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Production of Electricity from Human Waste as a Strategy for Curbing Electricity Generation Problem in Nigeria

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Abstract: This paper proposes method for generation of electricity using human waste. The human waste was subjected to anaerobic digestion in the biodigester which was taken to be the septic tank with little modification to enhance biogas production and collection. Biogas produced and collected was subjected to treatment to remove CO_2 and H_2S which were the major corrosive contaminants principally present in the raw biogas stream in order to prepare it as inlet gas for the gas turbine plant. Both single and combine cycle gas turbines were evaluated based on their capacities and electrical power output from unit volume of biomethane gas. FUTO NNDC Hostel with a capacity of 696 students was taken as case study. From the results, it was realised that a total biogas volume of 35 m^3 was produced daily from the NDDC hostel. This gave a total biomethane volume after treatment of 22.75 m^3. When this biomethane volume was used for electricity generation, it produced an electrical power of 5.21 KW per day for combine cycle gas turbine and 3.22 KW per day for single cycle gas turbine. The results on power usage reveals that the power generated from the NDDC hostel per day will serve the electrical energy needs of 626 households using a daily electrical energy of 0.2kwh if CCGT was used for power generation, and a total of 387 households using the same energy needs of 0.2kWh if single cycle gas turbine were used for power generation.

Keywords: Human Waste, Electricity, Biogas, Biomass, Biodigester

1. Introduction

Nigeria, with all its natural gas reserve has not been able to generate enough electricity for its nearly 190 million heads of population. The Nigeria national grid system has not covered most rural areas, as such those areas are without electricity infrastructures [1]. There is limited extension of the grid to most communities, and it would take decades to reach most areas in Nigeria. Since more than 70% of the Nigeria population live in rural areas; a large proportion of this number are without access to electricity supply. Furthermore, the available electricity capacity is insufficient to meet existing power needs of the less than 40% who have access to the national grid. Nigeria has barely reached a peak power generation of 5074MW in 2016 which represents roughly 26.7MW per million heads of population, a figure too low when compared to world acceptable average power needs of 1000 MW per million heads of population [2]. This low electric power generation has been blamed for decelerated growth in almost all sectors of the Nigeria economy.

Due to the rapidly increasing demand for electric power in Nigeria and the failure of electric power providers to meet up with the demand, there is need to consider other possible means of generating electricity other than the conventional grid-centered system. A promising means to achieve this is through renewable energy sources. Renewable energy offers great prospects as a solution to the Nigeria electricity problem and emerges as a developmental trend in the Nigeria electric power sector.

Of all the forms of renewable energy, bio-energy through biogas is most common. Biogas is produced from variety of processes which includes human waste, animal waste, waste water, landfills etc. Biogas is the product of anaerobic digestion of waste and is composed of methane, carbondioxide, hydrogen sulphide and other gases present in it. Methane gas being a major constituent of the decomposition of human waste is used in generation of electricity through gas turbine system [3].

Energy derivation from waste is a way to reduce fossil-fuel-generated electricity, thus minimizing pollutions associated with fossil fuel combustion processes. Similarly, the use of human wastes for electricity generation present a way for proper management of human wastes especially in rural areas where there is lack of municipal sewage system.

Production of biogas from human waste is an innovative way of managing human waste. Biogas from human waste can be used for, cooking, lighting and electricity generation. Beside this, recycling and reusing biogas from human was is an economical way of getting rid of health hazards. Additionally, the remaining sludge after the biogas production is useful in fertilizer production [4].

It is intended that in the nearer future every household will supply its own required quantity of electricity from the waste they produce. This electricity generated will be sufficient for all the domestic electrical needs of that home. This is the idea of a bio-home which is both innovative and conservative.

To produce electricity from human waste, there must be means to convert the human waste into biogas. The biogas production serves as the intermediary step in the conversion of human waste to electricity. In this process, biodigester capable of achieving anaerobic oxidation of the carbohydrate contents of the human waste is used. Biodigester comes in several designs, the designs are influenced by the type of waste it will contain and the use of the resulting biogas. In the fermentation of human waste, the septic tank can serve as the biodigester. To achieve this, septic tanks must be redesigned to enable rapid biogas production, capture and storage.

The production of electricity from human waste will ensure that electricity is produced and utilized in homes independently. Ultimately, this will reduce the load on grid electricity supply and help reduce occurrences of power outages and failures due to overload of the transformer and also minimize the financial involvements associated with purchase of electricity through a cost-effective production of electricity in-home.

1.1. Biogas

Biogas is the gas that is gotten by the fermentation of organic matter content in manure, sewage sludge, and municipal solid waste, in an anaerobic condition. Biogas is mixture of gases that comprise mainly methane and carbon dioxide, with other impurities in it. The equation of reaction for the production of biogas from organic waste is giving below.

$$2CH_2O \rightarrow CH_4 + CO_2$$

$$Carbohydrate \rightarrow Methane + carbondioxide$$

Aside methane and carbondioxide, other impurities are produced alongside the reaction. These includes hydrogen sulphide, nitrogen, hydrogen and water vapour. Hydrogen sulphide is responsible for the offensive odour that emanates from anaerobic digestion processes in the production of biogas. The amount of each gas in the mixture rely on many factors such as the type of digester and the kind of organic matter. Biogas as a source of energy is promising and renewable. In fuel cell it can be directly used as source of energy. When used in heating, it can release high amount of energy when burnt or used in CHP for the simultaneous production of heat and power. When processed it can be fed into natural gas networks or used as fuels in cars for vehicular transport being distributed by gas stations [5].

Methane is the major constituent of biogas and an important fuel for electricity generation when used in gas turbines or steam boilers. Methane produces far less carbon emission when burnt in comparison with other hydrocarbons.

