-scale production. Soybean as a bio-sourced feedstock is gaining more attention as the country ranked 13th largest producer of soybean in the world [43].

Oil palm is a cash crop grown in tropical region of Nigeria. It has valuable components beyond production of biofuel. The fruit comprises of kernel (endocarp) in which non-edible oil is extracted and the shell used as fuel or construction material and enclosed with pulp and mesocarp. The pulp is squeezed to extract edible (palm) oil. Meanwhile kernel oil is used primarily for the production of soap while palm oil can be utilized for soap production too. However, both oils can be subjected to transesterfication process to produce biodiesel. As the fourth most produced commodity in Nigeria, oil palm is grown in the tropical region of Nigeria via small scale farming, semi-wild palms and commercial palms plantations [24, 44]. Oil palm is a more preferred bio-sourced feedstock for biodiesel production compared to other oil crops such as soybeans, rapeseed or sunflowers due to its high oil content. Consequently, new oil palm plantations for biodiesel production are emerging in Nigeria and most of them are government-owned. Nigeria, Indonesia and Malaysia are top producers of palm oil in the world.

There are other energy and oil-bearing crops available for biofuel production in Nigeria. Coconut, sesame, groundnut and cotton are not presented. However, Table 2 summarized potential of derivable biofuels from ten bio-sourced feedstocks: cassava, groundnut, corn, sugarcane, soybeans, sesame, and cotton seed in Nigeria in order of decreasing biofuel yield.

Table 2: Biofuel potential production in Nigeria [24]

Derivable feedstock	Cultivated area (ha) 2007	Derivable bio-fuel type	Estimated Biofuel production potential (million litres, ML)
Sesame	196,000	Biodiesels	136.4
Palm oil	3,150,000	Biodiesels	18742.5
Palm kernel	3,150,000	Biodiesels	18742.5
Ground nut	2,230,000	Biodiesels	2361.6
Soybean	638,000	Biodiesels	284.5
Coconut	41,000	Bioethanol	110.2
Sugarcane	63,000	Bioethanol	378
Cotton seed	434,000	Biodiesels	141.1
Cassava	3,875,000	Bioethanol	15500
Sweet corn	3,944,000	Bioethanol	678.4

These first generation bio-sourced feedstocks are in competition with food and harnessing them for biofuel production is not sustainable as it deprives her growing population of the much needed energy food for survival. The availability non-food bio-sourced feedstock in Nigeria is highly encouraged for sustainable production of biofuel and it is presented next.

3.2.2. Agricultural Residue/Lignocellulosic and Wastes in Nigeria

Agricultural residues and waste generally constitute the second generation bio-sourced feedstocks for biofuel production. Nigeria has abundance supply of these feedstocks on daily basis and can harness them for biofuel production. These bio-sourced feedstocks are generally organic materials produced as byproduct during the harvesting and processing ofagricultural crops and animal rearing including waste from human activity. However, the residue from agricultural activity is presented in section 3.2.2.1. Wastes from human and industrial activities (Municipal, industrial, sewage) are presented in 3.2.2.2.

3.2.2.1: Agricultural Residues and Wastes

Agricultural residues are mostly non-edible (Lignocellulosic)**.** There are two categories of residues from agro-related activity. The residues that are mainly produced at the time of harvest are primary or field based residues while those produced along with the product during processing are secondary or processed based residues. The can be sourced from cropland (crop residue) and forest as forest residue [17]. However, these residues irrespective of the type are heterogeneous mixtures, varying in moisture content, bulk density, particle size and distribution depending on the mode of handling. Furthermore, they are usually fibrous, low in nitrogen and vary with geographical location [45].

Table 3: Proximate composition of major crop residues [45]

Crop residues	Moisture content (%)	Crude protein	Organic matter	Crude fibre	Ether extract	Ash	Nitrogen free extractives
Maize stover	10	2.8	85-91	28-46	1-2	9-15	35-53
Sorghum stover	10	3-6	96	31-35	1-2	4	50-56
Rice straw	10	2-9	75-90	20-45	1-4	10-25	29-48
Groundnut haulms	10-12	11-17	87-90	21-29	1.5-2.5	10-13	51-57
Cassava tops	70-80	17-27	89-90	8-26	3-8	6-11	35-60
Sugar cane tops	70-80	5-8	81-95	28-34	1.5-2.5	5-9	44-54
Cocoa pods	75	2-9	75-90	20-45	1-4	10-25	33-56
Empty oil palm fruit bunch	56	3-4	95	-	6-8	5	-

