

# Production of Biogas from Perennial and Biennial Crop Wastes: Peach Palm and Banana's Wastes as Alternative Biomass in Energy Generation and Environmental Sustainability

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**Abstract** There is growing global concern about the future of non-renewable biomass in form of fossil fuel and its attendant consequences on the environment as evident in global warming. There is also, ever growing demand for energy and the need for environmental sustainability. Renewable energy sources from agricultural wastes especially those from biennial and perennial crop can be employed in the generation of biogas that will not only be environmentally friendly but also capable of solving the challenges of competition of biofuel with food crops. This review focuses on the possibility of using biomass from banana and peach palm's wastes for biogas production with twin advantages of clean energy and environment. Biomethanation is one of the major processes of conversion of wastes to biogas in digesters via anaerobic digestion in the presence of micro-organisms in optimal environmental conditions in terms of temperature and pH. It is well known that fossil fuel is finite no matter the deposits or reserves the world can boast of today. Biomass on the other hand, is abundant, renewable and available world-wide. If this energy source is tapped into effectively with concerted efforts from all and sundry, the economies of the developing world in particular and the whole world in general will be better for it.

**Keywords** Biogas, Biomethanation, Biomass, Banana's wastes, Peach Palm's wastes, Anaerobic Digestion, Environmental Sustainability

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## 1. Introduction

The menace of environmental pollution and the urgent need for alternate energy free of its attendant green-house gases and effects due to anthropogenic influences on the natural ecosystems are on the increase globally. As human population increases globally so is a consequent increase in generation of pollutants and wastes that calls for desirable measures that will not only mitigate the effects of the wastes but also provide alternatives that will put such wastes in check and convert where possible, to veritable energy sources for the benefit of human race. New technologies are being developed globally on daily basis in turning the huge biomass of wastes to biogas, and these technologies involve multidisciplinary approaches. Biomass is a promising eco-friendly alternative source of renewable energy in the context of current energy scenarios. Current global energy supply is to a large extent based on fossil fuels (oil, natural gas, coal), of which the reserves are finite. Given the

growing world population, the increasing energy consumption per capita and the evidence of global warming, the necessity for long-term alternative energy sources is obvious and inevitable. For instance, methane (CH<sub>4</sub>) gas is a greenhouse gas that remains in the atmosphere for considerable length of time [17]. It was also reported by Ayodele and Emmanuel [4] that methane gas is more effective in trapping heat than carbon dioxide (CO<sub>2</sub>). Methane was first recognized as having practical and commercial value in the 1890s in England, where a specially designed septic tank was used to generate the gas for the purpose of lighting streets.

For these twin crises of fossil fuel depletion and environmental degradation, energy planning and technology improvement have become an important public agenda of most developed and developing countries. Because of this, the European Commission has decided that in 2020 20% of the energy used should be derived from renewable source [8]. Biomass is recognized as a renewable resource for energy production and is abundantly available around the world [36]. Biomass utilization in mainstream energy uses is receiving great attention due to environmental considerations and the increasing demands of energy worldwide [40]. Biomass can be converted to bio-fuel via different thermal, biological and

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physical processes. Development of renewable energy sources would seem sensible if it is linked with environmental sustainability criteria to ensure that they efficiently contribute to overall net public good. With virtually all of the biofuels currently produced in the United States sourced from either soybeans or corn, there is significant interest in developing a diverse array of biomass feed stocks that will not compete for food resources, hence the consideration of waste products of farms and other means. Biomass refers to the diverse materials obtained from plants and animals, which can be used as raw materials for the creation of useful energy in various forms and for diverse purposes [54]. Biomass includes a broad variety of raw materials such as wood, agricultural crops, byproducts of wood processing, agricultural and forestry industry products, manure and the organic fraction of waste streams. Variety of crops both wild and domestic such as switchgrass, big bluestem, wheat grass, sycamore, sweet gum, cottonwood, reed canary grass in Finland, willow grass and hemp in Sweden, poplar in Spain and Italy, sorghum, barley, maize, wheat and Brassica crops, sugar beet, leys, maize, cereals, potato and hemp have been used as biomass for biogas production all over the world. Also, Patrick *et al.* [35] observed that the major biomass world-wide is *Jatropha* plant which is currently generating interest in every economy of the world.

The utilization of food wastes has the potential to provide new revenue streams to crop producers and food processors while creating new sources of clean renewable energy and chemicals. Unused crops and food processing wastes represent additional sources of renewable biomass that do not directly compete with food production. Also, the use of wastes from banana and peach palm plantations amongst other biennial and perennial plants can serve as a lucrative and worthwhile venture in energy generation and production from wastes biomass.