1.2. Biogas from Human Waste

Human waste mea the waste products of the human digestive system and the human metabolism, which includes faeces and urine. Mainly the method of treating human waste in rural areas where there is no available municipal sewage system is by use of septic tank [6]. A septic tank is an underground chamber made of concrete, fiberglass, or plastic through which domestic wastewater flows for basic treatment. In the septic tank, settling and anaerobic processes reduce the solid contents and organic materials present. The solids settle out and break down in the tank. The liquid remains in the tank for a short time before overflowing into a sealed soak away or drain field where it infiltrates into the ground.

Modi [7] stated that septic tank is a combined sedimentation and digestion tank where sewage is held some days. During this period, there is a sedimentation of the suspended solids to the bottom. Anaerobic digestion of the settled solids follows giving rise to substantial reduction in the volume of the sludge, decrease in the biodegradable organic matter and the release of biogas. Traditionally septic tanks have functioned as a means of collecting human waste from human habitations. Innovation has discovered the use of septic tank as a bio-digester since the whole process occurring in the septic tank is anaerobic [8]. The sludge and scum that goes into the septic tanks after emit some mixture of gases after undergoing decomposition. This gases emitted of which methane is chief was not collected for economic use. Recently, the world especially developing countries are being faced with the problem of petroleum and coal combustion (which result in the emission of harmful gases into the atmosphere). This has led to various researches being carried out to access other sources of energy, like renewable energy which reduces or eliminates the emission of harmful gases [9].

2. Processes in Production and Use of Biogas from Human Waste

The processes undertaken in the production of biogas can be grouped into four namely:

1. Introduction of the input material
2. Digestion (fermentation), consisting of hydrolysis, acidogenesis, acetogenesis and methanogenesis
3. Collection of the biogas and treatment
4. Conversion of the biogas to renewable electricity and useful heat with cogeneration / combined heat and power
5. Post-treatment of the digestate

2.1. Introduction of the Input Material

The input material here is the human waste. The human waste is introduce from the toilet seat and travels through the delivery tube to the underground septic tank. The flush waste is stored in the pressure tight septic tank as biogenetic actions commence.

2.2. Digestion

The human waste is fed into the digester. This is first received in a primary pit or liquid storage tank from where it is then transferred to the digested. In the digester, a series of biological processes act on the materials to convert them to biogas through a process known as fermentation or anaerobic digestion.

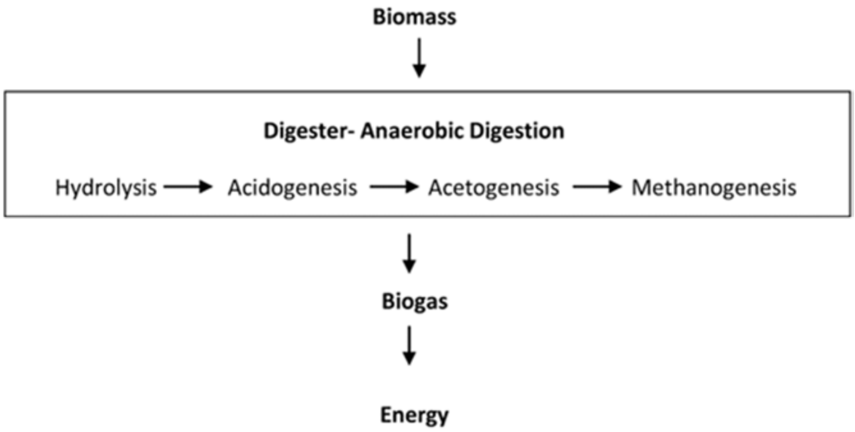

Figure 1. *Processes in anaerobic digestion of biomass.*

2.2.1. Hydrolysis

In the digester, the first process that occurs is hydrolysis. Generally, hydrolysis is a chemical reaction that result in the breakdown of water molecules into H^+ cations and OH^- anions. It is employed in the breakdown of large polymers in the presence of acidic catalyst. Biomass which is essentially large has to be broken down. Through hydrolysis these large size biomass is broken down into smaller molecules such as amino acids, fatty acids and simple sugars [10].

2.2.2. Acidogenesis

After, Hydrolysis, the next step of anaerobic digestion is acidogenesis. In this process, microorganisms further breakdown the resulting biomass after it has been hydrolysed. Acidogenesis is the next step of anaerobic digestion in which acidogenic microorganisms further break down the Biomass products after hydrolysis. These microorganisms are bacteria that create acidic environment in the digestion tank creating substances such as ammonia These fermentative bacteria produce an acidic environment in the digestive tank while creating ammonia, H_2, CO_2, H_2S, shorter volatile fatty acids, carbonic acids, alcohols, as well as trace amounts of other byproducts. H_2, CO_2, H_2S, shorter volatile fatty acids, carbonic acids, alcohols, as well as trace amounts of other byproducts [11].

2.2.3. Acetogenesis

During acetogenesis, acetate is created. This is a derivative of acetic acid formed by acetogens from the carbon and energy sources. These microorganism break down many of the products into acetic acids, CO_2 and H_2. They break it down to a level that methanogenesis can act on it to enable the production of methane as biofuel

2.2.4. Methanogenesis

This is the final stage of anaerobic digestion in which methanogens produce methane from the final products of acetogenesis as well as from some of the intermediate products from hydrolysis and acidogenesis. There are two general pathways involving the use of acetic acid and carbon dioxide, the two main products of the first three steps of anaerobic digestion, to create methane in methanogenesis

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (1)$$

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (2)$$

The biogas yield from the plant does not only depend on the type of feedstock, but also on the plant design, temperature of fermentation and time of retention [12].

