Paradigm Shift from Waste to Wealth through Biomass Conversion Technologies: A Panacea for Energy, Health and Environmental Challenges in Nigeria

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Keywords: biomass, conversion technology, biodigestion, and biogas.

Classification: DDC Code: 333.9539, LCC Code: TP339

Language: English

London Journals Press

LJP Copyright ID: 392973
Print ISSN: 2631-8474
Online ISSN: 2631-8482

London Journal of Engineering Research

Volume 22 | Issue 1 | Compilation 1.0

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ABSTRACT

The over-dependence on fossil fuel, estimated to be exhausted in less than five decades, is not sustainable and economical to the most populous country in Africa. Currently, Nigeria is battling with insufficient energy, polluted environment, and health challenges due to inequality in energy generation and consumption which promote the use of generators in the country. Meanwhile, biomass has been successfully exploited and adopted by advanced countries to break the fossil fuel monopoly and curtail its adverse effects on the environment and health. This paper projected biomass conversion technology as a panacea to the energy, environmental and, health challenges. Of the conversion technologies reviewed, bio-digestion has great potential in biogas production. The technology is cheap and, the feedstock is readily available for exploitation at a communal or individual level, making it an attractive alternative to attain energy self-sufficiency. Presently, there are several collaborative efforts between Nigeria and several countries concerning biogas generation. About 20 biogas pilot plant has been found to be operational within the country. However, replication of the technology in a different part of the country has been challenged by a lack of technical know-how, inadequate fund, and lack of awareness. Hopefully, much can be achieved as the low-level development of the technology is not encouraging. With government interventions and support from non-governmental organizations and others in the country, biogas plants can be constructed in all communities to replace generators thus eliminating the energy, environmental, and health challenges.

Keywords: biomass, conversion technology, biodigestion, and biogas.

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I. INTRODUCTION

The trio of energy, health and environmental issues in Nigeria constitutes a serious challenge to all aspects of her economy. They are related subjects of concern for decades and much research effort has been devoted towards addressing these issues for decades. This paper projects biomass conversion technology as a panacea for energy, health and environmental challenges in Nigeria. The conversion technology exploits mostly biomass/organic materials 'once regarded as waste' to proffer solution to the hydra-headed problems confronting Nigeria and beyond as energy, health and environment are global issues – a paradigm shift from waste to wealth.

Energy is the power required for transportation, heat, light and even in manufacture of products. It drives all sectors of the economy in terms of powering of heavy duty manufacturing and agricultural machinery in the industries, lighting, space heating and cooling in commercial and household buildings, powering electronic appliances, charging of phone and fuelling airplanes, ships and vehicles in the transport sector (Ampomah-Benefo, 2018; Edenseting *et al.,* 2020). Insufficiency in energy supply is the

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worst tragedy that can befall any 21st century society since life itself revolves around energy (Kosmo, 1989; Galadima *et al.*, 2011; Ampomah-Benefo *et al.,* 2013; Haiwen *et al.,* 2015). Obviously, there is no sector in the economy that is not powered by energy hence; it is a veritable indicator of the level of development of a country as such an ailing energy sector translates to ailing economy (Linnhoff and Dhole, 1992; Koh *et al*., 2008; Mitchell, 2008).

Globally, energy sources exploited generally are either non-renewable (conventional) or renewable (non-conventional). These energy sources are utilized worldwide but in different proportions according to availability and geographical location (Sorensen, 2004). Nigeria is endowed with inestimable renewable energy resources (hydro, geothermal, biomass and solar) and huge renewable energy resources (Table 1) mostly fossil fuel (Obonukut *et al.,* 2016).

Table 1: Renewable Energy Reserves in Nigeria

Fossil Fuel	Reserves	
	Natural Units	Energy Units (Btoe)
Crude Oil	36.22 billion barrels	5.03
Natural Gas	187 trillion SCP	4.19
Lignite and Coal	2.175 billion tonnes	1.52
Tar Sand	31 billion barrels equivalent	4.31

Source: Ozoegwu et al (2017)

The country is ranked 10th and the highest crude oil and Natural Gas producer in Africa indicating her significant contribution to the world's fossil-based energy supply (Obonukut *et al.,* 2016). Presently, the country depends mostly on fossil fuel regarded as conventional energy (Anowor *et al.,* 2014; Oyedepo *et al.,* 2019; Edenseting *et al.,* 2020). With the exponential growth rate in the population, the energy consumption rate does not commensurate with the energy production rate. Consequently, the over-dependence on fossil fuel in order to meet the soaring energy needs leads to over-exploitation of the country's hydrocarbon reserves as aggressive exploration strategies (enhanced oil recovery, subsea exploration) have been explored (Obonukut *et al.*, 2016). In the quest to address the energy issue, plunge us into a twin issue relating to environment and health. The genesis of these issues is extensively discussed (section 2) in order to address them from the root. Biomass resource in Nigeria is discussed in section 3. However, the aim of this review is to present the panacea to these challenging issues. To achieve this aim, the conversion technology required (section 4) and its prospect and challenges (section 5) of executing the technology in Nigeria are discussed. The way forward to successful take off of the project is addressed (Section 6) prior to conclusion.

II. THE GENESIS OF ENERGY, ENVIRONMENTAL AND HEALTH CHALLENGES IN NIGERIA

Nigerian has huge energy resources (e.g. oil, gas, hydro and solar) but exploited few of them (Obonukut *et al.,* 2016). With the potential to generate 12,522MW of electric power from existing plants, the country is only able to distribute about 4000 MW which is insufficient to more than 200 million people (Sambo, 2006; Udoh, 2020). As the largest economy in the sub-Saharan Africa, this insufficiency in energy has adverse impact on the industrial growth of the country (Ofoefule and Uzodinma, 2009; Abila, 2012). In order to improve the sector, Nigeria privatized the power sector leading to creation of 11 distribution companies (DISCOS), yet no remarkable positive impact as both the government and the Discos have continued to blame each other for the poor and unstable energy supply (Udoh, 2020). Consequently, most businesses have folded up while others relocated leaving the country to neighboring countries.