The current literature is inundated with biogas production from corn, soybean and other common annual crops which may raise some crucial debate on its competitiveness with food production for man and other animals. Shift to the use of biennial and perennial crops especially their wastes can ameliorate this. This review draws attention to the possibility of producing high quality biogas from banana and palm heart wastes biomass so as to advance the frontiers of knowledge in biogas technology bearing in mind its environmental sustainability. Energy (and other resources) recovery from these wastes therefore has the potential of greatly altering the situation - turning an environmental liability into a socioeconomic and poverty alleviation asset [53].

## 2. Biogas and Bio-methane

Biogas is generated when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion. Biogas is a renewable fuel. It is a mixture of methane (about 65%), carbon dioxide (CO<sub>2</sub>), and

impurities of hydrogen sulfide (H<sub>2</sub>S), CO<sub>2</sub> and water (Table 1). Technology is commercially available to remove H<sub>2</sub>S, CO<sub>2</sub> and water contaminants present in the biogas and landfill gas through processing to produce high-purity natural gas (RNG or biomethane) suitable for vehicles. When biogas is produced from biological material it is called bio-methane. After removal of contaminants, biomethane is the same as natural gas, and can be used as a transport fuel in the form of Liquid Natural Gas (LNG) or Compressed Natural Gas (CNG). Anaerobic Digestion (AD) technology is well established, hence biogas is often categorized as a 'first generation' biofuel. Bio-gas is widely used as a transport fuel in many European countries, notably Italy, which boasts of 650,000 gas powered vehicles. Sweden is a world leader in upgrading and use of biomethane for transport, and has many 'biogas vehicles', including private cars, buses, and even a biogas train and a biogas powered touring car team [18]. Germany is leading the field (biogas production) with almost 3, 900 biogas plants in operation in 2009, the majority using enlisted crops. Renewable natural gas (RNG) provides a clean, easily controlled source of renewable energy from organic waste materials, replacing fossil natural gas with a sustainable carbon neutral fuel option. **Anaerobic digestion** is the most commonly employed and technologically mature method; requiring only a low-oxygen environment for the naturally occurring breakdown of organic matter by bacteria.

**Table 1.** Components of Biogas

Typical composition of biogas	
<b>Methane</b>	50-80 %
<b>Carbon dioxide</b>	25-50 %
<b>Nitrogen</b>	0-10 %
<b>Hydrogen</b>	0-1 %
<b>Hydrogen sulphide</b>	0-3 %
<b>Oxygen</b>	0-2 %

Biogas is the gaseous emissions from anaerobic degradation of organic matter (from plants or animals) by a consortium of bacteria. Methane gas, the primary component of natural gas (98%), makes up 55-90% by volume of biogas, depending on the source of organic matter and conditions of degradation. Biogas is produced in all natural environments that have low levels of oxygen (O<sub>2</sub>) and have degradable organic matter present. These natural sources of biogas include: aquatic sediments, wet soils, buried organic matter, animal and insect digestive tracts, and in the core of some trees. Anthropogenic activities create additional sources including landfills, waste lagoons, and waste storage structures. Atmospheric emissions of biogas from natural and man-made sources contribute to climate change due to methane's potent greenhouse gas properties. Biogas technology permits the recovery of biogas from anaerobic digestion of organic matter using sealed vessels, and makes the biogas available for use as fuel for direct heating, electrical generation or mechanical power and other uses.

Biogas is often made from wastes but can be made from biomass energy feed stocks as well. It is well known that biogas, accounts for more than 60 percent of final energy used in Africa, 34 percent in Asia and 25 percent in Latin America [32]. One main advantage of biogas is the waste reduction potential. Biogas production by anaerobic digestion is popular for treating biodegradable waste because valuable fuel can be produced while destroying disease-causing pathogens and reducing the volume of disposed waste products.

Biogas burns more cleanly than coal, and emits less carbon dioxide per unit of energy. The carbon in biogas was recently extracted from the atmosphere by photosynthetic plants. Releasing it back into the atmosphere adds less total atmospheric carbon than burning fossil fuels.

Thus, biogas production reduces waste and produces energy. In addition, the residues from the digestion process can be used as high quality fertilizer. This closes the nutrient cycle. Digestion effectively eliminates environmental hazards, such as overproduction of liquid manure.