Crop Residues: These residues are generally materials left or burnt on farms after the harvest of desired crops and are known as primary or field based residues. The secondary (processed based) residue are left over along with the product during processing are secondary or processed based residues Research shows that the processed based (secondary residues) are more valuable as bio-sourced feedstocks due to their high energy content [46]. However, the field based (primary) residues can be used as bio-sourced feedstocks depending on chemical composition of the crop residue. The residue chemical composition varies depending on factors such as: age of residue or stage of harvest, physical composition including length of storage and harvesting practices [47]. The approximate compositions of some major crop residues available in Nigeria are presented in Table 3.

However, grasses can be loosely included in this group of feedstock. The residues are commonly used as manure (compost manure) to improve soil fertility. They are also used as fodder for livestock as well as erosion control for soil conservation. Prior to the next farming season especially during land preparation about 50% of the residue are burnt. Crop residues such as: straws, stalks, and bagasse can be used for biofuel production since they are non-edible. Some of the major crop residues available in Nigeria are presented in Table 4. The energy content of these residues is high and can contribute immensely to the nation's economy, particularly those from cassava, rice and maize.

Table 4: Crop residues and energy potential in Nigeria [48]

Crop	Product-ion ($\times 10^3$ t)	Residue type	RPR	Moisture Content (%)	Total residue (million tons)	% available	Weight available (million tons)	LHV (MJ/Kg)	Residue energy potential (PJ)
Rice	3368.24	Straw	1.757	12.71	7.86	100	7.86	16.02	125.92
		Husk	0.2	2.37	1.19	100	1.19	19.33	23
Maize	7676.85	Stalk	2	15	15.35	70	10.75	19.66	211.35
		Cob	0.273	7.53	2.1	100	2.1	16.28	34.19
		Husk	0.2	11.11	1.54	60	0.92	15.56	14.32
Cassava	42533.17	Stalks	2	15	85.07	20	17.01	17.5	297.68
		Peelings	3	50	127.6	60	76.56	10.61	812.3
Groundnut	3799.25	Shells	0.477	8.2	1.81	100	1.81	15.66	28.35
		Straw	2.3	15	8.74	50	4.37	17.58	76.83
Soybean	365.06	Straw	2.5	15	0.91	100	0.91	12.38	11.27
		Pods	1	15	0.37	100	0.37	12.38	4.58
Sugarcane	481.51	Bagasse	0.29	50	0.14	80	0.11	18.1	1.99
		Tops/leaves	0.3	10	0.14	100	0.14	15.81	2.21
Cotton	602.44	Stalk	3.743	12	2.25	100	2.25	18.61	41.87
Millet	5170.45	Straw	1.75	15	9.05	80	7.24	12.38	89.63
Sorghum	7140.96	Straw	1.25	15	8.93	80	7.14	12.38	88.39
Cowpea	3368.24	Shell	2.9		9.77	50	4.89	19.44	95.06
Total							**145.62**		**1958.94**

RPR – Residue to product ratio; LHV – lower heating value; PJ – petajoules

Ben-Iwo [17] reported that total amount of crop residue estimated to be potentially available for energy is 150 million tonnes and assuming 30% conversion of the residue to bioenergy, then Nigeria can generate 0.60 EJ which is 34% of the current energy consumed in Nigeria. However, most of the residues produced were not captured due to poor data management coupled with about 50% of the burnt residue during land clearing indicating that more can be achieved from residue to biofuel conversion in Nigeria.

Meanwhile, in processing these residues to biofuel, intractable waste products (spent residues) are often encountered and they are difficult to convert into valuable biofuels due high lignin, carbohydrates contents. However, such wastes can be further harnessed to syngas via thermochemical conversion in biorefineries instead of disposing into the environment [5].