To prevent businesses from crippling and as well cater for domestic energy needs, Nigerians have resorted to the use of generators for energy supply (Wjst and Boakye, 2007). This has led to increase in generator budget for many households and businesses within the country. Research shows that as at 2019, the number of generators (mostly petrol and some diesel) was between 22 million and 60 million in Nigeria (Ebrima, 2019). According to CBN report, Nigerian spent about USD 12 billion in 2019 and USD 14 billion in 2020 fueling generators (Ebrima, 2021). This increment (USD 2 billion) shows that all is not well with the sector, hence, the need to direct research effort toward this sector.

Furthermore, in an attempt to address the shortfall in energy with the procurement of generators especially diesel powered generators plunged the citizens into a serious environmental and health issues. Specifically, the cluster of generators in both residential, commercial and industrial building across Nigeria significantly contribute to noise and air pollution in the form of GHG emissions with associated health impacts such as asthma (Wjst and Boakye, 2007; Awofeso, 2016). It is worse if the generator (petrol) is in bad condition or diesel powered as their exhaust emits more than 40 toxic air contaminants in the fume including known/suspected carcinogenic substances such as benzene, arsenic and formaldehyde in addition to the GHG (Awofeso, 2016; Zhang, 2017; Vivekanandan, 2017). Wjst and Boakye (2007) reported that Nigeria has the highest prevalence of asthma in Africa. This perhaps is attributed to generators' fume.

Obviously, the capital flight associated with importation of generators and fuel coupled with the health and environmental issues are strong indicators that the use of generators is not a solution to the Nigerian energy challenge. Meanwhile, the over-dependence on fossil fuel in order to meet the soaring energy needs leads to over-exploitation of the country's hydrocarbon reserves (Obonukut *et al.*, 2016). This appears to be the solution to meet the energy demand, yet the resources are purely government-owned and are cheaply sold out abroad as Nigerian refineries gulped 1.64 trillion NGN in cumulative losses in 5 years (Udoh, 2020). As a last resort, Nigeria considers importation of petroleum products as cheaper than refining the product in the country's refineries (NNPC, 2015; Eboh, 2016). The government may not exploit the hydrocarbon resources wholly for domestic usage when it is actually the proceeds of these resources that are used to finance the economy especially when refining operation in the country is not economical.

Obviously, Nigerians will still pay heavily for fuel. However, this is not the issue as these resources would not be available forever. Recently, it was reported that Nigeria has 41 billion barrels of untapped crude oil reserves (NNPC, 2015; Ebrima, 2019; Udoh, 2020). Based on this data and with the level of average daily production (2 million barrels/day), the proven oil reserve will be exhausted within the next six decades. Similar prediction is applicable to Nigerian gas reserves as these hydrocarbon reserves take millions of years to replenish. Hence, research focus should be directed to finding alternative but renewable (infinite) sources of energy with minimal adverse impact on our environment in order to promote energy security and health.

Waste treatment/disposal is another challenge confronting the country. As expected, based on her population, the domestic, industrial and commercial activities generate huge waste. These wastes are seen to litter the street claiming more lands as number of dumping sites keeps increasing. Waste treatment/disposal is one of the environmental challenges confronting the modern societies not only Nigeria. Bio-waste (organic waste) constitutes over 60% of these wastes in the advanced nations and even more in the developing nations (Arvanitoyannis *et al.,* 2007; Cheng *et al.,* 2010; Mata-Alvarez *et al.*, 2014). However, these biological material (biomass) includes not only bio-waste but all materials from natural processes which in most cases are nuisance to our environment constituting waste (Babatola and Ojo, 2020; Edenseting *et al.,* 2020).

III. AVAILABILITY OF BIOMASS IN NIGERIA: INTEGRATING ENERGY AND ENVIRONMENTAL NEEDS

Biomass is organic material that comes from plants and animals related materials and it includes: crops, waste wood and trees (Bamgboye, 2012; Bruni *et al.,* 2010; Pisutpaisal *et al.,* 2014; Patel, 2017). It extended to household, municipal solid waste (Zhu *et al.,* 2010), industrial waste as well as waste waters (Gelegenis *et al.,* 2007). Biomass refers to energy derivable from sources of plant origin such as trees, grasses, agricultural crops and their derivatives, as well as animal wastes, wastes from food processing, aquatic plants and algae (Duku *et al.,* 2011; Edenseting *et al.,* 2020). Based on population and intense agricultural activities, Nigeria is the highest biomass producer in Africa (Babatola and Ojo, 2020). Table 2 shows the renewable energy reserves in Nigeria.

Table 2: Shows the renewable energy reserves in Nigeria

Energy sources	Reserves
Solar radiation	3.5–7.0 kWh/m2/day (4.2 million MWh/day using 0.1% land area)
Animal waste	211 million assorted animal (285.065 million tons/yr of production
Small hydropower	3,500 MW
Large hydropower	11,250 MW
Energy crops and agriculture residue	28.2 million hectares of arable land (30% of total land)
Wave and tidal energy	150,000 TJ/(1,759.6 toe/yr)
Fuel wood	11 million hectares of forest and wood land
Wind	2–4 m/s at 10 m in height (main land)
Crop residue	83 million tons/yr

Source: Ozoegwu et al. (2017)

Obviously, biomass is currently the largest renewable energy source with wider geographical spread than other renewable energy sources (solar, hydro, etc.). However, fossil fuel has been extensively exploited for many centuries while biofuel despite its availability, has been neglected perhaps rarely exploited conventionally (Abila, 2010; Ben-Iwo *et al.*, 2016). Biofuel is one of the renewable energy sources' competing with fossil fuel as its energy content is captured through natural processes and it is potentially renewable indefinitely. while fossil fuel is a non-renewable energy source as its energy content is captured through geological processes which take longer time to replenish hence continuously depleted (Sambo, 2006; Mohammed *et al.*, 2013). Unlike biofuel, fossil fuel is found in specific parts of the world making them more plentiful in some nations than others (Abila, 2012; Galadima *et al.*, 2011). To achieve more in meeting the energy need of the country as well as derive maximum benefit from utilization of vast available renewable resources, the over-dependence of the energy sector on fossil fuel that has slowed down the development of alternative fuels must be reversed (Giwa *et al.,* 2017). There is the need for diversification to achieve a wider energy supply mix which will ensure greater energy security for Nigeria. The way forward is the exploration of biomass which is abundant all over the country. As a renewable energy source, biomass products (Figure 1) are sustainable, limitless and environment friendly. Bioenergy sources have significant potential to improve and make a difference on the low level access to clean energy and electricity in Nigeria (Aliyu *et al.*, 2015; Oyedepo *et al.,* 2019).