Apart from waste materials, suitable feedstock also includes dedicated energy crops. The main disadvantage of energy crops when compared to waste materials is their need for additional agricultural land. Nevertheless, energy crops for biogas production have several advantages which make them very promising for the future. One main advantage is the production of considerably high yields of energy crops even when they are cultivated extensively. Chemical fertilizers and pesticides are not required or only in small amounts. Damaged and uneatable harvests resulting from unfavorable growing and weather conditions, as well as from pest contaminations are also suitable for biogas production. In addition, cultivations do not have to become fully ripe, since the whole plant can be used for biogas production. The production of biogas from energy crops as well as from bio-waste or municipal waste is very popular in Austria, Denmark, Germany and Italy.

Biogas containing methane is a valuable product of anaerobic digestion which can be utilized in the production of renewable energy. Biogas can be used for generating electricity and heat. It can also be burned directly for cooking, heating, lighting and process heat. Furthermore, even pilot fuel cells installations are operated with by biogas. In addition, biogas can be cleaned and upgraded to natural gas quality. The final product is biomethane, which has methane content between 95 and 100%. This upgraded biomethane is suitable for all natural gas applications. For instance, it can be fed into the natural gas grid or used for transport in vehicles. One of the major processes of conversion of wastes to biogas or biomethane is biomethanation.

### 3. Biomethanation

Biomethanation is a process by which organic material is microbiologically converted under anaerobic conditions to biogas. Three main physiological groups of microorganisms are involved\_ fermenting bacteria, organic acid oxidizing

bacteria, and methanogenic archaea. Microorganisms degrade organic matter via cascades of biochemical conversions to methane and carbon dioxide. Energy has a major economical and political role as an important resource traded worldwide. Biomethanation technology (BT) may be perceived as a potential alternative as it not only provides renewable source of energy but also utilizes recycling potential of degradable organic portion of solid waste generated by numerous activities in the country. BT is the anaerobic digestion of biodegradable organic waste in an enclosed space under controlled conditions of temperature, moisture, pH, etc (Table). It is a human engineered decomposing system wherein depending on the waste characteristics; the waste mass undergoes decomposition anaerobically thereby generating biogas comprising mainly methane and carbon dioxide. Microbes are nature's ultimate garbage disposal, devouring the dead, decomposing an inert material that litters Earth's surface. This is their specialty. Microorganisms are so good at it, such that humans have taken an increasing interest in coercing them to clean up our environmental messes. This approach is termed bioremediation, and it involves using microorganisms and other organisms that are naturally contaminants- or pollutants-philic. Genetically altered organisms have also been used to degrade environmental toxins. Scientists are designing or deploying microbes to purge sites of contaminants such as PCBs, oil, radioactive waste, gasoline and mercury, and new bioremediation research appears regularly on daily basis. Cellulose recycling in nature is in the order of 1015 kg per year [6]. This number is so high that we could make enough fuel ethanol to supply 100 times the energy requirements of the entire world in a rampant development scenario projection for 2035 [30]. Perennial and biennial crops are made up chiefly of cellulosic materials which can generate high amount of energy. This is an area that has not been fully explored. For instance, Table 2 below shows the quantities of biogas produced from various farm waste in which banana leaves (control) produced 81cm<sup>3</sup> volume of biogas. The table gives the comparison of biogas generation of banana leaves and Maize cob, Maize stalk, Water hyacinth, Elephant grass and Cow dung. The results shows that with the exception of the digester E in which Cow dung without yeast was used, all the other digesters (i.e A, B, C and D) in which Maize cob, Maize stalk, water hyacinth and elephant grass, were respectively used generated more biogas than the control digester in which banana leaves used, in spite of the fact that all the digesters were of equal slurry concentration.

Li et al. [25] report that in southern China, where banana plantation has a significant economic importance, pseudo-stems are normally cut and usually abandoned in the plantation to become organic waste and cause environmental pollution after harvesting of banana bunches. The same practice is reported to occur in India [47, 48]. When decomposed, these wastes may produce gases such as hydrogen sulfide and ammonia that can pose serious environmental hazards [23]. These wastes can be channeled

and utilized or converted into useful products for the benefit of mankind. According to Mophapaltra et al. [28], the core of the banana pseudo-stem is rich in polysaccharides with traces of other elements, and has very low content of lignin.

The theoretical potential of methane production from banana pseudo-stem can be determined based on the content of proteins, carbohydrates and fat reported by Aziz et al. [45]. Table 3 shows the nutritional and chemical components of unripe banana peel meal.