Table 5: Biomass stock in forest

FRA 2010 category	Forest Biomass (million metric tonnes oven-dry weight)			
	1990	2000	2005	2010
Above-ground biomass	3,459	2660	2261	1861
Below-ground biomass	830	638	543	447
Total living biomass	4289	3298	2804	2308
Dead wood	601	462	392	323
Total	**4890**	**3760**	**3,196**	**2,631**

Forest Residues: Like crop residues, forest residues are by-products of forest resources. They include by-products from wood processing such as: sawdust, sawmill rejects, veneer rejects, veneer log cores, edgings, slabs, trimmings, and other residues from carpentry and joinery. The availability of these residues is linked to the productivity of the processing industry. Simonyan and Fasina [48] reported that the residue yield from sawmill for export is between 15 and 20% of the total biomass (full tree) or 30 – 45% of the actual biomass (logs) delivered to sawmill. However, the composition, volume and quality determined the biomass types. Residues from forest in Nigeria are enormous as seen in Table 5. It is estimated that about 10 million hectares are forest reserves which is about 11.3% of the total land area of Nigeria [49]. Forest biomass is classified into above-ground biomass and below-ground biomass. All living biomass above the soil such as: barks, branches, foliage, seeds, stems and stumps are Above-ground biomass while all living biomass of live roots are Below-ground biomass [50].

Nigeria's land covers range from tropical rain forest in the south generating more residues (woody-biomass) than the Sahel savannah in the northern part of the country [39, 48]. Specifically, there are eight major forest types in Nigeria and these are: savanna woodland forest, lowland rain forest, freshwater swamp forest, mangrove forest, montane forest, riparian forest, plantain (agriculture) and plantain (forest). Table 6 and 7 show the forest resources and forest products in Nigeria, respectively. Forest residues: Forest residues, consisting of logging residues (tops, branches) and process residues (off-cuts, sawdust) from wood industries, and demolition wood, constitute a large potential which might be available at lower prices compared to logs. The availability of these resources depends on the efficiency of the industry they come from. Typical residue yield from a tropical sawmill for export is between 15 and 20% of the total biomass (full tree), or 30 to 45% of the actual biomass (e.g., logs) delivered to sawmill. These biomass types vary in composition, volume and quality (particularly moisture content – from 12 to 55% on a dry basis), depending on the processing steps and soils of origin [27].

Table 6: Forest resources in Nigeria

Forest types	Area in forest reserves (ha)	Portion of total forested area in reserves (%)	Area in free forest areas (ha)	Total areas of forest types in FRS study area (ha)	Portion of total forested area in FRS study area (%)	Portion of total forested area in FRS study area (%)
Savanna woodland	1,424,029	52.0	6,922,662	9,736,158	58.8	58.0
Lowland rainforest	832,237	30.4	1,580,928	2,881,755	13.4	17.2
Freshwater swamp forest	226,242	8.3	1,430,436	1,656,499	12.1	9.9
Mangrove forest	48,859	1.8	945,592	997,451	8.1	5.9
Montane forest	18,271	0.7	466,036	685,150	4.0	4.1
Riparian forest	46,583	1.7	431,537	509,415	3.7	3.0
Plantain agriculture	0	0	0	0	164,100	1.0

Table 7: Production of forest products in Nigeria

Product types	Production	
	m^3	tons
Chemical wood pulp	-	14,000
Industrial round wood	2,279,000	-
Woodfuel	63,214,728	-
Wood charcoal	-	3,940,089
Paper board	-	18,000
Particle board	40,000	-
Plywood	56,000	-
Printing /writing paper	-	1,000
Pulp wood/round/split	39,000	-
Recovered paper	-	8,000
Sawn logs + Veneer logs	7,100,000	-
Sawn wood	2,000,000	-
Veneer sheets	1,000	
Wrapping +packaging +board	-	18,000

Forest residue has the potential of contributing substantially nation's biofuel resources. These can be harnessed by utilizing its resources for industrial purposes. In industrialized nations, forest based companies are producing liquid biofuels and other biomaterials in 'biorefineries' [51]. Nigeria, with the huge potential has the opportunity of harnessing these bio-sourced feedstocks for biofuel generation.

3.2.2.2: Availability of Waste as Bio-Sourced Feedstocks

Nigeria is one of the most populated countries in Africa and huge wastes are generated on daily basis due to the daily activities of people. Hence, the environment is highly polluted with waste. The effect of waste on the environment is detrimental to life and as well occupied space in most cases lead to flood. Based on the originated source, the waste could municipal solid waste (MSW), food waste, industrial waste and animal waste [17].