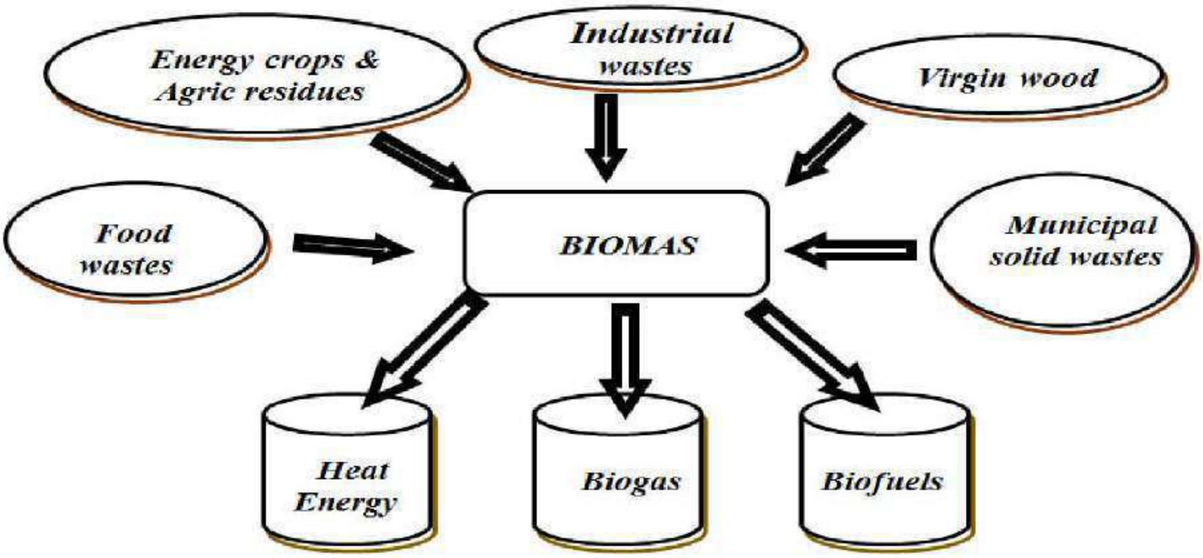


Figure 1: Biomass sources and products

Source: Oyedepo et al., 2019

Generally, biomass is compounds of carbon, oxygen, nitrogen and sulphur with high energy content (Aliyu *et al.,* 2015). It can be exploited depending on the type of conversion technology to generate energy which is environmental friendly and healthy. The conversion technology is presented next..

IV. BIOMASS CONVERSION TECHNOLOGY: MITIGATING ENERGY, ENVIRONMENTAL AND HEALTH CHALLENGES

Bio-sourced feedstocks can be converted into chemical, electrical or heat energy using various conversional processes. The energy obtained can be utilized onsite or stored and transported for future use. Generally, fuel generated from biomass can be in solid form as seen in charcoal and briquette; liquid form as seen in bioethanol; or gaseous form as seen in biogas (methane-rich gas). Myriads of biomass have been exploited for fuel and these include: agricultural and forest product residues (Bruni *et al.,* 2010; Patel, 2017), household and municipal solid waste, (Zhu, *et al.,* 2010) and industrial waste and waste waters (Gelegenis *et al.,* 2007).

Research effort should be directed towards harnessing these materials using appropriate technology to increase the rate of integration of renewable energy into the existing energy supply mix of Nigeria (McKendry, 2002; Evans and Furlong, 2003; Ullah *et al.,* 2015; Ben-Iwo *et al.* 2016). There are various technologies for biomass conversion and some of them are more advanced than others. A review of these technologies is critical to this study in order to assess which of them is suitable and adaptable for energy generation by developing countries.

4.1 Thermochemical Conversion

It involves thermal decomposition of carbonaceous material (biomass) to energy and other products. Specifically, this biomass conversion technological process exploits heat in transforming the bio-sourced feedstocks. The thermochemical conversion processes exploited are: incineration, pyrolysis and gasification. A brief review of these processes is necessary.

4.1.1 Incineration (combustion)

This involves burning of bio-sourced feedstocks in excess Oxygen. This technology involves the combustion (complete oxidation) of biomass in the presence of Oxygen. This is required for onsite consumption as the main product of incineration, heat energy, which cannot be easily stored but has to be consumed immediately. The process is favored when the moisture content of the feedstock is low and the oxidizer is oxygen-rich air. In view of this, the moisture content of the biomaterial must be assessed prior to incineration. The moisture content of the feedstock can be reduced or drive off by drying or heating (Komilis *et al.,* 2014). However, incomplete combustion of the feedstocks has been reported producing intermediate products like polycyclic aromatic hydrocarbons and dioxins in addition to CO (Ampomah-Benefo, 2018). This undesired development usually occurred when there is limited supply of air.

4.1.2 Pyrolysis

This process utilizes several process variables (temperature, rate of heating, particle size and residence time) to transform bio-sourced feedstocks in a reactor chamber to solid, liquid and gaseous fractions (Mohan *et al.,* 2006). Pyrolysis is an endothermic, irreversible process that occurs in absence of oxygen. Depending on the process condition, the process can be a slow pyrolysis or fast pyrolysis. The former (slow pyrolysis) occurs at about 350°C producing about 10 % oil (volatile component) and the rest being biochar. The latter (fast pyrolysis) occurs at about 700°C. In this case, bio-sourced feedstock decomposed rapidly to produce more than 70% biofuel and very little biochar (Bolalumi, 2016). However, biofuel production through this technology is energy intensive and alternative should be explored for economic and environmental impacts purpose.