One main advantage of methane production is the ability to use so-called "wet biomass" as feedstock source. Symbiotic groups of bacteria have different functions at different stages of the digestion process in order to break down complex organic materials. In order to promote bacterial activity, temperatures of at least 20°C are required. Generally, higher temperatures shorten processing time and reduce the required volume of the digester tank by 25% to 40 %. The choice of the process temperature depends on the feedstock and the utilized digester type. Thus, digesters have to be heated in colder climates in order to encourage the bacteria to carry out their function. Temperature is an important factor for anaerobic digestion since methane – producing bacteria operate most efficiently at temperatures 30 – 40°C or 50 – 60°C [23]. Digestion time ranges from a couple of weeks to a couple of months depending on feedstock and digester type as well as on the digestion temperature. The process is sensitive to low pH and the optimum pH lies between 6.5 and 7.5 [26]. Alkan-Ozkaynak

and Karthikeyan [3] showed that pretreatment of corn ethanol thin silage with lime does not only raise pH, but also eliminates some potentially inhibitory parts of the silage content such as oleic acid through precipitation by Ca. Previous experiences also show a methane generation through anaerobic digestion of 64-271 L CH<sub>4</sub>/kg dry matter and that fibre extraction and recovery for material production purposes, together with combinations of technologies for energy and nutrient recovery could be of large interest in countries with high generation of bio-waste [37]. The liberation of acetate from hemicellulose negatively impacts fermentations of cellulosic biomass, limiting the concentrations of substrate that can be effectively processed. Solvent-producing bacteria have the capacity to convert acetate to the less toxic product acetone. *T. saccharolyticum* has previously been engineered to produce ethanol at high yield by deletion of *ldh* encoding L-lactate dehydrogenase and *ack* and *pta* encoding acetate kinase and phosphotransacetylase [38]. Table 4 depicts the potentials of fibre extraction from some biennial and perennial crops and the percentage wet biomass needed in the process. The production of biogas for reducing fossil CO<sub>2</sub> emissions is one of the key strategic issues of the governments of the developed world and has resulted in the development of new process techniques and new technologies for the energetic use of biogas in domestic and industrial facilities. Biomethanation has the capacity to reduce the use of fossil fuels and thus reduce CO<sub>2</sub> emission.

**Table 2.** Comparison of Biogas Generation of Banana leaves and Maize cob, Maize stalk, Water hyacinth, Elephant grass and Cow dung

Time (Day)	Average volumes of Biogas generated (cm <sup>3</sup> ) daily Digesters of equal capacities					
	Control	A	B	C	D	E
01	45.00	110.00	70.00	64.00	72.50	0.00
02	22.00	59.00	20.50	92.50	90.0	0.00
03	14.00	48.00	0.00	52.50	55.00	0.00
04	0.00	49.00	10.00	40.00	94.00	10.00
05	0.00	47.00	15.00	75.00	62.00	12.00
06	0.00	35.00	10.00	50.00	41.50	8.50
07	0.00	22.50	10.00	20.00	30.00	0.00
08	0.00	0.00	0.00	0.00	20.50	0.00
09	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00
<b>Total</b>	81.00	370.50	135.50	394.00	465.50	30.50

Source: Adapted from [52]

**Table 3.** Chemical composition of unripe plantain peel meal

A Chemical Component	Unripe plantain peel meal (%)
Crude Protein	10.64
Crude Fiber	5.82
Ether Extract	9.57
Ash	12.82
Metabolisable Energy (Kcal/kg)	3918.90
B Minerals	mg per 100gm
Calcium	10.00
Phosphorus	34.00
Sodium	35
Magnesium	28
Copper	2
Iron	6.55
Zinc	--
Manganese	8
Iodine	--
Silica Free Ash	12.09
Sulphur	10
Potassium	401
Chlorine	125
C Vitamins	I.U./g
Vitamin A	0.28
Ascorbic Acid	11.00
Thiamine	0.03
Riboflavin	0.05
Niacin	0.65

Source: Adapted from [49]

**Table 4.** Potentials for fibre extraction from banana, papaya and peach-palm stem/pseudo stem

Species	% of wet biomass	Reference
Banana pseudo stem	8	[46]
Papaya stem	9	[46]
Peach palm stem	6	[46]
Banana pseudo stem	1.6-3.1	[47]
Banana pseudo stem	6.7	[45]