Municipal Solid Wastes (MSW): Nigerian urban areas are densely populated as such wastes from domestics, economics and industrial activities are generated on daily basis. Obviously, MSW increases with increasing activities related with industrialization and urbanization [52-53]. The municipal solid wastes (MSW) in Nigeria contain all sources of wastes from domestics, economics and industrial activities such as: refuse, construction and demolition debris, garbage, electronic wastes dumped on roadsides or any available open pits and even water sources not minding their impact on the health of the people and both aquatic and terrestrial animals [54].

Several studies carried out revealed the composition of MSW in terms of average percentage by weight. According to Bamgboye and Ojolo [55], MSW in Lagos Island contains 60.55 for vegetable materials, 15.38 for paper products, 6.26 for plastics/rubber, 3.78 for ferrous metals, 0.36 for non-ferrous metals, 2. 19 for glass and 3.48 for textiles. The vegetable products yield 5.15 liter /kg TS to 5.83 liter /kg TS. However, MSW generation rate of 1.10 kg/capita/day is reported in Ibadan [56-57]. With these studies as the basis of estimation, 3.168 million tonnes of waste was generated by the urban population in Nigeria in 2010. Assuming 60% recovery was achieved, 1.90 million tonnes (with equivalent energy of 186.33 GJ) of waste can potentially be converted into energy. Figure 7 shows composition of MSW in Nigeria.

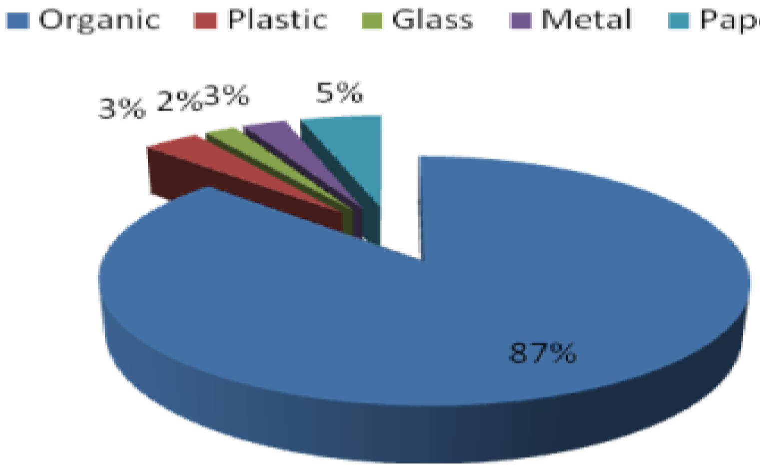

Figure 7: Municipal solid waste composition in Nigeria [56]

Food Industry Wastes: The processed based (secondary) residues are mainly generated by food processing industry, hotels, breweries, eateries and restaurants. The wastes could be solid or liquid foods or other related wastes that are not up to the specified quality control standards, peels and remains from crops, fruits and vegetables. To cater for the nutritional interest of the growing population of more than 200 million Nigerians and aliens, the number of food processing companies, restaurants, hotels and related service providers are on the increase resulting to corresponding increase in waste generated [2]. These wastes contain both soluble and insoluble organic matter when improperly disposed constitutes environmental pollution. These can be anaerobically digested to produce biogas or fermented to produce ethanol [48].

Industrial Waste: Industrial activities from chemical and process plants especially refineries and mineral processing industries generate large amounts of wastewater or sewage (sludge) which are discharged mostly to water source after treatment. However, these wastes may be organic or inorganic requiring different methods of treatment depending on the characteristics and quantity of wastewater. Bhattacharya *et al.* [58] classified these wastes as: Physical unit processes (filtration, screening, mixing, flocculation, sedimentation and floatation), chemical unit processes (precipitation, disinfestations and adsorption) and biological unit processes (aerobic processes, anaerobic processes and anoxic denitrification). These wastes can be anaerobically digested to produce biogas.

Animal and Human wastes: These are mainly human and animals feces (dungs), droppings of livestock and their remains (carcasses). They are mostly used as manure in order to improve soil fertility. The main components of these wastes are mainly organic material, moisture and ash. Consequently, animal wastes decomposed under aerobic conditions to produce CO_2 and stabilized organic materials. However, their decomposition under anaerobic conditions yield CH_4, CO_2 and stabilized organic materials [17]. The quantity of animal waste produced generally depends on the amount of feed consumed, the quality of the feed and the live weight of the animal [59]. Meanwhile, livestock generates huge amount of waste and this can be converted into biogas by anaerobic digestion while dungs of ruminant animals offer potential for biogas production. As at 2010, the population of livestock, average dry matter per animal per day, biogas yield per kg of dry matter, estimate of total dry dung production and the theoretical potential biogas yield per annum for Nigeria as presented in Table 8 was promising. In fact, Ben-Iwo *et al.* [17] reported that a total estimate of 15.762 million tons per year of dry matter from animal dung was calculated for 2010 with potential biogas yield of 4.19 × 109 m^3/year (29.25 GJ).