4.1.3 Gasification

This is another conversion technology for exploitation of bio-sourced feedstock. Synthesis gas (syngas), a combustible gas mixture is produced by partial oxidation of biomaterials (fuel). The temperature is relatively high (about 1000°C) with variable air to fuel ratio ranging from 1.5:1 to 1.8:1 producing mostly CO mixed with H_2 (Obonukut *et al.,* 2016; Wang *et al.,* 2017; Bassey *et al.,* 2020).

4.2 Biochemical Conversion

This is a conversion process in which bio-sourced feedstocks are turned into energy by microbial activities. It involves breakdown (catabolic processes) of substrates (biomass) into simple compounds that can be absorbed and used as nutrients by the microorganisms (Ampomah-Benefo, 2018). However, the process equally goes beyond catabolism as new substances are also formed through anabolic process as combustible gas (biogas) is formed. In addition, the microorganisms metabolize nutrients (substrates) for their survival and growth by producing enzymes (protein molecules) that break down specific substances. The factors exploited include: carbon source, pH, temperature, retention time, and adequate moisture content.

Enzymes are found in thousands from living cells of animals, plant microbes and from fungi and yeast. They can be intracellular (located inside the cell) or extracellular (located outside the cell). Their functions are specific in nature as they reduce the activation energy of biochemical reactions, thereby increasing reaction rates. Enzymes are used repeatedly as they remain unaffected structurally at the end of the chemical reactions (Grassian, 2005). Consequently, proteases and peptidases split proteins into small peptides and amino acids. Lipases split fat into three fatty acids and glycerol. Amylases split carbohydrates (polysaccharides and disacchari des). Enzymes (E) and substrates (S) combine to form an intermediate state, called enzyme–substrate complex (ES). A new product (P) is formed and the unchanged enzyme is ready to react again with the substrate (Equation 2.1).

$$E_S + S_S \rightleftharpoons ES_s \rightleftharpoons E_S + P_S \qquad 2.1$$

The process is economical with less adverse impact on the environment. It mimics the digestion process that occurs especially in human and ruminant animals where microbial actions in their intestines lead to the breakdown of food to release energy. It is the foundation on which this research is built as such in-depth discussion is necessary.

4.3 Biodigestion of Biomass

Digestion is a biology term relating to eating of food and biodigestion connotes a special type of eating by microbes. Digestion is a biological process whereby micro-organisms convert biological material (organic matter) into volatile components and water resulting to mass loss, destruction of pathogens. The process was formulated mainly for waste treatment/disposal just like pyrolysis, gasification, thermal incineration (combustion) and others. As waste treatment/disposal is another global concern in addition to energy crisis, an attempt to handle these two challenges plunged us into climate change (Arvanitoyannis *et al.,* 2007; Cheng *et al.,* 2010). Sludge digestion may involve decomposition of biological material by microbes in the presence of oxygen (aerobic digestion) or in the absence of oxygen (anaerobic digestion) as discussed next.

4.3.1 Aerobic Digestion of Bio-Sourced Feedstocks

This type of digestion by microbes utilizes bio-sourced feedstocks in the presence of oxygen and the end products are mainly CO_2 and water which are stable oxidized forms of carbon and hydrogen. However, if the organic contains Nitrogen and Sulphur, the end product may also include Ammonia/Nitrate and Sulphate. The process is cheap and it is useful in disposing waste as mass of the digestible waste reduces. The effluent is stable but not much useful to crops as fertilizers as Nitrogen is converted to ammonia gas (Bhat *et al.,* 2001). The process is not efficient for energy generation.

4.3.2 Anaerobic Digestion of Bio-Sourced Feedstocks

In this section, a brief description of the anaerobic biodigestion technology is presented (section 4.3.2.1). This is followed by biogas production and purification (section 4.3.2.2). In the concluding section, utility of anaerobic biodigestion technology is discussed (section 4.3.2.3).

Description of the Anaerobic Biodigestion Technology: It is a digestion of biomaterials by microbes in an oxygen-deficient chamber (digester). Anaerobic digestion produces methane, a major combustible constituent in biogas, in addition to CO_2. There are two types of anaerobic digestions depending on the solid content of the slurry to process. These wet digestion and dry digestion. A digestion is considered dry if the total solid content is above 50% of the slurry. On the other hand, a wet digestion involves more than 50% of water in the slurry (Teng 2014). Wet digestion is more efficient than the dry counterpart as it gives high quality products and this study seeks to achieve an improved biogas production by exploiting wet digestion (Zhang, 2017).

Specifically, research has shown that the advantage of using anaerobic over aerobic (though cheaper) is that it generates biogas and its effluent is a nutrient-rich biol (bio-fertilizer) with essential inorganic elements for plant growth like Nitrogen, Phosphorus, etc. which enriches not only the crops with nutrient but also the soil structure with no adverse effect on the environment (Bhat *et al.,* 2001; Vavilin *et al*., 2008). Anaerobic Digestion (AD) is the most promising way as it has the least aggressive effect on the environment compared to others (Suh and Roussaux, 2002). Anaerobic digestion process proffer solution to the energy crisis and climate change leaving the environment pollution-free when properly handled.

Biogas Production and Purification: Biogas is methane-rich gas produced during anaerobic digestion as microorganisms break down (eat) biomaterials in the absence of air (oxygen). The gas made up of methane CO_2, H_2S and water plus other trace gases. Methane is about 60-70% while others constitute the remaining 30 to 40%. The effluent or left over sludge after anaerobic digestion of the organic matter is called digestate. It is rich in plants nutrient used as liquid fertilizer for crop production. Other gases can be removed leaving only methane which is highly combustible as seen in natural gas (the primary component of the natural gas) during purification.