2.2.5. Collection of the Biogas

The biogas is captured in a gas storage tank which is located separately to the main digester, or in some cases can be its roof. The gas storage tank acts as a buffer in order to balance fluctuations in the production of gas in the digesters. The delivery pipe connects the digester to the gas storage tank. The biogas in the storage tank contain mixtures of methane, CO_2, H_2S, Nitrogen, Hydrogen and other gases. The typical composition of a biogas is given below.

Table 1. *Typical composition of biogas.*

Gas	Concentration%
CH_4	50-70
CO_2	25-30
N_2	0-10
H_2O	0-5
H_2S	0-3
O_2	0-3
C_XH_Y	0-1
NH_3	0.0.5
R_2SiO	0-50 mg/m^3

2.2.6. Treatment of the Biogas

The raw biogas from the digesters may not be useful immediately for production of electricity of for other uses. This is because it contains high proportions of CO_2 and H_2S and some traces of water vapour which are very corrosive compounds that may damage pipes and machines such as turbines or mechanical part. To this the raw biogas must be treated to get rid of the corrodants and thus increase methane compositions and biogas quality [10].

i. Removal of Hydrogen Sulphide

Hydrogen sulfide in biogas impairs all the pipeworks used and limits its lifetime. It is toxic and very corrosive to many kinds of steel. When biogas containing hydrogen sulphide is burnt it is converted to sulphur oxides corrodes metallic components and also produce acid gases. Hydrogen sulphide in the biogas can be removed by use of Iron (III) oxide (Fe_2O_3) and Zinc oxide. Activated charcoal can also be used to remove H_2S from biogas stream [10].

ii. Removal of Carbon dioxide

Biogas has a lot of CO_2 in it. To produce methane rich biogas, most of the CO_2 in the biogas has to be removed. A methane concentration of 95% in the biogas is essential in other downstream biogas usage. To reach this concentration, CO_2 has to be removed, some of the common ways used in the removal oc CO_2 from biogas are given below.

1. Water scrubbing
2. Membrane systems
3. Pressure swing adsorption (PSA)
4. Chemical CO_2 absorption
5. Amine gas treatment

The traditional way of removing CO_2 is through water scrubbing [10]. Water scrubbing is used to remove carbon dioxide but also hydrogen sulphide from biogas since these gases are more soluble in water than methane. The absorption process is purely physical. Usually the biogas is pressurized and fed to the bottom of a packed column where water is fed on the top. In more detail the typical scrubbing system consists of the Water scrubber with iron wool packed bed connected to a water tank, and two tyre tubes which are used in storing the pre-scrubbed (raw) biogas and the scrubbed (purified) biogas. The water scrubber has an inlet for the entry of the raw biogas and a discharge for the exit of the scrubbed biogas. Besides CO_2, the warm water takes up traces of H_2S and other impurities in the biogas. Only oxygen and nitrogen cannot be removed from the biogas by the water scrubbing process [13].

The basic ingredient of biogas purification using water scrubbers base ingredients are water, which flowed pressurized biogas purification column from the bottom of the column in order to reduce CO_2 and H_2S gases. The result of purification by using this method is that the levels of H_2S in biogas reduced by 32.8% while the CO_2 content decreased by 21.2%. Water wash gas scrubber technology increases the CH_4 content of biogas produced with anaerobic digesters. Water wash gas scrubber technology consists of the following main components: Absorption column and desorption column, compressor, blower, cooler and a subsequent dryer unit [13-15].

iii. Removal of Carbon dioxide using Pressure Swing Absorption

Pressure swing adsorption (PSA) systems, can be viewed as being molecular-sieves for carbon. PSA has been described are the second most commonly used biogas upgrading technology in Europe, after water scrubbing which is the most popular. A typical PSA system is composed of four vessels in series that are filled with adsorbent media which is capable of removing not only the CO_2 but also water vapour, N_2, and O_2 from the biogas flow.

Typically in order to eliminate CO_2 from biogas, the PSA upgrading takes place over 4 phases: pressure build-up, adsorption, depressurization and regeneration [13]. The pressure build-up occurs by equilibrating pressure with a vessel that is at depressurization stage. Final pressure build up occurs by injecting raw biogas. During adsorption, CO_2, N_2, and O_2 are adsorbed by the media and the purified gas discharges as pure methane to a quality which will be far less corrosive and has a higher calorific value.

iv. Removal of Carbon Dioxide using Membrane Systems

Developed gas-liquid membranes have been introduced, which operate at atmospheric pressures thereby reducing the energy consumption of compression. The use of specific solvent solutions allows the separation and recovery of the H_2S and CO_2 (Lems, 2012).

v. Removal of Water

Biogas can be dried by compression and/or cooling of the gas, by adsorption at activated charcoal or silica - gel, or by absorption, mostly in glycol solutions.

After the treatment of the biogas. Treated biogas often referred to as bio-methane is used in production of electricity. First the treated bio-methane is stored in a container and routed through connecting pipes to the gas turbine system. Compressors are needed depending on the inlet conditions of the turbine system to pressurize the gas before inlet into the turbine [13-15].

2.3. Biogas for Power Generation

The resulting treated biogas is sent to gas turbine for the production of electricity. The gas turbine has some inlet standards which must be met by the biogas before it is fed into it. Gas turbines requires that inlet gas be supplied at high pressures. To achieve this, gas compressors are used downstream of gas turbines to boost the biogas to the pressure required by the gas turbine inlet specification. Of course, the introduction of gas compressors will increase the cost capital cost of the biogas to electricity project. Depending on the volume of the gas, the distance and the pressure difference between the biogas in the storage tank and the inlet specification of the gas turbine, the compressors ma operate in stages [10].

Similar to natural gas, biogas conversion to electricity using gas turbines uses either single cycle gas turbines or combine cycle gas turbines. In combined-cycle power plant, gas and a steam turbines together are used to produce more electricity from the same fuel than a traditional single-cycle plants. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra electrical power. A combined cycle Power Plant produces high power outputs at high efficiencies (up to 60%) and with low emissions. In a conventional power plant has efficiency of about 33% electricity only and remaining 67% as waste. Small biogas turbines with power outputs of 30-75 kW are available in the market.

