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Prospects of Biomass Power Generation in Calabar, Nigeria

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Abstract: Nigeria has one of the lowest electricity generation rates in the world. This work is aimed at highlighting the contributions to the energy needs that can be achieved through the usage of biomass for electricity generation in the city of Calabar. The energy conversion technique is the bio-chemical process specifically Anaerobic Digestion. Analysis and calculations show that about 1.324 MW of electricity could be added to the local grid of the city of Calabar.

Keywords --Biomass, Energy conversion, Solid municipal waste, Energy generation, Anaerobic Digestion, Mega Watt

I. INTRODUCTION

In Nigeria, there is insufficient and unreliable power supply. An average Nigerian home, business premises etc experiences at least one power outage in a day if at all the power supply is available. For some areas power outages can last for weeks and even months in some cases. This has made many Nigerians to generate power for themselves through the use of standby generators.

The need to take care of the growing demand for stable and reliable power supply necessitates investment in the power sector; and the desire and need to be up to global standards. According to World Bank data, electricity consumption in kWh per capita in 2014 was 10,059; 15,546; 3,927; 7,035; and 12,984 for Australia, Canada, China, Germany and USA respectively. In the same report the value for Nigeria was 144. There is urgency on the need to improve the efficiency of the generation, distribution and transmission networks which are in a deplorable state.

Nigeria has one of the lowest rates of net electricity generation in the world. Therefore all areas in the country suffer one form of electrical power shortage or another. This is affecting large and small businesses, industries, homes and establishments. Besides, it has even forced many industries to relocate to neighboring countries for instance the Textile industries, Michelin etc. If the cities are grappling with shortages one can imagine what goes on in towns and villages.

Electrical energy generation in Nigeria is predominantly from burning fossil fuels and hydro electric dams. Most of the dams are not generating at the peak due to diminishing water levels, old equipment and poor maintenance. Even at their peak, these stations do not generate enough power for the nation's teeming populace.

Many electrification schemes have failed woefully due to lack of a strong desire of implementation by policy makers, neglect of responsibilities, lack of financial commitment and general neglect of the citizenry.

This simply means that most areas in Nigeria even though connected to the national grid do not enjoy secure and adequate electric power supply. The need to have alternative sources of generating electricity for communities cannot be overemphasized.

Solid waste is form of waste that is not in liquid or gaseous form. Solid waste is grouped under different form namely: agricultural, municipal, industrial and medical. Sewage sludge. Pathological waste, and garbage' which is generated from decaying by products of meat preparation are also classified under solid waste. Garbage is also gotten from putrefying fruits and vegetables.

The moisture content of these wastes is about 70 % and heating value of around $6x10^6$ J/Kg. Rubbish. There is a different form of solid waste that makes up 25% of moisture and has heating value of 15 x106J/kg. Dead animals and humam wastes have moisture contents up to 85% and can have heating value of up to 2. 5 x106J/kg. Some good examples of rubbish wastes are metals, paper, leather, rubber and glass [1].

Organic waste is accomplished through the process of biomethanation in a series of biochemical transformation-- hydrolysis, acidification and liquefaction followed by methane transformation. The process generates biogas with high content of methane (55–70%) which after proper pre-treatment are directly used as fuel by employing gas engines to generate electricity. This technology has dual benefits. This generates manure and biogas as end products [2].

The primary concern of Waste to Energy (WtE) power generation projects is that it should be developed where municipal population is above two million, it is viable only when adequate quantity and quality (percentage of biodegradable) of wastes is generated. While estimating waste availability, present segregation methods and intermediate process (like composting) have to be accounted for [2].

Agricultural crops and wastes, residues from operations involving keeping of livestocks, animal wastes, wastes from woods such as fast growing trees, municipal and industrial wastes all constitute biomass. Biomass grown specifically for use as fuels for energy production includes trees, grasses and oil plants.

Trees used as energy plants are those that can grow back after being cut off close to the ground .Grasses are most found in hot and wet climates and the type preferred for biomass usually have thin stems and examples include elephant grass, sugar cane, sweet sorghum and phalaris. Oil plants such as soybeans and sunflowers can be used for producing fuel for energy production [3].

The national benefits of using biomass for energy include lower sulfur emissions (which contribute to acid rain), reductions in greenhouse gas emissions, and less dependence on fossil fuels. Biomass has been used for a long time to heat or drive steam engines, but the methods used have become obsolete due to the fact that they were not environmentally friendly. The smoke produced comprises dangerous.

volatile organic compounds into the air.

Nigeria currently produces about 3.7 GW of electricity to the grid, 60% (2.2 GW) of which is from conventional non-renewable energy sources (coal and gas) while the remaining 40% (1.5 GW) is from hydro-energy source [4].