Biogas purification process is synonymous to biogas cleaning and scrubbing. The essence of purifying biogas is to remove other associated gases leaving only methane which is the most valuable energy component in biogas due to energy content. There are processes for removing CO_2, H_2S and moisture. These gases are more prevalent in biogas yet they have little value to the gas and need to be removed to improve the calorific value of the gas.Biogas is used for as fuel for cooking, run generator for production of electricity and stored as refrigerant in the compressor. The gas competes highly with liquefied petroleum gas (LPG) and even the more preferred as it is found to be: cheaper to produce, less explosive. LPG leads to high emission of NO_2 and CO_2 during combustion while biogas releases minimal emission of CO_2 during combustion in the burner. The differences between LPG and biogas are tabulated in Table 3.

Table 3: Differences between biogas and LPG

	Biogas	LPG
Source	Biomass (biofuel)	Hydrocarbon (fossil fuel)
Sustainability	Renewable	Non-renewable
Environment Impact	It releases pollutant (CH_4, NO_2, CO_2, SO_2, and NO) in negligible quantity which does not lead to global warming due to its low production rate	It releases pollutant (CO_2, CO, SO_2 and NO_2) in large quantity which increases global warming potential due to its high production rate
Pressure	It can be stored at atmospheric pressure which leads to higher level of safety and less explosive as relatively small quantity of biogas is stored- too little to pose any serious threat and a minuscule amount compared to any other gas connection	It is stored at 14 to 17 bar pressure and used in store at 0.2 bar pressure using a regulator
Risk factor	Safer as the storage pressure (1.0 atm) and low moisture content make it less explosive	Highly risky as leakage or improper usage has high possibility for explosion
Burner Efficiency	50 – 55%	60 -65%
Odorant	H_2S naturally present in the biogas is used to detect any leakage	Ethyl Mercaptan is additionally added as the odorant to detect any leakage
Availability	As long as organic waste is available, it can be generated any time and the biogas is readily available for use	Based on the market demand as the availability may vary. At times, one may wait for more than a month for LPG cylinder after booking
Cost	it is a onetime investment and lifetime enjoyment	It requires monthly expenses and frequent price hike
Thermal Expansion	Expansion is negligible	The ratio between the volume of the vaporized gas and the liquefied gas varies depending on the composition, pressure and temperature
Auto ignition	580°C	405°C
Health Impact	Neglible health hazards	Carbon particles are emitted during combustion. Prolong or repeated exposure causes serious health related problems

Source: Ampomah-Benefo (2018)

Utility of Anaerobic Biodigestion Technology: This is discussed in terms of treatment and disposal of fecal waste through biological filtration (Biofil digester toilet system and other bio-degradable wastes) and source of fertilizer for crop production.

Biofil Digester/Biodigester Toilet: It exploits science of anaerobic digestion to treats human feces (undigested waste) in the most environmental friendly manner devoid of odor, flies and cockroaches. This technology requires no sewage as such it takes very small space to install. Biodigestion of fecal waste is a sequence of process where micro - organisms/anaerobes decompose feces in the absence of oxygen. The microbe degrades the feces into biogas and water (liquid fertilizer). Air is prevented from entering into the system from the outside environment into the digester. The anaerobes access oxygen from the feces itself or alternatively from inorganic oxide from within the inbuilt material of the system.

The biodigestion technology exploited for fecal waste treatment provides an enclosed environment for natural process of anaerobic decomposition of feces and other biodegradable materials. The biodigester box achieves this through a process called RAB system. This system comprises: rapid separation of solid (feces) and liquid (water); anaerobic digestion of solid aided by bio-catalyst (enzyme) and bio-filtration of waste water. The system decomposes and digests waste very fast and turns toilet from water closet (WC) system into green water every minute. This is achieved through anaerobic digestion (biochemical reactions) caused by fusion of internally generated gas and natural heating elements that are sealed and tightly fixed into the system.

Millions of environmental friendly microbes (anaerobes) feed on the toilet waste till it (the waste) disappear completely leaving traces of organic fertilizer (sludge) in the anaerobic chamber. Meanwhile, the biodigester chamber itself is a filter bed. Thus, as the toilet waste water passes through several layers with grades of sand, fiber net and other porous materials, a clean, non-toxic and odorless water leaves the chamber into a the drainage (soaked pit, gutter or garden). The technology has an edge over the traditional septic tank toilet system. The benefits of biodigester toilet are enumerated next

1. Biodigester is cheap as it requires low cost of construction and installation compare to septic tank/soaked away system.
2. No dislodging of sewage evacuation because it does not get full. Thereby saving money spent on sewage disposal.
3. It last for over 50 years and requires zero or little maintenance.
4. Biofil toilet can be constructed in water logged area, dry land and any land irrespective of its topography.
5. It consumes small space and can be constructed in few days.
6. Flies, cockroaches and rodents are not attracted to biofil digester toilet hence pollution free.
7. It is odorless, smart compact and promotes good health as it does not contaminate underground water.
8. Biofill digester toilet has the capacity to generate cooking gas and gas to run generator

Bio-Fertilizer Production: Bio-fertilizer (organic fertilizer) is a product of anaerobic fermentation process, containing specific individual or group of soil microorganisms which improve plant growth and productivity through supply of easily utilizable form of nutrients. Food shortage is a global issue as hike in food prices caused millions to either reduce their rations while others are starved. Nigeria is not exempted as the country is not self-sufficient in food production. Generally, there is a global crusade for increased per capital agricultural production to alleviate food security challenges due to the expanding world population (Amigun and Musango, 2011). Farmers, a major stakeholder in food production have been encouraged to increase production in order to alleviate the impact and prevent the impending famine.

However, the poor soil, harsh climatic conditions, including high temperature and drought, the poor economic situation, lack of technological development and inefficient farming practices have significantly affected crop productivity in Nigeria (Galadima *et al.*, 2011). Presently, increasing crop productivity requires fertilizer (organic/inorganic) application to provide the necessary nutrients for plant growth. This has been major nutrient management method to alleviate the impact of poor soil as tons of fertilizers are imported into the country each year. Organic fertilizers, which are made from bio-sourced feedstocks have been used for centuries for improving plant productivity. However, challenges bordering on availability, cost, and management have limited the use of organic fertilizers in Nigeria. Chemical fertilizers are costly, unsustainable and contribute to the environmental pollution and soil structure degradation (Bhattacharyya and Palit, 2016). The several ecological damages caused by the overuse of chemical fertilizers have become increasingly uncontrollable and most times, irreversible, causing significant nutrient loss to soils.