## 4. Biogas and Biofuel

Biogas is only one of many types of biofuels which include solid, liquid or gaseous fuels from biomass. Biofuels include fuels derived from biomass conversion, as well as solid biomass, liquid fuels and various biogases [15]. Any combustible fuel derived from recent (non-fossil) living matter (biomass) may be considered a biofuel, including ethanol derived from plant products, biodiesel from plant or animal oils as well as biogas from biomass. All biofuels are produced from sources which are renewable and are included as a subset of renewable energy sources that also include energy produced from solar, hydro, tidal, wind, and geothermal sources. Biogas, like natural gas, has a low volumetric energy density compared to the liquid biofuels, ethanol and biodiesel. However, biogas may be purified to a natural gas equivalent fuel for pipeline injection and further

compressed for use as a transportation fuel. Methane, the principal component in biogas, has four times the volumetric energy density of hydrogen (H<sub>2</sub>) and is suitable for use in many types of fuel cell generators. Fuel yields depend on photosynthetic efficiency (less than 3% of solar energy is captured in even high yield crops), the efficiency of the conversion process, and the energy used in the production and conversion process (a significant cost for ethanol production). On a per acre basis, biogas production is far more efficient in capturing the energy found in energy crops. While the convenience and energy density of liquid fuels is an admirable target, if maximizing energy recovery from biomass and wastes is targeted, biogas production is the best choice. In addition, where ethanol and biodiesel production is used, biogas production from their waste products can improve the energy balance of the overall conversion process. Biofuels offer the advantage of coming from large, mainly under-utilized biomass resources that are sustainable and renewable in a closed carbon cycle that reduces environmental input [43].

Biofuels apply to solid, liquid or gaseous fuel produced from biological materials (biomass) which can be used for the generation of power, heat or fuel for motive power [59, 55, 56, 57]. In 2005, research revealed that bio-energy reserves/potential of Nigeria stood at: Fuel wood 13071,464 hectares, animal waste, 61 million tons per year, crop residues, 83 million tonnes [55]. It well known that Nigeria is the largest producer of cassava in the world and has the largest capacity for oil palm plantation which serves as a great source for biodiesel [1]. Table 5 shows the estimated biomass quantities in Nigeria. This stands the country in a good stead in turning these huge biomasses into valuable products that can enhance generation of income for both government and her citizens.

**Table 5.** Biomass resources and estimated quantities in Nigeria (2004)

Resource	Quantity (million tonnes)	Energy value (' 000 MJ)
Fuel wood	39.1000	531.0000
Agro-waste	11.2444	147.7000
Saw dust	1.8000	31.4333
Municipal solid waste	4.0750	

Source: [58, 60]

**Table 6.** Biogas production from groundnut waste

Day	Average ambient Temperature (°C)	Volume of	Gas	Produced (cm <sup>3</sup> )
		G1	G2	G3
1-5	29	20	70	10
6-10	29	310	00	24
11-15	29	50	188	190
16-20	30	00	00	25
21-25	30	10	00	00
26-30	30	00	00	00

Source: Oyeleke and Gweba, 2011.

**Table 7.** Biogas Yield from Chicken Droppings and Its codigestion with *Cymbopogon citratus* (lemon grass)

	Volume of Biogas produced (m <sup>3</sup> )	Average Biogas yield per day (m <sup>3</sup> /day)	Average of Biogas per kg Slurry (m <sup>3</sup> /kg)	Average daily yield of Biogas per kg Slurry (m <sup>3</sup> /kg/day)
<b>Before Scrubbing</b>	1.25 x 10 <sup>-1</sup>	4.17 x 10 <sup>-3</sup>	2.08 x 10 <sup>-2</sup>	6.95 x 10 <sup>-4</sup>
<b>After Scrubbing</b>	8.97 x 10 <sup>-2</sup>	2.99 x 10 <sup>-3</sup>	1.49 x 10 <sup>-2</sup>	4.98 x 10 <sup>-4</sup>
<b>Estimated Methane Content</b>	71.76%			

Source: Adapted from [2].

Biogas can be produced from a host of biomass which ranges from wastes of various kinds (Table 6) through biennial and perennial crops, to grasses of various kinds (Table 7) depending on the interest of the researcher.

## 5. Biomethanation and Composting Processes

Composting has been the age-long process applied by farmers in the production of manure as means of fertilization of arable land for food production. In today's world, the reduced organic and inorganic compounds produced by anaerobic microbial processes serve as carbon and energy reservoirs for photosynthetically fixed energy. Biogas and manure are the end products obtained from biomethanation and composting produces manure as the only product. Thus, comparatively biomethanation could be considered as better option for its compactness, cleaner operation and better product range (i.e. both gas as energy source and processed solid waste as manure). Composting is the aerobic decomposition of organic materials by microorganisms under controlled conditions. Biogas technology has become therefore interesting as a way to improve the energy release from agricultural residues, save plant nutrients, and improve health conditions and quality of life in the villages [41].