Furthermore, with a total population of about 200 million, Nigeria has huge potential bio-sourced feedstock from human waste. According Jossy [60], with estimated dry matter of 0.09 kg per head per day and 0.45 m^3 per kg dry matter as given by Jain [61], estimated biogas potential for the country with 200 million people will be huge. Presently, due to increasing interest in livestock production, poultry farming and general agricultural practice in addition to the ban on importation of these products, the quantity of dry matter from animal dung in 2020 could be ten times higher than that of 2010 indicating huge potential biogas yield to exploit.

Table 8: Animal wastes production and potential for biogas yield in Nigeria, 2010 [61-62]

Type	Population	Dry matter production kg/head/day*	Amount of dry matter produced per year kg	Biogas yield			
				Fraction recoverable	Amount of dry matter available per year kg	m^3 /kg dry matter**	Total potential m^3/year
Cattle	18,871,339	2.860	1.970×10^{10}	0.3	5.910×10^9	0.20	1.182×10^9
Goat	65,651,252	0.552	1.323×10^{10}	0.4	5.292×10^9	0.25	1.323×10^9
Pig	6,040,820	0.661	1.457×10^9	1.0	1.457×10^9	0.56	0.815×10^9
Sheep	37,422,554	0.329	4.493×10^9	0.3	1.348×10^9	0.25	0.337×10^9
Chicken	101,676,710	0.043	1.596×10^9	1.0	1.596×10^9	0.28	0.447×10^9
Duck	9,553,911	0.051	0.177×10^9	0.9	0.159×10^9	0.56	0.089×10^9
Total					15.76×10^9		4.19×10^9

Generally, agricultural residue and waste are generated on daily basis in Nigeria and utilizing them as bio-sourced feedstock for biofuel is more economical as it does not require irrigation, land and other agricultural inputs. Furthermore, the pervasive use of firewood especially in the rural areas would be curtailed and the wastes to biofuel conversion concept create a clean and healthy environment [63]. Biogas, a methane-rich gas produced by anaerobic treatment of these residues or waste is a multi-purpose as it eliminates waste/residue from the environment creating a pollution free environment thus circumventing the tremendous sanitary problem in Nigeria while generating the biogas. The technology is flexible and not capital nor energy intensive [63-64]. The technology is straightforward and practicable on both small and large scale. It can be implemented virtually everywhere in Nigeria utilizing household waste, sewage, industrial waste and other organic waste to biogas. Apart from utilizing biogas for electricity generation, the biofuel produces fertilizer as a valuable by-product. Moreover, the biogas can be upgraded/blended to transportation fuel [17].

Obviously, biogas production is an economical way of harnessing waste to generate electricity, produce fertilizer and more importantly fuel for cooking and transportation. Meanwhile, in Nigeria, the preferred use of biogas is as cooking fuel, this is attributed to the production capacity. However, electricity generation from biofuel would be more attractive for large-scale applications considering the poor electricity situation in the country [17]. Avalanche waste is generated in Nigeria daily and could be ten times as reported by Suberu *et al.*, [65] as shown in Table 9.

4. Emerging Biofuel Project in Nigeria

China, Brazil, India and several advanced nations have invested immensely into bioenergy research. As at 2010, China and India were the largest bioenergy producers with generating 20% and 17%, respectively of the world's bioenergy [66]. There is a growing interest in harnessing bio-resources for biofuel production in Nigeria. Consequently, the country along with the United States was the third and fourth largest bioenergy producers with shares of over 80% and below 4% respectively [66]. This motivated Clean Development Mechanism (CDM) of the Kyoto Protocol to persuade 15 rich countries to invest in developing green energy in Nigeria through the Nigerian National Petroleum Corporation (NNPC) renewable energy program (Automotive Biomass Programme). Germany through Germany's Renewable Energy, Energy Efficiency Partnership (REEEP) has responded with 70,000 Euros grants to NNPC [67]. Table 10 summarized several emerging projects harnessing bio-sourced feedstock for biofuel production in Nigeria.