Moreover, the demand for green agriculture and high-quality food supply has suggested a shift or a reduction in the application of chemical fertilizer. The world desires a chemical-free material and the quest for organic cosmetic, food and related products keeps increasing. There are several organic farms including the Obasanjo organic farms in Nigeria. The production process of bio-fertilizer via anaerobic biodigestion technology is economical and straight forward when compare to chemical fertilizers. However, key factors, including microbial strains, formulation type, carrier materials and field applications are critical during bio-fertilizer production (Manlay, 2000; Dioha *et al.*, 2005; Ndiaye *et al.,* 2010).

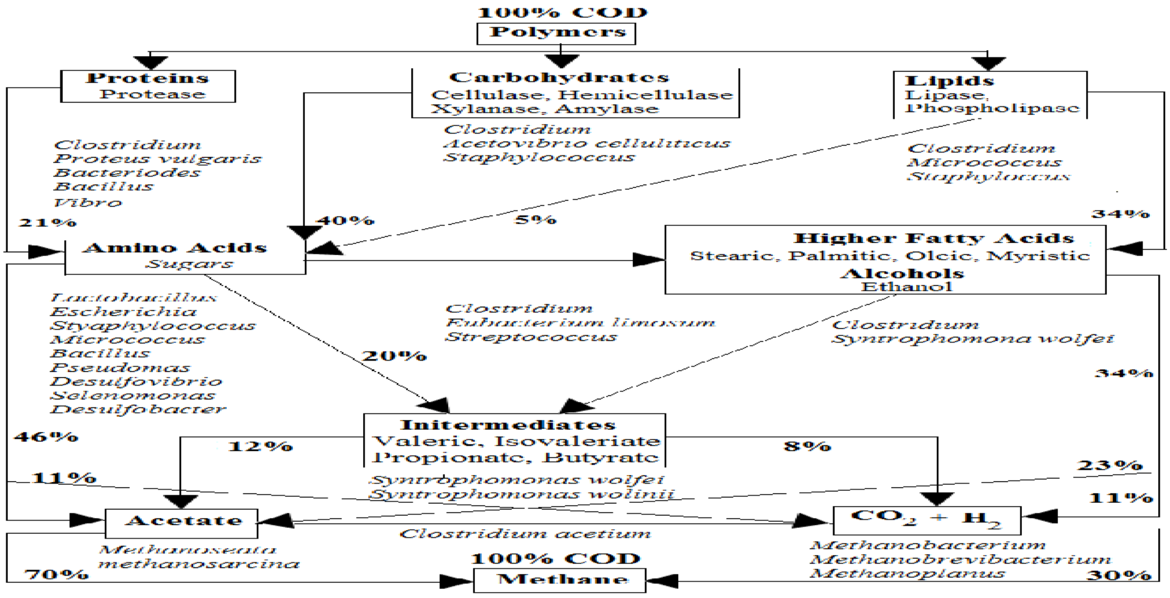
It is necessary to characterize the biol in order to assess potentially active and non-toxic microbes which can promote plant growth. The functional characterization of the biol is carried-out using general laboratory techniques, including differential culture media or qualitative testing. Functional characteristics are used as a general quality control factor for inoculants because they are quicker and cheaper than strain-specific assessment (Ndiaye *et al.,* 2010). Generally, digestion processes irrespective of types (aerobic and anaerobic) produces bio-fertilizer. The difference between the fertilizer from aerobic and that of anaerobic digestion is the availability of Nitrogen. This particular element (Nitrogen) is essential to plant growth as it constitutes the highest proportion in most of the fertilizers (chemical and organic).

In aerobic bio-fertilizer, most of the Nitrogen held in the sludge is lost to the air in the form of ammonia gas or dissolved in surface run-off in the form of Nitrate (leaching/erosion). In this case, the Nitrogen is not available to plants. This is a similar scenario where inorganic fertilizer on application is leached to Lakes, Lagoon and other water sources depriving plant of essential nutrients (Ndiaye *et al.,* 2010). This is not applicable to bio-fertilizer from anaerobic digestion process. In this process, the Nitrogen is converted to ammonium ions when its effluent is used as fertilizer. These ions affix themselves readily to the soil particles which make it difficult to oxidize to ammonia gas or dissolve in run-off water as Nitrate. Thus, much of the Nitrogen is accessible to plant as nutrient. Hence, bio-fertilizer from anaerobic biodigestion process is more superior to that of aerobic digestion.

However, bio-fertilizer from aerobic digestion has an edge over bio-fertilizer from anaerobic counterpart in terms of offensive odor emission. The offensive odor from the anaerobic bio-fertilizer during application is a critical issue as it pollutes the environment. Strategy to reduce or eliminate the odor while maintaining its fertilizing effect should be examined.

4.4 Biochemical Processes of Anaerobic Bio-Digestion Technology

The nitty-gritty of anaerobic biodigestion technology in terms of its biochemical and physicochemical processes are broken down into four stages: hydrolysis, acidogenesis (acidification), acetogenesis and methanogenesisn (Krich, 2005; Zhang, 2017). These are schematically represented in Figure 2.



Source: Mara and Horan (2003)

Figure 2: Metabolic pathways and microbial groups in anaerobic digestion

This process requires little energy while the rest of the energy is stored as biogas and nutrient-rich sludge (Wagner *et al.*, 2009; Herrmann *et al.*, 2016). These stages (Figure 3) are described in the following sections under the sub-headings hydrolysis (section 4.4.1), acidogenesis (section 4.4.2) acetogenesis (section 4.4.3) and methanogenesis (section 4.4.4).