Calorific Value (CV) is used to measure the energy content of fuel and it is expressed in Joules per kilogram. In the case of coal fuel, a typical value is approximately 30 MJ kg-1, while for oil the value is about 40 MJ kg-1. In fact the calorific value of Municipal Solid Waste (MSW) has increased to about 20% since the early 1970s, because of factors such as the decreasing quantity of ash in the waste from coal fires, and the increasing proportion of dry packing materials [5].

The caloric value of general waste is 8.14 MJkg-1 compared to 8-10 MJkg-1 for shale according to studies conducted by Eesti Energia in Estonia, a company that produces electricity and heat from waste materials [5].

The caloric value of general waste is 8.14 $MJkg^{-1}$ compared to 8-10 $MJkg^{-1}$ for shale according to studies conducted by Eesti Energia in Estonia, a company that produces electricity and heat from waste materials. After sorting out the waste into glass, paper, plastic and biodegradable waste, the unsorted waste is then used for electricity generation. Compared to commercial fuels, MSW are low fuels due to their low energy content, their low variations in fuel properties and the high content of chlorine and heavy metals [6].

World energy council in 2016 in a summit called Waste-to Energy (WtE) has some of its key findings as:

1. Treating residual waste with various WtE technologies is a viable option for disposal of MSW and energy generation. Many factors influence the choice of technology and every region have to properly assess its specific context to implement the most reasonable solution.
2. Biological WtE technologies will experience faster growth at an average of 9.7% per annum, as new technologies (e.g. anaerobic digestion) become commercially viable and penetrate the market [5].
3. The need to increase the share of renewable energy and reduce Green House Gas (GHG) emissions, along with raising environmental consciousness to protect the environment from polluting and unsustainable practices such as land filling, will have a positive impact on WtE market development.

MSW is not considered 100% renewable, since portions of MSW consist of non-renewable elements. Hence, only the biogenic proportion of waste (food, paper, wood, etc.) is considered renewable and this is reflected in the policies on energy extraction from waste.

Because waste is an undesired product of society, all waste producers, from municipalities to private sectors, must spend part of their economic resources for its collection, management and disposal. Typically, if waste is used for energy recovery, each waste producer is obliged to pay a tipping fee (or gate fee) to the WtE facility in order to dispose of the waste [7].

Global per capita solid waste generation has more than doubled over the first 15 years of this millennium and is expected to reach 2.2 billion tons per year by 2025, produced by 4.3 billion urban residents. As the human population is also forecasted to experience an unprecedented growth from currently ~7 to ~9 billion by 2050, the management of solid waste is becoming an increasingly pressing problem now and in near future. It is estimated that growing population will encounter food (~70 %), fuel (50 %), and freshwater (30 %) demands, resources that are already limited in many regions of the world [8].

Despite rising costs of solid waste management, and in spite of the looming threat to energy, food and unpolluted fresh water security and globalization, mankind continuous to dispose of an average 1.3 billion tones of food waste, 130 million tones of non-degradable fossil fuel derived from plastics and 52 million tones of metals in landfills annually [8].

There are certain reasons for not recovering energy from wastes and these are [6].

(i) Lower capital costs
(ii) Nearby heat demanding sites are not available and
(iii) Difficulties in maintaining continuous operation

There are various ways/ technologies for generating energy from MSW. These technologies use either bio-chemical conversion or thermal conversion processes. Bio-chemical conversion includes aerobic, digester, Vermi-composting; while thermal conversion includes incineration with or without heat recovery, pyrolysis and gasification, plasma pyrolysis and pelletization or Refuse Derivable Fuel (RDF) [2].

The objectives of this research are to use the abundant MSW present in the city of Calabar, Nigeria to generate electric power, highlight a suitable technology for doing this, and estimate the possible power addition to the city from this process and other gains accruable from this endevour.

Apart from the conventional conversion technique commonly used such as (pyrolysis, fluidized bed combustion and grate-type combustion [9],[10] discourse other technologies that increase fuel quality gotten from waste and their flexible use through production of Solid Recovered Fuel (SRF). Since MSW contains bioorganic substances like wood which produces carbon neutral energy, this reduces green house emissions [11].

Anaerobic digestion also known as biomethanation is a multi-functional process that integrates environmental protection, renewable energy production, nutrients and water recycling [12]. Advantages of anaerobic digestion are [13].

(I) Reduction in green house gases
(ii) Prevention of odor and release of pattogens
(iii) The nutrient rich residue can be utilized as fertilizer for cycling the nutrients back to the fields.

From life cycle perspective, anaerobic digestion is more attractive than incineration. Anaerobic digestion has low value of energy generated, needs a good recycling strategy. The most sophisticated technologies offer the most energy. Among all the technologies for converting waste to energy, anaerobic digestion is the least air polluting since all the gases are captured to produce methane [14].. The maximum, efficiency of anaerobic digesters to produce biogas based on heating values is 28% percent [15].