## 6. Biogas Production Technology

Agricultural biogas plants typically consist of a number of low digesters built either from concrete or metal. They are often topped by a twin-skinned gas storage bag, giving them a characteristic appearance. Majority of the biogas is produced from the first digestion tank with a lower gas yield being attained in the secondary digestate storage tank. The common technology for biogas production is the digestion of feedstock in specially designed digesters. These digesters must be strong enough to withstand the buildup of pressure and must provide anaerobic conditions for the bacteria needed in the digestion process. Today, there are many different technologies and digester types available. Generally, the size of biogas plants can vary from a small household system to large commercial plants of several thousand cubic meters. Digester size also influences logistics and vice versa. Therefore, they are often built near the source of the feedstock.

The water content of substrate influences the design and type of digester. One of the most common classifications regarding the water content of the substrate is wet digestion (which is fed with dry mass contents lower than 15% and into dry digestion which is fed with dry mass content between 20 and 40%). Wet digestion is usually applied to manure and sewage sludge whereas dry digestion is often applied to the fermentation of energy crops. The removal of H<sub>2</sub>S from the biogas is achieved by air dosage into the digester gas phase. Water vapour is removed by means of a water tap.

Furthermore, digesters can be classified by the number of process steps. Single-stage and two-stage digesters are the most common technologies today. Single-stage digesters are characterized by no special separation of different process steps (hydrolysis, acidification, methanisation). All process steps are conducted in one single digester. Digesters can also be classified according to the filling procedure and filling interval.

Co-digestion refers to the simultaneous anaerobic digestion of multiple organic wastes in one digester. Co-digestion is used to increase methane production from low-yielding or difficult-to-digest feed stocks. The co-digestion of manure, residuals of food processing and energy crops in continuous stirred reactor systems is an effective and reliable way for the production of biogas.

The presence of too much NH<sub>3</sub> or H<sub>2</sub>S can inhibit the production of methane. Wastes from fruits, vegetables, and grains contain large amounts of primary metabolites of lipids, proteins, and carbohydrates and a broad range of high-value bioactive compounds of phenolics, terpenoids, and alkaloids. Extraction techniques have been widely investigated to obtain valuable natural compounds from plant-based processing wastes. Wet plant-based food processing wastes, which are rich in sugars, vitamins, and minerals, have been used to produce fuel alcohols, organic acids, biodegradable polymers, enzymes, antioxidants, and vitamins in biological processes. Both high and low levels of nitrogen can inhibit the biogas process. The substrate composition not only has an influence on the process performance but also affect the composition of the produced biogas [7]. For instance, Table 8 depicts the various moisture contents of the feed stocks used in the biogas production process that can guarantee success in biogas production.

In addition, Maduagwu [51] studied the effect of pH on anaerobic biodegradation of the lingo-cellulose from maize cob and maize stalk using *Curvularia* spp. The study revealed

that pH 7.3 was the best and pH below 6.2 rendered the microbes inactive. Table 9 shows various buffering effects on the production of biogas. This shows that digester B in which 0.2M buffer solution was used generated highest volume of biogas when compared with the volumes of biogas generated in the control digester, A, C, D and E in which the molar concentrations were 0.0M, 0.1M, 0.3M,

0.4M and 0.5M respectively. Likewise, Table 10 shows the compositional comparison of the biogas generated at different operational conditions. The results revealed that though, the composition of the biogas generated was the same (CH<sub>4</sub>, CO<sub>2</sub> and H<sub>2</sub>S), but the percentages of the constituents gases differed at different operational conditions.

**Table 8.** Residue -to- Product Ratios (RPR) of Different crops

Residue	[61]		[62]	
	RPR	Moisture content	RPR	Moisture content
Rice straw	1.76	13%	1.5	Air dry weight
Wheat straw	1.75	15%	1.5	Air dry weight
Barely straw	1.75	15%	1.5	Air dry weight
Maize stalk	2.00	15%	1.0	Air dry weight
Maize cob	0.27	8%	--	--
Cotton stalk	2.76	12%	1.5	Air dry weight
Sugar cane (tops)	0.30	10%	0.25	Air dry weight
Sugarcane(bagasse)	1.29	50%	0.25	Air dry weight
Rice husk	0.27	12%	--	--