Figure 3: Stages in anaerobic digestion

4.4.1 Hydrolysis of Bio-Sourced Materials

This stage initiates the biodegradation/ biodigestion process and it mainly a catabolic process. Complex biopolymer constituting starch, protein, fat and oil (21 % proteins, 40 % of carbohydrates, and 39 % of lipids) are digested by fermentative bacteria to monosugar, amino acid, peptides, etc. (monomers and oligomers). The complex biomaterials are insoluble and difficult to be digested by microbes (Vavilin *et al.*, 2008). The hydrolytic microbes have to secrete different types of enzymes, mostly extracellular enzymes, which break down the larger molecules (polymers) into simpler soluble components (monomers).

Carbohydrates are broken down into simple sugars such as monosaccharides and disaccharides by cellulase, cellobiase, xylanase and amylase. Hydrolytic anaerobe called protease degrades proteins into amino acids, while lipase split lipids into short chain fatty acids and glycerol (Saha and Cotta, 2007). This stage is usually the rate limiting stage for lignocellulosic materials.

4.4.2 Acidogenesis of Monomers

This is the second stage after hydrolysis considered to be the stage with fastest reaction rate (Saha and Cotta, 2007). This is attributed to the fact that many organisms are more active during this stage than during the other 3 stages.

The products from the previous (hydrolysis) stage which are soluble monomers are the substrate exploited by different microbes (acidogens). As the name implies, the acid formers microbes include: bacteriodes, bifidobacterium, clostridium, lactobacillus, and streptococcus. They thrive in acidic medium at optimum pH range of 5.5 and 6.5. The substrates are mainly converted into various short chain volatile organic acids (acetic, propionic, butyric, succinic, lactic acid etc.), alcohols (methanol and ethanol), ammonia (from amino acids), carbon dioxide, and hydrogen.

4.4.3 Acetogenesis of Acidogen Substrates

This is the third stage where the digested monomers and oligomers in hydrolysis become acetate or Hydrogen and Carbondioxide in the presence of fermentative bacteria. This stage intertwines the second and the fourth stages. The acetogens which are hydrogen producing and consuming anaerobes convert the substrates which are the products from the second stage (propionates and butyrates lactate and ethanol) to produce H_2, CO_2, and acetate. Acetate can also be formed from CO_2 and H_2.

4.4.4 Methanogenesis and the Production of Biogas

This is the last step of the anaerobic digestion process and perhaps the rate limiting stage. It is strictly anaerobic and methane forming step. It is dominated by microorganisms called methanogens (methanobacterium, methanococcus, methanosarcina, and methanosaeta). The products of acetogenesis stage (Hydrogen, Acetate, and CO_2) constitute the substrates exploited to produce biogas (mostly CH_4 and CO_2). However, there are three main pathways leading to methane production in this stage. These are: acetoclastic methanogenesis, hydrogenotrophic methanogenesis and homoacetogenesis (Ampomah-Benefo, 2018).

Most of the methane (above 60%) is formed by acetoclastic methanogens (methanosarcina and methoanosaeta), where methanosarcina utilize acetate, hydrogen, formate, methylamines and methanol to form CH_4, and methanosaeta exploits only acetate to form CH_4 (Conrad, 1999; Ferry, 2011). Hydrogenotrophic methanogenesis converts H_2 and CO_2 to produce CH_4 and H_2O, as homoacetogenesis converts the same reactants (H_2 and CO_2) to produce CH_3COOH and H_2O. Ampomah-Benefo (2018) stated that due to the comparatively high Gibb's free energy of hydrogenotrophic pathway (-135 KJ mol-1), its forward reaction is thermodynamically more favorable than the homoacetogenic pathway (-104 KJ mol-1). It is crystal clear that the hydrogenotrophic pathway has a potential to keep the H_2 pressure low in the digester through its consumption. Table 4 shows the main methanogenic reactions pathways indicating some of the microorganisms exploited as well as their corresponding standard Gibb's free energies.

Table 4: Reactions pathways in methanogenesis

Pathway	Reaction	Microorganism	ΔG^o at 25°C (KJ mol^{-1})
Hydrogenotrophic methanogenesis	$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$	Methanobacterium, Methanobrevibacter	-135.0
Acetoclastic methanogenesis	$CH_3COOH \rightarrow CH_4 + CO_2$	Methanosaeta, Methanosacina	-31.0
Homoacetogenesis	$4H_2 + CO_2 \rightarrow CH_3COOH + 2H_2O$	Clostridium acetium	-104.0

Source: Ampomah-Benefo (2018)

The maximum biogas yield can be evaluated through the digestion efficiency of the biomass. The theoretical evaluation of the maximum yield of methane when the elementary composition of bio-sourced feedstock is known can be determined using approximate Buswell's equation (Ampomah-Benefo, 2018) Equation 2.2 is the modified form of Buswell's equation, which is a stoichiometric equation of biogas production from bio-sourced feedstock.

$$C_nH_hO_oN_nS_s + yH_2O \longrightarrow xCH_4 + nNH_3 + sH_2S + (c - x)CO_2 \qquad 2.2$$

Where $x = \frac{1}{8}(4c + h - 2o - 3n - 2s)$ and $y = \frac{1}{4}(4c - h - 2o + 3n + 3s)$

The evaluation requires stoichiometric reactions of the biomaterial constituents (carbohydrates, fats, and proteins). These are shown in Table 5.

Table 5: Stoichiometric reaction of biomass to produce biogas

Substrate	Chemical reaction
Carbohydrates	$C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4$
Fats	$C_{12}H_{24}O_6 + 3H_2O \longrightarrow \frac{9}{2}CO_2 + \frac{15}{2}CH_4$
Proteins	$C_{13}H_{25}O_7N_3S + 6H_2O \longrightarrow \frac{13}{2}CO_2 + \frac{13}{2}CH_4 + 3NH_3 + H_2S$

Source: Ampomah-Benefo (2018)

The prospect and challenges of executing the technology in Nigeria are discussed next.

V. THE PROSPECT AND CHALLENGES OF EXECUTING CONVERSION TECHNOLOGY IN NIGERIA

In this section, the challenges confronting its execution (section 5.1) are highlighted and the prospect of executing the technology is discussed (section 5.2).