[1] used plasma gasification to degrade the MSW. This is a process in which solid material containing carbon such as coal or biomass is converted into a gas called syngas which contains hydrogen and carbon monoxide. Gasification requires the removal of moisture from the biomass and this can be done by using an external heat source which is a drawback to this system. Drying costs increase quickly below 10% moisture.

According to [16] an ideal waste to energy plant for combined heat and power (CHP) can achieve overall energy efficiencies as high as 85% of the energy content in MSW.

[17] found out that gasification is more economical than land filling. This profitability was accessed by using the net value method and performing cost-benefit analysis of the project.

II. Methods of Conversion of Biomass

Electricity can be generated from biomass through a range of processes. These processes can be separated into three major groups; thermo-chemical, bio-chemical and physical-chemical conversion [18][19]. Thermo-chemical conversion consists of direct combustion of biomass in excess air, gasification in reduced air and pyrolys is in the absence of air. The greatest of the thermo-chemical process involves combustion which requires biomass fuels of low water content and high heating value such as woods, dry agricultural products etc. In the combustion process, biomass is burnt directly to produce thermal energy (heat) which is used to boil water to steam. The steam produced can be used by steam turbine and an electric generator coupled to steam turbine to produce electricity. The gasification of biomass e.g. agricultural waste, food waste and manure produce combustible gases (gaseous fuels) such as carbon monoxide and hydrogen, methane and synthesis gas (syngas which can be used as fuels for boilers, gas turbine to produce electricity and pyrolysis to produce solid/liquid (bio char, syngas and bio-oil used as liquid fuel), which can further be used in gas turbines and boilers to produce thermal and electric energy.

The bio-chemical process produces biogas which can be used to produce electricity and heat. It involves using microorganism to decompose wet biomass fuels such as municipal solid waste, animal manure, poultry litters, food wastes, sewage and industrial waste through fermentation and bio digestion. On the other hand, physical-chemical process is used to generate electricity from biomass by compacting dry biomass to form briquettes or pellets or oil extracted and through combustion generates thermal and electric energy.

a. Anaerobic Digestion of Biomass to Electricity:

In this study, anaerobic digestion of biomass to produce electricity is proposed due to advantages it has over other methods as stated in Section one In anaerobic digestion, organic matters present in different types of wastes such as municipal solid waste, animal manure, poultry litter, food wastes, sewage and industrial waste (such as sludge, agro-industrial wastes, energy crops) are decomposed by microorganism (bacteria) for at least 30 days to form biosolids, liquor and biogas. The biosolids are used for soil conditioner, liquor is used as liquid fertilizers while biogas, rich in methane (about 55 -70% in volume) is used to generate heat and electricity [20].

The conversion of biomass into electricity using anaerobic digestion is shown in Figure 1. The biomass fuels are fed into a reactor without oxygen called anaerobic reactor. The biomass is thereafter passed to the digester which is either mesophilic system (at a temperature of 35°C) or thermophilic system (at a temperature of 55°C), where it is decomposed by bacteria into heat, biogas which contains methane, carbon dioxide and small amounts of other gases such as hydrogen and hydrogen sulphide.

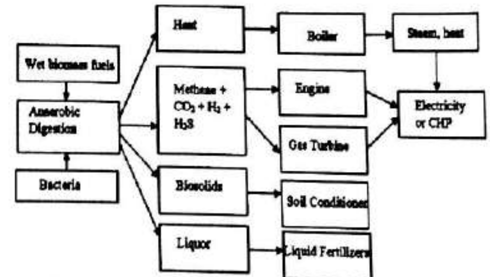

Figure 1: Anaerobic Digestion of Biomass to Electricity

The biogas is further separated from other components and is fed into a gas engine. The gas engine is then used to drive electric generator to generate electricity. The electricity from the generator can be used a standalone or supplied to the grid. In the proposed conversion process, heat generated will be used by the boiler to generate steam to drive steam turbine coupled to electric generator to generate electricity or Combine Heat and Power (CHP). In order to enhance the efficiency of biomass conversion to electricity, co-substrates example energy crop like corn can be added to the digester.

III. Materials and Method

This section quantifies and analyses how refuse are collected to the dump site in Calabar. Calabar is the State Capital of Cross River State in Nigeria. Calabar is located at the extreme Eastern part of Nigeria with Latitude 4.96° and Longitude 8.33°.

It is made of two Local Government Areas namely; Calabar South and Calabar Municipal Councils. The population of the State capital is estimated to be 461,796 with a square kilometer of 157 m^2.[21]. Different sources of wastes within the Stage can be optimized using intelligent methods [22] [23]to ensure steady source at all time.

Wastes generated by the inhabitant are collected at strategic locations across Calabar metropolis as shown in Figure 2. The dumpsite shown in figure 3 occupies a very large area that can be put to better use once the MSW are reduced through degradation and converted to electrical power.