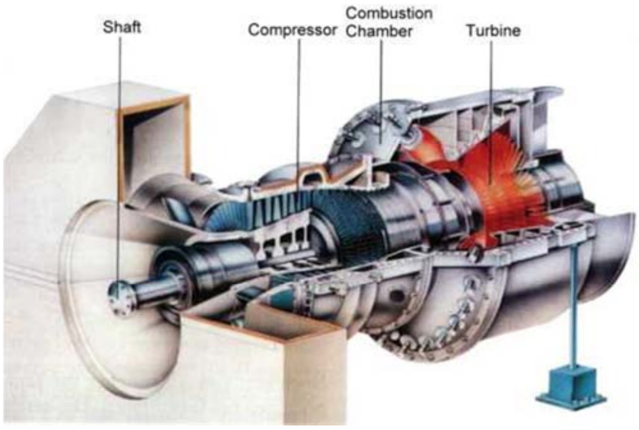

Figure 2. The schematic diagram of gas turbine power plant [16].

Micro gas turbines are small high - speed gas turbines with low combustion chamber pressures and temperatures. They are designed to deliver up to 200 kW of electrical power. Micro gas turbines are essentially single cycle gas turbines that are used for small scale electricity generation. They are manufactured in compact and portable sizes and can even be used in residential buildings for electricity generation.

2.4. Biodigester-Turbine System - Design and Construction

The biodigester-Gas turbine system consists of the following

1. The toilet system (biodigester system)
2. The biogas storage system
3. Digestate tank
4. Treatment unit
5. The gas compressor system
6. The turbine system

2.4.1. Toilet System (Biodigester System)

The toilet system comprise the toilet seat which receives the human waste (excreta), the drain pipe and the septic tank, and the biogas delivery pipe. The septic tank by construction and design acts as the biogas digester. The septic tank is constructed with an opening fitted with pipe for the collection of the biogas. The system should be designed to allow removal of the sludge digestate. The digestate is the fraction of the sewage sludge remaining after the anaerobic digestion and production of biogas has taken place. If the digestate is not removed, it inhibits further biodegradation in the septic tank and slows down biogas production.

Figure 3. Construction of the biodigester (septic tank) system.

2.4.2. The Biogas Storage System

The biogas from the septic tank (biodigester) is collected via a delivery pipe and temporarily stored in a tank. From the biogas storage tank the biogas is routed to treatment units. The storage vessel is constructed bearing in mind the volume of the biogas expected from the septic tank. The storage tank should be designed to withstand backflow of the biogas back to the septic tank

2.4.3. The Digestate Tank

The digestate is the fraction of the sewage sludge that remains after the extraction fermentation and extraction of the biogas. The digestate is the substance needed by farmers as manure or to be used in production of fertilizers.

2.4.4. The Treatment Unit

The raw biogas from the biogas storage is routed via pipes to the treatment unit for treatment. The raw biogas from the septic tank or biodigester contains a high percentage of CO_2 and H_2S and cannot be introduced into the turbine system to avoid corrosion and damage of the mechanical system of the turbine. The treatment unit is designed depending on the type of biogas treatment to be used, the desired purity of the gas and the volume of the feed biogas. The resulting treated biogas composed mainly of rich Biomethane is sent to Biomethane storage and from there it is set to the gas turbine for electricity generation.

2.4.5. Compressor Unit

Gas compressors are required downstream of the turbine to compress the Biomethane to the desired pressure necessary for the gas turbine intake. The gas compressors design is dependent on the composition of the Biomethane and, the volume of the feed gas to be compressed, the distance to the turbine, the type of gas turbine in use etc.