5.1 Challenges of Executing Conversion Technology in Nigeria

The conversion technology is not widespread in Nigeria despite its significance. This is attributed to:

1. *Lack of Technical Know-how*: Only limited number of skilled labor and specialists are available. Most Engineers are not well trained in the conversion technology and are not conversant with executing related projects. Skilled labors are required to operate and maintain renewable energy equipment. The absence of such ones especially in the rural areas is a major deterrent to the widespread adoption of the technology in Nigeria. Oyedepo *et al.* (2019) stated that remote areas with restricted access where on-hands maintenance is needed in terms of frequent visits by repair and maintenance staff is most affected. Consequently, failure to provide regular maintenance of the equipment when it is required leads to their complete breakdown, thereby defeating the purpose of the initial investment.
2. *Inadequate Fund:* Inadequate financial capacity to execute biomass conversion project is a serious barrier to the rapid uptake and development of renewable energy technologies in Nigeria. Access to loan facilities to execute these projects is unavailable. Government incentives are also inadequate. The cultivation of biofuel crops requires long-term loans and greater incentives. The NNPC sugarcane and cassava energy project can be replicated especially in the rural areas as the poverty level in these areas impedes farmers from getting loans, thus affecting their productivity.
3. *Lack of Awareness:* Generally, most Nigerians are not aware of the conversion technology. There is lack of awareness about what conversion technology options are available for exploitation and what benefits can be obtained from each of these options. This is the main issue, as the end users are ignorant of biomass potential for energy development.

This is attributed to improper means of information dissemination as people living in rural areas find it difficult to obtain relevant information on the technology.

5.2 The Prospect of Executing Conversion Technology in Nigeria

The technology exploited for the conversion of biomass to energy has been practiced for decades in the developed countries. China, Brazil, USA, Japan and others have invested hugely and had successfully added the technology to their energy mix. Generally, biofuel is mainly used for household heating, cooking and lighting, as well as energy production for agricultural and industrial processes. However, Nigeria is yet to breakeven since 1982 when biogas research started (REMP, 2005). The prospect is great as the country is endowed with huge bio-sourced feedstock irrespective of its category (Edenseting *et al.*, 2020). The research activity has been slow but steady as such not strong enough to make the technology attain commercial status in the country (Oyedepo *et al.,* 2019).

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 (Oyedepo, 2012; Ben-Iwo *et al.*, 2016; Edenseting *et al.,* 2020). 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 (Nwokeji, 2007). In Nigeria, Energy crops have been the only bio-sourced feedstock dedicated to biofuel production (Ben-Iwo *et al.*, 2016). There are dedicated sugarcane commercial farm by Nigerian National Petroleum Corporation (NNPC) and other investors for Automotive Biofuel Program (Ibeto *et al,* 2011; NNPC, 2015). 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 liters of fuel grade ethanol (Ohimain, 2010; Ben-Iwo *et al.*, 2016). Table 6 summarized several emerging projects harnessing bio-sourced feedstock for biofuel production in Nigeria.

Table 6: Emerging biofuel projects in Nigeria

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

Source: Ohimain (2010)

Presently, about twenty biogas pilot projects are domiciled in the country (Akinbomi *et al*., 2014). The prominent ones among them include: biogas plants at Zaria prison in Kaduna, Ojokoro in Lagos, Mayflower School Ikene in Ogun State and a biogas plant at Usman Danfodiyo University in Sokoto with capacity of the digesters ranges between 10 and 20 m^3 (Akinbomi *et al*., 2014). Furthermore, with collaboration with UNDP's "Africa 2000 Low Technology Biogas System", the UNDP introduced to Yobe, Jigawa and Kano States the floating drum, plastic balloon and tube types of biogas digesters. Since 2003, Kwachiri community in Kano state depended on the UNDP biogas project (using cow dung) for their daily cooking needs (Oyedepo *et al.,* 2019). Similarly the UNDP introduced biogas technology at some market abattoirs in some Northern States. However, most of the pilot bioenergy programs have not been successful. It is hoped that more can be achieved as the low level development of the technology is not encouraging. With government interventions and support from non-governmental organization and other individual in the country, biogas plant can be constructed in all communities to generate energy thereby replacing generators thereby eliminating the energy, environmental and health challenges.

VI. CONCLUSION

The potential of exploring biomass for energy development in Nigeria is huge. The effect is beyond achieving sustainable energy as a cleaner energy translates to a cleaner environment and sound health. The biomass conversion technology is cheap and the feedstock is readily available for exploitation at communal or individual level making it an attractive alternative to attain energy self-sufficiency. Consequently, rural to urban migration would be curtailed as individual community/household can exploit commonly found biomaterial to generate electricity making life more comfortable and positive impact to businesses.

The asthma and other related health challenges can be curtailed as the problem of generator noise and smoke would be fully addressed. This is true as country's hydrocarbon resources are state-owned as such no citizen is expected to harness it if even if the technology is cheap. The government does not have the political will to exploit these resources for energy development rather these resources are cheaply sold to other countries for immediate financial needs. Consequently, Nigerians have resorted to use of generators to meet their domestic and industrial energy needs. The impact of these generators on the environment in terms of noise and smoke contribute immensely on GHG emission.

Bioenergy has a major role as a source of dispatchable/portable energy and with high penetration of intermittent renewable commonly found in every household. The target of the project is to make the technology flexible and portable such that individual household or community can generate biogas and manage its effluent efficiently. This will ameliorate the problem of deforestation as it would be unreasonable to bypass these wastes generated within the community to cut trees in the forest for firewood. The time used to fetch firewood can be used for more profitable endeavor.

Generally, clean cooking using biogas eliminates smoke and inhalation of poisonous gases such as CO, NOx and Sox from incomplete combustion of firewood, diesel and poorly designed kerosene stoves thus eliminating health challenges associated with such fumes. In addition, age-long problem associated with open defecation, environmental pollution, contamination of water source, emission of odor would be eliminated as people will be conscious of transforming these wastes to wealth.

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