**Table 9.** Effect of Buffering on Biogas Generation Using Buffer Solution of pH 7.3 but different Molar Concentrations

Average volumes of biogas generated (cm<sup>3</sup>) daily  
Digesters of Equal Capacities

Time (Day)	Control	A	B	C	D	E
01	45.00	46.00	55.00	40.00	29.00	18.00
02	22.00	24.00	36.00	20.00	12.00	6.00
03	14.00	9.00	13.00	6.00	2.00	0.00
04	3.00	8.00	6.00	0.00	0.00	0.00
05	0.00	0.00	0.00	0.00	0.00	0.00
06	0.00	0.00	0.00	0.00	0.00	0.00
07	0.00	0.00	0.00	0.00	0.00	0.00
<b>Total</b>	81.00	88.00	110.00	66.00	43.00	24.00

Source: Adapted from [52]

**Table 10.** Compositional Comparison of the Biogas Generated at Different Operational Conditions

Condition of the slurry	Percent age Composition		
	CH <sub>4</sub>	CO <sub>2</sub>	H <sub>2</sub> S
Contained water	68.78	31.10	0.12
Contained buffer solution	65.54	34.22	0.24
Contained urea	63.86	35.80	0.34
Contained buffer solution & urea	59.94	39.63	0.43

Source: Adapted from [52]

### 6.1. Other Benefits Accruing from Biogas Production

Anaerobic digestion (AD) can be used to provide renewable energy from most organic material. AD produces 2 outputs\_ energy in the form of biogas and digestate as source of organic fertilizer. Crop based AD for energy can provides employment, increase diversity through the use of a wide range of crops, produces fuel which is clean, environmentally friendly and has multiple uses.

Agricultural biogas plants typically generate returns via the sale of electricity alone, this means that the gas engine is of particular importance for the success of the plant. In large farms where there is biogas plant the farmer can have dual advantages of the proper waste management as well as reducing the energy cost of the operations of the farm.

## 7. The Peach Palm (*Bactris gasipaes*) and Banana (*Musa spp.*)

The peach palm, *Bactris gasipaes* is an important tropical perennial agricultural crop cultivated for the fruits and heart of palm or 'palmito'\_the unexpanded leaves above the meristems. The peach palm (*Bactris gasipaes* Kunth, Areaceae) is a widely domesticated palm in the Neotropics, and is considered to have an Amazonian origin [11]. The fruits are a main component of subsistence diets in lowland humid regions, while the heart of palm has a considerable commercial value [12, 13] particularly in Brazil, Ecuador and Costa Rica where cultivation is almost totally devoted to the extraction of palmito [9]. The fruit has a high nutritional value, and is an important component of subsistence farming in resource-poor communities in lowland humid regions.

Banana is the second largest produced fruit after citrus, contributing about 16% of the world's total fruit production [20]. India is the largest producer of banana contributing 27% of world's banana production. Edible banana are either derived solely from *Musa accuminata* or are a hybrid between two wild diploid species, *Musa accuminata* Colla and *M. balbisiana* Colla. Common species grown worldwide include *M. sapientum*, *M. paradisiacal*, *M. cavendishii* (is the desert species\_ very sweet and less starchy).

## 8. Discussions

Given that wastes constitute large chunk of anthropogenic activities and the need for alternate energy source that is not only sustainable but also capable of replacing the fossil fuel which is finite and non-renewable the need for exploitation of other crops apart from those routinely used in biogas production can no longer be taken with levity. In addition, Current estimated oil reserve in Nigeria is 35.9 billion barrels with daily production capacity of 2.4 million barrels of crude oil. The 35.9 billion barrels of oil reserve will be depleted by 30-35 years period [1]. There is currently a movement towards reduced use of fuels from fossil origin; thus, fuel production from renewable biomass is becoming

increasingly acceptable [39].

Biomass means agriculturally produced raw materials which are available on renewable or recurring basis. It includes tree crops, plant fibres, cellulose based materials, industrial wastes and other biodegradable parts of municipal solid waste [29]. The production of biogas from palm heart's and banana wastes biomass separately and then, combined in varying proportions and, or percentages in a completely randomized block design can indicate the importance of perennial and biennial crop plants in generating high quality biogas since the energies were accumulated over the years from solar energy. For instance, the biennial crop, Sugar beet and its tops can give 450m<sup>3</sup> of methane/ton VS [7]. Although much work has not been done in this direction, it is also believed that the superiority of peach palm and other perennial crops in terms of biogas production may be better than those that can be gotten from biennial and annual crops' wastes. Use of fibers from peach-palm has also become increasingly popular in recent years and is not only limited to biogas production. Several producers of natural fiber based products currently use palm-fibres in production of parquet, panels and furniture [21, 34]. The best energy crops are durable, their dry matter yields are high and constant and their production costs are low. A perennial growth habit, low agrochemical requirements, effective conversion of solar energy to biomass and ease of conversion back to useful energy guarantee that energy efficiency of production is high and environmental impacts are low [19] since the methane and energy content of the gas generated usually varies and is dependent on the physical and chemical properties of the substrate used [10]. For instance, Alfa *et al.* [2] demonstrated that Biogas could be produced from *Cymbopogon citratus* in quantity and quality comparative with others in literature.