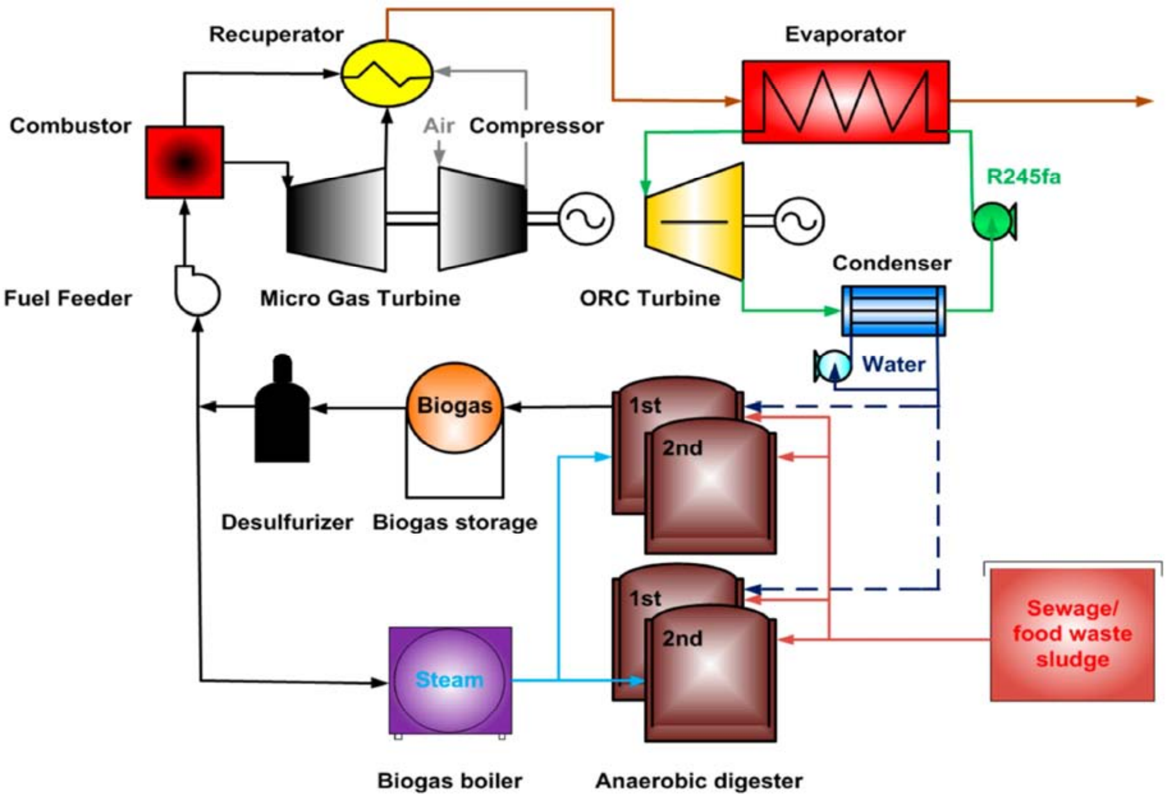

Figure 4. *Flow sheet of biogas to electricity system [17].*

3. Methodology

FUTO NDDC students hostel at the Federal University of Technology, Owerri is used as case study. The FUTO NDDC hostel has a total of 174 rooms with four (4) students per room making a total of 696 persons in the hostel. The following parametres are used in the study.

Table 2. *Parametres used for Evaluation.*

Parameter	Value
Average human waste produced per person per day	0.5kg
% Solid matter in human waste	35%
% Degradation of total human waste	60% for volatile solids and 50% for total solids
Estimated mole percent of methane in biogas	65%
Density of pure methane	0.668 kg/m^3 at NTP; 0.717 kg/m^3 at STP
Calorific value of Biomethane	36 MJ/m^3
Calorific value of pure methane	42 MJ/M^3

3.1. Determination of Biogas Produced

Number of rooms in the NDDC Hostel = 174

Number of students per room = 4

Total Number of people living in the NDDC Hostel = 696

Average mass of human waste produced per person per day = 0.5 kg

Total mass of waste produced in the hostel per day = 0.5 kg x 696 people = 348 kg/day

From table, dry matter content of human waste (Buswell) = 35%

Total dry matter mass of daily waste produced = 0.35 x 348kg = 121.8kg

According to Buswell, Carbon content of dry matter in the human waste = 24%

Total carbon content in the total human waste produced per day = 0.24 x 121.8 kg =29.23 kg

From table above, the% biodegradability of human waste is 60% for volatile solids and 50% for total solids [18]

Assuming volatile solids.

The mass of biodegradable matter = 0.6 x 29.23 kg = 17.54 kg (this is the carbon that will be converted to Biogas).

In the biogas, 65% of the biogas is methane

Mass of Methane carbon (CH_4-C) = 17.54 kg x 0.65 = 11.4 kg

Molar mass of methane = 16g and molar mass of carbon =12g

Mass of Methane = 11.4 kg x 16/12 =15.2 kg

At normal temperature and pressure, NTP (i.e. 20°C and 1 atm), the density of methane = 0.668 kg/m^3

Thus the volume of methane biogas produced = mass/density

$$\text{Volume of methane in the biogas} = \frac{15.2\text{kg}}{0.668\text{kg/M}^3} = 22.75\text{m}^3$$

Converting to cubic feet = 803.41 ft^3 of methane in the biogas.

For 1 person, the average volume of methane generated from human waste per day is $22.75\text{m}^3/696 = 0.033m^3\ (1.165\ \text{ft}^3)$

Note that this volume of methane corresponds to the 65% in the total biogas stream generated.

$$\text{Thus the total volume of biogas generated} = \frac{22.75\text{M}^3}{0.65} = 35\text{m}^3$$

Converting to cubic feet = 1236 ft^3 of biogas

For 1 person, the average volume of biogas generated from human waste per day is $35\ \text{m}^3/696 = 0.05m^3\ (1.77\ \text{ft}^3)$

Note that a person produces approximately 0.5kg of human waste per day which yields 0.05m^3/day of biogas. Thus 1 kg of human waste produces approximately 0.1m^3 of human waste

3.2. Estimation of the Electrical Equivalent of the Biogas

1kwh = 3412 Btu = 3.6MJ

Gas turbine efficiency affects heat rate.

100% efficient gas turbine will generate 3.6MJ/Kwh = 3412btu/ kWh

From table, the calorific value of pure methane is about 42MJ/m^3 – 45MJ/m^3

The calorific value of biogas depends on the percentage concentration of Methane in the biogas since methane is the only constituent of the biogas that has heating value. Raw biogas has heating value from 20-26MJ/ m^3, the CO_2 concentration of the biogas lowers the heating value. CO_2 removal and biogas treatment is done to increase the heating value and reduce corrosion tendencies of the gas.

For this study, the Biomethane from the biogas has a percentage composition of 95% and a caloric value of 36 MJ/m^3.

Thus, a 100% efficient gas turbine utilising biomethane with calorific value 36MJ/m^3 will generate 10 kWh /m^3

For a combine cycle gas turbine with 55% efficiency, the biomethane consumption of the turbine = 10 kWh /m^3 x 0.55 =5.5 kWh /m^3

The electrical power to be produced from the CCGT for 22.75 m^3 volume of methane = 5.5 kWh x 22.75m^3 = 125.13 kWh.

If the turbine used were as single gas turbine (34% efficiency), the electrical power produced would be = 10 kWh x 0.34 x 22.75 = 77.35 kWh.

3.3. Determination of Power Needs of a Home

If the electrical energy generated is to be sold or supplied to host communities, it is pertinent to ascertain the number of households or individuals that the electrical energy will be sufficient to meet. For this reason we calculate the electrical energy requirement of each household. For equipment ratings, check the label of equipment and record their values accordingly, otherwise check with local appliance dealers or product manufacturers for information.