Table 9: Waste generation in Nigeria [65]

Regional State capital	Cap/person/day (kg)	Monthly waste (t)	Annual waste (t)	Organic waste (%)	Annual organic (t)
Northeast					
Bauchi	0.31	25,395	304,740	64	195,033.60
Gombe	0.275	14,006	168,072	70	117,650.40
Yola	0.28	25,365	304,380	68	206,978.40
Damaturu	0.242	14,001	168,012	70	117,608.40
Maiduguri	0.28	32,956	395,472	66	261,011.52
Jalingo	0.25	14,253	171,036	70	119,725.20
Northwest					
Kano	0.56	156,676	1,880,112	51	958,857.12
Kaduna	0.23	44,433	533,196	63	335,931.48
Katstina	0.32	18,452	221,424	70	154,996.80
Sokoto	0.281	15,255	183,060	66	120,819.60
Birnin Kebbi	0.28	15,456	185,472	70	129,830.40
Gusau	0.26	14,967	179,604	71	127,518.84
Dutse	0.3	16,340	196,080	70	137,256.00
Northcentral					
Lafia	0.21	13,956	167,472	70	117,230.40
Lokoja	0.26	15,478	185,736	70	130,015.20
Makurdi	0.28	32,956	395,472	66	261,011.52
Ilorin	0.25	34,560	414,720	70	290,304.00
Mina	0.246	14,989	179,868	68	122,310.24
Jos	0.23	27,667	332,004	57	189,242.28
Southeast					
Abakaliki	0.23	14,346	172,152	70	120,506.40
Umuahia	0.23	15,895	190,740	65	123,981.00
Enugu	0.31	16,009	192,108	58	111,422.64
Awka	0.31	25,395	304,740	60	182,844.00
Owerri	0.297	15,846	190,152	70	133,106.40
Southwest					
Lagos	0.73	255,556	3,066,672	36	1,104,001.92
Osogbo	0.24	14,957	179,484	60	107,690.40
Ado Ekiti	0.28	14,784	177,408	65	115,315.20
Ibadan	0.31	135,391	1,624,692	61	991,062.12
Akure	0.32	15,089	181,976	60	108,640.80
Abeokuta	0.36	36,116	1,413,900	60	260,035.20
South–south					
Benin City	0.63	27,459	329,508	54	177,934.32
Yenagoa	0.23	14,246	170,952	65	111,118.80
Calabar	0.26	15,248	182,976	68	124,423.68
Port Harcourt	0.7	117,825	1,413,900	60	848,340.00
Asaba	0.28	15,950	191,400	60	114,840.00
Uyo	0.253	16,112	193,344	58	112,139.52
Other cities					
Aba	0.31	64,347	772,164	70	540,514.80
Onitsha	0.7	84,137	1,009,644	62	625,979.28
Abuja	0.281	14,684	176,208	65	114,535.20

Table 10: Emerging biofuel projects in Nigeria [36]