It is also believed that the mixture of palm heart's waste and banana's waste biomass can produce the highest volume of biogas (that is, the mixture of banana's wastes and palm heart's waste in a ratio of 3:2 might be the best option). This can be effectively tested by grouping the experimental units into blocks such that variability within each block is minimized and variability among blocks is maximized. According to Mophalatra *et al.* [28], the core of the banana pseudo-stem is rich in polysaccharides with traces of other elements, and has very low content of lignin. Also, the high content of holocellulose and low content of lignin make the banana pseudo-stem bark, an ideal material for application in pulping and papermaking [25]. This feature can also be exploited in terms of biogas production. Perennial crops require less maintenance and fewer inputs than do annual row crops, so they are cheaper and more sustainable to produce. Perennial energy crops need considerably less fertilizer, pesticide, herbicide, and fungicide than annual row crops. Perennial and biennial crops are known to be made up of high content of cellulose. These cellulosic materials can give large volume of biogas when the proper anaerobic digestion process is employed. In line with this thought, Larson [24] projects that future advanced cellulosic processes from perennial crops could bring reductions of

80–90 percent and higher in green house gases. Hoogwijk *et al.* [22] indicated that the bio- fuel production potential around 2050 could lie between about 70 and 300EJ fuel production capacity depending strongly on the development scenario.

Anaerobic digestion of energy crops through biomethanation requires in most cases prolonged hydraulic residence times from several weeks to months (for a period of 75 to 90 days for example). Nevertheless, if sustainability criteria are followed [14], the use of energy crops will reduce GHG emissions by replacing fossil fuels at least to some extent. EEA Technical Report [16] estimates the environmentally compatible overall bioenergy potential from agriculture in Europe in 2030 of up to 6 EJ. Africa and Nigeria in particular can key into the use of perennial crops so as not to be left out when the fossil fuels are depleted. Since this can lead to reduction of the amounts of emitted CO<sub>2</sub> by replacement of fossil fuels with biogas in vehicles and for production of electricity and heating [5]. Given the growing world population, increasing energy demand per capital and global warming, the need for a long term alternative energy supply is clear and inevitable.

## 9. Conclusions and Recommendations

Biomethanation can serve as a valuable process in biogas production from wastes from biennial and perennial crops thereby solving environmental problems as well as generating energy for both domestic and commercial use.

The main drawback from this analysis is that any banana and peach palm biogas plant will need government support, whether through tax exemptions, subsidizing or reduced subsidies on petrol, in order to provide a substantial financial return on investment.

In Brazil and the United States, large corporations dominate the bioenergy industry, but farmer cooperatives play a useful role in linking these large firms to independent growers [31]. This a good way to start and association of interested farmers (Cooperative) could serve as a means of assessing large capital from relevant organizations.

Banana and peach palm wastes like other perennial and biennial crops should be considered as economic resources that can be turned into valuable products in progressing towards a permanent solution to waste disposal problems and generation of renewable energy.

Feasible methods with optimal environmental conditions such as pH and temperature will have to be found and employed to solve the environmental problems to assure sustainability. These environmental conditions have to be factored into the design of the digesters.

The biogas process and biomethane production is also advantageous as it mediate the recirculation of nutrient from waste products to arable fields as residues from the whole process can be used as fertilizer.

Despite this potential, bioenergy must be viewed not as the single replacement for oil, but as one element in a wider

portfolio of renewable sources of energy\_ as part of the whole solution to energy and environmental crises.

Deliberate efforts should be made by the government in terms of massive capital investment, training of man-power in the field of biofuel or biodiesel development, granting tax holidays to would-be investors\_ companies and individuals, amongst many other things; and that if adequate policy frame-work is put in place and necessary political will is expressed and applied to the development and production of biodiesel in the country the economy would be better for it [35]. Same could also be applied to biogas production from peach palm and banana's wastes amongst others.

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