Table 3. *Power Ratings for a Typical Rural Home Appliances in FUTO.*

Appliance	Consumption (watts)	Number	Total wattage	hrs./day	Watt-hrs./day
Energy bulbs	10	6	60	8	480
DVD	40	1	40	3	120
Television	50	2	100	4	400
Mobile phones	5	4	20	2	40
Ceiling fan	25	8	200	5	1000
Radio cassette player	8	2	16	2	32
Total					2072

From the table above, each household requires an average power requirement of 2072watt-hr (0.2kWh) per day. The table below gives the relationship between energy produced and number of households required for its consumption. From table 5, the average energy needs of a typical home in FUTO is 0.2KWh.

3.4. Economics of Biogas Electricity Generation from Gas Turbine Systems

In evaluating the Economics of using biogas for electricity generation, it is important to consider the following factors: i) the type of plant to be used, ii) the capacity of the plant iii) the capital expenditure iv) the Operating expenditures.

In using biomethane-fuelled gas turbines for electricity generation, it is important to choose the type of turbine. The type of turbine may depend on the capacity of the plant, the financial strength etc. For small scale electricity generation micro-gas turbines dominate the electricity generation operations. Micro-gas turbine generators comes in various sizes and capacities but can handle electrical energies in the range of 5KW to 500KW. Medium to Large scale turbine system could be single cycle, combine cycle or combine cycle with carbon capture.

3.4.1. Economic Appraisal Techniques

Economic appraisal is done to ascertain the financial performance of the projects under varied conditions. In this, Key profit indicators are evaluated such as

1. Net cash recovery (NCR)
2. Net present value (NPV)
3. Pay-out Time (POT

4. Profit per dollar invested (P/$)
5. Discounted cashflow rate of return (DCFROR)

3.4.2. Evaluation Economics of Human Waste to Electricity Using Micro-turbines

From Literature the capital cost for Micro-turbine generators (single cycle) are within the range of $400/KW - $800/KW. While the operating cost ranges from $0.04/kWh - $0.10/kWh.

We evaluate the economic indices for microturbines generating the following quantity of electricity: 10KW, 50KW, 80KW, 100KW, 200KW, 500KW

3.4.3. Install Cost

For this work, the Install cost comprises the total capital cost plus the cost of installation of the biomethane electricity production turbine, this comprises the following: i) the capital cost of the microturbine ii) the land cost iii) the cost of biomethane digester iv) the cost of construction of the digester system v) the cost of separation equipment vi) the total cost of installations of all the units of biomethane and turbine system. The total install cost for this work is take to be $US600/KW

3.4.4. The Operating Cost

The total operating cost here comprises the following: i) the total cost incurred in collection and treatment of the biogas to biomethane and storage ii) the cost of running the turbine system to generate electricity ii) maintenance cost iv) Labour cost v) fuel cost vi) utility cost. The total operating cost take for this work is US$0.07/KW

According to the EEDC tariff plan, the cost of power for R2S customers (Residential) is N30.93/kWh. Using a Naira to dollar conversion factor of N360 to US$1, the tariff cost for R2 customers is US$0.086/kWh. We take 350 working days for 10 years of plant operations. This values will be used in evaluating the economic indices of the project.

4. Results

The result comprise two parts: the biogas turbine performance indices for the electricity generated and the economic analysis of the biogas to electricity project

4.1. Results for Electricity Output and Performance from the Biogas Turbine

Table 4 shows the electrical power generated from the conversion of human waste to biogas using anaerobic digesters.

Table 4. *Results from conversion of Human waste to electricity per day.*

Number of hostels	Capacity per hostel	Total capacity	Volume biogas produced per day		Volume of biomethane produced per day		Electrical Energy produced (kW)	
			m^3	ft^3	m^3	ft^3	CCGT	single cycle
1	696	696	35	1236.01	22.75	803.41	5.21	3.22
2	696	1392	70	2472.03	45.5	1606.82	10.43	6.45
3	696	2088	105	3708.04	68.25	2410.23	15.64	9.67
4	696	2784	140	4944.05	91	3213.63	20.85	12.89
5	696	3480	175	6180.07	113.75	4017.04	26.07	16.11
6	696	4176	210	7416.08	136.5	4820.45	31.28	19.34

The electrical energy equivalent of the table above is given below

If the people drop their waste continuously and the septic tank is closed and allowed to undergo fermentation for a period of 1 month. Then the accumulated biogas from the septic tank at the end of 1 month when it will be put to flow is given below.

Table 5. *Results from conversion of Human waste to electricity when waste is accumulated for 1 month.*

Number of hostels	Capacity per hostel	Total capacity	Volume biogas produced per month		Volume of biomethane produced per month		Electrical Energy produced at first opening (kW)	
			m^3	ft^3	m^3	ft^3	CCGT	Single cycle
1	696	696	1050	37080.40	682.5	24102.26	156.41	96.69
2	696	1392	2100	74160.80	1365	48204.52	312.81	193.38
3	696	2088	3150	111241.20	2047.5	72306.78	469.22	290.06
4	696	2784	4200	148321.60	2730	96409.04	625.63	386.75
5	696	3480	5250	185402.00	3412.5	120511.30	782.03	483.44
6	696	4176	6300	222482.40	4095	144613.56	938.44	580.13

Figure 5 and shows the relationship between kW of energy produced and the volume of biomethane gas produced from the human waste.