Fig.2: A Typical Waste Stand

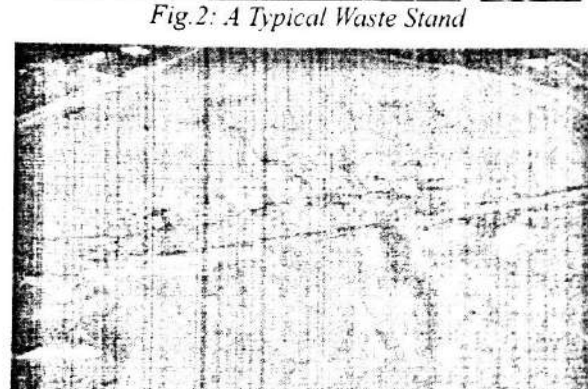

Fig. 3 Google Map of Lemna Waste Dump Site

The wastes are collected daily using trucks and dump at site located behind North West Petroleum Station, Lemna, Parliamentary Extension, Calabar. These wastes are not put to use but the odour generated from the dump site has become a nuisance to the inhabitants within the immediate environment and hence one of the reasons for this research. The research has revealed that about 30 Mega Watts (MW) of electricity can be generated from the waste which can serve as additional source of power supply to the city which suffers from frequent power outages.

The characteristic of sitting power plant is influenced by the cost of generation and distribution [1]. The Cross River State Government proposed to relocate the dump sited behind North West Petroleum Station, Lenna, Parliamentary Extension, Calabar, to a more viable dump site at Idundu which is about 10 km from the present dump site. The proposed plant in this work is to be cited at this new dump site in order to minimize handling and reduce the cost of transportation. It will also reduce cost in terms of electricity transmission and the site has minimal population.

IV. Calculations and Results

Information on refuse collection daily in Calabar is analysed as follows under the following sub-unit as shown in tables 1, 2 and 3.

. Table 1: Waste Collection in Markets

S/N	Location	No of Containers	No of Tons per Container	Quantity of Waste (Tons)
1	Watt Market	3	6	18
2	Akim Market	1	6	6
3	Mbukpa Market	1	6	6
4	Marian Market	2	6	12
5	Eight Miles Market	1	6	6
	Total			48

Collection of waste on the streets of Calabar is of two categories (1) using skip trucks, (2) using regular tippers. Tippers are used due to insufficient skip trucks

Table 2; Waste Collection using Skip Trucks

S/N	Location	No. of Containers	Tons per Containers	Quantity of Waste(Tons)
1	All Streets	230	2	460

Table 3: Waste Collection using Open Tippers

S/N	Location	No. of Tippers	No. of Trips	Tons per Trip	Quantity of Waste (Tons)
1	Calabar South	12	5	7	420
2	Calabar Municipal	11	5	7	385
		Total			805

The total waste collection in Calabar, includes waste collected from the markets, streets using skip waste trucks and open tippers is given as 1313 tons per day.

Due to some content of the refuse such as plastics, bottles etc, about seventy percent (70%) of wastes that are useful municipal waste.

Therefore 70% of the useful municipal waste collected per day = 1313 * (70/100) = 919.1 tons.

Total useful tones of refuse per day (70% of refuse collected per day) is 919.1 Therefore Total tones per hour = 919.1/2
= 38.30 t/h

Energy generation potentials (kWh) = NCV * W * 1000/860 = 1.16

* NCV * W

Power generation potentials (kW) = 1.16 * NCV * W/24 = 0.048

* NCV * W

Conversion efficiency = η

Net power generation potentials (kW) = NCV * W * 1000/860
= η

* 0.048 * NCV * W

NCV = 900kcal/kg, W = 38.30 tons/h and η = 80%

Net power generation potentials (kW) = 0.8 * 0.048 * 900 * 38.30×10^{-3}

= 1,324KW or 1.324 MW

V. Discussions

Tables 1 gives the summary of the waste collection from the five major markets in the city of Calabar, while tables 2 and 3 show the types of trucks used for the collection which determine the quantity of SMW collected per day. Due to the fact that from the analysis of the composition of the SMW, 70% make up the quantity that can be converted to biogas, it can be concluded that 919.1 tons of SMW are generated per day. Considering an efficiency of 80%, approximately 1.324MW of electricity will be added to the grid serving the city.

VI. Conclusions

As biomass power takes its rightful place in the global renewable energy market, the need to use this form of energy to boast electricity generation particularly in developing countries cannot be overemphasized. This work has been able to highlight ways in which the city of Calabar in Southern Nigeria can use the abundant SMW generated in the city to boast electricity generation, save the environment and create more jobs and business opportunities. Adding 1.324MW of electricity to the grid will surely go a long way towards making life more meaningful to the inhabitants of the city.

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