Project	Cost	Location	Owners	Feedstock	Feedstock quantity (tonnes / year)	Project summary, ethanol production / year	Land take (ha)	Project phase
Automotive biofuel project	$306M	Agasha, Guma, Benue State	NNPC/private sector	Sugarcane	1.8 million	75 million litres, 116,810 metric tonnes (sugar), 59 MW (electricity)	20,000 (16,000 will be cultivated)	Planning
Automotive biofuel project	$306M	Bukaru, Benue State	NNPC/private sector	Sugarcane	1.8 million	75 million litres, 116,810 metric tonnes (sugar), 59 MW (electricity)	20,000 (16,000 will be cultivated)	Planning
Automotive biofuel project	$306M	Kupto, Gombe state	NNPC/private sector	Sugarcane	1.8 million	75 million litres, 116,810 metric tonnes (sugar), 59 MW (electricity)	20,000 (16,000 will be cultivated)	Planning
Automotive biofuel project (Kwali Sugarcane ethanol project)	$80 - 100M	Abuja, FCT	NNPC/private sector	Sugarcane	1.8 million	120 million litres, 10–15 MW (electricity)	26,374 estimated	Planning
Automotive biofuel project	$125M	Ebenebe, Anambra State	NNPC/private sector	Cassava	3–4 million	40–60 million litres	15,000	Planning
Automotive biofuel project	$125M	Okeluse, Ondo State	NNPC/private sector	Cassava	3–4 million	40–60 million litres	15,000	Planning
Ethanol refinery and Sorghum farm	$70M	Arigidi Akoko, Ondo State	Global biofuel Ltd.	Sweet sorghum	1.05 million estimated	84 million litres bio-refineries + farm estimated	30,000 acquired	EPIC
Ethanol refinery and Sorghum farm	$92M	Illemso, Ekiti State	Global biofuel Ltd.	Sweet sorghum	385,000 estimated	30.8 million litres bio-refineries + farm estimated	11,000 acquired	EPIC
Ethanig (via Starcrest Nigeria Energy)	$300M estimated	Kastina Ala/Benue River Basin of Benue State	Private	Sugarcane	3.25 million estimated	100 million litres, sugar, and electricity	50,000	Planning
Ethanig (via Starcrest Nigeria Energy)	$300M estimated	Kebbi State	Private	Sugarcane	3.25 million estimated	100 million litres, sugar, and electricity	50,000	Conception
Savannah sugar company	$167M	Numan, Adamawa State	Dangote Industries Ltd	Sugarcane	1 million	Expansion to produce 100 million litres, 1 billion tonnes sugar, 100,000 metric tonnes fertilizer and 300 MW electricity	36,000 (Lau, Taraba State)	Planning
Kwara Casplex Ltd.	$90M estimated	Kwara State	Private/government	Cassava	300,000 estimated	38.86 million litres	15,000	EPIC
Oke-Ayedun Cassava ethanol project	$18M	Oke-Ayedun, Ekiti State	Ekiti State Government/ Private	Cassava	238,500	38.1 million litres bio-refinery + farm	15,000	EPIC
CrowNet Green Energy ethanol plant	$122M	Iyemero, Ekiti State	Ekiti State Government/ Private	Cassava	150,000	65 million litres, (100 t of starch and 50 t CO_2/day)	12,500	Operational (4 Sept. 2008)
Cassava ethanol plant	$115M	Taraba State	Taraba State	Cassava	300,000	72 million litres, 360,000 t of cassava flour, 1.87 million tonnes CO_2 and 57 MGy of liquid fertilizer, 1600 MW electricity	30,000	EPIC
Niger State Government ethanol plant	$90M estimated	Niger State	Niger State	Cassava	150,000	27 million litres, bio-refinery + farm estimated	15,000	EPIC
Cassava bioethanol project	$138M	Niger Delta region	NA	Cassava	0.32 million estimated	58 million litres/year bio-refinery + farm	20,000	Conception
Bioethanol from sugarcane/ molasses	$85M	Niger Delta region	NA	Sugarcane	0.857 million estimated	60 million litres	67,692 estimated	Conception
Cassava industrialization project	$16.4M	Ogun State	Private + Government	Cassava	75,000	3 million litres	5000	Conception
National Cassakero cooking fuel programme	$1B	36 states + Abuja	Private	Cassava	8 million	1.44 billion litres	400,000	EPIC