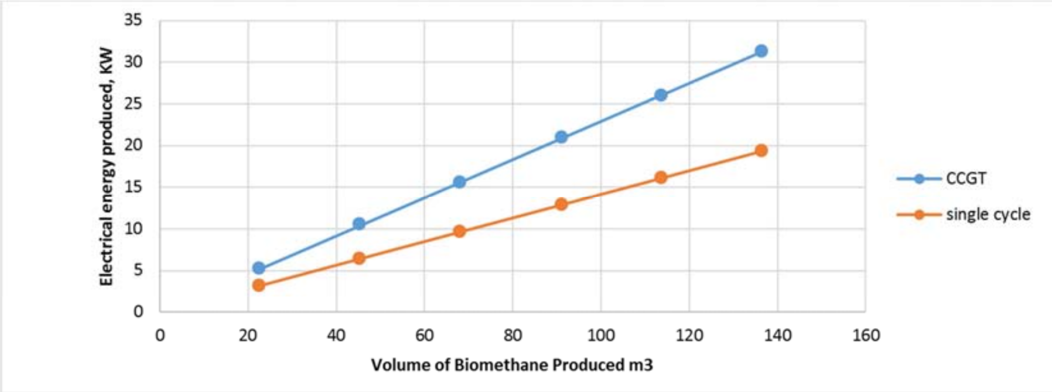

Figure 5. *Electrical energy Vs volume of biomethane yield for human waste decomposition per day.*

Table 6. *Table showing number of households that will utilize the power produced from human waste per day.*

Number of hostels	Total capacity	Electrical Energy produced at first opening (KW)		Number of households	
		CCGT	Single cycle	CCGT	Single cycle
1	696	5.21	3.22	626	387
2	1392	10.43	6.45	1251	774
3	2088	15.64	9.67	1877	1160
4	2784	20.85	12.89	2503	1547
5	3480	26.07	16.11	3128	1934
6	4176	31.28	19.34	3754	2321

If the waste were allowed for 1 month and the resulting biomethane produced is used to generate electricity, then the electricity produced and the number of households that it will be utilising the electrical energy is given in the table 7 below

Table 7. *Table showing number of households that will utilize the power produced from human waste for 1 month period.*

Number of hostels	Total capacity	Electrical Energy Produced at First Opening (KW)		Number of households	
		CCGT	Single cycle	CCGT	Single cycle
1	696	156.41	96.69	18769	11603
2	1392	312.81	193.38	37538	23205
3	2088	469.22	290.06	56306	34808
4	2784	625.63	386.75	75075	46410
5	3480	782.03	483.44	93844	58013
6	4176	938.44	580.13	112613	69615

4.2. Result for Economic Evaluation

The results of economic analyses of the human waste to electricity project are given and discussed below. Table 9 is the result for small scale electricity production using microturbine (single cycle) while table 10 is the result for electricity production for larger plant using combine cycle gas turbine (CCGT).

Table 8. *Results for Estimation of Capital and operating cost of the microturbine.*

Energy generated, KW	Power produced KWh	Turbine efficiency (%)	Volume of biomethane m^3	Total Install Cost, US$	Operating cost, US$
10	240	34	70.59	42353	16.8
50	1200	34	352.94	211765	84.0
80	1920	34	564.71	338824	134.4
100	2400	34	705.88	423529	168.0
200	4800	34	1411.76	847059	336.0
500	12000	34	3529.41	2117647	840.0

Table 9. *Economic analyses indices for electricity production from human waste at small scale using microturbine system.*

Economic indices	Electrical capacity		
	10KW	50KW	500KW
NCR (US$)	1344	6720	67200
NPV @ 10%(US$)	2258	11291	112915
POT (yrs)	4.46	4.46	4.46
DCF-ROR (%)	18.19	18.19	18.19
P/S	0.38	0.38	0.38

Table 10. *Economic analyses indices for electricity production from human waste at medium scale using combine cycle gas turbine (CCGT) system.*

Economic indices	Electrical capacity		
	1MW	2MW	5MW
NCR (US$)	302400	604800	1512000
NPV @ 10%(US$)	758117	1516234	3790585
POT (yrs)	3.64	3.64	3.64
DCF-ROR (%)	24.39	24.39	24.39
P/S	0.69	0.69	0.69

From tables 9 and 10, pay-out time of 4.4 years and 3.64 years for microturbine and CCGT respectively are observed; furethermore, DCF-ROR of 18.19% and 24.39% for microturbine and CCGT respectively are also observed; and NPV at 10% discount rate of US$112915 and US$ 3790585 for 500KW and 5MW of electricity produced from microturbine and CCGT respectively are realised.

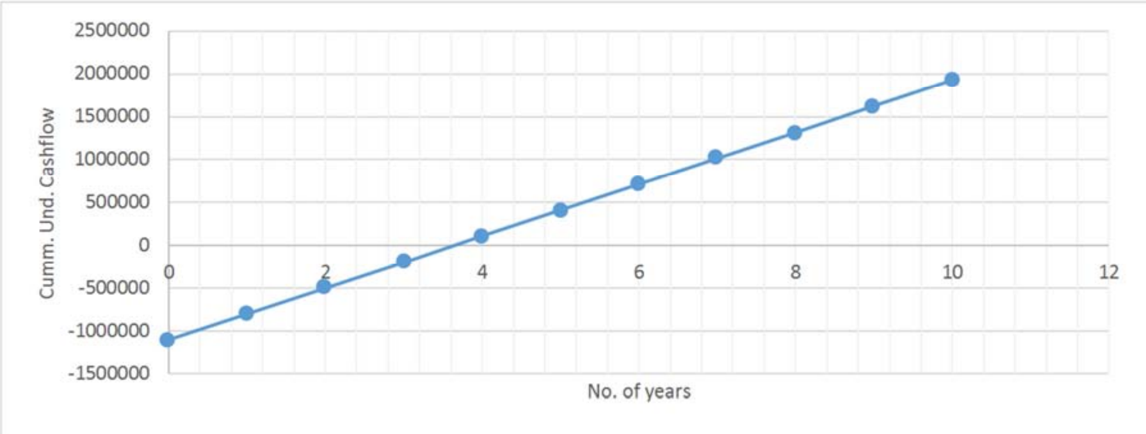

Figure 6. *Graphical illustration of Pay-Out-time for CCGT Electricity generation for 1 MW.*

Figures 6 shows the graphical representation of Payout for CCGT gas plant respectively. A pay-out time of 3.64 yrs was gotten

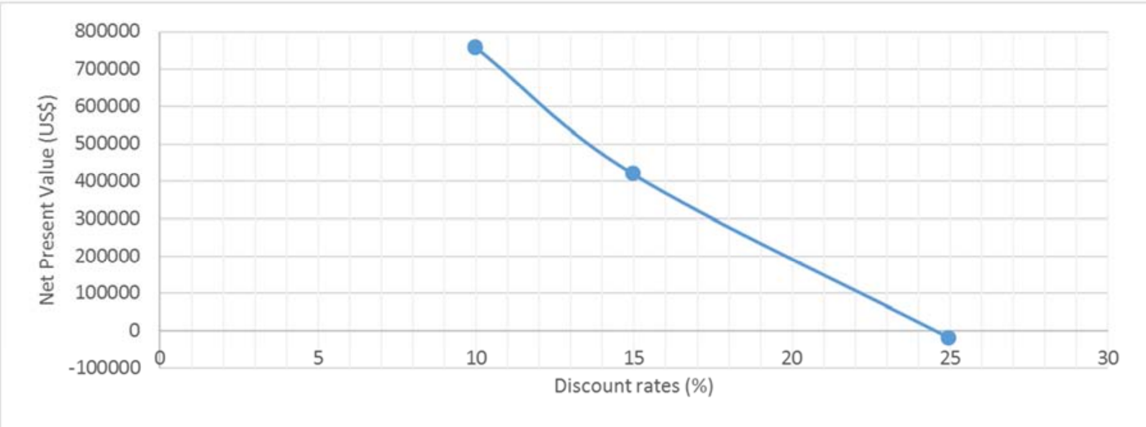

Figure 7. *Graphical illustration of DCF-ROR for CCGT Electricity generation for 1 MW.*

Figures 7 shows the DCF-ROR for CCGT electricity generation for 1 MW of electricity.

5. Discussion of Results

1. From table 4, the electricity produced from the NDDC hostel per day is 125.13 kWh and 77.35 for the CCGT and the single cycle gas turbines respectfully. This value is converted to electrical power equivalence of 5.2 kW and 3.2 kW respectfully.
2. If 6 hostels of the same capacity as FUTO NDDC hostel is considered, the biogas produced from the human wastes in the six hostels per day will be 210 m^3 which will give a biomethane volume of 136.5 m^3. this will give an electrical power of 31.28 kW and 19.34 kW for the CCGT and single cycle gas turbine respectfully on daily basis
3. If the wastes were consistently accumulated for 1 month period without opening. Then biogenetic activities will act on it and when eventually the septic

tank is opened for flow of biogas, the biogas volume that will be realized from the NDDC hostel is 1050 m^3. This corresponds to an electricity generation of 156.41 kW and 96.69 kW for the CCGT and single cycle gas turbine respectfully.

4. Combining 6 Hostels of NNDC capacity and allowing for a period of 1 month before producing biogas will give a biogas volume of 6300 m^3 and biomethane volume of 4095 m^3. The electricity produced from the bio methane for a CCGT gas turbine was 938.49kW and 580.13 kW for a single cycle gas turbine.
5. Table 8 shows the number of households that will be sufficiently supplied power from the electricity produced assuming the average power needs for each household is 0.2 kWh per day. From the table, the electricity produced from FUTO NDDC hostel per day will be sufficient to solve the electrical needs of 626 households if CCGT gas turbine were used and 387 households if a single cycle gas turbine were used. These households are people living in the FUTO community which are in close proximity to the university. These communities are FUTO market, Eziobodo, Umuchima, Ihiagwa, Emeabiam etc.
6. For a month period, the FUTO NDDC hostel will power 18769 households using CCGT and 11603 using single gas turbine.
7. From tables 9 and 10, the payout time for the microturbine and the CCGT gas plants are 4.46 and 3.64 respectively. This shows that the project is viable because of shorter payout for both the small scale using microturbine and the medium scale using CCGT.

6. Conclusions

Extensive evaluation on the use of human waste for production of electricity has been done. FUTO NDDC hostel has been taken for case study. The study reveals that much can there is great resource that lies in waste especially in human waste. This could be harnessed for production of electricity which could be used in powering the university hostels and surplus sold to the nearby FUTO communities. This will greatly cut down expenses incurred on running generators utilising gasoline or diesel in the university. it is evidently seen from the result that the daily electricity produced form one NDDC hostel could solve the daily electrical needs of about 626 households (when a CCGT gas turbine is used for electricity generation) utilising an average energy of 0.2 KWh per day. The economic analyses of the project reveals that the project is economically viable with short pay out time of 3.64 years when CCGT plant is used and 4.64 years when microturbines are used for electricity generation respectively.

The project is recommended for homes, schools, universities, banks, Hospitals and all public buildings as a way of domestically producing electricity. This will greatly reduce the dependence on grid electricity system and the attendant problems that comes with wit in Nigeria.

Nomenclature

CCGT – Combine Cycle Gas Turbine
HRSG – Heat Recovery Steam Generators
KW – Kilowatts
KWh – Kilowatt-hour
MJ – Megajoules
MW- Megawatts
NDDC – Niger Delta Development Commission.
NREEEP - National Renewable Energy and Energy Efficiency Policy
NTP – Normal Temperature and Pressure.
PSA – Pressure Swing Absorption
STP – Standard Temperature and Pressure

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