However, the energy crisis confronting the country as seen in epileptic power supply, recurrent fuel scarcity among others, Nigeria has started to diversify its sources of power and fuel supply to exploit its natural resources more effectively [3]. Bio-sourced feedstock to biofuel production is an attractive alternative to substitute for fossil fuel. Studies show that solid biofuels such as wood which are used mainly in developing countries including Nigeria account for about 69% of world renewable energy supply, while liquid biofuels such as biodiesel account for 4% of transportation supply and 0.5% of global Total Primary Energy Supply (TPES). Meanwhile, biogas share is about 1.5% and has the highest annual growth rate of 15% since 1990 compared to other biofuels [17]. Liquid biofuels have a significant annual growth rate of 11%, whereas solid biofuels have an annual growth rate of 1% [66]. Biofuel (Bioenergy) has been globally accepted as IEA Statistics reveal that since 1990, bioenergy share has been about 10% of global TPES with an average annual increase of 2% [66]. This is attributed to the quest for cleaner energy to curtail the adverse impact of fossil fuel on the environment. Nwokeji [67] reported that country's carbon credits in line with Kyoto protocol of which Nigeria is a signatory has attracted grants/funds to the NNPC and as well created opportunity for foreign exchange earnings in the country with the export of surplus products and freezing crude oil in the country that otherwise would have been used. Specifically, Nigeria earned about $150 million annually from the biofuel initiative and efforts are geared towards self-sufficiency rather than importing of ethanol [67]. In view of this development, several biofuel production programs have been initiated towards its actualization and Nigeria Automotive Biomass Programme is one of them. It was established to develop two major types of biofuels: biodiesel from oil palm and bioethanol from cassava and sugarcane and as well as integrate the downstream petroleum sector with the agricultural sector. The program is expected to expand the country's energy base and create commercial opportunities as Joint Ventures (JV's) with private sector under the support of agencies with the requisite expertise, such as the various agricultural research institutes in the country [3]. Petrobras and Coimex (Brazilian companies), Venezuela's PDVSA and others in collaboration with NNPC assisted with several biofuel production projects in Nigeria as indicated in Table 10. These include: technology transfer for converting cassava to ethanol [67]. However, conversion of starchy bio-sourced feedstocks such as cassava, maize, rice, sweet potato, and yam into bioethanol has been successfully commercialized in several countries including Brazil and USA. In 2011, 13.9 billion gallons of bioethanol (constituting 57.5% of global bioethanol production) was produced in USA from maize and similar achievements were reported about Brazil [48]. Nigeria's climatic conditions support the production of maize and other starchy feedstocks, so technology transfer, partnership with these countries and other related support towards biofuel production have contributed positively to biofuel production in Nigeria. Presently, as shown in Table 11, bioethanol, biodiesel, and biogas are the major biofuels produced in Nigeria. However industrial production of biogas which harnesses waste as the bio-sourced feedstock is more feasible compared to biodiesel which is still under investigation [2]. Meanwhile, bioethanol production using cassava as the main feedstock has already been established in Nigeria since 1973 [17]. Industrial production of biogas from waste should be given considerable research focus as it does not only promote a pollution free environment but also pose no threat to food crisis as well as deforestation.

Table 11: Biofuel production status in Nigeria [63]

Biofuel	Potential raw material	Industrial feasibility in Nigeria	Proposed use	Main advantage	Land use	Water use
Bioethanol	Sugarcane, sweet sorghum, cassava	Developing	Transportation	Reduced pollution, diversification of fuel mix	Sizeable	Sizeable
Biodiesel	Jatropha, oil palm, soy beans	Under investigation	Transportation	diversification of fuel mix	Depends on crop	Depends on crop
Biogas	MSW, Manure, Sewage	Good	Indoor combustion	Reduced deforestation, improved indoor air quality	None	Limited

5. Conclusion

Energy crisis is a global concern and Nigeria has been confronted with challenge of meeting her energy need for decades. This is attributed to overdependence on fossil fuel as if the fuel will be in existence forever. Series of crises witnessed so far is due to the increasing demand in energy by the teeming population which does not commensurate with the energy supply from its depleting source. Several countries turned to renewable sources of energy and the impact is beyond meeting their energy demand as these clean sources of energy is environmentally friendly. Biomass as a non-renewable source of energy is evenly distributed and could be harnessed into biofuel. Biofuel is an attractive alternative to substitute for fossil fuel. It is flexible as biofuel can be utilized for electricity generation and even upgraded to transportation fuel.

This review identifies bio-sourced feedstocks available in Nigeria which can be harnessed to supplement the country's energy demand. These bio-sourced feedstocks span across various classes of first, second and third generations from a wide variety of sources: energy crops, agricultural crop residues, forest resources, urban and other wastes which are distributed throughout the country due to favorable climatic condition and adequate fertile land. The country huge potential is enormous as Nigeria can adequately meet her energy demand from waste.

With support from other countries, there has been an upscale of activities by government towards increasing the energy mix within the country for electricity production through renewable sources as several biofuel production projects have been developed. The emergence of these projects would diversify the country’s fuel supply and maximize its use of natural resources. Sadly, most of the emerging biofuels projects in Nigeria utilize first generation bio-sourced feedstock for biofuel production. These feedstocks are mostly food crops and thus in competition with food which in an attempt to curb energy crisis lead to food crisis. However, with large availability of the bio-sourced feedstocks and the epileptic power supply and recurrent fuel scarcity or fuel importation, Nigeria is yet to effectively exploit these resources. With significant availability of non-food biomass resources, harnessing these non-edible bio-sourced feedstocks for biofuel production would address the potential food versus fuel conflict challenging biofuel production in Nigeria.

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